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

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EXECUTIVE SUMMARY

Recent monitoring and data analyses for the Harmer Creek and Grave Creek Westslope Cutthroat Trout (*Oncorhynchus clarkii lewisi*) populations indicate there was reduced recruitment for the 2017 to 2019 spawning year cohorts in the Harmer Creek population.[1] Additionally, the magnitude of reduced recruitment for the 2018 spawning year cohort in the Harmer Creek population was large enough to constitute recruitment failure. In contrast, recruitment in the Grave Creek population appears to have been at replacement levels in 2017 and 2019 and recruitment was above replacement for the 2020 spawn year in both the Harmer Creek and Grave Creek populations. When the low abundance of potential recruits was first reported, Teck Coal Limited (Teck Coal) promptly assembled a team of Subject Matter Experts (SMEs) to initiate an "Evaluation of Cause" (EoC). This document, which evaluates if sediment quality contributed to reduced recruitment for the 2017 to 2019 spawning year cohorts, is one of a series of SME reports undertaken as part of the EoC.

Sediments are a component of the aquatic habitats used by fish and their invertebrate prey. Aquatic sediments can serve as both a sink and/or a source of metals as well as polycyclic aromatic hydrocarbons (PAHs), both of which are more closely associated with fine sediment particles (e.g., clay, silt), which have a greater adsorptive capacity, than coarse (e.g., gravel, cobble) particles. Direct contact (e.g., via gills or skin) with or incidental ingestion (during feeding) of sediments and sediment-associated metals, metalloids, and PAHs may elicit toxic effects in fish and other aquatic organisms. For these reasons, and because Dry Creek and portions of Harmer and Grave creeks are downstream from Teck Coal's Elkview Operation (EVO), which is a potential source of metals, metalloids, and PAHs, sediment quality was evaluated as a stressor in the EoC. However, it is recognized that the predominant mining-related chemical stressors in the Elk River watershed have potential to exert adverse biological effects (if elevated to an effects level) through aqueous exposure (e.g., sulphate) and/or diet (e.g., selenium).

The adsorption, desorption, and subsequent concentrations of metals in sediments, pore water, and the water column are affected by many physicochemical factors that complicate the interpretation of sediment quality data. Consequently, potential risks to fish are less straightforward to evaluate than the physical impacts of sediment (e.g., infilling of interstitial spaces in spawning gravels). However, for fish, early life stages are generally considered to be the most sensitive in terms of sediment toxicity. Potential effects of compromised sediment quality on recruitment include reduced numbers of fertilized eggs or eggs surviving to swim up and

[1] Reduced recruitment was also identified for the 2018 spawning year cohort in the Grave Creek population.

decreased growth or increased mortality in age-0 to age-1 fish resulting from acute or chronic toxicity.

The evaluation of sediment quality as a causal or contributing factor in the reduced recruitment for Harmer Creek Westslope Cutthroat Trout consisted of two parts:

1. A comparison of sediment chemistry data collected from the Harmer Creek population area during the period of interest for reduced recruitment (i.e., from 2016 to 2020) to relevant guidelines and reference area normal ranges to identify Constituents of Potential Concern (COPCs); and

2. An evaluation of trends in sediment quality and other lines of evidence (e.g., bioavailability and species sensitivity) to identify key constituents of concern with respect to potential effects on Westslope Cutthroat Trout recruitment.

Sediment constituents with concentrations greater than the upper British Columbia Working Sediment Quality Guidelines (BC WSQG) and the upper boundaries of the regional reference area normal ranges in the Harmer Creek population area from 2016 to 2020 (i.e., the period of interest for reduced recruitment) were identified as COPCs. These included cadmium, nickel, and selenium. Elevated concentrations of cadmium and nickel were restricted to Dry Creek, a tributary to Harmer Creek. Concentrations of selenium were elevated in Dry Creek and the Harmer Creek Sedimentation Pond, the latter of which is immediately upstream from the dam/spillway that separates the Harmer Creek and Grave Creek population areas. Concentrations of cadmium, nickel, and selenium were not elevated in Harmer Creek between Dry Creek and the Harmer Creek Sedimentation Pond; however, the data were limited to a single sample collected in 2020.

The Harmer Creek Sedimentation Pond (Harmer Creek population area) and the lotic monitoring area just downstream from the pond (Grave Creek population area) were the only locations with more than one year of data to support statistical comparisons of COPC concentrations over time.[2] Selenium was the only sediment constituent in the Harmer Creek Sedimentation Pond that increased (i.e., by 525 percent [%]) over time and relative to both guidelines and regional reference area normal ranges during the period of reduced recruitment.

For pre-emergent life stages (e.g., alevins that have yet to emerge from the spawning gravel) of Westslope Cutthroat Trout, exposure to sediment-related constituents is via direct contact with deposited sediment (i.e., via gills or skin). For free-feeding life stages, exposure to

[2] The lotic monitoring area (RG_HACKDS) just downstream from the Harmer Creek Sedimentation Pond is likely influenced by selenium speciation and other conditions within the pond, despite being in the Grave, rather than Harmer, population area.

sediment-associated constituents can also occur via incidental ingestion of sediments when consuming prey items that originated on or within deposits of fine sediment.

A review of site photos, field notes, and relevant reports indicated that, overall, the habitats used by Westslope Cutthroat Trout in the Harmer Creek population area are primarily erosional with few, patchy deposits of the fine sediments that would be expected to have a greater adsorptive capacity for metals and PAHs. The Harmer Creek Sedimentation Pond has negligible documented fish use (see Chapter 4 of the EoC report).

It is possible that the 525% increase in selenium concentrations in Harmer Creek Sedimentation Pond sediments between 2013 and 2019 could reflect changing conditions upstream, where data were limited. However, given the spatial patterns of selenium speciation and tissue selenium concentrations in water and benthic invertebrates, respectively, it is likely that sediments collected from the Harmer Creek Sedimentation Pond are reflective of speciation conditions and processes within the pond. Substrates in Dry Creek (Harmer Creek population area) are heavily calcified and sequestration of mine-related constituents, including cadmium and nickel, within the calcite matrix likely reduces the bioavailable fraction of those metals and therefore the potential for adverse effects to Westslope Cutthroat Trout. Overall, few differences in sediment chemistry were identified between the Harmer Creek and Grave Creek population areas; however, the data sets for both areas were limited spatially and temporally.

Taken together, these lines of evidence indicate that compromised sediment quality alone was likely a minor contributor to the reduced recruitment for the 2017 to 2019 spawning year cohorts in the Harmer Creek Westslope Cutthroat Trout population. However, it is possible that exposure to selenium from combined sources (sediment, water, diet) contributed to lower recruitment. The role of selenium in the reduced recruitment observed in the Harmer Creek population area was evaluated in detail in separate SME reports for Water Quality and Selenium.

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ACRONYMS AND ABBREVIATIONS

AB – Alberta

ALS – ALS Environmental

AMP – Adaptive Management Plan

ANOVA – Analysis of Variance

BC – British Columbia

BC WSQG – British Columbia Working Sediment Quality Guideline

BCMOECCS – British Columbia Ministry of Environment and Climate Change Strategy

CCME – Canadian Council of Ministers of the Environment

COPC – Constituent of Potential Concern

CRC ICP-MS – Collision Reaction Cell Inductively Coupled Plasma-Mass Spectrometry

CSSS – Canadian Society of Soil Sciences

CVAAS – Cold Vapour Atomic Absorption Spectroscopy

CVAFS – Cold Vapour Atomic Fluorescence Spectrometry

Ecofish – Ecofish Research Ltd.

EEM – Environmental Effects Monitoring

EoC – Evaluation of Cause

EPA – Unites States Environmental Protection Agency

EVO – Elkview Operation

EVWQP – Elk Valley Water Quality Plan

FRO – Fording River Operation

GC/MS – Gas Chromatography with Mass Spectrometric Detection

GHO – Greenhills Operation

Golder – Golder Associates

HSD – Honestly Significant Difference

ISQG – Interim Sediment Quality Guideline

LAEMP – Local Aquatic Effects Monitoring Program

LEL – Lowest Effect Level

MCT – Measure of Central Tendency

Minnow – Minnow Environmental Inc.

MOD – Magnitude of Difference

PAH – Polycyclic Aromatic Hydrocarbon

PEL – Probable Effects Level

RAEMP – Regional Aquatic Effects Monitoring Program

R.P.Bio. – Registered Professional Biologist

SEL – Severe Effects Level

SME – Subject Matter Expert

Teck Coal – Teck Coal Limited

TOC – Total Organic Carbon

TSS – Total Suspended Solids

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 'qapi 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[3], 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, 2022)[4]. Westslope Cutthroat Trout populations in both Harmer and Grave Creeks are part of Teck Coal's monitoring program.

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.

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

[4] 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.

Data were analyzed from annual monitoring programs in the Harmer and Grave Creek population areas[5] from 2017 to 2021 (Thorley et al. 2022; Chapter 4, Evaluation of Cause), and several patterns related to recruitment[6] were identified:

- *Reduced Recruitment*[7] occurred during the 2017, 2018 and 2019 spawn years[8] 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*[9].
- Recruitment was *Above Replacement*[10] for the 2020 spawn year in both the Harmer and Grave Creek populations.

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

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

[5] 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.

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

[7] 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).

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

[9] 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).

[10] 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).

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.

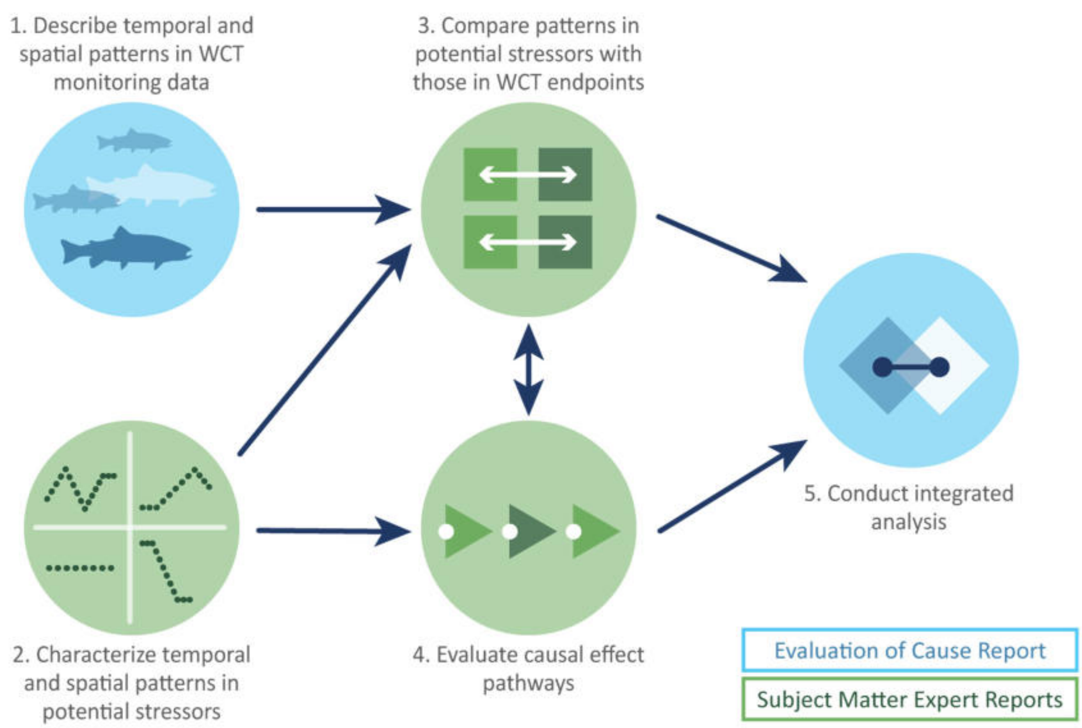
2. The Evaluation of Cause report. The SME reports provided the foundation for the Evaluation of Cause report, which was prepared by a subset of the Team and included input from SMEs.

   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.

Focus	Citation
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.
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.

Focus	Citation
Selenium	de Bruyn, A., Bollinger, T., & Luoma, S. (2022). *Subject Matter Expert Report: Selenium. Evaluation of Cause – Reduced Recruitment in the Harmer Creek Westslope Cutthroat Trout Population.* Report prepared for Teck Coal Limited. Prepared by ADEPT Environmental Sciences Ltd, TKB Ecosystem Health Services, and SNL PhD, LLC.
Small population size	Thorley, J. L., Hussein, N., Amish, S. J. (2022). *Subject Matter Expert Report: Small Population Size. Evaluation of Cause – Reduced Recruitment in the Harmer Creek Westslope Cutthroat Trout Population.* Report prepared for Teck Coal Limited. Prepared by Poisson Consulting and Conservation Genomics Consulting, LLC.
Telemetry analysis	Akaoka, K., & Hatfield, T. (2022). *Harmer and Grave Creeks Telemetry Movement Analysis.* Memo prepared for Teck Coal Limited. Prepared by Ecofish Research Ltd.
Total suspended solids	Durston, D., & Hatfield, T. (2022). *Subject Matter Expert Report: Total Suspended Solids. Evaluation of Cause – Reduced Recruitment in the Harmer Creek Westslope Cutthroat Trout Population.* Report prepared for Teck Coal Limited. Prepared by Ecofish Research Ltd.
Water quality	Warner, K., & Lancaster, S. (2022). *Subject Matter Expert Report: Surface Water Quality. Evaluation of Cause – Reduced Recruitment in the Harmer Creek Westslope Cutthroat Trout Population.* Report prepared for Teck Coal Limited. Prepared by WSP-Golder.
Water temperature and ice	Hocking, M., Whelan, C. & Hatfield, T. (2022). *Subject Matter Expert Report: Water Temperature and Ice. Evaluation of Cause – Reduced Recruitment in the Harmer Creek Westslope Cutthroat Trout Population.* Report prepared for Teck Coal Limited. Prepared by Ecofish Research Ltd.

1 INTRODUCTION

1.1 Background

1.1.1 Overall Background

Teck Coal Limited (Teck Coal) undertakes aquatic monitoring programs in the Elk Valley, including fish population monitoring. The Westslope Cutthroat Trout (*Oncorhynchus clarkii lewisi*) in Harmer Creek and Grave Creek were monitored in 1996, 2008, and 2013 and then annually since 2017. Based on data collected from 2017 to 2019, low abundances of juvenile Westslope Cutthroat Trout were reported (Cope and Cope 2020) and were considered indicative of recruitment failure in Harmer Creek. Teck Coal initiated an "Evaluation of Cause" (EoC) to evaluate and report on what may have contributed to the apparent recruitment failure. Data from annual monitoring programs completed in the Harmer and Grave Creek population areas[11] from 2017 to 2021 were analyzed (Chapter 4 of the EoC report [Harmer Creek Evaluation of Cause Team 2023]; Thorley et al. 2022) and several patterns related to recruitment[12] were identified:

- *Reduced recruitment*[13] occurred during the 2017, 2018, and 2019 spawn years[14] 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 large enough to constitute *recruitment failure*[15].
- Recruitment was *above replacement*[16] for the 2020 spawn year in both the Harmer and Grave Creek populations.

[11] The "Grave Creek population area" includes Grave Creek upstream of the waterfall and Harmer Creek downstream from the Harmer Creek Sedimentation Pond. The "Harmer Creek population area" includes Harmer Creek and its tributaries (including Dry Creek) upstream from the dam at the downstream end of the Harmer Creek Sedimentation Pond.

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

[13] For the purposes of the EoC, reduced recruitment is defined as a probability of greater than (>) 50 percent (%) that annual recruitment was less than (<) 100% of that required for population replacement (see Chapter 4 of the EoC report [Harmer Creek Evaluation of Cause Team 2023]).

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

[15] For the purposes of the EoC, recruitment failure is defined as a probability of >50% that annual recruitment was <10% of that required for population replacement (see Chapter 4 of the EoC report [Harmer Creek Evaluation of Cause Team, 2023]).

[16] For the purposes of the EoC, recruitment above replacement is defined as a probability of >50% that annual recruitment is >100% of that required for population replacement (see Chapter 4 of the EoC report [Harmer Creek Evaluation of Cause Team 2023]).

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

The EoC 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?** Investigating the overarching question included evaluating trends in both Westslope Cutthroat Trout population parameters (e.g., abundance, condition, recruitment) and the potential stressors[17] that could impact these parameters. Trends in Westslope Cutthroat Trout population parameters were evaluated based on monitoring data collected from 2017 to 2021 (Chapter 4 of the EoC report [Harmer Creek Evaluation of Cause Team 2023]; Thorley et al. 2022). The Grave Creek population area was use as a reference area for this evaluation.

The approach taken in the EoC to analyze potential stressors was to (1) characterize trends in each stressor for the Harmer Creek 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 recruitment failure of the 2018 spawn year, as appropriate, and (4) evaluate how each stressor trended relative to fish population parameters. The mechanisms by which the potential stressors could impact Westslope Cutthroat Trout were identified and it was determined if stressors were present at sufficient magnitude and duration to adversely affect Westslope Cutthroat Trout during the period of reduced recruitment. Together, these analyses were used in the EoC report to support conclusions regarding the relative contribution of each potential stressor to the reduced recruitment observed in the Harmer Creek population area.

This document is one of a series of Subject Matter Expert (SME) reports that support the overall Harmer Creek Westslope Cutthroat Trout EoC (Harmer Creek Evaluation of Cause Team 2023). For additional information, see the preceding Reader's Note.

[17] The EoC 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 EoC 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.

1.1.2 Report-specific Background

This report describes the investigation of compromised sediment quality as a causal or contributing factor in the reduced recruitment observed for the Harmer Creek Westslope Cutthroat Trout population.

Aquatic sediments can serve as both sink and/or a source of metals as well as polycyclic aromatic hydrocarbons (PAHs), either binding them into an unavailable form or releasing them into pore water (i.e., the water in the interstitial spaces between sediment particles) or the overlying water in forms that are potentially bioavailable. When considering bulk sediments, it is important to recognize that they are a mixture of minerals and organic compounds to which metals and PAHs may bind, and that bioavailability[18] varies among geochemical fractions (Baumann and Fisher 2011). The adsorption, desorption, and subsequent concentrations and distribution of metals and PAHs in sediments, pore water, and the water column are affected by many physicochemical factors, including pH, organic carbon content, grain size distribution, and redox conditions (Burton 1991; Paller and Knox 2013; Sprague 1995). For example, low pH waters increase the competition between metal ions and H^+ for binding sites in sediments and result in dissolution of metal complexes, thereby releasing free (aquo)[19] metal ions, which are more toxic than complexed metals, into the water column (Ali et al. 2019; Rieuwerts et al. 1998). These free (aquo) metal ions may be subsequently complexed organically or inorganically, depending on the conditions of the pore water. Concentrations of PAHs (e.g., Shi et al. 2007; Ukalska-Jaruga et al. 2018) and selenium (Van Derveer and Canton 1997; Wiramanaden et al. 2010) in sediments are expected to be strongly correlated with total organic carbon (TOC). Metals and PAHs are more closely associated with fine sediment particles (e.g., clay, silt), which have a greater adsorptive capacity, than coarse (e.g., gravel, cobble) particles (Christensen 1998; Rand et al. 1995; Zhang et al. 2014). Additionally, redox conditions can affect the speciation and bioavailability of certain metals and metalloids, like chromium, iron, manganese, and selenium (Burgess et al. 2013; Schwartz et al. 2016). In areas where calcite is abundant (as evidenced by high calcite index scores; see Zathey et al. 2021), sequestration of some metals, like cadmium, within the calcite matrix can influence bioavailability (Zhang et al. 2021) and complicate interpretation of sediment chemistry data. In general, constituent concentrations in pore water, rather than bulk sediment, better represent the concentrations available for uptake and partitioning into aquatic biota (Mayer et al. 2014; McGrath et al. 2019). Water column and pore

[18] Here, the bioavailable fraction of a constituent is considered to be the fraction that is available for uptake by aquatic organisms (i.e., the relevant exposure concentration) (National Research Council 2003).

[19] "Aquo" means that the metal is complexed by water molecules.

water concentrations are also a better predictor of toxicity than bulk sediment concentrations because metals and PAHs enter fish mainly through the gills and the digestive track, and to a lesser extent, through the skin (Baumann and Fisher 2011). For selenium, tissue chemistry data may be the best predictor of toxicity, given that water and diet are typically the major pathways associated with toxicity (Janz et al. 2010; Lemly 1987). Regardless, sediment chemistry is a useful line of evidence for interpreting the integrated effects of exposure to constituents in water, sediment, and diet on tissue chemistry and toxicity.

Westslope Cutthroat Trout often occupy headwater stream habitats, ideally those with a mix of run-riffle areas with coarse substrates (gravel and larger, depending on life stage) that are free of fines and pool habitats with cover (Government of Canada 2019; Hickman and Raleigh 1982). In particular, spawning occurs in riffle habitats with gravel substrates and low percentages of fines (Brown and Mackay 1995; COSEWIC 2006, 2016; Government of Canada 2019; Hickman and Raleigh 1982; Liknes and Graham 1988; Minnow 2021a). Accordingly, field crews performing redd surveys in Harmer and Grave creeks in 2021 noted that fish tended to spawn in gravel areas (Thorley 2021, pers. comm.).

Most research into the effects of sediments on salmonids has focused on the physical, rather than chemical, impacts of sediment on survival and recruitment (Hartman and Hakala 2006; Jensen et al. 2009; Magee et al. 1996; Weaver and Fraley 1993). Redds found in areas with high percentages of fine sediment exhibited reduced embryo survival and numbers of fry[20] (Magee et al. 1996; Weaver and Fraley 1993). Numerous studies have shown (as reviewed in Chapman 1988) that this is often due to “caking” of the redd surface, which prevents adequate oxygenation and flushing of metabolic wastes. Potential physical impacts of sedimentation on embryo-larval survival and the reduced recruitment in the Harmer Creek population were evaluated by Ecofish Research Ltd. (Ecofish; Durston and Hatfield 2022). By comparison, this report evaluates the potential effects of sediment chemistry on Westslope Cutthroat Trout recruitment in the Harmer Creek population area.

Early life stages of fish (e.g., embryos, alevins, fry) are generally considered to be the most sensitive in terms of toxicity. This is for a number of reasons including:

1. These life stages tend to be in close contact with the sediment:water interface (Pacle Decena et al. 2017);

[20] In the context of this SME report, Westslope Cutthroat Trout fry represent age-0 fish from swim-up until the January following their spawn year, when they are considered age-1 juveniles (Harmer Creek Evaluation of Cause Team 2023; Scott and Crossman 1988).

2. These early life stages are periods of rapid growth and major organ development and these processes can be particularly sensitive to chemical stressors in the environment (Ali et al. 2019); and

3. Even small developmental delays or slower growth in fish, which are common with exposure to metals and PAHs, can increase mortality (Jezierska et al. 2009; Young et al. 2018).

As previously indicated, direct contact with gills or skin is one potential mechanism of Westslope Cutthroat Trout exposure to sediment-related constituents. Eggs and alevins may be exposed to sediment-related constituents if fine sediments mobilized from upstream accumulate within the spawning and incubating substrates (Chapman 1988). Also, after emergence from the substrates, Westslope Cutthroat Trout fry establish territories in low-velocity habitats (i.e., back-water areas, eddies, and stream margins) before moving into habitats that are deeper and have higher water velocities as they grow (Bozek and Rahel 1991; Costello 2006; Moore and Gregory 1988a,b). The relatively short window when newly emerged fry use slow moving waters represents a critical period of development as well as a potential period of exposure to contaminants via direct contact with fine sediments that tend to accumulate in these slower-flowing areas (Burton 1991). Larger juvenile and adult[21] Westslope Cutthroat Trout typically occupy deeper pools and runs with abundant cover and large woody debris but a lower incidence of fine sediments (COSEWIC 2006, 2016; Government of Canada 2019). Therefore, direct contact with sediment-related constituents is expected to be highest for early life stages and lower for larger juveniles and adults.

Dietary uptake is another route of exposure to sediment-based constituents that is considered potentially relevant to the reduced recruitment in the Harmer Creek Westslope Cutthroat Trout population, specifically for free-feeding age-0 to age-1 fish (i.e., fry and juveniles) and spawning adults. Dietary exposure can occur either through incidental ingestion of sediment while feeding or indirectly via ingestion of prey items that have accumulated constituents from the sediment.[22] Overall, incidental ingestion of fine sediments and associated mine-related constituents is expected to be relatively low for Westslope Cutthroat Trout because, like other salmonids, they mainly consume invertebrate prey drifting in the water column (COSEWIC 2006, 2016; Elliot 1973; Fraser and Metcalfe 1997; Nakano et al. 1999). However, newly emerged fry

[21] Juveniles are defined as Westslope Cutthroat Trout that are age-1 or older with fork lengths <170 millimetres (mm). Fish with fork lengths greater than or equal to (≥) 170 mm are considered adults (Harmer Creek Evaluation of Cause Team 2023; Thorley et al. 2022; see also Wiebe et al. 2022).

[22] The direct effects of sediment chemistry on Westslope Cutthroat Trout recruitment were the focus of this SME report. Risks to Westslope Cutthroat Trout from consumption of prey that have accumulated metals and PAHs from water or sediment were not evaluated.

may "mouth" sediment particles (Burton 1991) and some trout diets can shift to a benthic feeding strategy, depending on the availability of invertebrate prey in drift (Kraus et al. 2016; Nakano et al. 1999). Trout that adopt a benthic feeding strategy might have a higher rate of incidental sediment ingestion than individuals that use a drift-based feeding strategy if microhabitats with fine sediments are targeted for feeding (i.e., fish that pick macroinvertebrates off rocks are less likely to ingest fine sediment than fish that consume invertebrates from deposits of fine sediment).

The investigation described in this SME report focused on two potential pathways of effects related to the reduced recruitment in the Harmer Creek Westslope Cutthroat Trout population (Figure 1.1):

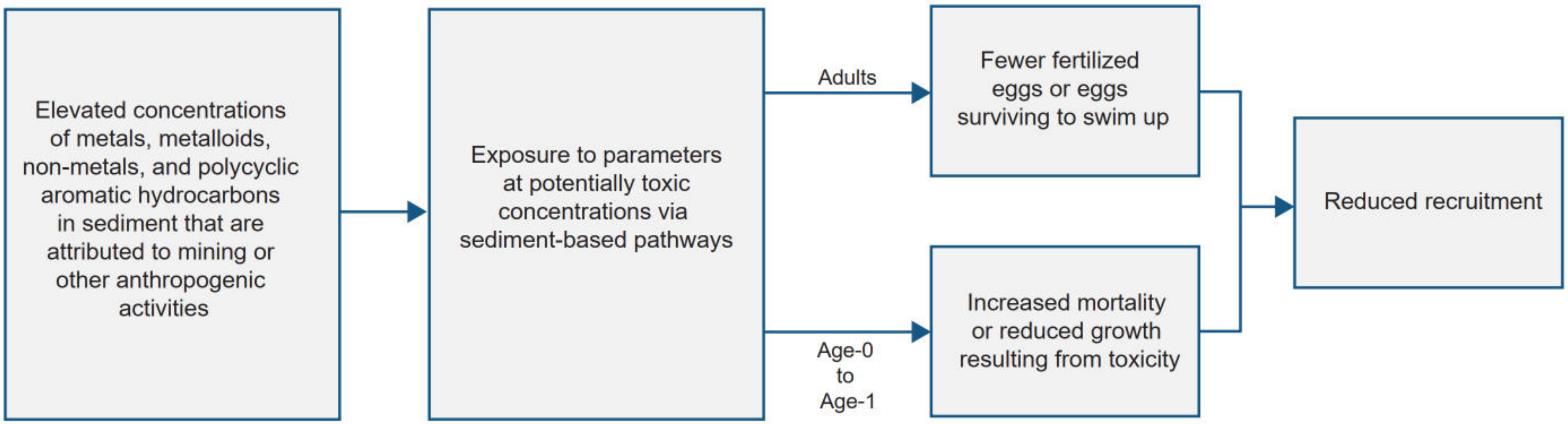
1. Exposure of adult spawners to sediment constituents leading to fewer fertilized eggs or eggs surviving to swim-up; and
2. Exposure of age-0[23] or age-1 fish to sediments leading to toxicity and subsequently reduced growth or mortality.

1.1.3 Author Qualifications

This project was managed by Ms. Amy Wiebe, who has a Master of Science degree in toxicology from the University of Saskatchewan and is a Registered Professional Biologist (R.P.Bio.). She has worked on a wide variety of projects related to aquatic toxicology, fish habitat, and fish health for proponents throughout western and northern Canada. Ms. Wiebe has 10 years of aquatic environmental consulting experience and has been managing projects for Teck Coal since joining Minnow Environmental Inc. (Minnow) in 2018. She is currently responsible for the design and implementation of monitoring programs to support Teck Coal's Greenhills Operation (GHO) and is a senior project advisor for the Study of the Reproductive Effects of Selenium on Columbia Spotted Frog (*Rana luteiventris*). Ms. Wiebe also recently managed an in-depth, multi-year study of lentic (slow-flowing or stagnant) aquatic habitats in the Elk River watershed.

Ms. Patricia Orr, who has a Master of Science degree from the University of Waterloo, specializing in aquatic biology and toxicology, fulfilled the role of senior project advisor. She has been working in aquatic environmental consulting since 1986 and was a co-founder of Minnow in 2000. Ms. Orr has been a consultant to Teck Coal and previous owners of the Elk Valley coal mines since 2002, managing a variety of projects such as: an investigation of the bioaccumulation and

[23] Age-0 includes embryos (from spawning to hatch) and alevins (from hatch until yolk sac absorption and swim up) in addition to fry (from swim up to the following January).



