FINAL
Bevan Avenue Groundwater Supply Development Project

Year 11 Environmental Monitoring Report

Prepared for:

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Executive Summary

The City of Abbotsford was granted approval under a BC Environmental Certificate (EAC) #W11-01 to increase the withdrawal of water from the Abbotsford – Sumas Aquifer (the Aquifer) to meet seasonal peak drinking water demands. The Bevan Wells Groundwater Supply Development Project (The Project) was initially intended to extract water at an increased rate from a maximum 74.9 liters per second (L/s) to 290 L/s during times of seasonal peak usage (May to September) until such time as an additional surface water supply was constructed. The original EAC expired December 31, 2015 but was extended to the end of 2016 to allow sufficient time to prepare a comprehensive amendment application to operate the wells indefinitely. The amendment allowing indefinite operation of the wells was granted on June 12, 2017.

Schedule B of the EAC outlines the City of Abbotsford's commitments with respect to the project. Condition #4 stipulates that the City must implement a monitoring program for the duration of operation of the project. The program includes monitoring surface water flows, surface water levels, and surface water quality. Conditions added in the 2017 Amendment include implementation of a monitoring and mitigation plan (Condition #22), which includes vegetation monitoring (Condition # 23), and inviting Matsqui First Nation to continue participation in existing fish habitat monitoring programs and participate in the new and expanded vegetation and fish habitat monitoring programs (Condition #27). If any unanticipated adverse effects are identified in the monitoring reports, then the City of Abbotsford must develop and implement appropriate mitigation measures to the satisfaction of the EAO.

As per Conditions #4 and #27, annual reporting is to be completed and submitted to the Environmental Assessment Office and Matsqui First Nation. This report summarizes the Year 11 (May 2021 to April 2022) monitoring data. The expanded monitoring programs were implemented in 2018 and continued in 2019-2022. Matsqui First Nation were invited to participate in the summer 2021 fish habitat and indicator plant monitoring events. They participated in the fish habitat monitoring on October 27 and 29 and the indicator plant monitoring on September 13, 15, and 16. They did not respond to the invitations to participate in July and August.

Flows measured in the creeks during 2021-22 were within range of previous measurements and did not exhibit any long-term declining trends. The seasonal low flows measured in Downes Creek remained above the 27.9 L/s threshold that represents a 10% reduction from the lowest flow measured in this creek in September 2008 (prior to commissioning of the

Bevan Wells). Creek flows below this amount may trigger further assessment and/or mitigation if due to the operation of the Bevan Wells.

A challenge arose with the flow measurements at the new Fishtrap Creek SCADA station. Due to variability in low flow measurements, it has not been possible to develop a rating curve for the site. As a result, to mitigate potential low-flow periods, the Fishtrap mitigation well was operated from July to October 2021.

Flow monitoring at several sites experienced challenges related to unusually high water levels. Flooding associated with an atmospheric river in November 2021 resulted in dislodging the WT-01 staff gauge, logger, and PVC pipe. The D-04 Hobo logger also went missing. High water persisted to the extent that the F-04 staff gauge was fully submerged in January 2022, and the stream was too deep for manual flow measurements.

Low water also presented challenges. The staff gauge at B-01 was above the water line from July through October 2021. Waechter Creek was dry at the WT-01 monitoring station from July through September 2021, and in May 2021 the water level was too low for an accurate manual flow measurement.

Year 11 of the water quality monitoring showed that the use of the Bevan Wells has not affected the surface water quality relative to baseline conditions. However, that the baseline condition is affected by agricultural and urban activities, so the baseline quality ranged from marginal to good in Year 1. There were no statistically significant decreases in the WQI at any of the monitoring sites. However, there was a significant improvement in the WQI at H-01.

Over the eleven years of monitoring trend tests showed significant downward trends in annual mean dissolved oxygen concentrations at B-01, H-02, and the Willband Creek reference site (W-01). In addition, there was a significant decreasing trend at H-02 during the July to October time period. There were no corresponding increases in the summer or annual temperatures. The lack of temperature trends along with decreasing dissolved oxygen at the reference site shows that the use of the Bevan Wells was not responsible for the decreases in dissolved oxygen.

Prior to Year 8, water quality in Downes Creek (D-01) and Fishtrap Creek (F-01 and F-02) was monitored in April, September, October, and January. Therefore, the available data were insufficient to analyze seasonal or annual trends. However, trends during each of the four months were analyzed. The only statistically significant trend in these watercourses was a decrease in dissolved oxygen in May at F-02.

Groundwater quality monitoring was conducted to compare the quality of augmentation flows relative to surface water quality guidelines. Water quality in the Garibaldi Park mitigation well (which discharges to Horn Creek) was good. The Allen Park mitigation well had consistently elevated arsenic concentrations, over three times the water quality guideline. However, a risk assessment completed in 2018 found that risks related to arsenic exposure would not be expected even if receptors in Boa Brook were exposed to undiluted groundwater In addition, annual average phosphorus concentrations in the Allen Park well were above the water quality objective for the Sumas River. The new Fishtrap Creek mitigation well also had an average phosphorus concentration above the objective for the Sumas River, but all other parameters were below guidelines to protect aquatic life.

The drinking water wells had generally good water quality. The average concentrations of arsenic, fluoride and iron were below the maximum guidelines for protection of aquatic life. However, concentrations of nitrate and copper were higher in the drinking water wells than in the mitigation wells.

The fish habitat monitoring program for Horn Creek and Boa Brook did not identify any changes over time that appeared to be associated with operation of the Bevan Wells. Over the eleven years of monitoring there were no statistically significant decreasing trends in bankfull width, wetted width, or bankfull depth.

Groundwater level monitoring in Year 11 showed that aquifer levels were generally consistent on a year-over-year basis in terms of the magnitude and seasonal variation. There was no evidence of a progressive year-over-year decline in water levels in any of the observation wells. Water levels in Laxton and Judson Lakes were also consistent with previous years' dat.

The fourth full year of stream flow, water quality, and mesohabitat monitoring was completed at the expanded monitoring sites in Fishtrap Creek and Downes Creek from May 2021 to April 2022. The fourth year of shallow groundwater monitoring and fifth year of vegetation monitoring were also completed during this time period. The results of these monitoring programs are presented in the current report.

No unanticipated adverse effects were identified in Year 11 monitoring. The four years of mesohabitat and shallow groundwater is not sufficient to draw conclusions, but there were no changes that would suggest an immediate need for a mitigation well for Downes Creek (Condition #25).

Minimum shallow groundwater levels could not be measured at two plots in Fishtrap Creek or at the three plots in Control Wetland B due to a layer of gravel that limited the depths to which the sensors could be installed. While these wells are limited in the depths they can measure, they provide other seasonal data, such as the timeline for the onset and end of the drought period.

There was an overall decrease in water level in the Downes Creek wetland from 2018 to 2022. The decrease did not correspond to withdrawals by the Bevan Wells. However, interpretation of the water level trend was hampered by lack of samples from August through October 2021. This omission was due to the presence of an active wasp nest near the staff gauge. After a member of the field crew was stung, the crew abandoned monitoring at this site as long as the wasp nest was present.

After five years of data collection, the vegetation monitoring showed neither major shift in species composition nor changes to ecosystem boundaries. Trend analyses of indicator plant (skunk cabbage) parameters showed decreases in average petiole length in two plots, one in the Horn Creek and one in the Downes Creek watershed but no trends at the watershed level. Thus, the vegetation monitoring showed no adverse effects attributable to operation of the Bevan Wells. However, the data are quite variable due to year-to-year differences in leaf drop and decay.

Four years of conducting the expanded monitoring program required by the 2017 Amendment have resulted in some challenges that may require adjustments to the program. Specific issues are related the expanded flow and mesohabitat monitoring stations.

Several expanded flow monitoring stations have consistently been problematic. The manual stream flow data recorded at B-02, D-02, D-03 and D-04 have been too variable to establish a stage-discharge rating curve, and Waechter Creek at WT-01 has frequently been dry during the summer. ENKON recommends that a qualified professional hydrologist in consultation with a qualified professional fisheries biologist re-evaluate the expanded flow monitoring sites to determine whether:

- monitoring at these sites can provide sufficiently accurate flows to determine temporal trends in summer low flows;
- sufficiently accurate flow monitoring can be achieved without significant channel configuration (e.g., weir installation) and if not, whether the flow data is valuable enough to warrant the disturbance to fish habitat; and
- whether the program objectives (identification of negative effects on fish habitat) can be achieved through seasonal flow monitoring (manual measurements) in conjunction with the current mesohabitat monitoring program.

For several years beavers have been active at F-02 and F-03, changing the site characteristics. It will be difficult to identify effects, if any, of the Bevan Wells on fish habitat at these sites due to the confounding influence of beaver activity. A qualified fisheries biologist should assess the possibility of finding additional or alternate mesohabitat monitoring sites that are unaffected by beavers, although these sites will not likely be available in some reaches.

Monitoring is continuing for Year 12 (May 2022 to April 2023), and results will be presented in a separate annual monitoring report.

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1.0 INTRODUCTION

1.1 Background

The Bevan Avenue Wells Groundwater Supply Development Project (the Project) was proposed in response to increasing summer water use demand in the City of Abbotsford (the City) and the District of Mission (Mission). The Bevan Avenue Wells are operated by the City on behalf of the Abbotsford Mission Water & Sewer Commission (AMWSC). In October 2010, the City submitted an *Application for an Environmental Assessment Certificate* (the *Application,* (Hemmera, 2010) for the Project in accordance with the requirements and guidance of the British Columbia Environmental Assessment Office (EAO), and as required under the British Columbia *Environmental Assessment Act S.B.C. 2002* (BC EAA) and the *Canadian Environmental Assessment Act* (CEAA). An Environmental Assessment Certificate (EAC) was awarded on May 10, 2011 (EAC number: W11-01) and allowed for the operation of the Bevan Wells for five years under prescribed conditions. The EAC was amended on June 12, 2017 to allow for the wells to operate indefinitely, with additional conditions.

Potential environmental effects of the Project are related to drawdown of water levels in the Abbotsford – Sumas Aquifer (the Aquifer), which may affect surface water flows and in turn fish and fish habitat. The original *Application* predicted that changes in surface flows would be below acceptable thresholds in the reaches of all evaluated watercourses except Horn Creek and its tributary, Boa Brook (Hemmera, 2010). A decrease in flow could change the quantity and potentially affect the quality of available habitat for fish. In particular, a decrease in flow could result in elevated water temperatures and a decrease in dissolved oxygen, which could directly affect fish. The most critical period for fish is mid-July to end of October, when base flow is at or near seasonal lows.

The subsequent *Amendment Application* (ENKON 2016) addressed long-term operation of the Project, including operation during extended (5 year) unusually dry periods. This assessment identified a potential for the Project to affect surface flows in Fishtrap Creek and Downes Creek and shallow groundwater that sustains wetlands, particularly in the Downes Creek watershed.

In order to mitigate potential effects to fish and fish habitat and in accordance with the terms and conditions of the EAC, the City installed and operates mitigation wells. Two wells, located in the headwaters of Horn Creek and Boa Brook, are intended to supplement predicted low flows to pre-Project levels. Both wells pump water to their respective creeks when measured flows at the Horn Creek station are below 25.2 L/s (equivalent to 90% of the minimum base flow of 28 L/s) and the Bevan Wells have pumped more than 175 ML during the preceding 30 days. A third mitigation well was installed in Fishtrap Creek in 2019.

In 2011, an Operational Environmental Management Plan (OEMP) was prepared for the Project by Hemmera. The intent of the mitigation measures described in the OEMP was to meet a standard of no negative change in water quality and stream flow as a result of the Project. The OEMP included a monitoring program, the purpose of which was to compare conditions in Horn Creek and Boa Brook during operation of the Bevan Avenue Wells and mitigation wells to baseline conditions.

The OEMP was updated in July 2018 (ENKON *et al.*, 2018) to address the new conditions in the amended EAC. This update expanded the aquatic monitoring program in Fishtrap Creek and Downes Creek and added vegetation and shallow groundwater monitoring programs. New monitoring sites and/or monitoring programs were established in the fall of 2017, and routine monitoring began in May 2018.

The goals of the monitoring program in the current OEMP are to:

- Assess the efficiency of the mitigation measures in protecting fish and fish habitat;
- Compare baseline conditions to conditions during operation of the Bevan Wells and, if applicable, the mitigation wells;
- Assess the ability of the mitigation measures to sufficiently supplement groundwater inputs to affected watercourses;
- Determine the need (if any) for further mitigation measures to protect instream fish habitat and riparian/wetland vegetation, especially in Downes Creek; and
- Verify the assessments presented in the original Application and the Amendment Application regarding potential residual effects of the Project on water quality, stream flows, riparian vegetation, and shallow groundwater.

This report presents the results of the Year 11 monitoring program, which began in May 2021 and concluded in April 2022. It includes comparisons of all years of the Project for which multi-year data are available. A summary and schedule of the Year 11 monitoring activities for groundwater, surface water, and fish habitat is presented in Table 1-1. Shallow groundwater monitoring sites are monitored continuously. Vegetation monitoring occurs annually in late summer.

Table 1-1 Monitoring Activities and Schedule (2021-2022) for the Bevan Wells Project

Component & Site	**2021** May	**2021** June	**2021** July	**2021** August	**2021** September	**2021** October	**2021** November	**2021** December	**2022** January	**2022** February	**2022** March	**2022** April
Water Quality Samples & *In-Situ* Water Quality												
Boa Brook (B-01)	x	x	x	x	x	x	x	x	x	x	x	x
Boa Brook (B-02)	x	x	x	x	x	x	x	x	x	x	x	x
Horn Creek (H-01)	x	x	x	x	x	x	x	x	x	x	x	x
Horn Creek (H-02)	x	x	x	x	x	x	x	x	x	x	x	x
Horn Creek (H-03)	x	x	x	x	x	x	x	x	x	x	x	x
Willband Creek (W-01)	x	x	x	x	x	x	x	x	x	x	x	x
Downes Creek (D-01)	x	x	x	x	x	x	x	x	x	x	x	x
Downes Creek (D-02)	x	x	x	x	x	x	x	x	x	x	x	x
Fishtrap Creek (F-01)	x	x	x	x	x	x	x	x	x	x	x	x
Fishtrap Creek (F-02)	x	x	x	x	x	x	x	x	x	x	x	x
Fishtrat Creek (FOF)	x	x	x	x	x	x	x	x	x	x	x	x
Fishtrap Creek (F-03)	-	-	x	x	x	x	-	-	-	-	-	-
Fishtrap Creek (F-04)	-	-	x	x	x	x	-	-	-	-	-	-
Duplicate	F-01	F-02	W-01	H-01	D-01	H-02	H-03	B-01	B-02	H-01	H-02	H-03
Number of sites	10	10	12	12	12	12	10	10	10	10	10	10
Manual Streamflow and Water Level												
Boa Brook (B-01)	x	x	x	x	x	x	-	-	x	-	-	x
Boa Brook (B-02)	x	-	x	-	x	-	-	-	x	-	-	-
Horn Creek (H-01)	x	x	x	x	x	x	-	-	x	-	-	x
Horn Creek (H-02)	x	x	x	x	x	x	-	-	x	-	-	x
Horn Creek (H-03)	x	x	x	x	x	x	-	-	x	-	-	x
Willband Creek (W-01)	x	x	x	x	x	x	-	-	x	-	-	x
Downes Creek (D-01)	x	x	x	x	x	x	-	-	x	-	-	x
Downes Creek (D-02)	x	-	x	-	x	-	-	-	x	-	-	-
Downes Creek (D-03)	x	-	x	-	x	-	-	-	x	-	-	-
Downes Creek (D-04)	x	-	x	-	x	-	-	-	x	-	-	-
Fishtrap Creek (F-01)	x	-	x	-	x	-	-	-	x	-	-	-
Fishtrap Creek (F-02)	x	-	x	-	x	-	-	-	x	-	-	-
Waechter (WT-01) +	x	-	x	-	x	-	-	-	x	-	-	-
Fishtrap Creek (F-04)	x	-	x	-	x	-	-	-	x	-	-	-
Judson Lake	x	x	x	x	x	x	x	x	x	x	x	x
Laxton Lake	x	x	x	x	x	x	x	x	x	x	x	x
Number of stream flow sites	14	6	14	6	14	6	0	0	14	0	0	6

Component & Site	2021 May	2021 June	2021 July	2021 August	2021 September	2021 October	2021 November	2021 December	2022 January	2022 February	2022 March	2022 April
Fish & Fish Habitat Monitoring												
Site 1 (Mesohabitat A, B, C)	-	-	x	x	x	x	-	-	-	-	-	-
Site 2 (Mesohabitat A, B)	-	-	x	x	x	x	-	-	-	-	-	-
Site 3 (Mesohabitat A, B, C)	-	-	x	x	x	x	-	-	-	-	-	-
Site 4 (Mesohabitat A, B)	-	-	x	x	x	x	-	-	-	-	-	-
Site 5 (Mesohabitat A, B, C, D)	-	-	x	x	x	x	-	-	-	-	-	-
Site 6 (Mesohabitat A, B)	-	-	x	x	x	x	-	-	-	-	-	-
Downes Creek (D-01) (pool & riffle)	-	-	-	-	-	-	-	-	-	-	-	-
Downes Creek (D-02) (pool & riffle)	-	-	x	x	x	x	-	-	-	-	-	-
Downes Creek (D-03) (pool & riffle)	-	-	x	x	x	x	-	-	-	-	-	-
Downes Creek (D-04) (pool & riffle)	-	-	x	x	x	x	-	-	-	-	-	-
Fishtrap Creek (F-01) (pool & riffle)	-	-	x	x	x	x	-	-	-	-	-	-
Fishtrap Creek (F-02) (pool & riffle)	-	-	x	x	x	x	-	-	-	-	-	-
Fishtrap Creek (F-03) (pool)	-	-	x	x	x	x	-	-	-	-	-	
Fishtrap Creek (F-04) (pool & riffle)	-	-	x	x	x	x	-	-	-	-	-	-
Number of sites	0	0	13	13	13	13	0	0	0	0	0	0
TEM, Indicator Plants, Snail Habitat												
Downes Creek TEM Sites (11 plots)	-	-	-	-	x *		-	-	-	-	-	-
Downes Creek Indicator Plants (8 Plots)	-	-	-	-	x **	-	-	-	-	-	-	-
Downes Creek Oregon Forestsnail Habitat	-	-	-	-	x	-	-	-	-	-	-	-
Fishtrap Creek TEM Sites (6 plots)	-	-	-	-	x *		-	-	-	-	-	-
Horn/Boa TEM Sites (4 plots)	-	-	-	-	x *		-	-	-	-	-	-
Horn/Boa Indicator Plants (2 Plots)	-	-	-	-	x **	-	-	-	-	-	-	-
Number of sites	0	0	0	0	22	10	0	0	0	0	0	0
Shallow Groundwater Well Monitoring												
Downes Creek (8 wells)	-	-	-	-	-	x	-	-	-	-	-	x
Control Wetland A (3 wells)	-	-	-	-	-	x	-	-	-	-	-	x
Control Wetland B (3 wells)	-	-	-	-	-	x	-	-	-	-	-	x
Control Wetland C (3 wells)	-	-	-	-	-	x	-	-	-	-	-	x
Fishtrap Creek (3 wells)	-	-	-	-	-	x	-	-	-	-	-	x
Horn Creek/Boa Brook (2 wells)	-	-	-	-	-	x	-	-	-	-	-	x
Number of sites	0	0	0	0	0	22	0	0	0	0	0	22
Groundwater Quality Monitoring												
Allen Park Mitigation Well	x	x	x	x	x	x	x	x	x	x	x	x
Garibaldi Park Mitigation Well	x	x	x	x	x	x	x	x	x	x	x	x
AMWSC Drinking Water Wells	x	x	x	x	x	x	x	x	x	x	x	x
Number of sites	3	3	3	3	3	3	3	3	3	3	3	3

Component & Site	2021 May	2021 June	2021 July	2021 August	2021 September	2021 October	2021 November	2021 December	2022 January	2022 February	2022 March	2022 April
Groundwater Level Monitoring												
Exhibition Park	x	x	x	x	x	x	x	x	x	x	x	x
Columbia Bible College	x	x	x	x	x	x	x	x	x	x	x	x
DND South Townline	x	x	x	x	x	x	x	x	x	x	x	x
Heritage RV	x	x	x	x	x	x	x	x	x	x	x	x
TW06-2 Bevan	x	x	x	x	x	x	x	x	x	x	x	x
TW06-3 Courthouse	x	x	x	x	x	x	x	x	x	x	x	x
Number of sites	6	6	6	6	6	6	6	6	6	6	6	6

+ Substituted for station F-03

*TEM Plots to be assessed between September 15 and October 15

**Indicator plant plots to be completed after 1065 degree-days above 10 degrees Celsius (approximately September 20th). Surveys should take place no later than October 1st.

1.2 Year 11 Operation

In Year 11 of the Project (May 1, 2021 to April 30, 2022) the Bevan Wells pumped 1,459 million litres per year (ML/year). This total is equivalent to 58% of the total groundwater diversion (2,505 ML/year) permitted in accordance with EA Certificate W11-01. The maximum daily pumping rate was 20.769 ML/day on April 13, 2022, which represents 83% of the 25-ML/day allowable maximum pumping rate.

The Allen Park and Garibaldi Park mitigation wells were not triggered in Year 11. Flows in Horn Creek did not drop below 25 L/s during at any other time during Year 11.

The Fishtrap Creek mitigation well came online on May 10, 2019. The associated flow monitoring station was completed in January 2021, but it has not been possible to develop a rating curve for the station. As a result, the mitigation well was turned on as a precaution and pumped from July 17 to October 8, 2021 (Appendix I).

Apart from maintenance and sampling, the Bevan Wells were used outside of the operating window from November 14, 2021 to January 21, 2022 due to the flood. During the November 2021 storm, the road to the Norrish Water Treatment Plant was not accessible due to two landslides. Therefore, the Bevan Wells and other sources were used for supply. The wells were also used from April 7 to 28, 2022, during repairs at Norrish.

2.0 SURFACE WATER MONITORING PROGRAM

Hydrological investigations undertaken during preparation of the *Application* determined that is potential for the Project to affect surface flows in Horn Creek and Boa Brook. Subsequent analysis undertaken for the *Amendment Application* identified the potential for effects on flows in Fishtrap Creek and Downes Creek during multi-year dry periods. Such decreases in flow have the potential to affect fish habitat and water quality through decreases in water volume, possibly resulting in increased concentrations of nutrients, elevated water temperature, and corresponding decreases in dissolved oxygen. The most critical period is late summer to early autumn, when base flows are at or near seasonal lows.

Mitigation for reduction in surface flows in Horn Creek and Boa Brook as a result of the Project operations consists of augmentation of surface flows with groundwater. This occurs when measured flows at the Horn Creek station are below 25.2 L/s (equivalent to 90% of the minimum base flow of 28 L/s) (Hemmera, 2011b). Flow augmentation for Fishtrap Creek came online in the summer of 2019 (Year 9) and was operated as a precaution in the summers of Year 9, Year 10, and Year 11, as the associated flow monitoring station initially was not operational and subsequently it was not possible to develop a rating curve for the station.

The Year 11 surface water monitoring program included the following:

- Streamflow measurements (watercourses);
- Water level measurements (water bodies);
- Collection of *in-situ* water quality measurements; and
- Collection of water quality samples for laboratory analysis.

2.1 Site Description

Water quality and/or stream flow measurements were taken at 15 sites (watercourses), and water levels were recorded at two sites (water bodies). These are described in Table 2-1 and shown in Figures 2-1 to Figure 2-3.

The monitoring sites on Horn Creek, Boa Brook, Fishtrap Creek, and Downes Creek are locations potentially impacted by the Project and/or the groundwater mitigation measures. Willband Creek was chosen as a control, as it is not expected to be affected by the Project, but is surrounded by land use (i.e., city park, urban mix of residential and commercial) similar to that around Horn Creek and Boa Brook (Hemmera, 2011).

