Ghost Watershed

Water Monitoring Program

CABiN Project

2025

BIOTA CONSULTANTS

A division of Aspen Croft Holdings Ltd.

March 2026

Ghost Watershed

Water Monitoring Program

CABiN Project

2025

Unpublished report submitted to:

Ghost Watershed Alliance Society
Cochrane, Alberta

Submitted by:

Biota Consultants
98 McGimpsey Road
Campbell River, B.C.
V9H 1K8

March 2026

Acknowledgements

Funding for this project was provided by the Department of Fisheries and Oceans Canada - Habitat Stewardship Program, Land Stewardship Centre, and Forest Resource Improvement Association - Forest Resource Improvement Program, which is sponsored by Bow River Basin Council and West Fraser Cochrane. The Executive Director of the Ghost Watershed Alliance Society, Marina Krainer, provided administrative and logistical support.

Professional and technical support was provided by Cordillera Consulting for the benthic macroinvertebrate taxonomic analysis. Equipment support was provided by Oak Environmental Inc. (Calgary, Alberta).

The field work could not have been completed without the help of volunteers. Special thanks to Emma Chong, Paul Fritz, Sharlene Fritz, Cal Hill, Judy Hill, Anne Holcroft-Weerstra, Karen Laustsen, Renée Lazor, Bob McAlpine and Karoliina Munter.

We are very grateful to those who reviewed the draft report and provided helpful comments and suggestions, particularly Sharlene Fritz, Cal Hill, Renée Lazor, Bob McAlpine and Karoliina Munter. Editing services were provided by Anne Holcroft-Weerstra.

Cover photo credit: Anne Holcroft-Weerstra – Measuring slope on the Ghost River, site GHO05.

Permission to Use

Suggested citation:
Biota Consultants. 2026. Ghost Watershed Water Monitoring Program CABiN Project 2025. Report to Ghost Watershed Alliance Society, Cochrane, Alberta. 82 pp.

Executive Summary

The Ghost Watershed Alliance Society (GWAS) began a water monitoring program in 2020 to aid in determining aquatic ecosystem health. This followed a recommendation in the *Ghost River State of the Watershed Report 2018* to sample aquatic invertebrates using the Canadian Aquatic Biomonitoring Network (CABiN) protocols, and using Ephemeroptera, Plecoptera and Trichoptera (EPT) ratios as a proxy for water quality.

In 2019, GWAS began participation in the STREAM (Sequencing the Rivers for Environmental Assessment and Monitoring) three-year pilot project, which uses CABiN methods to collect samples to identify benthic macroinvertebrates using environmental DNA (eDNA). GWAS then developed a multi-year water monitoring plan that incorporated the STREAM pilot project as well as the traditional CABiN sampling for morphological analysis. The latter provided data on benthic macroinvertebrate abundance, required to determine the EPT ratio, among other metrics. The STREAM project ended in 2023, and no samples have since been collected for eDNA analysis.

The water monitoring program began in the fall of 2020 when Biota Consultants was contracted to oversee the sampling of ten sites, eight along Waiparous Creek (WAP02 to WAP09) and two on the Ghost River (GHO01 and GHO02). In the second year (2021) of the program, the focus was the Ghost River (GHO03 to GHO07), but included one site on Johnson Creek (JOH01), whose headwaters had been affected by the Devil's Head/Black Rock wildfire in fall, 2020. In addition, two sites on Waiparous Creek below and above the confluence with Johnson Creek, WAP02 and WAP03, were resampled.

In 2022, the focus of the sampling program was tributaries of Waiparous Creek. This included resampling the Johnson Creek site from 2021, as well as sites WAP02 and WAP03. Human disturbance to the channel precluded sampling WAP02 at exactly the same location as in previous years. Instead a site slightly upstream was sampled and referred to as WAP02a.

From 2023 to 2025, key sites were resampled, and additional sites were added. Another focus in 2024 and 2025 was sampling further potential reference sites to be used in a reference model. This included two sites in 2025, on Meadow and Margaret creeks. In addition to resampling five key sites, the sites below and above the Rocky Mountain Cadet Training Centre (WAP06 and WAP07), first sampled in 2020, also were resampled, along with two sites on the

Ghost River, GHO03 and GHO05, first sampled in 2021. Natural fluvial action since 2021 at GHO03 resulted in unsuitable habitat, therefore a site slightly upstream was chosen to sample instead, referred to as GHO03a.

Based on lab analyses and direct measurements, water quality was within the parameters acceptable to benthic macroinvertebrates and fish at most sites in 2025. At the Aura Creek site, the steady increase in total suspended solids and turbidity is concerning. This could be attributed to the logging activity upstream. Dissolved nitrogen and nitrate have risen gradually at JOH01 over the five years of sampling, which may suggest nutrient loading. At JOH02, total Kjeldahl nitrogen was over five times greater than previous years sampled, which could be related to high cattle use of the riparian area in 2025. Dissolved nitrogen and nitrate were higher at GHO03 in 2025 versus 2021 which could be the result of the wildfire upstream in 2020. Reported concentrations of nitrogen at GHO05 in 2025 were considered to be extreme outliers and were omitted from the dataset.

The Hilsenhoff Biotic Index suggests high water quality at all sites (organic enrichment or pollution unlikely or possibly slight) with the exception of the Meadow Creek site, where some organic enrichment or pollution was probable (water quality rating of good). This may be related to horse use in the vicinity.

The Simpson's Index of Diversity and the Shannon-Wiener Index indicate the sites were at least moderately diverse in their community composition. The EPT ratio suggests high water quality at most of the sites, with EPT species more abundant than the pollution-tolerant chironomid family. The exception was the Meadow Creek site where the ratio was 0.37. This may be related to habitat. The relatively low EPT ratio initially had been a concern at the Johnson Creek sites, but the ratios were high at both sites in 2025.

The proportion of functional feeding groups (FFGs) varied among the sites, reflecting the habitat and adjacent riparian vegetation. At the Aura Creek site, scrapers dominated until 2025, when shredders became the dominant FFG, suggesting more leaf litter versus algae. Collector-gatherers have remained prominent at JOH01 and JOH02, suggesting greater sediment; however, scrapers were co-dominant at JOH02 in 2025. At the Waiparous Creek sites and GHO05, scrapers were dominant. Scrapers and collector-gatherers were co-dominants at GHO03/03a in both years sampled.

Table of Contents

Page

List of Tables

Page

List of Figures

1.0 Introduction

1.1 Background

The mission of the Ghost Watershed Alliance Society (GWAS) is to protect the integrity of the Ghost Watershed. One means of accomplishing this is to monitor water quality to determine aquatic ecosystem health. This was a recommendation in the *Ghost River State of the Watershed Report 2018* (ALCES and GWAS 2018), specifically sampling aquatic macroinvertebrates as biological indicators of watershed health using the Canadian Aquatic Biomonitoring Network (CABiN) protocols, and using Ephemeroptera, Plecoptera and Trichoptera (EPT) ratios as a proxy for water quality. CABiN methods include assessing physical and chemical parameters, and collecting benthic macroinvertebrates for morphological analysis to determine species abundance and diversity.

1.2 Introduction to CABiN

Environment and Climate Change Canada developed and introduced CABiN in 2006 to provide nationally standardized and scientifically rigorous protocols for sampling benthic macroinvertebrates, as well as a shared database of results from network participants across Canada. Participants vary from government bodies to industry, academia, and community-based groups such as GWAS.

While measuring water chemistry parameters provides a snapshot of water quality at the time of collection, sampling benthic macroinvertebrates can indicate long-term disturbances and cumulative impacts, as their well-being depends on the freshwater environment. Since their mobility is limited, they reflect the conditions at the site where they are collected. In addition, there are numerous groups and species that respond differently to different types of pollution.

As a large scale watershed assessment tool, CABiN has many different applications. Those of most importance to GWAS include:

- determining baseline conditions prior to changes in land use or environmental events such as wildfires;
- determining if tributaries or other potential sources of pollution are affecting water quality immediately downstream;
- assessing restoration and remediation efforts; and
- on-going monitoring.

Sampling results reflect all upstream influences on the watercourse, and sampling can be refined to tease out the source of an impact.

1.3 Reference Sites and Reference Model

Unless otherwise indicated, the information in this section is taken from Module 1 - *Introduction to CABIN* of the 2019 CABiN training course.

Two types of sites are sampled in CABiN, reference sites and test sites. Ideally, reference sites are at least minimally affected by human (post-European) activities, whereas the health of test sites is suspected to be compromised by human activities. Reference sites, therefore, represent healthy ecosystems with which test sites can be compared to determine if they are within the natural range of environmental variability, or are likely affected by anthropogenic impacts. Reference sites should represent the range of natural conditions (biota and habitat) in the area being sampled.

In some areas, such as the Ghost River watershed, the only sites with little or no anthropogenic impacts tend to be at higher elevations, and it is difficult to find undisturbed sites at lower elevations with which to compare test sites. It may then be justifiable to use sites with less intense impacts as reference sites, representing “best available” or “least disturbed” conditions.

Reference sites are used to create a CABiN reference condition model. This predictive model requires a large number of reference sites that represent the variety of ecoregions or physiographic zones within the study area. In 2024, the Miistakis Institute was contracted by the Oldman Watershed Council on behalf of the Eastern Slopes Collaborative[1] to identify areas within the eastern slopes of Alberta where reference conditions potentially exist (Sinnatamby and Sanderson 2024). Watersheds were divided according to the designated national ecoregion (Ecological Stratification Working Group 1995), and human activity gradient (HAG) scores were calculated and placed into ten categories. Recent wildfires were taken into account, along with anthropogenic point sources within 100 m of a stream or river. Potential sites were further refined by accepting HAG scores no higher than 4. With this information, the members of the Eastern Slopes Collaborative could focus their search for potential reference sites within each of their watersheds.

---

[1] The Eastern Slopes Collaborative is a consortium of Watershed Planning and Advisory Councils, watershed stewardship groups (including GWAS), First Nations land managers and other interested parties who seek to improve the watershed through education, monitoring, planning and action. Working together, a community-based aquatic monitoring program was developed across the eastern slopes of Alberta using the CABiN sampling protocol to assess local community needs, share expertise and resources, and secure additional resources as required. The collaborative also is tasked with developing a reference model for the eastern slopes that can be used for assessing test sites using the Reference Condition Approach.

Potential reference sites previously had been identified and sampled in the GWAS Water Monitoring Program, including JOH02 which was above most OHV activity occurring near Johnson Creek. The uppermost site on Waiparous Creek, WAP09, also was considered a potential site, as was the uppermost site on the Ghost River, GHO06, which was above the extent of the Devil's Head/Black Rock wildfire (CWF-156-2020)[2] and is located within the Ghost River Wilderness Area. None of these three sites were within polygons identified by Sinnatamby and Sanderson (2024) as containing acceptable levels of disturbance; however, four sites previously sampled were within these polygons, with HAG scores of 1 to 4, including AUR01. The recent clearcuts above AUR01 would clearly disqualify it now, apart from nearby OHV activity. Therefore it was recognized that the Misstakis Institute report should be used only as a guideline, since those familiar with the watershed are better able to make final judgements. Unfortunately, many potential reference sites are difficult or expensive to access, reducing the number that can be sampled.

1.4 GWAS Water Monitoring Program Plan

One site on Waiparous Creek (WAP01) was sampled as part of the field course in July, 2019. During the spring and summer of 2020, the GWAS CABiN team developed a strategic multi-year plan (*GWAS Water Monitoring Program Plan 2020*) to obtain information on the health of water courses within the Ghost River watershed. The intent was to augment existing information and to assist public land managers and other organizations tasked with water management responsibilities. This plan is a living document and continues to be updated. It adopts water quality indicators as per the CABiN protocol, using the *CABiN Field Manual – Wadeable Streams* (Environment Canada 2012).

The water monitoring program began in the fall of 2020 when ten sites were sampled, eight along Waiparous Creek (WAP02 to WAP09) and two on the Ghost River (GHO01 and GHO02). In this first year of the plan, the focus was mainly on sites above and below creek tributaries and other possible sites that might affect water quality as a result of land use activities (see Biota Consultants 2022a). In the second year (2021), the focus was the Ghost River (sites GHO03 to GHO07), with a slight modification due to the Devil’s Head/Black Rock wildfire which occurred in the fall of 2020 (see Biota Consultants 2022b). Since the fire encroached on the southwest fork of the headwaters of Johnson Creek, which is in the Waiparous Creek sub-basin, it was decided to sample this creek above its confluence with Waiparous Creek (JOH01). WAP02 and WAP03, located below and above the confluence with Johnson Creek, also were resampled. In 2022, tributaries to Waiparous Creek were sampled: Aura Creek (AUR01), Meadow Creek

[2] Code assigned by Alberta Agriculture and Forestry.

(MEA01), Lookout Creek (LOO01) and Margaret Creek (MAR01). In addition, Johnson Creek (JOH01) was resampled, along with WAP02 and WAP03 (see Biota Consultants 2023). The original WAP02 location was no longer suitable, therefore a slightly upstream site (WAP02a) was sampled instead (see section 3.1.3). In 2023, the focus was to add to the inventory of sites and to resample certain sites (GHO06, AUR01, JOH01, WAP02/02a and WAP03) to provide further monitoring data and information on variability (see Biota Consultants 2024). Natural fluvial action altered the original WAP03 location, and a more suitable site slightly upstream (WAP03a) was sampled instead (see section 3.1.3).

WAP02/02a and WAP03/03a, along with AUR01, JOH01 and JOH02 (first sampled in 2023) have become the five key sites that have been resampled every year following their first sampling. The reasons for annual resampling include:

- AUR01 - continued logging upstream until 2024, and study results suggesting an ongoing decline in water quality;
- JOH01 - importance to cutthroat trout, and ongoing unexpected and troubling results, particularly a relatively low EPT ratio;
- JOH02 - ongoing monitoring due to troubling results in 2023 (low EPT ratio);
- WAP02/02a and WAP03/03a - sampled every year since the beginning of the project, providing data on variability.

The water monitoring program in 2024 had a number of objectives. One was to resample the above key sites again. A second objective was to sample above and below another point source that might affect water quality as a result of land use activities, specifically a random campsite on Lesueur Creek. A third objective was to sample above and below a reclamation site by a bridge over Waiparous Creek. Lastly, there was an effort in 2024 to sample additional potential reference sites (see Biota Consultants 2025).

Over the first four years of the GWAS Water Monitoring Program, additional samples were taken for environmental DNA (eDNA) analysis as part of the STREAM (Sequencing the Rivers for Environmental Assessment and Monitoring) pilot project, along with samples for morphological analysis. The STREAM samples were sent to the Hajibabaei Lab at the Centre for Biodiversity Genomics (University of Guelph). Rather than quantifying abundance, eDNA testing determines the presence or absence of benthic macroinvertebrate species. The pilot project ended in 2023, therefore in 2025, samples were collected only for morphological analysis.

1.5 2025 Field Plan

The water monitoring program in 2025 had a number of objectives. One was to resample the five key sites (AUR01, JOH01, JOH02, WAP02/02a and WAP03/03a). A second objective was to resample Waiparous Creek above and below the wastewater lagoon of the Rocky Mountain Cadet Training Centre (WAP06 and WAP07), first sampled in 2020. Higher than normal use of the cadet camp was expected in the summer of 2025, perhaps putting pressure on the lagoon. A third objective was to resample above the old TransAlta diversion structure on the Ghost River (GHO05) prior to potential water diversion development. Lastly, further potential reference sites were sampled, one on Margaret Creek and one in the headwaters of Meadow Creek. These were in areas identified as potential reference sites by Sinnatamby and Sanderson (2024). In the field, it was decided to also resample a Ghost River site upstream of the Richards Road bridge (GHO03).

2.0 Methods

2.1 Field Sampling

The field sampling followed the same CABiN protocols as in 2020, described in *Ghost Watershed Water Monitoring Program CABiN/STREAM Project 2020* (Biota Consultants 2022a). A YSI-DSS multimeter again was rented from Oak Environmental Inc., whose staff calibrated it prior to field use. It was used to measure water temperature, dissolved oxygen, specific conductance and pH. Other water properties were measured in the lab by Bureau Veritas Laboratories in Calgary, Alberta.

Field sampling occurred between August 25th and September 3rd when there was low stream flow and sunny, mainly stable weather conditions. The CABiN Field Sheet is included in Appendix A. Site locations are mapped in Figure 1, and site name codes, date of sampling, and geographic locations are presented in Table 1. Air and water temperatures at the time of sampling are provided.

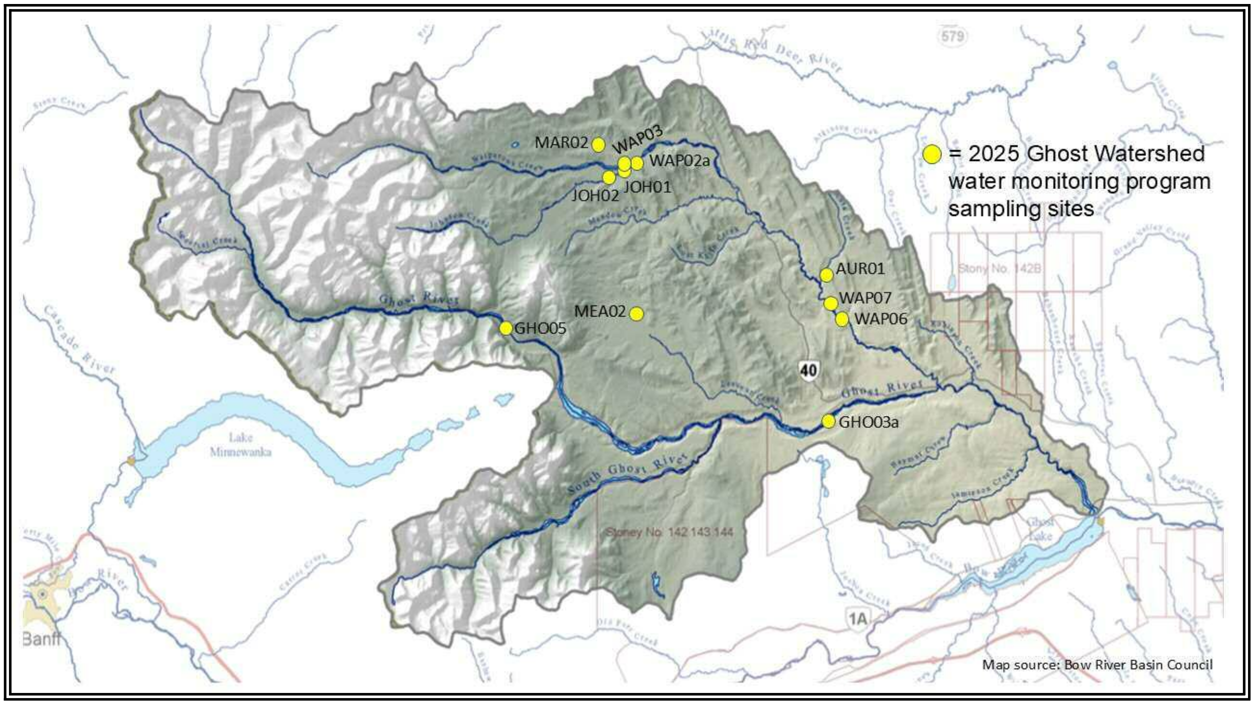


Figure 1. Sampling locations in 2025 within the Ghost River watershed.

WAP02a has been sampled from 2022 to 2025, but WAP03a was only sampled in 2023. In 2024 and 2025, further natural fluvial action allowed the original WAP03 site to be sampled (see section 3.1.3).

A similar issue arose with GHO03 upstream of the Richards Road bridge. Natural fluvial action since 2021, when the site was first sampled, resulted in unsuitable habitat at the original location. A site slightly upstream was chosen instead, referred to as GHO03a (see section 3.1.4).

When sampling the paired sites on Waiparous Creek and the two sites on Johnson Creek, the downstream site (i.e., WAP02a, WAP06, JOH01) was sampled prior to the upstream site (i.e., WAP03a, WAP07, JOH02) to ensure the downstream site was not disturbed by upstream activities.

Table 1. Location of sites sampled in 2025, plus sampling date, time of day, and conditions.

Code/ Date	Latitude	Longitude	Elevation (m)	Comments
WAP02a Aug. 25	51.39404°	-115.08606°	1563	Waiparous Creek below confluence with Johnson Creek Sampled in morning Sunny, air temperature 15.0°C, water temperature 9.3°C
WAP03 Aug. 25	51.39248°	-115.08936°	1568	Waiparous Creek above confluence with Johnson Creek Sampled in afternoon Sunny, air temperature 26.0°C, water temperature 14.8°C
JOH01 Aug. 25	51.39155°	-115.08944°	1569	Johnson Creek above confluence with Waiparous Creek Sampled in afternoon Sunny, air temperature 27.0°C, water temperature 12.3°C
JOH02 Aug. 25	51.38661°	-115.10668°	1596	Johnson Creek above former “Johnson bog” Sampled in late afternoon Sunny, air temperature 25.5°C, water temperature 13.5°C
AUR01 Aug. 26	51.33431°	-114.93510°	1384	Aura Creek above confluence with Waiparous Creek Sampled in afternoon Sunny, air temperature 24.5°C, water temperature 12.2°C
GHO05 Aug. 27	51.30992°	-115.19270°	1601	Ghost River upstream of old TransAlta water diversion structure (destroyed in 2013 flood); area burned in 2020 wildfire (CWF-156) Sampled in afternoon Sun and cloud, air temperature 23.5°C, water temperature 10.7°C
GHO03a Aug. 27	51.26932°	-115.92772°	1319	Ghost River upstream of Richards Road bridge Sampled in afternoon Sunny, air temperature 28.0°C, water temperature 13.5°C
MAR02 Aug. 28	51.40278°	-115.11649°	1578	Margaret Creek above all OHV trails Sampled in afternoon Sunny, air temperature 22.0°C, water temperature 8.0°C
WAP06 Aug. 29	51.319673°	-114.923780°	1344	Waiparous Creek below cadet camp Sampled in morning Sunny, air temperature 19.5°C, water temperature 9.8°C
WAP07 Aug. 29	51.324489°	-114.92968°	1349	Waiparous Creek above cadet camp Sampled in afternoon Sunny, air temperature 27.0°C, water temperature 13.5°C
MEA02 Sept. 3	51.319160°	-115.084439°	1540	Meadow Creek headwaters, downstream of Meadow Creek cabins, Brewster Company Ranch Sampled in afternoon Smoke haze, air temperature 24.0°C, water temperature 5.7°C

Biological sampling followed the CABiN protocols used in 2020 (Biota Consultants 2022a), with a minor modification. As in 2021 and following years, the sample jars containing the benthic macroinvertebrates were sealed by winding a strip of parafilm tightly around the outside of the jar and lid. The description of physical attributes of each site and the collection of water chemistry data followed the same protocols described by Biota Consultants (2022a).

2.2 Data Entry

All of the data, except the benthic macroinvertebrate community structure information, were entered into the CABiN database by the Project Manager. To reduce potential errors, the morphologic consultant (Cordillera Consulting Inc.) uploaded the benthic macroinvertebrate community data into the database.

3.0 Results and Discussion

3.1 Physical Characteristics

The physical characteristics of the eleven sample sites are presented in Table 2, ordered from downstream to upstream within the watershed. Those sites that had been sampled previously are discussed in the sections below.

MEA02 was a potential reference site near the headwaters of Meadow Creek just downstream from a horse camp, Brewster Company Ranch, where there are cabins for guests and grazing for the horses. The reach sampled flowed through a shrubby wetland complex and was one of the smallest streams sampled over the six years of the project, with a wetted width of only 2.1 m (Table 2). The mean particle size of 2.6 cm was smaller than most sample sites, with 10% sand or silt present.

The Margaret Creek site, MAR02, was approximately 50 m upstream of a cutline and OHV trail. It was also a small stream, with a wetted width of 3.4 m (Table 2). As with most sites sampled in the project, the substrate consisted of primarily pebble and cobble-size stones.

Substrate embeddedness refers to how deeply the dominant substrate is buried in the surrounding finer particles. Five categories of substrate embeddedness[3] were used. In areas modified by streamside activities (anthropogenic land uses), increased erosion can result in the accumulation of fine material in the interstitial spaces. The more embedded the substrate, the fewer interstitial spaces for macroinvertebrates to occupy, which can reduce productivity (Environment Canada 2012).

[3] Embedded Categories: 1) Completely embedded: 100% embedded; 2) 75% embedded; 3) 50% embedded; 4) 25% embedded; 5) 0% embedded

Table 2. Physical characteristics of the sample sites.