Causal Effects Pathway Diagram

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Figure 1.1

potential effects of aqueous selenium in lotic (flowing) and lentic aquatic habitats of the Elk River watershed downstream from coal mining; the design and implementation of local and regional aquatic effects monitoring programs; design and completion of various supporting studies; and provision of technical support to Teck Coal's Elk Valley Water Quality Plan (EVWQP), Adaptive Management Plan (AMP), and Tributary Management Plan. In addition to projects in the Elk River watershed, Ms. Orr has worked extensively across Canada to design and undertake studies evaluating the effects of effluents from metal mines (operating and closed/abandoned sites) and pulp and paper mills on aquatic receiving environments. She was the project manager responsible for developing the first Technical Guidance Document for Environmental Effects Monitoring (EEM) studies completed under the federal *Fisheries Act* and has also participated in the development of generic (federal and provincial) water quality guidelines, and various site-specific guidelines.

Dr. Jennifer Ings fulfilled the role of senior reviewer. Dr. Ings has a Doctor of Philosophy degree from the University of Waterloo, specializing in aquatic ecotoxicology, and completed two postdoctoral fellowships with renowned researchers in the field. She has worked on a large variety of projects related to the impact of anthropogenic effluents on the aquatic environment since 2001, including but not limited to pulp and paper mill effluent, municipal wastewater effluent, and oilsands process-affected waters. Dr. Ings has been working at Minnow since 2015 and has been managing projects for Teck Coal since 2017. She is currently in the role of Client Manager for Teck Coal and is a senior project advisor for a number of programs including the Regional Aquatic Effects Monitoring Program (RAEMP), the Fording River Operation (FRO) Local Aquatic Effects Monitoring Program (LAEMP), and the Elkview Operation (EVO) LAEMP, among other projects.

1.2 Objective

The objective of this report was to investigate the potential for sediment quality to adversely affect Westslope Cutthroat Trout in ways that may have caused or contributed to reduced recruitment of the 2017 to 2019 spawning year cohorts in the Harmer Creek population (Cope and Cope 2020; Harmer Creek Evaluation of Cause Team 2023; Thorley et al. 2022). Specifically, the intent was to answer the question "Were concentrations of metals, metalloids[24], and/or PAHs in sediment sufficiently elevated (i.e., relative to guidelines, reference area normal ranges, and historical concentrations) to result in adverse effects to Westslope Cutthroat Trout that could have caused or contributed to the reduced recruitment in Harmer Creek?".

[24] Metals and metalloids commonly included in a multi-element scan are hereafter collectively referred to as "metals".

1.3 Approach

The evaluation of sediment quality as a causal or contributing factor in the reduced recruitment observed for Harmer Creek Westslope Cutthroat Trout consisted of two parts:

1. A comparison of sediment chemistry data collected from the Harmer Creek population area during the period of interest for reduced recruitment to relevant guidelines and reference area normal ranges to identify Constituents of Potential Concern (COPCs); and

2. An evaluation of trends in sediment chemistry and other lines of evidence (e.g., bioavailability, and species sensitivity) to identify the key constituents of concern with respect to potential effects on Westslope Cutthroat Trout recruitment.

Sediment chemistry data were assessed relative to the lower and upper British Columbia Working Sediment Quality Guidelines (BC WSQG; BCMOECCS 2021a,b)[25], to identify constituents at concentrations above the guidelines (see Section 2.2.1 for additional background). Constituents with concentrations greater than the lower or upper BC WSQG were plotted. However, only those constituents with concentrations greater than the upper BC WSQG and reference area normal ranges in the Harmer Creek population area during the period of interest for reduced recruitment (i.e., 2016 to 2020) were considered COPCs. Trends in COPC concentrations (i.e., from 2013 to 2020, depending on available years of data) and other lines of evidence were evaluated to identify the key sediment constituents of concern for the period of reduced recruitment. Site-specific information and primary literature were used to evaluate differences between the Harmer Creek and Grave Creek population areas, data underlying the guidelines, factors that may modify toxicity, and possible exposure pathways relevant to effects on Westslope Cutthroat Trout recruitment.

For sediment quality to explain the reduced recruitment for the Harmer Creek Westslope Cutthroat Trout population, the data evaluation would be expected to show two or more of the following results:

- Constituent concentrations in sediments from the Harmer Creek population area that were elevated relative to BC WSQG and reference area normal ranges starting in 2016 or 2017;
- Greater concentrations in the Harmer Creek population area, compared to the Grave Creek population area; and

[25] Any reference to the BC WSQG includes the alert concentration for selenium, which was treated as an upper BC WSQG throughout this SME report.

- Effects to sediment quality in the Harmer Creek population area that were large in magnitude and widespread in area, which would be necessary to explain such a large magnitude of effect on Westslope Cutthroat Trout recruitment.

2 METHODS

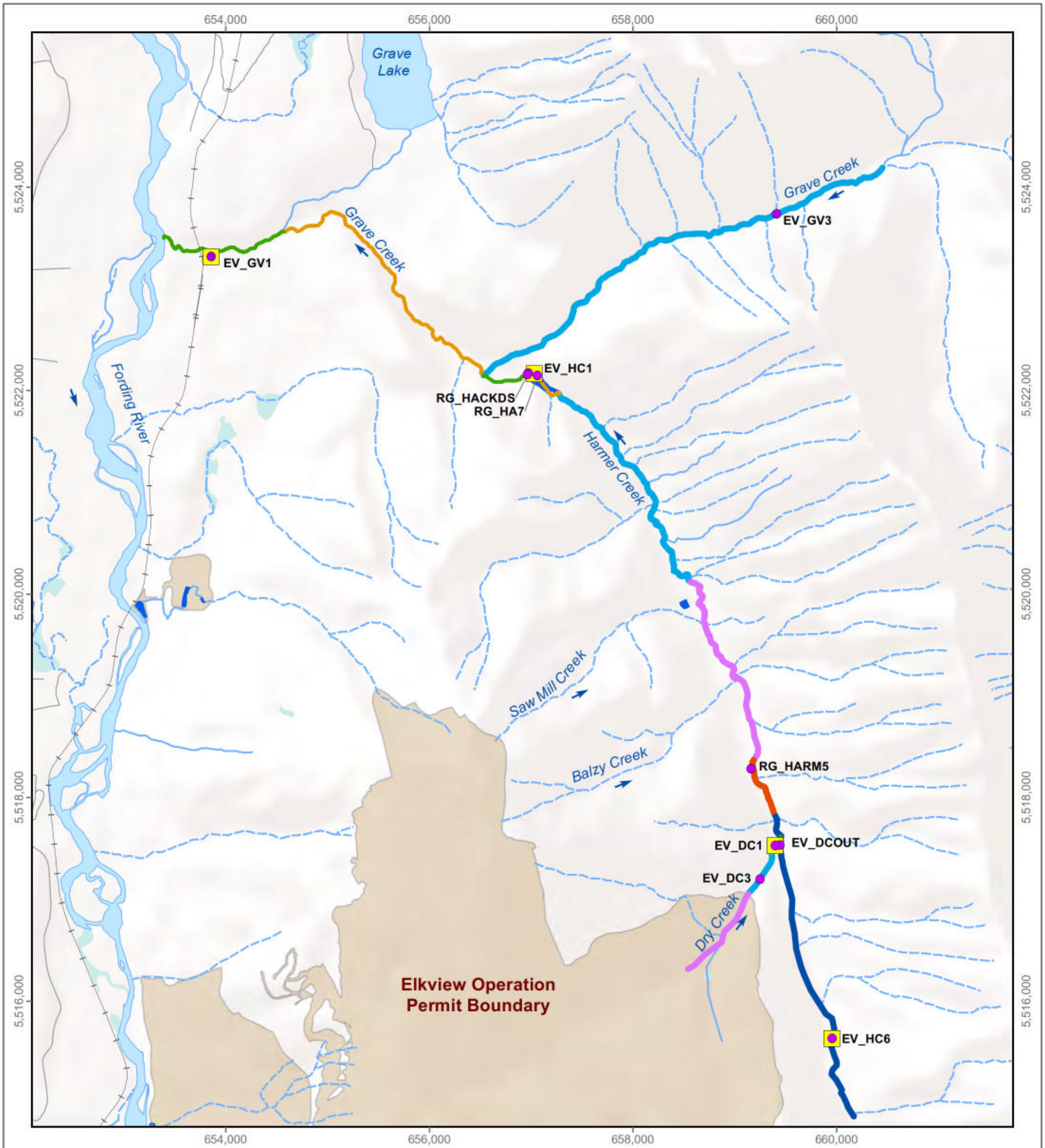
2.1 Data Sources

Sediment chemistry data for the Harmer Creek and Grave Creek population areas were compiled by Teck Coal and provided to the SMEs. Data collected to support various aquatic monitoring programs were available from 2013 and 2018 to 2020, depending on location (Figure 2.1; Table 2.1). Specifically, data sources included:

- RAEMP reports and data sets (Minnow 2020a; unpublished 2020 data from Minnow);
- 2013 Sediment Sampling Program for the Coal Mines in the Elk River Valley, British Columbia (BC; Minnow 2014a);
- Elkview Operations Baldy Ridge Extension Project Annex F – Surface Water and Sediment Quality Baseline Report (Golder 2015);
- Unpublished data from monitoring completed by Minnow in 2019; and
- Dry Creek Aquatic Health Baseline Study – Field Summary Report (Nupqu and Hemmera 2020).

Sediment chemistry samples were collected from Harmer Creek, downstream from the Harmer Creek dam/spillway at the outlet of Harmer Creek Sedimentation Pond (i.e., at RG_HACKDS) in 2018 to 2020 as part of the RAEMP (Figure 2.1; Table 2.1; Minnow 2018a, 2020a). Each year, a stainless-steel spoon was used to collect five replicate sediment samples from small deposits of fine sediment located in slow-moving habitats (e.g., backwaters, eddies, stream margins) beside riffle habitats that were dominated by larger substrates (i.e., cobble with some sand, gravel, and boulders) (Minnow 2020a). The top 1 to 2 centimetres (cm) of sediment was included in the samples, which were homogenized and then divided among sample containers. Sub-samples for analysis of metal concentrations, moisture content, TOC, and particle size were transferred to polyethylene bags and sub-samples for analysis of PAHs were placed in glass jars. Samples were stored cold, but not frozen, until analysis. Sediment chemistry sub-samples were homogenized and analyzed by ALS Environmental (ALS) in Calgary, Alberta (AB) prior to analysis using the following methods (Minnow 2020a):

- Metals by Collision Reaction Cell Inductively Coupled Plasma-Mass Spectrometry (CRC ICP-MS; United States Environmental Protection Agency [EPA] 200.2/6020A);
- Mercury by Cold Vapour Atomic Absorption Spectroscopy (CVAAS; EPA 200.2/245.7);
- Total inorganic carbon by treatment with acetic acid (Canadian Society of Soil Science [CSSS] 2008 P216-217);



LEGEND
- Sediment Sampling Location
- Teck Water Quality Station

Reach Break
- GRV-R1, HRM-R1, DC-R1
- GRV-R2, HRM-R2, DC-R2
- GRV-R3, HRM-R3, DC-R3
- HRM-R4, DC-R4
- HRM-R5
- HRM-R6

Sediment Sampling Areas on Dry, Harmer, and Grave Creeks, 2013 to 2020

0 0.75 1.5 3 km

N W E S

Projection: North American Datum 1983 UTM Zone 11
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Figure 2.1

Table 2.1: Sediment Chemistry Sampling Locations in the Harmer Creek and Grave Creek Westslope Cutthroat Trout Population Areas, 2013 to 2020

Westslope Cutthroat Trout Population	Status	Parent Biological Area Code [a]	Biological Area Description	UTMs for Biological Area Code (NAD83, 11U)		Codes Grouped under Parent Code	Data Years and No. of Replicates Per Sampling Event [b]
				Easting	Northing		
Harmer	Reference	EV_HC6	Harmer Creek upstream from Dry Creek	659954	5515635	-	2013 (1)
	Mine-exposed	EV_DC3	Dry Creek upstream from Dry Creek Sedimentation Pond	659248	5517201	-	2020 (1)
		EV_DC1 [c]	Dry Creek Sedimentation Pond	659354	5517484	-	2013 (1)
		EV_DCOUT	Dry Creek downstream from Dry Creek Sedimentation Pond	659423	5517558	-	2020 (1)
		RG_HARM5	Harmer Creek downstream from Dry Creek	659158	5518284	-	2020 (1)
		RG_HA7	Harmer Creek Sedimentation Pond	657057	5522152	RG_HA7	2013 (5), 2019 (5)
				657129	5522048	EV_HC2	2013 (1)
Grave	Reference	EV_GV3	Grave Creek upstream from Harmer Creek	659411	5523739	-	2013 (1)
	Mine-exposed	RG_HACKDS	Harmer Creek downstream from the dam/spillway at the downstream end of Harmer Creek Sedimentation Pond	656969	5522171	-	2018 to 2020 (5 per year)
		EV_GV1	Grave Creek near the confluence with the Elk River	653854	5523320	-	2013 (1)

Notes: UTMs = Universal Transverse Mercator coordinates; NAD = North American Datum; No. = number; - = no data/not applicable.

[a] The "Parent Biological Area Code" is used for all areas grouped under the parent code (e.g., RG_HA7 is used to refer to RG_HA7 and EV_HC2).

[b] Number of replicate samples collected is in brackets for each data collection year.

[c] Samples were collected from within Dry Creek Sedimentation Pond, but near the inflow.

- Total carbon by combustion method (CSSS 2008 21.2);
- PAHs by rotary extraction using hexane/acetone (EPA 3570/8270) followed by capillary column gas chromatography with mass spectrometric detection (GC/MS);
- Particle size distribution by dry sieving (coarse particles), wet sieving (sand), and the pipette sedimentation method (fine particles); and
- Moisture content by gravimetric analysis (i.e., samples were dried at 105 degrees Celsius [°C]).

Sediment samples were collected from Harmer Creek Sedimentation Pond in 2013 as part of the Sediment Sampling Program for the Coal Mines in the Elk River Valley, BC (Minnow 2014a). A four-inch (10.2 cm) diameter corer was used to collect five replicate samples from RG_HA7 (Figure 2.1; Table 2.1). Once a core was retrieved, a core extruder was used to push the sediment sample upwards toward the top of the core tube. An extrusion collar marked with 1 cm intervals was aligned with the top of the tube and the sediment was extruded upward to a depth of 2 cm. This 2 cm thick sample was removed with a core slicer and transferred to a plastic tub. This process was completed until sufficient sample volume for analysis was obtained (approximately n = 8 cores). A stainless-steel spoon was used to homogenize each sample and transfer the sediment into a glass jar (PAHs) and a Ziploc® bag (all other analyses). Samples were stored cold, but not frozen, until analysis. Sediment chemistry samples were homogenized and analyzed by ALS in Burnaby, BC. Mercury concentrations were determined by Cold Vapour Atomic Fluorescence Spectrometry (CVAFS) and carbon content was determine using methods from Bartels and Sparks (2009). All other analytical methods were consistent with those described above for the 2018 to 2020 RAEMP samples (Minnow 2014a, 2018b, 2020a).

Sediment chemistry samples were also collected from lotic habitats within Harmer and Grave creeks, as well as in Harmer Creek Sedimentation Pond, in 2013 to support the Elkview Operations Baldy Ridge Extension Project baseline (Figure 2.1; Golder 2015). One replicate sample was collected per area (Table 2.1). Areas with deposits of fine sediments were targeted and sampling methods were consistent with the RAEMP. Samples were kept cool until they could be analyzed for particle size, TOC, metals, and PAHs at ALS in Burnaby, BC.

Sediment chemistry samples (n = 5 replicates) were collected from Harmer Creek Sedimentation Pond in 2019 (Figure 2.1; Table 2.1; unpublished data set from Minnow). A Petite Ponar was used to collect the samples and a stainless-steel spoon was used to remove the top 1 to 2 cm of sediment from each Petite Ponar grab. The top 1 to 2 cm of sediment was retained and successive Petite Ponar grabs were completed until a sufficiently large sample was obtained for chemical analyses. Sample handling, shipping, and analyses were consistent with the 2018 to 2020 RAEMP samples (Minnow 2018b, 2020a).

Sediment sampling was completed in 2020 to support the Dry Creek Aquatic Health Baseline Study (Nupqu and Hemmera 2020). Two samples were collected in Dry Creek (EV_DC3 and EV_DCOUT) and one was collected in Harmer Creek between the Dry Creek mouth and the inflow to the Harmer Creek Sedimentation Pond (RG_HARM5; Figure 2.1; Table 2.1). Samples were collected from deposits of soft, fine sediments located along the banks of the creeks; however, other aspects of the sampling methods differed from those used for the RAEMP (see Section 3.3). For the Dry Creek Aquatic Health Baseline Study, a gloved hand was used to remove the top 10 cm of material[26] before collecting the underlying sediment for chemistry analyses. Pebbles, chunks of calcite, and other larger debris were removed from the samples and discarded; the remaining fine sediment was transferred to glass jars (Nupqu and Hemmera 2020). Samples were analyzed by ALS in Calgary, AB using analytical methods consistent with the 2018 to 2020 RAEMP samples (Minnow 2018b, 2020a; Nupqu and Hemmera 2020).

2.2 Identification of Constituents of Potential Concern

2.2.1 Comparisons to Guidelines and Reference Area Normal Ranges

The first step in the COPC identification process involved tabulating and comparing concentrations of metals and PAHs in sediment samples from 2013 to 2020 (Table 2.1) to BC WSQG (BCMOECSS 2021a,b). Data for samples collected from the Grave Creek population area (where recruitment was likely at replacement levels) were included in the data table to support the integrated assessment in Section 2.3. Data for constituents without BC WSQG were included in the data table but were not considered further in the assessment of sediment quality. The rationale for this approach was that guidelines are generally developed on a priority basis. This prioritization is based on potential risks associated with the toxic properties of constituents, exposure levels, and concerns or input from stakeholder groups (CCME 2001; CEPA 1999). Uncertainties associated with this approach are discussed in Section 3.3).

The BC WSQG represent guidelines that were derived by other jurisdictions and adopted by the British Columbia Ministry of Environment and Climate Change Strategy (BCMOECCS) to support protection of aquatic life (BCMOECCS 2021b). The guidelines adopted by the BCMOECCS generally have two values and are based on concentrations of constituents in the sediment that

[26] This material included pine needles, plant material, small gravel particles, and calcite particles; fine sediments comprised approximately 40% of the material that was removed prior to sampling the underlying sediment (Morrison 2021a,b, pers. comm.). It is therefore possible that sediments deposited in 2020 were discarded and the samples collected in 2020 contain sediments deposited in years prior (e.g., 2018 and 2019).

would be unlikely to cause adverse effects to aquatic biota (including fish). The lower guideline value (i.e., the lower BC WSQG) represents concentrations that protect aquatic life from the adverse effects of a potentially toxic constituent in most situations. The upper guideline value (i.e., the upper BC WSQG) represents concentrations that are considered likely to cause adverse effects in aquatic biota (BCMOECCS 2021b). Together, these guidelines can be used to assess the potential for adverse biological effects, and represent three concentration ranges[27]:

- Concentrations less than the lower BC WSQG (adverse biological effects are rarely expected);
- Concentrations between the lower WSQG and upper WSQG (adverse biological effects may occur occasionally); and
- Concentrations greater than the upper guideline (adverse biological effects are expected to occur more frequently than at lower concentrations).

Comparisons to sediment quality guidelines are a means to identify areas with a potential risk of adverse effects to biota based on constituent concentrations in the sediment, but do not indicate that the risk is unacceptable and, in most cases, additional assessments are required to understand the implications of sediment constituents with concentrations that are elevated compared to the guidelines. Most sediment quality guidelines have been developed based on studies of effects to benthic invertebrates in the field relative to the concentrations of constituents in sediments present at the same locations. The guideline derivation approach assumes that any constituents present in the sediment mixture may have caused or contributed to the observed effects whereas investigations into specific causative factors or interactions among constituents were not typically completed (BCMOECCS 2021b). Such an approach allows for confidence that concentrations below the guidelines are unlikely to cause adverse effects, but there is uncertainty whether adverse effects will occur at concentrations greater than the guidelines (CCME 1995). There is also uncertainty regarding the applicability of guidelines to other biota, in particular non-benthic fish species such as Westslope Cutthroat Trout. Overall, comparison of metals and PAHs in sediments to BC WSQG represents a highly conservative approach to assessing the risk for adverse effects that may impact Westslope Cutthroat Trout recruitment.

Constituents with sediment concentrations greater than the lower or upper BC WSQG were plotted relative to BC WSQG and regional reference area normal ranges. The regional reference area normal ranges presented in the plots represent the 2.5th and 97.5th percentiles of the

[27] Selenium is the sole exception. Adverse biological effects are expected to be rare below the alert concentration (which is treated like an upper WSQG in this report). However, at concentrations above the alert concentration, there may be a greater risk for bioaccumulation and adverse biological effects in species or groups (i.e., egg-laying vertebrates) that are particularly sensitive to selenium (BC MOE 2014).

reference area data for a particular constituent (Minnow 2020a,b). For lotic habitats, regional reference area normal ranges were calculated from sediment chemistry data collected as part of the RAEMP (Minnow 2020a).[28] Reference area normal ranges derived as part of the Lentic Area Supporting Study (Minnow 2020b) were applied to depositional areas, specifically Dry Creek Sedimentation Pond (EV_DC1) and Harmer Creek Sedimentation Pond (RG_HA7; Figure 2.1; Table 2.1). In the Elk River watershed, the concentrations of many constituents in sediment from areas considered to be in reference condition (i.e., areas unexposed to mine-influence) are above the lower BC WSQG (Minnow 2020a,b). Consequently, the upper limits of regional reference normal ranges for both lotic and lentic areas are greater than the respective lower BC WSQG for many constituents, including selenium (Minnow 2020b; Minnow 2021b; Minnow and Lotic 2021). The guideline comparison and generation of data plots were performed in R (R Core Team 2020).

2.2.2 Temporal Consideration

Data tables and plots were further evaluated to identify constituents with concentrations that were elevated relative to upper BC WSQG and reference area normal ranges in the Harmer Creek population area specifically during the period of interest associated with reduced recruitment. Constituents with concentrations that were greater than the upper BC WSQG and regional reference area normal ranges in the Harmer Creek population area between 2016 and 2020 were identified as COPCs and were evaluated in more detail as described in Section 2.3.

2.3 Detailed Evaluation of Trends and Other Lines of Evidence

2.3.1 Overview

Constituents identified as COPCs based on the steps described in Sections 2.2.1 and 2.2.2 were included in the detailed assessments of temporal trends in sediment chemistry, potential exposure pathways, bioavailability, and relative species sensitivity. The objective of the detailed assessment was to determine if sediment concentrations of one or more of the COPCs may have contributed to potential effects on Westslope Cutthroat Trout recruitment in the Harmer Creek population area (i.e., to identify “key constituents of concern”).

2.3.2 Evaluation of Trends

Trends in sediment characteristics (e.g., TOC, particle size distributions) and COPC concentrations over time were assessed for areas with two or more years of data using an Analysis of Variance (ANOVA) with a *Year* factor, an equal-variance t-test, or equivalent non-parametric tests, as appropriate. The best transformation was chosen as the transformation

[28] The most up-to-date regional reference area normal ranges for lotic sediments were first reported in the 2020 GHO LAEMP report (Minnow 2021b).

(i.e., $\log_{10}$, or untransformed) for which a Shapiro-Wilk's test on the residuals gave the highest p-value (i.e., most normally distributed). Significance of the pairwise comparisons was assessed with α of 0.05 in a Tukey's Honestly Significant Difference (HSD) test, which corrects for the number of comparisons.

To support the interpretation of the temporal comparisons, a magnitude of difference (MOD) was calculated for each year compared to the first, or base, year of sampling (e.g., 2013 for RG_HA7; Table 2.1). The MOD was calculated based on the following equation:

$$MOD = (MCT_{\text{given year}} - MCT_{\text{base year}}) / (MCT_{\text{base year}}) \times 100$$

where MCT is the measure of central tendency (mean for untransformed data, geometric mean for $\log_{10}$-transformed data, and median for non-parametric tests).

To the extent possible based on the output tables and plots, qualitative comparisons of trends in COPC concentrations were made for the Harmer Creek and Grave Creek population areas. Statistical comparisons among population areas could not be completed due to the sparsity of data.

2.3.3 Potential Exposure Pathways

Aquatic organisms can be exposed to metals and PAHs via water, sediment, or dietary pathways. Dissolved metals in the water column are considered the form most readily available for uptake (John and Leventhal 1995) but many metals and PAHs accumulate in sediment, which can then act as a source of contaminants, depending on chemical conditions (e.g., pH, redox) (Ingersoll 1995; see also Section 1.1.2). Concentrations of contaminants in pore water and/or the water just above the sediment surface are often much higher than concentrations in the overlying water column due to their close contact with the sediments and the processes that occur within (Rand et al. 1995).[29] For metals in sediments to exert acute toxic effects to fish, conditions need to favour partitioning from the sediment to pore water or surface water (Mayer et al. 2014). For organisms in close association with the sediment, ingestion is also considered a significant route of uptake for bioaccumulative substances (Rand et al. 1995).

Information regarding the spatial distributions of fine sediments and fish use were examined to evaluate possible exposure pathways relevant to potential recruitment effects in Westslope Cutthroat Trout from the Harmer Creek population area. The presence and distribution of fine sediments within the Harmer Creek and Grave Creek population areas and information on fish use were compiled from the reports listed in Section 2.1, as well as field photos and data sheets

[29] The potential for waterborne metals and PAHs to have caused or contributed to the reduced recruitment in the Harmer Creek Westslope Cutthroat Trout population was evaluated in the SME report for Water Quality (Warner and de Bruyn 2022).

from the RAEMP and other monitoring programs (unpublished data from Minnow and from 2021 spring spawning surveys). This information was examined to assess the potential for different life-stages of Harmer Creek Westslope Cutthroat Trout to contact fine sediments and sediment-associated constituents. Data for the Grave Creek population area were used to support identification of any differences in the spatial distributions of fine sediments and fish use that might explain why recruitment effects were observed in the Harmer Creek, but not the Grave Creek, population area.

2.3.4 Bioavailability and Species Sensitivity

Benthic invertebrate community data were evaluated as an indicator of potential biological effects of constituents in sediment. As part of this evaluation, species sensitivity distributions presented in the scientific literature were evaluated. If the relevant literature indicates benthic invertebrates are as or more sensitive to a particular COPC than Westslope Cutthroat Trout or other salmonids, then benthic invertebrates were considered to be a sensitive indicator of potential effects to Westslope Cutthroat Trout.

The potential for various abiotic factors to influence the expression of COPC toxicity to Westslope Cutthroat Trout recruitment were also evaluated, based on relevant literature. Supporting information from other SME reports (e.g., de Bruyn et al. 2022; Warner and de Bruyn 2022) were also considered.

3 RESULTS

3.1 Constituents of Potential Concern

Concentrations of arsenic, cadmium, manganese, nickel, selenium, zinc, benz(a)anthracene, benzo(a)pyrene, chrysene, dibenz(a,h)anthracene, fluoranthene, fluorene, 2-methylnapthalene, naphthalene, phenanthrene, and pyrene were greater than the lower, and sometimes also the upper, BC WSQG in one or more samples collected from the Harmer Creek and Grave Creek population areas from 2013 to 2020 (Figure 3.1; Appendix Table A.1). The upper boundaries of reference area normal ranges were greater than the lower guideline for all of these substances, except benz(a)anthracene, benzo(a)pyrene, dibenz(a,h)anthracene, and fluoranthene in lotic habitats, where reference area normal ranges have not yet been established. The reference area normal ranges were also greater than the alert concentration for selenium (lotic and lentic) and the upper BC WSQG for fluorene (lentic only), 2-methylnaphthalene (lotic and lentic), naphthalene (lentic only), and phenanthrene (lotic and lentic) (Figure 3.1; Appendix Table A.1).

The metals that were found at concentrations greater than the upper BC WSQG and reference area normal ranges in sediment samples collected between 2013 and 2020 were cadmium (Dry Creek), manganese (Harmer Creek downstream from the Harmer Creek Sedimentation Pond), nickel (Dry Creek), and selenium (Dry Creek, Harmer Creek Sedimentation Pond, and Harmer Creek downstream from the Harmer Creek Sedimentation Pond; Figure 3.1; Appendix Table A.1). However, cadmium, nickel, and selenium were the only constituents with concentrations that were elevated relative to the upper BC WSQG and reference area normal ranges in the Harmer Creek population area during the period of interest for reduced recruitment (i.e., from 2016 to 2020; Figure 3.1; Appendix Table A.1). Specifically, cadmium, nickel, and selenium concentrations were elevated in Dry Creek in 2020 (although these samples could have contained sediments from years prior; see Sections 2.1 and 3.3) and selenium concentrations were elevated in the Harmer Creek Sedimentation Pond in 2019. Therefore, cadmium, nickel, and selenium were identified as sediment COPCs and evaluated in more detail (Sections 2.3 and 3.2). Manganese was not identified as a COPC because elevated concentrations occurred in the Grave Creek, but not the Harmer Creek, population area (Figure 3.1; Appendix Table A.1).