Table 2-1 Surface Water Monitoring Sites

Water Feature	Site ID	Description	UTM Northing	UTM Easting
Watercourses				
Boa Brook	B-01	Boa Brook mitigation well outfall	5433683	550844
	B-02	Hydrometric station - Boa Brook, downstream of mitigation well outfall (monitoring station was moved in 2018 to a suitable location for level logger installation)	5434336	550671
		Water quality - Boa Brook, downstream of mitigation well outfall	5434298	550651
Downes Creek	D-01	Downes Creek (monitoring station was moved in September 2014 due to a hazardous tree)	5435965	549189
	D-02	Located 30m upstream of Downes Road	5435905	549143
	D-03	Approximately 20m downstream of headwall	5435425	549298
	D-04	Approximately 60m upstream from pedestrian bridge.	5435296	549169
Fishtrap Creek	F-01	Confluence of Enns Brook and Fishtrap Creek	5433158	546746
	F-02	Fishtrap Creek downstream from Marshall Road Extension[a]	5431962	545250
	F-03	Near previously established staff gauge (water quality only)	5430294	544294
	F-04	Flow logger installed at right bank piles under Echo Rd Bridge	5430337	544026
Horn Creek	H-01	Horn Creek headwaters, upstream of mitigation well outfall	5433951	550190
	H-02	Horn Creek, downstream of confluence with Boa Brook	5434380	550784
	H-03	Horn Creek, downstream of mitigation well outfall	5434025	550234
Waechter Creek	WT-01	Waechter Creek at 1266 Hope Road (hydrometric only; site selected because F-03 was unsuitable for installing a level logger) [b]	5430425	544487
Willband Creek	W-01	Willband Creek (control site)	5432998	551363
Water Bodies				
Judson Lake	-	Judson Lake (discussed with groundwater program)	5427980	548328
Laxton Lake	-	Laxton Lake (discussed with groundwater program)	5428820	547457

Note: UTM Coordinates are NAD83, Zone 10U

[a] Station was moved to 10U 545221 E 5431928 N in September 2018 to avoid conflict with Marshall Road widening and culvert replacement works.

[b] The flow at F-03 can be calculated by subtracting flow at WT-01 from F-04.

2.2 Schedule

2.2.1 Water Quality

In-situ water quality measurements and samples for laboratory analyses collected at 11 locations (B-01, B-02, H-01, H-02, H-03, F-01, F-02, FOF, D-01, D-02, and W-01) on a monthly basis. The remaining locations (F-03 and F-04) had water quality samples collected only in July, August, September, and October (Table 1-1).

2.2.2 Stream Flow

The hydrometric network for the Bevan Wells monitoring program included automated hydrometric stations installed on Horn Creek (H-02), Fishtrap Creek (F-01 and F-02), Downes Creek (D-01), and Willband Creek (W 01). The automated hydrometric stations were installed by Piteau in 2008. The site on Horn Creek (H-02) was vandalized and taken out of the monitoring program early in Year 3. It was replaced with a SCADA monitoring station.

In 2019, new flow monitoring stations were installed on Fishtrap Creek near F-02 and Downes Creek near D-01. The Fishtrap Creek station transmits data to SCADA, while the Downes Creek station uploads data to FlowWorks via cellular telemetry. Kerr Wood Leidal (KWL) has assumed responsibility for maintenance and manual flow measurements at these two stations plus the Horn Creek SCADA station.

The expanded monitoring program (ENKON, 2018a) included installation of level loggers at the following locations:

- H-02 on Horn Creek as a back-up to the SCADA system (Figure 2-1);
- B-02 to better characterize flows in Boa Brook on a continuous basis (Figure 2-1);
- D-02, D-03, and D-04 to characterize flows within the Downes Bowl tributaries to Downes Creek on a continuous basis (Figure 2-2); and
- WT-01 (on Waechter Creek in lieu of F-03) and F-04 to better characterize flows within Fishtrap Creek on a continuous basis (Figure 2-3).

Manual stream flow measurements were made or attempted monthly from May through October 2021 plus January and April 2022. These months capture the high flows in January, the early dry season in April, May and June, and summer low flows which typically extend from July to October.

Legend

- ▲ Surface water monitoring location
- Abbotsford-Sumas aquifer
- Streams
- Waterbody

Prepared by: ENKON Environmental Ltd.

Created: December 2019
Projection:
NAD 83 UTM Zone 10N
1:6,000

Horn Creek, Boa Brook & Willband Creek Surface Water Monitoring Sites

City of Abbotsford

Figure 2-1

Legend

- Surface water monitoring location
- DownesTrails
- Abbotsford-Sumas aquifer
- Waterbody

Watercourses (CoA Modified)

- Class A (fish-bearing)
- Class Ao (overwintering)
- Class B (food and nutrient)
- Permanent (Unclassified)

Prepared by: ENKON Environmental Ltd.

Created: December 2019
Projection:
NAD 83 UTM Zone 10N
1:2,500

Downes Creek Surface Water Monitoring Sites

City of Abbotsford

Figure 2-2

Legend

- Surface water monitoring location
- Abbotsford-Sumas aquifer
- Streams
- Waterbody

Prepared by: ENKON Environmental Ltd.

Created: December 2019
Projection:
NAD 83 UTM Zone 10N
1:10,000

Fishtrap Creek
Surface Water Monitoring Sites

City of Abbotsford

Figure 2-3

2.3 Study Methods

2.3.1 Stream Flow

Stream flow monitoring at Horn Creek and Fishtrap Creek SCADA stations and the Downes Creek FlowWorks station was conducted by KWL. The methods and results of this monitoring program are attached in Appendix A with supporting information from the Horn Creek events log in Appendix B.

The original and expanded stream flow and water level monitoring program included:

- Download of data from the monitoring sites where water level loggers are installed; and
- Stream flow transects at each of the 14 monitoring sites listed in Table 2-1 and Table 2-2.

Table 2-2 Hydrology Stations on Streams

Site ID	Stream Flow Transect	Automated Data Logger
H-01	X	
H-02	X	X
H-03	X	
B-01	X	
B-02	X	X
D-01	X	X
D-02	X	X
D-03	X	X
D-04	X	X
F-01	X	X
F-02	X	X
WT-01	X	X
F-04	X	X
W-01	X	X

Stream transects were conducted in accordance with the methods described in *The Manual of British Columbia Hydrometric Standards* (RISC, 2009). Stream flow was measured with a SonTek FlowTracker or FlowTracker2® handheld Acoustic Doppler Velocimeter (ADV®).

Concurrent stage and flow measurements were used to establish a stage-discharge relationship for each instrumented station. These relationships were used to estimate flowrates from the hourly water level records. Equivalent water level elevations were determined by correcting the measured levels against a surveyed datum.

2.3.2 Water Quality

2.3.2.1 Parameters Monitored

The water quality monitoring program included:

- *In-situ* water quality monitoring of dissolved oxygen, pH, specific conductance, and temperature;
- Field monitoring of turbidity;
- Monitoring of nutrients (nitrate/nitrite, ammonia, and phosphorus);
- Monitoring of total metals;
- Monitoring of water hardness;
- Monitoring of total fluoride; and
- Coordination of scheduling and sampling locations with surface water flow monitoring.

Potential surface water quality effects of the Project are predicted to be from reduced flows rather than inputs of new contaminants. Watercourses and water quality in the Abbotsford area are currently affected by agricultural and urban activities. Physical and chemical analyses of water samples collected during the field program were reflective of these concerns. In addition to the monitoring of nutrients, total metals analysis was added to the analysis requirements for all surface water samples beginning in October 2012 due to the elevated background levels of arsenic and fluoride in the Abbotsford-Sumas aquifer groundwater (Hemmera, August 2011).

The selected water quality attributes are described below:

- **Turbidity –** A measure of the optical properties of a water sample induced mostly by suspended particulate matter which results in a scattering of light as it passes through water. High levels are commonly the result of suspended solids and can reduce biological productivity of the water or prey capture success by visual predators such as trout and salmon. Turbidity guidelines primarily deal with induced increases above background level. The City of Abbotsford’s Erosion and Sediment Control Bylaw specifies 25 NTUs as the maximum limit. This is meant to be measured at point of release rather than above background. Turbidity below 8 NTU is used to define “clear” flow (Singleton, 2001).
- **Dissolved Oxygen –** A measure of the amount of oxygen dissolved in water, essential to the survival and health of most aquatic organisms. Turbulent water

contains more dissolved oxygen than stagnant water. Water also contains more oxygen at saturation at colder temperatures. Anthropogenic inputs such as agricultural runoff and other organic materials use oxygen as they decompose, reducing dissolved oxygen levels.

- **Temperature –** Aquatic organisms have an optimal temperature range outside of which they become stressed, more susceptible to disease, and grow more slowly. Increased temperature contributes to algal growth and is a contributing factor toward eutrophication of a watercourse. Temperature also affects the toxicities of a range of other substances, including ammonia.

- **pH –** Aquatic organisms have an optimal pH range outside of which they become stressed, more susceptible to disease, and grow more slowly. pH is a factor in the toxicities of numerous pollutants, including ammonia. Eutrophication may cause a slight rise in pH in watercourses during the daytime due to photosynthesis.

- **Nitrate and Nitrite –** Nitrate and nitrite occur naturally but also can be introduced by anthropogenic sources such as agricultural and urban run-off. Both nitrate and nitrite are useable by plants. Nitrite is an intermediate step in the nitrification of ammonia. It is unstable in surface waters and rapidly degrades to nitrate, the most oxidized and stable form of nitrogen in a water body. Nitrate can contribute to the eutrophication of water bodies, and nitrite can be toxic to aquatic organisms.

- **Ammonia –** The most reduced inorganic form of nitrogen in water, and an essential plant nutrient. Excess ammonia contributes to eutrophication of water bodies and is toxic to aquatic life at high concentrations. Ammonia occurs naturally at low concentrations but similarly to nitrate can be introduced by anthropogenic sources such as agricultural and urban run-off.

- **Total Phosphorus –** Both inorganic and organic forms of phosphorus can be present as dissolved or particulate matter. Phosphorus is generally the limiting nutrient to plant growth in fresh water and is found in very low concentrations in natural waters. Anthropogenic inputs of phosphorus include agricultural and urban run-off and industrial effluents. Such inputs are often responsible for eutrophication of freshwater systems.

- **Total Metals –** As noted in the *Surface Water and Mitigation Well Groundwater Quality Report* (Hemmera, August 2011), no metals concentrations of potential concern were detected in the single sampling event; however, the report recommended further sampling due to high detection limits for arsenic, cadmium, chromium, and zinc in historical surface water samples.

- **Total Fluoride –** The *Surface Water and Mitigation Well Groundwater Quality Report* (Hemmera, August 2011) recommended that additional groundwater samples from the drinking water and mitigation wells should be taken to determine the range of fluoride (and arsenic) concentrations in the aquifer.

2.3.2.2 Sampling Methods

Water quality sampling was done in accordance with the *BC Field Sampling Manual* (Ministry of Environment, 2013) and Resources Information Standards Committee (RISC) guidelines (Cavanagh, 1994; RISC, 1998). Sampling containers and preservatives were obtained from Bureau Veritas (BV). *In-situ* parameters (pH, temperature, dissolved oxygen, and conductivity) were measured with a YSI Professional Plus multi-parameter meter with the probe placed directly into the stream flows. Field turbidity was measured using a LaMotte 2020e turbidity meter. Sample containers were filled directly from the stream. Water samples were sent to BV for chemical analyses.

2.3.2.3 Quality Assurance and Quality Control

Quality assurance (QA) procedures during field sampling included:

- Proper maintenance and calibration of field equipment;
- Labelling sample containers prior to collection with company information, project identification, station identification, sample date and time;
- Keeping samples cool and dark, and preserving as specified for the type of sample;
- Delivering samples to the laboratory within specific holding times; and
- Keeping accurate records for sample chain-of-custody.

The following quality control samples were collected during each sampling event:

- **Duplicate samples –** two samples collected at the same location and time;
- **Travel blanks -** a bottle of deionized water filled and preserved at the analytical laboratory, then taken into the field in the sample cooler and returned unopened to the laboratory; and
- **Field blanks –** prepared by filling the sample bottles with deionized water in the field and then preserving the samples, if appropriate.

Analyses were completed by an analytical laboratory accredited by the Canadian Association for Environmental Analytical Laboratories (CAEAL). Internal laboratory QA/QC procedures are consistent with the *BC Environmental Laboratory Manual* (Ministry of Environment and Climate Change Strategy, 2020) and include the use of quality control samples such as blanks, duplicates, and reference materials (standards, spikes, etc.). Values exceeding set standards or control limits undergo an internal review process.

2.3.2.4 Data Analysis

Results of laboratory analyses were entered into the CCME Water Quality Index (WQI) Calculator 2.0 (CCME, 2017). The CCME water quality index summarizes the results of a number of water quality variables in comparison to established criteria in order to describe water bodies as “poor”, “marginal”, “fair”, “good” or “excellent”[1]. This approach was used both here and during the environmental assessment, as the streams under study are not in pristine condition and on some occasions, do not meet federal and provincial water quality guidelines for selected parameters. The water quality index allows for a comparison of overall changes in stream quality over time, which is a more meaningful analysis in the context of potential impacts of the Project than comparison to set criteria.

Annual reports for Year 1 to Year 7 used the CCME Water Quality Index Calculator 1.2 (CCME, 2011a). The Year 8 annual report (ENKON 2020) used Version 2 of the WQI Calculator and the 19 parameters and associated guidelines listed in Table 2-3. The WQI values for Years 2 through 7 were updated using the same calculations in order to make the data for these years comparable. [2] Subsequent years’ WQI values also have been determined using WQI Calculator Version 2 and the 19 parameters listed in Table 2-3.

2.4 Results

2.4.1 Stream Flow

2.4.1.1 Original Hydrometric Monitoring Program Sites

The original hydrometric monitoring sites include Horn Creek 2 (H-02), Fishtrap Creek 1 (F-01) Fishtrap Creek 2 (F-02B, which replaces station F-02), Downes Creek D-01), and Willband Creek (W-01). Water levels are graphed in Figure 2-4, and flows are shown in Figure 2-5. Total daily precipitation at the Abbotsford Airport (recorded by Environment Canada) is included on Figure 2-4. The graphs and discussion of stream flow data for these stations extends to October 2022.

---

[1] **Excellent (E):** (CCME WQI Value 95-100) – water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels. These index values can only be obtained if all measurements are within objectives virtually all of the time.

Good (G): (CCME WQI Value 80-94) – water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels.

Fair (F): (CCME WQI Value 65-79) – water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels.

Marginal (M): (CCME WQI Value 45-64) – water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels.

Poor (P): (CCME WQI Value 0-44) – water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels.

[2] The Year 1 WQI was not recalculated because the raw water quality data were unavailable.

Table 2-3 Water Quality Criteria Used in the Water Quality Index Calculation

Parameter	Source	Criteria
Nitrate as N (mg/L as N)	CCME	2.9 mg/L as N
Nitrite as N (mg/L as N)	CCME	0.06 mg/L as N
Ammonia (mg/L as N)	CCME	Temperature and pH dependent.
Phosphorus (mg/L)	SSWQG	0.03 mg/L
Dissolved Oxygen (mg/L)	BCWQG	Species and life stage dependent. In study area streams, July 1 to October 31: ≥8 mg/L November 1 to June 30: ≥11 mg/L
Temperature (°C)	BCWQG	Species and life stage dependent. In study area streams, July 1 to October 31: ≤15°C November 1 to June 30: ≤13°C
pH	BCWQG	Between 6.5 and 9
Fluoride	CCME	0.12 mg/L (interim guideline)
Total Metals	CCME	
Arsenic		5 µg/L
Cadmium		$10^{(0.083(\log[\text{hardness}])-2.46)}$
Chromium VI		1 µg/L
Copper		$0.2 * e^{0.8545[\ln(hardness)]-1.465}$
Iron		300 µg/L
Lead		$e^{1.273[\ln(hardness)]-4.705}$
Mercury (inorganic)		0.026
Nickel		$e^{0.76[\ln(hardness)]+1.06}$
Selenium		1 µg/L
Silver		0.1 µg/L
Zinc		30 µg/L

CCME – Canadian Council of Ministers of the Environment; BCWQG – British Columbia Water Quality Guideline; SSWQG - Site-Specific Water Quality Guidelines (for the Sumas River)

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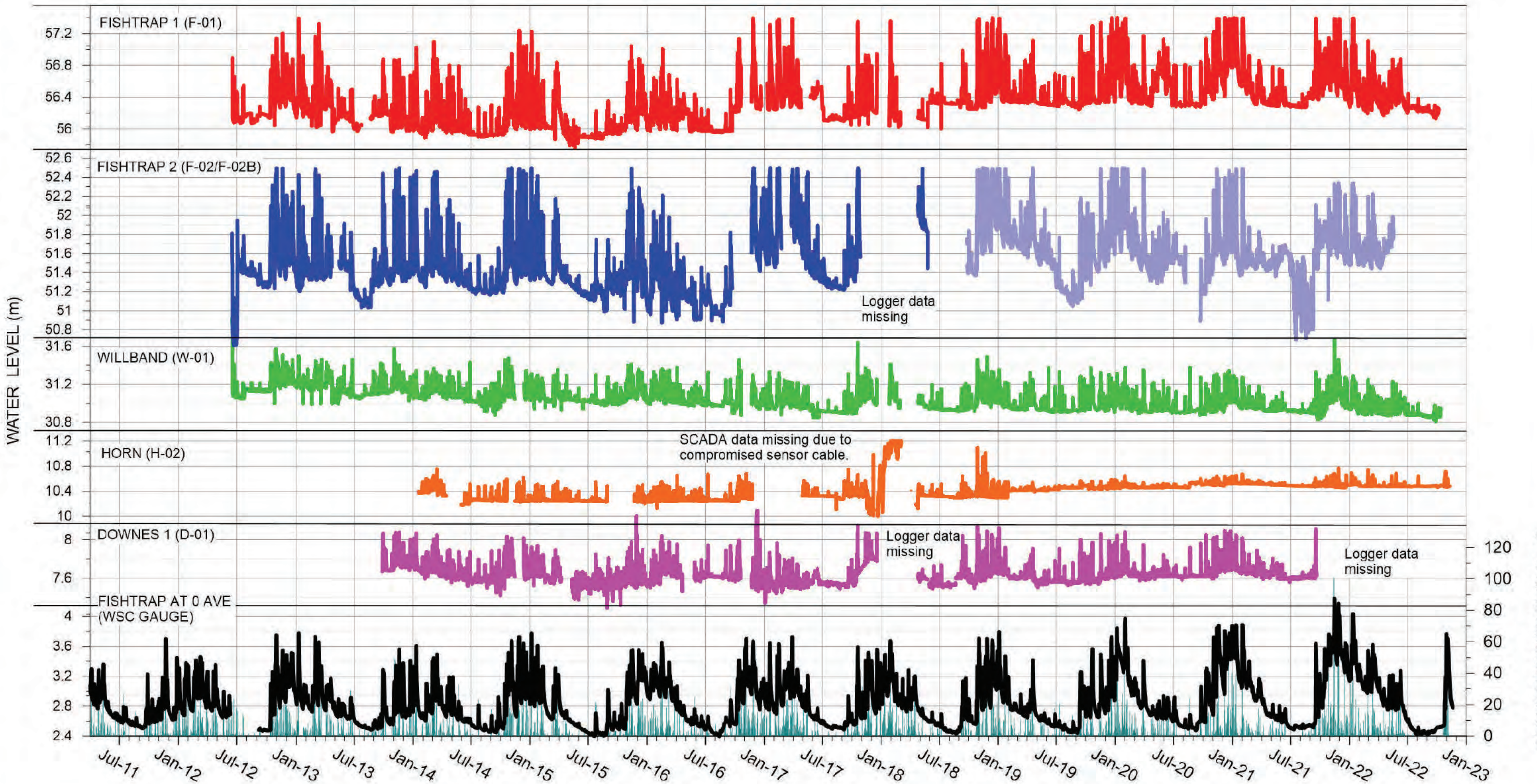


Fishtrap 1 (F-01)
Fishtrap 2 (F-02)
Fishtrap 2 (F-02B)
Willband (W-01)
Horn (H-02)
Downes (D-01)
Fishtrap at 0 Ave (WSC gauge)
Precipitation

Water levels shown as elevations for all except Fishtrap at 0 Ave

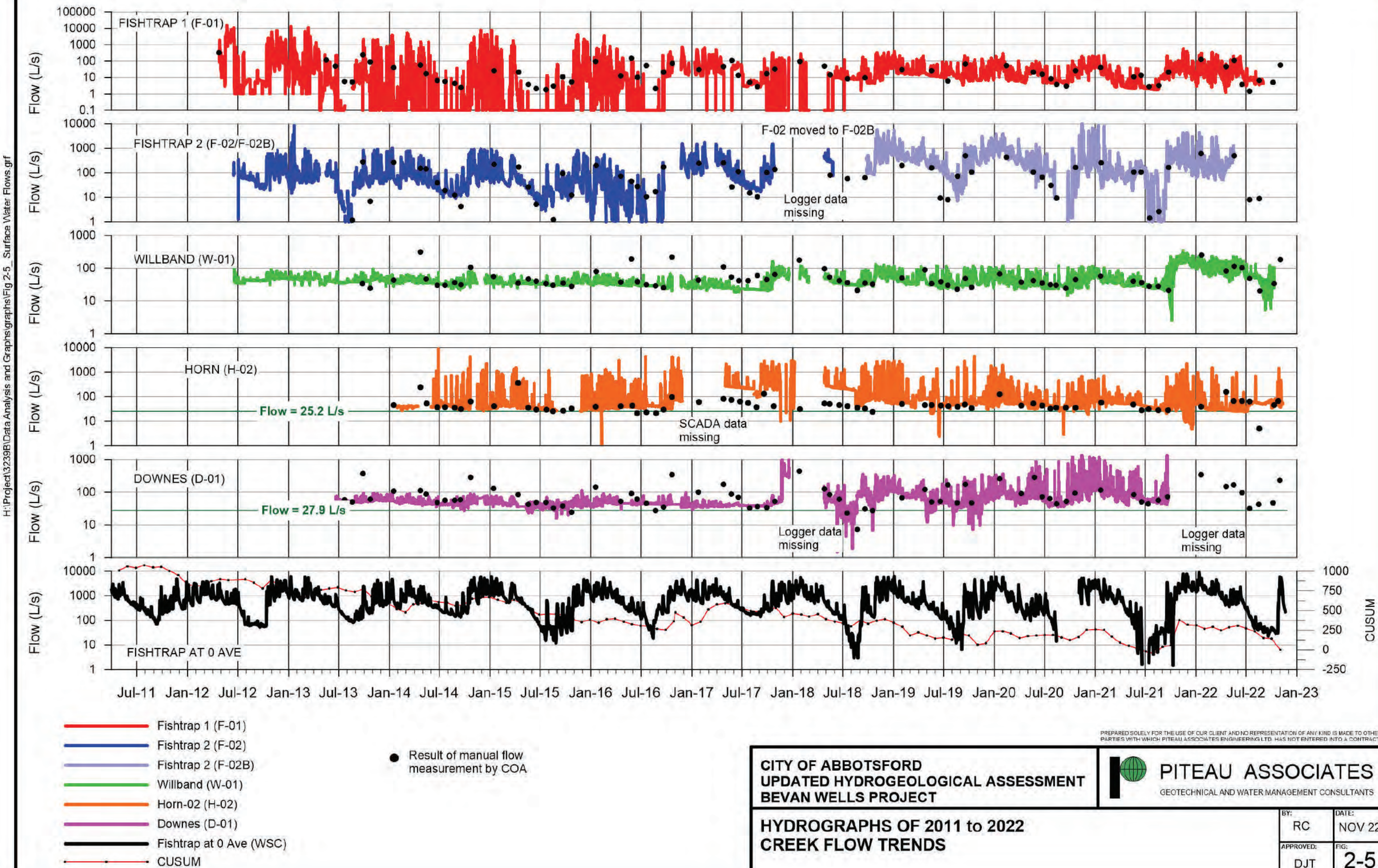
All precipitation data from Environment Canada station at Abbotsford Airport.

CITY OF ABBOTSFORD
UPDATED HYDROGEOLOGICAL ASSESSMENT
BEVAN WELLS PROJECT

PITEAU ASSOCIATES
GEOTECHNICAL AND WATER MANAGEMENT CONSULTANTS

HYDROGRAPHS OF 2011 TO 2022
SURFACE WATER LEVEL TRENDS

BY:	DATE:
RC	NOV 22
APPROVED:	FIG:
DJT	2-4



CITY OF ABBOTSFORD
UPDATED HYDROGEOLOGICAL ASSESSMENT
BEVAN WELLS PROJECT

PITEAU ASSOCIATES
GEOTECHNICAL AND WATER MANAGEMENT CONSULTANTS

HYDROGRAPHS OF 2011 to 2022
CREEK FLOW TRENDS

BY:	DATE:
RC	NOV 22
APPROVED: DJT	FIG: 2-5

Flows measured in the creeks during 2021-22 were within range of previous measurements and did not exhibit any long-term declining trends. The seasonal low flows measured in Downes Creek remained above the 27.9 L/s threshold that represents a 10% reduction from the lowest flow measured in this creek in September 2008 (prior to commissioning of the Bevan Wells). Creek flows below this amount may trigger further assessment and/or mitigation if due to the operation of the Bevan Wells.

The pressure transducer installed in Downes Creek to monitor water levels stopped working in September, 2021. As a result, continuous water level and estimated flow rate (developed from stage-discharge relationship) at Downes Creek is not available from September 2021 onward. Manual water levels and manual creek flow measurements are available at Downes Creek throughout 2022.