Attributes	Site										
	AUR01	**MEA02**	**MAR02**	**JOH01**	**JOH02**	**WAP06**	**WAP07**	**WAP02a**	**WAP03**	**GHO03a**	**GHO05**
Elevation (m)	1384	1540	1578	1569	1596	1344	1349	1563	1568	1319	1601
Bankfull width (m)	3.6	3.5	4.1	8.8	7.9	41.6	19.4	15.4	27.9	46.5	18.4
Wetted width (m)	2.9	2.1	3.4	6.7	7.7	14.9	18.3	13.8	13.7	25.6	10.6
Bankfull wetted depth (cm)	17.8	22.2	31.5	30.0	28.0	99.0	55.0	91.0	85.0	48.0	55.5
Maximum channel depth (cm)	6.8	27.3	18.4	30.5	32.0	35.7	28.5	38.2	24.4	29.3	32.0
Average channel depth (cm)	5.8	22.2	13.3	25.2	17.1	30.5	22.1	21.3	14.0	22.9	26.9
Maximum velocity (m/s)	0.3431	0.6264	0.5241	0.9603	1.3288	1.2291	1.0759	1.0293	0.7412	1.3937	1.2049
Average velocity (m/s)	0.3285	0.5131	0.4614	0.7908	0.7098	0.9198	0.9249	0.5839	0.5562	1.1576	1.0694
Slope (m/m)	0.0165	0.0129	0.0100	0.0187	0.0113	0.0115	0.0059	0.0102	0.0139	0.0103	0.0097
Substrate embeddedness (%)	25	25	25	25	0	25	0	25	25	0	25
Dominant substrate (cm)	3.2-6.4	6.4-12.8	1.6-3.2	6.4-12.8	3.2-6.4	6.4-12.8	6.4-12.8	6.4-12.8	6.4-12.8	3.2-6.4	3.2-6.4
2nd dominant substrate (cm)	1.6-3.2	3.2-6.4	6.4-12.8	3.2-6.4	1.6-3.2	3.2-6.4	1.6-3.2	3.2-6.4	3.2-6.4	6.4-12.8	6.4-12.8
Surrounding material (cm)	0.2-1.6	<0.1	0.2-1.6	0.2-1.6	0.1-0.2	0.2-1.6	0.2-1.6	0.2-1.6	0.2-1.6	1.6-3.2	0.2-1.6
Geometric mean particle size (cm)	4.4	2.6	5.1	6.5	3.9	6.7	4.2	6.7	6.3	4.9	5.6
% Sand	0	10	0	0	0	0	0	1	1	0	0
% Gravel	3	7	5	2	7	0	11	2	1	0	0
% Pebble	78	39	54	43	78	38	52	38	44	78	58
% Cobble	19	44	41	55	15	61	37	58	54	22	41
% Boulder	0	0	0	0	0	1	0	1	0	0	1

Note: Sand = fine sand, silt or clay (<0.1 cm) or coarse sand (0.1 - 0.2 cm); Gravel = 0.2 - 1.6 cm; Pebble = small (1.6 - 3.2 cm) or large (3.2 - 6.4 cm); Cobble = small (6.4 - 12.8 cm) or large (12.8 - 25.6 cm); Boulder = >25.6 cm.

3.1.1 Aura Creek

Aura Creek is a small tributary of Waiparous Creek. The Aura Creek site, situated just upstream of the Waiparous Creek flood plain, was first sampled in 2022. Logging had taken place in the upper watershed by then, which began in 2020. Sampling of AUR01 has continued in subsequent years. Prior to the sampling date in 2023, clearcuts were confined to the upper reaches of the creek. Lower reaches were logged over the winter of 2023/2024, including immediately upstream of the sampling site.

AUR01 has one of the lowest wetted widths of all sites sampled over the six years of the project, at 2.9 m in 2025, with an average channel depth of only 5.8 cm (Table 3). It also has had comparitively low velocity. The location of the tape, when it was stretched across the creek to determine the physical attributes, was not exactly the same over the years, which will have contributed to the variation in the data among years (Table 3). There was an increase in embeddedness in 2024, and an overall decrease in particle size. In 2025, these trends had reversed.

Table 3. Comparison of physical attributes at the Aura Creek site (AUR01) from 2022 to 2025.

Attributes	**Site and Date of Sampling**			
	AUR01			
	Sept. 12 2022	**Aug. 29 2023**	**Sept. 4 2024**	**Aug. 26 2025**
Bankfull width (m)	4.70	3.30	5.20	3.61
Wetted width (m)	2.20	2.00	2.53	2.92
Bankfull wetted depth (cm)	35.0	17.5	23.3	17.8
Maximum channel depth (cm)	7.2	7.5	6.8	6.8
Avg channel depth (cm)	5.9	4.5	4.8	5.8
Maximum velocity (m/s)	0.4202	0.3431	0.5050	0.3431
Avg velocity (m/s)	0.2007	0.2341	0.4137	0.3285
Slope (m/m)	0.0269	0.0275	0.0231	0.0165
Substrate embeddedness (%)	25	25	50	25
Dominant substrate (cm)	3.2-6.4	3.2-6.4	1.6-3.2	3.2-6.4
2nd dominant substrate (cm)	1.6-3.2	1.6-3.2	3.2-6.4	1.6-3.2
Surrounding material (cm)	0.2-1.6	0.2-1.6	0.2-1.6	0.2-1.6
Geometric mean particle size (cm)	3.1	3.9	2.8	4.4
% Sand	0	0	0	0
% Gravel	20	5	12	3
% Pebble	63	71	81	78
% Cobble	16	24	7	19
% Boulder	1	0	0	0
% Bedrock	0	0	0	0

3.1.2 Johnson Creek

The location of JOH01 was approximately 155 m upstream from its confluence with Waiparous Creek. It had been previously sampled in the preceding four years. As with AUR01, the exact location where the various bank and channel measurements were made differed among years, which will have contributed to some of the variability. Variations in physical attributes tended to be relatively subtle among years, although velocity had increased in 2024, and mean particle size declined in last two years (Table 4).

JOH02 was approximately 1.5 km upstream of JOH01, within a shrubby wetland complex. There was little variation in physical attributes among the three years of sampling, although average velocity has declined (Table 5).

Table 4. Comparison of physical attributes at Johnson Creek site JOH01 from 2021 to 2025.

Attributes	**Site and Date of Sampling**				
	JOH01				
	Sept. 7 2021	**Aug. 30 2022**	**Aug. 31 2023**	**Aug. 27 2024**	**Aug. 25 2025**
Bankfull width (m)	6.70	6.20	7.00	9.10	8.80
Wetted width (m)	5.60	5.40	5.80	5.69	6.65
Bankfull wetted depth (cm)	23.0	7.4	12.0	23.0	30.0
Maximum channel depth (cm)	23.5	23.8	26.3	28.2	30.5
Avg channel depth (cm)	18.5	21.8	22.1	20.7	25.2
Maximum velocity (m/s)	0.8287	0.7799	0.9078	1.2606	0.9603
Avg velocity (m/s)	0.5658	0.6798	0.6712	1.0300	0.7908
Slope (m/m)	0.0085	0.0085	0.0085	0.0120	0.0187
Substrate embeddedness (%)	25	25	25	25	25
Dominant substrate (cm)	6.4-12.8	6.4-12.8	6.4-12.8	6.4-12.8	6.4-12.8
2nd dominant substrate (cm)	12.8-25.6	3.2-6.4	3.2-6.4	3.2-6.4	3.2-6.4
Surrounding material (cm)	0.2-1.6	0.1-0.2	02.-1.6	0.1-0.2	0.2-1.6
Geometric mean particle size (cm)	9.6	7.1	8.5	6.3	6.5
% Sand	0	0	0	0	0
% Gravel	0	1	2	4	2
% Pebble	29	44	33	41	43
% Cobble	67	50	59	54	55
% Boulder	4	5	6	1	0
% Bedrock	0	0	0	0	0

Table 5. Comparison of physical attributes at Johnson Creek site JOH02 from 2023 to 2025.

Attributes	**Site and Date of Sampling**		
	JOH02		
	Aug. 31 2023	**Aug. 30 2024**	**Aug. 25 2025**
Bankfull width (m)	8.00	7.34	7.90
Wetted width (m)	5.50	5.42	7.70
Bankfull wetted depth (cm)	24.3	33.0	28.0
Maximum channel depth (cm)	18.0	21.2	32.0
Avg channel depth (cm)	15.6	17.8	17.1
Maximum velocity (m/s)	1.4353	1.1968	1.3288
Avg velocity (m/s)	1.0042	0.9910	0.7098
Slope (m/m)	0.0071	0.0556	0.0113
Substrate embeddedness (%)	0	0	0
Dominant substrate (cm)	3.2-6.4	3.2-6.4	3.2-6.4
2nd dominant substrate (cm)	1.6-3.2	1.6-3.2	1.6-3.2
Surrounding material (cm)	0.2-1.6	0.1-0.2	0.1-0.2
Geometric mean particle size (cm)	3.6	3.5	3.9
% Sand	0	0	0
% Gravel	7	6	7
% Pebble	82	83	78
% Cobble	11	11	15
% Boulder	0	0	0
% Bedrock	0	0	0

3.1.3 Waiparous Creek

Five years had elapsed since WAP06 and WAP07 were last sampled, below and above the wastewater lagoon of the cadet camp, and again, the exact location where the various bank and channel measurements were made differed slightly between years. A notable difference at WAP06 was the higher particle size in 2025, with a greater number of cobble-size stones versus pebble-size (Table 6). At WAP07, embeddedness had declined and the dominant substrate size was greater, although the mean particle size was similar.

Table 6. Comparison of physical attributes at Waiparous Creek sites WAP06 and WAP07 in 2020 and 2025.

Attributes	**Site and Date of Sampling**			
	WAP06		**WAP07**	
	Sept. 10 2020	**Aug. 29 2025**	**Sept. 10 2020**	**Aug. 29 2025**
Bankfull width (m)	17.2	41.6	18.0	19.4
Wetted width (m)	15.7	14.9	9.2	18.3
Bankfull wetted depth (cm)	46.0	99.0	30.0	55.0
Maximum channel depth (cm)	30.5	35.7	42.5	28.5
Avg channel depth (cm)	20.1	30.5	26.4	22.1
Maximum velocity (m/s)	1.1720	1.2291	1.9300	1.0759
Avg velocity (m/s)	1.0030	0.9198	1.1240	0.9249
Slope (m/m)	0.0020	0.0115	0.0020	0.0059
Substrate embeddedness (%)	25	25	25	0
Dominant substrate (cm)	3.2-6.4	6.4-12.8	1.6-3.2	6.4-12.8
2nd dominant substrate (cm)	1.6-3.2	3.2-6.4	3.2-6.4	1.6-3.2
Surrounding material (cm)	0.2-1.6	0.2-1.6	0.2-1.6	0.2-1.6
Geometric mean particle size (cm)	4.1	6.7	4.0	4.2
% Sand	0	0	0	0
% Gravel	7	0	9	11
% Pebble	73	38	63	52
% Cobble	20	61	28	37
% Boulder	0	1	0	0
% Bedrock	0	0	0	0

2025 was the sixth consecutive year that sites on Waiparous Creek below and above the confluence with Johnson Creek were sampled. Despite attempts to select reach locations at these two sites with similar stream channel characteristics, the heterogeneous nature of the stream channel, along with annual fluvial action and human interference altering the stream channel, made this impossible. In 2022, human interference below the confluence with Johnson Creek was so great that the original WAP02 location no longer contained riffle habitat. As a result, the sampling site was moved slightly upstream to WAP02a. These sites bordered random campsites. In all six years, alteration of stream flow occurred from placement of rock dams at the edge of the creek and/or across the creek. The WAP02a site was again sampled in 2025.

The velocity at the slightly upstream location of WAP02a had been less than the location of WAP02 (Table 7), which was attributed to the full or partial rock dams upstream. The velocity was much higher at WAP02a in 2024, with fewer rock dams and no full dams. It was less in 2025, however, with one full rock dam upstream. The geometric mean particle size of the substrate had been declining each year, corresponding to the decline in velocity. In 2024, however, the velocity was substantially higher and the particle size was larger, but in 2025, velocity was lower but particle size was larger.

Table 7. Comparison of physical attributes at Waiparous Creek sites WAP02/WAP02a from 2020 to 2025.

Attributes	Site and Date of Sampling					
	WAP02		WAP02a			
	Sept. 1 2020	Sept. 2 2021	Sept. 7 2022	Aug. 30 2023	Aug. 27 2024	Aug. 25 2025
Bankfull width (m)	17.00	12.02	15.30	14.50	16.20	15.40
Wetted width (m)	9.60	10.35	7.78	14.20	8.72	13.80
Bankfull wetted depth (cm)	26.5	17.0	32.7	21.2	14.0	91.0
Maximum channel depth (cm)	27.0	21.2	42.6	28.1	37.5	38.2
Avg channel depth (cm)	17.4	17.2	23.8	16.8	26.7	21.3
Maximum velocity (m/s)	1.2528	1.3065	1.0759	1.0293	1.4285	1.0293
Avg velocity (m/s)	0.8760	0.8630	0.7192	0.5841	1.2244	0.5839
Slope (m/m)	0.0138	0.0110	0.0233	0.0008	0.0092	0.0102
Substrate embeddedness (%)	25	25	25	0	25	25
Dominant substrate (cm)	6.4-12.8	3.2-6.4	6.4-12.8	3.2-6.4	3.2-6.4	6.4-12.8
2nd dominant substrate (cm)	12.8-25.6	6.4-12.8	3.2-6.4	6.4-12.8	6.4-12.8	3.2-6.4
Surrounding material (cm)	0.2-1.6	0.1-0.2	0.2-1.6	0.2-1.6	0.2-1.6	0.2-1.6
Geometric mean particle size (cm)	10.3	6.9	5.3	5.0	6.3	6.7
% Sand	0	0	0	0	0	1
% Gravel	1	0	2	3	2	2
% Pebble	23	49	50	62	50	38
% Cobble	68	51	46	35	45	58
% Boulder	8	0	0	0	3	1
% Bedrock	0	0	2	0	0	0

In 2023, natural fluvial action and low stream flow had altered the original WAP03 site enough to eliminate riffle habitat, therefore sampling occurred slightly upstream and the site was named WAP03a. Further natural fluvial action altered the reach again, resulting in more appropriate habitat in 2024 at the original WAP03 site, although the channel had shifted slightly to the south. Therefore, WAP03 was resampled. The channel was similar in 2025, allowing WAP03 to be sampled again. As would be expected, physcial attributes and substrate measurements have varied over the six years. Of note, is the decline in velocity in 2025 (Table 8).

Table 8. Comparison of physical attributes at Waiparous Creek sites WAP03/WAP03a from 2020 to 2025.

Attributes	**Site and Date of Sampling**					
	WAP03			**WAP03a**	**WAP03**	
	Sept. 3 2020	**Sept. 2 2021**	**Sept. 7 2022**	**Aug. 30 2023**	**Aug. 27 2024**	**Aug. 25 2025**
Bankfull width (m)	15.00	21.90	18.50	11.50	19.20	27.90
Wetted width (m)	6.90	8.90	4.18	7.60	9.40	13.70
Bankfull wetted depth (cm)	56.0	57.0	55.0	34.5	27.5	85.0
Maximum channel depth (cm)	22.0	24.2	32.8	23.4	31.6	24.4
Avg channel depth (cm)	16.4	15.2	26.8	18.2	21.8	14.0
Maximum velocity (m/s)	1.1293	1.0850	1.2838	1.0575	1.3214	0.7412
Avg velocity (m/s)	0.8650	0.7305	1.0052	0.8191	0.9192	0.5562
Slope (m/m)	0.0150	0.0087	0.0087	0.0133	0.0650	0.0139
Substrate embeddedness (%)	25	25	0	0	25	25
Dominant substrate (cm)	3.2-6.4	3.2-6.4	6.4-12.8	6.4-12.8	3.2-6.4	6.4-12.8
2nd dominant substrate (cm)	6.4-12.8	6.4-12.8	12.8-25.6	3.2-6.4	6.4-12.8	3.2-6.4
Surrounding material (cm)	0.2-1.6	0.2-1.6	0.2-1.6	0.2-1.6	0.2-1.6	0.2-1.6
Geometric mean particle size (cm)	5.9	5.8	10.0	7.7	6.4	6.3
% Sand	0	0	0	0	0	1
% Gravel	1	1	1	0	2	1
% Pebble	56	57	21	39	48	44
% Cobble	41	37	67	58	42	54
% Boulder	2	2	11	3	4	0
% Bedrock	0	3	0	0	4	0

3.1.4 Ghost River

Over the four years since GHO03 was first sampled, major changes in the river bed had occurred due to fluvial action, eliminating riffle habitat at the original location. A more appropriate site slightly upstream was selected and named GHO03a. The main channel was sampled, which contained approximately two thirds of the flow. The wide gravel floodplain at this site resulted in a very wide bankfull width of 46.50 m (Table 9). Of note at GHO03a is the very low embeddness. 80% of the sampled substrate was not embedded and 20% was only one quarter embedded.

The habitat at the GHO05 site was similar to 2021, although the exact location where the various bank and channel measurements were made differed slightly between years. Of note is the decrease in pebble-size substrate and increase in cobble-size substrate, and the decrease in embeddedness with only a slight decrease in velocity (Table 9).

Table 9. Comparison of physical attributes at Ghost River sites GHO03a and GHO05 in 2021 and 2025.

Attributes	**Site and Date of Sampling**			
	GHO03	**GHO03a**	**GHO05**	
	Aug. 26 2021	**Aug. 27 2025**	**Aug. 30 2021**	**Aug. 27 2025**
Bankfull width (m)	13.32	46.50	14.92	18.40
Wetted width (m)	12.52	25.60	13.20	10.60
Bankfull wetted depth (cm)	19.7	48.0	47.0	55.5
Maximum channel depth (cm)	45.5	29.3	31.0	32.0
Avg channel depth (cm)	36.6	22.9	24.6	26.9
Maximum velocity (m/s)	1.3435	1.3937	1.2450	1.2049
Avg velocity (m/s)	1.2165	1.1576	1.1288	1.0694
Slope (m/m)	0.0096	0.0103	0.0050	0.0097
Substrate embeddedness (%)	25	0	50	25
Dominant substrate (cm)	3.2-6.4	3.2-6.4	3.2-6.4	3.2-6.4
2nd dominant substrate (cm)	6.4-12.8	6.4-12.8	1.6-3.2	6.4-12.8
Surrounding material (cm)	0.1-0.2	1.6-3.2	0.2-1.6	0.2-1.6
Geometric mean particle size (cm)	5.95	4.90	4.20	5.60
% Sand	0	0	0	0
% Gravel	0	0	2	0
% Pebble	60	78	79	58
% Cobble	39	22	19	41
% Boulder	1	0	0	1
% Bedrock	0	0	0	0

3.2 Land Use

Forest or shrubland habitat was present at all sites and was the dominant adjacent land use at all but the Waiparous Creek sites, where the dominant activities in the surrounding area were random camping, day-use and off-highway vehicle (OHV) use (Table 10). OHV use occurred upstream of all sites to varying degrees with the exception of MEA02. However, MEA02 was immediately downstream of a horse camp facility (Brewster Company Ranch) and within a winter grazing area for horses. Logging was a dominant activity at the Aura Creek site.

Table 10. Land uses adjacent and upstream of each site. Xs in bold indicate dominant land use(s).

Site	Land Use Location	Land Use								
		Forest/ Shrub	Grazing	Logging	OHV	Day-use	Camping	Shooting	Commercial/ Youth Camps	Rural Residential
AUR01	Adjacent	**x**	x	**x**	x					
	Upstream	x	x	**x**	x					
MEA02	Adjacent	**x**	x						**x**	
	Upstream	**x**	x							
MAR02	Adjacent	**x**			x					
	Upstream	**x**			x					
JOH01	Adjacent	**x**			x	x				
	Upstream	**x**			x					
JOH02	Adjacent	**x**	x		x					
	Upstream	**x**	x		x					
WAP06	Adjacent	**x**	x		x					
	Upstream	**x**	x	x	x				x	
WAP07	Adjacent	**x**	x		x				x	
	Upstream	**x**	x	x	x					
WAP02a	Adjacent	x			**x**	**x**	**x**			
& WAP03	Upstream	**x**			x	x	x	x		
GHO03a	Adjacent	**x**								x
	Upstream	**x**	x	x	x					x
GHO05	Adjacent	**x**			x					
	Upstream	**x**			x					

In the previous two years of sampling at JOH02, grazing was not considered a land use although the site was within a grazing lease. In 2025, however, grazing and trampling by cattle was evident, including pugged[4] areas beside the creek (Figures 2 and 3), introducing sediment. Numerous incised cattle trails criss-crossed the adjacent shrubby meadow (Figure 3).

[4] Pugged: Having extensive and deep depressions in soft soil from large animal hooves, resulting in hummocky ground with permanent high areas between low moist to wet areas. The high areas tend to be much drier than the depressed areas, creating a drier system than would naturally occur.

Figure 2. Trampling and pugging by cattle on the shores of Johnson Creek, at JOH02.

Figure 3. Incised cattle trails leading to Johnson Creek, at JOH02, with evidence of pugging.

3.3 Water Attributes and Chemical Analysis

The chemical attributes (i.e., pH, dissolved oxygen, anions, nutrients) of water samples, along with the physical attributes (i.e., total suspended solids, turbidity, specific conductance, temperature), are presented for each site in Table 11. The chemical analyses suggest the water quality at the time of sampling was within the parameters acceptable for benthic macroinvertebrates and fish (Government of Alberta 2018) in almost all instances. The surface water quality guidelines and criteria, including brief narratives, are presented in Table 12.

Table 11. Chemical and physical attributes of water samples at each site[5].

Tests	Site										
	AUR01	**MEA02**	**MAR02**	**JOH01**	**JOH02**	**WAP06**	**WAP07**	**WAP02a**	**WAP03**	**GHO03a**	**GHO05**
Air Temperature (°C)	24.5	24.0	22.0	27.0	25.5	19.5	27.0	15.0	26.0	28.0	23.5
Water Temperature (°C)	12.2	5.7	8.0	12.3	13.5	9.8	13.5	9.3	14.8	13.5	10.7
Dissolved Oxygen (mg/L)	9.14	10.61	10.13	8.85	8.16	9.44	8.89	9.14	8.40	8.72	9.16
Specific Conductance (µS/cm)	463.3	438.4	235.5	341.1	338.7	375.8	368.0	352.1	355.6	349.4	361.9
pH	8.47	8.06	8.30	7.93	7.93	8.45	8.48	7.89	7.89	7.75	7.53
Total Suspended Solids (mg/L)	7.9	1.3	<1.0	2.5	2.3	<1.0	1.2	1.3	<0.99	<1.0	<1.0
Turbidity (lab) (NTU)	12.00	<0.10	0.14	<0.10	<0.10	<0.10	0.12	<0.10	<0.10	<0.10	<0.10
Anions (mg/L)											
Alkalinity (Total as $CaCO_3$)	280	250	140	180	170	200	190	170	170	170	150
Alkalinity (PP as $CaCO_3$)	15.0	<1.0	<1.0	<1.0	<1.0	4.7	5.6	<1.0	<1.0	<1.0	<1.0
Bicarbonate (HCO_3)	310	310	170	220	210	230	220	210	210	200	180
Carbonate (CO_3)	18.0	<1.0	<1.0	<1.0	<1.0	5.7	6.7	<1.0	<1.0	<1.0	<1.0
Hydroxide (OH)	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Nutrients (mg/L)											
Total Phosphorus (P)	0.011	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
Dissolved Nitrogen (N)*	0.50	0.31	0.27	0.42	0.43	0.27	0.43	0.30	0.18	0.40	-
Nitrate (N)	<0.040	0.22	0.055	0.34	0.33	0.086	0.065	0.22	0.11	0.29	0.38
Nitrite (N)	<0.040	<0.040	<0.040	<0.040	<0.040	<0.040	<0.040	<0.040	<0.040	<0.040	<0.040
Dissolved Total Kjeldahl Nitrogen**	0.500	0.087	0.220	0.080	0.100	0.270	0.430	0.088	0.072	0.110	-

Note: Lab analyses by Bureau Veritas Laboratories, Calgary, Alberta.
* Dissolved nitrogen includes total Kjeldahl nitrogen, nitrate and nitrite.
** Total Kjeldahl nitrogen (TKN) includes ammonia, ammonium and organic nitrogen.

[5] The reported values for dissolved nitrogen and total Kjeldahl nitrogen at GHO05 were 47 and 46 mg/L, respectively. Attempts were made to clarify this result with Bureau Veritas but the lab indicated there was no error. The values have been excluded from the dataset as extreme outliers.

Table 12. Surface water quality guidelines and criteria for protection of freshwater aquatic life.