The PAHs that were found at concentrations greater than the upper BC WSQG and reference area normal ranges in sediment samples collected between 2013 and 2020 were chrysene and dibenz(a,h)anthracene (Harmer Creek Sedimentation Pond), fluorene and phenanthrene (Harmer Creek Sedimentation Pond and Harmer Creek downstream from the Harmer Creek Sedimentation Pond), and 2-methylnaphthalene (Harmer Creek downstream from the Harmer

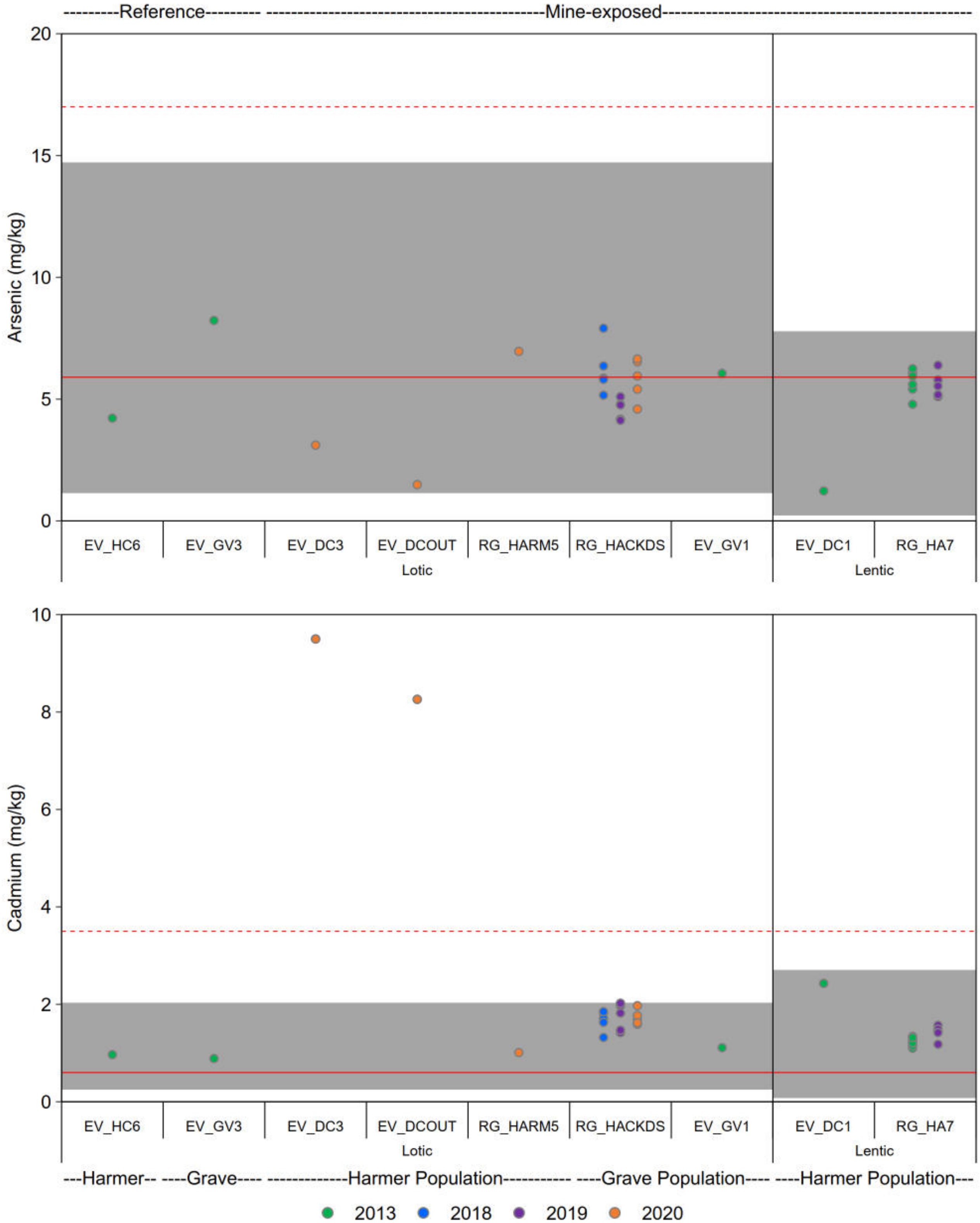
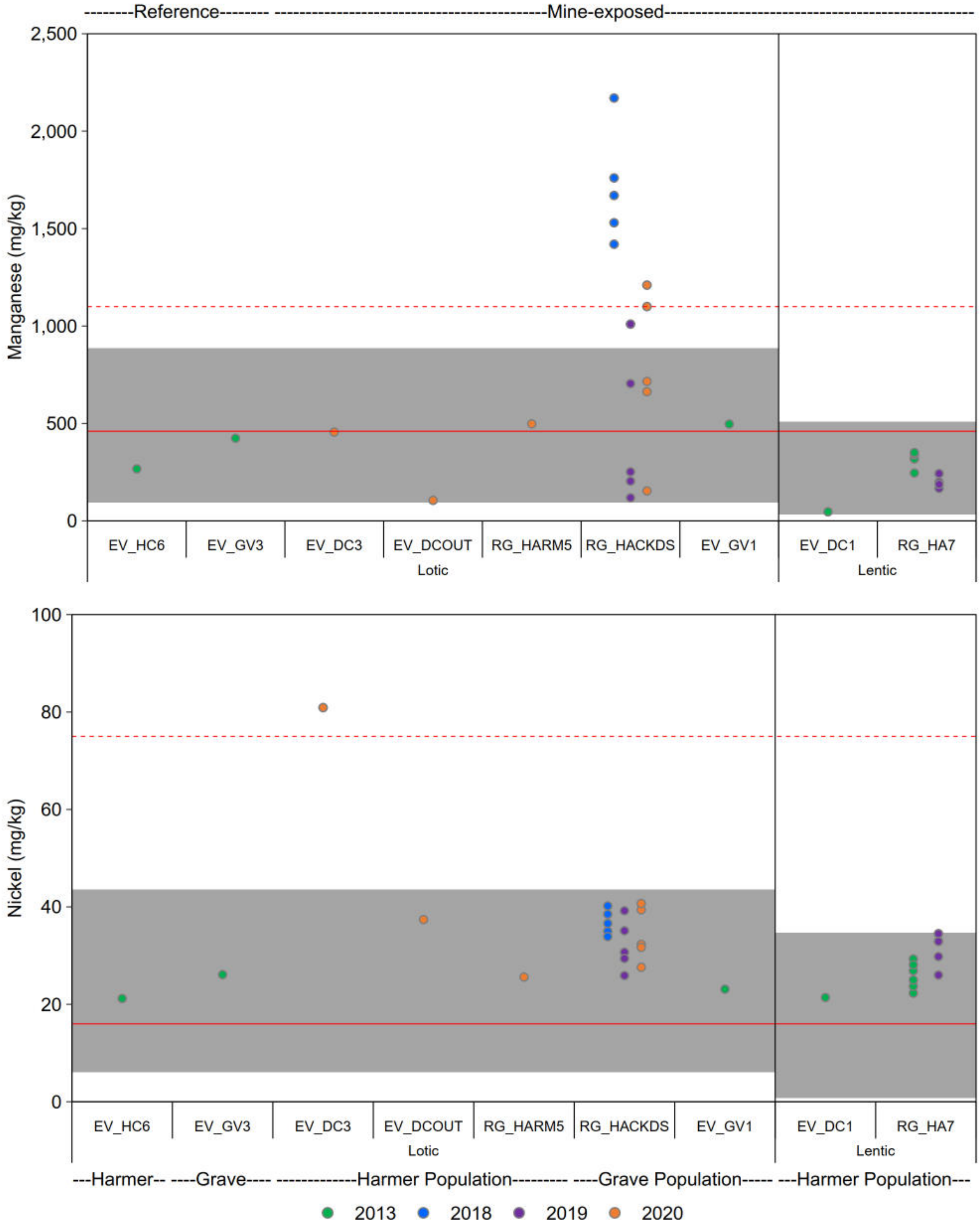


Figure 3.1: Constituents in Dry, Harmer, and Grave Creek Sediments with Concentrations Greater than Guidelines, 2013 to 2020

Notes: Values below the laboratory detection limit are shown with an open circle. Grey shading represents the reference area normal range (2.5th to 97.5th percentiles of reference area data collected as part of the Regional Aquatic Effects Monitoring Program [RAEMP] and the Lentic Area Supporting Study). Solid line = lower BC WSQG, dashed line = upper BC WSQG.



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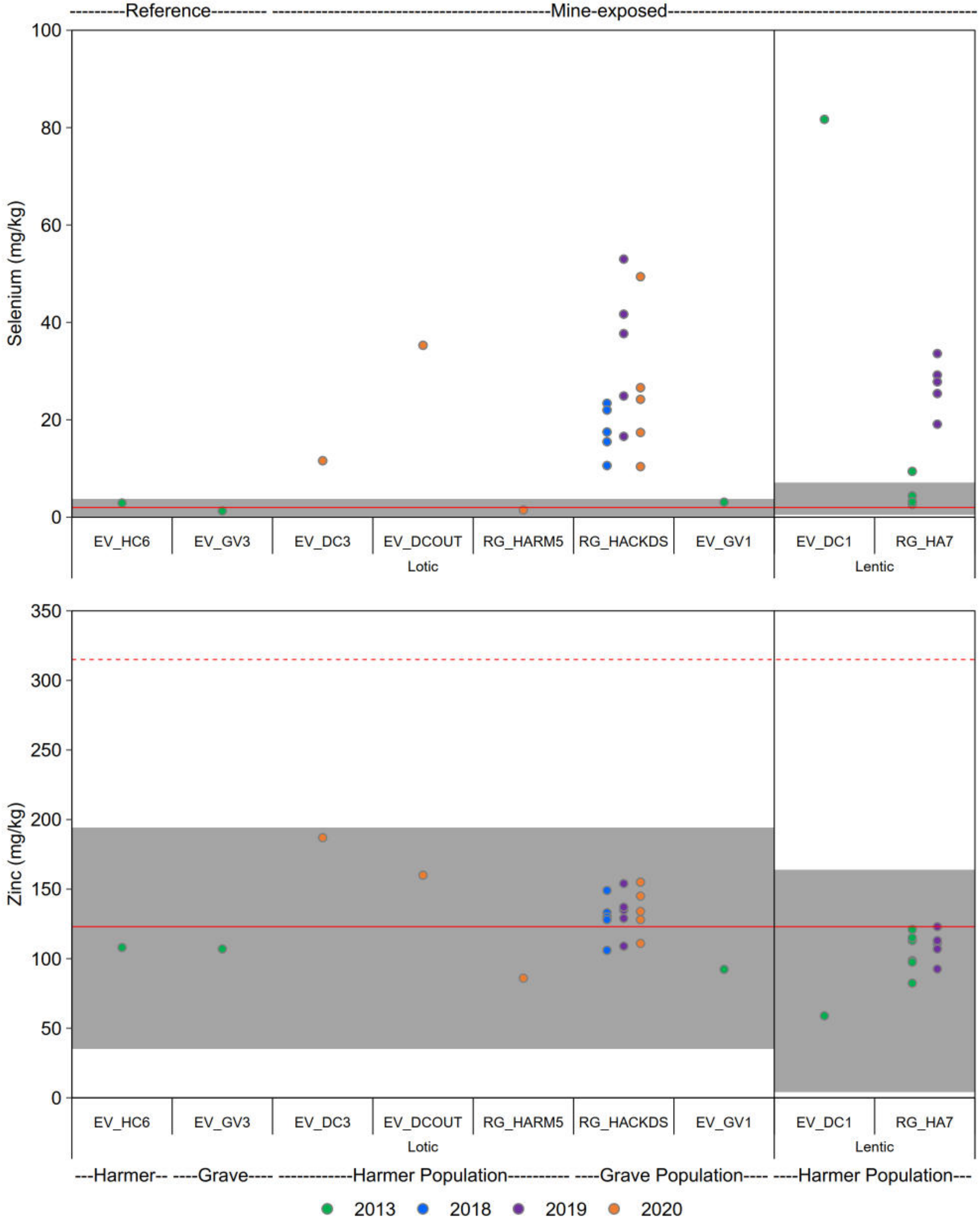


Figure 3.1: Constituents in Dry, Harmer, and Grave Creek Sediments with Concentrations Greater than Guidelines, 2013 to 2020

Notes: Values below the laboratory detection limit are shown with an open circle. Grey shading represents the reference area normal range (2.5th to 97.5th percentiles of reference area data collected as part of the Regional Aquatic Effects Monitoring Program [RAEMP] and the Lentic Area Supporting Study). Solid line = lower BC WSQG, dashed line = upper BC WSQG.

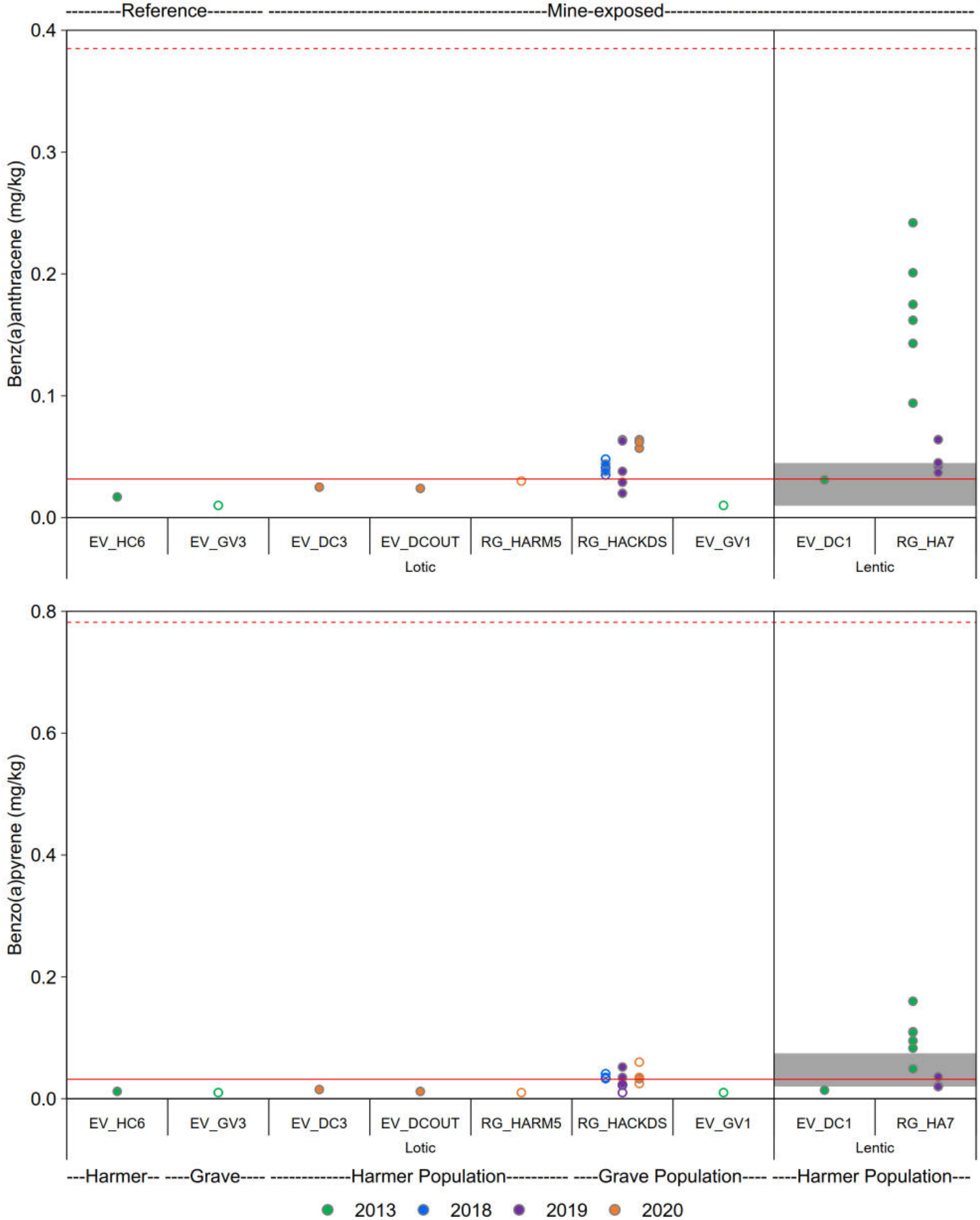
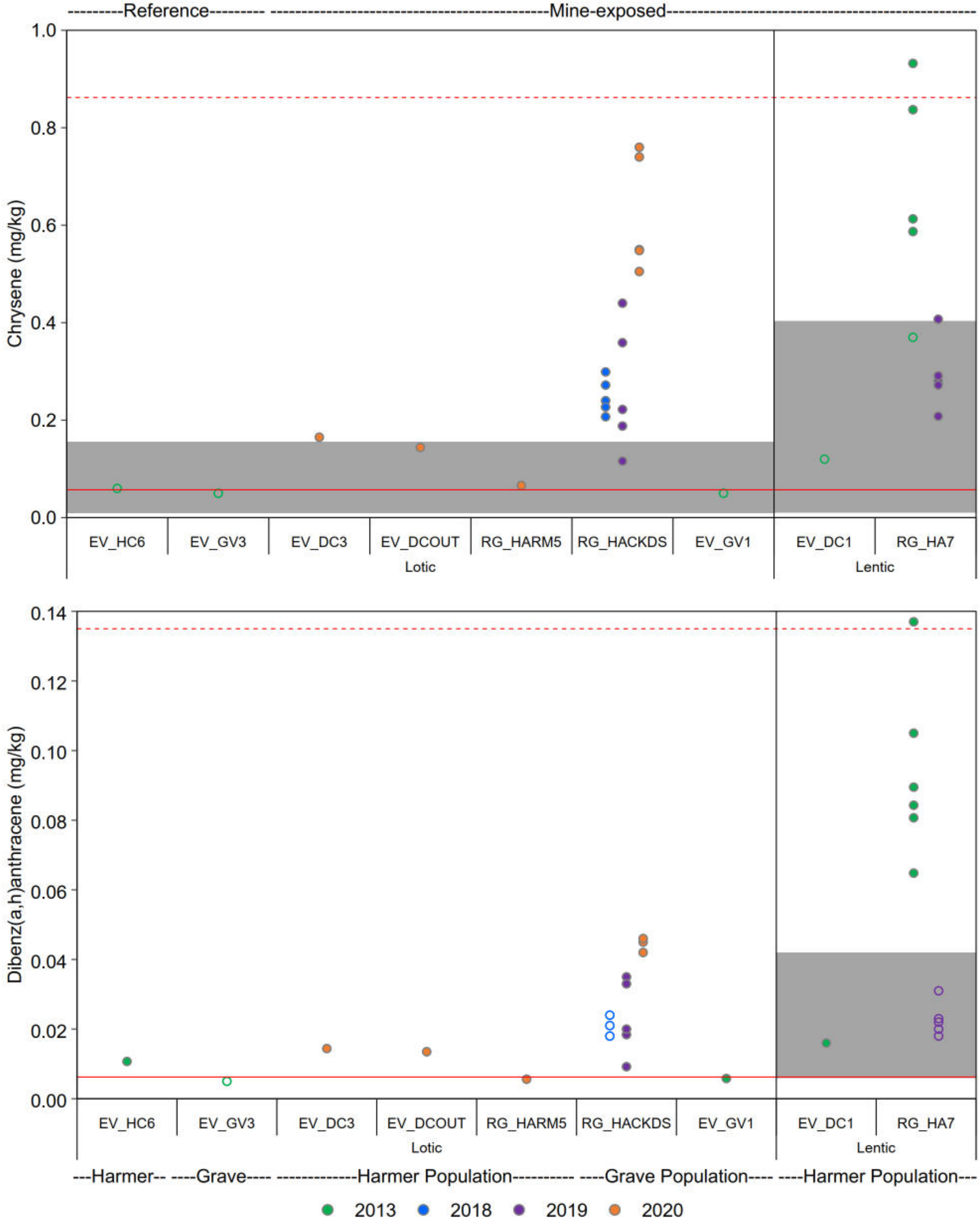


Figure 3.1: Constituents in Dry, Harmer, and Grave Creek Sediments with Concentrations Greater than Guidelines, 2013 to 2020

Notes: Values below the laboratory detection limit are shown with an open circle. Grey shading represents the reference area normal range (2.5th to 97.5th percentiles of reference area data collected as part of the Regional Aquatic Effects Monitoring Program [RAEMP] and the Lentic Area Supporting Study). Solid line = lower BC WSQG, dashed line = upper BC WSQG.



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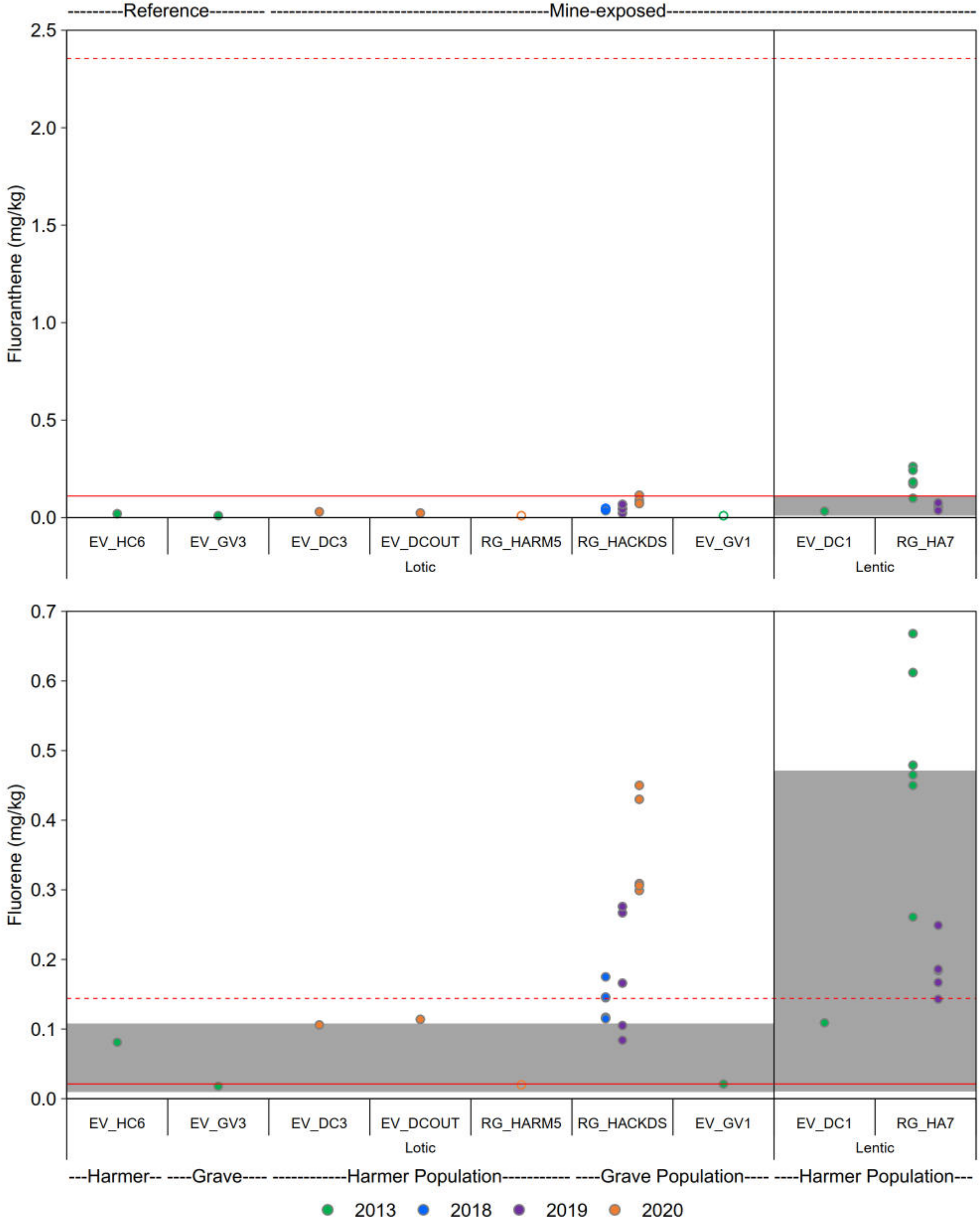

Figure 3.1: Constituents in Dry, Harmer, and Grave Creek Sediments with Concentrations Greater than Guidelines, 2013 to 2020

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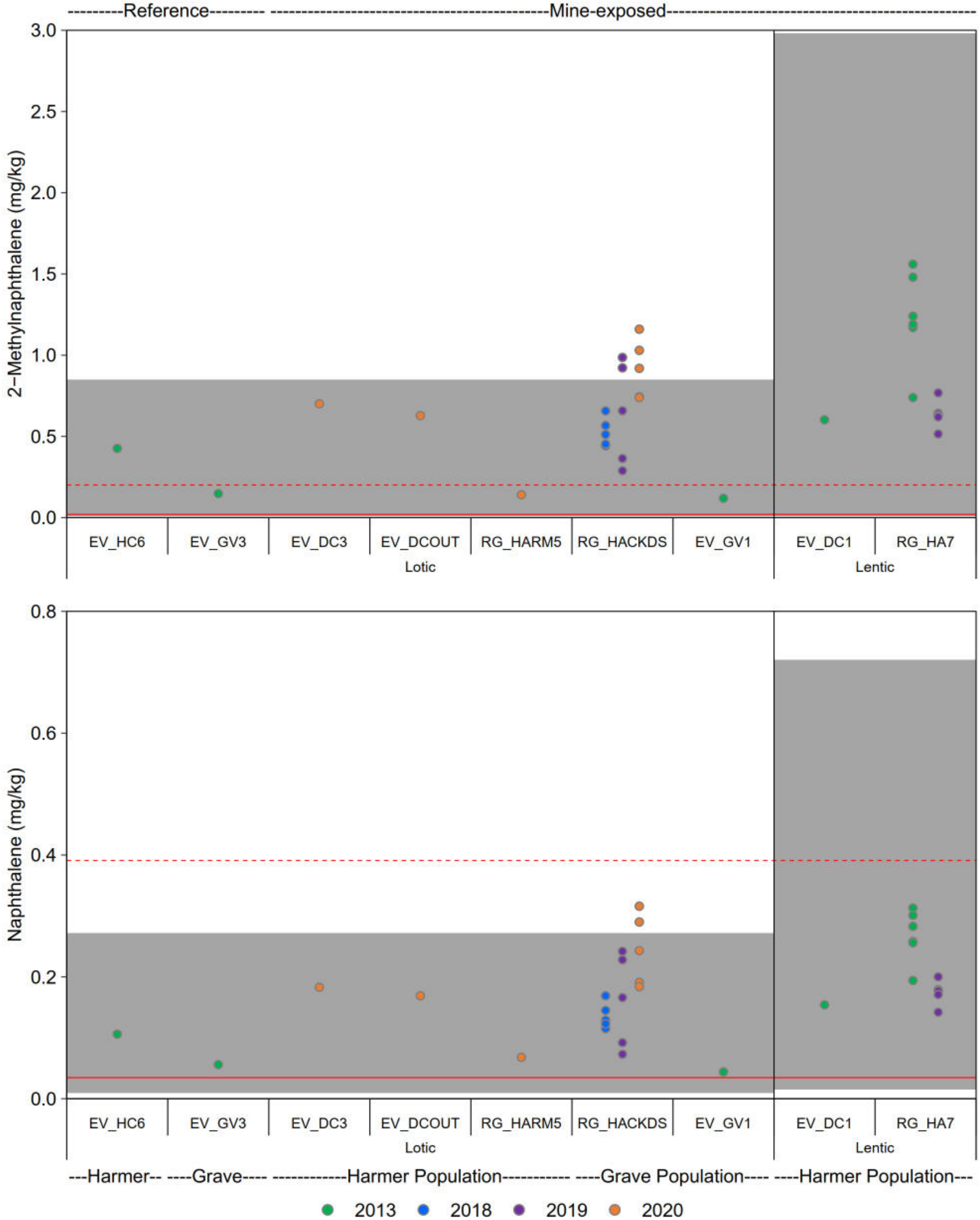

Figure 3.1: Constituents in Dry, Harmer, and Grave Creek Sediments with Concentrations Greater than Guidelines, 2013 to 2020

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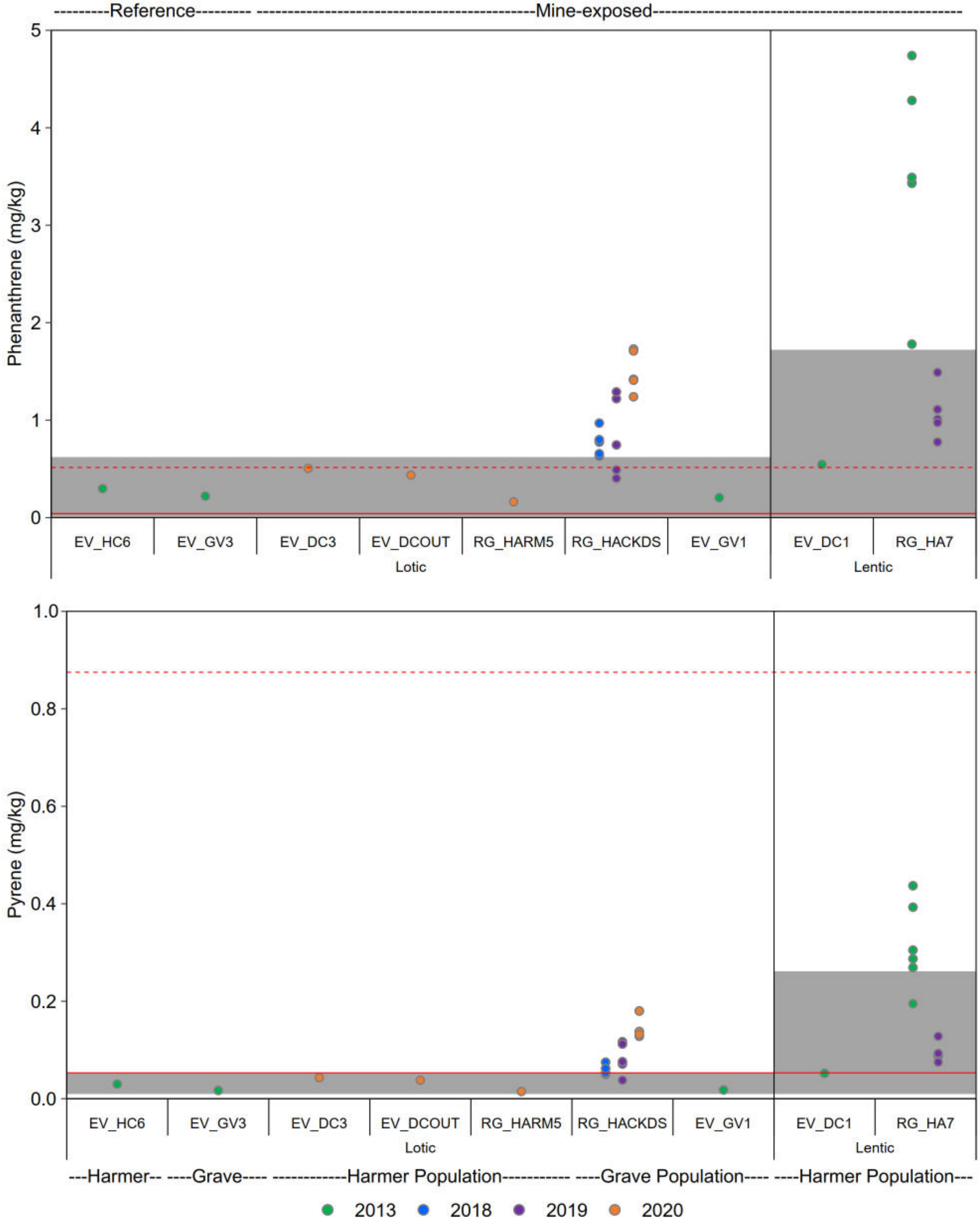


Figure 3.1: Constituents in Dry, Harmer, and Grave Creek Sediments with Concentrations Greater than Guidelines, 2013 to 2020

Notes: Values below the laboratory detection limit are shown with an open circle. Grey shading represents the reference area normal range (2.5th to 97.5th percentiles of reference area data collected as part of the Regional Aquatic Effects Monitoring Program [RAEMP] and the Lentic Area Supporting Study). Solid line = lower BC WSQG, dashed line = upper BC WSQG.