Discrete manual creek flow measurements observed low flows (below 27.9 L/s) in Downes Creek in the summer of 2018 and the summer of 2022. The low flows could be attributed to lower-than-average precipitation during the spring and summer, as indicated by the steepness of the CUSUM line between April and September 2018, and between June to September 2022, and were thus not due to pumping of the Bevan Wells. Short term excursions of the calculated flow (based on stage-discharge relationships) below the 27.9 L/s threshold occurred in the summer of 2019 but were not substantiated by manual flow measurements. The occurrence of calculated flow at Downes Creek below the 27.9 L/s threshold likely reflects the high sensitivity of calculated flows to changes in the apparent water level in the creek (i.e., stage).

The low flows in Fishtrap Creek at 0 Ave in 2018 likely reflect withdrawals from the creek, as low flows measured in the upper reaches of Fishtrap Creek (F-01) were greater. A similar low flow trend was reported for this monitoring station in September 2019 and may also have been caused by creek withdrawals. Based on the absence of lower water levels in the majority of water level monitoring stations (Section 4.2.4), it is unlikely to be associated with operation of the Bevan Wells. Due to the occurrence of erratic and unreliable trends in the data reported for Fishtrap Creek at 0 Avenue that occurred in mid-August 2020, the relevant data record has been omitted, and the low flows were not recorded. The low flow period observed in Fishtrap Creek at 0^{th} Avenue between June 2021 and October 2021 may be attributed to the combination of dryer than normal summer and withdraws from the creek in the same period, as evident by the similar low flow period also observed in F-02B in the summer of 2022.

Although calculated flows at Fishtrap Creek stations F-01 prior to July 2018 are unreliable, more recent calculated flows at this location correlate well with measured flows and are within the range indicated by measured flows prior to 2018. Flows measured at station F-02B on Fishtrap Creek are within the range indicated by measured flows at nearby station F-02 that was discontinued in 2018. Calculated flows at F-02B based on water levels measured after a period of no-data between approximately mid-August to late-September 2020 are erratic and appear unreliable. Low flows measured in July and August 2021 are attributed to a combination of declining CUSUM trend for the same period and withdraws from the creek.

The Fishtrap 2 station is transitioning from F-02B to a new station. Data from the new station was monitored to trigger the Fishtrap Creek mitigation well. However, as previously noted, the data proved to be unreliable. To mitigate potential low-flow periods, the Fishtrap mitigation well was operated from July to October 2021.

Observed and calculated flows in Horn Creek (H-02) generally showed expected seasonal fluctuations and were within previously observed levels. With the exception of a single manual flow reading in August 2022, lower flow rates were not reported in Horn Creek. However, the observed low flow rate does not correspond to a lower water level at the same time in the creek. Therefore, the low flow rate reading in August 2022 may be attributed to a change in the flow measurement methodology or measurement error.

Observed and calculated flows in Willband Creek showed a slight decreasing trend up to October 2021, followed by a noticeable increase in water level and flow from October 2021 onward into 2022. Willband Creek is the reference station that is outside the influence of the Bevan Wells.

2.4.1.2 Expanded Hydrometric Monitoring Program Sites

Year 11 represents the fourth year of monitoring at new hydrometric stations established at Boa Brook (B-02), Downes Creek (D-02, D-03 and D-04), Fishtrap Creek (F-04) and Waechter Creek (WT-01); thus, no year-over-year trend analysis was completed. Water levels at these sites are shown in Figure 2-6.

Stream flows at Fishtrap Creek F-03 and F-04 and Waechter Creek WT-01 are presented in Figure 2-7. The flows at F-03 on Fishtrap Creek were derived by subtracting flows at WT-01 from F-04. The F-04 logger failed sometime during the fall or winter of 2020-21. It could not be downloaded in April 2021, and data after September 28, 2020 could not be recovered. An attempt was made to replace the battery, but the logger itself was inoperable. A new logger was installed on August 4, 2021. As a result, it was not possible to calculate F-03 flows for the period from the end of September 2020 through July 2021.

Flow measurements at WT-01 were also problematic. In May 2021, the creek was too shallow to obtain a reliable flow measurement. In July, August, and September 2021 the creek bed was dry, and there was no water at the staff gauge. An additional issue was identified in January 2022, when the field crew noted that the staff gauge was missing. In March 2022, the field crew reported that the PVC pipe and Hobo logger were also missing. These losses likely occurred due to the Fraser Valley flooding in November 2021. The logger, PVC pipe, and staff gauge were recovered in May and reinstalled 70 m downstream of the previous location on May 26, 2022. Thus, valid logger data are unavailable from November 15, 2021 to May 26, 2022. Likewise, F-03 flow could not be calculated for this period.

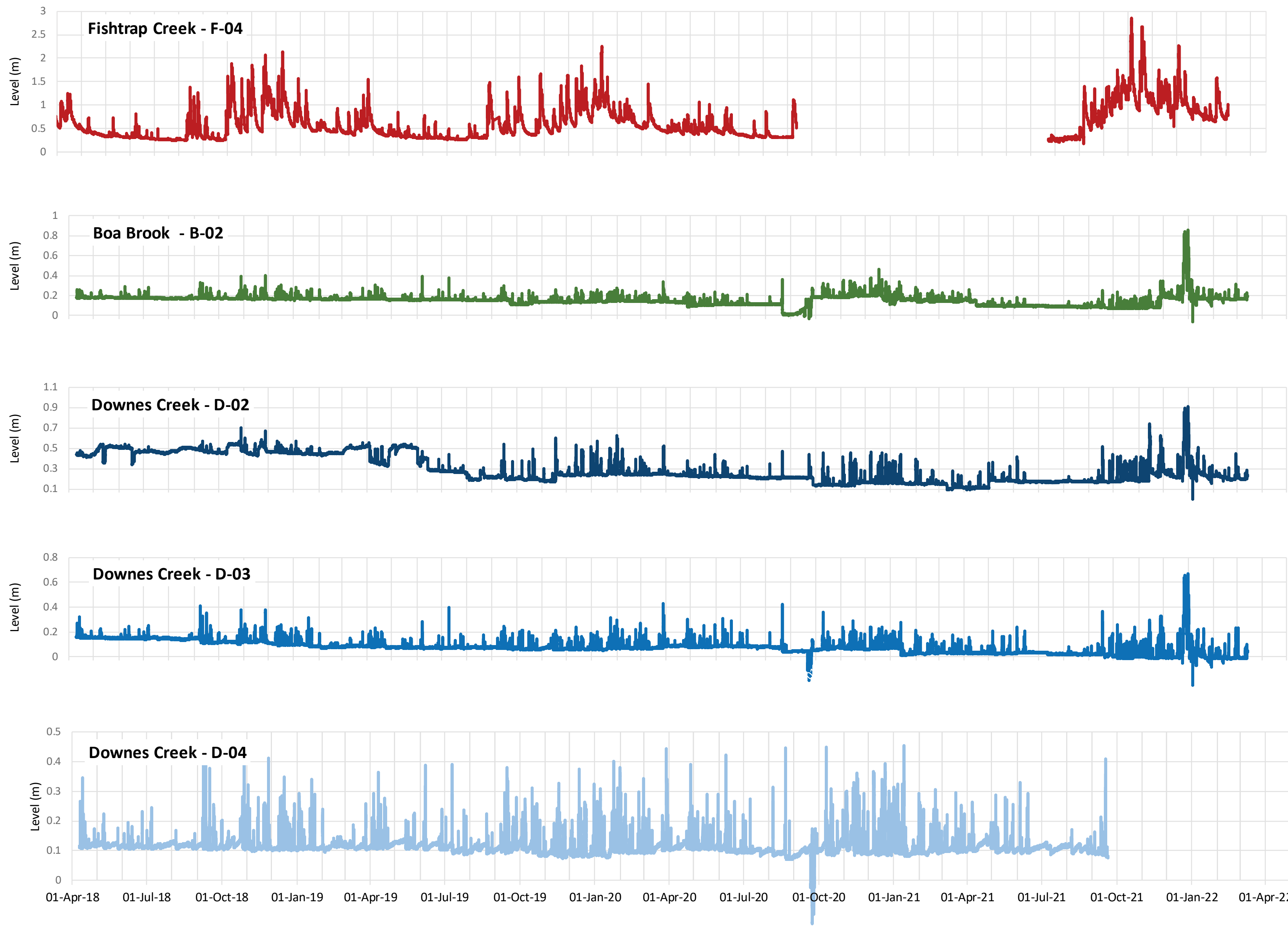


Figure 2-6 Surface Water Levels at Expanded Hydrometric Monitoring Sites

The significance of the ratings curves for both F-04 and WT-01 deteriorated in Year 11. Manually measured low flows at Fishtrap Creek in September 2020 and August 2021 were significantly lower than the calculated flows (Figure 2-7). However, the September 2021 measured flow matched the calculated flow relatively well, as did the October 2021 measured flow at WT-01.

Flows could not be calculated from the water level data recorded at the three Downes Creek hydrometric stations and the B-02 station on Boa Brook as stage-discharged rating curves could not be established. Based on the manual streamflow measurements recorded in Year 11 (Appendix C), flows at B-02 ranged from 6.5 L/s (August 18, 2021) to 41.4 L/s (January 18, 2022). These flows were also the minimum and maximum recorded over the October 2017 – April 2022 monitoring period. In Year 11, stream flows at D-03 and D-04, respectively, ranged from 1.3 L/s (July 12) to 6.3 L/s (Jan. 18) and 1.6 L/s (August 17) to 3.3 L/s (January 18). Minimum flows over the monitoring period were 0.7 L/s at D-03 and 1.0 L/s at D-04 on July 21, 2020. Maximum flows were 9.1 L/s at D-03 and 24.4 L/s at D-03 on May 25, 2020.

In 2018 and 2019, the D-02 hydrometric station was frequently inundated by a beaver dam, which influenced the water levels recorded by the pressure transducer. Large variations in flows, especially very low flow in May 2019, are attributed to beaver dam removal and reconstruction. The beaver dam was not present in August 2019 or subsequently. Flows and staff gauge readings (stages) measured from May 2020 to January 2021 produced a weak stage-discharge relationship (R^2 = 0.61). However, addition of the Year 11 data reduced R^2 to 0.32. Flows measured at D-02 in Year 11 ranged from 32.1 L/s (September 20) to 67.6 L/s (January 18). Over the monitoring period, flows ranged from 0.6 L/s on August 23, 2018 to 80.7 L/s on May 25, 2020. The minimum flow after the summer of 2019, when the stream was no longer affected by beaver dams, was 17.5 L/s on April 8, 2020.

2.4.2 Water Quality

2.4.2.1 Background

A major purpose of the water quality monitoring program is to compare conditions during operation of the Bevan Avenue Wells, and, potentially, during operation of the mitigation wells, to baseline conditions. The intent of project mitigation measures is to meet a standard of no negative change in water quality as a result of the Project. The CCME Water Quality Index (WQI) summarized overall water quality based the extent to which multiple parameters meet federal and provincial guidelines. Thus, the data analysis includes comparing CCME WQI ratings from year to year over the life of the Project. In addition, as the number of years of monitoring increases it becomes possible to conduct statistical analysis of temporal trends in both the WQI and in parameters of particular concern.

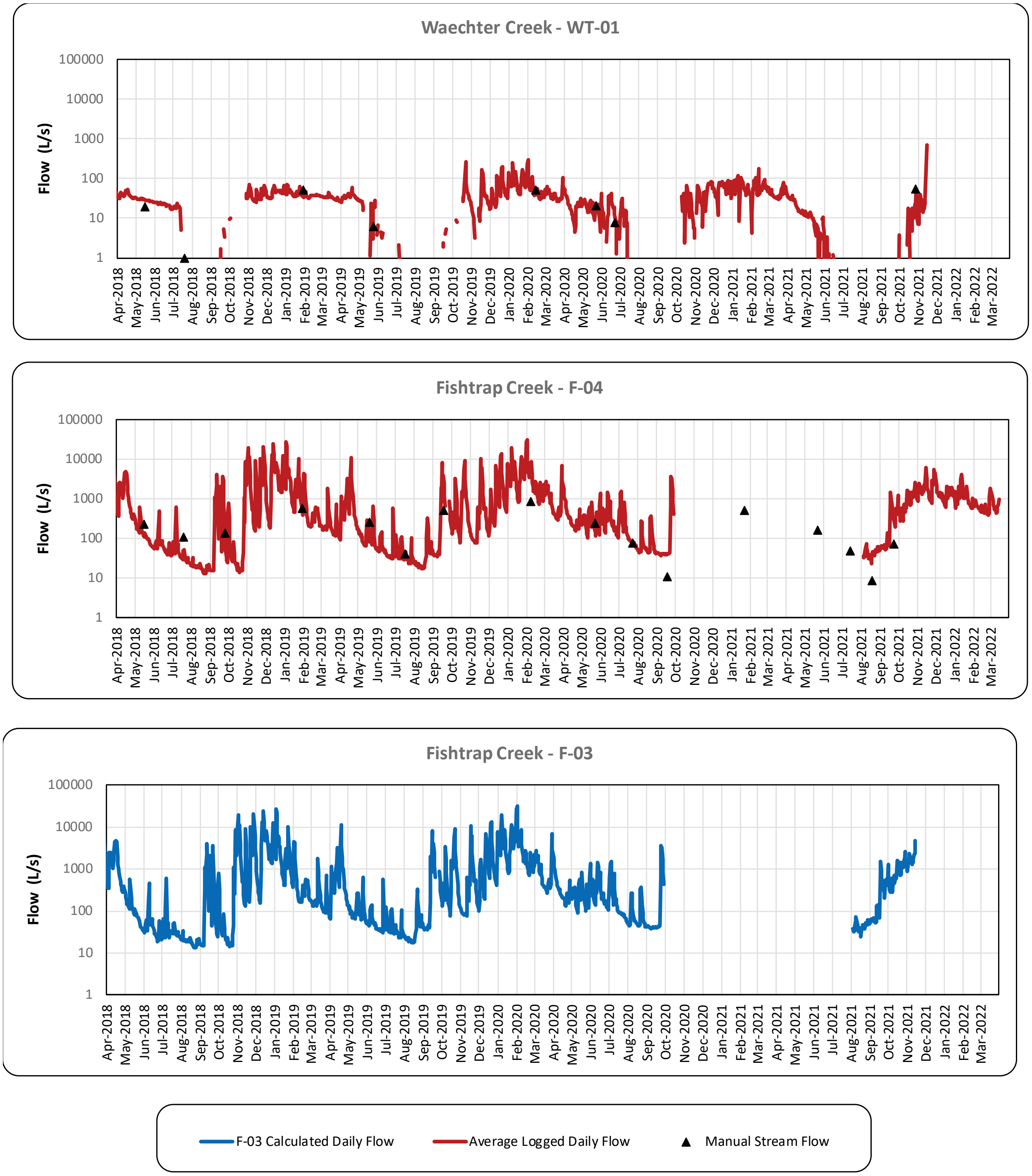


Figure 2-7 Flows at Expanded Hydrometric Monitoring Sites at Fishtrap Creek

Comparison of water quality data to provincial and federal guidelines for freshwater aquatic life should be performed with care when assessing project effects or mitigation effectiveness, as the streams in the monitoring program area are impacted by urban influences and in some cases already exceed various guidelines. However, a discussion of the results in relation to these guidelines is provided to add detail to the CCME WQI ratings and to establish baseline conditions and subsequent changes in these streams. Table 2-3 describes the guidelines used in calculating the CCME WQI ratings and referred to in the discussion of results below. Raw surface water quality results are located in Appendix D (tables) and Appendix E (laboratory reports). Temporal graphs of Years 1 through 11 surface water quality data are located in Appendix F.

2.4.2.2 CCME Water Quality Index Results

Table 2-4 contains the results of the CCME WQI calculations for Year 11. According to the WQI, water quality at most sites was good or fair, with only B-01 rated “marginal.” The Year 11 results are consistent with or slightly better than the baseline results from Year 1 and reflect the fact that water quality in the Abbotsford area is affected by agricultural and urban activities. Potential surface water quality effects of the Project would result from reduced flows producing higher temperatures, lower dissolved oxygen, and lower dilutions rather than inputs of new contaminants.

WQI results for Years 2 through 11 showed some variability but no apparent downward trends (Figure 2-8), suggesting that the use of the Bevan Wells has not significantly affected the water quality in Boa Brook, Horn Creek, Downes Creek, or Fishtrap Creek. Year-to-year variability included upward or downward changes of one category, but differences in the absolute value of the WQI generally were small (Table 2-5).

The mean frequencies of water quality parameters not meeting applicable guidelines from Year 2 to Year 11 are summarized in Figure 2-9. Dissolved oxygen, temperature, phosphorus, fluoride, and a variety of metals did not consistently meet their respective guidelines at any monitoring site. Dissolved oxygen was particularly problematic in the headwaters of Boa Brook and Horn Creek with on average 92.5% and 90.5% of the samples at B-01 and H-01, respectively, having concentrations below the minimum guideline. FOF, which has been monitored only since 2019, had 94.5% of the monthly dissolved oxygen concentrations below the minimum guideline, while F-03 and F-04, which have been monitored from July through October since 2018, had 95% and 100% of dissolved oxygen concentrations below the guideline. In addition, over 50% of the samples from H-03, F-01, F-02, and W-01 (the reference site) did not meet the guideline for dissolved oxygen.

Historically, between 28.2% and 30.3% of the samples from Fishtrap Creek (F-01 and F-02, respectively) have not met the seasonal guidelines for temperature. These incidences occurred most frequently in May. However, from 2018 to 2021 the temperatures in Fishtrap Creek were elevated from April or May through August or September. Among the other monitoring sites the frequencies of temperature exceedances ranged from 11.2% at D-01 to 22.5% at H-01.

Table 2-4 CCME Water Quality Index Results for Year 11

Station	F1	F2	F3	CCME WQI	Sum of Failed Tests	Normalized Sum of Excursion	Total Samples	Number of Variables Tested	Total Tests	Number of Failed Tests	Number of Passed Tests	Number of Tests Below Detection	WQI Category
B-01	47.4	29.4	20.9	65.6	60.1	0.3	12	19	228	67	161	49	F
B-02	42.1	12.3	10.7	73.9	27.3	0.1	12	19	228	28	200	79	F
D-01	26.3	8.8	3	83.9	7.2	0	12	19	228	20	208	100	G
D-02	21.1	11	5.7	85.9	13.8	0.1	12	19	228	25	203	109	G
F-01	36.8	17.1	9.5	75.9	24	0.1	12	19	228	39	189	75	F
F-02	31.6	13.2	17.2	77.9	47.4	0.2	12	19	228	30	198	98	F
F-03	26.3	17.5	18.2	78.9	12.7	0.2	3	19	57	10	47	23	F
F-04	31.6	17.5	10.6	78.3	6.8	0.1	3	19	57	10	47	20	F
FOF	47.4	18.9	27.6	66.5	86.9	0.4	12	19	228	43	185	77	F
H-01	47.4	16.7	6	70.8	14.6	0.1	12	19	228	38	190	75	F
H-02	21.1	5.7	1.4	87.4	3.2	0	12	19	228	13	215	95	G
H-03	36.8	9.6	3.7	77.9	8.9	0	12	19	228	22	206	74	F
W-01	31.6	11	6.2	80.4	15.1	0.1	12	19	228	25	203	84	G

F1 (Scope) – Percent of parameters not meeting guidelines

F2 (Frequency) – Percent of individual tests not meeting guidelines

F3 (Amplitude) – Amount by which failed test values do not meet their guidelines

WQI – Water Quality Index

WQI Categories: G – Good (80-94), F – Fair (65-79), M – Marginal (45-64)

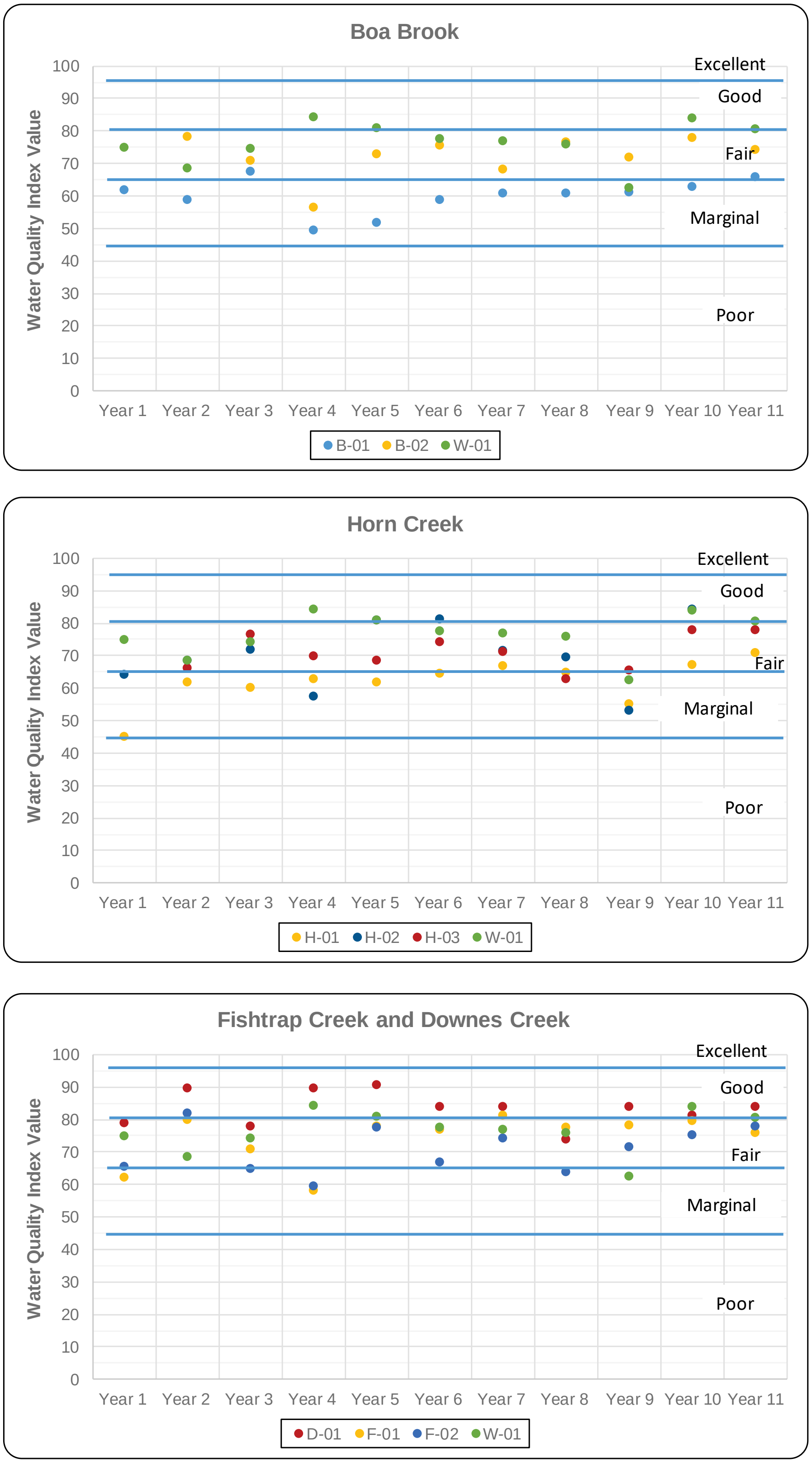


Figure 2-8 Variability in the CCME Water Quality Index, Year 1 to Year 11

Table 2-5 Comparison of the CCME Water Quality Index Results for Year 1 to Year 11

Station	Year 11 WQI	Rating	Year 10 WQI	Rating	Year 9 WQI	Rating	Year 8 WQI	Rating	Year 7 WQI	Rating	Year 6 WQI	Rating	Year 5 WQI	Rating	Year 4 WQI	Rating	Year 3 WQI	Rating	Year 2 WQI	Rating	Year 1 WQI	Rating
B-01	65.6	F	62.7	M	61.1	M	60.8	M	60.7	M	58.5	M	51.6	M	49.4	M	67.3	F	58.7	M	61.6	M
B-02	73.9	F	77.6	F	71.8	F	76.3	F	68.1	F	75.4	F	72.7	F	56.2	M	70.8	F	78.1	F	--	--
D-01	83.9	G	81.2	G	84.0	G	73.9	F	84.0	G	83.7	G	90.5	G	89.7	G	77.9	F	89.5	G	78.9	F
F-01	75.9	F	79.6	F	78.3	F	77.5	F	81.2	G	76.9	F	77.9	F	58.2	M	70.8	F	79.7	F	62.2	M
F-02	77.9	F	75.0	F	71.5	F	63.7	M	74.0	F	66.7	F	77.5	F	59.3	M	64.7	M	81.8	G	65.4	F
H-01	70.8	F	67.2	F	55.2	M	64.6	M	66.7	F	64.4	M	61.9	M	62.7	M	60.1	M	61.9	M	45.0	M
H-02	87.4	G	84.3	G	53.1	M	69.3	F	71.4	F	81.3	G	80.9	G	57.5	M	71.7	F	68.5	F	64.2	M
H-03	77.9	F	77.9	F	65.3	F	62.9	M	71.0	F	74.3	F	68.5	F	69.7	F	76.6	F	66.2	F	--	--
W-01	80.4	G	83.7	G	62.4	M	75.7	F	76.9	F	77.4	F	80.7	G	84.2	G	74.3	F	68.3	F	74.8	F

WQI – Water Quality Index

WQI Categories: G – Good (80-94), F – Fair (65-79), M – Marginal (45-64)

Note that the Downes Creek location was moved in September 2014 due to hazardous trees in the area. Thus, Year 4 represents baseline conditions for the current monitoring location.