Water Quality Variable (Substance or Condition)	Short-term (Acute)	Long-term (Chronic)	Notes and Direction
Alkalinity (as $CaCO_3$) (mg/L)	-	20	A minimum value, unless natural conditions are less, in which case the guideline cannot be lower than 25% of the natural level.
Bicarbonate (HCO_3)	-	-	
Carbonate (CO_3)	-	-	
Hydroxide (OH)	-	-	
Nitrate – N (mg/L)	>124	>3.0	As N. For protection from toxicity. Does not consider eutrophication effects.
Nitrite – N (mg/L)	Varies	Varies	As N. Varies with chloride.
Nitrogen – total (inorganic + organic)	-	Narrative	Nitrogen (total) and phosphorus concentrations should be maintained to prevent detrimental changes to algal and aquatic plant communities, aquatic biodiversity, oxygen levels and recreational quality. Where priorities warrant, develop site-specific nutrient objectives and management plans.
Dissolved Oxygen (mg/L) (Minimum values)	5	6.5	See Alberta Environmental Protection (1997) for guidance when natural conditions do not meet guidelines. Long-term is 7 day mean, short-term is instantaneous value.
	-	8.3	For mid-May to end of June, to protect mayfly emergence.
	-	9.5	For areas and times where and when larval fish develop within gravel beds.
Total Phosphorous (mg/L)	-	Narrative	For major rivers and for surface waters not covered by specific guidelines, nitrogen (total) and phosphorus concentrations should be maintained to prevent detrimental changes to algal and aquatic plant communities, aquatic biodiversity, oxygen levels, and recreational quality. Where priorities warrant, develop site-specific nutrient objectives and management plans.

Table 12. Continued

Water Quality Variable (Substance or Condition)	Short-term (Acute)	Long-term (Chronic)	Notes and Direction
pH (Safe range)		6.5 - 9.0	Not to be altered by more than 0.5 units from background.
Total Suspended Solids (TSS) (mg/L)	Narrative	Narrative	<u>During clear flows or for clear waters</u>: Maximum increase of 25 mg/L from background for any short-term exposure (e.g., 24 hr period). Maximum average increase of 5 mg/L from background levels for longer term exposures (greater than 24 hr). <u>During high flow or for turbid waters</u>: Maximum increase of 25 mg/L from background levels at any time when background levels are between 25 and 250 mg/L. Should not increase more than 10% of background levels when background is $\geq$250 mg/L.
Specific Conductance	-	-	
Turbidity (NTU)	Narrative	Narrative	<u>For clear waters</u>: Maximum increase of 8 NTU from background for any short-term exposure (e.g., 24 hr period). Maximum average increase of 2 NTU from background levels for longer term exposures (greater than 24 hr). <u>For high flow or turbid waters</u>: Maximum increase of 8 NTU from background levels at any time when background levels are between 8 and 80 NTU. Should not increase more than 10% of background levels when background is >80 NTU.

Source: Government of Alberta (2018)

The water quality guidelines for Alberta surface waters (Government of Alberta 2018) do not provide values for specific conductivity or for three main anions: bicarbonate (HCO_3), carbonate (CO_3) and hydroxide (HO). Further discussion is provided below on specific conductivity and on the relationship of the three anions to alkalinity and inorganic carbon.

3.3.1 Alkalinity, Inorganic Carbon, Hardness and pH

A full description of alkalinity, inorganic carbon, hardness and pH is given in the report on the 2020 monitoring program (Biota Consultants 2022a).

Alkalinity, as expressed by the total $CaCO_{3,}$ was lowest at MAR02 (140 mg/L) and highest at AUR01 (280 mg/L) (Table 11). These values are well above the minimum 20 mg/L level indicated in Table 12. The hardness of a water body is regulated largely by the levels of calcium and magnesium salts. Hard water contains cations with a charge of 2+, especially Ca^{2+} and Mg^{2+} (Casiday and Frey 1998). The water at sites AUR01, MEA02, WAP06 and WAP07 would be classified as very hard according to the USGS Water Science School (2018a) classification, whereas water at the other sites would be classified as hard:

Soft = 0 to 60 mg/L $CaCO_3$
Moderately hard = >60 to 120 mg/L $CaCO_3$
Hard = >120 to 180 mg/L $CaCO_3$
Very hard = >180 mg/L $CaCO_3$

The pH of the samples varied from 7.53 to 8.48, which is in the safe range for acute toxicity according to Government of Alberta (2018) criteria (Table 12).

3.3.2 Specific Conductance (Conductivity)

Conductivity is a numerical expression of water's ability to conduct an electrical current, usually expressed in microsiemens per centimetre (µS/cm). Since conductivity increases with temperature, reporting conductivity at the reference temperature of 25°C allows data to easily be compared (FEI 2014a). Specific conductance is a conductivity measurement made at, or corrected to, 25°C (Miller *et al.* 1988). The lowest specific conductance value was at MAR02 (235.5 µS/cm), while the highest value occurred at AUR01 (463.3 µS/cm) (Table 11).

There is no set standard for the conductivity of water (Table 12) because conductivity can differ regionally and between neighbouring streams if there is enough difference in the surrounding geology, or if one source has a separate inflow (FEI 2014a). Freshwater that runs through granite bedrock will have a very low conductivity value, whereas clay- and limestone-derived soils can contribute to higher conductivity values (LCRA 2014). Despite the lack of standards and the fact that the surrounding environment can affect conductivity, there are approximate values that can be expected based on the source of the water. Freshwater streams vary from 100 to 2,000 µS/cm whereas industrial wastewater is in the order of 10,000 µS/cm (American Public Health Assoc. *et al.* 1999, as cited in FEI 2014a; Clean Water Team 2004).

A full discussion on specific conductance is provided in Biota Consultants (2022a). Specific conductance is one of the most useful and commonly measured water quality parameters (Miller *et al.* 1988). It is the basis of most salinity and total dissolved solids calculations, and is an early indicator of change in a water body. Most water bodies maintain a fairly constant conductivity that can be used as a baseline for future comparisons (EPA 2012, as cited in FEI 2014a). Therefore, conductivity is a useful tracer of point source discharges (Environment Canada 2012). A significant change in conductivity, whether due to natural flooding, evaporation or man-made pollution, can be detrimental to water quality, hence to aquatic insects (FEI 2014a). The 2020 to 2025 data provide baseline measurements for comparison in the future. Of those sites sampled more than once, there has not been a significant change in specific conductance.

3.3.3 Total Suspended Solids, Turbidity and Dissolved Oxygen

3.3.3.1 Total Suspended Solids

Total suspended solids (TSS) were <1.0 mg/L at five of the sites and up to 7.9 mg/L at AUR01 (Table 11). A TSS measurement of less than 20 mg/L generally appears clear, while levels over 40 mg/L may begin to appear cloudy (Michigan Department of Environmental Quality n.d., as cited in FEI 2014b).

Particles in the water column that are larger than 2 microns comprise TSS. Anything smaller (average filter size) is considered to be a dissolved solid. Most suspended solids are made up of inorganic materials such as sand and silt; however, bacteria, algae, plankton, and organic particles from decaying plants and animals can also contribute to the TSS concentration, i.e., anything drifting or floating in the water (Murphy 2007; EPA 2012, as cited in FEI 2014b). Water clarity is significantly affected, declining as the amount of solids increases. Water temperature then increases, which reduces dissolved oxygen (FEI 2014b).

Suspended solids can adversely affect aquatic organisms in several ways:

- Clog the filtering systems of fish and some immature stages of insects (e.g., caddisfly larvae);
- Cause physical injury to delicate eye and gill membranes by abrasion;
- Restrict food availability to fish, affecting growth rates;
- Restrict normal movements and migrations of fish; and
- Inhibit egg development (Alabaster and Lloyd 1984, as cited in CCME 1999).

For further information on suspended and settleable solids, please see Biota Consultants (2022a).

3.3.3.2 Turbidity

Turbidity is often reported as nephelometric turbidity units (NTU) and is a measure of relative water clarity. Turbid water can appear cloudy, murky, hazy, muddy, coloured or opaque. At 5 NTU, water appears clear, at 55 NTU it is obviously cloudy, and at 500 NTU, it appears completely opaque (USGS Water Science School 2018b). The majority of sites had turbidity values between <0.10 NTU to 0.14 NTU (Table 11), which are considered very low (Table 12). The highest value was still relatively low at 12.00 NTU (AUR01), where the water continued to be clear.

Turbidity in water results from the presence of suspended matter such as clay, silt, finely divided inorganic and decaying organic material, soluble coloured organic compounds, and living organisms that are held in suspension by turbulent flow (McNeely *et al.* 1979, as cited in CCME 2008). Coloured dissolved organic matter, also known as humic stain, also can cause turbity. This is produced from decaying underwater vegetation and the release of tannins and other molecules. Water will appear red or brown, depending on the type of flora present. These dissolved substances may be too small to be considered suspended solids, but they contribute to turbidity by affecting water clarity (FEI 2014b).

By blocking sunlight, turbity can inhibit photosynthesis, thereby reducing plant growth, which in turn reduces dissolved oxygen. If the turbidity blocks enough sunlight to kill aquatic vegetation, aquatic organisms that rely on underwater plants also will decline (FEI 2014b).

Turbidity and TSS are related, as both reduce water clarity; however, turbidity is not a direct measurement of suspended materials in water. It is often used to indicate changes in the TSS concentration without providing an exact measurement of solids (EPA 2012, as cited in FEI 2014b). Since the correlation between turbidity and the weight of suspended (or total suspended) and settleable solids is often tenuous, both should be assessed.

3.3.3.3 Dissolved Oxygen and Temperature

The dissolved oxygen values were within acceptable limits, ranging from 8.16 to 10.61 mg/L (Table 11). Dissolved oxygen (DO) is the concentration of free oxygen (O_2) present in water or other liquids, and is usually measured in mg/L. An O_2 level that is too low or too high can affect water quality, harming aquatic life (FEI 2013). The amount of O_2 dissolved in water primarily depends on temperature, atmospheric (barometric) pressure and salinity, and can be introduced through turbulence (e.g., rapids, waterfalls, waves) (FEI 2013). Temperature is the main factor, as cold water can hold more oxygen (Environment Canada 2012). Therefore, water temperature and the amount of DO are important in assessing water quality due to their influence on organisms within a body of water. Please see Biota Consultants (2022a) for a further discussion on factors influencing DO and the effects of DO on aquatic fauna.

3.3.4 Comparison of Sites Among Years

A comparison among years of the physical and chemical attributes of the water samples at those sites sampled more than once are presented in Tables 13 to 17. There were slight variations between years at each site, but almost all were within the guidelines. This variation is expected in a natural environment.

3.3.4.1 Aura Creek

Total suspended solids and turbidity have continued to increase at AUR01 from 2022 to 2025 (Table 13), which may be related to land uses upstream, such as logging. The higher measurements did not affect the level of DO; however, further monitoring would be prudent.

Table 13. Comparison of physical and chemical attributes of water samples at the Aura Creek site (AUR01) from 2022 to 2025.

Tests	**Site and Date of Sampling**			
	AUR01			
	Sept. 12 2022	**Aug. 29 2023**	**Sept. 4 2024**	**Aug. 26 2025**
Air Temperature (°C)	14.0	25.0	16.5	24.5
Water Temperature (°C)	8.1	13.4	11.4	12.2
Dissolved Oxygen (mg/L)	9.53	9.40	9.43	9.14
Specific Conductance (µS/cm)	459.4	456.7	445.4	463.3
pH	8.24	8.35	8.42	8.47
Total Suspended Solids (mg/L)	<1.0	2.2	5.5	7.9
Turbidity (NTU)	2.50	4.60	6.60	12.00
Anions (mg/L)				
Alkalinity (Total as $CaCO_3$)	260	260	250	280
Alkalinity (PP as $CaCO_3$)	<1.0	5.0	13.0	15.0
Bicarbonate (HCO_3)	320	310	270	310
Carbonate (CO_3)	<1.0	6.0	16.0	18.0
Hydroxide (OH)	<1.0	<1.0	<1.0	<1.0
Nutrients (mg/L)				
Total Phosphorus (P)	<0.003	0.004	0.006	0.011
Dissolved Nitrogen (N)	0.36	0.46	0.56	0.50
Nitrate (N)	0.01	<0.010	<0.010	<0.040
Nitrite (N)	<0.010	<0.010	<0.010	<0.040
Dissolved Total Kjeldahl Nitrogen	0.347	0.455	0.560	0.500

Carbonate and alkalinity (PP as CaCO3) values have also climbed over the four years of sampling at AUR01, and there have been slight increases in phosphorous and dissolved nitrogen, although dissolved nitrogen was lower in 2025 than 2024 (Table 13). The increase in carbonates is likely due to a proportional increase in groundwater contribution, or from decay of organic materials (i.e., leaves, twigs, soil, etc.) that causes release of CO_2 in the stream, which combines to make Ca/Mg carbonates or bicarbonates (R. McAlpine, pers. comm.). This is supported by the increase in phosphorus and organic nitrogen over the years. Such increases can result from forestry activities or fire (R. McAlpine, pers. comm.).

3.3.4.2 Johnson Creek

Dissolved nitrogen and nitrate have gradually increased at JOH01 over the five years of sampling, although to a lesser extent in 2025 (Table 14). Total Kjeldahl nitrogen (TKN) increased over five-fold at JOH02 in 2025, with a corresponding increase in dissolved nitrogen (Table 14). This might be attributed to manure input from the cattle that used the site in 2025.

Table 14. Comparison among years of physical and chemical attributes of water samples at Johnson Creek sites (JOH01 and JOH02).

Tests	**Site and Date of Sampling**							
	JOH01					**JOH02**		
	Sept. 7 2021	**Aug. 30 2022**	**Aug. 31 2023**	**Aug. 27 2024**	**Aug. 25 2025**	**Aug. 31 2023**	**Aug. 30 2024**	**Aug. 25 2025**
Air Temperature (°C)	16.0	21.0	14.0	19.5	27.0	17.5	16.5	25.5
Water Temperature (°C)	6.2	9.8	8.2	12.2	12.3	8.4	6.2	13.5
Dissolved Oxygen (mg/L)	10.24	9.61	9.76	8.42	8.85	9.97	9.49	8.16
Specific Conductance (µS/cm)	335.8	323.1	392.2	334.0	341.1	324.9	331.9	338.7
pH	8.21	8.23	8.17	8.40	7.93	8.18	8.17	7.93
Total Suspended Solids (mg/L)	<1.0	<1.0	1.5	<1.0	2.5	1.1	2.5	2.3
Turbidity (NTU)	0.11	0.40	0.11	0.24	<0.10	0.11	0.90	<0.10
<u>Anions</u> (mg/L)								
Alkalinity (Total as $CaCO_3$)	150	170	140	160	180	160	180	170
Alkalinity (PP as $CaCO_3$)	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	4.6	<1.0
Bicarbonate (HCO_3)	190	210	180	190	220	200	200	210
Carbonate (CO_3)	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	5.5	<1.0
Hydroxide (OH)	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
<u>Nutrients</u> (mg/L)								
Total Phosphorus (P)	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
Dissolved Nitrogen (N)	0.16	0.29	0.35	0.41	0.42	0.34	0.33	0.43
Nitrate (N)	0.17	0.24	0.32	0.33	0.34	0.33	0.37	0.33
Nitrite (N)	<0.010	<0.010	<0.010	<0.010	<0.040	<0.010	<0.010	<0.040
Dissolved Total Kjeldahl Nitrogen	-	0.055	0.030	0.079	0.080	<0.020	<0.020	0.100

3.3.4.3 Waiparous Creek

The physical and chemical attributes of the water samples between 2020 and 2025 at WAP06 and WAP07 were comparable with the exception of alkalinity, carbonates and dissolved nitrogen, which were higher at both sites in 2025 (Table 15). The magnitude of increase in dissolved nitrogen was slightly higher at the upstream site of WAP07.

Table 15. Comparison of physical and chemical attributes of water samples at Waiparous Creek sites WAP06 and WAP07 in 2020 and 2025.

Tests	**Site and Date of Sampling**			
	WAP06		**WAP07**	
	Sept. 10 2020	**Aug. 29 2025**	**Sept. 10 2020**	**Aug. 29 2025**
Air Temperature (°C)	16.1	19.5	25.0	27.0
Water Temperature (°C)	8.3	9.8	12.5	13.5
Dissolved Oxygen (mg/L)	10.24	9.44	9.30	8.89
Specific Conductance (µS/cm)	345.4	375.8	340.3	368.0
pH	8.34	8.45	8.25	8.48
Total Suspended Solids (mg/L)	1.3	<1.0	<1.0	1.2
Turbidity (NTU)	0.26	<0.10	0.22	0.12
Anions (mg/L)				
Alkalinity (Total as $CaCO_3$)	160	200	160	190
Alkalinity (PP as $CaCO_3$)	1.1	4.7	1.8	5.6
Bicarbonate (HCO_3)	200	230	190	220
Carbonate (CO_3)	1.3	5.7	2.2	6.7
Hydroxide (OH)	<1.0	<1.0	<1.0	<1.0
Nutrients (mg/L)				
Total Phosphorus (P)	<0.003	<0.003	<0.003	<0.003
Dissolved Nitrogen (N)	0.14	0.27	0.16	0.43
Nitrate (N)	0.080	0.086	0.074	0.065
Nitrite (N)	<0.010	<0.040	<0.010	<0.040
Dissolved Total Kjeldahl Nitrogen	0.064	0.180	0.085	0.370

The outflow from Johnson Creek may have influenced the chemical attributes of Waiparous Creek below the confluence. The consistently higher dissolved nitrogen and nitrate at WAP02/02a versus WAP03/03a (Tables 16 and 17) possibly resulted from the even higher dissolved nitrogen and nitrate at JOH01, although these differences are within the range of natural variation.

Table 16. Comparison of physical and chemical attributes of water samples at Waiparous Creek sites WAP02/WAP02a from 2020 to 2025.

Tests	**Site and Date of Sampling**					
	WAP02		**WAP02a**			
	Sept. 1 2020	**Sept. 2 2021**	**Sept. 7 2022**	**Aug. 30 2023**	**Aug. 27 2024**	**Aug. 25 2025**
Air Temperature (°C)	22.5	10.5	21.5	22.5	21.0	15.0
Water Temperature (°C)	15.0	7.4	12.7	12.2	12.4	9.3
Dissolved Oxygen (mg/L)	8.97	9.92	8.04	9.05	8.91	9.14
Specific Conductance (µS/cm)	316.6	336.8	333.7	341.7	350.4	352.1
pH	8.18	8.29	8.04	8.24	8.13	7.89
Total Suspended Solids (mg/L)	1.2	<1.0	<1.0	<1.0	<1.0	1.3
Turbidity (NTU)	<0.10	0.22	0.30	0.54	0.24	<0.10
Anions (mg/L)						
Alkalinity (Total as $CaCO_3$)	150	140	160	160	140	170
Alkalinity (PP as $CaCO_3$)	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Bicarbonate (HCO_3)	180	170	200	190	170	210
Carbonate (CO_3)	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Hydroxide (OH)	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Nutrients (mg/L)						
Total Phosphorus (P)	<0.0030	<0.0030	<0.0030	<0.0030	<0.003	<0.003
Dissolved Nitrogen (N)	0.26	0.13	0.23	0.22	0.27	0.30
Nitrate (N)	0.12	0.13	0.19	0.23	0.24	0.22
Nitrite (N)	<0.010	<0.010	<0.010	<0.010	<0.010	<0.040
Dissolved Total Kjeldahl Nitrogen	0.140	-	0.040	<0.020	0.021	0.088

Table 17. Comparison of physical and chemical attributes of water samples at Waiparous Creek sites WAP03/WAP03a from 2020 to 2025.

Tests	Site and Date of Sampling					
	WAP03			WAP03a	WAP03	
	Sept. 3 2020	Sept. 2 2021	Sept. 7 2022	Aug. 30 2023	Aug. 27 2024	Aug. 25 2025
Air Temperature (°C)	17.5	19.0	23.0	25.5	20.5	26.0
Water Temperature (°C)	12.8	10.2	15.7	15.9	13.2	14.8
Dissolved Oxygen (mg/L)	8.77	9.28	8.27	8.27	8.42	8.40
Specific Conductance (µS/cm)	320.2	336.7	339.0	352.0	356.6	355.6
pH	8.38	8.38	8.27	8.18	8.32	7.89
Total Suspended Solids (mg/L)	2.0	<1.0	<1.0	<1.0	<1.0	<0.99
Turbidity (NTU)	<0.10	0.11	0.20	0.19	0.21	<0.10
Anions (mg/L)						
Alkalinity (Total as $CaCO_3$)	140	130	140	140	130	170
Alkalinity (PP as $CaCO_3$)	1.4	<1.0	<1.0	<1.0	<1.0	<1.0
Bicarbonate (HCO_3)	160	160	180	180	160	210
Carbonate (CO_3)	1.7	<1.0	<1.0	<1.0	<1.0	<1.0
Hydroxide (OH)	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Nutrients (mg/L)						
Total Phosphorus (P)	<0.0030	<0.0030	<0.0030	<0.0030	<0.003	<0.003
Dissolved Nitrogen (N)	0.25	0.13	0.14	0.12	0.22	0.18
Nitrate (N)	0.068	0.13	0.11	0.14	0.18	0.11
Nitrite (N)	<0.010	<0.010	<0.010	<0.010	<0.010	<0.040
Dissolved Total Kjeldahl Nitrogen	0.190	-	0.032	<0.020	0.047	0.072

3.3.4.4 Ghost River

Between 2021 and 2025, water quality measurements at GHO03 and GHO05 were relatively similar, although there was a decline in pH and slight increase in alkalinity at both sites. Dissolved nitrogen concentration increased at GHO03 from 0.25 to 0.40 mg/L. The laboratory reported extremely high lab-measured dissolved nitrogen and lab-calculated TKN concentrations at GHO05 in 2025, 47 and 46 mg/L, respectively. The laboratory was contacted repeatedly to clarify if a potential error was possible. According to the laboratory, no errors were indicated when reviewing the results; however, the sample had been discarded and could not be re-run by the time requests for clarification were made. Despite the laboratory not identifying an error, these results are not included in Table 18 since the reported dissolved nitrogen concentration is considered to be an extreme outlier based on professional opinion, with no logical explanation (K. Munter, pers. comm.).

Nitrogen is one of the nutrients that may increase in concentration in rivers following wildfire, which may explain the higher dissolved nitrogen and nitrate concentrations at GHO03 in 2025. At GHO05, however, the reported dissolved nitrogen concentration in 2025 was several hundred-fold higher than the elevated concentrations resulting from wildfires reported in the literature (Hauer and Spencer 1998; Bladon et al. 2008; Rhoades et al. 2017; Brucker et al. 2025). In late October, 2020, shortly after the wildfire, water quality samples were taken at the same location as GHO05 by staff from fRI Research, Alberta Agriculture and Forestry and the City of Calgary. Results indicated 0.0025 mg/L of nitrite and 0.18 mg/L of nitrate plus nitrite. Neither total dissolved nitrogen nor TKN were measured. In 2021, the nitrite measurement was <0.010 mg/L, and nitrate plus nitrite was 0.21 mg/L (Table 18). In 2025, a nitrate level of approximately two-fold was measured (Table 18), but the reported dissolved nitrogen concentraton was almost 224 times that in 2021. It does not appear this can be attributed to the wildfire.

Table 18. Comparison of physical and chemical attributes of water samples at Ghost River sites GHO03/03a and GHO05 in 2021 and 2025.

Tests	**Site and Date of Sampling**			
	GHO03	**GHO03a**	**GHO05**	
	Aug. 26 2021	**Aug. 27 2025**	**Aug. 30 2021**	**Aug. 27 2025**
Air Temperature (°C)	17.0	28.0	18.0	23.5
Water Temperature (°C)	9.6	13.5	9.8	10.7
Dissolved Oxygen (mg/L)	9.53	8.72	9.18	9.16
Specific Conductance (µS/cm)	340.3	349.4	351.9	361.9
pH	8.24	7.75	8.32	7.53
Total Suspended Solids (mg/L)	<1.0	<1.0	<1.0	<1.0
Turbidity (NTU)	0.14	<0.10	0.13	<0.10
<u>Anions</u> (mg/L)				
Alkalinity (Total as $CaCO_3$)	140	170	120	150
Alkalinity (PP as $CaCO_3$)	<1.0	<1.0	<1.0	<1.0
Bicarbonate (HCO_3)	180	200	150	180
Carbonate (CO_3)	<1.0	<1.0	<1.0	<1.0
Hydroxide (OH)	<1.0	<1.0	<1.0	<1.0
<u>Nutrients</u> (mg/L)				
Total Phosphorus (P)	0.0040	<0.003	<0.003	<0.003
Dissolved Nitrogen (N)	0.25	0.40	0.21	-
Nitrate (N)	0.21	0.29	0.21	0.38
Nitrite (N)	<0.010	<0.040	<0.010	<0.040
Dissolved Total Kjeldahl Nitrogen*	-	0.110	-	-

* TKN not calculated by laboratory in 2021.

Wildfire effects tend to decline over time, often after three to eight years after a fire (Hauer and Spencer 1998; Bladon et al. 2008; Brucker et al. 2025), and up to 14 years after extensive high-severity wildfires (Rhoades et al. 2017). However, the extremely high concentration of dissolved nitrogen reported at GHO05 in 2025 would not be expected after the five years since the fire. A year after the Lost Creek fire in southwestern Alberta in 2003, mean concentrations of nitrate, total nitrogen and ammonium were 6.5, 5.3 and 1.5 times greater, respectively, in streams located in burned watersheds versus reference streams (Bladon et al. 2008). Values declined rapidly over the three seasons post-fire, except during snowmelt and after precipitation events. The maximum nitrate, total nitrogen and ammonium concentrations post-fire were 1.6679 mg/L, 3.4134 mg/L and 0.0094 mg/L, respectively (Bladon et al. 2008).