Creek Sedimentation Pond) (Figure 3.1; Appendix Table A.1). However, elevated PAH concentrations in the Harmer Creek population area (relative to the upper BC WSQG and reference area normal ranges) were limited to the Harmer Creek Sedimentation Pond in 2013 (i.e., prior to the period of reduced recruitment; Figure 3.1; Appendix Table A.1). Therefore, because no PAHs were elevated relative to the upper BC WSQG and reference area normal ranges in the Harmer Creek population area during the period of interest for the reduction in recruitment, no PAHs were identified as COPCs.

3.2 Detailed Evaluation of Trends and Other Lines of Evidence

3.2.1 Evaluation of Trends

Harmer Creek Sedimentation Pond (RG_HA7) was the only sediment sampling location in the Harmer Creek population area that had more than one year of sediment chemistry data (i.e., for 2013 and 2019; Table 2.1). There were no significant changes in sediment particle size or TOC in Harmer Creek Sedimentation Pond between 2013 and 2019 (Table 3.1), which suggests that any temporal changes in constituent concentrations were not likely attributable to changes in these characteristics over time. Although PAHs were not the focus of the trend evaluation, notable decreases (i.e., 35 to 82 percent [%]) in concentrations over time were identified for all PAHs measured in Harmer Creek Sedimentation Pond sediments (Table 3.1). Concentrations of some non-COPC metals increased over the same time period (i.e., boron, calcium, chromium, lithium, potassium, strontium, thallium, and uranium; Table 3.1) but were still less than the upper BC WSQG and within reference area normal ranges.

Concentrations of cadmium, nickel, and selenium (i.e., the COPCs identified in Section 3.1) in the Harmer Creek Sedimentation Pond sediments (Harmer Creek population area) increased between 2013 and 2019 (Figure 3.2; Table 3.1). However, concentrations of cadmium and nickel in Harmer Creek Sedimentation Pond were within reference area normal ranges in 2013 and 2019 (i.e., concentrations were comparable to those measured in sediments from natural and naturalized lentic areas unexposed to mining; Figure 3.1). Selenium concentrations in sediment from Harmer Creek Sedimentation Pond exhibited a 525% increase over time, shifting from within the reference area normal range in 2013 for four out of five replicates to well above the reference area normal range at all (n = 5) replicate stations in 2019 (Figure 3.2; Table 3.1).

The sediment sampling location on Harmer Creek, downstream from the outlet of Harmer Creek Sedimentation Pond (i.e., RG_HACKDS), was the only other location with multiple years of sediment chemistry data (i.e., 2018 to 2020 Figure 3.3; Table 3.2). Because RG_HACKDS is in the Grave Creek population area, data for this location were used to draw comparisons between trends in cadmium, nickel, and selenium concentrations in the Harmer Creek versus Grave Creek

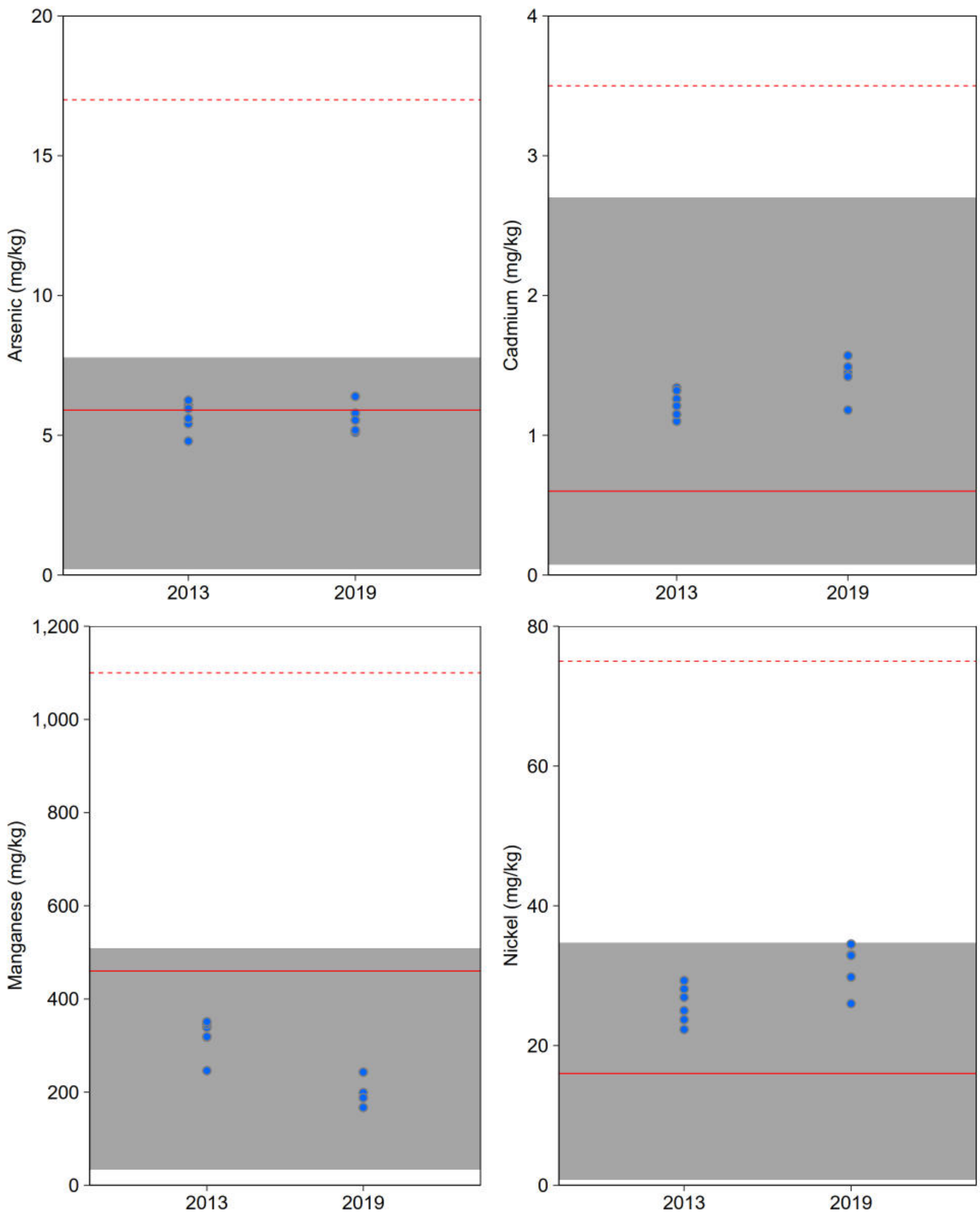
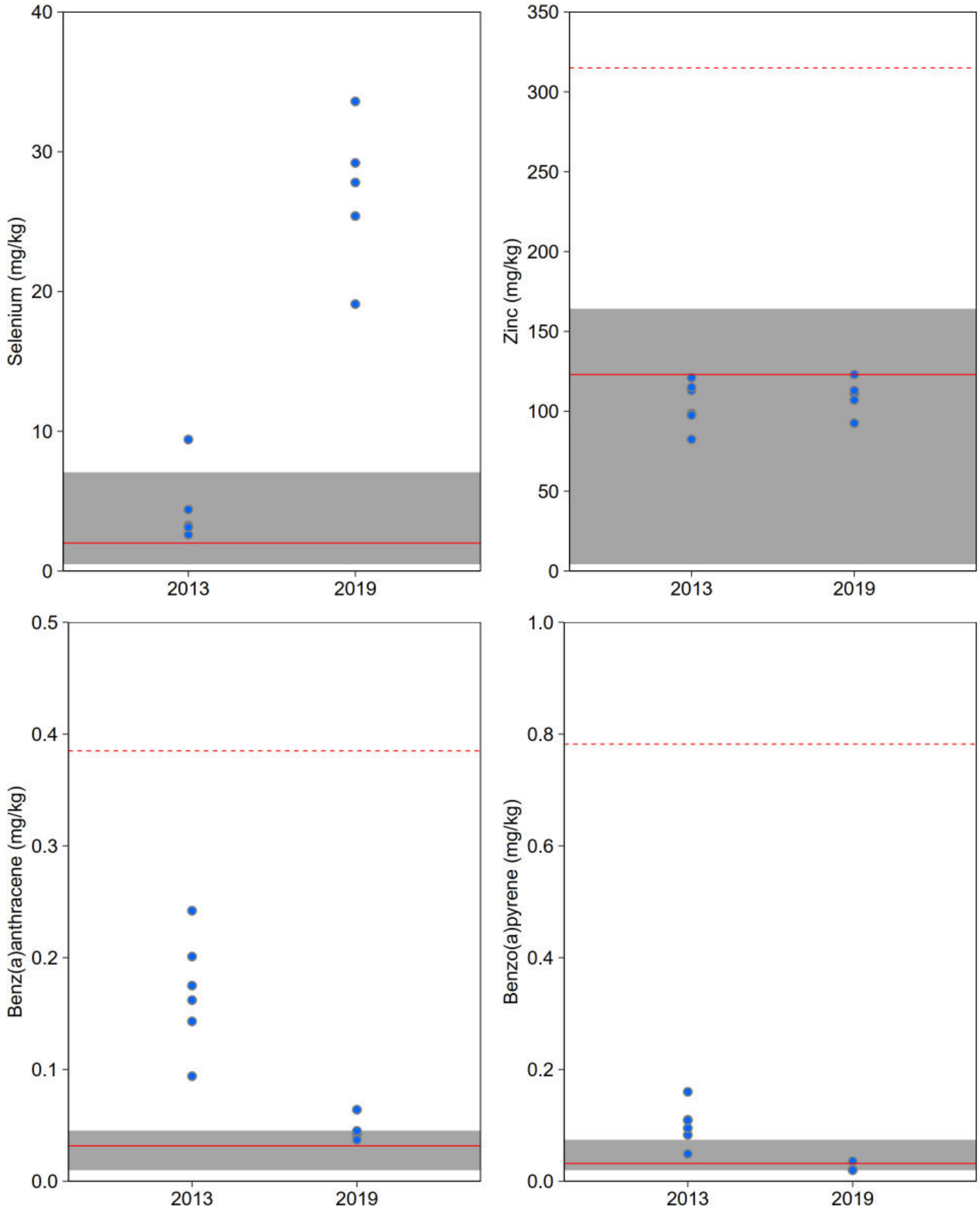


Figure 3.2: Constituents in Harmer Creek Sedimentation Pond (RG_HA7) Sediments with Concentrations Greater than Guidelines, 2013 to 2019

Notes: Values below the laboratory detection limit are shown with an open circle. Shading represents the reference area normal range (2.5th to 97.5th percentiles of reference area data collected as part of the Lentic Area Supporting Study). Solid line = lower BC WSQG, dashed line = upper BC WSQG. Manganese was plotted because concentrations in the Grave Creek population area were greater than BC WSQG.



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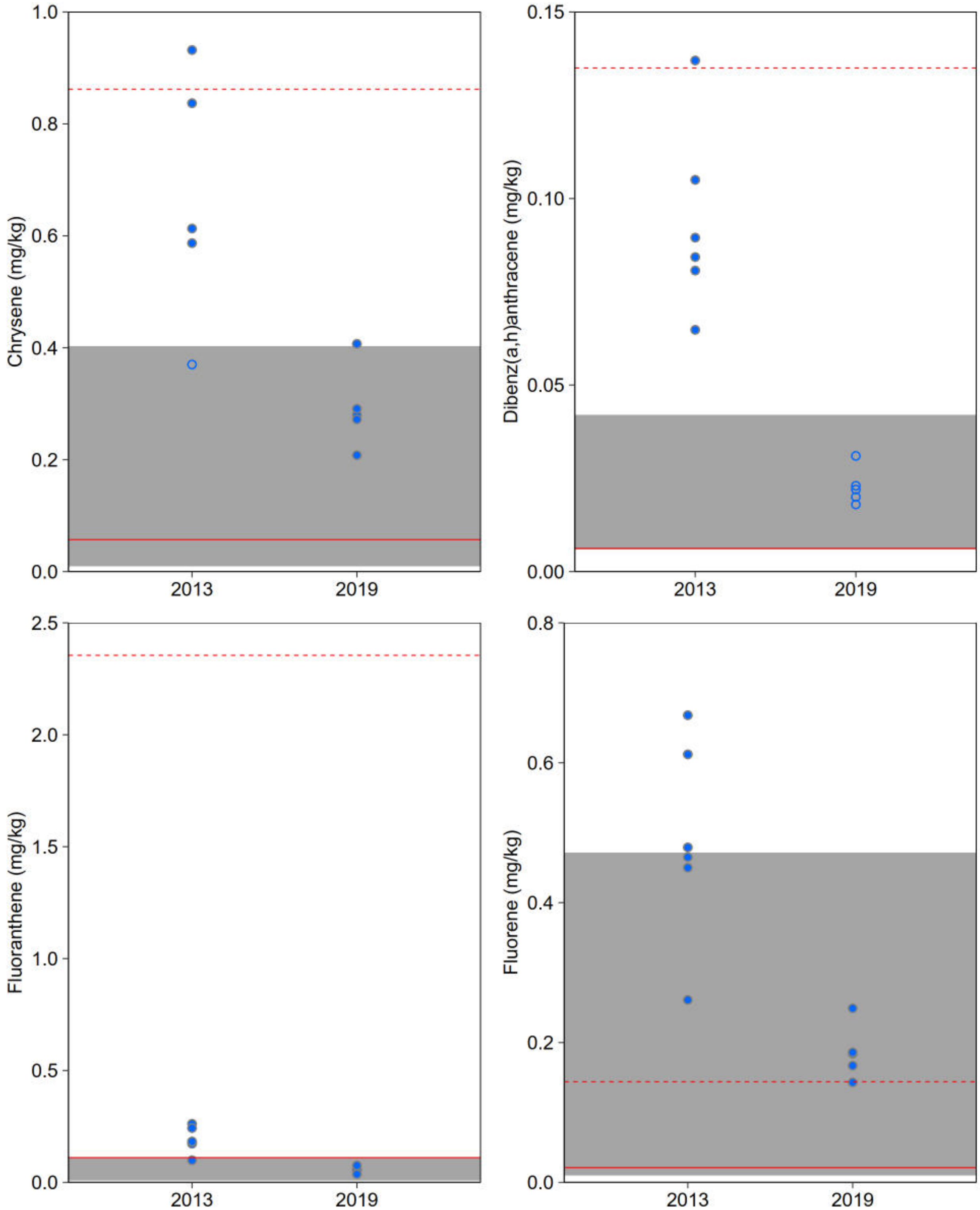

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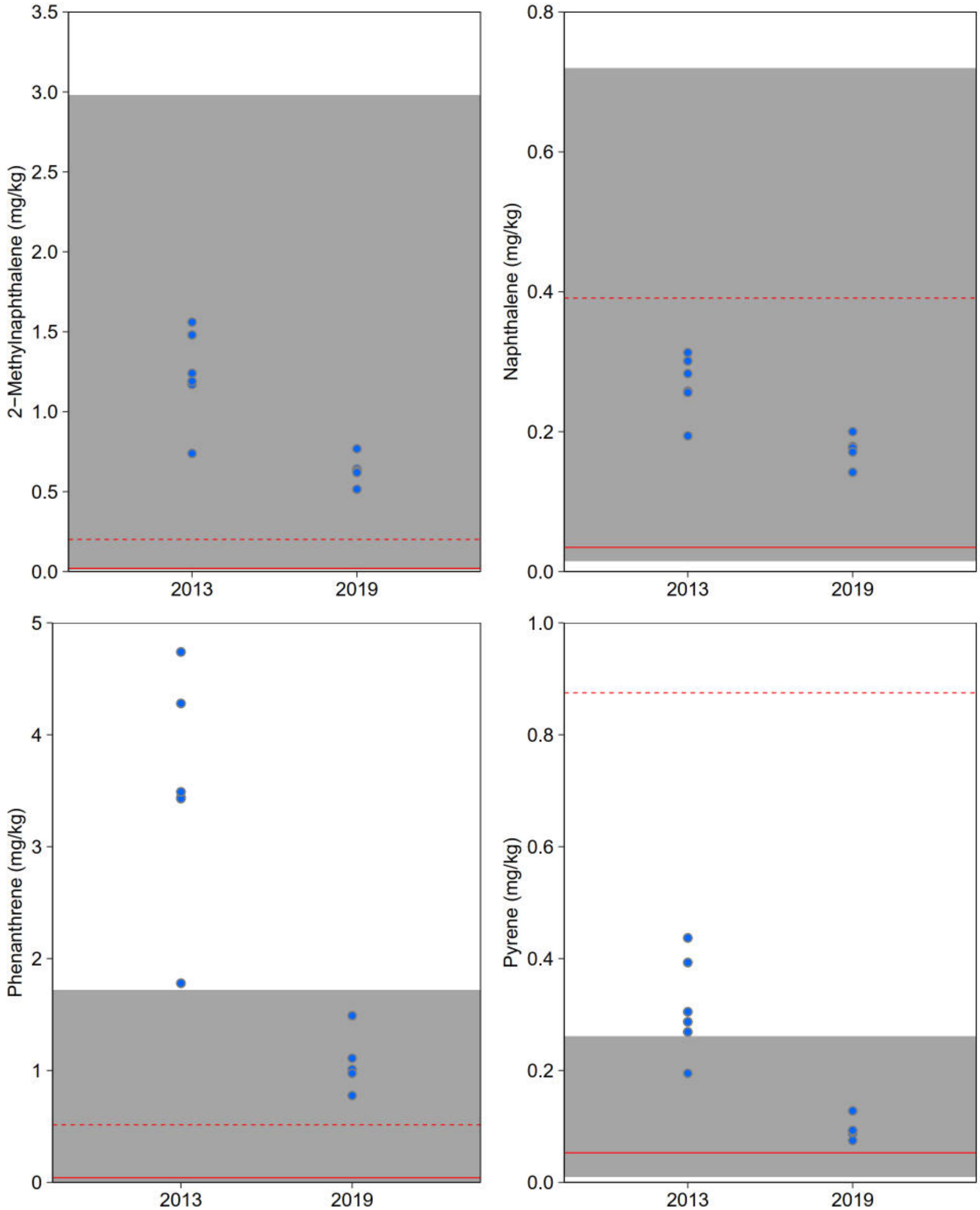

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Notes: Values below the laboratory detection limit are shown with an open circle. Shading represents the reference area normal range (2.5th to 97.5th percentiles of reference area data collected as part of the Lentic Area Supporting Study). Solid line = lower BC WSQG, dashed line = upper BC WSQG. Manganese was plotted because concentrations in the Grave Creek population area were greater than BC WSQG.

Table 3.1: Temporal Changes in Sediment Composition and Chemistry in Harmer Creek Sedimentation Pond (RG_HA7), Harmer Creek Population Area, 2013 to 2019

Parameter		Test	Summary Statistic	Measure of Central Tendency [a]		P-value [b]	Magnitude of Difference (%) [c]	Temporal differences [d]	
								2013	2019
Particle Sizes and Organic Carbon	% Gravel (>2 mm)	M-W	Median	1.00	1.00	0.287	ns	A	A
	% Sand (0.125 mm to 0.063 mm)	tequal	Mean	6.28	7.72	0.613	ns	A	A
	% Sand (0.25 mm to 0.125 mm)	M-W	Median	1.00	2.00	0.346	ns	A	A
	% Sand (0.50 mm to 0.25 mm)	M-W	Median	1.00	1.00	1.000	ns	A	A
	% Sand (1.00 mm to 0.50 mm)	M-W	Median	1.00	1.00	0.502	ns	A	A
	% Silt (0.0312 mm to 0.004 mm)	tequal	Mean	47.5	46.8	0.853	ns	A	A
	% Silt (0.063 mm to 0.0312 mm)	tequal	Mean	31.0	30.9	0.965	ns	A	A
	% Clay (<4 µm)	tequal	Mean	12.3	10.5	0.582	ns	A	A
	Total Organic Carbon	tequal	Mean	18.0	15.4	0.211	ns	A	A
Metals	Aluminum (Al)	tequal	Mean	6,983	7,770	0.103	ns	A	A
	Antimony (Sb)	tequal	Mean	0.757	0.696	0.356	ns	A	A
	Arsenic (As)	tequal	Mean	5.68	5.60	0.812	ns	A	A
	Barium (Ba)	tequal	Mean	183	184	0.888	ns	A	A
	Beryllium (Be)	tequal	Mean	0.692	0.704	0.807	ns	A	A
	Bismuth (Bi)	-	-	-	-	-	-	-	-
	Boron (B)	tequal	Mean	5.98	6.86	0.029	15	B	A
	Cadmium (Cd)	tequal	Mean	1.23	1.42	0.027	16	B	A
	Calcium (Ca)	tequal	Mean	16,967	23,760	0.009	40	B	A
	Chromium (Cr)	tequal	Mean	10.8	12.4	0.049	14	B	A
	Cobalt (Co)	tequal	Mean	6.65	6.17	0.415	ns	A	A
	Copper (Cu)	tequal	Mean	21.2	20.6	0.745	ns	A	A
	Iron (Fe)	tequal	Mean	13,833	14,120	0.775	ns	A	A
	Lead (Pb)	tequal	Mean	11.4	10.4	0.290	ns	A	A
	Lithium (Li)	tequal	Mean	7.27	8.44	0.008	16	B	A
	Magnesium (Mg)	tequal	Mean	4,918	5,568	0.128	ns	A	A
	Manganese (Mn)	tequal	Mean	320	208	<0.001	-35	A	B
	Mercury (Hg)	tequal	Mean	0.0848	0.0799	0.438	ns	A	A
	Molybdenum (Mo)	tequal	Mean	1.60	1.52	0.442	ns	A	A
	Nickel (Ni)	tequal	Mean	25.9	31.2	0.017	21	B	A
	Phosphorus (P)	tequal	Mean	1,128	1,166	0.554	ns	A	A
	Potassium (K)	tequal	Mean	1,635	1,882	0.041	15	B	A
	Selenium (Se)	tequal	Mean	4.32	27.0	<0.001	525	B	A
	Silver (Ag)	tequal	Mean	0.258	0.272	0.615	ns	A	A
	Sodium (Na)	M-W	Median	100	92.0	0.324	ns	A	A
	Strontium (Sr)	tequal	Mean	32.0	38.5	0.004	20	B	A
	Thallium (Tl)	tequal	Mean	0.193	0.279	<0.001	44	B	A
	Tin (Sn)	-	-	-	-	-	-	-	-
	Titanium (Ti)	tequal	Mean	25.0	22.3	0.505	ns	A	A
	Uranium (U)	tequal	Mean	0.899	1.61	<0.001	80	B	A
	Vanadium (V)	tequal	Mean	25.6	26.8	0.430	ns	A	A
	Zinc (Zn)	tequal	Mean	105	109	0.563	ns	A	A
	Zirconium (Zr)	-	-	-	-	-	-	-	-
PAHs	Acenaphthene	-	-	-	-	-	-	-	-
	Acenaphthylene	-	-	-	-	-	-	-	-
	Acridine	-	-	-	-	-	-	-	-
	Anthracene	-	-	-	-	-	-	-	-
	Benz(a)anthracene	tequal	Mean	0.170	0.0460	<0.001	-73	A	B
	Benzo(a)pyrene	tequal	Mean	0.101	0.0234	0.001	-77	A	B
	Benzo(b)fluoranthene	-	-	-	-	-	-	-	-
	Benzo(b,j,k)fluoranthene	tequal	Geometric Mean	0.601	0.106	<0.001	-82	A	B
	Benzo(g,h,i)perylene	tequal	Mean	0.126	0.0344	<0.001	-73	A	B
	Benzo(k)fluoranthene	M-W	Median	0.0575	0.0160	0.005	-72	A	B
	Chrysene	M-W	Median	0.613	0.280	0.016	-54	A	B
	Dibenz(a,h)anthracene	M-W	Median	0.0869	0.0310	0.005	-64	A	B
	Fluoranthene	tequal	Mean	0.189	0.0564	<0.001	-70	A	B
	Fluorene	tequal	Mean	0.489	0.186	0.001	-62	A	B
	Indeno(1,2,3-c,d)pyrene	M-W	Median	0.0405	0.0160	0.008	-61	A	B
	1-Methylnaphthalene	-	-	-	-	-	-	-	-
	2-Methylnaphthalene	tequal	Mean	1.23	0.635	0.002	-48	A	B
	Naphthalene	tequal	Mean	0.268	0.174	0.002	-35	A	B
	Phenanthrene	tequal	Geometric Mean	3.38	1.05	<0.001	-69	A	B
	Pyrene	tequal	Mean	0.314	0.0950	<0.001	-70	A	B
	Quinoline	-	-	-	-	-	-	-	-

P-value <0.05.
Significant increase in concentration (post-hoc p-value <0.05).
Significant decrease in concentration (post-hoc p-value <0.05).

Notes: % = percent; > = greater than; mm = millimetres; M-W = non-parametric Mann-Whitney test; ns = not significant; tequal = equal variances t-test; < = less than; µm = micrometres; - = insufficient data for comparison where insufficient data is either 100% censored data or only one year of data; PAHs = polycyclic aromatic hydrocarbons; TOC = total organic carbon; mg/kg = milligrams per kilogram; MOD = Magnitude of Difference.

[a] Values are expressed in units of % for particle sizes and TOC and mg/kg for metals and PAHs.

[b] The presence of annual variation was determined by a significant *Year* term (α = 0.05).

[c] The MOD was calculated as the concentrations in 2019 minus the concentrations in 2013 divided by the concentrations in 2013 × 100.

[d] Significance between each year determined using all pairwise comparisons with Tukey's correction. Years that share a letter are not significantly different. Letters were assigned such that the highest magnitude is assigned an "A".