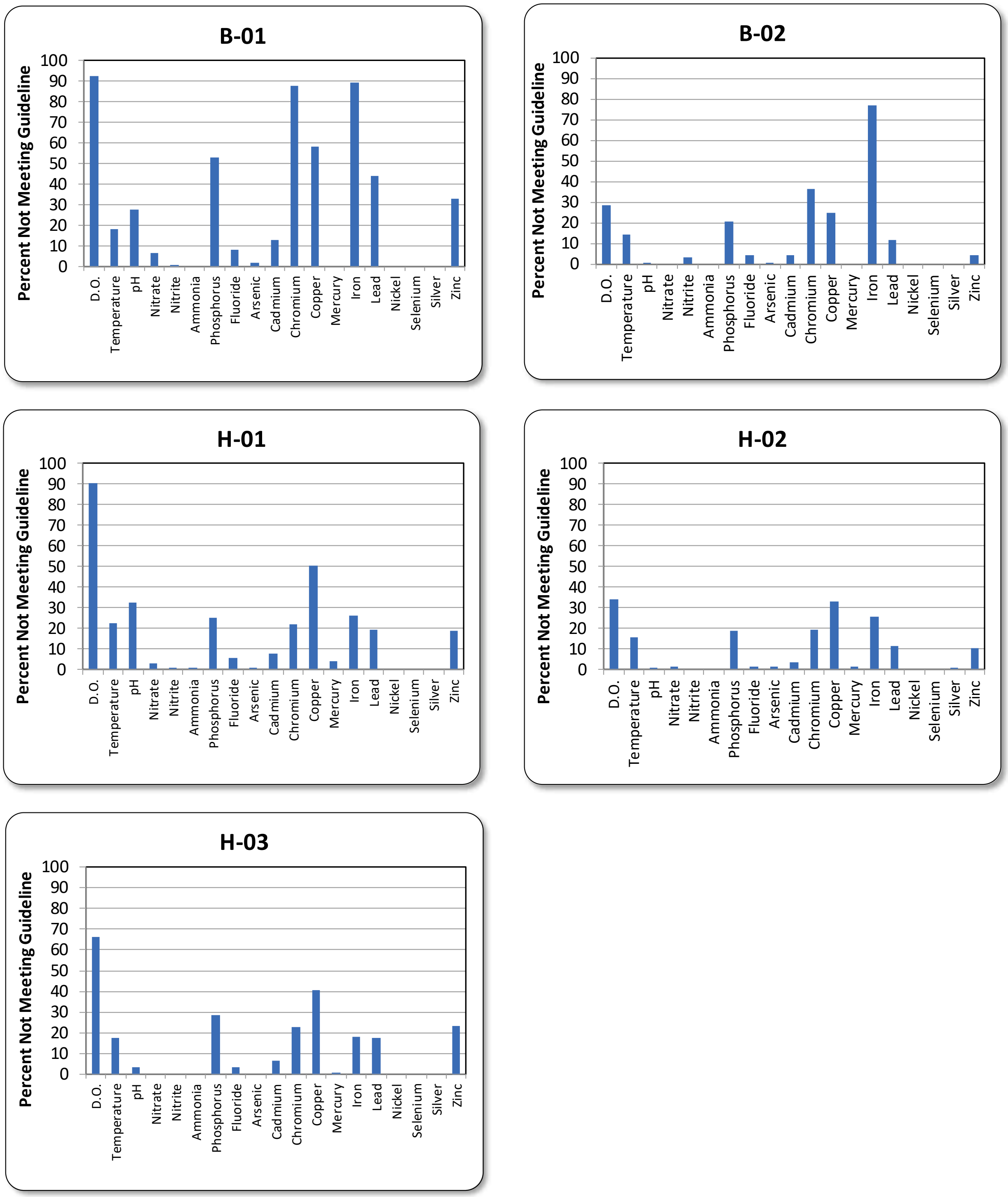


Figure 2-9 Mean Frequencies of Water Quality Parameters Not Meeting Guidelines, 2012-2022

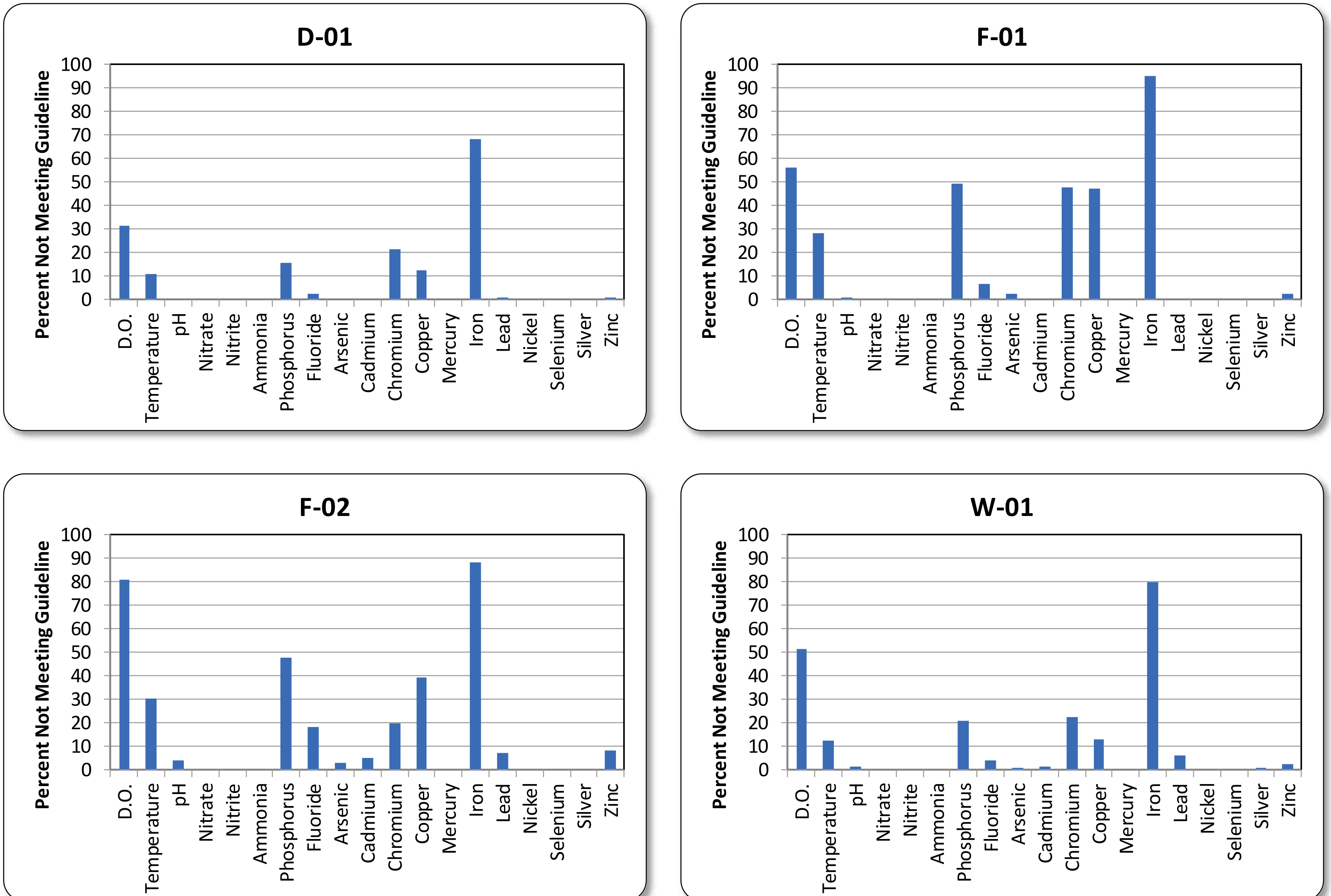


Figure 2-9 Mean Frequencies of Water Quality Parameters Not Meeting Guidelines, 2012-2022 (Continued)

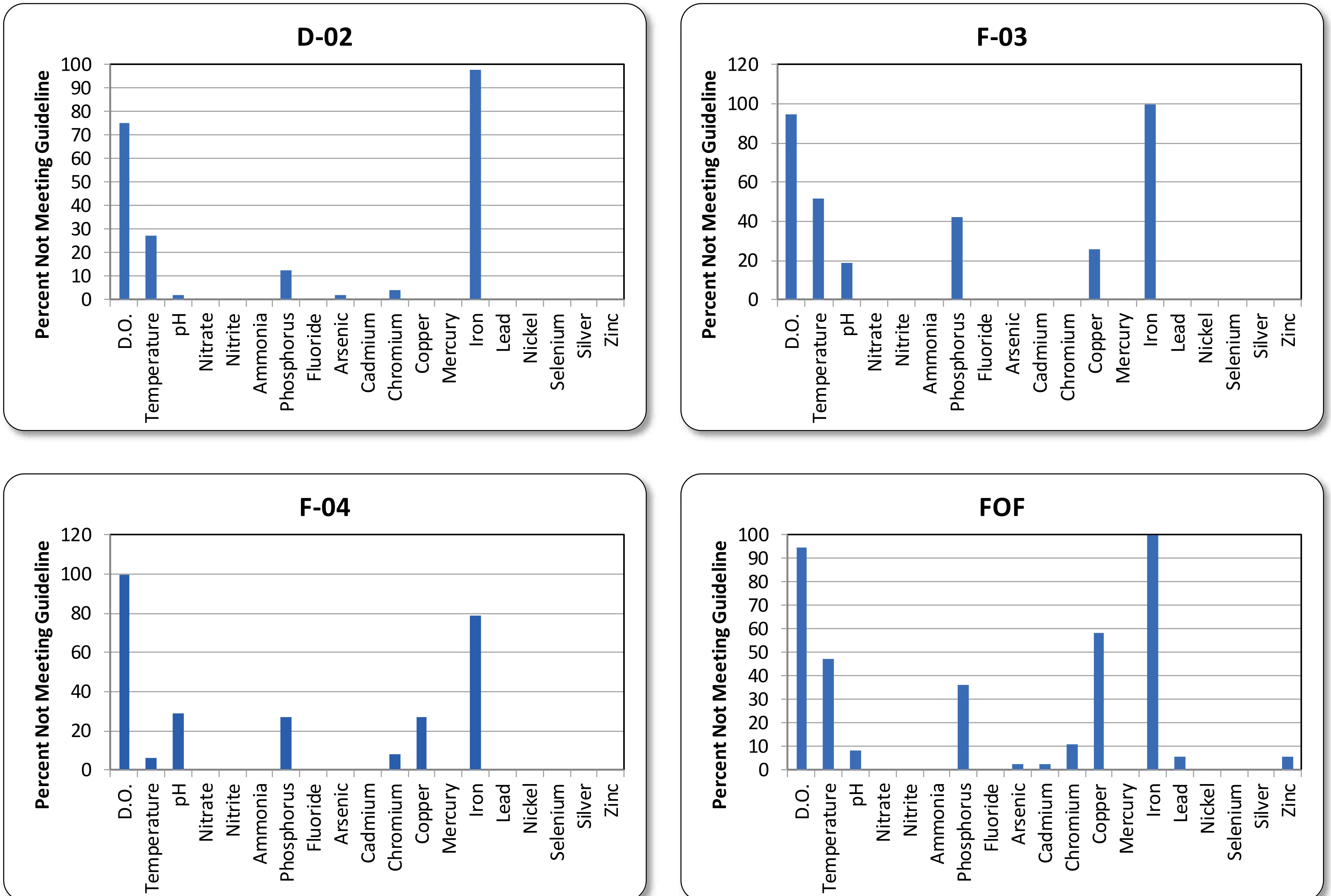


Figure 2-9 Mean Frequencies of Water Quality Parameters Not Meeting Guidelines, 2018-2022 (Continued)

Exceedances at all sites occurred most commonly in May and June, when the winter temperature guideline applies, but there were occasional exceedances in July, August, or September, when the summer guideline applies. In particular, temperatures at most sites were elevated in August 2019.

On average, phosphorus did not meet its guideline in over 50% of the samples from B-01 and ≥48% of the samples from F-01 and F-02, while exceedances occurred in 15.8% to 28.3% of samples from the remaining long-term monitoring sites. The metals most frequently not meeting guidelines were chromium, copper, and iron (Figure 2-9, Appendix G). The metals data suggest an impact from urban sources.

2.4.2.3 Temporal Trend Analysis

Mann-Kendall non-parametric trend tests were performed using the MAKESENS application for Excel (Salmi *et al*. 2002). Trends were assessed on an annual basis and on a seasonal (July-October) basis. Only sites that had at least eight data points for annual and seasonal means were assessed. Parameters tested included the WQI (annual basis only) plus *in-situ* dissolved oxygen and temperature (annual and seasonal basis). Dissolved oxygen and temperature are parameters of particular interest because of their importance for fish habitat quality and because decreases in stream flow can result in higher summer water temperatures and resulting decreases in dissolved oxygen.

The Mann-Kendall test showed no statistically significant decrease in the WQI at any of monitoring sites. However, there was a significant improvement in the WQI at H-01 (Table 2-6).

Table 2-6 Statistical Significance of Mann-Kendall Trends in the CCME Water Quality Index at the Bevan Wells Monitoring Sites

Site	First Year	Last Year	n	Z	Significance
B-01	Year 1	Year 11	11	1.40	
B-02	Year 2	Year 11	10	0.537	
D-01	Year 1	Year 11	11	-0.234	
F-01	Year 1	Year 11	11	0.934	
F-02	Year 1	Year 11	11	0.778	
H-01	Year 1	Year 11	11	2.58	**p <0.01**
H-02	Year 1	Year 11	11	1.40	
H-03	Year 2	Year 11	10	0.629	
W-01	Year 1	Year 11	11	0.467	

MAKESENS calculates the Z approximation to the Mann-Kendall S-statistic for n ≥10.
Negative values of Z or S represent downward trends; positive values represent upward trends.
Blank – Probability (p) >0.1. Significance set at p <0.05.

The tests showed significant negative (downward) trends in annual mean dissolved oxygen concentrations at B-01, H-02 and the Willband Creek reference site (Table 2-7). In addition, there was a significant decreasing trend at H-02 during the summer (July to October) time period. There were no corresponding increases in the summer or annual temperatures, which suggests that the use of the Bevan Wells was not responsible for the decreases in dissolved oxygen. There were no significant trends in dissolved oxygen at the other monitoring sites on Boa Brook and Horn Creek.

Table 2-7 Statistical Significance of Mann-Kendall Trends in Dissolved Oxygen and Temperature at the Monitoring Sites in Boa Brook, Horn Creek, and Willband Creek

Parameter	Site	Time Series	First Year	Last Year	N	S or Z	Significance
Dissolved Oxygen	B-01	Annual	Year 1	Year 11	11	-3.11	**p <0.01**
		Jul - Oct	Year 1	Year 11	11	-1.87	p <0.10
	B-02	Annual	Year 3	Year 11	9	-12	
		Jul - Oct	Year 3	Year 11	9	-10	
	H-01	Annual	Year 1	Year 11	11	-0.311	
		Jul - Oct	Year 1	Year 11	11	-0.156	
	H-02	Annual	Year 1	Year 11	11	-2.96	**p <0.01**
		Jul - Oct	Year 1	Year 11	11	-2.34	**p <0.05**
	H-03	Annual	Year 1	Year 11	9	-6	
		Jul - Oct	Year 1	Year 11	9	-8	
	W-01	Annual	Year 1	Year 11	11	-2.02	**p<0.05**
		Jul - Oct	Year 1	Year 11	11	-1.25	
Temperature	B-01	Annual	Year 1				
		Jul - Oct	Year 1	Year 11	11	1.56	
	B-02	Annual	Year 3	Year 11	11	0.311	
		Jul - Oct	Year 3	Year 11	9	8	
	H-01	Annual	Year 1	Year 11	9	4	
		Jul - Oct	Year 1	Year 11	11	1.09	
	H-02	Annual	Year 1	Year 11	11	0.467	
		Jul - Oct	Year 1	Year 11	11	1.87	p <0.10
	H-03	Annual	Year 1	Year 11	11	-0.156	
		Jul - Oct	Year 1	Year 11	9	6	
	W-01	Annual	Year 1	Year 11	9	6	
		Jul - Oct	Year 1	Year 11	11	0.623	

MAKESENS calculates the Z approximation to the Mann-Kendall S-statistic for $n \geq 10$.
Negative values of Z or S represent downward trends; positive values represent upward trends.
p – probability. Blank indicates $p > 0.1$. Significance (indicated by **bold**) set at $p < 0.05$.

Prior to Year 8, water quality in Downes Creek (D-01) and Fishtrap Creek (F-01 and F-02) was monitored in April, September, October, and January. Therefore, the available data were insufficient to analyze seasonal or annual trends. However, trends during each of the four months were analyzed. The only statistically significant trend in these watercourses was a decreased in dissolved oxygen in May at F-02 (Table 2-8).

2.4.2.4 Quality Control Results for Surface Water Samples

<u>Laboratory QC</u>

Appendix E contains the full report of ALS's and BV's QC samples and results. Overall, the laboratory's QC results were good with most samples meeting the laboratory's data quality objectives (DQO). Several spike recoveries did not meet the DQO for all metals. These tests and parameters are listed in Table 2-9. However, BV noted in all cases that the results of the multi-element scans met acceptability criteria.

<u>Field QC</u>

Field QC included one travel blank, one field blank, and one duplicate sample per month. Complete field QC results are presented in Appendix D.

The results of the travel blanks were excellent with no analytes detected in 9 of the 12 blanks. The May 2021 travel blank contained total phosphorus, while the March 2022 sample contained nitrate, and the October 2021 sample contained total sodium. The concentrations of all three substances were <2 times the detection limit. Phosphorus and sodium were not detected in the corresponding field blanks, while the nitrate concentration in the field blank was lower than that in the travel blank. Thus, contamination in the travel blanks apparently did not affect the sample results.

Results of the field blanks also were excellent overall. The only substances detected were total ammonia and total copper in the January 2022 field blank and nitrate in three field blanks (July 2021, January 2022, and March 2022. The concentrations of nitrate and copper in the blanks were <3 times the detection limits. The concentration of total ammonia was extremely elevated at 1.4 mg/L (over 93 times the detection limit) and higher than the concentration in any associated sample.

The Resource Inventory Standards Committee (RISC, 1998) recommends that concentrations of parameters detected in blanks not exceed 10% of the applicable water quality guideline(s) or 10% of the sample concentrations. The nitrate concentrations in all three affected field blanks were <0.2% of the CCME guideline (2.9 mg/L as N). The concentration of copper in the January 2022 blank was 38% of the most restrictive CCME guideline (2 μg/L for hardness <50 mg/L as $CaCO_3$) and might have contributed to guideline exceedances observed at D-01 and FOF. Guideline comparisons for ammonia were not compromised because all ammonia concentrations met the applicable guideline.

Table 2-8 Statistical Significance of Mann-Kendall Trends in Dissolved Oxygen and Temperature at the Monitoring Sites in Downes Creek and Fishtrap Creek

Parameter	Site	Time Series	First Year	Last Year	n	Z or S	Significance
Dissolved Oxygen	D-01	May	2013	2022	10	0.358	
		September	2012	2022	10	0.179	
		October	2013	2022	10	0.00	
		January	2012	2022	9	-10	
	F-01	May	2013	2022	9	-6	
		September	2012	2022	11	1.09	
		October	2013	2022	10	0.179	
		January	2012	2022	9	-6	
	F-02	May	2013	2022	10	-2.33	**p<0.05**
		September	2014	2022	9	18	p<0.1
		October	2013	2022	10	-1.17	
		January	2013	2022	10	-1.43	
Temperature	D-01	May	2013	2022	10	-0.716	
		September	2012	2022	10	1.07	
		October	2013	2022	10	0.00	
		January	2012	2022	11	1.17	
	F-01	May	2013	2022	10	-0.72	
		September	2012	2022	11	0.62	
		October	2013	2022	10	0.09	
		January	2012	2022	11	1.64	
	F-02	May	2013	2022	10	-0.27	
		September	2014	2022	9	13	
		October	2013	2022	10	0.00	
		January	2013	2022	10	1.17	

MAKESENS calculates the Z approximation to the Mann-Kendall S-statistic for n ≥10.
Negative values of Z or S represent downward trends; positive values represent upward trends.
p – probability. Blank indicates p >0.1. Significance (indicated by **bold**) set at p <0.05.

Table 2-9 Parameters Not Meeting the Laboratory Quality Control Limits

Parameter	Sample Batch	QC Test and Units	Result	DQO
Total Mercury	Jul. 13	Spike Recovery (%)	74%	80-120
Total Mercury	Jul. 14	Spike Recovery (%)	78%	80-120
Total Mercury	Sep. 23	Spike Recovery (%)	73%	80-120
Total Mercury	Oct. 25	Spike Recovery (%)	74%	80-120
Total Mercury	Nov. 26	Spike Recovery (%)	121%	80-120
Total Mercury	Dec. 15	Spike Recovery (%)	73%	80-120
Total Aluminum	Jan. 18 & 19	Spike Recovery (%)	126%	80-120
Total Bismuth	Mar. 14	Spike Recovery (%)	79%	80-120
Total Iron	Mar. 14	Spike Recovery (%)	123%	80-120
Total Silicon	Mar. 14	Spike Recovery (%)	127%	80-120
Total Zirconium	Mar. 14	Spike Recovery (%)	128%	80-120
Total Bismuth	Apr. 20	Spike Recovery (%)	64%	80-120

Results of the most field duplicate samples were excellent with relative percent differences (RPD) rarely exceeding the 25% recommended by RISC (1998) for field duplicates in which one or both concentrations are ≥5 times the detection limit. The primary exception was the January 2022 field blank in which RPDs for total ammonia, total phosphorus, nitrite, aluminum, copper, iron, manganese, magnesium, and potassium were elevated. The duplicate samples were collected ten minutes apart and thus might have been affected by short-term environmental variability.

2.5 Successes, Challenges and Suggested Changes

During the monitoring period April 2021 – Oct 2021 at the new Fishtrap Creek SCADA station, two low flow measurements at two significantly different water levels (0.55 m and 0.95 m) had the same flow of approximately 11 L/s. Having the same flow measured at two different stages makes it difficult to develop a rating curve as the rating curve relies on each water level having a unique flow associated with it. Having two different stages (especially 0.4 m apart) with the same flow has created an uncertainty in the rating curve, especially at the low flow end of the curve. It is not clear whether the flows are being affected by the hydraulic conditions at the site, the significant instream vegetation, both, or other factors. Until more flow measurements can be completed at the low end of the flow regime to confirm the current flow measurements it is not possible to provide reliable low flow time series data for this period.

Flow monitoring at several sites experienced challenges related to unusually high water levels. Flooding associated with an atmospheric river in November 2021 resulted in dislodging the WT-01 flow monitoring station (staff gauge, PVC pipe, and Hobo logger). High water persisted to the extent that the F-04 staff gauge was fully submerged in January 2022, and the stream was too deep for manual flow measurements. The D-04 Hobo logger was missing in January 2022, although it might have been stolen rather than washed away.

Low water also presented challenges. The staff gauge at B-01 was above the water line from July through October 2021. Waechter Creek was dry at the WT-01 monitoring station from July through September 2021, and in May 2021 the water level was too low for an accurate manual flow measurement. A dry channel was previously an issue at WT-01 in August 2020.

The expanded flow monitoring stations have consistently been problematic. The manual stream flow data recorded at B-02, D-02, D-03 and D-04 have been too variable to establish a stage-discharge rating curve. Waechter Creek at WT-01 has frequently been dry during the summer. Additionally, high winter flows in 2022 made some sites unsuitable for wading measurements, and the atmospheric river in November 2021 caused the loss of two monitoring stations. ENKON recommends that a qualified professional hydrologist in consultation with a qualified professional fisheries biologist re-evaluate the expanded flow monitoring sites to determine whether:

- monitoring at these sites can provide sufficiently accurate flows to determine temporal trends in summer low flows;
- sufficiently accurate flow monitoring can be achieved without significant channel configuration (e.g., weir installation) and if not, whether the flow data is valuable enough to warrant the disturbance to fish habitat; and
- whether the program objectives (identification of negative effects on fish habitat) can be achieved through seasonal flow monitoring (manual measurements) in conjunction with the current mesohabitat monitoring program.