Although the 2025 dissolved nitrogen and TKN concentrations at GHO05 have been considered extreme outliers, it is recognized that nitrogen concentrations at GHO03 and GHO05 may be affected by the 2020 wildfire. The chemistry panel that was used does not make the contribution of organic and inorganic nitrogen clear. If ammonia is measured along with dissolved nitrogen and TKN, total organic nitrogen could be separated from inorganic nitrogen to determine the primary contribution of nitrogen within the TKN.

3.4 Benthic Macroinvertebrate Morphological Analysis

In addition to measuring chemical and physical parameters, CABiN uses benthic macroinvertebrates as indicators of aquatic ecosystem health (Environment Canada 2012). Organisms in natural aquatic systems are continuously exposed to fluctuations in their environment. Some species adapt to these changes, whereas other species cannot (CCME 2008).

The orders Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies) (EPT) are taxa that tend to be sensitive to pollution or degraded aquatic environments. The EPT index is the proportion of these taxa in the benthic invertebrate community. In contrast, the family Chironomidae (non-biting midges) in the order Diptera generally are tolerant of degraded waterbodies. Therefore, determining the ratio of chironomids to EPT species can be a good indicator of water quality depending on the habitat present. Monitoring the ratio over time can be used to determine whether the community is changing, either because of anthropogenic influences (using test sites) or naturally-caused influences (using reference condition sites). Metric indices using the data collected in GWAS's water monitoring program can provide information on the abundance, richness, diversity and evenness of the community.

The community/population data and analyses are presented in the appendices. Appendix B contains the common names of the orders and families of the benthic macroinvertebrates that were identified in 2025. Appendix C contains the entire raw data set of the benthic macroinvertebrates identified based on morphological characteristics. Appendix D contains this taxonomic data at the family level. Appendix E contains the metric indices for the entire 2025 taxonomic data to the genus/species level based on morphological identification.

Within CABiN, the metrics are classified into four main groups: measurements of richness, measurements of abundance or community composition, functional group measures and biotic indices. A description of these taxonomic data analyses is provided in the report on the 2020 monitoring program (Biota Consultants 2022a). All of the metric results are presented in Appendix E, and key results are summarized below.

3.4.1 Richness Measurements

The number of different species present is a measure of richness. This can be the total number of species at a site, or the number within a taxon(s), or the number within a functional group (i.e., predators, shredder-herbivores, collector-gatherers, scrapers, collector-filterers, omnivores, parasites, piercer-herbivores or unclassified types). Species richness does not take into account the number of individuals of each species present. Rather, it gives as much weight to those species represented by very few individuals as to those represented by many individuals.

Diversity/evenness measurements take into account the abundance and distribution among the taxa present (e.g., Simpson's Diversity/Evenness Index and Shannon-Wiener Diversity Index). Diverse communities are indicators of "good" water quality.

The Simpson's Index of Diversity indicates that the community composition of most sites sampled in 2025 were highly diverse (Figure 4). AUR01 had the lowest diversity with a value of 0.69, followed by WAP07 at 0.75. Similarly, values for the Shannon-Wiener Diversity Index were lowest for Aura Creek (1.75). Simpson's Index of Diversity was similar among years at the Aura Creek, Johnson Creek and Ghost River sites. It was higher at WAP06 and lower at WAP07 in 2025 versus 2020. It has varied slightly over the six years of sampling at WAP02/02a and WAP03/03a, with dips in 2021 and 2022, respectively (Figure 4).

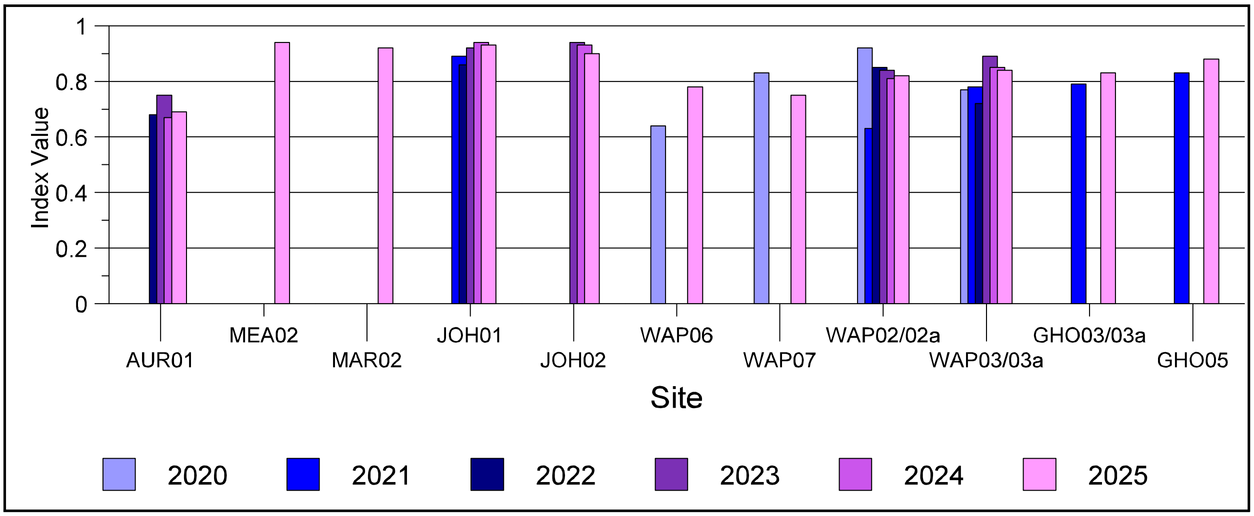


Figure 4. Simpson's Index of Diversity (1-D) for each site over the year(s) of sampling.

3.4.2 Abundance and Compositional Measures

Abundance can be expressed as the sum of all organisms present at a selected taxonomic level or within a specified group. Composition of taxa within the population can be expressed numerically or as a percentage of the population. Shifts within the population can alter the structure at various trophic levels, as certain species increase or decrease due to changes in the aquatic environment. The abundance and compositional measures that are presented include:

- EPT ratio: EPT/(chironomids+ EPT): the abundance of EPT individuals divided by the abundance of chironomids plus the EPT individuals (expressed as a value from 1 to 0).
- % Diptera that are Chironomidae: Chironomidae tend to be more tolerant than other families of Diptera.
- % Trichoptera that are Hydropsychidae: Hydropsychidae tend to be more tolerant than other families of Trichoptera.
- % Ephemeroptera that are Baetidae: Baetidae tend to be more tolerant than other families of Ephemeroptera.

The following graphs illustrate the relationship between the Ephemeroptera, Plecoptera, Trichoptera (Figure 5) and Diptera at each site (Figure 6). Of the EPT species, the Ephemeroptera dominated at all sites except AUR01 where Plecoptera were dominant (Figure 5). Ephemeroptera were dominant at AUR01, however, in the previous three years, and were much lower in abundance at the Johnson Creek sites in the past (Biota Consultants 2022b, 2023, 2024, 2025). Trichoptera were very low in abundance at many of the sites, and were not detected in the morphological sample from WAP03. They were most abundant at GHO05, at 9.83%, followed by MEA02 at 6.18% (Figure 5).

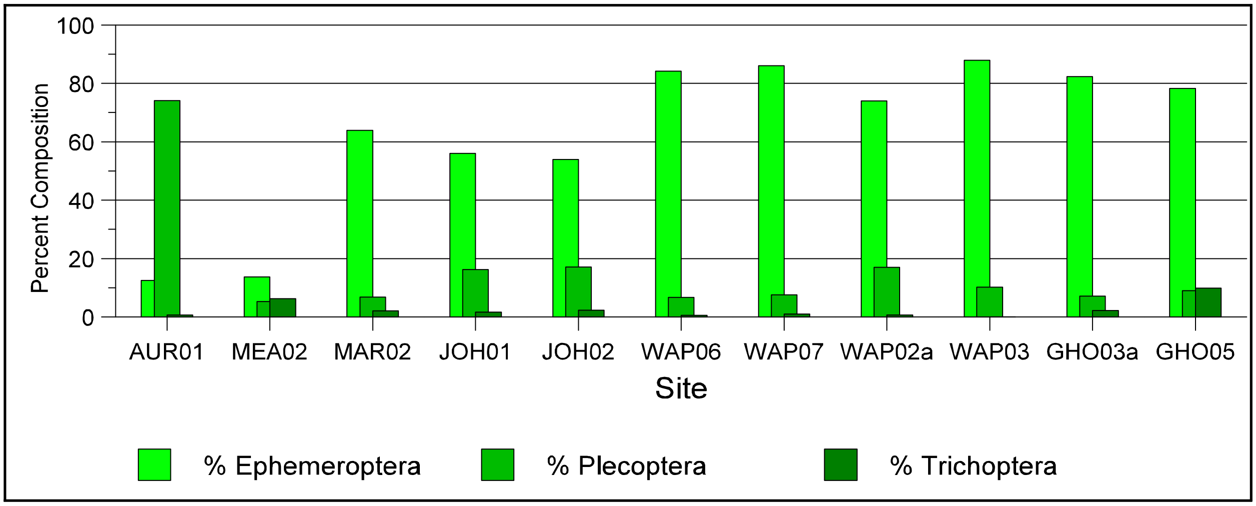


Figure 5. Percent composition of EPT orders at each site.

The EPT species were more prevalent than Diptera species at all sites except MEA02 (Figure 6). 2025 was the first year that EPT species were much more abundant than Diptera and chironomids at the Johnson Creek sites (Biota Consultants 2022b, 2023, 2024, 2025). Chironomid flies comprised at least 80% of the Diptera species at all sites except at MEA02, JOH02, WAP02/02a and WAP03/03a, where they were fewer (Figure 7).

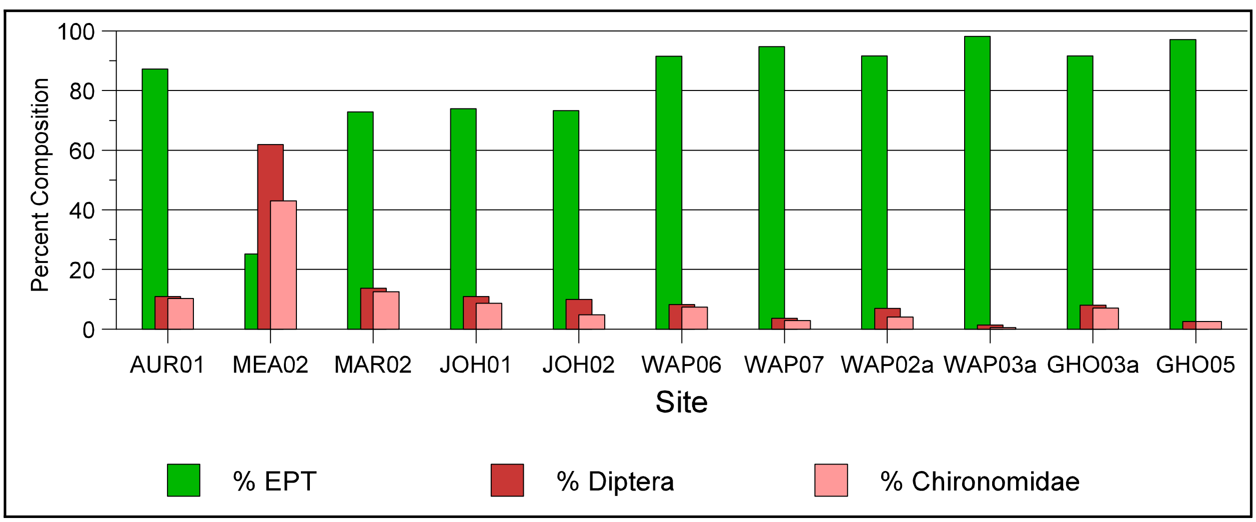


Figure 6. Percent composition of EPT orders, Diptera order and chironomid family at each site.

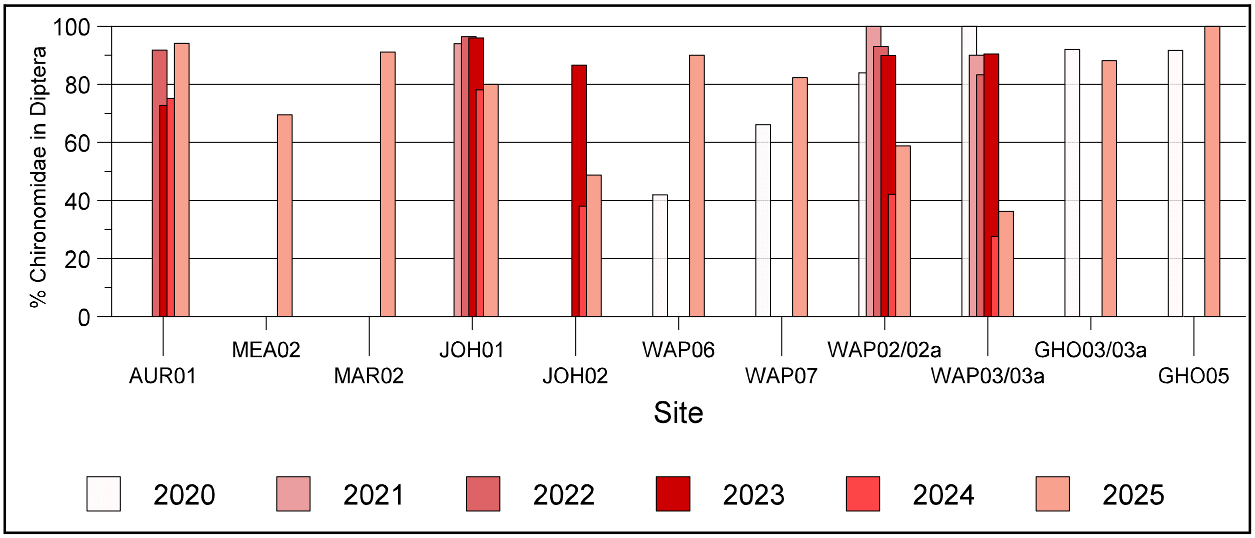


Figure 7. Percent of Diptera that were chironomid flies at each site over the year(s) of sampling.

The EPT ratio puts this into perspective (Figure 8). The ratios at the Johnson Creek sites have increased markedly over the years. The consistent high values at WAP02/02a and WAP03/03a suggest good water quality. The Meadow Creek site had the lowest value, at 0.37, the second lowest of any site over the six years of sampling.

The lowest EPT ratio of 0.13 was in 2024 at the Lost Knife Creek site (LOS01), where the substrate was largely silt (Biota Consultants 2025). Fine substrates like sand and silt provide a unique habitat for benthic macroinvertebrates where specialist taxa dominate. EPT have few taxa that are well suited to fine substrates whereas Chironomidae and other invertebrates are more common (A. Martens, pers. comm.). The streambed at MEA02 was primarily pebbles and cobbles, but was comprised of a greater proportion of fine substrates than the other sites sampled. This may explain why the EPT ratio differed at LOS01 and MEA02, reflecting the stream characteristics rather than indicating poor water quality.

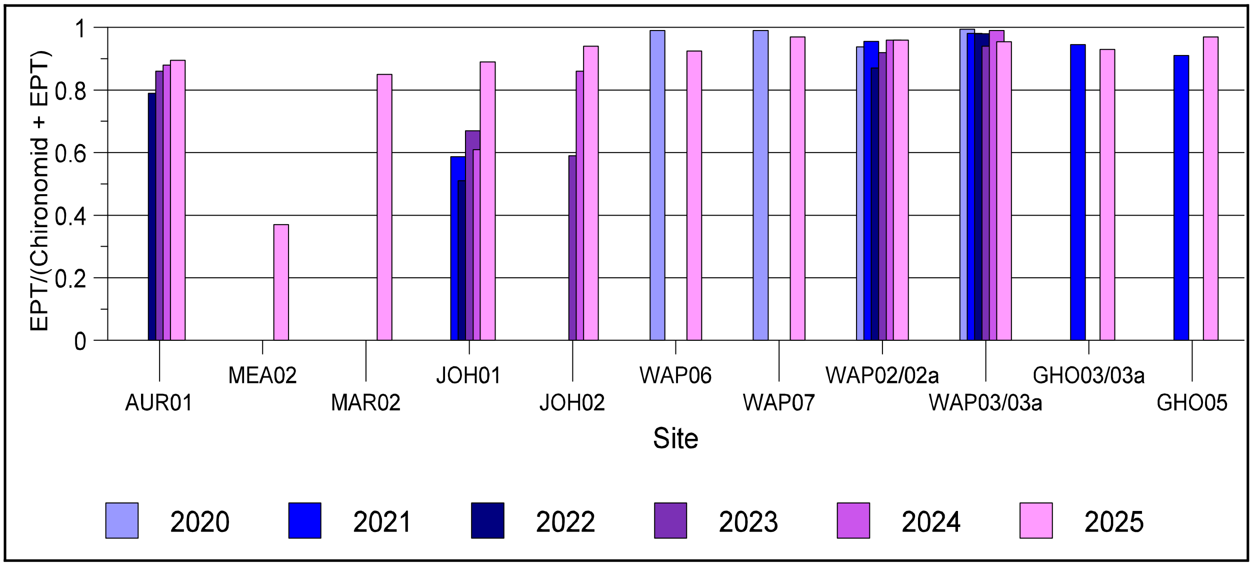


Figure 8. EPT/(chironomid + EPT) ratio for each site using percent community composition over the year(s) of sampling.

Based on the first five years of the water monitoring program, the two Johnson Creek sites were of concern with respect to the benthic macroinvertebrate community. The Devil's Head/Black Rock fire may be at least partially responsible for the previous low EPT ratios at the Johnson Creek sites, but no data were collected prior to the fire for comparison. There is high OHV activity on some upstream sections of Johnson Creek, but these are below JOH02. In 2025, however, there were no concerns at either of the Johnson Creek sites based on the EPT ratios.

The percentage of Trichoptera within the community at each site was very low to moderate, ranging from 0% to 9.83% (Figure 5). Hydropsychidae, a family within Trichoptera that is more tolerant to adverse conditions, was found only at the Ghost River sites (Figure 9). All 34 (100%) of the Trichoptera specimens at GHO03a were Hydropsychidae. The proportion of the Trichoptera that were Hydropsychidae has been variable at the other sites that have been sampled more than once (Figure 9).

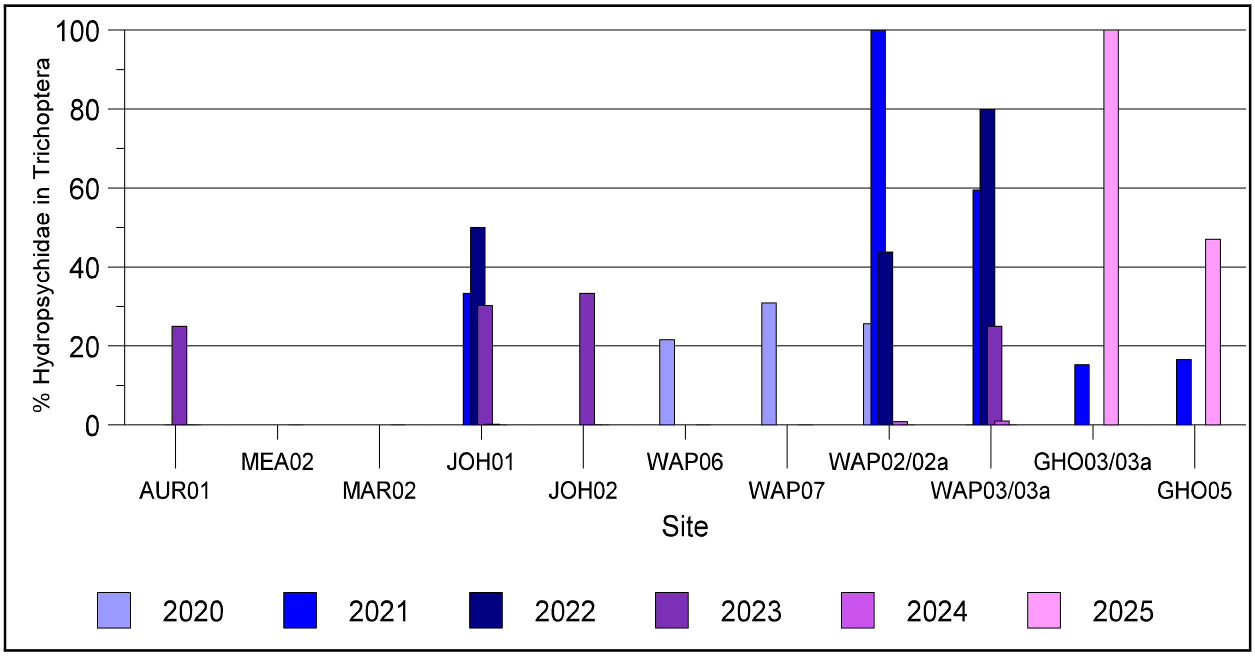


Figure 9. Percent of Trichoptera that were in the family Hydropsychidae at each site over the year(s) of sampling.

The percent of Baetidae, a family within Ephemeroptera that is more tolerant to adverse conditions, also was variable among the sites and between years (Figure 10). It was highest at JOH01.

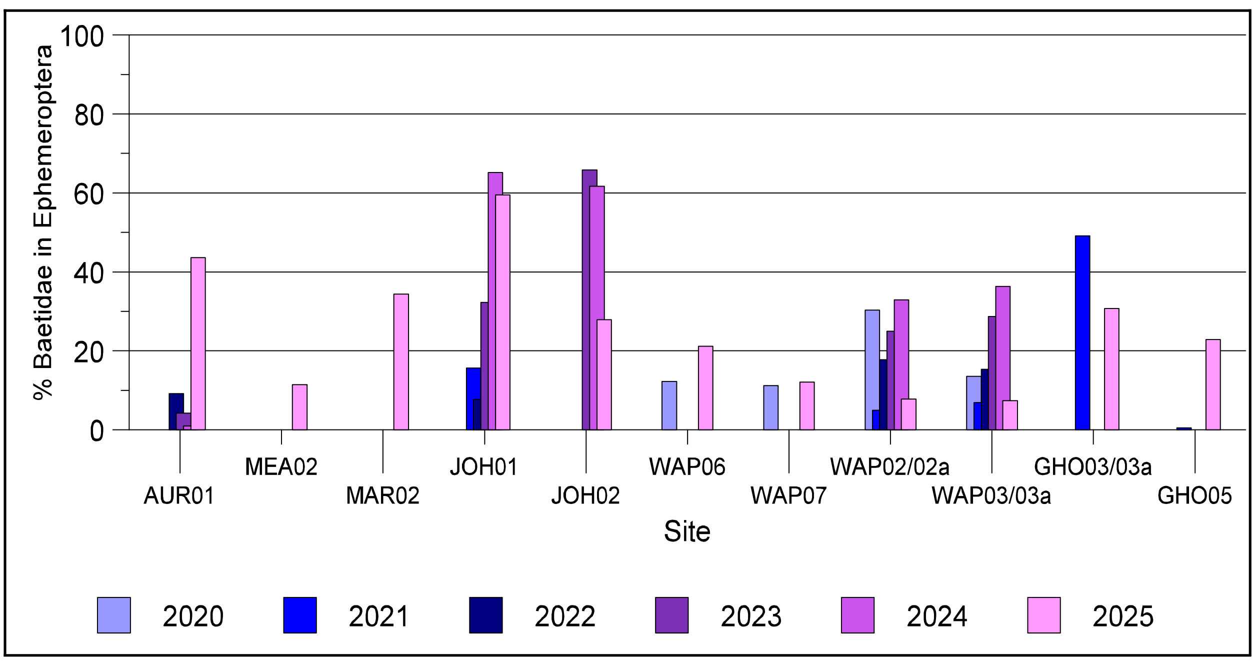


Figure 10. Percent of Ephemeroptera that were in the family Baetidae at each site over the year(s) of sampling.

3.4.3 Functional Feeding Groups

A functional feeding group (FFG) is a classification based on the benthic macroinvertebrate's primary method of obtaining food, and therefore can include several different taxa. There are five main groups (Cummins 1973, 2021):

- shredders, which eat leaf litter, rooted aquatic vascular plants or other coarse particulate organic matter (CPOM; >1 mm);
- scrapers/grazers, which eat algae and other associated material;
- collector-gatherers, which eat fine particulate organic matter (FPOM; $\leq$1 mm) on or in the stream sediments;
- collector-filterers, which filter fine particulate organic matter from the water column; and
- predators, which prey on live invertebrates.

Comparing FFGs in a stream is a way to simplify analyses without the need to identify all specimens to lower taxon levels (Cummins 2021). The FFGs present depend on the type of available food, which varies with stream characteristics and adjacent riparian vegetation. Their abundance will differ along the upstream to downstream continuum, with a higher proportion of shredders upstream versus downstream, and lower proportion of collectors (Vannote *et al.* 1980). Min *et al.* (2019) discovered that FFG distribution was largely influenced by stream width and slope.