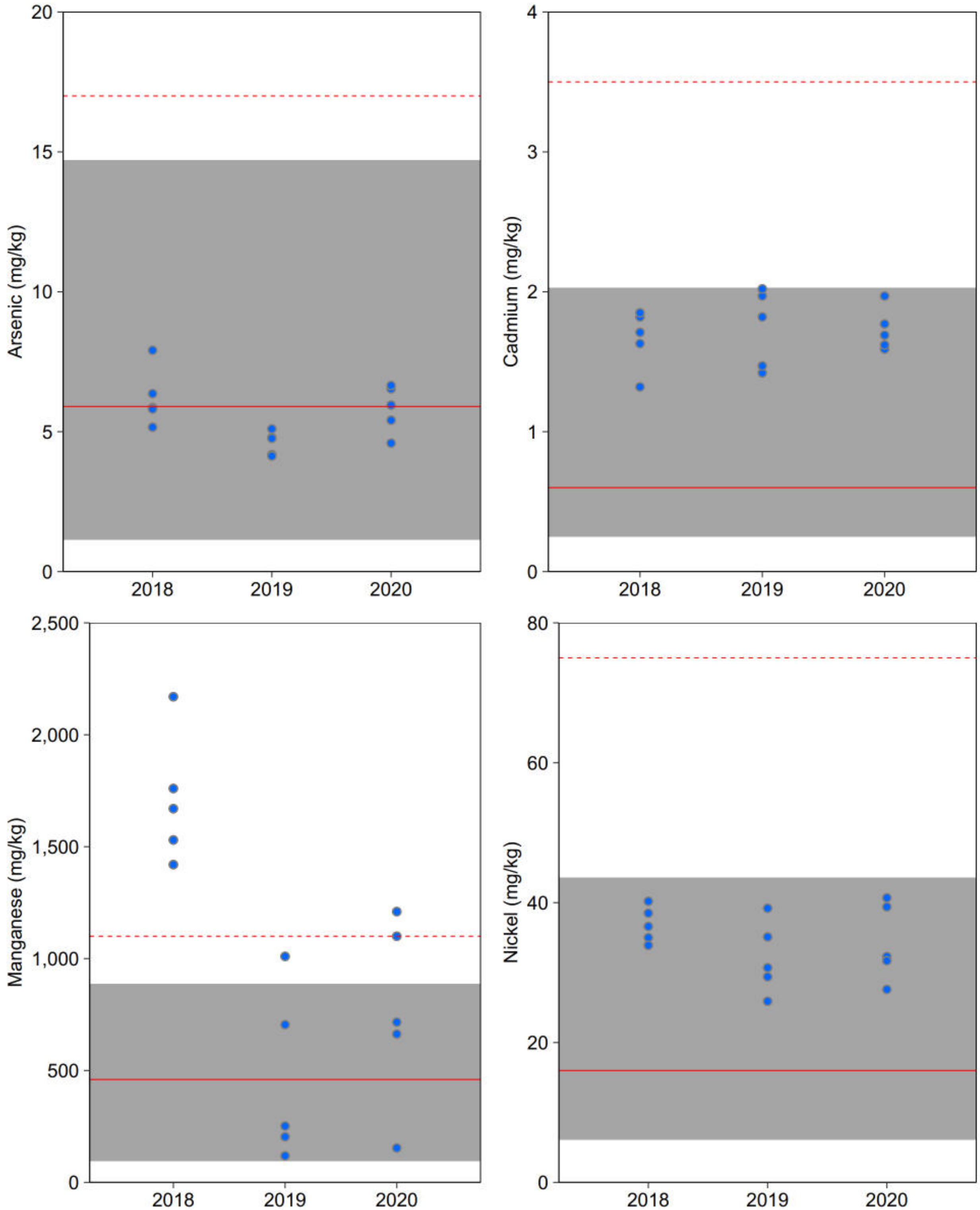

Figure 3.3: Constituents in Sediments from RG_HACKDS, Downstream from the Harmer Creek Sedimentation Pond, with Concentrations Greater than Guidelines, 2018 to 2020

Notes: Values below the laboratory detection limit are shown with an open circle. Shading represents the reference area normal range (2.5th to 97.5th percentiles of reference area data collected as part of the Regional Aquatic Effects Monitoring Program [RAEMP]). Solid line = lower BC WSQG, dashed line = upper BC WSQG.

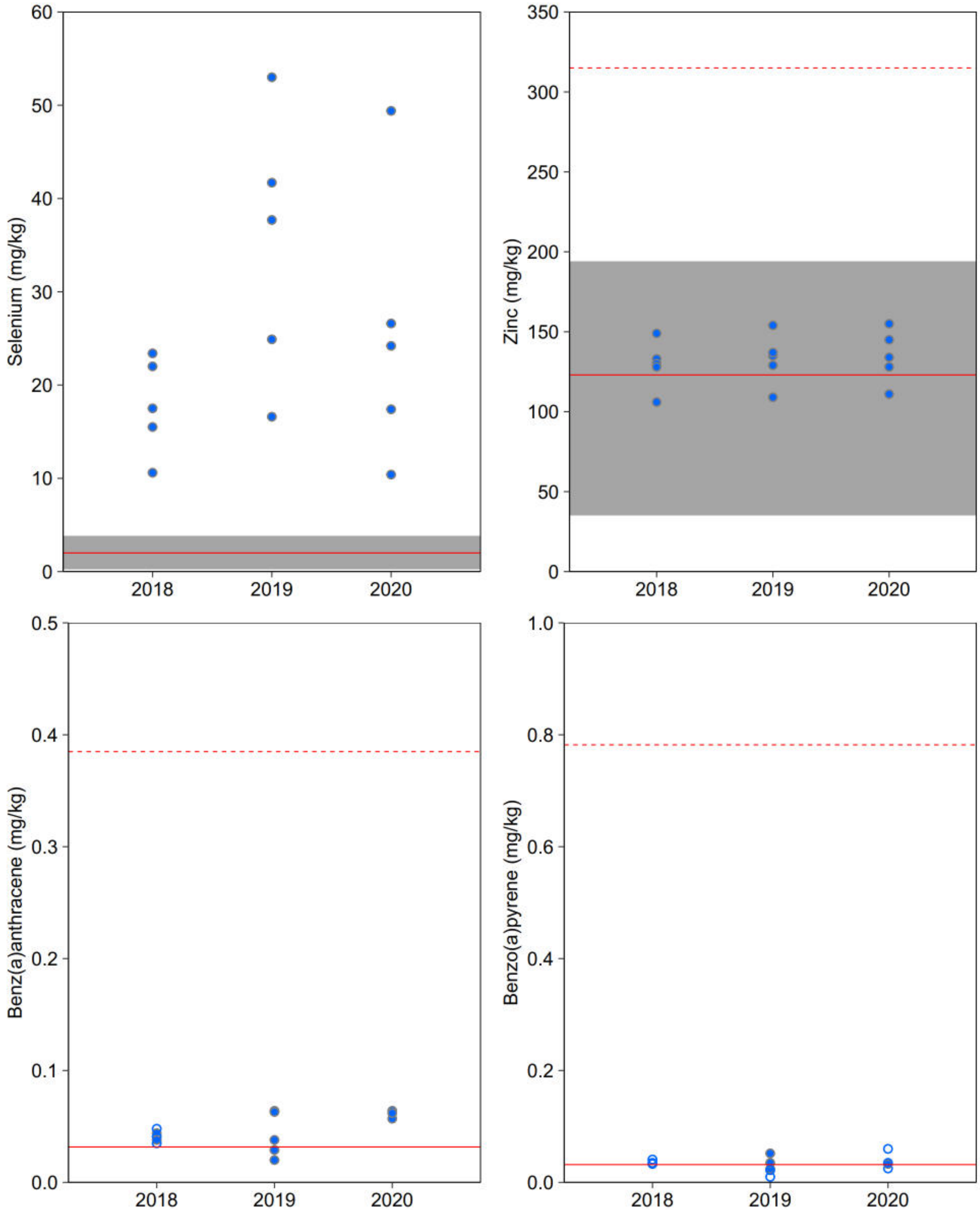

Figure 3.3: Constituents in Sediments from RG_HACKDS, Downstream from the Harmer Creek Sedimentation Pond, with Concentrations Greater than Guidelines, 2018 to 2020

Notes: Values below the laboratory detection limit are shown with an open circle. Shading represents the reference area normal range (2.5th to 97.5th percentiles of reference area data collected as part of the Regional Aquatic Effects Monitoring Program [RAEMP]). Solid line = lower BC WSQG, dashed line = upper BC WSQG.

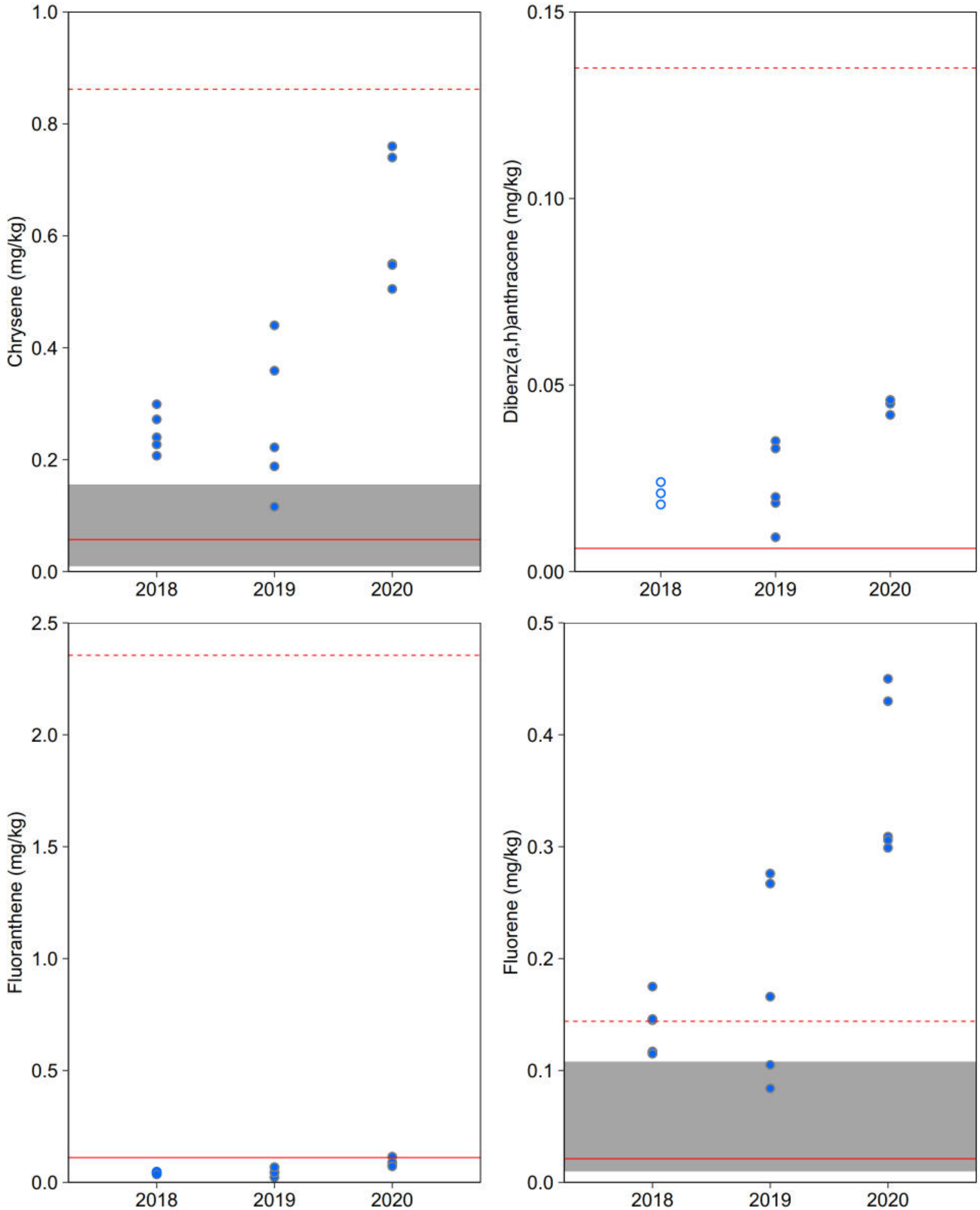

Figure 3.3: Constituents in Sediments from RG_HACKDS, Downstream from the Harmer Creek Sedimentation Pond, with Concentrations Greater than Guidelines, 2018 to 2020

Notes: Values below the laboratory detection limit are shown with an open circle. Shading represents the reference area normal range (2.5th to 97.5th percentiles of reference area data collected as part of the Regional Aquatic Effects Monitoring Program [RAEMP]). Solid line = lower BC WSQG, dashed line = upper BC WSQG.

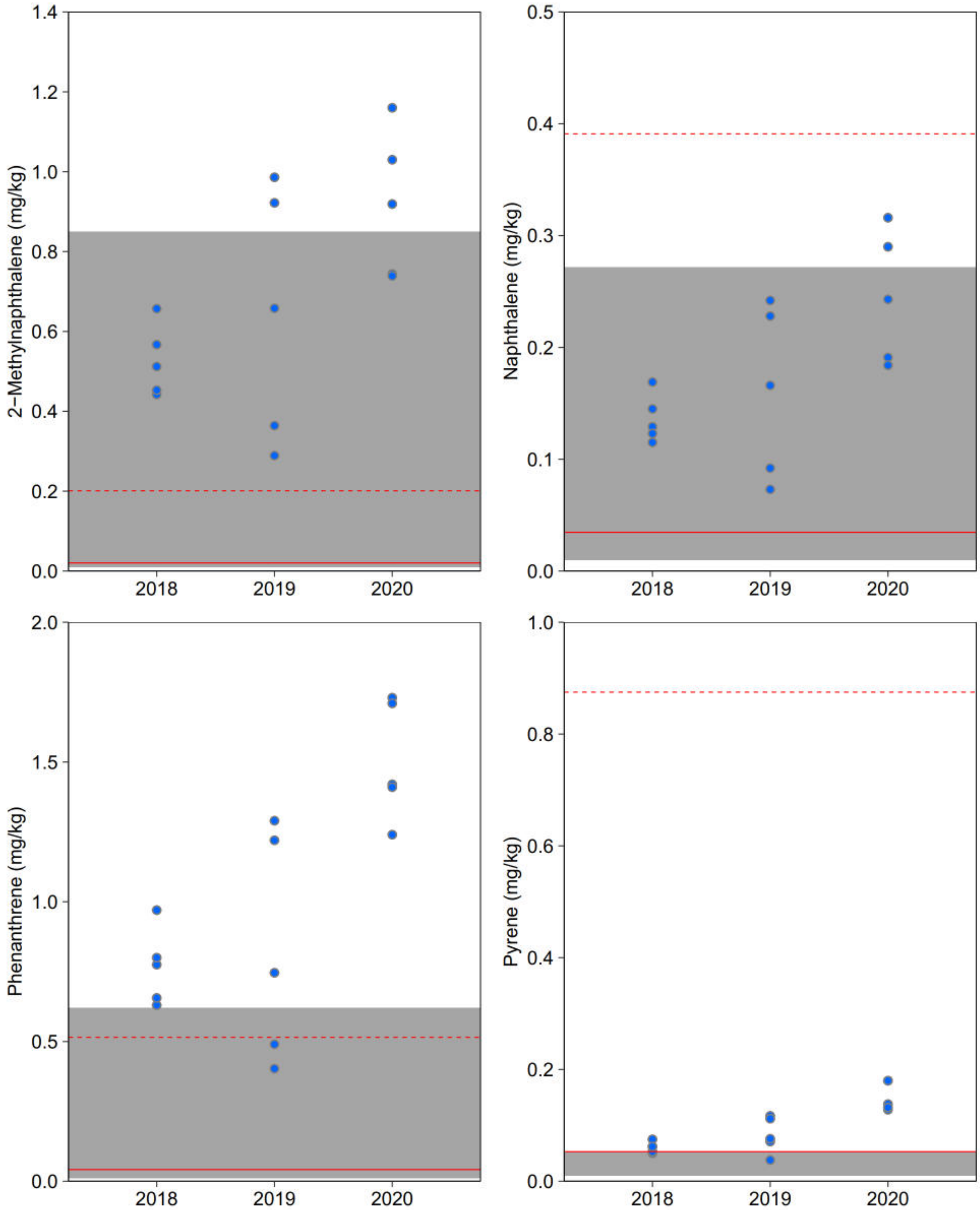

Figure 3.3: Constituents in Sediments from RG_HACKDS, Downstream from the Harmer Creek Sedimentation Pond, with Concentrations Greater than Guidelines, 2018 to 2020

Notes: Values below the laboratory detection limit are shown with an open circle. Shading represents the reference area normal range (2.5th to 97.5th percentiles of reference area data collected as part of the Regional Aquatic Effects Monitoring Program [RAEMP]). Solid line = lower BC WSQG, dashed line = upper BC WSQG.

Table 3.2: Temporal Changes in Sediment Composition and Chemistry at RG_HACKDS, in the Grave Creek Population Area, Downstream from the Harmer Creek Sedimentation Pond, 2018 to 2019

	Parameter	Test	Summary Statistic	Measure of Central Tendency [a]			P-value [b]	Magnitude of Difference (%) [c]			Temporal differences [d]		
				2018	2019	2020		2019 vs 2018	2020 vs 2018	2020 vs 2019	2018	2019	2020
Particle Sizes and Organic Carbon	% Gravel (>2 mm)	K-W	Median	1.00	2.10	1.00	0.138	ns	ns	ns	A	A	A
	% Sand (0.125 mm to 0.063 mm)	ANOVA	Mean	2.42	2.38	2.72	0.678	ns	ns	ns	A	A	A
	% Sand (0.25 mm to 0.125 mm)	K-W	Median	1.60	1.70	1.60	0.939	ns	ns	ns	A	A	A
	% Sand (0.50 mm to 0.25 mm)	K-W	Median	1.30	1.70	1.50	0.910	ns	ns	ns	A	A	A
	% Sand (1.00 mm to 0.50 mm)	K-W	Median	1.20	1.00	1.20	0.804	ns	ns	ns	A	A	A
	% Sand (2.00 mm - 1.00 mm)	K-W	Median	1.00	1.30	1.90	0.115	ns	ns	ns	A	A	A
	% Silt (0.0312 mm to 0.004 mm)	K-W	Median	46.6	46.7	50.0	0.075	ns	ns	ns	A	A	A
	% Silt (0.063 mm to 0.0312 mm)	ANOVA	Mean	30.7	32.8	27.4	0.096	ns	ns	ns	A	A	A
	% Clay (<4 µm)	ANOVA	Mean	15.0	9.04	12.7	<0.001	-40	ns	41	A	B	A
	Total Organic Carbon	ANOVA	Mean	10.8	11.3	11.4	0.498	ns	ns	ns	A	A	A
Metals	Aluminum (Al)	ANOVA	Mean	8,226	8,424	10,378	0.072	ns	ns	ns	A	A	A
	Antimony (Sb)	ANOVA	Mean	0.582	0.574	0.502	0.351	ns	ns	ns	A	A	A
	Arsenic (As)	ANOVA	Mean	6.22	4.59	5.83	0.020	-26	ns	ns	A	B	AB
	Barium (Ba)	K-W	Median	204	189	220	0.141	ns	ns	ns	A	A	A
	Beryllium (Be)	ANOVA	Mean	0.636	0.614	0.724	0.076	ns	ns	ns	A	A	A
	Bismuth (Bi)	-	-	-	-	-	-	-	-	-	-	-	-
	Boron (B)	K-W	Median	10.8	10.5	10.6	0.717	ns	ns	ns	A	A	A
	Cadmium (Cd)	ANOVA	Mean	1.67	1.74	1.73	0.853	ns	ns	ns	A	A	A
	Chromium (Cr)	ANOVA	Mean	21.1	12.9	16.6	0.020	-39	ns	ns	A	B	AB
	Cobalt (Co)	ANOVA	Mean	6.76	5.23	6.74	0.056	ns	ns	ns	A	A	A
	Copper (Cu)	ANOVA	Mean	16.1	16.4	19.1	0.020	ns	19	17	B	B	A
	Iron (Fe)	ANOVA	Mean	16,600	13,100	15,320	0.044	-21	ns	ns	A	B	AB
	Lead (Pb)	ANOVA	Mean	9.06	8.87	11.0	0.007	ns	22	24	B	B	A
	Lithium (Li)	ANOVA	Mean	7.76	8.38	11.4	<0.001	ns	47	37	B	B	A
	Magnesium (Mg)	K-W	Median	7,940	7,240	6,690	0.085	ns	ns	ns	A	A	A
	Manganese (Mn)	ANOVA	Mean	1,710	458	769	<0.001	-73	-55	ns	A	B	B
	Mercury (Hg)	ANOVA	Mean	0.0588	0.0722	0.0867	<0.001	ns	48	20	B	B	A

P-value <0.05.
Significant increase in concentration (post-hoc p-value <0.05).
Significant decrease in concentration (post-hoc p-value <0.05).

Notes: > = greater than; mm = millimetres; K-W = non-parametric Kruskal-Wallis test; ns = not significant; ANOVA = Analysis of Variance; < = less than; µm = micrometres; - = insufficient data for comparison

kilogram; MCT = Measure of Central Tendency.

[a]

[b] The presence of annual variation was determined by a significant *Year* term (α = 0.05) using an ANOVA with factor *Year*.

[c] Magnitude of Difference (MOD) was calculated as the MCT in each year minus the MCT in the first year divided by the MCT in the fist year × 100.

[d] Significance between each year determined using all pairwise comparisons with Tukey's correction. Years that share a letter are not significantly different. Letters were assigned such that the highest magnitude is assigned an "A".

Table 3.2: Temporal Changes in Sediment Composition and Chemistry at RG_HACKDS, in the Grave Creek Population Area, Downstream from the Harmer Creek Sedimentation Pond, 2018 to 2019

Parameter		Test	Summary Statistic	Measure of Central Tendency [a]			P-value [b]	Magnitude of Difference (%) [c]			Temporal differences [d]		
				2018	2019	2020		2019 vs 2018	2020 vs 2018	2020 vs 2019	2018	2019	2020
Metals	Molybdenum (Mo)	ANOVA	Mean	1.74	1.43	1.50	0.016	-18	ns	ns	A	B	AB
	Nickel (Ni)	ANOVA	Mean	36.8	32.1	34.3	0.298	ns	ns	ns	A	A	A
	Phosphorus (P)	ANOVA	Mean	1,468	1,312	1,362	0.315	ns	ns	ns	A	A	A
	Potassium (K)	K-W	Median	2,320	1,980	2,550	0.016	ns	ns	29	AB	B	A
	Selenium (Se)	ANOVA	Mean	17.8	34.8	25.6	0.131	ns	ns	ns	A	A	A
	Silver (Ag)	ANOVA	Mean	0.192	0.208	0.232	0.053	ns	ns	ns	A	A	A
	Sodium (Na)	ANOVA	Mean	99.2	79.8	119	0.014	ns	ns	49	AB	B	A
	Strontium (Sr)	ANOVA	Mean	60.0	55.3	55.0	0.437	ns	ns	ns	A	A	A
	Thallium (Tl)	K-W	Median	0.323	0.314	0.352	0.116	ns	ns	ns	A	A	A
	Tin (Sn)	-	-	-	-	-	-	-	-	-	-	-	-
	Titanium (Ti)	ANOVA	Mean	14.1	15.7	12.2	0.516	ns	ns	ns	A	A	A
	Uranium (U)	ANOVA	Mean	0.964	1.44	1.21	0.092	ns	ns	ns	A	A	A
	Vanadium (V)	ANOVA	Mean	27.3	25.4	32.6	0.046	ns	ns	28	AB	B	A
	Zinc (Zn)	ANOVA	Mean	129	133	135	0.866	ns	ns	ns	A	A	A
	Zirconium (Zr)	K-W	Median	1.00	1.00	1.00	0.449	ns	ns	ns	A	A	A
PAHs	Acenaphthene	-	-	-	-	-	-	-	-	-	-	-	-
	Acenaphthylene	-	-	-	-	-	-	-	-	-	-	-	-
	Acridine	K-W	Median	0.240	0.240	0.240	0.449	ns	ns	ns	A	A	A
	Anthracene	-	-	-	-	-	-	-	-	-	-	-	-
	Benz(a)anthracene	K-W	Median	0.0480	0.0380	0.0620	0.201	ns	ns	ns	A	A	A
	Benzo(a)pyrene	K-W	Median	0.0600	0.0520	0.0600	0.273	ns	ns	ns	A	A	A
	Benzo(b)fluoranthene	-	-	-	-	-	-	-	-	-	-	-	-
	Benzo(b,j,k)fluoranthene	tequal	Mean	-	0.124	0.230	0.017	-	-	86	-	B	A
	Benzo(g,h,i)perylene	K-W	Median	0.0480	0.0340	0.0770	0.008	ns	60	126	B	B	A
	Benzo(k)fluoranthene	-	-	-	-	-	-	-	-	-	-	-	-
	Chrysene	ANOVA	Mean	0.249	0.265	0.621	<0.001	ns	149	134	B	B	A

(grey) P-value <0.05.
(blue) Significant increase in concentration (post-hoc p-value <0.05).
(green) Significant decrease in concentration (post-hoc p-value <0.05).

μm = micrometres; - = insufficient data for comparison where insufficient data is either 100% censored data or only one year of data; PAHs = polycyclic aromatic hydrocarbons; tequal = equal variances t-test; TOC = total organic carbon; mg/kg = milligrams per kilogram; MCT = Measure of Central Tendency.

[a]

[b] The presence of annual variation was determined by a significant *Year* term (α = 0.05) using an ANOVA with factor *Year*.

[c] Magnitude of Difference (MOD) was calculated as the MCT in each year minus the MCT in the first year divided by the MCT in the fist year × 100.

[d] Significance between each year determined using all pairwise comparisons with Tukey's correction. Years that share a letter are not significantly different. Letters were assigned such that the highest magnitude is assigned an "A".

Table 3.2: Temporal Changes in Sediment Composition and Chemistry at RG_HACKDS, in the Grave Creek Population Area, Downstream from the Harmer Creek Sedimentation Pond, 2018 to 2019

Parameter		Test	Summary Statistic	Measure of Central Tendency [a]			P-value [b]	Magnitude of Difference (%) [c]			Temporal differences [d]		
				2018	2019	2020		2019 vs 2018	2020 vs 2018	2020 vs 2019	2018	2019	2020
PAHs	Dibenz(a,h)anthracene	K-W	Median	0.0240	0.0200	0.0450	0.045	ns	ns	125	AB	B	A
	Fluoranthene	K-W	Median	0.0470	0.0470	0.0835	0.017	ns	78	78	B	B	A
	Fluorene	ANOVA	Mean	0.140	0.180	0.359	<0.001	ns	157	100	B	B	A
	Indeno(1,2,3-c,d)pyrene	K-W	Median	0.110	0.110	0.110	0.645	ns	ns	ns	A	A	A
	1-Methylnaphthalene	-	-	-	-	-	-	-	-	-	-	-	-
	2-Methylnaphthalene	ANOVA	Mean	0.526	0.644	0.918	0.039	ns	75	ns	B	AB	A
	Naphthalene	ANOVA	Mean	0.136	0.160	0.245	0.026	ns	80	ns	B	AB	A
	Phenanthrene	ANOVA	Mean	0.766	0.830	1.50	0.002	ns	96	81	B	B	A
	Pyrene	ANOVA	Mean	0.0604	0.0828	0.152	<0.001	ns	151	83	B	B	A
	Quinoline	-	-	-	-	-	-	-	-	-	-	-	-

P-value <0.05.

Significant increase in concentration (post-hoc p-value <0.05).

Significant decrease in concentration (post-hoc p-value <0.05).

Notes: > = greater than; mm = millimetres; K-W = non-parametric Kruskal-Wallis test; ns = not significant; ANOVA = Analysis of Variance; < = less than; µm = micrometres; - = insufficient data for comparison

kilogram; MCT = Measure of Central Tendency.

[a]

[b] The presence of annual variation was determined by a significant *Year* term (α = 0.05) using an ANOVA with factor *Year*.

[c] Magnitude of Difference (MOD) was calculated as the MCT in each year minus the MCT in the first year divided by the MCT in the fist year × 100.

[d] Significance between each year determined using all pairwise comparisons with Tukey's correction. Years that share a letter are not significantly different. Letters were assigned such that the highest magnitude is assigned an "A".

population areas. However, these comparisons were limited because RG_HACKDS is immediately downstream from the Harmer Creek Sedimentation Pond and sediment chemistry at this location is likely influenced by conditions in the pond (i.e., is not reflective of conditions throughout the entirety of the Grave Creek population area). Regardless, there were no significant changes in cadmium, nickel, or selenium concentrations at RG_HACKDS over time from 2018 to 2020 (Figure 3.3; Table 3.2), which suggested that increases in COPC concentrations in sediment in the Harmer Creek Sedimentation Pond were likely attributable to conditions unique to the Harmer Creek population area, and potentially within the pond itself.

Based on the spatially and temporally limited sediment quality data set, it is uncertain whether changes in sediment quality within Harmer Creek Sedimentation Pond reflect changes to sediment quality upstream and whether changes in the pond were gradual from 2013 to 2019 or occurred abruptly. Sampling areas upstream of Harmer Creek Sedimentation Pond, including Dry Creek Sedimentation Pond, had only one year of data each, so changes over time could not be evaluated for those locations. For this reason, it was impossible to determine if sediment quality in Dry Creek Sedimentation Pond, which was sampled in 2013 only, followed the same general temporal pattern as the Harmer Creek Sedimentation Pond. Data for RG_HACKDS, which is downstream from Harmer Creek Sedimentation Pond, in the Grave Creek population area, may provide some indication of the timing of changes in sediment quality within the pond. In 2019, the concentrations of cadmium, nickel, and selenium in the pond and at RG_HACKDS overlapped. Data were not available from the Harmer Creek Sedimentation Pond in 2018 or 2020, however concentrations at RG_HACKDS did not change over time during that period. Assuming that concentrations downstream of the pond are reflective of concentrations in the pond, the 2018 to 2020 data for RG_HACKDS suggest that increases in sediment concentrations of cadmium, nickel, and selenium in Harmer Creek Sedimentation Pond may have occurred before 2018.