3.0 FISH HABITAT PROGRAM

3.1 Background

The following section describes the fish habitat monitoring program that was conducted as per the requirements of the OEMP (ENKON, 2018) and the Fish Habitat Characterization Work Plan (Hemmera, 2011a). The objectives of the monitoring program are to assess the effectiveness of mitigation in minimizing effects to fish and fish habitat if flows in Horn Creek, Boa Brook, Fishtrap Creek and/or Downes Creek are reduced by use of the Bevan Wells.

Although fish species lists for Horn Creek and Boa Brook are not available, these streams form part of the Willband Creek watershed, which does have a list of identified species (MoE, 2012). Based on the fish species list for Willband Creek, fish species assumed to be present within headwater areas including tributary streams such as Horn Creek and Boa Brook include Coastal Cutthroat Trout (*Oncorhynchus clarkii clarkii*), Coho Salmon (*O. kisutch*) and Threespine Stickleback (*Gasterosteus aculeatus*) (Hemmera, 2010). Golder Associates (Golder) biologists conducted fish salvage activities in the headwaters reach of Horn Creek in August 2011 prior to in stream works; species caught during this work included Rainbow Trout (*O. mykiss*), Cutthroat Trout and Coho Salmon (personal communication, Rob Hoogendor, Golder, 2011).

Fish sampling conducted by ENKON (2016) documented Coho Salmon and Cutthroat Trout within Downes Creek headwaters. Fish were found to be well distributed within the Downes Bowl stream network, often far upstream and in proximity to the immediate channel headwaters. Fishtrap Creek supports populations of Salish sucker (*Catostomus sp.)* and Nooksack Dace (*Rhinichthys cataractae*) which are listed as endangered under Schedule 1 of the federal *Species at Risk Act* (SARA). Salmonids species present in Fishtrap Creek include Coho, Cutthroat Trout, and Rainbow Trout.

3.2 Monitoring Sites

During Year 1 of the monitoring program, six representative sites for the assessment of fish habitat (approximately 50 m long, one per reach) were chosen (two on Boa Brook and four on Horn Creek) based on aerial photographs and topographic maps. Sites were chosen to coincide with water quality/stream flow sites, where possible. These site locations were confirmed during the sampling event in July 2011. Mesohabitats within each reach were identified (e.g., pools, glides, runs, riffles, cascades, etc.), and one site per mesohabitat type present was then chosen at random and georeferenced to establish a transect.

In fall 2017, additional fish habitat monitoring sites were established at Downes Creek and Fishtrap Creek, as required by the Mitigation Plan (ENKON 2017), which was developed as part of the 2017 EAC amendment. Seven sites were selected (three on Downes Creek and four on Fishtrap Creek). Mesohabitat sites were set up consistent with the pre-existing mesohabitat sites at Boa Brook and Horn Creek. Monitoring of these sites commenced in summer 2018. Mesohabitat site locations are described in Table 3-1 and shown on Figure 3-1, 3-2 and 3-3.

3.3 Schedule

The period where base flows are most likely to be affected in the subject streams is during the summer and early fall. This occurs after salmonid fry emergence (spring) and before adult chum (mid-October to November) and coho spawning migrations (November to December). Fish habitat monitoring was carried out once a month beginning in July and ending in October. In accordance with Condition #27 of the amended EA certificate, a representative from Matsqui First Nations was invited to accompany ENKON monitoring staff on each visit. A Matsqui First Nations representative accompanied ENKON on October 27 and 29. The Matsqui representative assisted with data collection and input and equipment coordination. The Matsqui First Nation did not respond to the invitations to participate in July and August. In September the Matsqui elected to participate in vegetation monitoring rather than mesohabitat monitoring.

3.4 Methods

The methods for fish habitat monitoring are described below and were adapted from Lewis et al.(2004). During the Year 1 to Year 7 monitoring, general characteristics that were assessed over each 50 m site reach included:

- Mesohabitat Types;
- Channel type: confinement, channel pattern, islands/bars;
- D95 Particle Diameter;
- Gradient;
- Substrate Type: % of each size class;
- Cover: presence of deep pools, boulders, in stream vegetation, overhanging vegetation, large woody debris (LWD) and/or canopy closure; and

During the Year 8 through Year 11 monitoring program substrate, D95 particle diameter and cover were assessed at each mesohabitat within a site, rather than at the reach level as was done in previous monitoring years.

Table 3-1 Fish Mesohabitat Sites

Watercourse	Site	Mesohabitat Site	Northing	Easting	Mesohabitat Type
Horn Creek	1	1A	5434383	550784	Riffle
		1B			Run
	2	2A	5434420	550482	Pool
		2B			Riffle
		2C			Run
	3	3A	5434412	550693	Run
		3B			Riffle
		3C			Pool
	6	6A	5434032	550243	Run
		6B			Riffle
Boa Brook	4	4A	5434288	550643	Run
		4B			Pool
	5	5A	5433794	550812	Pool
		5B			Riffle
		5C			Run
		5D			Pool
Downes Creek	D-02	D-02 riffle	5435914	549145	Riffle
		D-02 pool	5435897	549141	Pool
	D-03	D-03 riffle	5435429	549298	Riffle
		D-03 pool	5435450	549280	Pool
	D-04	D-04 riffle	5435292	549174	Riffle
		D-04 pool	5435333	549181	Pool
Fishtrap Creek	F-01	F-01 riffle	5433414	546387	Riffle
		F-01 pool	5433389	546388	Pool
	F-02	F-02 riffle	5431957	545249	Riffle
		F-02 pool	5432145	545274	Pool
	F-03	F-03 pool	5430294	544039	Pool
	F-04	F-04 riffle	5430325	544016	Riffle
		F-04 pool	5430354	544039	Pool

Note: UTM Coordinates are NAD83, Zone 10U

At each selected mesohabitat site within the reach, physical characteristics (i.e., channel width, bankfull depth and wetted width) were assessed. A transect was established and marked with flagging tape and coordinates were established with a Garmin GPS unit.

All information was recorded in the field on RISC site cards. Photo documentation of each transect and site sampled was taken following protocols in the *British Columbia Photo Documentation Guidelines for Aquatic Inventory* (RISC, 1996).

3.5 Results

3.5.1 Biophysical Characteristics

Biophysical habitat characteristics measured at the 13 sites at Horn Creek, Boa Brook, Downes Creek and Fishtrap Creek are described below. A summary of biophysical data is presented in Appendix H.

3.5.1.1 Horn Creek

Biophysical habitat characteristics were measured at three sites within the project area along Horn Creek (Figure 3-1).

<u>Site 1 – Horn Creek</u>

Site 1 is located downstream of the confluence of Horn Creek and Boa Brook. This site was chosen to coincide with water quality monitoring site H-02 and to represent the reach of Horn Creek between Boa Brook and Maclure Road. Two mesohabitat types were identified here: a riffle (Mesohabitat Site 1A) and a run (Mesohabitat Site 1B).

Channel morphology at Site 1 was straight, unconfined, and had a low gradient (1-2%). The reach has undercut banks, over hanging vegetation and trace amounts of instream vegetation and small woody debris (SWD). One piece of suspended large woody debris (LWD) upstream from Site 1A was swept downstream between the August 2020 and September 2020 monitoring visits. Deep pools were only observed at Site 1A.

The substrate at Site 1A shifted from a fines (40%) and gravel (55%) mix to primarily fines (83%) in September 2020. By July 2021 (Year 11) the substrate had shifted to 20% fines and 75% gravel, but the proportion of fines increased over the summer, reaching 60% in October. In September ENKON noted that the pool had infilled with fines. Minimal cobbles (5%) were present. D95 ranged from 11 cm to 18 cm for both sites. Embeddedness ranged from 15% to 30% throughout the reach during the four monitoring visits. Canopy closure was moderate for both sites, averaging 29% and 54% for Site 1A and Site 1B, respectively.

Legend

- Mesohabitat site
- Abbotsford-Sumas aquifer
- Streams
- Waterbody

Prepared by:
ENKON Environmental Ltd.

Horn Creek and Boa Brook Mesohabitat Monitoring Sites

City of Abbotsford

Created: December 2019
Projection:
NAD 83 UTM Zone 10N
1:3,000

Figure 3-1

Legend

- Mesohabitat site
- DownesTrails
- Abbotsford-Sumas aquifer
- Waterbody

Watercourses (CoA Modified)

- Class A (fish-bearing)
- Class Ao (overwintering)
- Class B (food and nutrient)
- Permanent (Unclassified)

Prepared by: ENKON Environmental Ltd.

Created: December 2019
Projection:
NAD 83 UTM Zone 10N
1:2,500

Downes Creek Mesohabitat Monitoring Sites

City of Abbotsford

Figure 3-2

Legend

- Mesohabitat site
- Abbotsford-Sumas aquifer
- Streams
- Waterbody

Prepared by: ENKON Environmental Ltd.

Created: December 2019
Projection:
NAD 83 UTM Zone 10N
1:10,000

Fishtrap Creek
Mesohabitat Monitoring Sites

City of Abbotsford

Figure 3-3

Photographs 3-1 Site 1 (Horn Creek) – July and September 2021

1A Facing Downstream (July 2021)

1B Facing Downstream (September 2021)

Site 2 – Horn Creek

Site 2 is located upstream of Trafalgar Road and between two unnamed tributaries to Horn Creek. Three mesohabitat types were identified here: a pool (Mesohabitat Site 2A), a run (Mesohabitat Site 2B), and a riffle (Mesohabitat Site 2C).

Site 2 had a confined sinuous and straight channel and gradient of 2%. Sand and gravel side bars were observed during all monitoring events. This site had good salmonid rearing habitat values, along with moderate values for overwintering and spawning habitat.

The pool mesohabitat (2A) substrate was dominated by gravel (average 60%). The proportion of fines ranged from 10% to 20% throughout the 2021 monitoring visits. Cobble and boulders remained consistent throughout the monitoring season averaging at 10% and 14%, respectively. Embeddedness was consistent, ranging from 10% to 15%.

The dominant cover type was boulders with deep pools as the subdominant cover type. Trace amounts of overhanging vegetation, instream vegetation, SWD and LWD were also present. Crown closure averaged at 59% throughout the monitoring season.

The run mesohabitat (2B) had predominately gravel substrate (average 41%), with lesser amounts of cobble (26%), fines (14%), and boulders (19%). Cover within the site was dominated by boulders with SWD and LWD being the subdominant cover. A small section of undercut bank and trace amounts of overhanging vegetation were also available for cover. Crown closure dropped from 50% in July 2020 to 5-15% in the later months of 2020 and ranged from 0% to 10% in 2021 . D95 averaged 16.5 cm.

Site 2C (riffle) had substrate composition similar to Site 2B. Gravels dominated (53%) with lesser amounts of cobble (13%), fines (20%), and boulders (15%). Undercut bank was the dominant cover type with a subdominant component of boulders. After the August 2020 site visit crown closure dropped from 50% to 0%-5% and remained low (0%-15%) throughout the 2021 monitoring period. Site 2C had an average D95 of 14 cm.

The average substrate embeddedness for this reach ranged from 11% at Site 2A and 2B to 10% at Site 2C in Year 11.

Photographs 3-2 Site 2 (Horn Creek) – July and September 2021

2A Facing Upstream (September 2021)

2B Facing Upstream (July 2021)

2C Facing Downstream (September 2021)

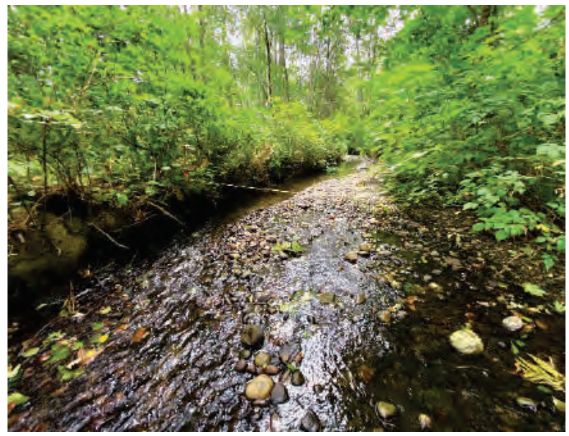
<u>Site 3 – Horn Creek</u>

Site 3 is located between the Trafalgar Street culvert and the confluence of Horn Creek and its tributary Boa Brook. Three mesohabitat types were identified here: a run (Mesohabitat Site 3A), a riffle (Mesohabitat Site 3B) and a pool (Mesohabitat Site 3C).

Channel morphology at Site 3 was straight and frequently confined with a gradient of 1% to 2%. Sand and gravel side bars were observed during all monitoring events. Site 3 had good rearing and overwintering habitat values, along with moderate spawning habitat values for salmonids.

Photographs 3-3 Site 3 (Horn Creek) – August 2021

3A Facing Downstream



3B Facing Downstream

3C Facing Downstream

The dominant substrate material at Site 3A (run mesohabitat) was gravel (60%). Fines served as the subdominant material (23%), with small amounts of cobble (13%) and boulders (5%). The dominant cover type was undercut banks with overhanging vegetation subdominant and deep pools subdominant in July 2021 only. Trace amounts of instream vegetation, LWD, SWD, and boulders were also present as potential cover. Crown closure ranged from 45% to 70%.

Site 3B had a substrate composition dominated by gravels (73%) with fines (19%) and cobble (9%). The dominant cover type was undercut banks with overhanging vegetation as the subdominant cover. Trace amounts of instream vegetation, SWD and LWD were also present. Crown closure was less than site 3A, ranging from at 35% to 50%.

In 2020, the substrate composition changed from primarily gravels in July and August to 85% fines in September to October. Fines remained dominant in 2021, ranging from 55% to 75%. The dominant cover type was deep pools with undercut banks and sometimes overhanging vegetation subdominant. Instream vegetation and SWD were also present in trace amounts. Crown closure ranged from 0% to 20% at Site 3C.

Embeddedness across all three mesohabitat sites ranged from 18% at 3B and 3C to 25% at 3A. Site 3C had the smallest D95 (average 11 cm) while Sites 3A and 3B had average D95 values of 16 cm and 13 cm, respectively.

<u>Site 6 – Horn Creek</u>

Site 6 represents the headwaters reach of Horn Creek and overlaps with water quality monitoring site H-03. Two mesohabitat types were identified here: a run (Mesohabitat Site 6A) and a riffle (Mesohabitat Site 6B). This reach of Horn Creek is almost entirely fed by urban storm water and may see more variable flows than reaches farther downstream (Piteau, 2010).

The channel pattern at Site 6 was straight. The site had a confined channel, with an average gradient of 1.9%. Site 6 had good rearing and moderate overwintering habitat values, but limited spawning habitat potential for salmonids.

Photographs 3-4 Site 6 (Horn Creek) – August 2021

6A Facing Upstream

6B Facing Downstream

At the pool mesohabitat site (6A), substrate consisted of gravel (63%), fines (23%), and cobbles (14%). Deep pools were the dominant cover type for this site with overhanging vegetation and LWD being the subdominant. Other cover types were present in trace amounts; they included instream vegetation, undercut banks, and SWD. Crown closure was high, averaging 83%, and much higher than at the riffle site (6B).

Site 6B had a substrate composition of gravel (60%), cobbles (21%), fines (11%), and boulders (7.5%). The dominant cover type for 6B was boulders, except that overhanging vegetation was dominant in September 2021. Overhanging vegetation was subdominant in July, August, and October with deep pool also identified as a subdominant cover type in October. A new scour pool had formed earlier in the year as noted during the July 2021 monitoring visit. Instream vegetation, undercut banks, and SWD were present in trace amounts. Crown closure averaged 19%.

On average, the D95 and embeddedness were very similar between the two mesohabitat sites. D95 averaged 15 cm at Site 6A and 17 cm at Site 6B. Embeddedness was slightly lower at 6B (9%) than at Site 6B (11%).

Boa Brook

Site 4 – Boa Brook

Site 4 is situated as close to surface water monitoring site B-01 as possible while still representing a reach where meaningful measurements of stream flow and other habitat characteristics are possible. It represents the headwater reach of Boa Brook, delineated at its downstream end by a steeper gradient section of the stream. One mesohabitat site, a run (Mesohabitat Site 4A), was identified at this location in 2011, and in 2012 a pool was added (Site 4B).

Photographs 3-5 Site 4 (Boa Brook) – September 2021

4A Facing Downstream

4B Facing Upstream

Site 4 had a confined, sinuous channel with a gradient of 1.5%. Side bars consisting of fines were present during most monitoring visits. Crown closure was variable, ranging from 10% to 20% in July, August, and September 2021 but reaching 95% in October at both Site 4 mesohabitat locations. The substrate at both 4A and 4B was entirely fines. Cover at the run mesohabitat (4A) site was dominated by SWD and LWD with trace amounts of overhanging vegetation in September and October. Dominant cover at the pool mesohabitat (4B) was deep pool with undercut banks and SWD subdominant. Trace amounts of LWD were also present. Overall fish habitat quality at Site 4 was poor due the location in the upper headwaters of Boa Brook, along with the lack of spawning habitat, overwintering habitat, and limited cover for salmonids.

Site 5 – Boa Brook

Site 5 represents the reach between the confluence with Horn Creek and a steeper gradient section of Boa Brook as identified by online mapping (MoE, 2011). The location of Site 5 was somewhat constrained by access concerns, as most of this reach of Boa Brook can only be accessed through private property. Three mesohabitat types were identified here: two pools (Mesohabitat Site 5A and 5D), a riffle (Mesohabitat Site 5B); and a run (Mesohabitat Site 5C).

The channel at Site 5 was meandering and frequently confined by steep ravine slopes. The average gradient was 2%, although this measurement may not be accurate due to the short lines of sight at Site 5. Side sand and gravel bars were recorded at all Site 5 mesohabitats.

The dominant cover type for the four mesohabitat sites included undercut banks, some extending as far as 70 cm. However, at Site 5A deep pool habitat became dominant from August through October 2021 with undercut banks subdominant. The subdominant cover at sites 5B 5C, and 5D was overhanging vegetation. Site 5A also had a subdominant cover of LWD. All sites had trace amounts of SWD, and all sites had variable traces of instream vegetation. Field staff recorded a few boulders at Sites 5B and 5D. Crown closure was relatively high the four sites with averages ranging from 76% to 89%.

Substrate composition varied among the four sites. Fines were dominant at Site 5A (60%-90%) and 5C (70%-90%), while gravel dominated at 5B (70%-90%) and 5D (60%-70%). Cobble percentages were low, averaging between 0% and 4% at the four sites.

Average embeddedness ranged from 11% (5B) to 29% (5A). Average D95 was similar across all four sites ranging from 7 cm (5A) to 11 cm (5C). Site 5 had moderate quality habitat values for salmonid rearing and overwintering, but only relatively low spawning habitat values due to the shallowness of the stream and low amounts of spawning gravel.

Photographs 3-6 Site 5 (Boa Brook) – Summer 2021

5A Facing Upstream (August 2021)

5B Facing Upstream (July 2021)

5C Facing Upstream (July 2021)

5D Facing Downstream (September 2021)

Downes Creek

Year 11 represents the fourth year of fish habitat monitoring at Downes Creek. Three sites were established within the headwater tributaries of Downes Creek.

D-02

Site D-02 is located approximately 30 m upstream from Downes Road (Figure 3-2). D-02 is located on a tributary that drains the Downes Creek headwaters and overlaps with water quality monitoring site D-02. It represents the lower reach of the stream, between the

Downes wetland and the confluence with Downes Creek. Two mesohabitats were identified here: a pool (D-02-pool) and a riffle (D-02-riffle).

D-02 is a low gradient (2%) stream with a straight and confined channel. A side barwas noted at D-02 pool in July 2021 but not during any of the subsequent assessments. Substrate at the D-02 pool mesohabitat site averaged 98% fines. In July 2021, 10% gravel was present with an embeddeness of 5%. During the rest of Year 11 the substrate was entirely fines. Cover for fish was predominately deep pool with subdominants of overhanging vegetation and instream vegetation. Crown closure averaged 50%.

On average, substrate at the D-02 riffle site consisted of 53% gravel and 48% fines. Between August and October 2021, the proportion of fines increased from 40% to 70%. A similar increase in fines was noted in October 2020. The dominant cover type at the riffle was overhanging vegetation with subdominant instream vegetation. Crown closure was high, averaging 94%. D95 averaged 6 cm with embeddedness at 21%.

Photographs 3-7 D-02 (Downes Creek) – October 2021

Site D-02-Pool Facing Upstream

Site D-02-Riffle Facing Upstream

<u>D-03</u>

D-03 is located at a potentially fish-bearing headwater tributary within Downes Creek Bowl (Figure 3-2). Two mesohabitats were identified here: a pool (D-03-pool) and a riffle (D-03-riffle). D-03-riffle and D-03-pool are located immediately downstream and approximately 30 m downstream of the hydrometric station, respectively. D-03 is characterized as a frequently confined to confined stream with a straight channel. Gravel and sand side bars were present at both mesohabitat sites.

The substrate at the riffle mesohabitat was variable with gravel ranging from 35% to 85% and fines ranging from 10% to 60%. The proportion of cobble was relatively consistent and 5% to 10%. Cover for fish was predominately overhanging vegetation with subdominant component of SWD (July and August) and instream vegetation (September and October). The pool mesohabitat substrate was predominately gravel (65%) and fines (29%) with a lesser amount of cobble (6%). The average substrate embeddedness at the riffle and pool mesohabitat were 18% and 8%, respectively. D95 ranged from 10 cm to 14 cm. Crown closure higher at the pool site (61%) than at the riffle site (38%).

Photographs 3-8 D-03 (Downes Creek) – August and September 2021

D-03 Riffle Facing Upstream (August 2021)

D-03 Pool Facing Downstream (September 2021)

D-04

D-04 is located at a potentially fish bearing headwater tributary within Downes Creek Bowl (Figure 3-2). Two mesohabitats were identified here: a pool (D-04-pool) and a riffle (D-04-riffle). The D-04-riffle mesohabitat site is located immediately upstream of the hydrometric station. The D-04-pool mesohabitat site is located approximately 30 m downstream from the hydrometric station at a scour pool with confirmed fish presence. D-04 is classified as an occasionally confined to confined, sinuous channel with some straight sections and an average gradient of 2.8%. The pool mesohabitat had a sand and gravel side bar during all monitoring visits.

The riffle mesohabitat was dominated by gravel (63%), followed by fines (28%), and lesser amounts of cobble (9%). The substrate had an average embeddedness of 18%. D95 averaged 12 cm. Crown closure was 10% to 20% from July through September 2021 but increased to 90% in October 2021. Cover for fish was predominantly undercut banks with overhanging vegetation subdominant and trace amounts of SWD and instream vegetation.

Substrate at the pool mesohabitat site was dominated by gravel (70%), followed by fines (24%), and lesser amounts of cobble (5%) and boulders (2.5%). Embeddedness was 11% on average with an average D95 of 7 cm. Crown closure was high at 83%. Cover for fish was dominated deep pool with overhanging vegetation subdominant, and variable amounts of SWD, LWD, and instream vegetation.

Photographs 3-9 D-04 (Downes Creek) – August 2021

D-04 Pool Facing Upstream

D-04 Riffle Facing Upstream

Fishtrap Creek

F-01

F-01 is located at the headwaters of Fishtrap Creek north of Highway 1 at Gardner Park off Livingstone Avenue. It overlaps with water quality monitoring site F-01. Two mesohabitat sites were established here: a pool (F-01-pool) located 11 m north of the hydrometric station and a riffle (F-01-riffle) located 20 m downstream from the station.

F-01 is characterized as a low gradient (approximately 1-2%), straight channel with a riffle-pool morphology. The reach has been channelized and is confined on both banks. The substrate at the riffle mesohabitat site varied over the monitoring period with fines ranging from 20% to 100% and gravel ranging from 0% to 60%, with minimal amounts of fines (7%), cobble (5%), and boulders (5%). The substrate was embedded by an average 12%. Average D95 was 13 cm from July through September 2021. The water was very deep in October 2021 when the substrate was characterized as 100% fines. High water made the channel unsafe to wade and possibly affected the accuracy of substrate estimates. Cover at this mesohabitat site included overhanging vegetation (dominant), boulders (usually subdominant), with deep pool habitat dominant in October. Canopy closure increased from 20% in July to 90% in October.

The pool site substrate was entirely fines from July through September 2021. The substrate composition shifted to 60% fines, 35% gravel, and 5% boulder in October when the water level was high. The dominant cover type was deep pool with SWD, overhanging vegetation, and instream vegetation as the subdominant types. Canopy closure increased from 35% in July to 80% in October.

Photographs 3-10 F-01 (Fishtrap Creek) – August and October 2021

F-01 Pool Facing Upstream (August 2021)

F-01 Riffle Facing Downstream (October 2021)

F-02

F-02 is located on Fishtrap Creek at the Marshall Road Extension and overlaps with water quality monitoring site F-02. Two mesohabitats were established here: a pool (F-02-pool) located 35 m upstream of Mt Lehman Road and a riffle (F-02-riffle) located 30 m downstream of the Marshall Road extension. F-02 is a low gradient (<1%), confined to frequently confined, riffle-pool channel located within an agricultural area. It had no bars or islands. Beaver dams were noted upstream and downstream of the pool site in August 2021.