The presence of certain groups, or the ratio of certain groups with respect to other groups, has been shown to be related to stream health. In general, specialists (e.g., many of the shredder species) are presumed to be more sensitive and therefore associated with healthy streams, whereas generalists (e.g., many of the collector species), with their broader diet, are presumed to be more tolerant to disturbance (Cummins and Klug 1979; Barbour *et al.* 1999). Cummins (2021) determined ratios of the relative numbers of FFGs that can be used as surrogates for stream ecological conditions. For example, a 2:1 ratio of collector-filterers to collector-gatherers suggests abnormal turbidity, with an unusually high concentration of FPOM. Fu *et al.* (2014), Bhawsar *et al.* (2015) and Birara *et al.* (2020) discovered that streams with the same FFGs had similar land use patterns in their catchment areas.

Caution is advised when comparing FFGs at the same site over multiple years for several reasons. At the family level, there are often different FFGs within the same family, and at the species level, there may be different FFGs at different growth stages. In addition, data reporting changed in 2023 from having blanks for taxa where the FFG could not be specified, to having those taxa reported as "other", i.e., unclassified (S. Finlayson, pers. comm.). As a result, since 2023 the other category tends to be larger versus the previous years.

3.4.3.1 Functional Feeding Groups at Meadow and Margaret Creek Sites

The graphical illustration of the FFGs at MEA02 and MAR02 is presented in Figure 11. Almost half the specimens were unclassified at MEA02. Unclassified data usually results from a lack of information in reference materials on the taxa identified. Of the remaining 56%, collector-gatherers and predators dominated. No scrapers were observed. There were no collector-filterers at MAR02, where collector-gatherers were the most abundant.

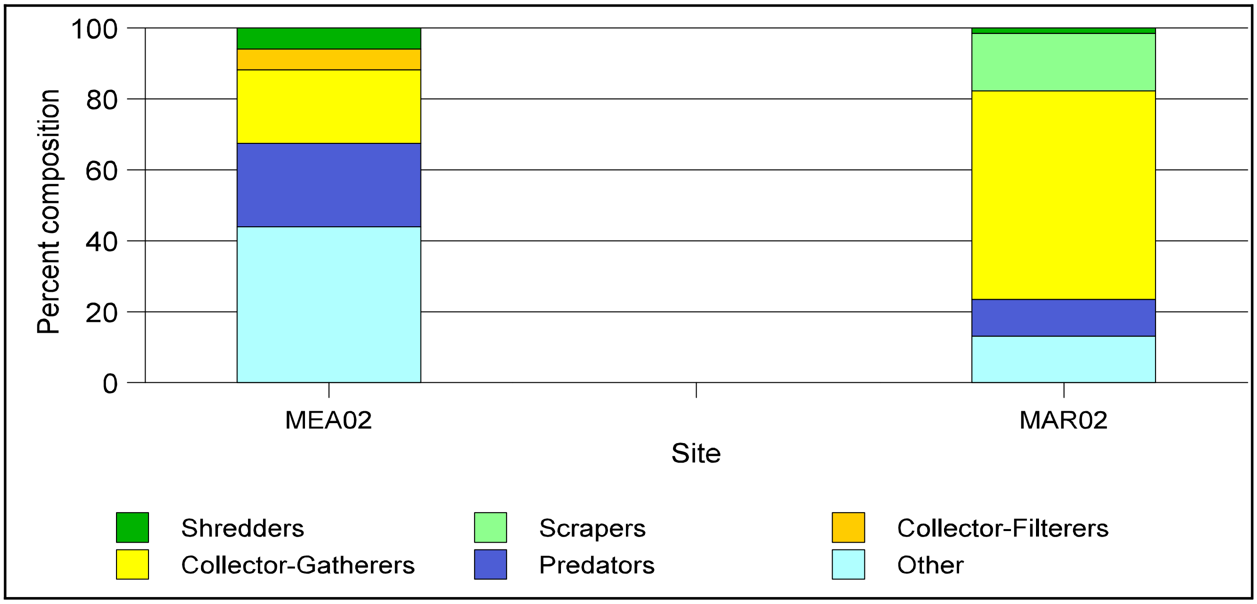


Figure 11. Percent of functional feeding groups at Meadow Creek and Margaret Creek.

3.4.3.2 Functional Feeding Groups at Aura Creek Site

The scrapers, which had been dominant over the previous three years at AUR01, were replaced by shredders in 2025 (Figure 12). There was also a marked increase in collector-filterers.

3.4.3.3 Functional Feeding Groups at Johnson Creek Sites

In the first two years of sampling at JOH01, collector-gatherers were prominent, suggesting greater sediment, but declined over the following two years. They again were dominant in 2025, however (Figure 13). There was also an increase in scrapers and a decline in shredders. Scrapers increased at JOH02 as well, dominating along with collector-gatherers (Figure 13).

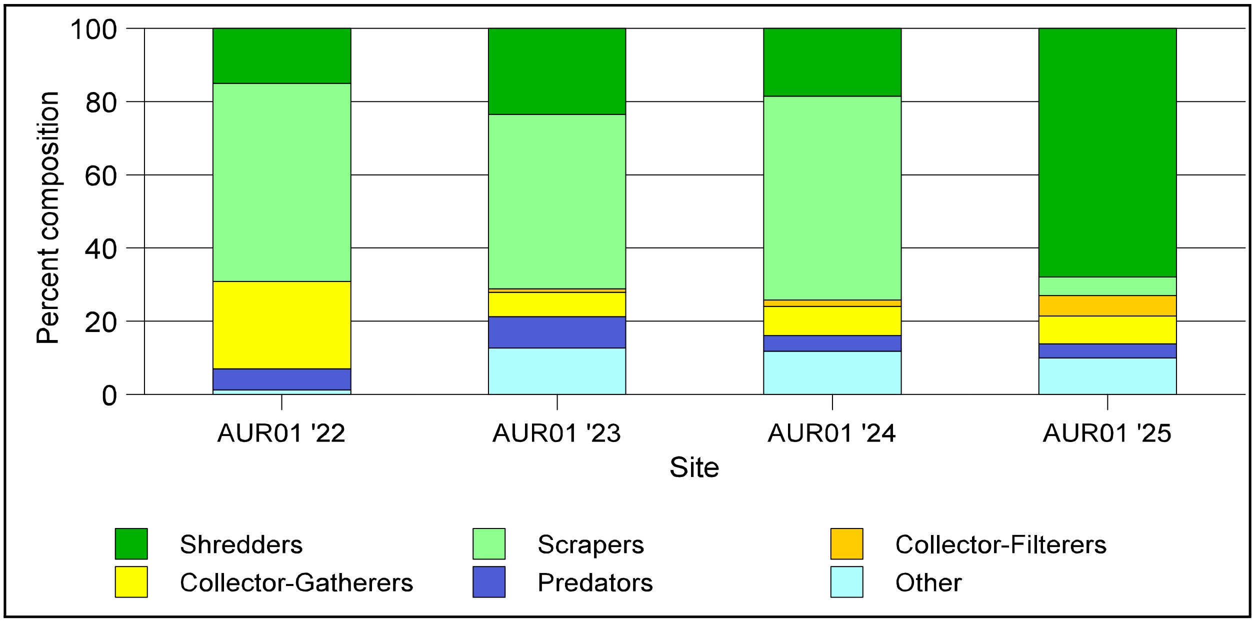


Figure 12. Percent of functional feeding groups at Aura Creek site from 2022 to 2025.

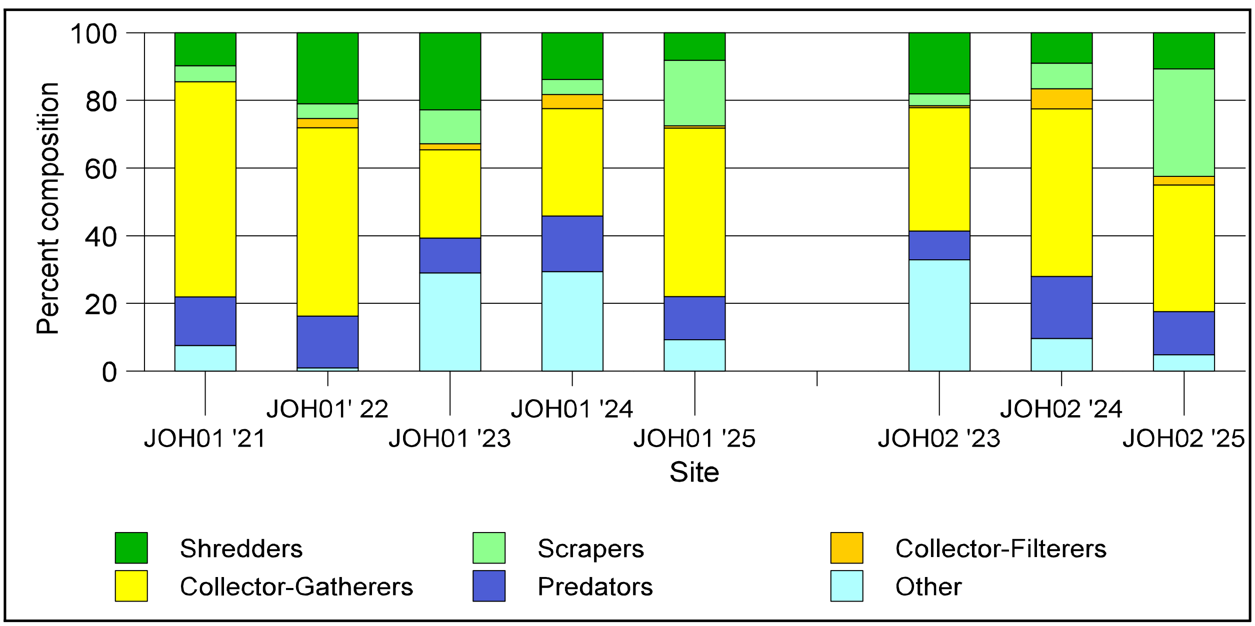


Figure 13. Percent of functional feeding groups at the Johnson Creek sites over the years of sampling.

3.4.3.4 Functional Feeding Groups at Waiparous Creek Sites

There was a significant decline in shredders at both WAP06 and WAP07 between the sampling dates of 2020 and 2025, and an increase in collector-gatherers at WAP06 (Figure 14). Scrapers were most abundant both years at WAP06. The percent of scrapers was much higher in 2025 versus 2020 at WAP07, whereas collector-gatherers and predators declined, along with shredders (Figure 14).

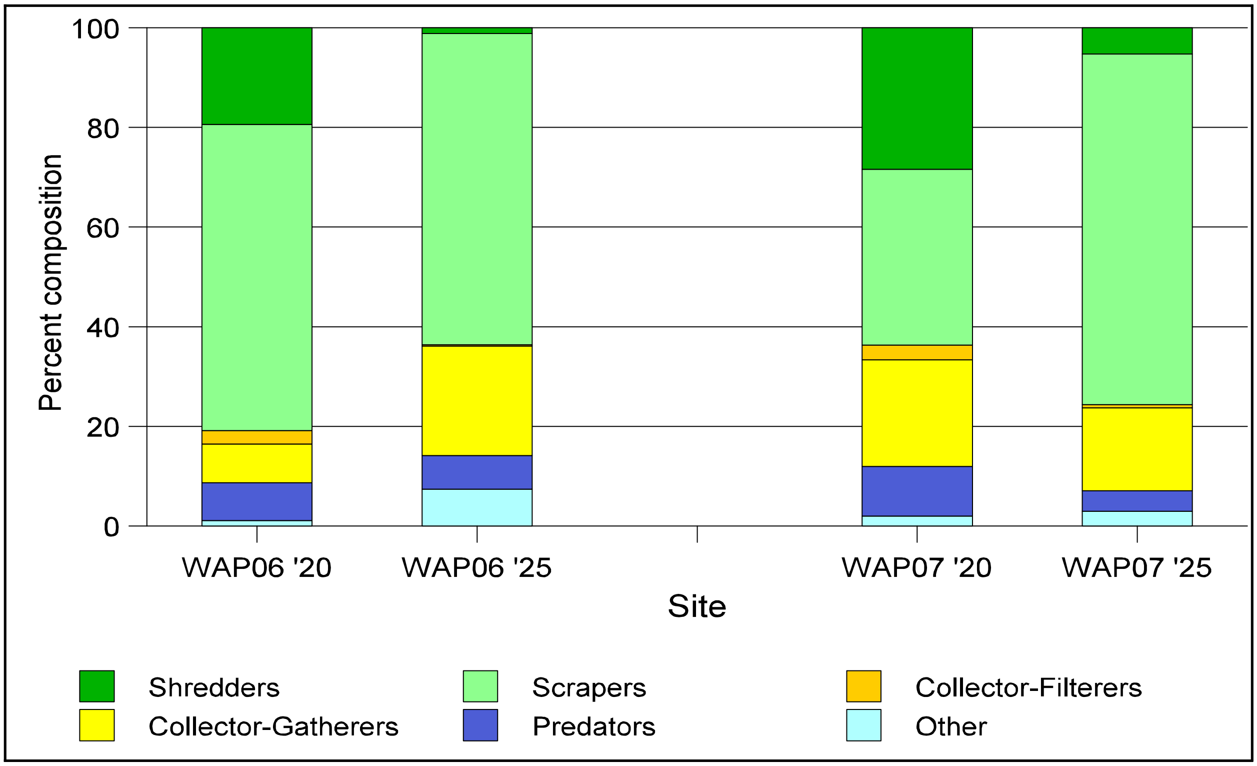


Figure 14. Percent of functional feeding groups at WAP06 and WAP07 in 2020 and 2025.

The six years of data at WAP02/02a and WAP03/03a show the variability in FFG communities over time (Figures 15 and 16). The scrapers at WAP02/02a have become the dominant FFG, whereas shredders and collector-gatherers have declined (Figure 15). There was a similar pattern at WAP03/03a (Figure 16).

At both sites, natural alterations in the stream channel were evident between successive years, which may have contributed to variations in the FFG composition. In addition, the human disturbance in the stream channel at and near WAP02/02a may have had an influence, as well as the fact that WAP02a is slightly upstream of WAP02. This variability probably has more impact on the benthic macroinvertebrate population trends and community shifts than any influence from Johnson Creek.

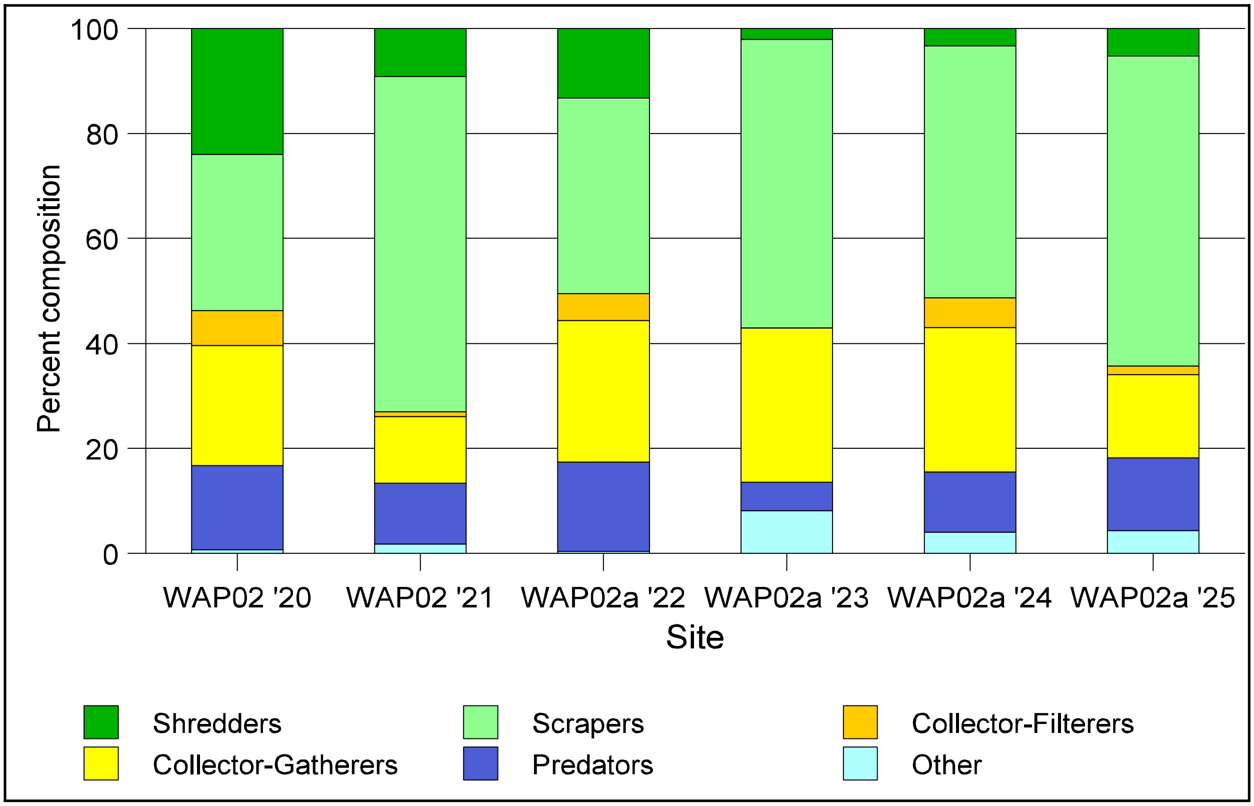


Figure 15. Percent of functional feeding groups at WAP02/WAP02a from 2020 to 2025.

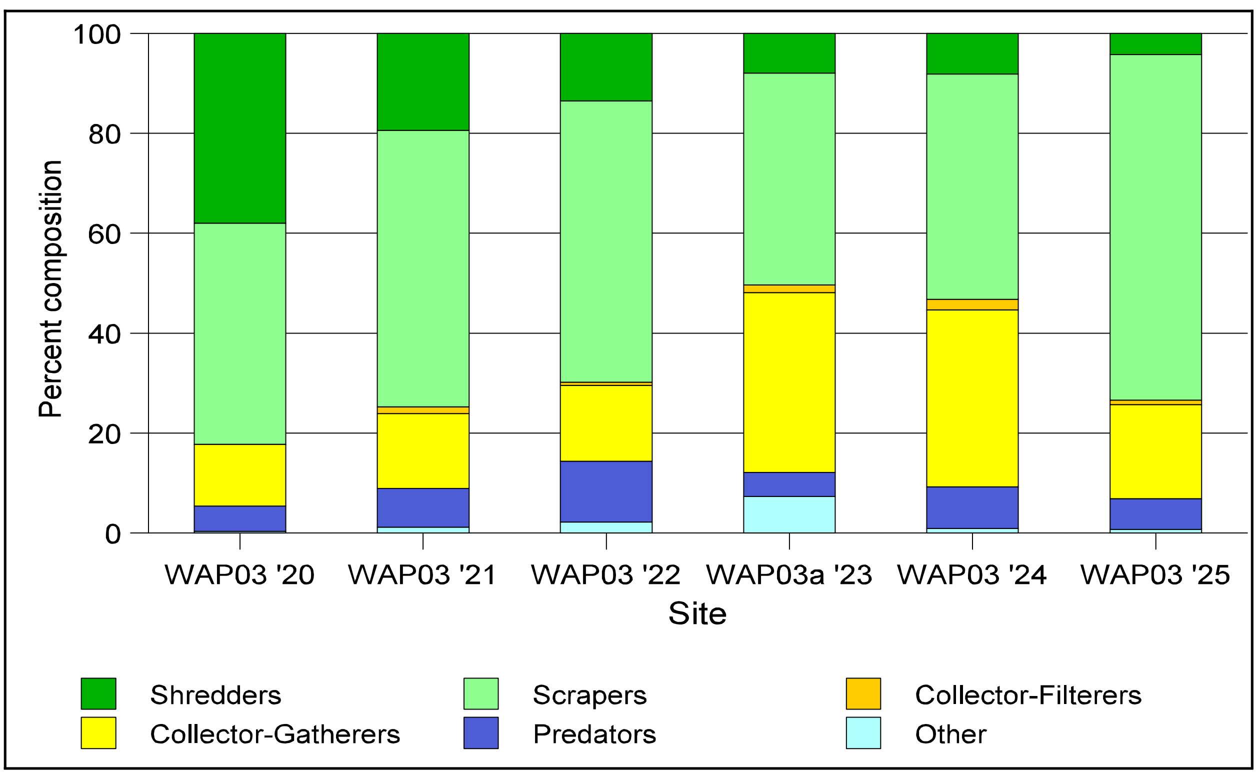


Figure 16. Percent of functional feeding groups at WAP03/WAP03a from 2020 to 2025.

3.4.3.5 Functional Feeding Groups at Ghost River Sites

Scrapers and collector-gatherers were most abundant at GHO03 in 2021 and GHO03a in 2025. At GHO05, all FFGs were more abundant in 2025 with the exception of the shredders. Scrapers were dominant both years.

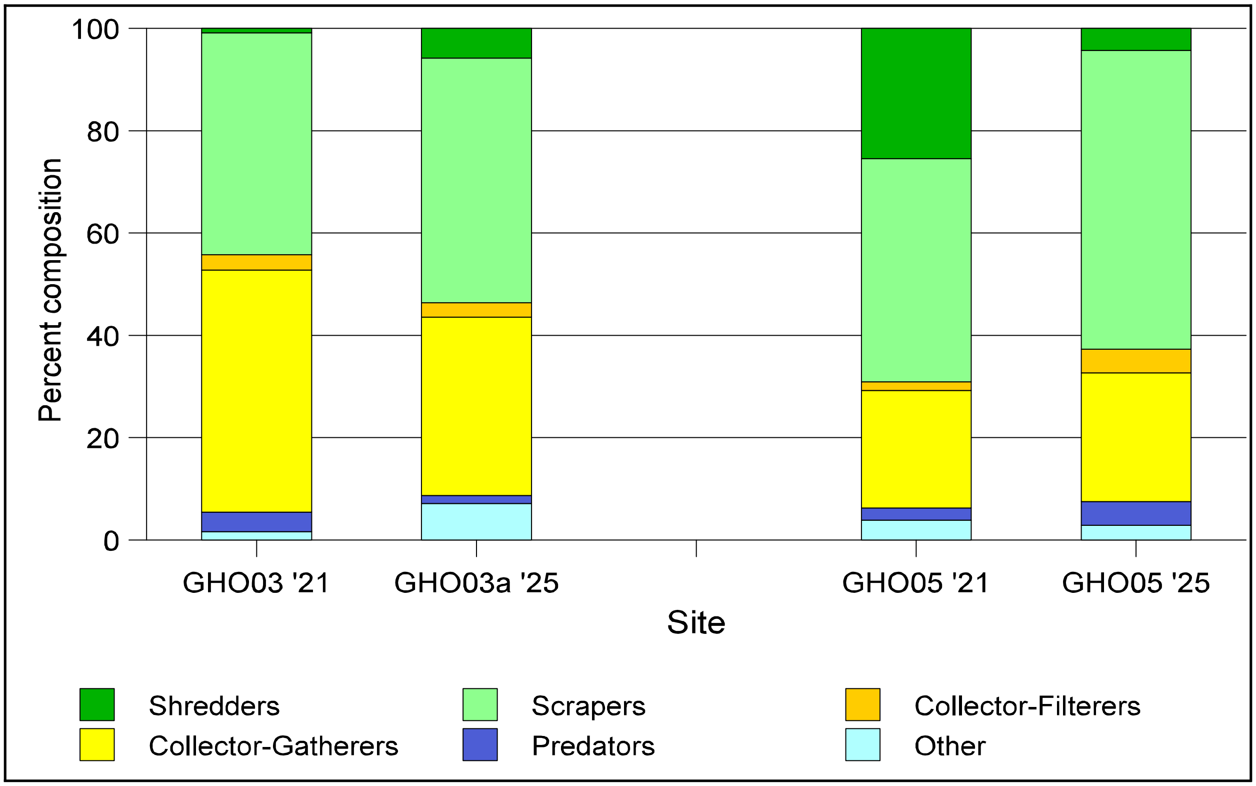


Figure 17. Percent of functional feeding groups at Ghost River sites in 2021 and 2025.

3.4.4 Hilsenhoff Biotic Index

The Hilsenhoff Biotic Index (HBI) estimates organic and nutrient enrichment or pollution, which cause lower dissolved oxygen levels (Hilsenhoff 1987). Tolerance values are assigned to each taxa at the genus/species level based on their response to low dissolved oxygen and hence organic pollution, and the average for all individuals in a sample is calculated. Index scores range from 0 to 10 (Table 19). Sensitive taxa have low scores and tolerant taxa (e.g., many chironomid species) have high scores, therefore an increase in the index suggests decreased water quality due to organic enrichment or pollution (Hilsenhoff 1987).

Table 19. Hilsenhoff Biotic Index (HBI) categories.

Biotic Index	Water Quality	Degree of Organic Pollution
0.00–3.50	Excellent	Organic pollution unlikely
3.51–4.50	Very Good	Possible slight organic pollution
4.51–5.50	Good	Some organic pollution probable
5.51–6.50	Fair	Fairly substantial pollution likely
6.51–7.50	Fairly Poor	Substantial pollution likely
7.51–8.50	Poor	Very substantial pollution likely
8.51–10.00	Very Poor	Severe organic pollution likely

The water quality at the majority of the sites was rated as excellent or very good, with possible slight organic enrichment or pollution (Figure 18). The exception was the Meadow Creek site which was rated as good, at 5.40, suggesting some organic enrichment or pollution is probable. Chironomid species were abundant at this site, with silt and sand partially covering the stream bed and forming the interstitial material. Fine substrates are likely to store more carbon and nutrient material naturally than streams with larger substrates (R. McAlpine, pers. comm.).