3.2.2 Exposure to Constituents Associated with Fine Sediments

Westslope Cutthroat Trout prefer flowing stream habitats with coarse substrates (gravel and larger, depending on life stage) that are free of fines (Government of Canada 2019; Hickman and Raleigh 1982). However, low-velocity habitats (i.e., back-water areas, eddies, and stream margins) used by newly-emerged fry before they move into deeper, faster-flowing habitats may contain a greater proportion of fine substrates. Overall, habitats used by Westslope Cutthroat Trout in the Harmer Creek population area are primarily erosional with few, small, patchy deposits of fine sediments (Appendix Photos A.1 to A.17).

At EV_DC3 on Dry Creek, upstream of the Dry Creek Sedimentation Pond (Figure 2.1; Table 2.1), the substrates are heavily calcified (Appendix Photo A.2).[30] In 2020, field crews noted that fine sediment deposits were spatially limited at this location and there was only a light layer of fines on top of the calcite (Nupqu and Hemmera 2020). Concentrations of cadmium, nickel, and selenium (see Section 3.1 and Figure 3.1) in sediment samples collected from this location in 2020 were above upper BC WSQG and reference area normal ranges. Fish use of Dry Creek Reach 3, where EV_DV3 is located (Figure 2.1), includes spawning, rearing, and overwintering activities (i.e., is used by life stages relevant to recruitment). However, spawning suitability in Dry Creek was poor during (and prior to) the years of reduced recruitment due to the presence and magnitude of calcite formation at that location (Cloutier et al. 2022) .

Historical sediment deposits in Dry Creek Sedimentation Pond are largely also covered in calcite (Appendix Photo A.3; Moore 2021a, pers. comm.); however, soft substrates were observed on the south side of the pond during fish salvage activities in 2017 (Golder 2017). The 2017 fish salvage included Dry Creek Sedimentation Pond, Dry Creek Reaches 3 to 6, and the South Tributary to Dry Creek (Golder 2017). No age-1 fish were captured from Dry Creek; age-2+ juveniles and adults were found throughout Dry Creek and at densities similar to the Harmer Creek main stem (Chapter 4 of the EoC report [Harmer Creek Evaluation of Cause Team 2023]; Thorley et al. 2022).

Similar to EV_DC3, substrates at EV_DCOUT, approximately 50 metres (m) downstream from the Dry Creek Sedimentation Pond, are heavily calcified. In 2020, patches of sediment deposits approximately 5 cm thick were observed on top of the calcite (Appendix Photo A.5; Nupqu and Hemmera 2020). Concentrations of cadmium and selenium (see Section 3.1 and Figure 3.1) in sediment samples collected from this location in 2020 were above upper BC WSQG and reference area normal ranges. The higher sediment selenium concentrations at EV_DCOUT are considered reflective of higher selenium bioavailability immediately downstream of the Dry Creek Sedimentation Pond and are corroborated by selenium speciation and benthic invertebrate tissue chemistry data (de Bruyn et al. 2022). This is because sedimentation ponds have some lentic characteristics (e.g., longer residence times) that enhance conversion of selenate to selenite and organoselenium compounds, thereby enhancing bioavailability and bioaccumulation of selenium within and downstream of the ponds (de Bruyn et al. 2022; Van Derveer and Canton 1997). Conversely, selenate usually predominates in lotic environments (May et al. 2007). Unlike cadmium and selenium, concentrations of nickel were between the lower and upper BC WSQG and within the reference area normal range at EV_DCOUT. To date, there has been no evidence to suggest Westslope Cutthroat Trout use

[30] Dry Creek was identified as a priority creek for calcite management in the EVWQP (Teck Resources 2014).

habitats in Dry Creek downstream from the Dry Creek Sedimentation Pond for overwintering or spawning (Cope and Cope 2020; Golder 2017; Thorley et al. 2022).

The next downstream sediment sampling location at RG_HARM5 (Figure 2.1) is associated with a section of Harmer Creek that is dominated by larger substrates and is used for spawning and rearing by Westslope Cutthroat Trout (Figure 2.1; Appendix Photos A.6 to A.8; Cope and Cope 2020). Concentrations of cadmium and nickel (see Section 3.1 and Figure 3.1) in sediment samples from this location in 2020 were less than the upper BC WSQG (but still greater than the lower BC WSQG), within reference area normal ranges, and generally lower relative to concentrations at other monitoring locations in the Harmer Creek and Grave Creek population areas (Figure 3.1; Appendix Table A.1). Concentrations of selenium were less than the alert concentration (which is treated as an upper guideline) and within the reference area normal range (Figure 3.1; Appendix Table A.1). The lower sediment selenium concentrations here, relative to EV_DCOUT, likely reflect the decreasing influence of the Dry Creek Sedimentation Pond with increasing distance downstream; again, this is supported by co-located water and tissue chemistry data (de Bruyn et al. 2022).

To date, sediment sampling has not been completed at RG_HACKUS (Harmer Creek upstream from the Harmer Creek Sedimentation Pond; Appendix Photos A.9 to A.13), which is a RAEMP monitoring station between RG_HARM5 and Harmer Creek Sedimentation Pond. However, site photos were reviewed for sediment characteristics because RG_HACKUS is within an area of relatively high spawning and rearing density (Cope and Cope 2020; Harmer Creek Evaluation of Cause Team 2023; Thorley et al. 2022). Similar to RG_HARM5 larger substrates also predominate at RG_HACKUS.

Harmer Creek Sedimentation Pond is a depositional habitat and substrates are characterized as silty, homogenous, dark brown/black sediments with organic matter (Minnow 2014a,b). Selenium was the only COPC in Harmer Creek Sedimentation Pond with concentrations greater than the BC WSQG and reference area normal range in 2019. Concentrations of selenium in the Harmer Creek Sedimentation Pond sediments are considered reflective of speciation conditions in the pond (de Bruyn et al. 2022). Regardless, Harmer Creek Sedimentation Pond has negligible documented fish use (see Chapter 4 of the EoC report) and exposure to sediment deposits within the pond (via direct contact or incidental ingestion) is therefore considered unlikely.

During redd surveys completed in June 2021 to support Teck Coal's annual Westslope Cutthroat Trout monitoring, the field crew noted that sediment deposition in Harmer Creek was highest along the stream margins and the edges of pools (Thorley 2021, pers. comm.). The field crew also noted that although it is possible that redds in this system can accumulate some fine sediments over the course of the summer incubation period (Appendix Photo A.18), this is not unique to the Harmer Creek population area (i.e., this type of accumulation occurs in Grave Creek and the Upper Fording River; Robinson 2021, pers. comm.). During a site visit completed on July 20, 2021, Teck Coal personnel noted the presence of recently deposited fine, silty sediment among the rocks in Harmer Creek, within approximately 50 m upstream from the inlet to the Harmer Creek Sedimentation Pond (Appendix Photo A.14; Moore 2021b, pers. comm.).

Similar to the Harmer Creek population, habitats accessible to the Grave Creek Westslope Cutthroat Trout population are primarily erosional with few, patchy deposits of fine sediments (Appendix Photos A.19 to A.28). In September 2018, the RAEMP field crew noted that RG_HACKDS, which is downstream from, and influenced by, the Harmer Creek Sedimentation Pond, was dominated by cobble substrates and that many different small patches of fines had to be sampled to achieve the required sediment sample volume for chemistry analyses. Calcification of the substrates was also evident. There is evidence of fish use (spawning, rearing, and overwintering) in Reach 1 of Harmer Creek (Grave Creek population area), where RG_HACKDS is located (Harmer Creek Evaluation of Cause Team 2023). Each of the biological monitoring areas on Grave Creek upstream and downstream of Harmer Creek appear to be dominated by larger substrates with intermittent patches of fine sediments along margins or on rocks (e.g., Appendix Photos A.24 and A.26).

Site-specific evidence and evidence from the literature indicate Westslope Cutthroat Trout generally spawn in higher velocity areas where deposition of fine sediments is likely to be lower (Brown and Mackay 1995; Liknes and Graham 1988; Minnow 2021a, unpublished data from Minnow). Additionally, total suspended solids (TSS) concentrations in the Harmer Creek population area during the period of reduced recruitment were similar or better than conditions prior to 2016 and were consistent with the Grave Creek population area, which did not experience reduced recruitment (Durston and Hatfield 2022). Therefore, a large upstream release of fine sediments (and associated cadmium, nickel, and selenium) that could have covered redds or settled into interstitial spaces used by early life stages during the years associated with reduced recruitment is considered unlikely.

After emergence, cutthroat trout fry establish territories in low-velocity habitats, which are more likely to accumulate fine sediments, before moving into habitats that are deeper and have higher water velocities (Bozek and Rahel 1991; Costello 2006; Moore and Gregory 1988a,b). As stated in Section 1.1.2, Westslope Cutthroat Trout typically feed on invertebrates in drift (COSEWIC 2006, 2016; Elliot 1973; Fraser and Metcalfe 1997; Nakano et al. 1999) and when fish do shift to a benthic feeding strategy, they mainly target invertebrates attached to coarse substrates, rather than fine sediments (Nakano et al. 1999). Therefore, the potential for incidental ingestion of fine sediments is considered low for this species, unless prey like chironomids, which are typically more abundant in fine sediment, are targeted. Overall, it is expected that direct contact with elevated concentrations of cadmium, nickel, and selenium in sediments in the Harmer Creek population area (i.e., relative to BC WSQG and reference area normal ranges) was likely infrequent. The possible exception may be some unknown proportion of fry that targeted prey that were more closely associated with fine sediments.

Additionally, if sediments with cadmium, nickel, and selenium concentrations greater than the BC WSQG and reference area normal ranges were widespread and contributing to toxicity, adverse impacts to benthic invertebrate communities would be expected (Besser et al. 2011; Clements 2004; Custer et al. 2016; McGrath et al. 2019; Mebane et al. 2020). Because a variety of benthic invertebrate taxa are more sensitive to cadmium and nickel than fish (see Section 3.2.3), adverse impacts to benthic invertebrate communities might be expected before impacts to fish are observed. For selenium, higher concentrations in sediments are considered to be generally indicative of higher bioavailability (de Bruyn et al. 2022); however, it is very difficult to link selenium concentrations in benthic invertebrate and fish tissues to concentrations in sediment. This is due to variability in water retention times, bioaccumulation and transformation and the base of the food web, and heterogeneity in the spatial distribution of fine sediments and benthic invertebrate taxa or fish (de Bruyn et al. 2022; Hamilton 2004; Hamilton and Lemly 1999). Regardless, Wiebe et al. (2022) concluded that benthic invertebrate abundances and community characteristics in the Harmer Creek population area (including Dry Creek) during the period of interest for the recruitment failures (i.e., 2017 to 2020) were generally[31] comparable to those observed in prior years, in reference areas unimpacted by mining, and in the Grave Creek population area. Furthermore, benthic invertebrate communities have been sampled more frequently and at more locations than sediment, which assists in understanding benthic conditions when and where sediment quality data were unavailable.

3.2.3 Bioavailability and Species Sensitivity

3.2.3.1 Cadmium

As previously indicated, sediment concentrations of cadmium that were elevated relative to the upper BC WSQG and reference area normal ranges in the Harmer Creek population area during the period of reduced recruitment were restricted to sampling locations on Dry Creek (Figure 3.1; Appendix Table A.1). Calcite is abundant in Dry Creek (see Section 3.2.2 and

[31] Ephemeropteran abundance at EV_DC3 and plecopteran abundance at EV_DCOUT (both on Dry Creek) were below regional reference area normal ranges in 2020; however, no other years of data were available for these locations for comparison (Wiebe et al. 2022). Total benthic invertebrate abundances in Dry Creek in 2020 were within the reference area normal range and comparable to 2013 data for the reference area on Harmer Creek upstream from Dry Creek (Wiebe et al. 2022).

Appendix Photos A.2 to A.5) and cadmium is known to be incorporated into the calcite matrix during its formation (Shirvani et al. 2006; SRK 2020; Zhang et al. 2020). Sediment samples submitted for analysis may have included fine calcite particles, thus explaining the higher concentrations of cadmium in Dry Creek sediments than other sampling areas. Calcium concentrations were elevated in sediment samples from Dry Creek (164,000 and 236,000 milligrams per kilogram [mg/kg]) compared to areas in Harmer Creek (10,200 to 52,700 mg/kg), providing evidence that calcite was likely present in the Dry Creek amples (Appendix Table A.1). Cadmium concentrations were below the upper BC WSQG and within the reference area normal range downstream in Harmer Creek where little calcite accumulation has been observed; Figure 3.1; Minnow 2020a; Zathey et al. 2021).

It is considered likely that the reported cadmium concentrations in the sediment samples from Dry Creek overpredict the bioavailable fraction of cadmium at that location because sequestration of cadmium in calcite generally reduces its bioavailability (Zhang et al. 2020). Other factors that can affect cadmium bioavailability in sediments include organic matter, pH, and redox conditions (and resulting formation of iron and manganese hydroxides and sulphides; CCME 1999; Jaagumagi 1993). Cadmium was not identified as a potential stressor causing or contributing to the reductions in recruitment, based on the SME evaluation of water quality (Warner and de Bruyn 2022).

The lower and upper BC WSQG for cadmium were adopted from the Canadian Council of Ministers of the Environment (CCME) and are equivalent to the Interim Sediment Quality Guideline (ISQG) and Probable Effects Level (PEL), respectively. The CCME guidelines are based primarily on patterns of benthic community response relative to cadmium concentrations in field-collected sediments with multiple other constituents present (CCME 1999). Therefore, the guidelines are not necessarily based on a causal relationship and biological effects will not necessarily occur at sediment concentrations that are above the cadmium guidelines (see Section 2.2.1 for more details).

Toxicity literature based on exposure of aquatic biota to water-borne cadmium indicate that trout are more sensitive than some benthic invertebrate taxa (e.g., *Rhithrogena* sp.; (CCME 2014; Mebane et al. 2012) but less sensitive than others (e.g., *Ephemerella* and *Lepidistoma* sp.; Mebane et al. 2020). Monitoring results for the Harmer Creek population area have shown that benthic invertebrate communities have total and family abundances comparable to undisturbed reference areas (Section 3.2.2; Wiebe et al. 2022). It is therefore considered likely that cadmium concentrations in sediment were not sufficiently high or bioavailable to adversely affect Westslope Cutthroat Trout recruitment (including fry potentially exposed directly to fine sediments), particularly in Harmer Creek, which supports most fish use.

A decrease in cadmium tolerance with an increase in fish size has been observed for multiple species of salmonids, including Westslope Cutthroat Trout, Chinook Salmon (*Oncorhynchus tshawytscha*), Rainbow Trout and Steelhead Trout (*Oncorhynchus mykiss*), Arctic Grayling (*Thymallus arcticus*), and Coho Salmon (*Oncorhynchus kisutch*) (Buhl and Hamilton 1991; Chapman 1978; Mebane et al. 2012). Buhl and Hamilton (1991) found that juvenile Arctic Grayling, Coho Salmon, and Rainbow Trout were more sensitive to cadmium than alevins. Toxicity tests with alevins, five- to eight-month-old parr, and smolts of Chinook Salmon and Steelhead Trout produced the same results (Chapman 1978). Therefore, it is anticipated that older, larger juveniles would be more likely to be affected by cadmium in sediments than alevins, which is contradictory to a pattern of reduced recruitment in which effects likely occurred among early life stages.

Overall, it is considered unlikely that cadmium in sediments caused or contributed to the reduced recruitment in the Harmer Creek population area. Cadmium was identified as a COPC based on samples collected from Dry Creek in 2020; however, because cadmium was likely integrated into the calcite matrix in Dry Creek, its bioavailability was likely lower than the reported concentrations suggest. Although few data were available for the area between Dry Creek and Harmer Creek Sedimentation Pond, biological effects within this section of Harmer Creek are considered unlikely. Concentrations in the sample collected from this location in 2020 and samples from further downstream in the pond were consistently less than the upper BC WSQG and within the reference area normal range. Additionally, cadmium is more likely to affect older juveniles than early life stages relevant to the reduction in recruitment and use of Dry Creek by early life stages is expected to be lower than other locations on Harmer Creek (Thorley et al. 2022). Benthic invertebrate community metrics were also generally within reference area normal ranges in Dry Creek, suggesting that cadmium concentrations in sediment were not causing biological effects.

3.2.3.2 Nickel

Sediment concentrations of nickel that were elevated relative to the upper BC WSQG and the reference area normal ranges in the Harmer Creek population area during the period of reduced recruitment were restricted to EV_DC3 on Dry Creek, upstream of the Dry Creek Sedimentation Pond, in 2020 (Figure 3.1; Appendix Table A.1). Again, calcite is abundant in Dry Creek (see Section 3.2.2 and Appendix Photos A.2 to A.5) and nickel can become incorporated into the calcite matrix during its formation (SRK 2020; Zhang et al. 2020). Calcium concentrations were elevated in sediment samples from Dry Creek (164,000 and 236,000 mg/kg) compared to areas in Harmer Creek (10,200 to 52,700 mg/kg), providing evidence that calcite was likely present in the Dry Creek samples (Appendix Table A.1).

The nickel concentrations in the sediment samples from Dry Creek likely overpredict the bioavailable fraction because sequestration of nickel in calcite generally reduces its bioavailability (Zhang et al. 2020). Other factors that can affect nickel bioavailability in sediments include pH, organic matter, and redox conditions (and resulting formation of iron and manganese hydroxides and sulphides; Jaagumagi 1993; Schlekat et al. 2016). Sediment pH values less than 6 can promote mobilization of nickel (and therefore potentially increase bioavailability; Jaagumagi 1993); however, none of the field-collected sediments had pH values that low (Appendix Table A.1). Nickel was not identified as a potential stressor causing or contributing to the reduced recruitment in the Harmer Creek Westslope Cutthroat Trout population, based on the SME evaluation of water quality (Warner and de Bruyn 2022).

The lower and upper BC WSQG for nickel were adopted from the Ontario Provincial Sediment Quality Guidelines (Jaagumagi 1993) and are equivalent to the Lowest Effect Level (LEL) and Severe Effect Level (SEL), respectively. The LEL and SEL were calculated based on patterns of benthic invertebrate responses relative to nickel concentrations in sediment samples collected from field sites in Ontario, in and near the Great Lakes, where other constituents were also present (Jaagumagi 1993). Therefore, the guidelines are not necessarily based on a causal relationship and biological effects will not necessarily occur at sediment concentrations that are above the cadmium guidelines (see Section 2.2.1 for more details).

Toxicity literature based on exposure of aquatic biota to water-borne nickel indicate that trout are not uniquely sensitive compared to invertebrates (Mebane et al. 2020). Monitoring results for the Harmer Creek population area have shown that benthic invertebrate communities have total and family abundances comparable to undisturbed reference areas (Section 3.2.2; Wiebe et al. 2022). This suggests that nickel concentrations in sediment were not sufficiently high or bioavailable to adversely affect Westslope Cutthroat Trout recruitment.

Toxicity tests with Rainbow Trout, Arctic Grayling, and Coho Salmon demonstrated that alevins are more tolerant of elevated nickel concentrations in water than juveniles of the same species (Buhl and Hamilton 1991); however, another study demonstrated the opposite pattern for Rainbow Trout alevins and juveniles (Pyle 2000). Therefore, it is unclear whether exposure to elevated nickel concentrations in sediments would have been more likely to affect alevins versus older, larger juveniles.

Overall, it is considered unlikely that nickel concentrations in sediments caused or contributed to the reduced recruitment in the Harmer Creek population area. Nickel was identified as a COPC based on a single sample collected from Dry Creek in 2020 (i.e., concentrations in all other samples were less than the upper BC WSQG and within the reference area normal range). However, because nickel was likely integrated into the calcite matrix in at this location, the bioavailability of nickel was likely lower than the reported concentration suggests. Additionally, benthic invertebrate community metrics were generally within reference area normal ranges throughout the Harmer Creek population area, suggesting that nickel concentrations in sediment were not likely to cause biological effects.

3.2.3.3 Selenium

Few sediment samples were collected from the Harmer Creek population area during the period of reduced recruitment, but data from 2019 and 2020 indicate sediment concentrations of selenium were elevated relative to the alert concentration (treated as an upper BC WSQG) and reference area normal ranges in the Harmer Creek Sedimentation Pond and Dry Creek, respectively (Figure 3.1; Appendix Table A.1). As previously indicated, calcite is abundant in Dry Creek (see Section 3.2.2 and Appendix Photos A.2 to A.5) and selenium can become incorporated into the calcite matrix, albeit to a lesser extent than cadmium or nickel, during its formation (SRK 2020). The elevated calcium concentrations in the sediment chemistry samples from Dry Creek suggest that fine calcite particles may have been present in the samples submitted for analysis (Appendix Table A.1). This, along with selenium speciation data, may also explain why selenium concentrations in the samples from Dry Creek were elevated well above the concentration reported at the next downstream station on Harmer Creek (RG_HARM5) in 2020, where calcite presence and concretion are much lower (Figures 2.1 and 3.1; Appendix Table A.1; Zathey et al. 2021).

Ranges of selenium concentrations among sampling areas on Dry Creek, in Harmer Creek Sedimentation Pond, and Harmer Creek downstream from the Harmer Creek Sedimentation Pond overlapped from 2018 to 2020 (Figure 3.1). However, selenium concentrations in sediment samples from Harmer Creek Sedimentation Pond exhibited a 525% increase over time from 2013 to 2019 (Figure 3.1; Appendix Table A.1). The cause(s) of the observed increase in sediment selenium concentration after 2013 are currently uncertain but could include factors such as: 1) increased selenium particulate loading (selenium loading in sediment that enters the pond); 2) increases in aqueous selenium concentrations (higher concentrations would translate to a larger diffusive flux into sediments); 3) a change in trophic status and increased production of organic matter (change in sediment redox conditions leading to higher rates of selenium bioreduction and fixation in sediments); and/or 4) a decrease in the sedimentation rate within the pond (for a given diffusive flux into sediments, higher sediment selenium concentrations would be expected at lower sedimentation rates) (Martin 2021, pers. comm.).

Insufficient data (one sample from 2013) were available evaluate whether similar changes in sediment quality occurred in the Dry Creek Sedimentation Pond over the same time period. However, the SME report from Golder Associates (Golder; Warner and de Bruyn 2022) concluded that aqueous selenium concentrations increased over time in the Dry Creek Sedimentation Pond and maximum concentrations from 2017 to 2020 were greater than the EVWQP Level 2 Benchmark (187 micrograms per litre [µg/L]; Teck Resources 2014) for reproductive effects in fish. Aqueous selenium concentrations were also elevated in Harmer Creek Sedimentation Pond during the period of reduced recruitment (Warner and de Bruyn 2022). Additionally, the highest concentrations of selenoamino-acid metabolites in water occurred immediately downstream from the Dry Creek and Harmer Creek sedimentation ponds (de Bruyn et al. 2022; Warner and de Bruyn 2022).

Selenium has been associated with reduced recruitment and recruitment failure among egg-laying vertebrates, including fish (e.g., Janz et al. 2010). Therefore, the observation that selenium concentrations in sediment increased in the Harmer Creek Sedimentation Pond during the period of reduced recruitment is notable. However, potential effects of selenium on fish are more reliably evaluated through analysis of tissue selenium concentrations in benthic invertebrate prey (as an indicator of dietary exposure) and in fish themselves, than through evaluation of sediment concentrations (BCMOE 2014). Temporal and spatial differences in benthic invertebrate and Westslope Cutthroat Trout tissue chemistry, as it relates to the EoC, are assessed in detail in the SME report prepared by Golder (Warner and de Bruyn 2022). Because of the complexity of selenium behaviour and effects in aquatic systems, a separate, selenium-focused supplemental evaluation was also completed to support the EoC (de Bruyn et al. 2022). Therefore, potential effects of selenium were not evaluated further with respect to sediment quality but the results of the sediment quality evaluation indicate that selenium should be considered a key constituent of concern.

3.3 Data Gaps and Uncertainties

The spatial and temporal representation of the sediment chemistry data set was limited. The only sampling area within the Harmer Creek population area having data available for both the period of interest for reduced recruitment and years prior was Harmer Creek Sedimentation Pond, which has negligible documented fish use. Additionally, because no sampling was completed in the Harmer Creek Sedimentation Pond between 2013 and 2019, it is unclear whether increases in selenium concentrations were gradual or sudden or if they occurred primarily before 2016 (i.e., prior to the period of reduced recruitment) or more recently. However, based on the dominant habitat characteristics of the Harmer Creek population area (lotic), accumulations of fine-grained sediments with elevated constituent concentrations are assumed to be rare and patchy overall.

The sediment samples collected in 2020 may represent older, rather than recently deposited, fine sediments. In 2020, deposits of fine sediment were sampled by first removing and discarding the top 10 cm of material, approximately 40% of which was fine sediments, and then collecting the underlying sediment for chemistry analyses (Morris 2021a,b, pers. comm.; Nupqu and Hemmera 2020). This sampling approach is inconsistent with the other sediment sampling methods employed in Harmer and Grave creeks (Section 2.1) whereby the top 1 to 2 cm of sediment was targeted. Samples composed of the top 1 to 2 cm of sediment would be more likely to represent recently-deposited fine sediments and the reported metal and PAH concentrations would therefore be more closely linked to the timing of collection (i.e., samples collected in fall 2020 would be likely to contain sediments deposited that year). For samples collected from deposits deeper than 10 cm, there is a greater chance that sediment deposits were older and that reported metal and PAH concentrations may not be representative of current conditions in the system (i.e., the samples collected in fall 2020 may be composed primarily of sediments deposited in years prior).

Even when sediment constituent concentrations are greater than BC WSQG and reference area normal ranges, it is uncertain if biological effects may result. This is due to factors regarding the basis for guideline derivation (see Sections 2.2.1 and 3.2.3), as well as habitat factors that affect constituent bioavailability such as TOC, redox conditions, and incorporation of some constituents into the calcite matrix within heavily calcified areas. Generally, comparisons to guidelines tend to over-predict effects. Benthic invertebrate communities in the Harmer Creek population areas were generally similar to those in the Grave Creek population area and undisturbed reference habitats, suggesting negligible effects to benthic invertebrate community composition from exposure to sediment-related constituents. Selenium was the only sediment COPC in Harmer Creek Sedimentation Pond that increased substantially relative to both guidelines and regional reference area normal ranges during the period of reduced recruitment but potential effects of selenium are more reliably evaluated through analysis of tissue selenium concentrations. As indicated previously, the assessment of selenium concentrations in tissues was completed by Golder (Warner and de Bruyn 2022). Also, the primarily drift-based feeding habits of Westslope Cutthroat Trout make the likelihood of dietary exposure via ingestion of fine-grained sediments low.

A number of constituents in sediment did not have guidelines. This is due to factors underlying basis for guideline derivation, including the prioritization of constituents based on their properties, exposure information, and stakeholder interest, as well as the availability of relevant toxicity data (CCME 2001; Kwok et al. 2014). The approach taken the in the evaluation of sediment quality assumes that constituents for which sediment quality guidelines have been derived (i.e., constituents that were considered “priority” constituents; CCME 2001; CEPA 1999) adequately represent the potential for adverse effects to Westslope Cutthroat Trout recruitment.

The evaluation of other lines of evidence (e.g., benthic invertebrate community data) in addition to guideline comparisons lends support to the overall conclusions of the evaluation.

4 CONCLUSIONS AND STRENGTH OF EVIDENCE

To support the overall Harmer Creek Westslope Cutthroat Trout EoC, Minnow evaluated the potential for metals and PAHs in sediment to have caused or contributed to reduced recruitment in the Harmer Creek Westslope Cutthroat Trout population. The conclusions of the sediment quality evaluation are as follows:

- Cadmium and nickel concentrations in sediment samples collected from Dry Creek in 2020 were elevated relative to upper BC WSQG and reference area normal ranges; however reported concentrations likely overestimate the bioavailable fractions of both metals;
- Concentrations of selenium, a constituent that is known to adversely affect fish recruitment, were elevated in sediment samples from Dry Creek and Harmer Creek Sedimentation Pond relative to upper BC WSQG and reference area normal ranges in 2020 and concentrations in Harmer Creek Sedimentation Pond increased by 525% from 2013 to 2019; and
- Exposure of early life stages and adult spawners to constituents associated with fine-grained sediments is likely infrequent, based on limited distributions of fine sediments and observed patterns of fish use (e.g., the Harmer Creek Sedimentation Pond has negligible documented fish use).

However, there are uncertainties related to the following:

- Spatial and temporal limitations of the chemistry data set that that precluded statistical comparisons between the Harmer Creek and Grave Creek population areas and among years at some locations (e.g., within Dry Creek in the Harmer population area);
- Whether sediment chemistry samples collected from Dry Creek and Harmer Creek Reach 5 in 2020 represent recently-deposited fine sediments or older deposits from years prior to 2020;
- The bioavailability of COPCs in sediment samples and the sensitivity of Westslope Cutthroat Trout; and
- The role of sediment chemistry constituents for which guidelines have not been derived.