The riffle mesohabitat site was dominated by 90%-100% fines, except in October 2021, when the water was high, and fines decreased to 20%. In addition to fines, the October substrate consisted of 55% graver, 10% cobble, and 15% boulder. SWD and LWD were the dominant cover types from July through September. Deep pool cover dominated in October. Crown closure was averaged 80% from July through September but decreased to 40% in October.

Substrate at the F-02 pool mesohabitat changed the 2021 monitoring period, with the proportion of fines increasing from 40% to 100% and gravel decreasing from 40%-50% to 0%. Average D95 was 10 cm with an average embeddedness of 17%. Cover for fish consisted of deep pool (dominant), with subdominant overhanging and instream vegetation. Undercut banks were subdominant in July only. SWD and LWD were also present, particularly in October. Crown closure averaged 65% at the pool mesohabitat site.

Photographs 3-11 F-02 (Fishtrap Creek) – August 2021

F-02 Pool Facing Upstream

F-02 Riffle Facing Downstream

F-03

F-03 is located near the existing F-03 staff gauge, approximately 115 m upstream from the confluence with Waechter Creek. The site overlaps with the F-03 water quality monitoring site. One mesohabitat (F-03-pool) was established at F-03. The mesohabitat represents pool habitat, as the reach is a continuous sequence of beaver dam impoundments. No riffle habitat was present at the F-03 site.

F-03 lies within an agricultural area and is characterized as a low gradient (<1%), frequently confined, straight to sinuous channel. Substrate was dominated by fines (88%), followed by gravel (10%), and cobble (3%). No canopy cover was present at the site. Cover was primarily deep pool with some undercut banks, overhanging vegetation and instream vegetation. Water depth and clarity limited the visual assessment of substrate composition.

Photograph 3-12 F-03 (Fishtrap Creek) – August 2021

F-03 Pool Facing Downstream

F-04

F-04 is the downstream-most station on Fishtrap Creek. The site overlaps with the F-04 water quality monitoring station. Two mesohabitats were identified here: one pool (F-04-pool) and one riffle (F-04-riffle). The pool and riffle mesohabitats are located 15 m upstream and 15 m downstream of the Echo Road bridge, respectively. F-04 is a low gradient (0-1%) stream with a linear, confined channel. It lies within an agricultural area. The canopy at F-04 was open (0% closure at the riffle site and 0%-30% closure at the pool site).

Substrate at the riffle mesohabitat consisted of a mix of gravel (50%) and fines (48%) with minimal cobble (3%). The substrate was embedded by 11% on average. The average D95 for the riffle site was 7.4 cm. Cover at the site consisted of instream vegetation and overhanging vegetation with subdominant undercut banks.

Water depth and clarity limited the visual assessment of substrate composition at the pool mesohabitat. Substrate at the pool mesohabitat averaged 85% fines, 10% gravel and 3% cobble. Cover was primarily deep pools with overhanging and instream vegetation as the subdominant cover. Trace amounts of boulders and undercut banks were present.

Photographs 3-13 F-04 (Fishtrap Creek) – October 2021

F-04 Pool Facing Upstream **F-04 Riffle Facing Downstream**

3.5.2 Changes in Biophysical Parameters over Time

Year 1 (2011) through to Year 11 (2021) physical measurement data collected at the Horn Creek and Boa Brook mesohabitat sites were analysed to determine whether adverse effects on aquatic habitat have occurred subsequent to increased extraction from the aquifer by the Bevan Wells. The Downes Creek and Fishtrap Creek mesohabitat sites were not included in the statistical analysis, as only four years of mesohabitat monitoring has been conducted in these streams, but results were graphed for illustrative purposes.

The physical measurement data, including wetted width, bankfull width and bankfull depth, were statistically analysed using a Mann-Kendall non-parametric trend analysis. Substrate monitoring data was not analyzed because the Year 8 to Year 11 substrate data was collected using a different method compared to previous monitoring years and is not directly comparable to the Year 1 to Year 7 data.

3.5.2.1 Physical Measurements

<u>Wetted Width</u>

Wetted width can be used as an indicator of habitat area for fish and benthic invertebrates. It is sensitive to changes in flow volumes. A reduction in wetted width from reductions in flow typically results in a reduction in benthic invertebrate production, which in turn may result in reduced food sources for fish and other aquatic organisms.

In an urban setting, wetted width can be variable; as even a small rain event can result in high flows and increased wetted widths. Furthermore, results may be hard to interpret between years as high flow events (especially in the fall and winter months) may alter the channel geometry. Figure 3-4 to Figure 3-7 show the results of the wetted width monitoring at all mesohabitats monitoring sites through 2021.

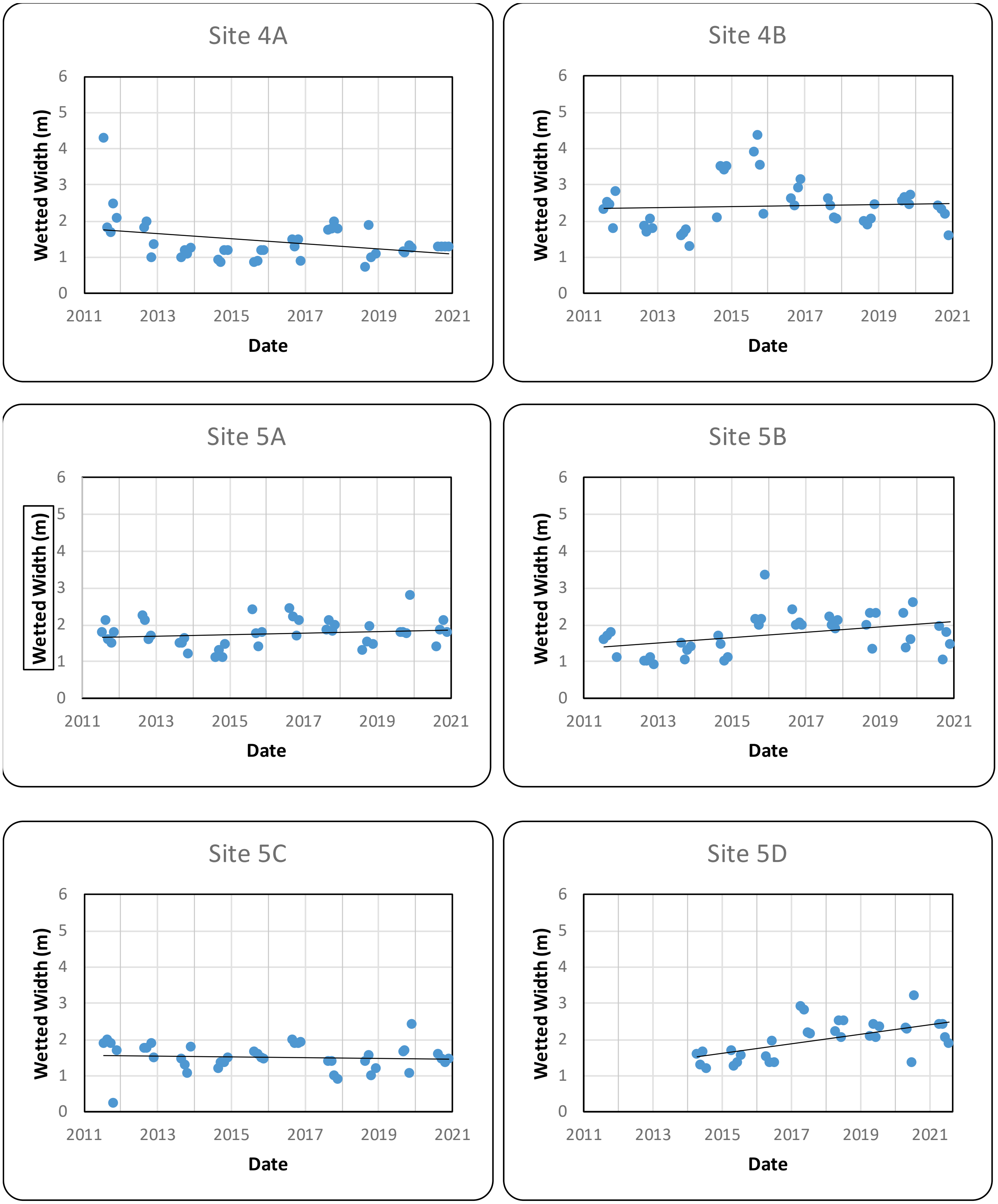


Figure 3-4 Wetted Width at Boa Brook Mesohabitat Sites (2012 to 2021)

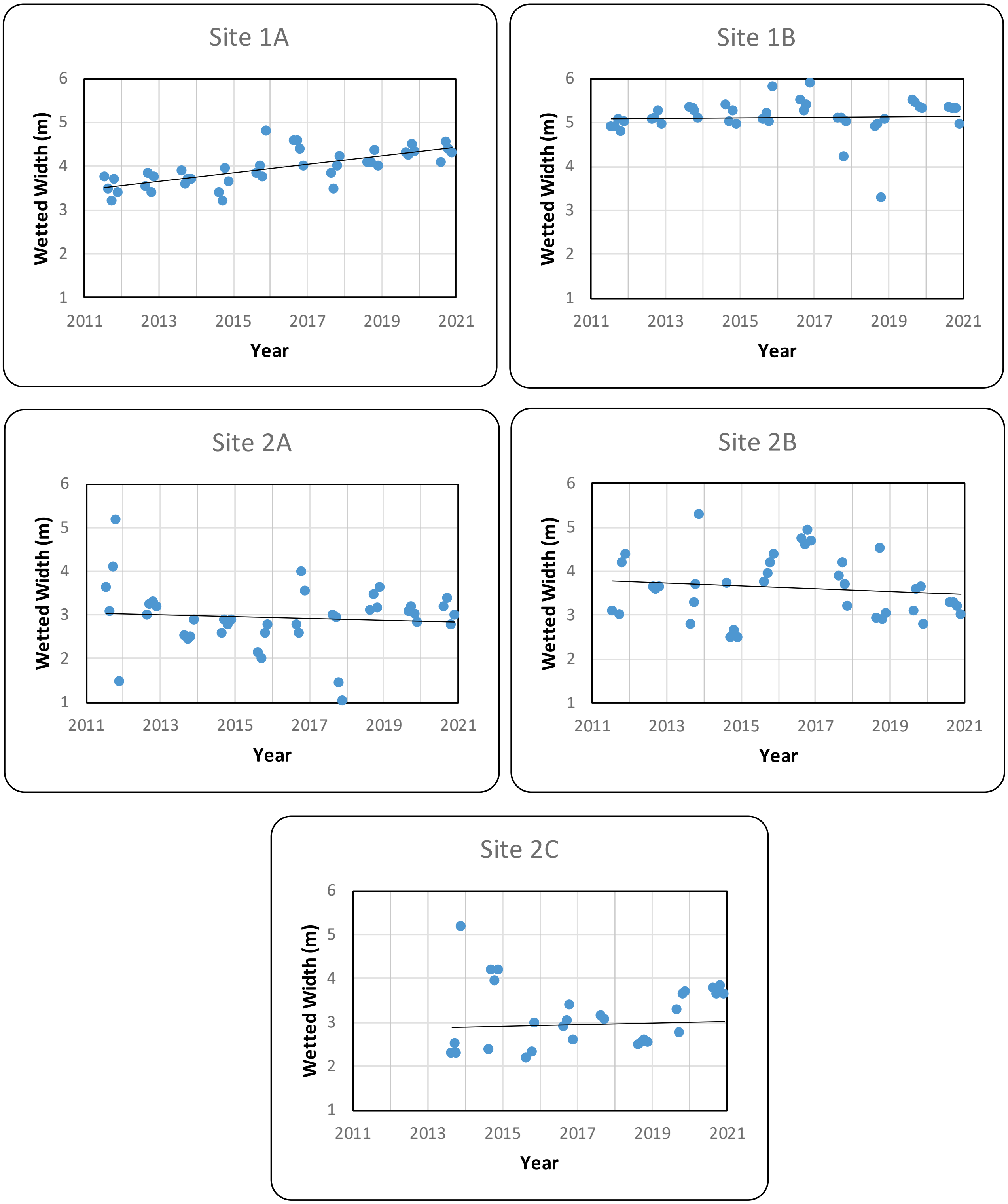


Figure 3-5 Wetted Width at Horn Creek Mesohabitat Sites (2012 to 2021)

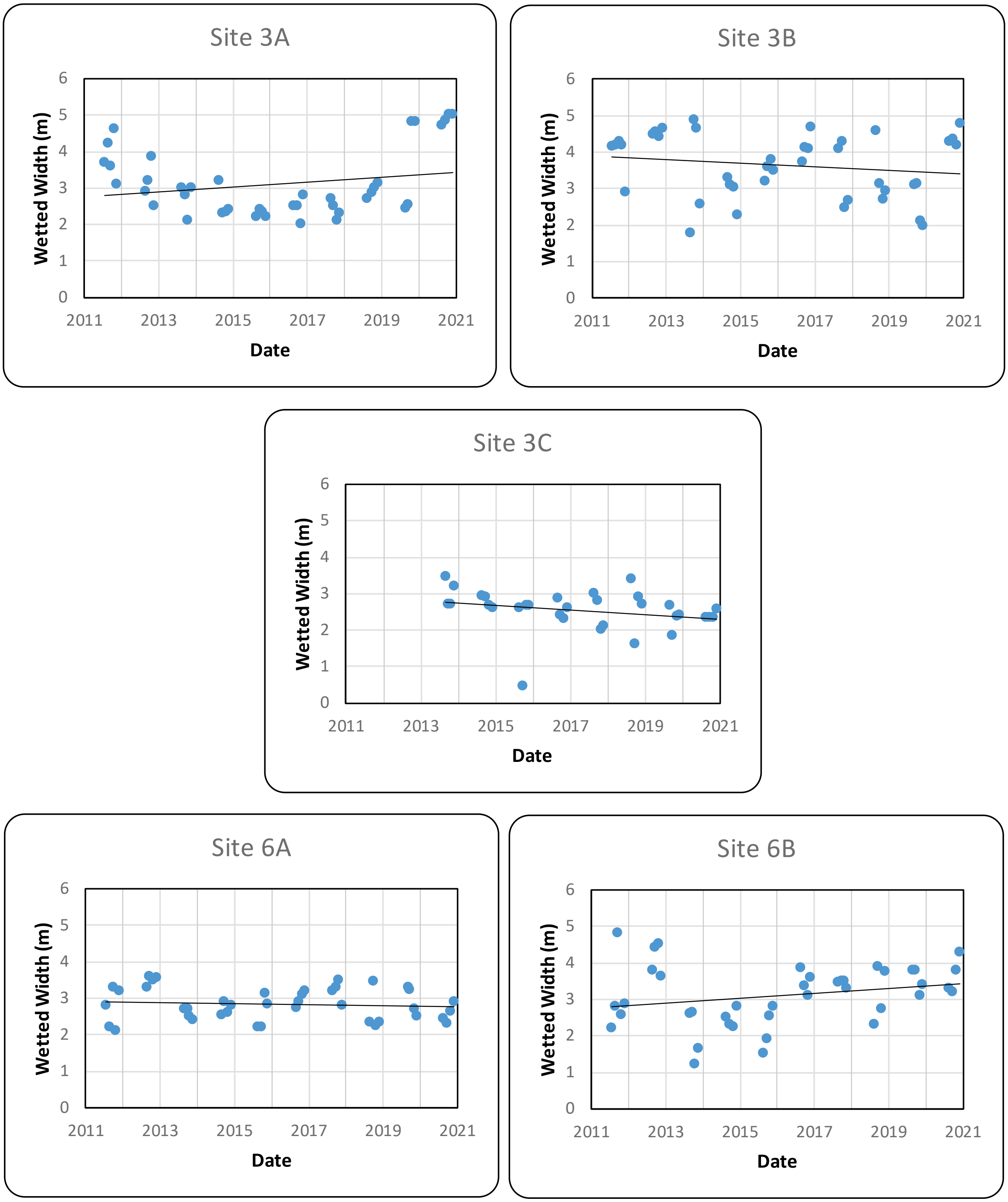


Figure 3-5 Wetted Width at Horn Creek Mesohabitat Sites (2012 to 2021) (Continued)

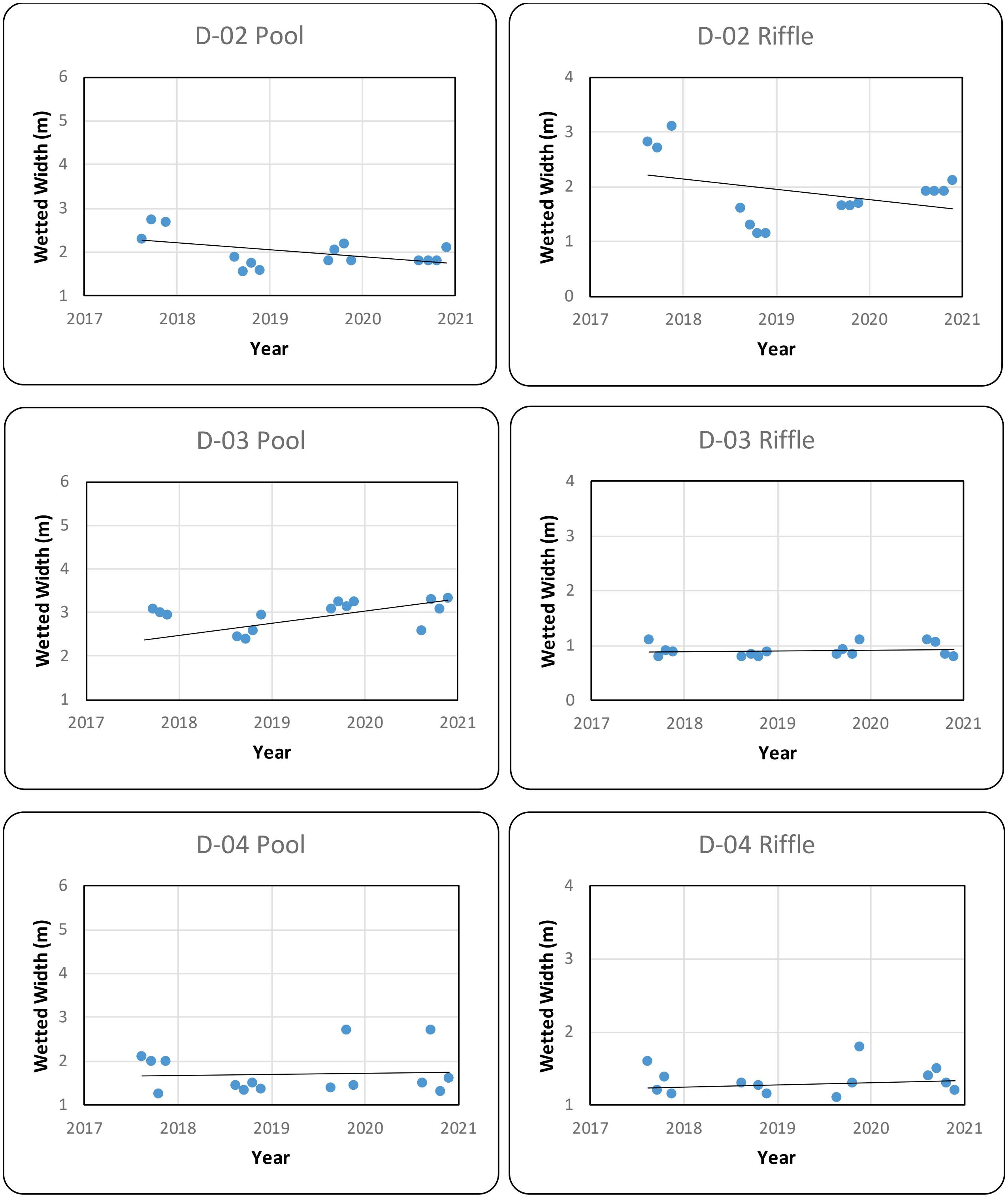


Figure 3-6 Wetted Width at Downes Creek Mesohabitat Sites (2018 to 2021)

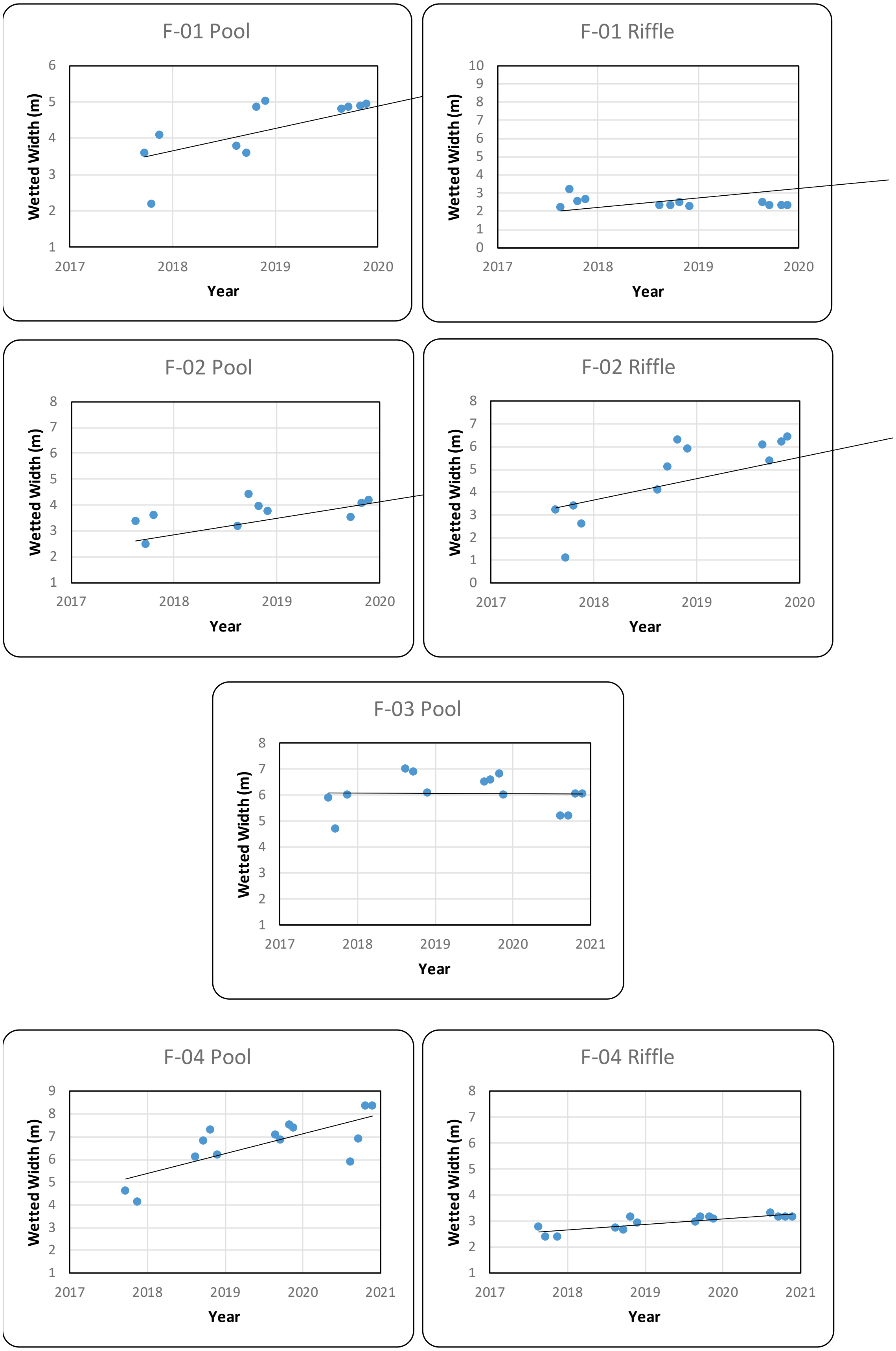


Figure 3-7 Wetted Width at Fishtrap Creek Mesohabitat Sites (2018 to 2021)

The Mann-Kendall tests showed no significant negative or positive trends in the average wetted width at the Boa Brook mesohabitat sites during the 2012 to 2021 monitoring period (Table 3-2). At Horn Creek, a significant increasing trend in the average wetted width was observed at site 1A ($p < 0.05$). No significant trends (increasing or decreasing) were observed at the other Horn Creek sites.