In previous years, sites WAP02/02a and WAP03/03a on Waiparous Creek were rated as excellent, but organic enrichment increased in 2023 and has remained at a higher level (Figure 16); however, it dropped to just within the threshold of the "excellent" category in 2025 (<3.5). In contrast, organic enrichment at the Aura Creek site has declined, resulting in a water quality rating of excellent in 2025. Water quality at WAP06, WAP07 and GHO05 was less in 2025 compared to the previous year sampled, but was the same at GHO03/03a.

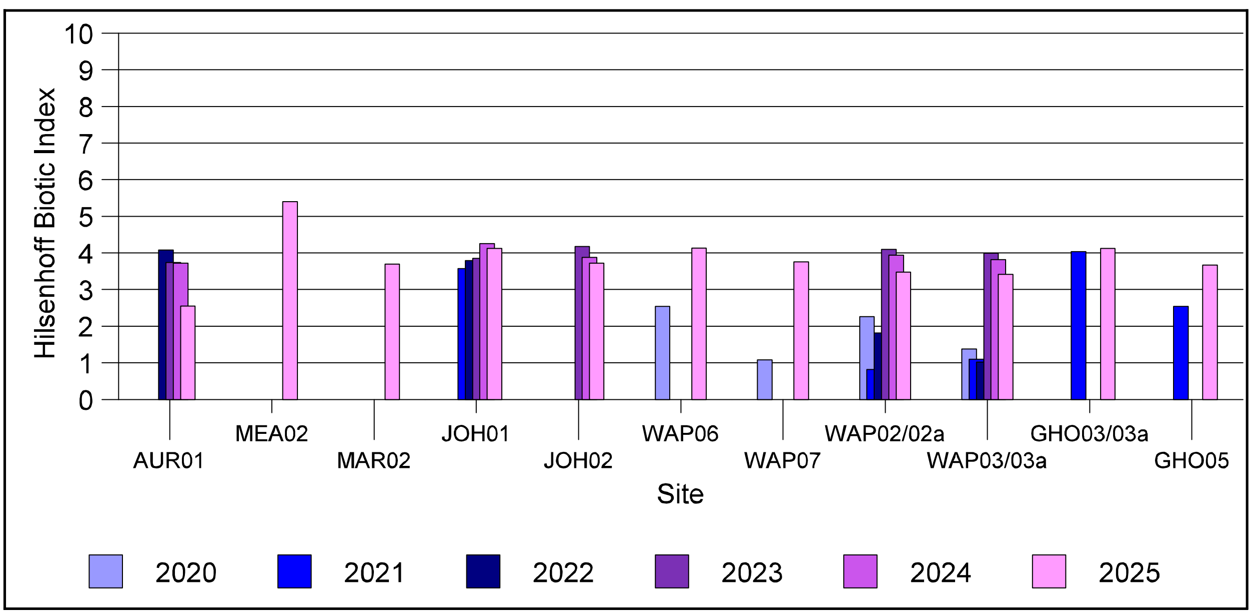


Figure 18. Hilsenhoff Biotic Index for each site.

4.0 Summary and Conclusions

4.1 Comparison of All Sites

The analyses of chemical and physical attributes of the water samples indicate high water quality at most of the eleven sites, where water quality parameters fell within acceptable limits for benthic macroinvertebrates and fish.

Johnson Creek may be affected by nutrient loading, which might have influenced the chemical attributes of Waiparous Creek below the confluence. The higher dissolved nitrogen and nitrate at WAP02/02a versus WAP03/03a possibly was a result of the even higher dissolved nitrogen and nitrate at JOH01, although this may be just natural variation.

The Hilsenhoff Biotic Index suggests high water quality at almost all sites with respect to organic enrichment or pollution. The Meadow Creek site, a potential reference site, rated slightly lower, as good quality, suggesting some organic enrichment or pollution is probable. Horse grazing is a land use in the area and could contribute towards organic pollution. In addition, silt and sand partially covered the stream bed, which are likely to store more carbon and nutrient material than larger substrates.

The Simpson's Index of Diversity and the Shannon-Wiener Index indicate that most sites were highly diverse in their benthic macroinvertebrate community composition, with the lowest diversity at AUR01.

The EPT ratio suggests high water quality at most of the sites, with EPT species in much greater abundance than the pollution-tolerant chironomid family. The exception was MEA02 where the ratio was 0.37, potentially raising concerns, although it could be habitat-related.

The more tolerant Hydropsychidae family within the order Trichoptera was found only at the two Ghost River sites. In contrast, the more tolerant Baetidae family within the order Ephemeroptera was identified at all sites, varying in abundance. Baetidae were lowest at WAP02a and WAP03, and highest at JOH01, followed by AUR01.

The proportion of FFGs varied among the sites, largely reflecting the habitat and adjacent riparian vegetation. Scrapers were dominant or prominent at the Waiparous Creek and Ghost River sites and at JOH02, suggesting more algae; collector-gatherers were dominant or prominent at MEA02, MAR02, GHO03a and the Johnson Creek sites, suggesting greater sediment; shredders were dominant at AUR01, suggesting greater leaf litter; and predators were prominant at MEA02.

4.2 Comparison Among Years of Aura Creek Site

The physical characteristics of AUR01 were not markedly different among years. However, TSS and turbidity have increased over the four years sampled, potentially raising concerns. In contrast, the Hilsenhoff Biotic Index has progressed from very good to excellent water quality in 2025.

Species diversity has remained similar among years and the EPT ratio has gradually increased, suggesting a healthy ecosystem. Hydropsychidae have been variable, either absent or relatively low in abundance. Baetidae had been relatively low, but rose to 44% of the Ephemeroptera in 2025. The proportion of FFGs differed among years, with scrapers dominating until 2025, when shredders became the dominant FFG.

4.3 Comparison Among Years of Johnson Creek Sites

Variations in the physical attributes of JOH01 tended to be relatively subtle among years. There were slight variations in physical and chemical attributes of the water samples, but all were within the guidelines. There has been a gradual increase in dissolved nitrogen and nitrate over the five years of sampling. The Hilsenhoff Biotic Index has varied little, remaining in the "very good" category indicating possible slight organic enrichment or pollution.

Diversity indices indicate highly diverse community composition in all five years. The EPT ratio had been lower than most sites, but increased markedly in 2025 to 0.89. The percent of Hydropsychidae within the Trichoptera was initially variable, but Hydropsychidae were absent in the last two years. In contrast, the percent of Baetidae within the Ephemeroptera increased in 2024 and remained high in 2025. The proportion of FFGs differed among years, but collector-gatherers have remained prominent. Shredders were co-dominant in 2023 but have since declined.

Average velocity at JOH02 has declined over the three years of sampling. There were slight variations in the physical and chemical attributes of the water samples. TKN was over five times greater in 2025, with a corresponding increase in dissolved nitrogen. This could be related to the high cattle use of the riparian area. The Hilsenhoff Biotic Index has declined slightly over the three years of sampling but continues to rate very good.

As with JOH01, diversity indices indicate highly diverse community composition in all five years. The EPT ratio increased at JOH02 from 2023 to 2025, from 0.59 to 0.94. Hydropsychidae were present in 2023 but absent in 2024 and 2025. The percent of Baetidae within the Ephemeroptera has declined. Of the FFGs, collector-gatherers remained prominent, but scrapers were co-dominant in 2025.

In 2025, health indicators no longer suggested concerns with water quality at JOH01 and JOH02. Further monitoring due to the initial concerns may no longer be necessary.

4.4 Comparison Among Years of Waiparous Creek Sites

4.4.1 WAP06 and WAP07

In 2025, the particle size was larger at WAP06 versus 2020, with a greater number of cobble-size stones versus pebble-size. At WAP07, embeddedness had declined and the dominant substrate size was greater, although the mean particle size was similar.

Alkalinity, carbonates and dissolved nitrogen were higher at both sites in 2025. The magnitude of increase in dissolved nitrogen was slightly higher at the upstream site of WAP07. There was little difference in the other physical and chemical attributes of the water samples. Based on the Hilsenhoff Biotic Index, water quality declined from excellent to very good at both sites.

Benthic macroinvertebrate populations have been moderately to highly diverse in the years sampled. The EPT ratio has remained high at both sites. Hydropsychidae were present in 2020 but absent in 2025. Baetidae were present both years, but formed a relatively low percent of the total Ephemeroptera.

Of the FFGs, scrapers dominated at WAP06, with shredders next in abundance in 2020 and collector-gatherers next in abundance in 2025. At WAP07, shredders, collector-gatherers and scrapers were similar in abundance in 2020, but scrapers became dominant in 2025.

Despite increased use of the cadet camp in the summer of 2025, there was no evidence of increased pollution downstream of the wastewater lagoon. Therefore, no further sampling appears to be warranted.

4.4.2 WAP02/02a and WAP03/03a

The physical characteristics varied among years at WAP02/02a and WAP03/03a largely as a result of natural variability in the stream channel from fluvial events, and, in the case of WAP02/02a, human alteration of the stream channel. Average velocity at WAP02a over the years appears to be related to the human-made rock dams upstream, declining again in 2025 when there was one full rock dam across the creek compared to 2024 when there was not. The decline in velocity did not result in a smaller mean particle size, however. There was also a decline in velocity at WAP03 in 2025.

There were slight variations in physical and chemical attributes of the water samples, but all were within the guidelines. The Hilsenhoff Biotic Index had consistently been in the “excellent” category at both sites, indicating organic enrichment or pollution was unlikely, but dropped to the “very good” category in 2023, suggesting possible slight organic enrichment. In 2025, it again was rated excellent at both sites.

The diversity indices indicate high diversity in benthic macroinvertebrates over most of the six years of sampling. The EPT ratio also has been high, suggesting good water quality. The percent of Hydropsychidae within the Trichoptera and the percent of Baetidae within the Ephemeroptera has been variable at both sites.

The proportion of FFGs varied among the years. At WAP02/02a, there was a notable decline in shredders over the six years, and scrapers remained prominent. The other FFGs have cycled up and down. At WAP03/03a, the shredders have declined and scrapers have remained prominent, dominating in 2025. Collector-gatherers were co-dominants in 2023 and 2024, but declined in 2025. The variation in the stream channels may explain these differences.

4.5 Comparison Among Years of Ghost River Sites

The site sampled upstream of Richards Road (GHO03/03a) was in a slightly different location in each of the years sampled, which contributed to different physical characteristics.
Physical and chemical attributes of the water samples varied slightly, but no concerns were suggested. The higher concentrations of dissolved nitrogen and nitrate in 2025 could be attributed to 2020 wildfire upstream. The Hilsenhoff Biotic Index indicated very good water quality in both years.

Between the four years of sampling GHO05, pebble-size substrate decreased in size and cobble-size substrate increased, with less embeddedness. Physical and chemical attributes of the water samples differed to varying degrees. Most notable was the level of nitrate which was almost two times higher in 2025 compared to 2021, again possibly due to the 2020 wildfire. The reported concentrations of dissolved nitrogen and TKN were considered to be extreme outliers and were omitted from the data. Water quality decreased according to the Hilsenhoff Biotic Index, from excellent to very good.

The populations were highly diverse at both sites in each of the years sampled, and the EPT ratio was high. The percent of Hydropsychidae within Trichoptera was substantially higher in 2025 compared to 2021. The same was true of Baetidae at GHO05, but at GHO03/03a, the percent was less.

Of the FFGs, scrapers and collector-gatherers were co-dominants at GHO03/03a in both years sampled. At GHO05, scrapers were most abundant both years and all FFGs were more abundant in 2025 versus 2021 with the exception of the shredders.

4.6 Reference Sites

As a potential reference site, MEA02 was the farthest upstream location as possible on Meadow Creek that could be sampled using CABiN methods. The headwaters of the creek do not have a defined stream channel. Instead, the creek originates from a shrubby wetland complex. It forms a defined stream channel through the horse camp, which was immediately upstream of MEA02. As such, the site was not an ideal reference site due to the upstream human activity. However, compromises are needed when pristine sites are not available. The site differed somewhat from other sites sampled over the course of the CABiN project, with a significant amount of silt and sand on the stream bed, possibly resulting in the high chironomid population. It also would not experience flooding to the same degree as many downstream locations, with the buffering effect of the adjacent shrubby wetland. However, there may be other similar sites in adjacent eastern slopes watersheds. If so, it may still provide a valuable data point for the reference model.

MAR02 was the highest upstream site on Margaret Creek that could be accessed easily using ordinary 4x4 vehicles. An OHV trail crossed the creek over 2 km upstream of the site, and another approximately 5 km upstream, but there was a bridge over the creek in both instances, therefore less impact than would be the case otherwise. As a potential reference site, MAR02 also is not ideal with respect to pristine conditions, but is the best available site.

5.0 General Recommendations

- Adequate annual funding for this program should be maintained.

- The *GWAS Water Monitoring Program Plan* should continue to be followed, allowing flexibility if circumstances materialize that suggest a deviation.

- Further sampling should occur at AUR01 to monitor the levels of TSS and turbidity.

- Consideration could be given to taking water samples at GHO05 to obtain accurate data on nitrogen concentrations. (It is not necessary to conduct further sampling of the benthic macroinvertebrates at GHO05.)

- In future water sampling, ammonia should be added to the chemistry panel as a chemical to measure. In the case of elevated nitrogen concentrations, this would provide information on the contribution of total organic nitrogen versus inorganic nitrogen within the TKN.

- If possible, at least one additional site on Johnson Creek above JOH02 would help to determine the health of the creek, above all/most OHV activity and livestock use.

- The sites sampled from 2020 to 2025 should be monitored as frequently as possible, as funds will allow and as personnel are available, giving priority to sites where water quality may be more comprised. (If monitoring in successive years, three years may be considered adequate, but CABiN does not specify a frequency.)

- Consideration should be given to using drone technology as a tool for stream reconnaissance to view upstream reaches that are not easily accessed by foot or vehicle.

- Prior to conducting the field sampling, the survey team should read and fully understand the methodology presented in the *CABiN Field Manual – Wadeable Streams*.

- A practice run through all of the methods should be conducted prior to data collection.

- Certain tasks, such as kicknetting, should only be conducted by qualified personnel, whereas other tasks may be done by volunteers who have been trained by the CABiN-certified personnel or previously trained volunteers. Because not all of the trained volunteers may be present on each field day, volunteers should be encouraged to try different tasks to become familiar with them in case they are required to perform them at some time.

- During the sampling, the field team must adhere to the proper procedures and order of tasks to maintain quality assurance/quality control (QA/QC) of each sample.

- To maintain consistency, the same laboratories that were originally selected and used from 2020 to 2025 (water chemical and benthic macroinvertebrate analysis) should continue to be used.

6.0 Literature Cited

ALCES and GWAS (ALCES Landscape and Land-use Ltd. and Ghost Watershed Alliance Society). 2018. Ghost River State of the Watershed Report 2018. ALCES Landscape and Land-use Ltd., Calgary and Ghost Watershed Alliance Society, Cochrane, Alberta. 197 p.

Alberta Environmental Protection. 1997. Alberta Water Quality Guideline for the Protection of Freshwater Aquatic Life – Dissolved Oxygen. Standards and Guidelines Branch, Environmental Assessment Division, Environmental Regulatory Service, Edmonton. Pub. No.:T/391. 73 p. https://open.alberta.ca/dataset/82793404-d376-4b9e-a399-94da6e279b0a/resource/f223f816-1268-4f4e-9698-78824bb8a5fe/download/7254.pdf (Accessed March 31, 2026)

Barbour, M.T., J. Gerritsen, B.D. Snyder and J.B. Stribling. 1999. Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates, and Fish. Second Edition. U.S. Environmental Protection Agency, Office of Water, Washington, DC. EPA 841-B-99-002. https://www.epa.gov/sites/production/files/2019-02/documents/rapid-bioassessment-streams-rivers-1999.pdf (Accessed March 31, 2026)

Bhawsar, A., M. A. Bhat and V. Vyas. 2015. Distribution and composition of macroinvertebrates functional feeding groups with reference to catchment area in Barna Sub-Basin of Narmada River Basin. International Journal of Scientific Research in Environmental Sciences 3:385-393. https://www.researchgate.net/publication/283482853_Distribution_and_Composition_of_Macroinvertebrates_Functional_Feeding_Groups_With_Reference_to_Catchment_Area_In_Barna_Sub-Basin_of_Narmada_River_Basin (Accessed March 31, 2026)

Biota Consultants. 2022a. Ghost Watershed Water Monitoring Program CABiN/STREAM Project 2020. Report to Ghost Watershed Alliance Society, Cochrane, Alberta. 68 pp.

Biota Consultants. 2022b. Ghost Watershed Water Monitoring Program CABiN/STREAM Project 2021. Report to Ghost Watershed Alliance Society, Cochrane, Alberta. 64 pp.

Biota Consultants. 2023. Ghost Watershed Water Monitoring Program CABiN/STREAM Project 2022. Report to Ghost Watershed Alliance Society, Cochrane, Alberta. 64 pp.

Biota Consultants. 2024. Ghost Watershed Water Monitoring Program CABiN/STREAM Project 2023. Report to Ghost Watershed Alliance Society, Cochrane, Alberta. 74 pp.

Biota Consultants. 2025. Ghost Watershed Water Monitoring Program CABiN/STREAM Project 2024. Report to Ghost Watershed Alliance Society, Cochrane, Alberta. 71 pp.

Birara, M., S. Agembe, K. Kiptum and M. Mingist. 2020. Distribution and composition of benthic macroinvertebrates functional feeding groups and ecosystem attributes under different land use patterns in Kipsinende River, Kenya. International Journal of Fisheries and Aquatic Studies. 8:112-119. https://www.researchgate.net/publication/344253528_Distribution_and_composition_of_benthic_macroinvertebrates_functional_feeding_groups_and_ecosystem_attributes_under_different_land_use_patterns_in_Kipsinende_River_Kenya (Accessed March 31, 2026)

Bladon, K.D., U. Silins, M.J. Wagner, M. Stone, M.B. Emelko, C.A. Mdenoza, K.J. Devito and S. Boon. 2008. Wildfire impacts on nitrogen concentration and production from headwater streams in southern Alberta's Rocky Mountains. Can. J. For. Res. 38:2359-2371.

Brucker, K.P., B. Livneh, F. L. Rosario-Ortiz, F. Yao, A.P. Williams, W. C. Becker, S. K. Kampf and B. Rajagopalan. 2025. Wildfires drive multi-year water quality degradation over the western United States. Communications Earth & Environment 6:489.

CCME (Canadian Council of Ministers of the Environment). 1999. Canadian Environmental Quality Guidelines. Canadian Council of Ministers of the Environment, Winnipeg, Manitoba. 2005 - Update 5.0. Publication No. 1299.

CCME (Canadian Council of Ministers of the Environment). 2008. Canadian Water Quality Guidelines. Prepared by the Task Force on Water Quality Guidelines of the Canadian Council of Ministers of the Environment. https://www.ccme.ca/files/Resources/supporting_scientific_documents/cwqg_pn_1040.pdf (Accessed March 10, 2021)

Casiday, R. and R. Frey. 1998. Water Hardness: Inorganic Reactions Experiment. Department of Chemistry, Washington University, Missouri. http://www.chemistry.wustl.edu/~edudev/LabTutorials/Water/FreshWater/hardness.html (Accessed May 9, 2021)

Clean Water Team. 2004. Electrical Conductivity/salinity Fact Sheet. FS-3.1.3.0(EC). in: The Clean Water Team Guidance Compendium for Watershed Monitoring and Assessment, Version 2.0. Division of Water Quality, California State Water Resources Control Board (SWRCB), Sacramento, California. https://www.waterboards.ca.gov/water_issues//programs/swamp/docs/cwt/guidance/3130en.pdf (Accessed March 31, 2026)

Cummins, K. W. 1973. Trophic relations of aquatic insects. Annual Review of Entomology 18:183–206. https://sci-hub.se/10.1146/annurev.en.18.010173.001151 (Accessed March 31, 2024)

Cummins, K. W. 2021. The use of macroinvertebrate functional feeding group analysis to evaluate, monitor and restore stream ecosystem condition. Rep. Glob. Health Res. 4: 129. https://www.gavinpublishers.com/article/view/the-use-of-macroinvertebrate-functional-feeding-group-analysis-to-evaluate-monitor-and-restore-stream-ecosystem-condition (Accessed March 31, 2026)

Cummins, K.W. and M.J. Klug. 1979. Feeding ecology of stream invertebrates. Annual Review of Ecology and Systematics 10:147-172.

Ecological Stratification Working Group. 1995. A National Ecological Framework for Canada. Agriculture and Agri-Food Canada, Research Branch, Centre for Land and Biological Resources Research and Environment Canada, State of the Environment Directorate, Ecozone Analysis Branch, Ottawa/Hull, Ontario. Map https://sis.agr.gc.ca/cansis/publications/maps/eco/all/regions/eco_all_regions_7m_canada_en.jpg (accessed March 31, 2026)

Environment Canada. 2012. Canadian Aquatic Biomonitoring Network Field Manual – Wadeable Streams. Cat. No: En84-87/2012E-PDF. 57 p.

FEI (Fondriest Environmental, Inc.). 2013. Dissolved Oxygen. Fundamentals of Environmental Measurements. 19 Nov. 2013. https://www.fondriest.com/environmental-measurements/parameters/water-quality/dissolved-oxygen/ (Accessed March 31, 2026)

FEI (Fondriest Environmental, Inc.). 2014a. Conductivity, Salinity and Total Dissolved Solids. Fundamentals of Environmental Measurements. 3 March 2014. https://www.fondriest.com/environmental-measurements/parameters/water-quality/conductivity-salinity-tds/ (Accessed March 31, 2026)

FEI (Fondriest Environmental, Inc.). 2014b. Turbidity, Total Suspended Solids and Water Clarity. Fundamentals of Environmental Measurements. 13 June 2014. https://www.fondriest.com/environmental-measurements/parameters/water-quality/turbidity-total-suspended-solids-water-clarity/ (Accessed March 31, 2026)

Fu, L., Jiang, Y., J. Ding, Q. Liu, Q. Peng and M. Kang. 2016. Impacts of land use and environmental factors on macroinvertebrate functional feeding groups in the Dongjiang River basin, southeast China. Journal of Freshwater Ecology. 31:21-35. https://www.tandfonline.com/doi/full/10.1080/02705060.2015.1017847 (Accessed March 31, 2026)

Government of Alberta. 2018. Environmental Quality Guidelines for Alberta Surface Waters. Water Policy Branch, Alberta Environment and Parks. Edmonton, Alberta. AEP, Water Policy, 2014, No. 1. 53 p. https://open.alberta.ca/dataset/5298aadb-f5cc-4160-8620-ad139bb985d8/resource/38ed9bb1-233f-4e28-b344-808670b20dae/download/environmentalqualitysurfacewaters-mar28-2018.pdf (Accessed March 31, 2026)

Hauer, F.R. and C.N. Spencer. 1998. Phosphorus and nitrogen dynamics in streams associated with wildfire: A study of immediate and longterm effects. Int. J. Wildland Fire 814:183-198.

Hilsenhoff, W. L. 1987. An improved biotic index of organic stream pollution. The Great Lakes Entomologist 20:31-39.

LCRA (Lower Colorado River Authority). 2014. Water Quality Indicators. https://www.lcra.org/water/quality/colorado-river-watch-network/water-quality-indicators/ (Accessed on March 31, 2026)

Miller, R. L., W. L. Bradford and N. E. Peters. 1988. Specific conductance: Theoretical considerations and application to analytical quality control. U.S. Geological Survey Water-Supply Paper 2311. 16 p. http://pubs.usgs.gov/wsp/2311/report.pdf (Accessed March 31, 2026)

Min, J., Y. Kim and D. Kong. 2019. Spatial distribution patterns of benthic macroinvertebrate functional feeding groups by stream size and gradient in Republic of Korea. Journal of Freshwater Ecology 34:715-738. https://www.tandfonline.com/doi/full/10.1080/02705060.2019.1677793 (Accessed March 31, 2026)

Murphy, S. 2007. General Information on Solids. USGS Water Quality Monitoring. Boulder, Colorado. http://bcn.boulder.co.us/basin/data/NEW/info/TSS.html (Accessed March 31, 2026)

Rhoades, C., S. Miller, T. Corvino, A. Chow and F. McCormick. 2017. Stream water quality concerns linger long after the smoke clears: Learning from front range wildfires. Colorado Water. March/April 2017: 22-26.

Sinnatamby, N. and K. Sanderson. 2024. Technical Report for CABIN Reference Site Selection for the Alberta East Slopes. Unpublished document prepared for Oldman Watershed Council. Miistakis Institute, Mount Royal Univeristy, Calgary, Alberta. 16 pp.