Based on the available data, the role of sediment quality as a causal or contributing factor in the reduced recruitment reported for the Harmer Creek Westslope Cutthroat Trout population is judged to be minor. Fine sediment is scarce in lotic habitats frequented by Westslope Cutthroat Trout and the Harmer Creek Sedimentation Pond has negligible documented fish use (see EoC Chapter 4). Additionally, during the years of reduced recruitment, benthic invertebrate communities (which would be expected to show signs of impairment at elevated bioavailable concentrations of COPCs) were generally comparable to previous years and to the Grave Creek population area. It is also likely that concentrations of cadmium, nickel, and, to a lesser extent, selenium, in the samples collected from Dry Creek in 2020 overestimate the bioavailable fractions of these constituents due to their incorporation into the calcite matrix at that location and the presence of fine calcite particles in the samples submitted for analysis. Sediment chemistry data for sampling areas upstream from the Harmer Creek Sedimentation Pond, including the Dry Creek Sedimentation Pond, were insufficient to complete temporal comparisons. However, sediment selenium concentrations in the Harmer Creek Sedimentation Pond were higher during the period of recruitment decline relative to before, and maternal transfer and dietary uptake of selenium have been identified as potential causes of reduced recruitment in other systems (Janz et al. 2010; Rasmussen et al. 2007). Consequently, selenium is considered a key constituent of concern and cannot be ruled out as a potential contributor to the reduced recruitment reported for the 2017 to 2019 spawning year cohorts. The potential role of selenium accumulated from various sources (water, sediment, benthic invertebrate prey) in reducing recruitment for the Harmer Creek Westslope Cutthroat Trout population has been evaluated in greater detail by other SMEs (de Bruyn et al. 2022; Warner and de Bruyn 2022). The evaluation completed by Warner and de Bruyn (2022) indicated that bioaccumulated selenium in Dry Creek, within and downstream from the Dry Creek Sedimentation Pond, may have contributed to the reduced recruitment, despite limited fish use of these areas.

The level of confidence in the findings presented in this SME report is considered moderate because data gaps were either offset by other lines of corroborating evidence (i.e., benthic invertebrate community data) or, in the case of selenium, are addressed as part of focused assessments (de Bruyn et al. 2022; Warner and de Bruyn 2022). Reducing some of the uncertainties identified in Section 3.3 could result in sediment chemistry being identified as a moderate contributor to the reduced recruitment reported for the 2017 to 2019 spawning year cohorts. In particular, sediment chemistry data for the Harmer Creek mainstem between Dry Creek and Harmer Sedimentation Pond were limited (i.e., a single sample collected from RG_HARM5 in 2020). Sampling was also limited in Dry Creek[32] and the bioavailable fractions of cadmium, nickel, and selenium in the samples are unknown, but concentrations in bulk sediments were elevated relative to BC WSQG and the reference area normal ranges. Additionally, the evaluation of tissue chemistry data (Warner and de Bruyn 2022) indicated that bioaccumulated

[32] Only one sample was collected from the Dry Creek Sedimentation Pond in 2013. One sample each were collected from upstream (EV_DC3) and downstream (EV_DCOUT) of the pond in 2020; however, the 2020 samples may be representative of sediments deposited earlier than that (see Figures 2.1 and 3.1 and Sections 2.1 and 3.3).

selenium in Dry Creek, within and downstream of the pond, may have contributed to the reduction in recruitment.

Ultimately, it is not anticipated that addressing the key uncertainties identified in Section 3.3 would change the conclusions of the assessment to the extent that sediment chemistry would be reclassified as explaining most, if not all, of the reduction in recruitment. Even a worst-case condition in which the bioavailable concentrations of cadmium, nickel, and/or selenium in Dry Creek sediments were high enough to cause complete recruitment failure in Dry Creek would be unlikely to have a such a large effect on recruitment of the overall population. This is because Dry Creek represents only 22% of the Harmer Creek population area and very few redds have been found there historically, likely due to the high levels of calcite that have persisted in Dry Creek since well before the period of reduced recruitment (Harmer Creek Evaluation of Cause Team 2023; Thorley et al. 2022).

Sediment sampling in lotic habitats within Dry, Harmer, and Grave creeks was completed in September and early October 2021 as part of the fall surveys for the RAEMP; sampling methods were consistent with previous years of sampling completed by Minnow. Sediment coring was also completed in Harmer Creek Sedimentation Pond and Dry Creek Sedimentation Pond in late September 2021. These sampling events were not completed to support the EoC and our interpretation of the role sediment quality played in the reduced recruitment for the Harmer Creek Westslope Cutthroat Trout population. Rather, the results of the fall 2021 sampling are expected to support ongoing and future management by reducing uncertainties and improving the spatial coverage of sediment quality data, the understanding of the distribution of fine sediments, the ability to assess changes over time, and the understanding of relative risk from sedimentation ponds. Data from sampling completed in 2021 will be reported and interpreted by Teck Coal in deliverables separate from the EoC.

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APPENDIX A
SUPPORTING INFORMATION

Photo A.1: **Substrate at EV_HC6 on Harmer Creek upstream from Dry Creek (Harmer Creek population area), September 2014.**

Photo A.2: **Substrate at EV_DC3 on Dry Creek upstream from Dry Creek Sedimentation Pond (Harmer Creek population area), September 2020 (Nupqu and Hemmera 2020).**

Photo A.3: **Dry Creek Sedimentation Pond (EV_DC1; Harmer Creek population area), August 2013 (photo credit: Lotic Environmental Ltd.).**

Photo A.4: **Substrate at EV_DCOUT on Dry Creek downstream from Dry Creek Sedimentation Pond (Harmer Creek population area), September 2020 (Nupqu and Hemmera 2020).**

Photo A.5: Substrate at EV_DCOUT on Dry Creek downstream from Dry Creek Sedimentation Pond (Harmer Creek population area), September 2020 (Nupqu and Hemmera 2020).

Photo A.6: Substrate at RG_HARM5 on Harmer Creek downstream from Dry Creek (Harmer Creek population area), September 2015.

Photo A.7: **Substrate at RG_HARM5 on Harmer Creek downstream from Dry Creek (Harmer Creek population area), September 2020 (Nupqu and Hemmera 2020).**

Photo A.8: **Substrate at RG_HARM5 on Harmer Creek downstream from Dry Creek (Harmer Creek population area), September 2020 (Nupqu and Hemmera 2020).**

Photo A.9: Substrate at RG_HACKUS on Harmer Creek upstream from the Harmer Creek Sedimentation Pond (Harmer Creek population area), September 2012.

Photo A.10: Substrate at RG_HACKUS on Harmer Creek upstream from the Harmer Creek Sedimentation Pond (Harmer Creek population area), September 2012.

Photo A.11: **Substrate at RG_HACKUS on Harmer Creek upstream from the Harmer Creek Sedimentation Pond (Harmer Creek population area), September 2015.**

Photo A.12: **Substrate at RG_HACKUS on Harmer Creek upstream from the Harmer Creek Sedimentation Pond (Harmer Creek population area), September 2016.**

Photo A.13: **Substrate at RG_HACKUS on Harmer Creek upstream from the Harmer Creek Sedimentation Pond (Harmer Creek population area), September 2018.**

Photo A.14: **Harmer Creek Upstream from the inlet to the Harmer Creek Sedimentation Pond (RG_HA7; Harmer Creek population area), July 2021.**

Photo A.15: Harmer Creek Sedimentation Pond inlet (RG_HA7; Harmer Creek population area), July 2013.

Photo A.16: Harmer Creek Sedimentation Pond (RG_HA7; Harmer Creek population area), July 2021.

Photo A.17: Harmer Creek Sedimentation Pond (RG_HA7; Harmer Creek population area), July 2021.

Photo A.18: Fry on Top of Redd (Harmer Creek population area), August 2021 (photo credit: Mike Robinson).

Photo A.19: **Substrate at RG_HACKDS on Harmer Creek downstream from the Harmer Creek Sedimentation Pond (Grave Creek population area), September 2014.**

Photo A.20: **Substrate at RG_HACKDS on Harmer Creek downstream from the Harmer Creek Sedimentation Pond (Grave Creek population area), September 2018.**

Photo A.21: **Substrate at RG_HACKDS on Harmer Creek downstream from the Harmer Creek Sedimentation Pond (Grave Creek population area), September 2018.**

Photo A.22: **Substrate at RG_HACKDS on Harmer Creek downstream from the Harmer Creek Sedimentation Pond (Grave Creek population area), July 2021.**

Photo A.23: Substrate at RG_GRUHA on Grave Creek upstream from Harmer Creek (Grave Creek population area), September 2015.

Photo A.24: Substrate at RG_GRUHA on Grave Creek upstream from Harmer Creek (Grave Creek population area), September 2015.

Photo A.25: **Substrate at RG_GRACK on Grave Creek downstream from Harmer Creek (Grave Creek population area), September 2012.**

Photo A.26: **Substrate at EV_GV1 on Grave Creek near the confluence with the Elk River (Grave Creek population area), September 2012.**

Photo A.27: **Substrate at EV_GV1 on Grave Creek near the confluence with the Elk River (Grave Creek population area), September 2014.**

Photo A.28: **Substrate at EV_GV1 on Grave Creek near the confluence with the Elk River (Grave Creek population area), September 2018.**

Table A.1: Sediment Quality at Reference and Mine-exposed Areas on Harmer, Grave, and Dry Creeks, 2013 to 2020

Analyte		Units	BC WSQG [a,b]		Harmer Population				
					Reference	Mine-exposed			
					Harmer Creek	Dry Creek			Harmer Creek
					EV_HC6	EV_DC3	EV_DC1	EV_DCOUT	RG_HARM5
			Lower	Upper	-	-	-	-	-
					21-Oct-13	22-Sep-20	21-Oct-13	22-Sep-20	21-Sep-20
Physical Tests	Moisture	%	-	-	79.2	57.8	60.0	49.8	30.4
	pH(1:2)	pH	-	-	8.05	8.25	8.14	8.31	7.91
	pH (lab)	pH	-	-	nd	nd	nd	nd	nd
Particle Size	% Gravel (>2 mm)	%	-	-	<0.1	3.00	11.4	<1	<1
	% Sand (0.125 mm to 0.063 mm)	%	-	-	nd	12.7	nd	12.4	13.1
	% Sand (0.25 mm to 0.125 mm)	%	-	-	nd	22.8	nd	17.0	15.9
	% Sand (0.50 mm to 0.25 mm)	%	-	-	nd	13.8	nd	13.5	10.9
	% Sand (1.00 mm to 0.50 mm)	%	-	-	nd	4.20	nd	11.5	7.40
	% Sand (2.00 mm to 1.00 mm)	%	-	-	nd	2.00	nd	<1	3.10
	% Silt (0.0312 mm to 0.004 mm)	%	-	-	nd	19.6	nd	21.9	22.3
	% Silt (0.063 mm to 0.0312 mm)	%	-	-	nd	18.1	nd	18.7	17.2
	% Silt (0.063 mm to 4 µm)	%	-	-	77.8	nd	43.6	nd	nd
	% Clay (<4 µm)	%	-	-	5.39	3.80	4.15	4.80	9.70
Organic Carbon	Total Organic Carbon	%	-	-	8.92	9.30	5.24	7.50	4.67
Metals	Aluminum (Al)	mg/kg	-	-	6,230	6,360	2,490	3,850	9,230
	Antimony (Sb)	mg/kg	-	-	0.410	0.400	0.250	0.260	0.600
	Arsenic (As)	mg/kg	5.9	17	4.22	3.11	1.23	1.49	6.96
	Barium (Ba)	mg/kg	-	-	78.0	128	99.9	113	137
	Beryllium (Be)	mg/kg	-	-	0.420	0.390	0.180	0.230	0.600
	Bismuth (Bi)	mg/kg	-	-	<0.1	<0.2	<0.1	<0.2	<0.2
	Boron (B)	mg/kg	-	-	<10	10.5	<10	6.80	7.60
	Cadmium (Cd)	mg/kg	0.6	3.5	0.967	9.50	2.43	8.26	1.01
	Calcium (Ca)	mg/kg	-	-	52,700	164,000	140,000	236,000	10,200
	Chromium (Cr)	mg/kg	37.3	90	19.4	8.65	4.29	5.59	14.5
	Cobalt (Co)	mg/kg	-	-	3.11	3.70	1.26	1.74	6.76
	Copper (Cu)	mg/kg	35.7	197	10.5	14.1	5.19	7.35	15.5
	Iron (Fe)	mg/kg	21,200	43,766	8,720	7,810	3,880	3,940	16,500
	Lead (Pb)	mg/kg	35	91.3	6.67	5.54	3.00	3.02	9.17
	Lithium (Li)	mg/kg	-	-	10.0	6.80	<5	4.90	8.90
	Magnesium (Mg)	mg/kg	-	-	20,200	5,810	4,090	7,050	4,240
	Manganese (Mn)	mg/kg	460	1,100	267	456	47.0	106	498
	Mercury (Hg)	mg/kg	0.17	0.486	0.0800	0.114	0.0316	0.0703	0.0844
	Molybdenum (Mo)	mg/kg	25	23,000	1.08	0.770	0.480	0.510	1.68
	Nickel (Ni)	mg/kg	16	75	21.2	80.9	21.4	37.4	25.6
	Phosphorus (P)	mg/kg	-	-	1,330	781	583	489	1,710
	Potassium (K)	mg/kg	-	-	1,220	1,410	720	990	1,810
	Selenium (Se)	mg/kg	2		2.91	11.6	81.7	35.3	1.48
	Silver (Ag)	mg/kg	0.500	-	0.115	0.150	0.0740	<0.1	0.210
	Sodium (Na)	mg/kg	-	-	100	108	<100	123	57.0
	Strontium (Sr)	mg/kg	-	-	56.1	70.0	92.7	92.6	28.2
	Thallium (Tl)	mg/kg	-	-	0.488	0.538	0.191	0.309	0.271
	Tin (Sn)	mg/kg	-	-	0.380	<2	<0.2	<2	<2
	Titanium (Ti)	mg/kg	-	-	53.7	23.7	14.5	20.0	24.7
	Uranium (U)	mg/kg	-	-	1.27	1.61	3.04	2.59	0.912
	Vanadium (V)	mg/kg	-	-	17.6	17.4	9.26	11.0	27.6
	Zinc (Zn)	mg/kg	123	315	108	187	58.9	160	86.0
	Zirconium (Zr)	mg/kg	-	-	nd	1.30	nd	<1	1.10
Polycyclic Aromatic Hydrocarbons	Acenaphthene	mg/kg	0.00671	0.0889	<0.025	<0.039	<0.035	<0.039	<0.01
	Acenaphthylene	mg/kg	0.00587	0.128	<0.005	<0.006	<0.005	<0.005	<0.005
	Acridine	mg/kg	-	-	nd	<0.07	nd	<0.08	<0.01
	Anthracene	mg/kg	0.0469	0.245	<0.012	<0.004	<0.025	<0.004	<0.004
	Benz(a)anthracene	mg/kg	0.0317	0.385	0.0170	0.0250	0.0310	0.0240	<0.03
	Benzo(a)pyrene	mg/kg	0.0319	0.782	0.0120	0.0150	0.0140	0.0120	<0.01
	Benzo(b)fluoranthene	mg/kg	-	-	0.0350	nd	0.0610	nd	nd
	Benzo(b,j)fluoranthene	mg/kg	-	-	0.0350	0.0700	0.0610	0.0610	0.0300
	Benzo(g,h,i)perylene	mg/kg	0.170	0.32	0.0200	0.0280	0.0270	0.0260	<0.01
	Benzo(k)fluoranthene	mg/kg	0.240	13.4	<0.01	<0.01	<0.01	<0.01	<0.01
	Chrysene	mg/kg	0.057	0.862	<0.06	0.165	<0.12	0.144	0.0660
	Dibenz(a,h)anthracene	mg/kg	0.00622	0.135	0.0107	0.0144	0.0160	0.0135	0.00560
	Fluoranthene	mg/kg	0.111	2.355	0.0200	0.0300	0.0330	0.0240	<0.01
	Fluorene	mg/kg	0.021	0.144	0.0810	0.106	0.109	0.114	<0.02
	Indeno(1,2,3-c,d)pyrene	mg/kg	0.2	3.2	<0.01	<0.01	<0.01	0.0100	<0.01
	1-Methylnaphthalene	mg/kg			nd	nd	nd	nd	nd
	2-Methylnaphthalene	mg/kg	0.0202	0.201	0.426	0.701	0.602	0.628	0.141
	Naphthalene	mg/kg	0.0346	0.391	0.106	0.183	0.154	0.169	0.0680
	Phenanthrene	mg/kg	0.0419	0.515	0.298	0.505	0.545	0.437	0.162
	Pyrene	mg/kg	0.0530	0.875	0.0300	0.0430	0.0520	0.0380	0.0150
	Quinoline	mg/kg	-	-	nd	<0.05	nd	<0.05	<0.05

Concentration is <LRL and LRL exceeds the lower BC WSQG.
Concentration is <LRL and LRL exceeds the upper BC WSQG or alert concentration for selenium.
Concentration exceeds the lower BC WSQG.
Concentration exceeds the upper BC WSQG or alert concentration for selenium.

Notes: BC WSQG = British Columbia Working Sediment Quality Guideline; - = not applicable; nd = no data; % = percent; > = greater than; mm = millimetres; < = less than; µm = micrometres; mg/kg = milligrams per kilogram; LRL = Laboratory Reporting Limit; BCMOECCS = British Columbia Ministry of Environment and Climate Change Strategy.

[a] The 2 mg/kg alert concentration from BCMOECCS (2021a) was applied; there is currently no BC WSQG for selenium.

[b] BC WSQG for the protection of freshwater aquatic life (BCMOECCS 2021b).

Table A.1: Sediment Quality at Reference and Mine-exposed Areas on Harmer, Grave, and Dry Creeks, 2013 to 2020

	Analyte	Units	BC WSQG [a,b]		Harmer Population - Mine-exposed - Harmer Sediment Pond - RG_HA7				
			Lower	Upper	RG_HA7-1 12-Aug-13	RG_HA7-2 12-Aug-13	RG_HA7-3 12-Aug-13	RG_HA7-4 12-Aug-13	RG_HA7-5 12-Aug-13
Physical Tests	Moisture	%	-	-	47.7	45.0	47.4	50.6	51.2
	pH(1:2)	pH	-	-	7.67	7.63	7.73	7.74	7.74
	pH (lab)	pH	-	-	nd	nd	nd	nd	nd
Particle Size	% Gravel (>2 mm)	%	-	-	0.180	<0.1	<0.1	<0.1	<0.1
	% Sand (0.125 mm to 0.063 mm)	%	-	-	7.09	12.2	7.67	1.13	3.31
	% Sand (0.25 mm to 0.125 mm)	%	-	-	5.36	2.37	0.470	<0.1	0.110
	% Sand (0.50 mm to 0.25 mm)	%	-	-	1.33	<0.1	<0.1	<0.1	<0.1
	% Sand (1.00 mm to 0.50 mm)	%	-	-	0.140	<0.1	<0.1	<0.1	<0.1
	% Sand (2.00 mm to 1.00 mm)	%	-	-	<0.1	<0.1	<0.1	<0.1	<0.1
	% Silt (0.0312 mm to 0.004 mm)	%	-	-	42.4	42.4	47.2	54.4	51.1
	% Silt (0.063 mm to 0.0312 mm)	%	-	-	37.8	34.2	32.3	25.3	25.6
	% Silt (0.063 mm to 4 µm)	%	-	-	nd	nd	nd	nd	nd
	% Clay (<4 µm)	%	-	-	5.70	8.75	12.3	19.1	19.9
Organic Carbon	Total Organic Carbon	%	-	-	24.1	18.2	17.6	18.4	18.1
Metals	Aluminum (Al)	mg/kg	-	-	6,090	7,020	7,490	7,220	7,400
	Antimony (Sb)	mg/kg	-	-	0.620	0.710	0.830	0.890	0.860
	Arsenic (As)	mg/kg	5.9	17	4.79	5.60	6.07	6.25	5.95
	Barium (Ba)	mg/kg	-	-	163	181	198	194	196
	Beryllium (Be)	mg/kg	-	-	0.600	0.660	0.740	0.770	0.770
	Bismuth (Bi)	mg/kg	-	-	0.130	0.150	0.170	0.190	0.180
	Boron (B)	mg/kg	-	-	6.40	6.40	6.10	5.40	5.60
	Cadmium (Cd)	mg/kg	0.6	3.5	1.10	1.26	1.21	1.34	1.32
	Calcium (Ca)	mg/kg	-	-	14,700	16,300	16,800	15,900	16,400
	Chromium (Cr)	mg/kg	37.3	90	9.32	10.8	12.0	10.8	11.7
	Cobalt (Co)	mg/kg	-	-	5.52	6.33	6.98	7.98	7.58
	Copper (Cu)	mg/kg	35.7	197	16.9	20.0	22.6	25.6	24.0
	Iron (Fe)	mg/kg	21,200	43,766	10,900	13,100	14,400	15,800	15,000
	Lead (Pb)	mg/kg	35	91.3	9.20	10.7	12.1	13.6	13.0
	Lithium (Li)	mg/kg	-	-	6.70	7.00	7.60	7.30	7.50
	Magnesium (Mg)	mg/kg	-	-	4,120	4,750	5,110	4,610	4,560
	Manganese (Mn)	mg/kg	460	1,100	318	319	339	346	351
	Mercury (Hg)	mg/kg	0.17	0.486	0.0756	0.0986	0.0807	0.0894	0.0904
	Molybdenum (Mo)	mg/kg	25	23,000	1.41	1.61	1.71	1.81	1.74
	Nickel (Ni)	mg/kg	16	75	22.3	25.0	26.9	29.3	28.1
	Phosphorus (P)	mg/kg	-	-	928	1,060	1,230	1,140	1,130
	Potassium (K)	mg/kg	-	-	1,460	1,670	1,760	1,590	1,720
	Selenium (Se)	mg/kg	2		3.26	4.40	2.60	3.14	3.13
	Silver (Ag)	mg/kg	0.500	-	0.211	0.237	0.270	0.323	0.306
	Sodium (Na)	mg/kg	-	-	<100	nd	nd	nd	nd
	Strontium (Sr)	mg/kg	-	-	29.0	31.6	32.9	32.5	32.9
	Thallium (Tl)	mg/kg	-	-	0.208	0.214	0.186	0.167	0.170
	Tin (Sn)	mg/kg	-	-	0.300	0.650	0.810	1.02	0.750
	Titanium (Ti)	mg/kg	-	-	33.2	20.6	29.5	27.4	17.9
	Uranium (U)	mg/kg	-	-	0.817	0.956	0.910	0.942	0.922
	Vanadium (V)	mg/kg	-	-	22.1	25.6	27.4	26.6	27.3
	Zinc (Zn)	mg/kg	123	315	82.4	97.5	113	121	115
	Zirconium (Zr)	mg/kg	-	-	nd	nd	nd	nd	nd
Polycyclic Aromatic Hydrocarbons	Acenaphthene	mg/kg	0.00671	0.0889	<0.2	<0.2	<0.2	<0.3	<0.3
	Acenaphthylene	mg/kg	0.00587	0.128	<0.02	<0.02	<0.02	<0.02	<0.02
	Acridine	mg/kg	-	-	nd	nd	nd	nd	nd
	Anthracene	mg/kg	0.0469	0.245	<0.07	<0.1	<0.07	<0.2	<0.09
	Benz(a)anthracene	mg/kg	0.0317	0.385	0.175	0.143	0.162	0.242	0.201
	Benzo(a)pyrene	mg/kg	0.0319	0.782	0.110	0.0830	0.0950	0.160	0.109
	Benzo(b)fluoranthene	mg/kg	-	-	0.527	0.574	0.586	0.927	0.741
	Benzo(b,j)fluoranthene	mg/kg	-	-	0.579	0.637	0.633	0.998	0.812
	Benzo(g,h,i)perylene	mg/kg	0.170	0.32	0.119	0.113	0.119	0.174	0.136
	Benzo(k)fluoranthene	mg/kg	0.240	13.4	0.0530	0.0620	0.0470	0.0710	0.0710
	Chrysene	mg/kg	0.057	0.862	0.587	nd	0.613	0.932	0.837
	Dibenz(a,h)anthracene	mg/kg	0.00622	0.135	0.0843	0.0807	0.0895	0.137	0.105
	Fluoranthene	mg/kg	0.111	2.355	0.175	0.173	0.183	0.262	0.243
	Fluorene	mg/kg	0.021	0.144	0.465	0.450	0.479	0.668	0.612
	Indeno(1,2,3-c,d)pyrene	mg/kg	0.2	3.2	0.0420	0.0300	0.0390	0.0610	0.0480
	1-Methylnaphthalene	mg/kg			nd	nd	nd	nd	nd
	2-Methylnaphthalene	mg/kg	0.0202	0.201	1.24	1.17	1.19	1.56	1.48
	Naphthalene	mg/kg	0.0346	0.391	0.283	0.258	0.256	0.313	0.301
	Phenanthrene	mg/kg	0.0419	0.515	3.44	3.43	3.49	4.74	4.28
	Pyrene	mg/kg	0.0530	0.875	0.287	0.269	0.305	0.437	0.393
	Quinoline	mg/kg	-	-	nd	nd	nd	nd	nd

Concentration is <LRL and LRL exceeds the lower BC WSQG.
Concentration is <LRL and LRL exceeds the upper BC WSQG or alert concentration for selenium.
Concentration exceeds the lower BC WSQG.
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Notes: BC WSQG = British Columbia Working Sediment Quality Guideline; - = not applicable; nd = no data; % = percent; > = greater than; mm = millimetres; < = less than; µm = micrometres; mg/kg = milligrams per kilogram; LRL = Laboratory Reporting Limit; BCMOECCS = British Columbia Ministry of Environment and Climate Change Strategy.

[a] The 2 mg/kg alert concentration from BCMOECCS (2021a) was applied; there is currently no BC WSQG for selenium.

[b] BC WSQG for the protection of freshwater aquatic life (BCMOECCS 2021b).