Table 3-2 Statistical Significance of Mann-Kendall Trends in Wetted Width at the Bevan Wells Mesohabitat Monitoring Sites

Mesohabitat Site	First Year	Last Year	n	Mann-Kendall S or Z	Significance
1A (Horn Creek)	2012	2021	10	2.50	**p <0.05**
1B (Horn Creek)	2012	2021	10	0.537	
2A (Horn Creek)	2012	2021	10	-0.358	
2B (Horn Creek)	2012	2021	10	-1.25	
2C (Horn Creek)	2014	2021	8	4	
3A (Horn Creek)	2012	2021	10	0.00	
3B (Horn Creek)	2012	2021	10	-0.894	
3C (Horn Creek)	2014	2021	8	-12	
4A (Boa Brook)	2012	2021	10	-0.269	
4B (Boa Brook)	2012	2021	10	0.00	
5A (Boa Brook)	2012	2021	10	0.716	
5B (Boa Brook)	2012	2021	10	0.629	
5C (Boa Brook)	2012	2021	10	-0.269	
5D (Boa Brook)	2014	2021	8	10	
6A (Horn Creek)	2012	2021	10	-0.358	
6B (Horn Creek)	2012	2021	10	1.07	

MAKESENS calculates the Z approximation to the Mann-Kendall S-statistic for $n \geq 10$.
Negative values of Z or S represent downward trends; positive values represent upward trends.
p – probability. Blank indicates $p > 0.1$. Significance set at $p < 0.05$.

Four years of monitoring is not enough to detect trends at the Downs Creek and Fishtrap Creek with any degree of confidence. However, the data presented in Figures 3-6 and 3-7 do not show consistent changes from site to site within a watercourse, nor do they suggest potential decreases in available habitat.

<u>Bankfull Width and Depth</u>

The bankfull width of a stream is defined by major high flow events, typically in the fall and winter months, and may not be strongly influenced by reductions in flow in the summer period. Bankfull depth is measured from the bankfull width elevation to the elevation of the channel thalweg (deepest portion of channel cross section). In the low flow period, bankfull depth may be sensitive to flow reductions due to sediment deposition. However, once high flows occur, the sediment may be scoured away returning bankfull depth to typical levels.

Figure 3-8 to Figure 3-11 show the results of the bankfull width and depth monitoring at the mesohabitats monitoring sites through 2021. In a system where flows are decreasing, a negative trend in bankfull width and depth over time may be expected. The Mann-Kendall tests showed a statistically significant decreasing trend ($p<0.05$) in bankfull width at 6B on Horn Creek (Table 3-3). In contrast, there were significant increasing trends in bankfull width at mesohabitat sites 1A, 1B, and 2A ($p <0.05$) on Horn Creek and 4B ($p <0.001$) and 5A and 5B ($p<0.05$) on Boa Brook. There were no significant negative trends in bankfull depth at the Horn Creek and Boa Brook mesohabitat sites, but there was a significant ($p<0.05$) increase in bankfull depth at 1A on Horn Creek.

Table 3-3 Statistical Significance of Mann-Kendall Trends in Bankfull Width and Depth at the Bevan Wells Mesohabitat Monitoring Sites

Mesohabitat Site	First Year	Last Year	n	Bankfull Width		Bankfull Depth	
				Mann-Kendall S or Z	Significance	Mann-Kendall S or Z	Significance
1A (Horn Creek)	2012	2021	10	3.22	**p<0.01**	2.50	**p <0.05**
1B (Horn Creek)	2012	2021	10	2.50	**p<0.05**	0.537	
2A (Horn Creek)	2012	2021	10	2.68	**p<0.01**	-0.358	
2B (Horn Creek)	2012	2021	10	1.79	p<0.1	-1.25	
2C (Horn Creek)	2014	2021	8	-4		4	
3A (Horn Creek)	2012	2021	10	0.988		0.00	
3B (Horn Creek)	2012	2021	10	1.43		-0.894	
3C (Horn Creek)	2014	2021	8	-2		-12	
4A (Boa Brook)	2012	2021	10	1.79	p<0.1	-0.269	
4B (Boa Brook)	2012	2021	10	3.58	**p<0.001**	0.00	
5A (Boa Brook)	2012	2021	10	1.97	**p<0.05**	0.716	
5B (Boa Brook)	2012	2021	10	2.50	**p<0.05**	0.629	
5C (Boa Brook)	2012	2021	10	0.629		-0.269	
5D (Boa Brook)	2014	2021	8	14		10	
6A (Horn Creek)	2012	2021	10	-0.894		-0.358	
6B (Horn Creek)	2012	2021	10	-1.97	**p<0.05**	1.07	

MAKESENS calculates the Z approximation to the Mann-Kendall S-statistic for $n \geq 10$.
Negative values of Z or S represent downward trends; positive values represent upward trends.
p – probability. Blank indicates $p >0.1$. Significance set at $p <0.05$.

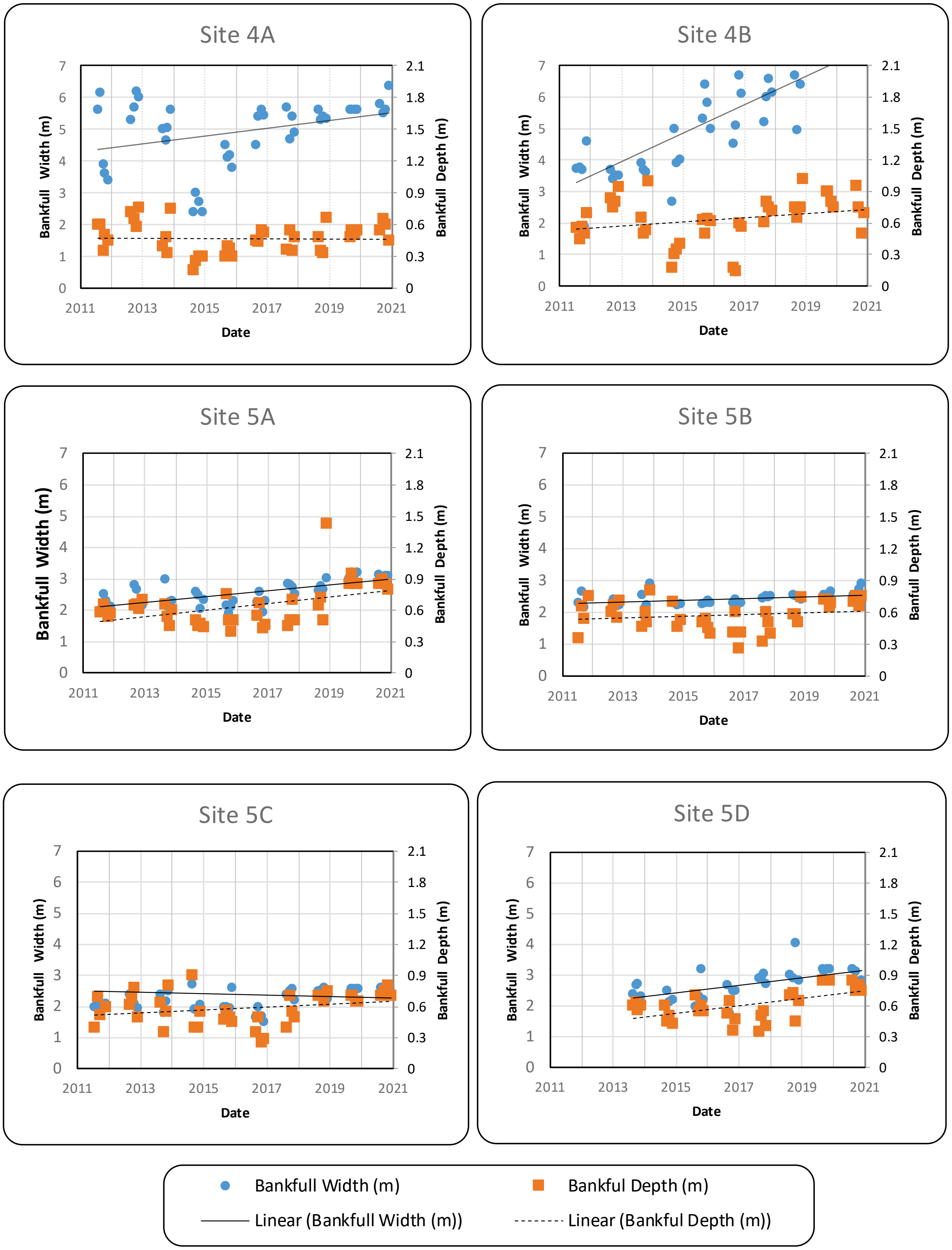


Figure 3-8 Bankfull Width and Depth at Boa Brook Mesohabitat Sites (2012 to 2021)

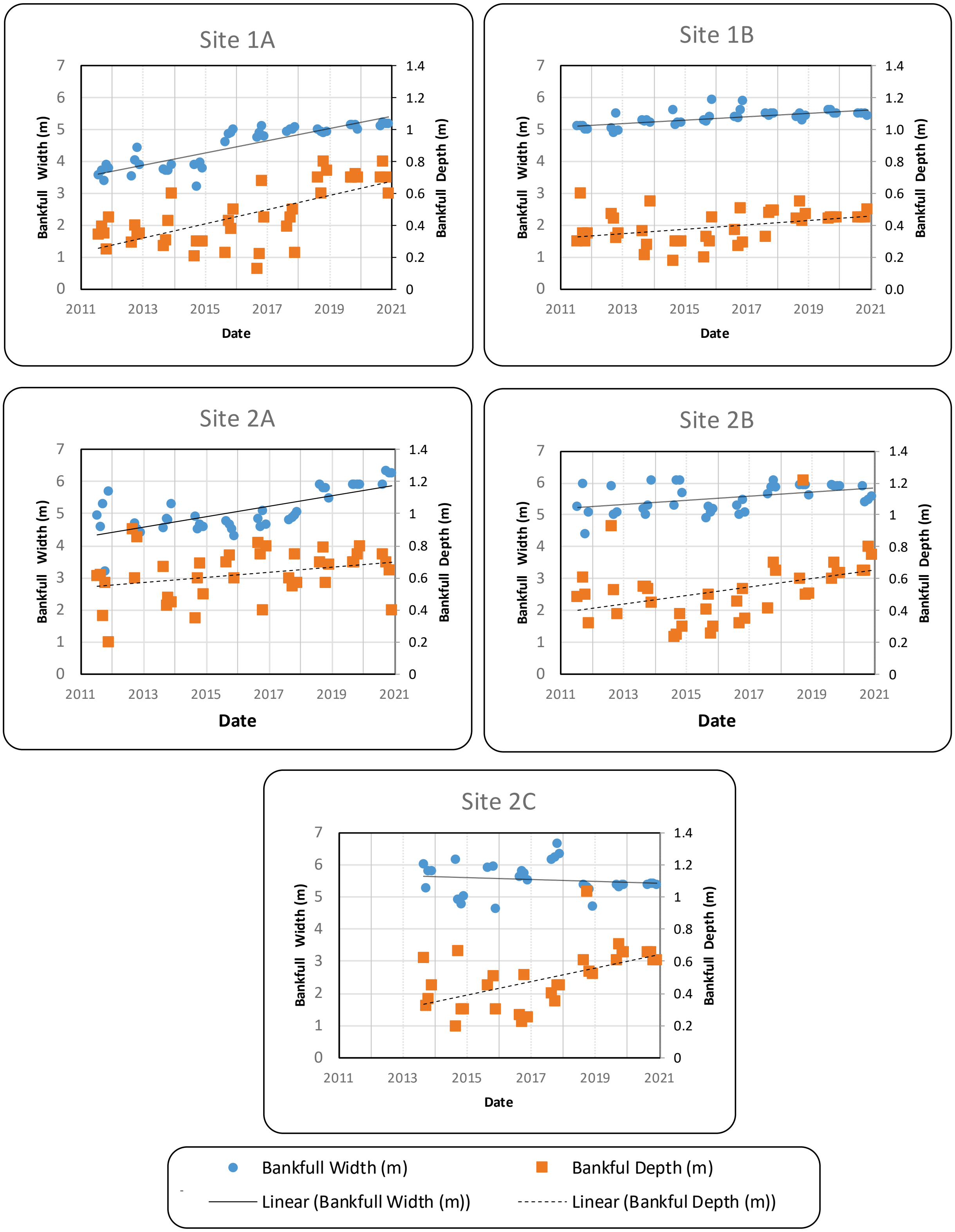


Figure 3-9 Bankfull Width and Depth at Horn Creek Mesohabitat Sites (2012 to 2021)

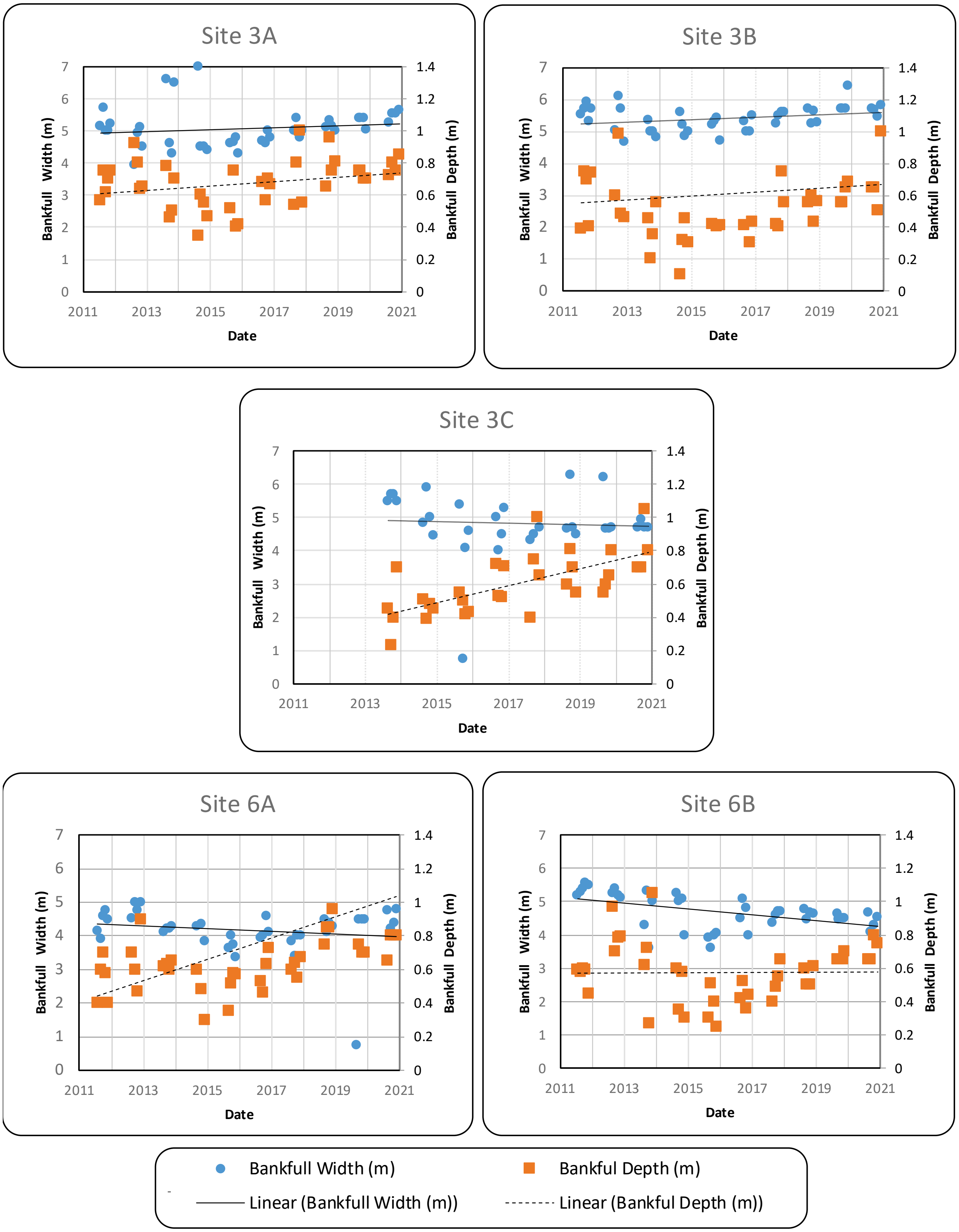


Figure 3-10 Bankfull Width and Depth at Horn Creek Mesohabitat Sites (2012 to 2021) (Continued)

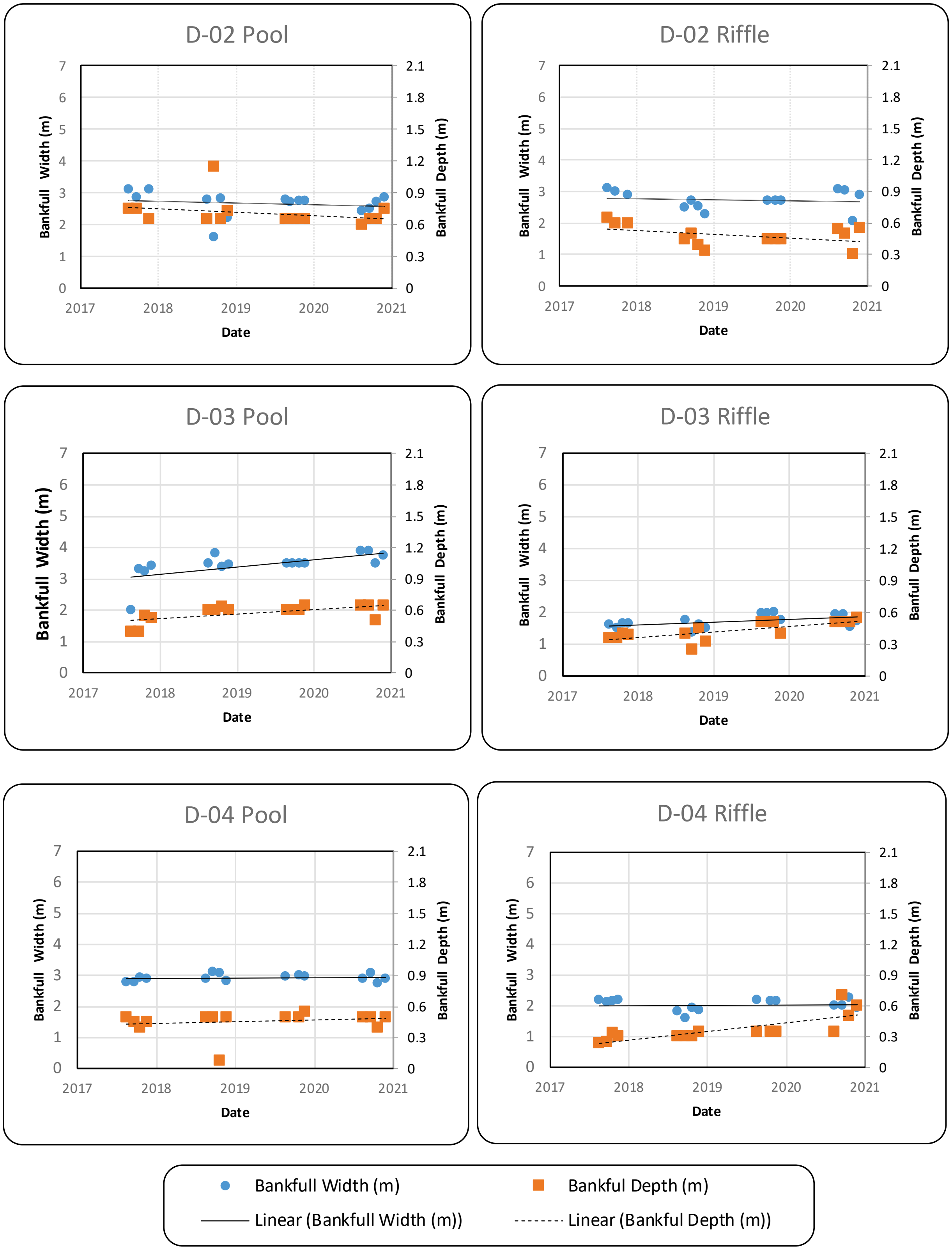


Figure 3-10 Bankfull Width and Depth at Downes Creek Mesohabitat Sites (2018 to 2021)

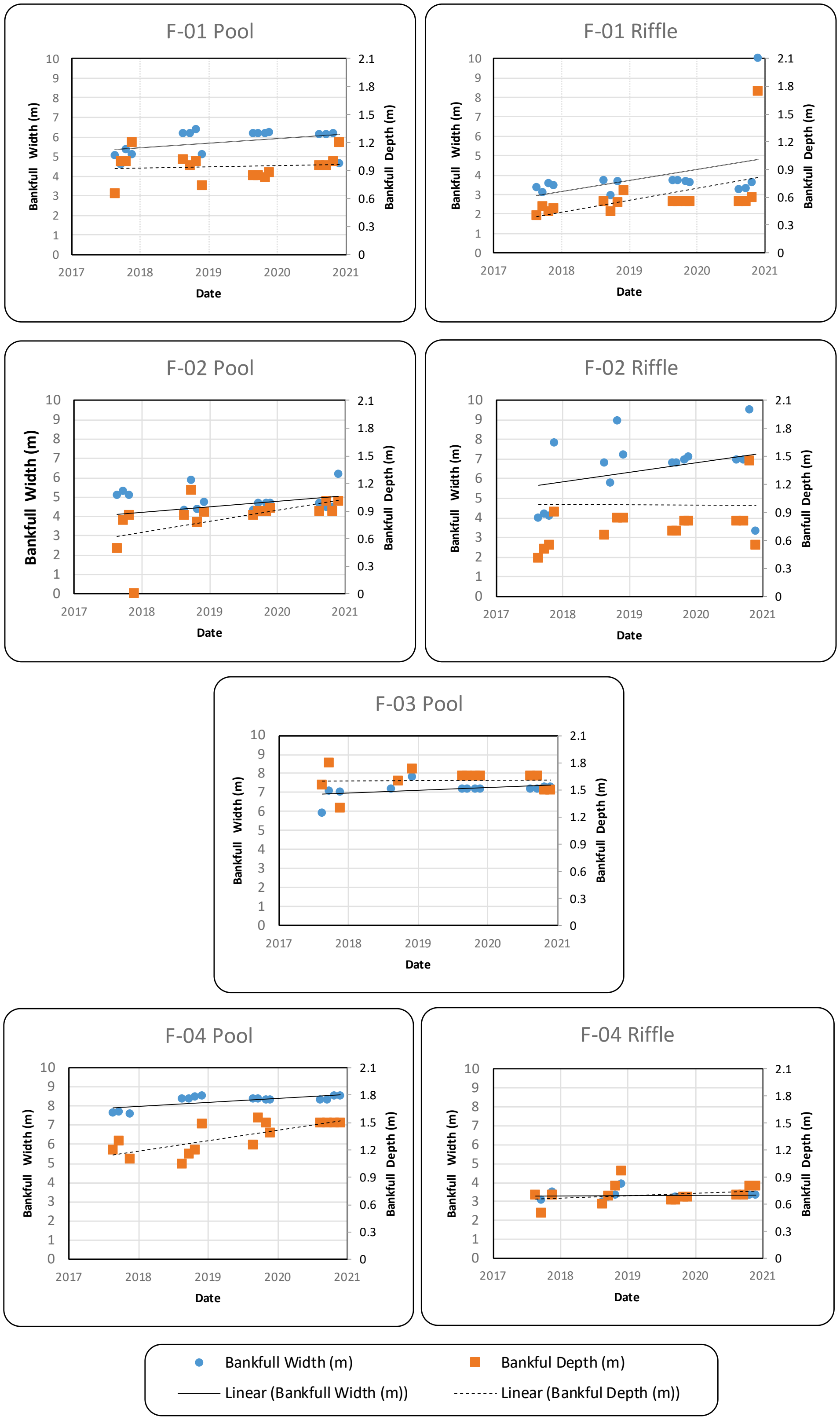


Figure 3-11 Bankfull Width and Depth at Fishtrap Creek Mesohabitat Sites (2018 to 2021)

As discussed for wetted width, four years of monitoring is not enough to detect trends with any degree of confidence. The data presented in Figures 3-10 and 3-11 do not show consistent changes in either bankfull width or depth from site to site within Downs Creek or Fishtrap Creek, nor do they suggest potential decreases in available habitat.

3.6 Successes, Challenges and Suggested Changes

As a result of beaver dams mesohabitat site F-03 was too deep to wade to collect physical channel measurements during all 2021 site visits. This was also the case in 2021. Beaver activity affected the F-02-riffle site in September 2021. Beavers were also active in 2020, changing the site characteristics over the monitoring season. It will be difficult to identify effects, if any, of the Bevan Wells on fish habitat at these sites due to the confounding influence of beaver activity. A qualified fisheries biologist should assess the possibility of finding additional or alternate mesohabitat monitoring sites that are unaffected by beavers, although these sites will not likely be available in some reaches.