USGS (United States Geological Survey) Water Science School. 2018a. Hardness of Water. https://www.usgs.gov/special-topic/water-science-school/science/hardness-water?qt-science_center_objects=0#qt-science_center_objects (Accessed March 31, 2026).

USGS (United States Geological Survey) Water Science School. 2018b. Turbidity and Water. https://www.usgs.gov/special-topics/water-science-school/science/turbidity-and-water (Accessed March 31, 2026).

Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell and C. E. Cushing. 1980. The river continuum concept. Can. J. Fish. Aquat. Sci. 37:130-137. https://vdocument.in/download/vannote-1980.html (Accessed March 31, 2023)

7.0 Personal Communications

Finlayson, Scott	President and Head Taxonomist, Cordillera Consulting Inc., Summerland, BC.
Martens, Adam	CABIN Taxonomist, Fresh Water Quality Monitoring and Surveillance – Pacific & Athabasca-Arctic Watershed, Environment and Climate Change Canada, Government of Canada, Vancouver, BC.
McAlpine, Robert	Limnologist and Water Quality Specialist, W.Q. Consulting Services Ltd., Calgary, Alberta.
Munter, Karoliina	Senior Aquatic Biologist, Avanti Environmental Consulting Ltd., Calgary, Alberta.

Appendix A
CABiN Field Sheet

Field Crew: ____________________ Site Code: ____________

Sampling Date (DD/MM/YYYY): ____________________

☐ **Occupational Health & Safety: Site Inspection Sheet completed (see page 6)**

PRIMARY SITE DATA

CABIN Study Name: ____________________ Local Basin Name: ____________________

River/Stream Name: ____________________ Stream Order: (map scale 1:50,000) ____________

Select one: ☐ Test Site ☐ Potential Reference Site

Geographical Description/Notes:

Surrounding Land Use: (check those present) Information Source: ____________

☐ Forest ☐ Field/Pasture ☐ Agriculture ☐ Residential/Urban

☐ Logging ☐ Mining ☐ Commercial/Industrial ☐ Other ________

Dominant Surrounding Land Use: (check one) Information Source: ____________

☐ Forest ☐ Field/Pasture ☐ Agriculture ☐ Residential/Urban

☐ Logging ☐ Mining ☐ Commercial/Industrial ☐ Other ________

Location Data

Latitude: __________N Longitude: - __________W (DMS or DD)

Elevation: ______(fasl *or* masl) GPS Datum: ☐ GRS80 (NAD83/WGS84) ☐ Other: ______

Site Location Map Drawing

Note: Indicate north

Field Crew: ______________________________ Site Code: ______________

Sampling Date (DD/MM/YYYY): ____________________

Photos

☐ Field Sheet ☐ Upstream ☐ Downstream ☐ Across Site ☐ Aerial View

☐ Substrate (exposed) ☐ Substrate (aquatic) ☐ Other ____________________

REACH DATA *(represents 6 times bankfull width)*

1. Habitat Types: *(check those present)*

   ☐ Riffle ☐ Rapids ☐ Straight run ☐ Pool/Back Eddy

2. Canopy Coverage: *(stand in middle of stream and look up, check one)*

   ☐ 0 % ☐ 1-25 % ☐ 26-50 % ☐ 51-75 % ☐ 76-100 %

3. Macrophyte Coverage: *(not algae or moss, check one)*

   ☐ 0 % ☐ 1-25 % ☐ 26-50 % ☐ 51-75 % ☐ 76-100 %

4. Streamside Vegetation: (*check those present)*

   ☐ ferns/grasses ☐ shrubs ☐ deciduous trees ☐ coniferous trees

5. Dominant Streamside Vegetation: *(check one)*

   ☐ ferns/grasses ☐ shrubs ☐ deciduous trees ☐ coniferous trees

6. Periphyton Coverage on Substrate: *(benthic algae, not moss, check one*)

   ☐ **1 -** Thin layer, no obvious colour (< 0.5 mm thick)

   ☐ **2** - Yellow-brown to light green colour (0.5-1 mm thick)

   ☐ **3** - Patches of thicker green to brown algae (1-5 mm thick)

   ☐ **4** - Numerous large clumps of green to dark brown algae (5-20 mm thick)

   ☐ **5** - Rocks are mostly obscured by algal mat, extensive green, brown to black algal mass may have long strands (> 20 mm thick)

Note: 1 through 5 represent categories entered into the CABIN database.

BENTHIC MACROINVERTEBRATE DATA

Habitat sampled (*check one*): ☐ riffle ☐ rapids ☐ straight run

400 µm mesh Kick Net *	
Person sampling	
Sampling time (i.e. 3 min.)	
No. of sample jars	
Typical depth in kick area (cm)	

Preservative used: ______________

Sampled sieved on site using the "Bucket Swirling Method":

☐ YES ☐ NO

If YES, debris collected for QA/QC ☐

***** Note: Indicate if a sampling method other than the recommended 400 µm mesh kick net is used.

Field Crew: ______________________________________ Site Code: ________________

Sampling Date (DD/MM/YYYY): _________________________

WATER CHEMISTRY DATA **Time:**__________ (24 hr clock) **Time zone**: ______________

Air Temp: _______________(ºC) Water Temp: __________(ºC) pH: ______________

Specific Conductance: ________(µs/cm) DO: _________(mg/L) Turbidity: ________(NTU)

Check if water samples were collected for the following analyses:

☐ TSS (Total Suspended Solids)

☐ Nitrogen (i.e. Total, Nitrate, Nitrite, Dissolved, and/or Ammonia)

☐ Phosphorus (Total, Ortho, and/or Dissolved)

☐ Major Ions (i.e. Alkalinity, Hardness, Chloride, and/or Sulphate) ☐ Other________________

Note: Determining alkalinity is recommended, as are other analyses, but not required for CABIN assessments.

CHANNEL DATA

Slope - Indicate how slope was measured: (check one)

☐ **Calculated from map**

Scale: ______________ (Note: small scale map recommended if field measurement is not possible - i.e. 1:20,000).

contour interval (vertical distance) __________ (m),

distance between contour intervals (horizontal distance) __________ (m)

slope = vertical distance/horizontal distance =_______________

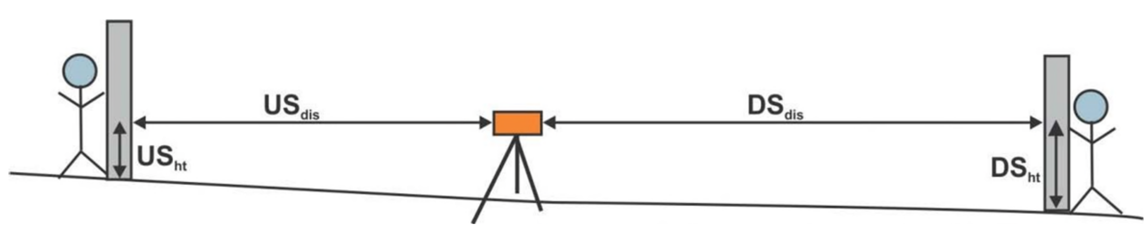
OR

☐ **Measured in field**

Circle device used and fill out table according to device:

a. Survey Equipment b. Hand Level & Measuring Tape

Measurements	Upstream (U/S)	Downstream(D/S)	Calculation
[a]Top Hairline (T)			
[a]Mid Hairline (ht) OR [b]Height of rod			
[a]Bottom Hairline (B)			
[b]Distance (dis) OR [a]T-B x 100	aUS_{dis}=T-B	aDS_{dis}=T-B	US_{dis}+DS_{dis}=
Change in height (Δht)			DS_{ht}-US_{ht}=
Slope (Δht/total dis)			



Field Crew: ______________________________ Site Code: ______________

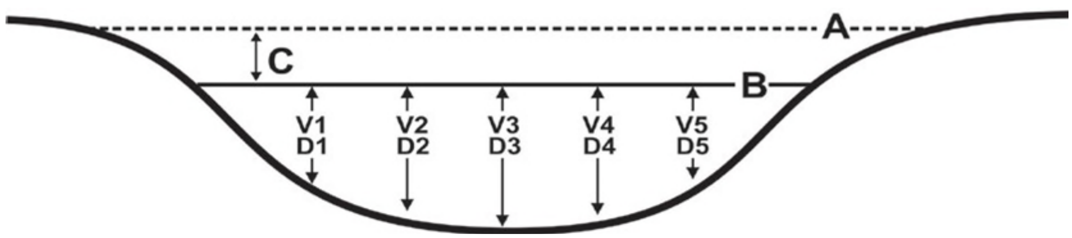
Sampling Date (DD/MM/YYYY): ____________________

Widths and Depth

Location at site: ______________________ (Indicate where in sample reach, ex. d/s of kick area)

A - Bankfull Width: ________ (m) B - Wetted Stream Width: _________ (m)

C - Bankfull–Wetted Depth (height from water surface to Bankfull): ________________ (cm)



Note:
Wetted widths > 5 m, measure a minimum of 5-6 equidistant locations.
Wetted widths < 5 m, measure 3-4 equidistant locations.

Velocity and Depth

Check appropriate velocity measuring device and fill out the appropriate section in chart below. Distance from shore and depth are required regardless of method:

☐ **Velocity Head Rod (or ruler)**: Velocity Equation (m/s) = √ [2(∆D/100) * 9.81]

☐ **Rotary meters**: Gurley/Price/Mini-Price/Propeller (Refer to specific meter conversion chart for calculation)

☐ **Direct velocity measurements**: ☐ Marsh-McBirney ☐ Sontek or ☐ Other____________

	1	2	3	4	5	6	AVG
Distance from Shore (m)							
Depth (**D**) (cm)							
Velocity Head Rod (ruler)							
Flowing water Depth (**D_1**) (cm)							
Depth of Stagnation (**D_2**) (cm)							
Change in depth (**$\Delta D = D_2 - D_1$**) (cm)							
Rotary meter							
Revolutions							
Time (minimum 40 seconds)							
Direct Measurement or calculation							
Velocity (**V**) (m/s)							

Field Crew: ______________________________ Site Code: ______________

Sampling Date (DD/MM/YYYY): ______________________

SUBSTRATE DATA

1. 100 Pebble Count & Substrate Embeddedness

- Measure the intermediate axis (100 rocks) and embeddedness (10 rocks) of substrate in the stream bed.
- Indicate **B** for bedrock, **S** for sand/silt/clay (particles < 0.2 cm) and **O** for organic material.
- Embededness categories (**E**):
  - Completely embedded = 1
  - 75% embedded = ¾
  - 50% embedded= ½
  - 25% embedded = ¼
  - Unembedded = 0

2. Surrounding/Interstitial Material

Circle the substrate size category for the surrounding material.

Substrate Size Class	Category
Organic Cover	0
< 0.1 cm (fine sand, silt or clay)	1
0.1-0.2 cm (coarse sand)	2
0.2-1.6 cm (gravel)	3
1.6-3.2 cm (small pebble)	4
3.2-6.4 cm (large pebble)	5
6.4-12.8 cm (small cobble)	6
12.8-25.6 cm (cobble)	7
> 25.6 cm (boulder)	8
Bedrock	9

	Diameter (cm)	E		Diameter (cm)	E		Diameter (cm)	E		Diameter (cm)	E
1			26			51			76		
2			27			52			77		
3			28			53			78		
4			29			54			79		
5			30			55			80		
6			31			56			81		
7			32			57			82		
8			33			58			83		
9			34			59			84		
10			35			60			85		
11			36			61			86		
12			37			62			87		
13			38			63			88		
14			39			64			89		
15			40			65			90		
16			41			66			91		
17			42			67			92		
18			43			68			93		
19			44			69			94		
20			45			70			95		
21			46			71			96		
22			47			72			97		
23			48			73			98		
24			49			74			99		
25			50			75			100		

Note: The Wolman D50 (i.e. median diameter), Wolman Dg (i.e. geometric mean diameter) and the % composition of the substrate classes will be calculated automatically in the CABIN database using the 100 pebble data. All 100 pebbles must be measured in order for the CABIN database tool to perform substrate calculations.

Field Crew: ______________________________________ Site Code: ________________

Sampling Date (DD/MM/YYYY): ________________________

SITE INSPECTION

Site Inspected by: ________________________________

Communication Information

☐ Itinerary left with contact person (include contact numbers)

Contact Person: __________________________ Time checked-in: _______

Form of communication: ☐ radio ☐ cell ☐ satellite ☐ hotel/pay phone ☐ SPOT

Phone number: (   ) ____________

Vehicle Safety

☐ Safety equipment (first aid, fire extinguisher, blanket, emergency kit in vehicle)

☐ Equipment and chemicals safely secured for transport

☐ Vehicle parked in safe location; pylons, hazard light, reflective vests if necessary

Notes:

Shore & Wading Safety

☐ Wading Task Hazard Analysis read by all field staff

☐ Wading Safe Work Procedures read by all field staff

☐ Instream hazards identified (i.e. log jams, deep pools, slippery rocks)

☐ PFD worn

☐ Appropriate footwear, waders, wading belt

☐ Belay used

Notes:

Appendix B
Benthic Macroinvertebrate Common Names

Order	Family	Common Name
Coleoptera		Beetles
	Dytiscidae	Predaceous diving beetles
	Elmidae	Riffle beetles
Diptera		Flies
	Ceratopogonidae	Biting midges
	Chironomidae	Non-biting midges
	Empididae	Dagger flies, balloon flies
	Muscidae	House flies, stable flies*
	Psychodidae	Moth flies, sand flies
	Simuliidae	Black flies
	Tipulidae	Craneflies
Ephemeroptera		Mayflies
	Ameletidae	Combmouthed minnow mayflies
	Baetidae	Small minnow mayflies
	Ephemerellidae	Spiny crawler mayflies
	Heptageniidae	Flat-headed mayflies
	Leptophlebiidae	Prong-gilled mayflies
Plecoptera		Stoneflies
	Capniidae	Small winter stoneflies
	Chloroperlidae	Green stoneflies
	Leuctridae	Rolled-winged stoneflies
	Nemouridae	Spring stoneflies
	Perlidae	Common stoneflies
	Perlodidae	Springflies
	Pteronarcyidae	Giant stoneflies
	Taeniopterygidae	Winter stoneflies
Trichoptera		Caddisflies
	Brachycentridae	Humpless casemaker caddisflies
	Glossosomatidae	Saddle casemaker caddisflies
	Hydropsychidae	Net-spinning caddisflies
	Lepidostomatidae	Bizarre caddisflies
	Limnephilidae	Tube-case caddisflies
	Rhyacophilidae	Free-living caddisflies
Trombidiformes		Mites
	Aturidae	Water mites
	Feltriidae	Water mites

Order	Family	Common Name
	Halacaridae	Meiobenthic mites
	Hydryphantidae	Water mites
	Hygrobatidae	Water mites
	Lebertiidae	Water mites
	Sperchontidae	Water mites
	Torrenticolidae	Torrent mites
Veneroida		Bivalve molluscs
	Pisidiidae	Pea clams, fingernail clams
Basommatophora		Pulmonate freshwater snails
	Planorbidae	Ram's horn snails
Hypsogastropoda		Marine gastropods
	Hydrobiidae	Mud snails
Lumbriculida		Microdrile oligochaetes (worms)
	Lumbriculidae	Aquatic worms
Tubificida		Annelid worms
	Enchytraeidae	Microdrile oligochaetes (worms)
	Naididae	Clitellate oligochaete worms

* Genus *Limnophora* (hunter-fly) identified, the larvae of which are aquatic

Appendix C
Benthic Macroinvertebrates Identified Using Morphological Characteristics

Taxa	Site										
	AUR01	MEA02	MAR02	WAP06	WAP07	JOH01	JOH02	WAP02a	WAP03	GHO03a	GHO05
Phylum: Arthropoda											
Subphylum: Hexapoda											
Class: Insecta											
Order: Ephemeroptera	0	0	0	0	0	0	0	0	0	0	0
Family: Ameletidae	0	0	0	0	0	0	0	0	0	0	0
Ameletus	0	0	82	8	17	0	0	0	4	14	12
Family: Baetidae	0	0	9	54	156	0	28	0	4	67	16
Acentrella	0	0	0	46	11	30	36	3	4	0	0
Baetis	85	25	182	208	89	57	8	41	36	248	40
Baetis bicaudatus	0	0	318	0	0	2	6	0	0	0	132
Baetis rhodani group	0	17	145	121	44	41	22	13	9	81	60
Family: Ephemerellidae	25	167	509	17	67	7	39	50	42	24	20
Drunella	0	8	0	4	0	0	0	0	0	10	0
Drunella coloradensis	0	0	0	0	0	2	0	0	0	0	0
Drunella doddsii	0	0	0	0	0	17	8	44	51	38	68
Drunella grandis group	0	142	118	0	33	0	0	0	0	5	0
Ephemerella	0	8	0	0	0	0	3	0	0	19	0
Ephemerella excrucians complex	0	0	36	13	6	2	0	0	4	29	0
Family: Heptageniidae	85	0	327	146	517	296	347	384	218	567	236
Cinygmula	0	0	145	29	89	2	0	53	36	52	24
Epeorus	0	0	0	38	0	7	8	50	122	5	128
Rhithrogena	0	0	0	33	28	148	317	94	189	124	348
Family: Leptophlebiidae	0	0	27	4	17	2	3	0	0	5	0
Order: Plecoptera	0	8	0	4	0	0	0	3	2	0	4
Family: Capniidae	0	0	27	21	0	0	0	9	18	14	0

Taxa	Site										
	AUR01	MEA02	MAR02	WAP06	WAP07	JOH01	JOH02	WAP02a	WAP03	GHO03a	GHO05
Family: Chloroperlidae	0	0	100	13	39	11	0	28	18	5	4
Neaviperla	0	0	0	0	0	0	0	0	2	5	4
Suwallia	0	0	0	0	0	0	0	0	0	0	48
Sweltsa	5	0	64	0	17	4	6	66	22	10	0
Family: Leuctridae	0	0	0	0	0	0	3	0	0	0	0
Family: Nemouridae	790	42	0	0	39	0	0	0	2	0	4
Nemoura	320	0	0	0	0	0	0	0	0	0	0
Visoka cataractae	0	0	0	0	0	0	0	0	0	0	4
Zapada	0	0	0	0	22	0	0	6	0	5	0
Zapada cinctipes	15	92	0	75	139	2	11	16	0	52	4
Zapada columbiana	0	0	0	0	0	0	0	0	0	5	4
Zapada oregonensis group	0	0	0	0	0	0	0	0	2	0	0
Family: Perlidae	0	0	0	71	33	13	14	16	2	0	0
Doroneuria	0	0	0	13	28	7	0	6	0	0	0
Hesperoperla	0	0	0	8	6	4	0	6	0	5	4
Family: Perlodidae	0	0	0	4	11	2	0	0	0	0	0
Isogenoides	0	0	0	0	0	2	6	0	0	0	0
Kogotus	30	0	0	0	6	0	0	0	0	0	0
Megarcys	0	0	9	0	0	0	3	0	2	0	0
Family: Pteronarcyidae	0	0	0	0	0	0	0	0	0	0	0
Pteronarcella	0	0	0	0	0	0	8	6	0	0	8
Family: Taeniopterygidae	0	0	0	0	0	4	22	6	13	10	36
Order: Trichoptera	0	0	0	0	0	0	0	0	0	0	0
Family: Brachycentridae	0	0	0	0	0	0	3	0	0	0	0
Family: Glossosomatidae	0	0	9	0	0	0	3	0	0	0	12
Glossosoma	0	0	0	0	0	2	0	0	0	0	60
Family: Hydropsychidae	0	0	0	0	0	0	0	0	0	29	64
Parapsyche	0	0	0	0	0	0	0	0	0	5	0

Taxa	Site										
	AUR01	MEA02	MAR02	WAP06	WAP07	JOH01	JOH02	WAP02a	WAP03	GHO03a	GHO05
Family: Lepidostomatidae	0	0	0	0	0	0	0	0	0	0	0
Lepidostoma	0	0	9	0	0	0	3	0	0	0	0
Family: Limnephilidae	0	8	0	0	0	0	0	0	0	0	0
Dicosmoecus	5	0	0	0	0	0	0	0	0	0	0
Ecclisomyia	0	158	0	0	0	0	0	0	0	0	0
Family: Rhyacophilidae	0	0	0	0	0	0	0	0	0	0	0
Rhyacophila	5	0	0	0	6	0	0	0	0	0	0
Rhyacophila betteni group	0	0	36	0	0	0	0	0	0	0	0
Rhyacophila brunnea/vemna group	0	0	9	21	6	2	0	0	0	0	0
Rhyacophila narvae	0	0	0	0	33	0	0	6	0	0	0
Order: Diptera	0	0	0	0	0	0	0	0	0	0	0
Family: Ceratopogonidae	0	133	9	0	0	0	0	0	0	0	0
Culicoides	0	8	0	0	0	0	0	0	0	0	0
Mallochohelea	0	325	0	4	28	0	0	3	0	0	0
Family: Chironomidae	15	8	18	4	6	4	3	3	0	14	0
Subfamily: Chironominae	0	0	0	0	0	0	0	0	0	0	0
Tribe: Chironomini	0	0	0	0	0	0	0	0	0	0	0
Pagastiella	0	0	18	0	0	0	0	0	0	0	0
Tribe: Tanytarsini	0	0	0	0	0	0	0	0	0	0	0
Micropsectra	5	8	36	25	22	0	0	9	0	10	0
Stempellinella	0	0	0	0	0	0	0	0	0	5	4
Subfamily: Diamesinae	0	0	0	0	0	0	0	0	0	0	0
Tribe: Diamesini	0	0	0	0	0	0	0	0	0	0	0
Diamesa	25	100	0	0	0	0	0	0	0	0	0
Pagastia	0	125	0	0	6	2	3	0	0	5	0
Pseudodiamesa	0	8	0	0	0	0	0	0	0	0	0
Subfamily: Orthocladiinae	0	0	0	0	0	0	0	0	0	0	0
Brillia	0	0	0	4	0	0	0	6	0	0	0

Taxa	Site										
	AUR01	MEA02	MAR02	WAP06	WAP07	JOH01	JOH02	WAP02a	WAP03	GHO03a	GHO05
Corynoneura	0	0	9	8	0	0	0	0	0	0	0
Diplocladius cultriger	0	50	0	0	0	0	0	0	0	0	0
Eukiefferiella	5	233	36	17	0	0	0	6	4	10	4
Heterotrissocladius	0	0	9	0	0	0	0	0	0	0	0
Hydrobaenus	0	108	18	0	0	0	0	0	0	0	0
Hydrosmittia	0	8	0	0	0	0	0	0	0	0	0
Limnophyes	0	8	0	4	0	0	0	0	0	0	0
Lopescladius	0	0	0	4	0	0	0	0	0	0	0
Orthocladius complex	75	283	182	29	33	46	22	0	0	0	24
Paracladius	0	0	0	0	0	2	0	0	0	0	0
Parametriocnemus	0	0	0	0	6	0	0	0	0	0	0
Parorthocladius	0	158	0	0	0	0	0	0	0	0	0
Rheocricotopus	0	50	9	4	0	0	0	3	0	24	4
Tvetenia	35	8	18	13	17	0	0	13	0	43	0
Subfamily: Tanypodinae	0	0	0	0	0	0	0	0	0	0	0
Tribe: Pentaneurini	0	0	0	0	0	0	0	0	0	0	0
Thienemannimyia group	0	0	18	0	6	0	0	0	0	0	0
Family: Empididae	0	8	0	0	0	2	0	0	0	0	0
Neoplasta	5	0	9	8	0	0	0	0	0	0	0
Oreogeton	5	0	9	0	0	0	0	0	0	0	0
Family: Muscidae	0	0	0	0	0	0	0	0	0	0	0
Limnophora	0	8	0	0	0	0	0	0	0	0	0
Family: Psychodidae	0	0	0	0	0	0	0	0	0	0	0
Pericoma/Telmatoscopus	0	0	0	0	11	0	0	0	0	0	0
Family: Simuliidae	0	0	0	0	6	0	0	0	0	0	0
Prosimulium/Helodon	0	0	0	0	0	2	0	0	0	0	0
Simulium	0	0	0	8	44	0	3	16	7	10	0
Family: Tipulidae	0	0	0	0	0	0	0	0	0	0	0
Antocha	0	0	0	8	6	0	0	0	0	0	0
Dicranota	0	8	0	0	0	2	3	0	0	5	0