Table A.1: Sediment Quality at Reference and Mine-exposed Areas on Harmer, Grave, and Dry Creeks, 2013 to 2020

	Analyte	Units	BC WSQG [a,b]		Harmer Population					
					Mine-exposed					
					Harmer Sediment Pond					
					RG_HA7					
			Lower	Upper	RG_HA7-1	RG_HA7-1	RG_HA7-2	RG_HA7-3	RG_HA7-4	RG_HA7-5
Physical Tests	Moisture	%	-	-	54.5	61.0	70.9	58.6	65.4	62.1
	pH(1:2)	pH	-	-	7.99	7.70	7.58	7.64	7.47	7.85
	pH (lab)	pH	-	-	nd	nd	nd	nd	nd	nd
Particle Size	% Gravel (>2 mm)	%	-	-	0.390	nd	<1	<1	<1	<1
	% Sand (0.125 mm to 0.063 mm)	%	-	-	nd	6.30	2.50	5.30	12.9	11.6
	% Sand (0.25 mm to 0.125 mm)	%	-	-	nd	2.00	<1	1.50	9.20	2.70
	% Sand (0.50 mm to 0.25 mm)	%	-	-	nd	<1	<1	<1	1.90	<1
	% Sand (1.00 mm to 0.50 mm)	%	-	-	nd	nd	<1	<1	<1	<1
	% Sand (2.00 mm to 1.00 mm)	%	-	-	nd	<1	<1	<1	<1	<1
	% Silt (0.0312 mm to 0.004 mm)	%	-	-	nd	48.9	53.4	49.5	37.9	44.4
	% Silt (0.063 mm to 0.0312 mm)	%	-	-	nd	30.7	27.1	31.5	31.4	33.9
	% Silt (0.063 mm to 4 µm)	%	-	-	86.8	nd	nd	nd	nd	nd
	% Clay (<4 µm)	%	-	-	8.29	11.3	16.4	11.8	6.20	7.00
Organic Carbon	Total Organic Carbon	%	-	-	11.6	12.8	15.7	14.9	17.2	16.5
Metals	Aluminum (Al)	mg/kg	-	-	6,680	7,960	9,000	8,040	7,240	6,610
	Antimony (Sb)	mg/kg	-	-	0.630	0.710	0.800	0.730	0.600	0.640
	Arsenic (As)	mg/kg	5.9	17	5.41	5.79	6.39	5.54	5.10	5.18
	Barium (Ba)	mg/kg	-	-	166	199	202	184	173	164
	Beryllium (Be)	mg/kg	-	-	0.610	0.690	0.810	0.770	0.620	0.630
	Bismuth (Bi)	mg/kg	-	-	0.140	nd	nd	nd	nd	nd
	Boron (B)	mg/kg	-	-	nd	6.70	6.80	6.80	7.80	6.20
	Cadmium (Cd)	mg/kg	0.6	3.5	1.15	1.45	1.57	1.49	1.42	1.18
	Calcium (Ca)	mg/kg	-	-	21,700	30,000	26,300	20,300	22,500	19,700
	Chromium (Cr)	mg/kg	37.3	90	10.5	12.8	14.0	12.9	12.0	10.4
	Cobalt (Co)	mg/kg	-	-	5.51	6.37	7.20	6.43	5.43	5.43
	Copper (Cu)	mg/kg	35.7	197	18.1	21.0	24.3	21.8	18.2	17.5
	Iron (Fe)	mg/kg	21,200	43,766	13,800	14,500	16,400	13,800	13,400	12,500
	Lead (Pb)	mg/kg	35	91.3	10.1	10.7	12.0	11.0	9.34	9.02
	Lithium (Li)	mg/kg	-	-	7.50	9.00	9.40	8.10	8.20	7.50
	Magnesium (Mg)	mg/kg	-	-	6,360	6,020	5,870	5,410	5,580	4,960
	Manganese (Mn)	mg/kg	460	1,100	246	243	199	167	188	243
	Mercury (Hg)	mg/kg	0.17	0.486	0.0741	0.0842	0.0932	0.0836	0.0715	0.0668
	Molybdenum (Mo)	mg/kg	25	23,000	1.32	1.47	1.75	1.48	1.50	1.38
	Nickel (Ni)	mg/kg	16	75	23.7	33.0	34.5	32.9	29.8	26.0
	Phosphorus (P)	mg/kg	-	-	1,280	1,220	1,210	1,120	1,200	1,080
	Potassium (K)	mg/kg	-	-	1,610	1,910	2,200	1,960	1,740	1,600
	Selenium (Se)	mg/kg	2		9.41	33.6	29.2	27.8	19.1	25.4
	Silver (Ag)	mg/kg	0.500	-	0.200	0.280	0.320	0.290	0.240	0.230
	Sodium (Na)	mg/kg	-	-	<100	106	99.0	92.0	92.0	90.0
	Strontium (Sr)	mg/kg	-	-	33.2	42.4	42.4	37.4	36.9	33.4
	Thallium (Tl)	mg/kg	-	-	0.215	0.291	0.266	0.271	0.312	0.256
	Tin (Sn)	mg/kg	-	-	0.360	nd	nd	nd	nd	nd
	Titanium (Ti)	mg/kg	-	-	21.4	33.9	23.6	15.8	19.8	18.3
	Uranium (U)	mg/kg	-	-	0.846	1.91	1.76	1.82	1.38	1.20
	Vanadium (V)	mg/kg	-	-	24.8	27.4	30.7	27.8	25.1	23.2
	Zinc (Zn)	mg/kg	123	315	98.7	111	123	113	107	92.6
	Zirconium (Zr)	mg/kg	-	-	nd	1.40	1.40	1.50	1.60	1.10
Polycyclic Aromatic Hydrocarbons	Acenaphthene	mg/kg	0.00671	0.0889	<0.09	<0.073	<0.064	<0.075	<0.055	<0.1
	Acenaphthylene	mg/kg	0.00587	0.128	<0.015	<0.005	<0.008	<0.005	<0.007	<0.008
	Acridine	mg/kg	-	-	nd	<0.01	<0.016	<0.01	<0.014	<0.013
	Anthracene	mg/kg	0.0469	0.245	<0.07	<0.01	<0.008	<0.007	<0.0056	<0.008
	Benz(a)anthracene	mg/kg	0.0317	0.385	0.0940	0.0420	0.0420	0.0450	0.0370	0.0640
	Benzo(a)pyrene	mg/kg	0.0319	0.782	0.0490	0.0200	0.0200	0.0210	0.0200	0.0360
	Benzo(b)fluoranthene	mg/kg	-	-	0.230	nd	nd	nd	nd	nd
	Benzo(b,j)fluoranthene	mg/kg	-	-	0.249	0.105	0.102	0.104	0.0800	0.151
	Benzo(g,h,i)perylene	mg/kg	0.170	0.32	0.0930	0.0320	0.0320	0.0340	0.0290	0.0450
	Benzo(k)fluoranthene	mg/kg	0.240	13.4	0.0190	<0.01	<0.016	<0.01	<0.014	<0.013
	Chrysene	mg/kg	0.057	0.862	<0.37	0.280	0.272	0.291	0.208	0.407
	Dibenz(a,h)anthracene	mg/kg	0.00622	0.135	0.0648	<0.022	<0.02	<0.023	<0.018	<0.031
	Fluoranthene	mg/kg	0.111	2.355	0.0990	0.0530	0.0610	0.0550	0.0370	0.0760
	Fluorene	mg/kg	0.021	0.144	0.261	0.184	0.167	0.186	0.143	0.249
	Indeno(1,2,3-c,d)pyrene	mg/kg	0.2	3.2	0.0270	0.0120	<0.016	0.0120	<0.014	0.0180
	1-Methylnaphthalene	mg/kg			nd	nd	nd	nd	nd	nd
	2-Methylnaphthalene	mg/kg	0.0202	0.201	0.739	0.642	0.629	0.620	0.515	0.768
	Naphthalene	mg/kg	0.0346	0.391	0.194	0.179	0.177	0.171	0.142	0.200
	Phenanthrene	mg/kg	0.0419	0.515	1.78	1.01	0.975	1.11	0.776	1.49
	Pyrene	mg/kg	0.0530	0.875	0.195	0.0870	0.0920	0.0930	0.0750	0.128
	Quinoline	mg/kg	-	-	nd	<0.01	<0.016	<0.01	<0.014	<0.013

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[a] The 2 mg/kg alert concentration from BCMOECCS (2021a) was applied; there is currently no BC WSQG for selenium.

[b] BC WSQG for the protection of freshwater aquatic life (BCMOECCS 2021b).

Table A.1: Sediment Quality at Reference and Mine-exposed Areas on Harmer, Grave, and Dry Creeks, 2013 to 2020

Analyte		Units	BC WSQG [a,b]		Grave Population					
					Reference	Mine-exposed				
					Grave Creek	Harmer Creek				
					EV_GV3	RG_HACKDS				
			Lower	Upper	-	RG_HACKDS-1	RG_HACKDS-2	RG_HACKDS-3	RG_HACKDS-4	RG_HACKDS-5
Physical Tests	Moisture	%	-	-	65.2	86.3	85.8	86.9	90.3	89.3
	pH(1:2)	pH	-	-	8.21	7.65	7.69	7.75	7.78	7.53
	pH (lab)	pH	-	-	nd	nd	nd	nd	nd	nd
Particle Size	% Gravel (>2 mm)	%	-	-	3.81	1.00	<1	<1	<1	<1
	% Sand (0.125 mm to 0.063 mm)	%	-	-	nd	1.80	2.70	1.90	2.90	2.80
	% Sand (0.25 mm to 0.125 mm)	%	-	-	nd	<1	1.60	1.40	2.10	2.50
	% Sand (0.50 mm to 0.25 mm)	%	-	-	nd	<1	1.30	1.30	2.00	1.90
	% Sand (1.00 mm to 0.50 mm)	%	-	-	nd	<1	1.50	1.10	1.30	1.20
	% Sand (2.00 mm to 1.00 mm)	%	-	-	nd	<1	<1	<1	<1	<1
	% Silt (0.0312 mm to 0.004 mm)	%	-	-	nd	48.0	45.8	46.6	47.0	45.8
	% Silt (0.063 mm to 0.0312 mm)	%	-	-	nd	29.7	30.9	30.0	31.3	31.5
	% Silt (0.063 mm to 4 µm)	%	-	-	69.6	nd	nd	nd	nd	nd
	% Clay (<4 µm)	%	-	-	6.77	17.0	15.3	16.5	12.7	13.5
Organic Carbon	Total Organic Carbon	%	-	-	3.30	11.2	11.1	10.7	9.80	11.1
Metals	Aluminum (Al)	mg/kg	-	-	10,000	10,100	5,140	8,840	8,970	8,080
	Antimony (Sb)	mg/kg	-	-	0.580	0.670	0.410	0.620	0.590	0.620
	Arsenic (As)	mg/kg	5.9	17	8.23	6.36	5.16	5.86	7.91	5.81
	Barium (Ba)	mg/kg	-	-	380	226	142	204	216	195
	Beryllium (Be)	mg/kg	-	-	0.680	0.750	0.490	0.700	0.630	0.610
	Bismuth (Bi)	mg/kg	-	-	0.200	<0.2	<0.2	<0.2	<0.2	<0.2
	Boron (B)	mg/kg	-	-	10.0	12.8	<5	11.9	10.8	10.3
	Cadmium (Cd)	mg/kg	0.6	3.5	0.887	1.82	1.32	1.71	1.63	1.85
	Calcium (Ca)	mg/kg	-	-	17,700	57,900	92,400	58,700	51,100	60,500
	Chromium (Cr)	mg/kg	37.3	90	15.1	18.3	30.5	24.8	16.9	15.2
	Cobalt (Co)	mg/kg	-	-	6.76	7.99	5.58	6.74	6.53	6.94
	Copper (Cu)	mg/kg	35.7	197	21.6	18.3	12.8	16.6	16.8	16.0
	Iron (Fe)	mg/kg	21,200	43,766	20,700	17,400	14,900	15,400	20,800	14,500
	Lead (Pb)	mg/kg	35	91.3	11.6	10.4	7.16	9.98	8.94	8.80
	Lithium (Li)	mg/kg	-	-	15.0	10.0	5.80	8.40	7.40	7.20
	Magnesium (Mg)	mg/kg	-	-	6,960	7,940	14,100	9,100	7,900	7,630
	Manganese (Mn)	mg/kg	460	1,100	424	2,170	1,530	1,760	1,420	1,670
	Mercury (Hg)	mg/kg	0.17	0.486	0.0671	0.0653	0.0414	0.0670	0.0590	0.0613
	Molybdenum (Mo)	mg/kg	25	23,000	2.93	1.75	1.80	1.93	1.56	1.64
	Nickel (Ni)	mg/kg	16	75	26.1	40.2	35.0	38.5	33.9	36.6
	Phosphorus (P)	mg/kg	-	-	1,340	1,610	1,170	1,480	1,630	1,450
	Potassium (K)	mg/kg	-	-	2,280	2,640	1,130	2,320	2,430	2,160
	Selenium (Se)	mg/kg	2		1.29	23.4	10.6	22.0	15.5	17.5
	Silver (Ag)	mg/kg	0.500	-	0.200	0.220	0.140	0.220	0.190	0.190
	Sodium (Na)	mg/kg	-	-	110	111	81.0	114	94.0	96.0
	Strontium (Sr)	mg/kg	-	-	45.8	61.6	67.1	61.2	54.0	56.1
	Thallium (Tl)	mg/kg	-	-	0.391	0.358	0.203	0.349	0.312	0.323
	Tin (Sn)	mg/kg	-	-	0.540	<2	<2	<2	<2	<2
	Titanium (Ti)	mg/kg	-	-	35.5	18.3	4.50	15.0	17.2	15.3
	Uranium (U)	mg/kg	-	-	0.784	1.09	0.791	1.03	0.871	1.04
	Vanadium (V)	mg/kg	-	-	27.0	32.8	17.3	28.9	31.0	26.5
	Zinc (Zn)	mg/kg	123	315	107	149	106	133	130	128
	Zirconium (Zr)	mg/kg	-	-	nd	<1	<1	<1	<1	<1
Polycyclic Aromatic Hydrocarbons	Acenaphthene	mg/kg	0.00671	0.0889	<0.01	<0.058	<0.047	<0.039	<0.04	<0.052
	Acenaphthylene	mg/kg	0.00587	0.128	<0.005	<0.017	<0.016	<0.018	<0.024	<0.021
	Acridine	mg/kg	-	-	nd	<0.033	<0.032	<0.035	<0.048	0.115
	Anthracene	mg/kg	0.0469	0.245	<0.004	<0.013	<0.013	<0.014	<0.019	<0.016
	Benz(a)anthracene	mg/kg	0.0317	0.385	<0.01	0.0440	0.0380	<0.035	<0.048	<0.041
	Benzo(a)pyrene	mg/kg	0.0319	0.782	<0.01	<0.033	nd	<0.035	nd	<0.041
	Benzo(b)fluoranthene	mg/kg	-	-	0.0220	nd	nd	nd	nd	nd
	Benzo(b,j)fluoranthene	mg/kg	-	-	0.0220	nd	nd	nd	nd	nd
	Benzo(g,h,i)perylene	mg/kg	0.170	0.32	<0.01	0.0400	0.0350	<0.035	<0.048	<0.041
	Benzo(k)fluoranthene	mg/kg	0.240	13.4	<0.01	<0.033	<0.032	<0.035	<0.048	<0.041
	Chrysene	mg/kg	0.057	0.862	<0.05	0.299	0.240	0.207	0.227	0.272
	Dibenz(a,h)anthracene	mg/kg	0.00622	0.135	<0.005	nd	nd	<0.018	<0.024	<0.021
	Fluoranthene	mg/kg	0.111	2.355	0.0100	0.0470	0.0380	0.0360	<0.048	<0.041
	Fluorene	mg/kg	0.021	0.144	0.0180	0.175	0.145	0.117	0.115	0.146
	Indeno(1,2,3-c,d)pyrene	mg/kg	0.2	3.2	<0.01	<0.033	<0.032	<0.035	nd	<0.041
	1-Methylnaphthalene	mg/kg			nd	nd	nd	nd	nd	nd
	2-Methylnaphthalene	mg/kg	0.0202	0.201	0.148	0.657	0.512	0.442	0.453	0.567
	Naphthalene	mg/kg	0.0346	0.391	0.0560	0.169	0.129	0.115	0.123	0.145
	Phenanthrene	mg/kg	0.0419	0.515	0.221	0.970	0.775	0.630	0.656	0.800
	Pyrene	mg/kg	0.0530	0.875	0.0170	0.0750	0.0620	0.0500	0.0530	0.0620
	Quinoline	mg/kg	-	-	nd	<0.033	<0.032	<0.035	<0.048	<0.041

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Table A.1: Sediment Quality at Reference and Mine-exposed Areas on Harmer, Grave, and Dry Creeks, 2013 to 2020

Analyte		Units	BC WSQG [a,b]		Grave Population					
					Mine-exposed					
					Harmer Creek					
					RG_HACKDS					
			Lower	Upper	RG_HACKDS-1 08-Sep-19	RG_HACKDS-2 08-Sep-19	RG_HACKDS-3 08-Sep-19	RG_HACKDS-4 08-Sep-19	RG_HACKDS-5 08-Sep-19	RG_HACKDS-1 16-Sep-20
Physical Tests	Moisture	%	-	-	59.9	73.2	80.5	77.7	77.5	91.4
	pH(1:2)	pH	-	-	7.83	7.85	7.75	7.73	8.00	nd
	pH (lab)	pH	-	-	nd	nd	nd	nd	nd	8.39
Particle Size	% Gravel (>2 mm)	%	-	-	<1	3.40	15.9	2.10	<1	6.00
	% Sand (0.125 mm to 0.063 mm)	%	-	-	3.00	1.70	2.10	1.80	3.30	1.80
	% Sand (0.25 mm to 0.125 mm)	%	-	-	1.40	1.70	2.60	<1	2.10	1.20
	% Sand (0.50 mm to 0.25 mm)	%	-	-	<1	1.70	3.70	<1	1.70	1.50
	% Sand (1.00 mm to 0.50 mm)	%	-	-	<1	<1	3.30	<1	1.90	1.20
	% Sand (2.00 mm to 1.00 mm)	%	-	-	<1	<1	3.10	1.90	1.30	1.90
	% Silt (0.0312 mm to 0.004 mm)	%	-	-	49.7	44.5	36.2	48.6	46.7	48.0
	% Silt (0.063 mm to 0.0312 mm)	%	-	-	36.9	35.7	23.8	34.4	33.2	24.7
	% Silt (0.063 mm to 4 µm)	%	-	-	nd	nd	nd	nd	nd	nd
	% Clay (<4 µm)	%	-	-	7.60	9.90	9.30	8.50	9.90	13.7
Organic Carbon	Total Organic Carbon	%	-	-	9.73	12.8	11.6	12.2	10.4	11.2
Metals	Aluminum (Al)	mg/kg	-	-	6,460	9,970	9,230	8,060	8,400	12,000
	Antimony (Sb)	mg/kg	-	-	0.660	0.730	0.520	0.470	0.490	0.560
	Arsenic (As)	mg/kg	5.9	17	4.18	5.10	4.79	4.13	4.76	6.53
	Barium (Ba)	mg/kg	-	-	148	186	194	208	189	231
	Beryllium (Be)	mg/kg	-	-	0.600	0.690	0.640	0.560	0.580	0.750
	Bismuth (Bi)	mg/kg	-	-	<0.2	<0.2	<0.2	<0.2	<0.2	<0.4
	Boron (B)	mg/kg	-	-	7.90	10.8	11.2	10.5	9.00	11.0
	Cadmium (Cd)	mg/kg	0.6	3.5	1.42	1.47	1.97	1.82	2.02	1.69
	Calcium (Ca)	mg/kg	-	-	40,900	48,100	52,600	68,400	59,500	39,200
	Chromium (Cr)	mg/kg	37.3	90	10.5	15.0	14.2	12.6	12.2	18.4
	Cobalt (Co)	mg/kg	-	-	4.44	4.69	6.35	4.66	5.99	7.80
	Copper (Cu)	mg/kg	35.7	197	16.6	17.5	17.2	14.9	15.6	20.4
	Iron (Fe)	mg/kg	21,200	43,766	11,700	13,900	13,700	12,800	13,400	16,900
	Lead (Pb)	mg/kg	35	91.3	8.91	9.18	9.14	8.16	8.97	11.6
	Lithium (Li)	mg/kg	-	-	7.90	9.60	8.60	7.80	8.00	12.9
	Magnesium (Mg)	mg/kg	-	-	7,240	10,000	7,730	6,050	6,470	7,200
	Manganese (Mn)	mg/kg	460	1,100	119	204	705	252	1,010	1,210
	Mercury (Hg)	mg/kg	0.17	0.486	0.0675	0.0670	0.0817	0.0703	0.0746	0.0923
	Molybdenum (Mo)	mg/kg	25	23,000	1.44	1.59	1.60	1.30	1.22	1.59
	Nickel (Ni)	mg/kg	16	75	25.9	30.7	39.2	29.4	35.1	39.4
	Phosphorus (P)	mg/kg	-	-	1,110	1,390	1,520	1,250	1,290	1,380
	Potassium (K)	mg/kg	-	-	1,490	2,240	2,140	1,980	1,970	2,790
	Selenium (Se)	mg/kg	2		41.7	53.0	37.7	24.9	16.6	10.4
	Silver (Ag)	mg/kg	0.500	-	0.210	0.200	0.220	0.200	0.210	0.250
	Sodium (Na)	mg/kg	-	-	65.0	85.0	86.0	82.0	81.0	130
	Strontium (Sr)	mg/kg	-	-	45.9	54.7	55.4	65.2	55.1	59.7
	Thallium (Tl)	mg/kg	-	-	0.301	0.336	0.342	0.314	0.312	0.370
	Tin (Sn)	mg/kg	-	-	<2	<2	<2	<2	<2	<4
	Titanium (Ti)	mg/kg	-	-	13.5	19.3	17.1	16.8	11.8	16.5
	Uranium (U)	mg/kg	-	-	1.55	1.42	2.18	1.11	0.949	1.01
	Vanadium (V)	mg/kg	-	-	21.9	30.1	27.1	24.2	23.9	34.6
	Zinc (Zn)	mg/kg	123	315	109	129	154	135	137	145
	Zirconium (Zr)	mg/kg	-	-	1.10	1.00	<1	<1	<1	nd
Polycyclic Aromatic Hydrocarbons	Acenaphthene	mg/kg	0.00671	0.0889	<0.03	<0.037	<0.093	<0.06	<0.11	<0.14
	Acenaphthylene								<0.012	<0.03
	Acridine	mg/kg	-	-	<0.05	<0.062	<0.16	<0.095	nd	<0.21
	Anthracene									
	Benz(a)anthracene	mg/kg	0.0317	0.385	0.0200	0.0290	0.0640	0.0380	0.0630	nd
	Benzo(a)pyrene	mg/kg	0.0319	0.782	<0.01	0.0240	0.0350	<0.022	0.0520	<0.06
	Benzo(b)fluoranthene	mg/kg	-	-	nd	nd	nd	nd	nd	nd
	Benzo(b,j)fluoranthene	mg/kg	-	-	0.0450	0.123	0.147	0.0870	0.218	0.278
	Benzo(g,h,i)perylene	mg/kg	0.170	0.32	0.0160	0.0320	0.0580	0.0340	0.0600	0.0950
	Benzo(k)fluoranthene	mg/kg	0.240	13.4	<0.01	<0.019	<0.025	<0.022	<0.024	<0.06
	Chrysene	mg/kg	0.057	0.862	0.116	0.188	0.359	0.222	0.440	0.760
	Dibenz(a,h)anthracene						0.0350	0.0200	0.0330	nd
	Fluoranthene	mg/kg	0.111	2.355	0.0230	0.0470	0.0680	0.0430	0.0680	0.115
	Fluorene	mg/kg	0.021	0.144	0.0840	0.105	0.267	0.166	0.276	0.450
	Indeno(1,2,3-c,d)pyrene	mg/kg	0.2	3.2	<0.01	<0.019	<0.025	<0.022	0.0430	<0.06
	1-Methylnaphthalene	mg/kg			nd	nd	nd	nd	nd	nd
	2-Methylnaphthalene	mg/kg	0.0202	0.201	0.289	0.364	0.986	0.658	0.922	1.16
	Naphthalene	mg/kg	0.0346	0.391	0.0730	0.0920	0.242	0.166	0.228	0.316
	Phenanthrene	mg/kg	0.0419	0.515	0.403	0.490	1.22	0.746	1.29	1.73
	Pyrene	mg/kg	0.0530	0.875	0.0380	0.0710	0.117	0.0760	0.112	0.180
	Quinoline	mg/kg	-	-	<0.01	<0.019	<0.025	<0.022	<0.024	<0.06

Concentration is <LRL and LRL exceeds the lower BC WSQG.

Concentration is <LRL and LRL exceeds the upper BC WSQG or alert concentration for selenium.

Concentration exceeds the lower BC WSQG.

Concentration exceeds the upper BC WSQG or alert concentration for selenium.

Notes: BC WSQG = British Columbia Working Sediment Quality Guideline; - = not applicable; nd = no data; % = percent; > = greater than; mm = millimetres; < = less than; µm = micrometres; mg/kg = milligrams per kilogram; LRL = Laboratory Reporting Limit; BCMOECCS = British Columbia Ministry of Environment and Climate Change Strategy.

[a] The 2 mg/kg alert concentration from BCMOECCS (2021a) was applied; there is currently no BC WSQG for selenium.

[b] BC WSQG for the protection of freshwater aquatic life (BCMOECCS 2021b).

Table A.1: **Sediment Quality at Reference and Mine-exposed Areas on Harmer, Grave, and Dry Creeks, 2013 to 2020**

Analyte		Units	BC WSQG [a,b]		Grave Population				
					Mine-exposed				
					Harmer Creek				Grave Creek
					RG_HACKDS				EV_GV1-1
			Lower	Upper	RG_HACKDS-2	RG_HACKDS-3	RG_HACKDS-4	RG_HACKDS-5	-
					16-Sep-20	16-Sep-20	16-Sep-20	16-Sep-20	21-Oct-13
Physical Tests	Moisture	%	-	-	95.5	80.7	84.9	86.7	54.5
	pH(1:2)	pH	-	-	nd	7.83	7.87	7.79	8.34
	pH (lab)	pH	-	-	8.12	nd	nd	nd	nd
Particle Size	% Gravel (>2 mm)	%	-	-	<1	<1	<1	1.80	2.17
	% Sand (0.125 mm to 0.063 mm)	%	-	-	2.40	3.70	2.80	2.90	nd
	% Sand (0.25 mm to 0.125 mm)	%	-	-	1.60	2.30	1.30	1.90	nd
	% Sand (0.50 mm to 0.25 mm)	%	-	-	1.80	1.50	1.30	1.90	nd
	% Sand (1.00 mm to 0.50 mm)	%	-	-	2.30	<1	1.10	2.00	nd
	% Sand (2.00 mm to 1.00 mm)	%	-	-	2.50	<1	<1	2.00	nd
	% Silt (0.0312 mm to 0.004 mm)	%	-	-	50.0	50.2	50.2	46.8	nd
	% Silt (0.063 mm to 0.0312 mm)	%	-	-	24.1	31.9	29.0	27.5	nd
	% Silt (0.063 mm to 4 µm)	%	-	-	nd	nd	nd	nd	37.1
	% Clay (<4 µm)	%	-	-	14.5	8.70	13.6	13.1	2.20
Organic Carbon	Total Organic Carbon	%	-	-	11.3	10.5	11.9	12.0	2.42
Metals	Aluminum (Al)	mg/kg	-	-	10,900	9,300	9,590	10,100	6,560
	Antimony (Sb)	mg/kg	-	-	0.530	0.440	0.470	0.510	0.490
	Arsenic (As)	mg/kg	5.9	17	6.65	4.59	5.41	5.95	6.06
	Barium (Ba)	mg/kg	-	-	244	172	220	209	332
	Beryllium (Be)	mg/kg	-	-	0.810	0.710	0.680	0.670	0.490
	Bismuth (Bi)	mg/kg	-	-	<0.4	<0.2	<0.2	<0.2	0.140
	Boron (B)	mg/kg	-	-	10.0	9.60	10.6	12.7	<10
	Cadmium (Cd)	mg/kg	0.6	3.5	1.97	1.59	1.77	1.62	1.11
	Calcium (Ca)	mg/kg	-	-	33,700	35,300	43,200	53,300	40,300
	Chromium (Cr)	mg/kg	37.3	90	17.7	14.6	15.5	16.6	12.0
	Cobalt (Co)	mg/kg	-	-	7.91	4.78	6.45	6.76	5.10
	Copper (Cu)	mg/kg	35.7	197	21.2	18.5	17.7	17.9	16.3
	Iron (Fe)	mg/kg	21,200	43,766	17,300	12,300	15,100	15,000	15,400
	Lead (Pb)	mg/kg	35	91.3	12.0	9.63	10.3	11.5	8.99
	Lithium (Li)	mg/kg	-	-	12.2	10.6	10.0	11.5	11.0
	Magnesium (Mg)	mg/kg	-	-	5,900	6,690	5,930	8,430	9,720
	Manganese (Mn)	mg/kg	460	1,100	1,100	154	663	716	497
	Mercury (Hg)	mg/kg	0.17	0.486	0.0985	0.0803	0.0836	0.0788	0.0476
	Molybdenum (Mo)	mg/kg	25	23,000	1.58	1.32	1.43	1.59	2.15
	Nickel (Ni)	mg/kg	16	75	40.7	27.6	32.3	31.7	23.1
	Phosphorus (P)	mg/kg	-	-	1,510	1,200	1,460	1,260	1,280
	Potassium (K)	mg/kg	-	-	2,800	2,430	2,470	2,550	1,380
	Selenium (Se)	mg/kg	2		24.2	49.4	26.6	17.4	3.08
	Silver (Ag)	mg/kg	0.500	-	0.260	0.220	0.220	0.210	0.150
	Sodium (Na)	mg/kg	-	-	110	94.0	102	159	<100
	Strontium (Sr)	mg/kg	-	-	49.3	46.8	53.5	65.8	54.4
	Thallium (Tl)	mg/kg	-	-	0.390	0.337	0.323	0.352	0.283
	Tin (Sn)	mg/kg	-	-	<4	<2	<2	<2	0.500
	Titanium (Ti)	mg/kg	-	-	8.00	7.20	11.2	18.3	14.2
	Uranium (U)	mg/kg	-	-	1.06	1.41	1.07	1.48	0.806
	Vanadium (V)	mg/kg	-	-	33.8	30.1	30.5	34.1	19.7
	Zinc (Zn)	mg/kg	123	315	155	111	134	128	92.3
	Zirconium (Zr)	mg/kg	-	-	nd	<1	<1	<1	nd
Polycyclic Aromatic Hydrocarbons	Acenaphthene	mg/kg	0.00671	0.0889	<0.06	<0.09	<0.09	<0.07	<0.01
	Acenaphthylene	mg/kg	0.00587	0.128	<0.055	<0.025	<0.03	<0.0175	<0.005
	Acridine	mg/kg	-	-	<0.24	<0.15	<0.18	nd	nd
	Anthracene	mg/kg	0.0469	0.245	<0.044	<0.025	<0.03	<0.014	<0.007
	Benz(a)anthracene	mg/kg	0.0317	0.385	nd	0.0570	0.0640	0.0620	<0.01
	Benzo(a)pyrene	mg/kg	0.0319	0.782	nd	<0.025	0.0330	<0.035	<0.01
	Benzo(b)fluoranthene	mg/kg	-	-	nd	nd	nd	nd	0.0250
	Benzo(b,j)fluoranthene	mg/kg	-	-	0.280	0.191	0.206	0.196	0.0250
	Benzo(g,h,i)perylene	mg/kg	0.170	0.32	0.130	0.0770	0.0760	0.0690	<0.01
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	Chrysene	mg/kg	0.057	0.862	0.740	0.550	0.548	0.505	<0.05
	Dibenz(a,h)anthracene	mg/kg	0.00622	0.135	nd	0.0450	0.0420	0.0460	0.00580
	Fluoranthene	mg/kg	0.111	2.355	nd	0.0770	0.0900	0.0720	<0.01
	Fluorene	mg/kg	0.021	0.144	0.430	0.309	0.299	0.306	0.0210
	Indeno(1,2,3-c,d)pyrene	mg/kg	0.2	3.2	<0.11	<0.025	0.0310	<0.035	<0.01
	1-Methylnaphthalene	mg/kg			nd	nd	nd	nd	nd
	2-Methylnaphthalene	mg/kg	0.0202	0.201	1.03	0.744	0.919	0.739	0.119
	Naphthalene	mg/kg	0.0346	0.391	0.290	0.191	0.243	0.184	0.0440
	Phenanthrene	mg/kg	0.0419	0.515	1.71	1.42	1.41	1.24	0.205
	Pyrene	mg/kg	0.0530	0.875	0.180	0.128	0.138	0.132	0.0180
	Quinoline	mg/kg	-	-	<0.11	<0.025	<0.03	<0.035	nd

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