Taxa	Site										
	AUR01	MEA02	MAR02	WAP06	WAP07	JOH01	JOH02	WAP02a	WAP03	GHO03a	GHO05
Hexatoma	0	0	9	0	6	0	0	9	0	0	0
Tipula	0	17	0	0	0	0	0	0	0	0	0
Order: Coleoptera	0	0	0	0	0	0	0	0	0	0	0
Family: Dytiscidae	0	0	0	0	0	0	0	0	0	0	0
Subfamily: Hydroporinae	0	0	36	0	0	0	0	0	0	0	0
Family: Elmidae	5	0	200	71	200	0	0	0	0	0	0
Heterlimnius	0	0	118	96	95	0	6	6	0	0	0
Subphylum: Chelicerata											
Class: Arachnida											
Order: Trombidiformes	0	0	0	0	6	0	0	0	2	0	4
Family: Aturidae	0	0	0	0	0	0	0	0	0	0	0
Aturus	0	8	0	0	0	0	0	0	0	0	0
Family: Feltriidae	0	0	0	0	0	0	0	0	0	0	0
Feltria	0	8	0	0	0	0	0	0	0	0	0
Family: Halacaridae	0	42	0	0	0	0	0	0	0	0	0
Family: Hydryphantidae	0	0	0	0	0	0	0	0	0	0	0
Albertathyas	0	8	0	0	0	0	0	0	0	0	0
Protzia	0	0	0	0	0	0	3	0	0	0	0
Family: Hygrobatidae	0	0	0	0	0	0	0	0	0	0	0
Atractides	10	0	0	4	0	0	0	0	0	0	0
Hygrobates	0	0	18	0	0	0	0	0	0	0	0
Family: Lebertiidae	0	0	0	0	0	0	0	0	0	0	0
Lebertia	5	83	9	0	6	2	8	0	2	0	0
Family: Sperchontidae	0	0	0	0	0	0	0	0	0	0	0
Sperchon	5	17	18	4	0	0	0	0	0	0	0
Family: Torrenticolidae	0	0	0	0	0	0	0	0	0	0	0
Testudacarus	0	0	0	13	0	0	0	3	0	0	0
Torrenticola	0	0	0	4	28	0	0	3	0	0	0

Taxa	Site										
	AUR01	MEA02	MAR02	WAP06	WAP07	JOH01	JOH02	WAP02a	WAP03	GHO03a	GHO05
Phylum: Annelida											
Subphylum: Clitellata											
Class: Oligochaeta											
Order: Lumbriculida	0	0	0	0	0	0	0	0	0	0	0
Family: Lumbriculidae	0	0	0	0	0	0	0	0	0	0	0
Rhynchelmis	5	0	0	0	0	0	0	0	0	0	0
Order: Tubificida	0	0	0	0	0	0	0	0	0	0	0
Family: Enchytraeidae	0	0	0	0	0	0	0	0	0	0	0
Enchytraeus	0	0	0	0	0	0	0	0	0	5	0
Family: Naididae	0	0	0	0	0	0	0	0	0	0	0
Limnodrilus	0	25	0	0	0	0	0	0	0	0	0
Phylum: Mollusca											
Class: Bivalvia											
Order: Veneroida	0	0	0	0	0	0	0	0	0	0	0
Family: Pisidiidae	0	133	0	0	0	0	0	0	0	0	0
Pisidium	0	25	0	0	0	0	0	0	0	0	0
Class: Gastropoda											
Order: Basommatophora	0	0	0	0	0	0	0	0	0	0	0
Family: Planorbidae	0	0	0	0	0	0	0	3	0	0	0
Order: Hypsogastropoda	0	0	0	0	0	0	0	0	0	0	0
Family: Hydrobiidae	0	0	0	4	0	0	0	0	0	0	0
Totals:	**1565**	**2686**	**2967**	**1287**	**1991**	**728**	**958**	**989**	**817**	**1564**	**1384**

Taxa	Site										
	AUR01	MEA02	MAR02	WAP06	WAP07	JOH01	JOH02	WAP02a	WAP03	GHO03a	GHO05
Taxa present but not included:											
Phylum: Arthropoda											
Subphylum: Hexapoda											
Class: Insecta											
Order: Homoptera	0	0	0	0	0	0	0	0	0	0	0
Family: Cicadellidae	0	0	0	0	0	0	3	0	0	0	0
Class: Copepoda	5	8	0	4	0	0	3	0	0	0	0
Subphylum: Crustacea											
Class: Ostracoda	5	8	0	0	0	0	3	3	0	0	0
Phylum: Annelida											
Subphylum: Clitellata											
Class: Oligochaeta											
Order: Tubificida	0	0	0	0	0	0	0	0	0	0	0
Family: Lumbricidae	0	0	0	33	0	0	0	0	0	0	0
Phylum: Nemata	0	8	0	4	0	0	0	3	0	0	0
Phylum: Platyhelminthes											
Class: Turbellaria	0	8	0	0	0	0	0	0	0	0	4
Totals:	**10**	**32**	**0**	**41**	**0**	**0**	**9**	**6**	**0**	**0**	**4**

Appendix D
Benthic Macroinvertebrates Identified at the Family Level Using Morphological Characteristics

Taxa	Site										
	AUR01	MEA02	MAR02	WAP06	WAP07	JOH01	JOH02	WAP02a	WAP03	GHO03a	GHO05
Phylum: Arthropoda											
Subphylum: Hexapoda											
Class: Insecta											
Order: Ephemeroptera	0	0	0	0	0	0	0	0	0	0	0
Family: Ameletidae	0	0	82	8	17	0	0	0	4	14	12
Family: Baetidae	85	42	654	429	300	130	100	57	53	396	248
Family: Ephemerellidae	25	325	663	34	106	28	50	94	97	125	88
Family: Heptageniidae	85	0	472	246	634	453	672	581	565	748	736
Family: Leptophlebiidae	0	0	27	4	17	2	3	0	0	5	0
Order: Plecoptera	0	8	0	4	0	0	0	3	2	0	4
Family: Capniidae	0	0	27	21	0	0	0	9	18	14	0
Family: Chloroperlidae	5	0	164	13	56	15	6	94	42	20	56
Family: Leuctridae	0	0	0	0	0	0	3	0	0	0	0
Family: Nemouridae	1125	134	0	75	200	2	11	22	4	62	16
Family: Perlidae	0	0	0	92	67	24	14	28	2	5	4
Family: Perlodidae	30	0	9	4	17	4	9	0	2	0	0
Family: Pteronarcyidae	0	0	0	0	0	0	8	6	0	0	8
Family: Taeniopterygidae	0	0	0	0	0	4	22	6	13	10	36
Order: Trichoptera	0	0	0	0	0	0	0	0	0	0	0
Family: Brachycentridae	0	0	0	0	0	0	3	0	0	0	0
Family: Glossosomatidae	0	0	9	0	0	2	3	0	0	0	72
Family: Hydropsychidae	0	0	0	0	0	0	0	0	0	34	64
Family: Lepidostomatidae	0	0	9	0	0	0	3	0	0	0	0
Family: Limnephilidae	5	166	0	0	0	0	0	0	0	0	0
Family: Rhyacophilidae	5	0	45	21	45	2	0	6	0	0	0

Taxa	Site										
	AUR01	MEA02	MAR02	WAP06	WAP07	JOH01	JOH02	WAP02a	WAP03	GHO03a	GHO05
Order: Diptera	0	0	0	0	0	0	0	0	0	0	0
Family: Ceratopogonidae	0	466	9	4	28	0	0	3	0	0	0
Family: Chironomidae	160	1155	371	112	96	54	28	40	4	111	36
Family: Empididae	10	8	18	8	0	2	0	0	0	0	0
Family: Muscidae	0	8	0	0	0	0	0	0	0	0	0
Family: Psychodidae	0	0	0	0	11	0	0	0	0	0	0
Family: Simuliidae	0	0	0	8	50	2	3	16	7	10	0
Family: Tipulidae	0	25	9	8	12	2	3	9	0	5	0
Order: Coleoptera	0	0	0	0	0	0	0	0	0	0	0
Family: Dytiscidae	0	0	36	0	0	0	0	0	0	0	0
Family: Elmidae	5	0	318	167	295	0	6	6	0	0	0
Subphylum: Chelicerata	0	0	0	0	0	0	0	0	0	0	0
Class: Arachnida	0	0	0	0	0	0	0	0	0	0	0
Order: Trombidiformes	0	0	0	0	6	0	0	0	2	0	4
Family: Aturidae	0	8	0	0	0	0	0	0	0	0	0
Family: Feltriidae	0	8	0	0	0	0	0	0	0	0	0
Family: Halacaridae	0	42	0	0	0	0	0	0	0	0	0
Family: Hydryphantidae	0	8	0	0	0	0	3	0	0	0	0
Family: Hygrobatidae	10	0	18	4	0	0	0	0	0	0	0
Family: Lebertiidae	5	83	9	0	6	2	8	0	2	0	0
Family: Sperchontidae	5	17	18	4	0	0	0	0	0	0	0
Family: Torrenticolidae	0	0	0	17	28	0	0	6	0	0	0
Phylum: Annelida											
Subphylum: Clitellata											
Class: Oligochaeta											
Order: Lumbriculida	0	0	0	0	0	0	0	0	0	0	0
Family: Lumbriculidae	5	0	0	0	0	0	0	0	0	0	0

Taxa	Site										
	AUR01	MEA02	MAR02	WAP06	WAP07	JOH01	JOH02	WAP02a	WAP03	GHO03a	GHO05
Order: Tubificida	0	0	0	0	0	0	0	0	0	0	0
Family: Enchytraeidae	0	0	0	0	0	0	0	0	0	5	0
Family: Naididae	0	25	0	0	0	0	0	0	0	0	0
Phylum: Mollusca											
Class: Bivalvia											
Order: Veneroida	0	0	0	0	0	0	0	0	0	0	0
Family: Pisidiidae	0	158	0	0	0	0	0	0	0	0	0
Class: Gastropoda											
Order: Basommatophora	0	0	0	0	0	0	0	0	0	0	0
Family: Planorbidae	0	0	0	0	0	0	0	3	0	0	0
Order: Hypsogastropoda	0	0	0	0	0	0	0	0	0	0	0
Family: Hydrobiidae	0	0	0	4	0	0	0	0	0	0	0
Totals:	**1565**	**2686**	**2967**	**1287**	**1991**	**728**	**958**	**989**	**817**	**1564**	**1384**

Taxa present but not included:

Phylum: Arthropoda											
Subphylum: Hexapoda											
Class: Insecta											
Order: Homoptera	0	0	0	0	0	0	0	0	0	0	0
Family: Cicadellidae	0	0	0	0	0	0	3	0	0	0	0
Class: Copepoda	5	8	0	4	0	0	3	0	0	0	0
Subphylum: Crustacea											
Class: Ostracoda	5	8	0	0	0	0	3	3	0	0	0

Taxa	Site										
	AUR01	MEA02	MAR02	WAP06	WAP07	JOH01	JOH02	WAP02a	WAP03	GHO03a	GHO05
Phylum: Annelida											
Subphylum: Clitellata											
Class: Oligochaeta											
Order: Tubificida	0	0	0	0	0	0	0	0	0	0	0
Family: Lumbricidae	0	0	0	33	0	0	0	0	0	0	0
Phylum: Nemata	0	8	0	4	0	0	0	3	0	0	0
Phylum: Platyhelminthes											
Class: Turbellaria	0	8	0	0	0	0	0	0	0	0	4
Totals:	**10**	**32**	**0**	**41**	**0**	**0**	**9**	**6**	**0**	**0**	**4**

Appendix E

Metric Indices of the Benthic Macroinvertebrates

(Genus/Species Level)

Metric	Site										
	AUR01	MEA02	MAR02	WAP06	WAP07	JOH01	JOH02	WAP02a	WAP03	GHO03a	GHO05
Richness Measures											
Species Richness	21	38	37	39	37	29	29	31	23	33	25
EPT Richness	9	10	17	19	22	22	21	19	19	24	20
Ephemeroptera Richness	3	6	9	11	10	11	10	8	10	13	9
Plecoptera Richness	4	2	4	7	9	9	8	10	9	9	9
Trichoptera Richness	2	2	4	1	3	2	3	1	0	2	2
Chironomidae Richness	5	13	10	9	6	3	3	5	1	6	4
Oligochaeta Richness	1	1	0	1	0	0	0	0	0	1	0
Non-Chiro. Non-Olig. Richness	15	24	27	29	31	26	26	26	22	26	21
Abundance Measures											
Corrected Abundance	1565	2686	2967	1287	1991	728	958	989	817	1564	1384
EPT Abundance	1365	675	2161	951	1459	666	907	906	802	1433	1344
Dominance Measures											
1st Dominant Taxon	Nemouridae	*Mallochohelea*	Ephemerel-lidae	*Baetis*	Heptageniidae	Heptageniidae	Heptageniidae	Heptageniidae	Heptageniidae	Heptageniidae	*Rhithrogena*
1st Dominant Abundance	790	325	509	208	517	296	347	384	218	567	348
2nd Dominant Taxon	*Nemoura*	*Orthocladius* complex	Heptageniidae	Heptageniidae	Elmidae	*Rhithrogena*	*Rhithrogena*	*Rhithrogena*	*Rhithrogena*	*Baetis*	Heptageniidae
2nd Dominant Abundance	320	283	327	146	200	148	317	94	189	248	236
3rd Dominant Taxon	Heptageniidae	*Eukiefferiella*	*Baetis bicaudatus*	*Baetis rhodani* grp	Baetidae	*Baetis*	Ephemerel-lidae	*Sweltsa*	*Epeorus*	*Rhithrogena*	*Baetis bicaudatus*
3rd Dominant Abundance	85	233	318	121	156	57	39	66	122	124	132
% 1 Dominant Taxon	50.48%	12.10%	17.16%	16.16%	25.97%	40.66%	36.22%	38.83%	26.68%	36.25%	25.14%
% 2 Dominant Taxon	20.45%	10.54%	11.02%	11.34%	10.05%	20.33%	33.09%	9.50%	23.13%	15.86%	17.05%
% 3 Dominant Taxon	5.43%	8.67%	10.72%	9.40%	7.84%	7.83%	4.07%	6.67%	14.93%	7.93%	9.54%

Metric	Site										
	AUR01	MEA02	MAR02	WAP06	WAP07	JOH01	JOH02	WAP02a	WAP03	GHO03a	GHO05
Percent Dominance	76.36%	31.31%	38.90%	36.90%	43.86%	68.82%	73.38%	55.00%	64.74%	60.04%	51.73%
Community Composition											
% Ephemeroptera	12.46%	13.66%	63.97%	56.02%	53.94%	84.20%	86.12%	74.01%	88.00%	82.35%	78.32%
% Plecoptera	74.12%	5.29%	6.74%	16.24%	17.08%	6.73%	7.62%	16.99%	10.16%	7.10%	8.96%
% Trichoptera	0.64%	6.18%	2.12%	1.63%	2.26%	0.55%	0.94%	0.61%	0.00%	2.17%	9.83%
% EPT	87.22%	25.13%	72.83%	73.89%	73.28%	91.48%	94.68%	91.61%	98.16%	91.62%	97.11%
% Diptera	10.86%	61.88%	13.72%	10.88%	9.89%	8.24%	3.55%	6.88%	1.35%	8.06%	2.60%
% Oligochaeta	0.32%	0.93%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.32%	0.00%
% Baetidae	5.43%	1.56%	22.04%	33.33%	15.07%	17.86%	10.44%	5.76%	6.49%	25.32%	17.92%
% Chironomidae	10.22%	43.00%	12.50%	8.70%	4.82%	7.42%	2.92%	4.04%	0.49%	7.10%	2.60%
% Odonata	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Functional Group Composition											
% Predators	0.89%	2.94%	1.31%	3.11%	2.36%	3.43%	1.57%	4.75%	2.69%	0.38%	1.08%
% Shredder-Herbivores	14.38%	0.60%	0.13%	1.86%	1.81%	0.41%	1.46%	1.42%	1.96%	1.15%	0.94%
% Collector-Gatherers	3.32%	5.62%	7.55%	13.68%	7.53%	13.05%	6.89%	5.76%	8.57%	8.06%	6.72%
% Scrapers	1.09%	0.00%	1.79%	4.66%	5.73%	28.71%	25.37%	18.91%	31.09%	10.04%	14.60%
% Macrophyte-Herbivore	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
% Collector-Filterer	0.00%	0.71%	0.00%	0.16%	0.45%	0.14%	0.21%	0.51%	0.37%	0.58%	1.23%
% Omnivore	0.13%	2.05%	0.17%	0.39%	0.00%	0.14%	0.31%	0.51%	0.24%	0.45%	0.29%
% Parasite	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
% Piercer-Herbivore	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
% Gatherer	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
% Unclassified	0.19%	0.11%	0.07%	0.16%	0.05%	0.27%	0.21%	0.20%	0.24%	0.26%	0.14%
Functional Group Richness											
Predators Richness	8	12	14	12	16	12	7	10	6	5	4
Shredder-Herbivores Richness	3	2	2	3	3	2	4	5	4	5	5
Collector-Gatherers Richness	8	18	19	18	19	10	12	9	8	15	8
Scrapers Richness	1		3	5	3	5	4	5	4	4	6

Metric	Site										
	AUR01	MEA02	MAR02	WAP06	WAP07	JOH01	JOH02	WAP02a	WAP03	GHO03a	GHO05
MH Richness											
CF Richness		2		1	2	1	2	1	1	3	2
OM Richness	2	4	2	2		1	1	3	1	2	3
PA Richness											
Piercer-Herbivore Richness											
Gatherer Richness											
Unclassified	1	3	1	2	1	1	2	2	2	2	2
Voltinism Composition											
% Univoltine	0.96%	4.62%	3.07%	6.76%	7.84%	3.16%	2.92%	6.07%	6.73%	8.82%	6.07%
% Semivoltine	0.64%	0.00%	8.90%	5.52%	10.90%	0.55%	0.63%	6.67%	2.69%	0.96%	0.58%
% Multivoltine	5.43%	1.23%	6.13%	16.78%	6.68%	7.83%	1.15%	5.76%	5.26%	16.50%	2.89%
Voltinism Richness											
Univoltine	1	5	2	3	2	4	5	2	2	6	3
Semivoltine	2	0	1	1	1	1	1	1	1	2	2
Multivoltine	1	2	1	2	2	1	2	2	2	2	0
Diversity/Evenness Measures											
Shannon-Wiener H' (log 10)	0.76	1.34	1.29	1.33	1.27	0.91	0.87	1.07	0.98	1.06	1.1
Shannon-Wiener H' (log 2)	2.52	4.45	4.28	4.42	4.23	3.04	2.88	3.57	3.26	3.52	3.66
Shannon-Wiener H' (log e)	1.75	3.09	2.97	3.07	2.93	2.1	2	2.47	2.26	2.44	2.54
Simpson's Index (D)	0.31	0.06	0.08	0.07	0.1	0.22	0.25	0.18	0.16	0.17	0.12
Simpson's Index of Diversity (1 - D)	0.69	0.94	0.92	0.93	0.9	0.78	0.75	0.82	0.84	0.83	0.88
Simpson's Reciprocal Index (1/D)	3.26	16.51	13.11	14.19	9.93	4.52	4.03	5.62	6.31	5.74	8.18
Biotic Indices											
Hilsenhoff Biotic Index	2.55	5.4	3.69	4.12	3.72	4.13	3.76	3.48	3.41	4.12	3.67

Appendix F
Metric Indices of the Benthic Macroinvertebrates
(Family Level)

Metric	Site										
	AUR01	MEA02	MAR02	JOH01	JOH02	WAP06	WAP07	WAP02a	WAP03	GHO03a	GHO05
Richness Measures											
Species Richness	15	18	20	22	19	16	20	18	15	15	14
EPT Richness	8	4	11	11	10	11	14	10	10	11	11
Ephemeroptera Richness	3	2	5	5	5	4	4	3	4	5	4
Plecoptera Richness	3	1	3	5	4	5	7	6	6	5	5
Trichoptera Richness	2	1	3	1	1	2	3	1		1	2
Chironomidae Richness	1	1	1	1	1	1	1	1	1	1	1
Oligochaeta Richness	1	1								1	
Non-Chiro. Non-Olig. Richness	13	16	19	21	18	15	19	17	14	13	13
Abundance Measures											
Corrected Abundance	1565	2686	2967	1287	1991	728	958	989	817	1564	1384
EPT Abundance	1365	675	2161	951	1459	666	907	906	802	1433	1344
Dominance Measures											
1st Dominant Taxon	Nemouridae	Chironomidae	Ephemerellidae	Baetidae	Heptageniidae	Heptageniidae	Heptageniidae	Heptageniidae	Heptageniidae	Heptageniidae	Heptageniidae
1st Dominant Abundance	1125	1155	663	429	634	453	672	581	565	748	736
2nd Dominant Taxon	Chironomidae	Ceratopogonidae	Baetidae	Heptageniidae	Baetidae	Baetidae	Baetidae	Ephemerellidae	Ephemerellidae	Baetidae	Baetidae
2nd Dominant Abundance	160	466	654	246	300	130	100	94	97	396	248
3rd Dominant Taxon	Baetidae	Ephemerellidae	Heptageniidae	Elmidae	Elmidae	Chironomidae	Ephemerellidae	Chloroperlidae	Baetidae	Ephemerellidae	Ephemerellidae
3rd Dominant Abundance	85	325	472	167	295	54	50	94	53	125	88
% 1 Dominant Taxon	71.88%	43.00%	22.35%	33.33%	31.84%	62.23%	70.15%	58.75%	69.16%	47.83%	53.18%
% 2 Dominant Taxon	10.22%	17.35%	22.04%	19.11%	15.07%	17.86%	10.44%	9.50%	11.87%	25.32%	17.92%
% 3 Dominant Taxon	5.43%	12.10%	15.91%	12.98%	14.82%	7.42%	5.22%	9.50%	6.49%	7.99%	6.36%
Percent Dominance	87.53%	72.45%	60.30%	65.42%	61.73%	87.51%	85.81%	77.75%	87.52%	81.14%	77.46%

Metric	Site										
	AUR01	MEA02	MAR02	JOH01	JOH02	WAP06	WAP07	WAP02a	WAP03	GHO03a	GHO05
Community Composition											
% Ephemeroptera	12.46%	13.66%	63.97%	56.02%	53.94%	84.20%	86.12%	74.01%	88.00%	82.35%	78.32%
% Plecoptera	74.12%	5.29%	6.74%	16.24%	17.08%	6.73%	7.62%	16.99%	10.16%	7.10%	8.96%
% Trichoptera	0.64%	6.18%	2.12%	1.63%	2.26%	0.55%	0.94%	0.61%	0.00%	2.17%	9.83%
% EPT	87.22%	25.13%	72.83%	73.89%	73.28%	91.48%	94.68%	91.61%	98.16%	91.62%	97.11%
% Diptera	10.86%	61.88%	13.72%	10.88%	9.89%	8.24%	3.55%	6.88%	1.35%	8.06%	2.60%
% Oligochaeta	0.32%	0.93%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.32%	0.00%
% Baetidae	5.43%	1.56%	22.04%	33.33%	15.07%	17.86%	10.44%	5.76%	6.49%	25.32%	17.92%
% Chironomidae	10.22%	43.00%	12.50%	8.70%	4.82%	7.42%	2.92%	4.04%	0.49%	7.10%	2.60%
% Odonata	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Functional Group Composition											
% Predators	4.15%	23.49%	10.38%	12.67%	12.71%	6.73%	4.18%	13.85%	6.12%	1.60%	4.62%
% Shredder-Herbivores	71.88%	5.92%	1.52%	8.08%	10.65%	1.10%	5.22%	5.26%	4.28%	5.82%	4.34%
% Collector-Gatherers	7.99%	20.77%	58.78%	49.88%	37.47%	21.98%	16.60%	15.87%	18.85%	34.85%	25.14%
% Scrapers	5.43%	0.00%	16.21%	19.43%	31.84%	62.50%	70.46%	59.05%	69.16%	47.83%	58.38%
% Macrophyte-Herbivore	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
% Collector-Filterer	0.00%	5.88%	0.00%	0.62%	2.51%	0.27%	0.63%	1.62%	0.86%	2.81%	4.62%
% Omnivore	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
% Parasite	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
% Piercer-Herbivore	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
% Gatherer	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
% Unclassified	10.54%	43.93%	13.11%	9.32%	4.82%	7.42%	2.92%	4.35%	0.73%	7.10%	2.89%
Voltinism Composition											
% Univoltine	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
% Semivoltine	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
% Multivoltine	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Metric	Site										
	AUR01	MEA02	MAR02	JOH01	JOH02	WAP06	WAP07	WAP02a	WAP03	GHO03a	GHO05
Diversity/Evenness Measures											
Shannon-Wiener H' (log 10)	0.76	1.34	1.29	1.33	1.27	0.91	0.87	1.07	0.98	1.06	1.1
Shannon-Wiener H' (log 2)	2.52	4.45	4.28	4.42	4.23	3.04	2.88	3.57	3.26	3.52	3.66
Shannon-Wiener H' (log e)	1.75	3.09	2.97	3.07	2.93	2.1	2	2.47	2.26	2.44	2.54
Simpson's Index (D)	0.31	0.06	0.08	0.07	0.1	0.22	0.25	0.18	0.16	0.17	0.12
Simpson's Index of Diversity (1 - D)	0.69	0.94	0.92	0.93	0.9	0.78	0.75	0.82	0.84	0.83	0.88
Simpson's Reciprocal Index (1/D)	3.26	16.51	13.11	14.19	9.93	4.52	4.03	5.62	6.31	5.74	8.18
Biotic Indices											
Hilsenhoff Biotic Index	2.55	5.4	3.69	4.12	3.72	4.13	3.76	3.48	3.41	4.12	3.67