4.0 GROUNDWATER PROGRAM

4.1 Well Water Quality Monitoring

4.1.1 Background

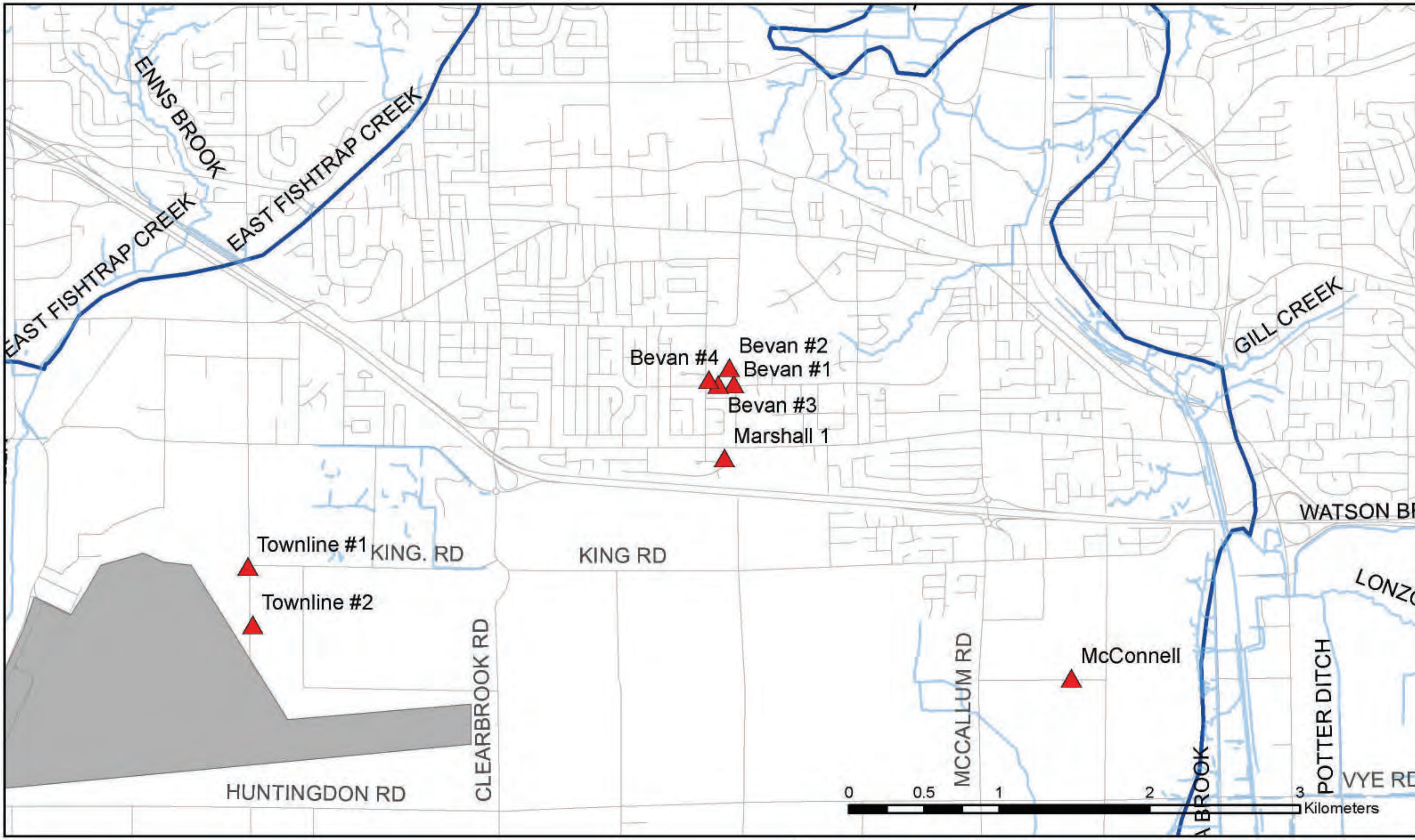
During installation of the mitigation wells in summer 2011, Hemmera investigated groundwater quality in comparison with existing background surface water quality in the receiving waters of Horn Creek and Boa Brook. No constituents of potential concern (COPC) were identified as a result of potential groundwater inputs into Horn Creek and Boa Brook (Hemmera, 2011c). However, the report recommended that additional samples from the mitigation and other water wells within the same aquifer be taken to determine the range of arsenic and fluoride concentrations. Subsequent data analysis showed a potential concern with arsenic in Allen Park mitigation well, which discharges to Boa Brook (ENKON, 2016).

4.1.2 Testing Program

The mitigation wells and are tested monthly for most of the same parameters as the surface water monitoring sites. Testing of the mitigation well for Fishtrap Creek began in 2019. Abbotsford also monitors water quality in 19 drinking water wells, of which nine are considered representative for comparison with the mitigation wells. The representative wells were the four Bevan Wells plus Marshall #1, Marshall #3, McConnell, Townline #1, and Townline #2 (Figure 4-1).

4.1.3 Groundwater Quality Results

Table 4-1 shows average water quality in the Allen Park mitigation well for Years 2 through 11. The results are compared with water quality guidelines for protection of aquatic life to illustrate the implications of this well's discharging to Boa Brook. The Allen Park well had consistently elevated arsenic concentrations. Yearly average arsenic concentrations ranged from 15.1 µg/L to 16.9 µg/L or over 3 times the 5-µg/L water quality guideline. Fluoride concentrations in this well were consistently above the 0.12-mg/L CCME guideline but met the current BC guideline, 0.4 mg/L to >1.0 mg/L, depending upon hardness (MoE, 2017). In addition, average phosphorus concentrations in the Allen Park well have consistently been above the 0.03-mg/L water quality objective for the Sumas River.



Legend

- Drinking Wells
- Streams
- Roads
- Airport
- Abbotsford-Sumas aquifer

Scale: 1:35,000

Prepared by:
ENKON
Environmental Ltd.

Drinking Water Well Locations

City of Abbotsford

Figure 4-1

December 2019

Document Path: N:\GIS_Base\1021\016_Bevan_Yr8\DrinkingWellLocations_R03.mxd

Table 4-1 Average Water Quality of the Allen Park Mitigation Well (Year 2 – Year 11)

Parameter	Units	Average										Guidelines for Freshwater Aquatic Life		
		Year 2	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**	**Year 11**	**CCME**	**BCWQG**	**SSWQG**
pH	pH	8.17	8.33	8.33	8.30	8.21	8.29	8.48	8.47	8.45	8.26	6.5 to 9.0	6.5 to 9.0	6.5 to 9.0
Ammonia (N)	mg/L	0.361	0.105	0.120	0.193	0.199	0.232	N/A	0.123	0.120	0.13	See Appendix		
Total Phosphorous (P)	mg/L	0.182	0.186	0.175	0.149	0.149	0.151	N/A	0.195	0.209	0.19	See Appendix		0.03
Nitrate (N)	mg/L	0.02	0.002	<	<	<	0.358	<	<	<	0.0023	13 (long term)	3 (long term)	2.93
Nitrite (N)	mg/L	0.005	0.001	<	<	<	<	<	<	<	<	0.06	See Appendix	0.02
Total Hardness ($CaCO_3$)	mg/L	31.5	40.6	43.1	56.1	58.0	62.2	55.7	56.3	52.4	53.8			
Fluoride (F)	mg/L	0.178	0.178	0.150	0.147	0.154	0.189	0.204	0.207	0.210	0.21	0.12	See Appendix	
Total Aluminum (Al)	µg/L	4.00	2.18	4.03	1.58	<	4.3	5.1	4.3	3.4	3.3	See Appendix	See Appendix	
Total Antimony (Sb)	µg/L	0.4	<	0.025	<	0.117	<	<	<	<	<		9 (Sb III)	
Total Arsenic (As)	µg/L	15.5	16.1	16.3	16.6	16.5	15.1	16.4	16.6	16.9	16.9	5	5	
Total Barium (Ba)	µg/L	12.3	15.5	17.2	23.6	26.1	24.9	25.6	25.1	24.0	24.9		1000	
Total Beryllium (Be)	µg/L	0.08	<	<	N/A	N/A	N/A	<	<	<	<		0.13	
Total Bismuth (Bi)	µg/L	1	<	<	N/A	N/A	N/A	<	<	<	<			
Total Boron (B)	µg/L	120	133	115	167	166	155	173	159	166	169	1500 (long term)	1200	
Total Cadmium (Cd)	µg/L	0.011	0.003	0.001	0.001	0.004	0.003	0.0053	0.0050	0.015	<	See Appendix	See Appendix	
Total Chromium (Cr)	µg/L	0.80	<	<	<	0.167	0.592	0.80	0.70	0.47	<	1 (Cr VI), 8.9 (Cr III)		See Appendix
Total Cobalt (Co)	µg/L	0.5	<	<	N/A	N/A	N/A	<	0.233	0.133	<		110	
Total Copper (Cu)	µg/L	0.388	0.418	0.600	0.675	0.717	0.961	1.03	0.885	0.548	1.05	See Appendix		See Appendix
Total Iron (Fe)	µg/L	20.9	23.9	32.3	52.5	35.0	32.2	26.8	26.1	20.1	33	300	1000	
Total Lead (Pb)	µg/L	0.464	0.152	0.078	0.142	0.175	0.210	0.423	0.357	0.187	0.30	See Appendix	See Appendix	See Appendix
Total Lithium (Li)	µg/L	5.0	<	<	N/A	N/A	N/A	1.0	1.0	1.4	<			
Total Manganese (Mn)	µg/L	10.2	13	15.4	20.3	21	18.7	19.4	19.0	18.0	18.6		See Appendix	
Total Mercury (Hg)	µg/L	0.026	<	<	<	<	<	N/A	0.0051	0.0040	<	0.026		
Total Molybdenum (Mo)	µg/L	3.46	4.29	3.83	N/A	N/A	N/A	7.73	7.54	7.91	8.1	73	2000	
Total Nickel (Ni)	µg/L	1	<	0.025	0.083	0.292	0.214	1.02	0.833	0.667	1.1	See Appendix	See Appendix	
Total Selenium (Se)	µg/L	0.08	<	<	<	<	0.106	<	0.050	0.067	<	1	1	
Total Silver (Ag)	µg/L	0.016	<	<	<	<	<	<	<	<	<	0.25	See Appendix	
Total Strontium (Sr)	µg/L	137	57.0	57.6	N/A	N/A	N/A	77.9	84.2	77.9	80.2			
Total Thallium (Tl)	µg/L	0.04	0.017	<	N/A	N/A	N/A	<	<	<	<	0.8	0.3	
Total Tin (Sn)	µg/L	5.0	1.7	<	N/A	N/A	N/A	0.4	<	<	<			
Total Titanium (Ti)	µg/L	4.0	1.7	<	N/A	N/A	N/A	<	<	<	<			
Total Uranium (U)	µg/L	0.08	<	0.01	0.06	0.07	0.08	0.165	0.153	0.073	<	15 (long term)	8.5	
Total Vanadium (V)	µg/L	4.0	<	<	N/A	N/A	N/A	<	<	<	<			
Total Zinc (Zn)	µg/L	4.22	<	2.72	0.42	0.67	5.88	<	4.33	3.73	5.3	30	See Appendix	See Appendix
Total Zirconium (Zr)	µg/L	0.5	<	<	N/A	N/A	N/A	<	<	<	<			
Total Calcium (Ca)	mg/L	6.69	8.73	8.81	11.6	11.8	13.3	11.7	11.7	11.1	11.2			
Total Magnesium (Mg)	mg/L	3.60	4.52	5.12	6.58	6.95	7.02	6.48	6.55	5.96	6.25			
Total Potassium (K)	mg/L	4.60	5.15	5.23	N/A	N/A	N/A	6.45	6.36	6.15	6.29			
Total Silicon (Si)	mg/L	6.87	7.04	6.99	N/A	N/A	N/A	7.33	7.32	7.46	7.52			
Total Sodium (Na)	mg/L	43.0	49.1	41.0	N/A	N/A	N/A	67.2	66.7	68.1	65.8			
Total Sulphur (S)	mg/L	5.46	6.44	5.80	N/A	N/A	N/A	8.0	8.0	8.0	7.8			

< - Not detected

N/A - Not analyzed

Due to concerns about the arsenic concentrations in the Allen Park mitigation well and their potential effects on aquatic life in Boa Brook, the City commissioned a risk assessment. Based on a comparison of the maximum groundwater arsenic concentrations to selected toxicity data, the assessment concluded that risks related to arsenic exposure would not be expected even if receptors in Boa Brook were exposed to undiluted groundwater (SLR Consulting (Canada) Ltd., 2018).

Average water quality in the Garibaldi Park mitigation well is presented in Table 4-2. The water quality of this well was good with annual average arsenic concentrations ranging from 0.59 µg/L to 1.9 µg/L and fluoride concentrations ranging from <0.020 mg/L to 0.045 mg/L.

Table 4-3 shows the average water quality of the Fishtrap Creek mitigation well. The water quality in this well was generally good with average arsenic concentrations ranging from 0.96 µg/L to 1.06 µg/L and average fluoride concentrations ranging from 0.055 mg/L to 0.056 mg/L. All other parameters except total phosphorus had concentrations below guidelines to protect aquatic life. However, the average total phosphorus concentrations ranged from 0.037 mg/L to 0.060 mg/L and were above the 0.03-mg/L water quality objective for the Sumas River.

The results for the eight drinking water wells are presented for comparison with water quality of the mitigation wells (Tables 4-4 and 4-5). The average concentrations of arsenic, fluoride and iron were below the maximum guidelines for protection of aquatic life. However, concentrations of copper in most drinking water wells and nitrate in some wells were higher than in the mitigation wells. This also was the case in Years 9 and 10.

4.2 Groundwater Level Program

The groundwater level monitoring program consisted of three components:

- Continuous (real-time through the City's Supervisory Control and Data Acquisition (SCADA) system) monitoring of water levels in the Bevan Avenue Wells, Marshall Road Wells, and the mitigation wells;
- Measurements of water levels in seven existing[3] monitoring wells;
- Recording of water levels in Judson Lake and Laxton Lake.

4.2.1 Site Description

Groundwater levels were measured at seven monitoring well locations. The M14-2 (near H-02) and M14-1 (near H-03) monitoring wells were added in February 2014. The wells are described in Table 4-6 below and shown in Figure 4-2. Another groundwater well, TW05-1, located in Highland Park, was originally included in the OEMP groundwater monitoring program. This well

[3] Plus analysis of data from one well (MW6-59) monitored by the Clearbrook Water District and seven observation wells (#2, #8, #15, #272, #299, #301 & #441) monitored by the Ministry of Environment and Climate Change Strategy.

Table 4-2 Average Water Quality of the Garibaldi Park Mitigation Well (Year 2 – Year 11)

Parameter:	Units:	Average										Guidelines for Freshwater Aquatic Life		
		Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	CCME	BCWQG	SSWQG
pH	pH	7.81	7.81	7.63	7.18	7.11	7.43	7.66	7.70	7.57	7.51	6.5 to 9.0	6.5 to 9.0	6.5 to 9.0
Ammonia (N)	mg/L	0.007	0.062	0.016	0.086	0.092	0.127	N/A	0.0057	0.0092	0.018	See Appendix		
Total Phosphorous (P)	mg/L	0.006	0.006	0.015	0.036	0.0068	0.021	N/A	0.0073	0.0061	0.0048	See Appendix		0.03
Nitrate (N)	mg/L	2.32	2.25	2.31	2.24	2.23	2.17	2.15	2.13	2.03	2.09	13 (long term)	3 (long term)	2.93
Nitrite (N)	mg/L	0.005	<	<	<	<	<	<	0.0010	0.0013	<	0.06	See Appendix	0.02
Total Hardness ($CaCO_3$)	mg/L	93	102	104	106	109	104	110	113	111	113			
Fluoride (F)	mg/L	0.025	0.024	0.025	<	<	0.045	0.020	0.021	0.030	<	0.12	See Appendix	
Total Aluminum (Al)	µg/L	4.28	1.41	1.34	0.58	2.42	1.55	<	4.4	3.0	3.1	See Appendix	See Appendix	
Total Antimony (Sb)	µg/L	0.4	<	0.017	<	0.017	0.048	<	<	<	<		9 (SbIII)	
Total Arsenic (As)	µg/L	0.6	0.7	0.7	1.9	0.7	1.8	0.70	0.630	0.632	0.59	5	5	
Total Barium (Ba)	µg/L	8.3	8.7	9.3	10.6	9.8	11.6	17.5	16.7	9.63	10.1		1000	
Total Beryllium (Be)	µg/L	0.08	<	<	N/A	N/A	N/A	<	<	<	<		0.13	
Total Bismuth (Bi)	µg/L	1	<	<	N/A	N/A	N/A	<	<	<	<			
Total Boron (B)	µg/L	40	<	7.42	34.5	23.3	34.5	78.0	70.8	25.0	<	1500 (long term)	1200	
Total Cadmium (Cd)	µg/L	0.023	0.020	0.019	0.017	0.043	0.021	0.022	0.021	0.020	0.018	See Appendix	See Appendix	
Total Chromium (Cr)	µg/L	0.820	<	0.375	0.933	1.24	1.23	1.03	0.953	0.859	1.1	1 (Cr VI), 8.9 (Cr III)		See Appendix
Total Cobalt (Co)	µg/L	0.5	<	<	N/A	N/A	N/A	0.26	0.233	0.133	<		110	
Total Copper (Cu)	µg/L	2.62	2.69	2.77	3.33	2.83	2.98	2.87	2.99	2.48	1.71	See Appendix		See Appendix
Total Iron (Fe)	µg/L	203	104	107	58	56	41	29	28	28	43	300	1000	
Total Lead (Pb)	µg/L	1.26	0.518	0.645	0.625	0.550	1.84	1.59	0.474	0.293	0.27	See Appendix	See Appendix	See Appendix
Total Lithium (Li)	µg/L	5.0	<	<	N/A	N/A	N/A	1.7	1.7	1.8	<			
Total Manganese (Mn)	µg/L	1.5	0.6	0.9	2.43	1.00	2.58	<0.30	0.29	0.54	1.0		See Appendix	
Total Mercury (Hg)	µg/L	0.026	<	0.002	<	<	<	N/A	0.0053	0.0040	<	0.026		
Total Molybdenum (Mo)	µg/L	1	<	<	N/A	N/A	N/A	<0.77	0.699	0.412	<	73	2000	
Total Nickel (Ni)	µg/L	1.5	0.708	1.16	1.07	1.03	0.79	<1.4	0.85	0.82	<	See Appendix	See Appendix	
Total Selenium (Se)	µg/L	0.486	0.473	0.492	0.333	0.389	0.556	0.510	0.554	0.516	0.56	1	1	
Total Silver (Ag)	µg/L	0.016	0.003	0.004	<	<	<	<	<	<	<	0.25	See Appendix	
Total Strontium (Sr)	µg/L	110	120	123	N/A	N/A	N/A	135	140	138	139			
Total Thallium (Tl)	µg/L	0.04	<	<	N/A	N/A	N/A	<	<	<	<	0.8	0.3	
Total Tin (Sn)	µg/L	5	<	<	N/A	N/A	N/A	0.45	<	<	<			
Total Titanium (Ti)	µg/L	4	<	<	N/A	N/A	N/A	<	<	<	<			
Total Uranium (U)	µg/L	0.136	0.161	0.154	0.158	0.168	0.149	0.19	0.18	0.14	0.14	15 (long term)	8.5	
Total Vanadium (V)	µg/L	4	<	<	N/A	N/A	N/A	1.26	<	2.46	<			
Total Zinc (Zn)	µg/L	10.8	12.1	14.5	17.4	19.6	16.8	27.5	14.0	15.3	10.9	30	See Appendix	See Appendix
Total Zirconium (Zr)	µg/L	0.5	<	<	N/A	N/A	N/A	<	<	<	0.12			
Total Calcium (Ca)	mg/L	25.4	28.1	28.6	28.9	29.7	28.2	30.2	31.1	30.5	31.1			
Total Magnesium (Mg)	mg/L	7.16	7.63	7.83	8.08	8.37	8.25	8.40	8.64	8.44	8.46			
Total Potassium (K)	mg/L	1.2	1.31	1.31	N/A	N/A	N/A	<1.83	1.78	1.33	1.36			
Total Silicon (Si)	mg/L	10.7	11.5	11.6	N/A	N/A	N/A	11.3	11.2	11.1	11.5			
Total Sodium (Na)	mg/L	5.89	57.4	6.43	N/A	N/A	N/A	6.87	7.06	6.91	6.93			
Total Sulphur (S)	mg/L	4.2	4.6	4.8	N/A	N/A	N/A	5.0	5.0	5.1	4.9			

< - Not detected

N/A - Not analyzed

Table 4-3 Average Water Quality of the Fishtrap Creek Mitigation Well

Parameter:	Units:	2019 - 2020	2020 - 2021	2021 - 2022	Guidelines for Freshwater Aquatic Life		
					CCME	BCWQG	SSWQG
pH	pH	8.27	8.25	8.12	6.5 to 9.0	6.5 to 9.0	6.5 to 9.0
Ammonia (N)	mg/L	0.156	0.154	0.15	See Appendix		
Total Phosphorous (P)	mg/L	0.060	0.048	0.037	See Appendix		0.03
Nitrate (N) - Calculated	mg/L	<	<	0.0022	13 (long term)	3 (long term)	2.93
Nitrite (N)	mg/L	<	<	<	0.06	See Appendix	0.02
Total Hardness ($CaCO_3$)	mg/L	108	113	118			
Fluoride (F)	mg/L	0.055	0.055	0.056	0.12	See Appendix	
Total Aluminum (Al)	µg/L	3.0	3.0	3.1	See Appendix	See Appendix	
Total Antimony (Sb)	µg/L	<	<	<		9 (SbIII)	
Total Arsenic (As)	µg/L	1.06	1.03	0.96	5	5	
Total Barium (Ba)	µg/L	20.3	21.1	22.1		1000	
Total Beryllium (Be)	µg/L	<	<	<		0.13	
Total Bismuth (Bi)	µg/L	<	<	<			
Total Boron (B)	µg/L	17.1	27.8	<	1500 (long term)	1200	
Total Cadmium (Cd)	µg/L	<	<	<	See Appendix	See Appendix	
Total Chromium (Cr)	µg/L	<	<	<	1 (Cr VI), 8.9 (Cr III)		See Appendix
Total Cobalt (Co)	µg/L	<	<	<		110	
Total Copper (Cu)	µg/L	<	<	0.54	See Appendix		See Appendix
Total Iron (Fe)	µg/L	58	92	98	300	1000	
Total Lead (Pb)	µg/L	0.065	0.11	<	See Appendix	See Appendix	See Appendix
Total Lithium (Li)	µg/L	1.03	1.35	<			
Total Manganese (Mn)	µg/L	96.4	100	104		See Appendix	
Total Mercury (Hg)	µg/L	<	<	<	0.026		
Total Molybdenum (Mo)	µg/L	0.645	0.748	1.0	73	2000	
Total Nickel (Ni)	µg/L	<	<	<	See Appendix	See Appendix	
Total Selenium (Se)	µg/L	<	<	<	1	1	
Total Silver (Ag)	µg/L	<	<	<	0.25	See Appendix	
Total Strontium (Sr)	µg/L	106	122	115			
Total Thallium (Tl)	µg/L	<	<	<	0.8	0.3	
Total Tin (Sn)	µg/L	<	<	<			
Total Titanium (Ti)	µg/L	<	1.88	<			
Total Uranium (U)	µg/L	N/A	<	<	15 (long term)	8.5	
Total Vanadium (V)	µg/L	<	<	<			
Total Zinc (Zn)	µg/L	5.2	5.4	5.2	30	See Appendix	See Appendix
Total Zirconium (Zr)	µg/L	<	<	<			
Total Calcium (Ca)	mg/L	29.5	31.1	32.5			
Total Magnesium (Mg)	mg/L	8.43	8.68	9.01			
Total Potassium (K)	mg/L	2.76	2.74	2.83			
Total Silicon (Si)	mg/L	12.1	12.0	12.3			
Total Sodium (Na)	mg/L	11.9	11.1	11.8			
Total Sulphur (S)	mg/L	4.7	4.9	5.0			

< - Not detected

N/A - Not analyzed

Table 4-4 Average Water Quality of Selected Drinking Water Wells (Year 11)

Parameter	Units	Bevan #1	Bevan #2	Bevan #3	Bevan #4	Marshall #1	Marshall #3	Townline #2	McConnell
pH	pH	6.71	6.72	6.65	6.58	7.53	7.20	6.69	7.00
Alkalinity (total, as $CaCO_3$)	mg/L	50	63	48	40	120	110	52	89
Conductivity	µS/cm	240	230	230	220	400	320	190	340
Colour	CU	<5	<5	<5	<5	<5	<5	<5	<5
Fluoride	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.050	<0.05	<0.050
Sulphate	mg/L	16	12	13	11	43	36	15	71
Turbidity	NTU	0.1	0.1	0.1	0.1	0.1	0.1	0.38	0.1
Nitrate (as N)	mg/L	<3.39	3.03	3.15	3.18	0.083	0.296	3.41	1.00
Nitrite (as N)	mg/L	<0.0020	<0.0021	<0.0020	<0.0020	<0.0037	<0.0020	<0.0020	<0.040
Total Aluminum (Al)	µg/L	<3.3	<5.2	<3	<3	<3.5	<3	<3	<3
Total Antimony (Sb)	µg/L	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Total Arsenic (As)	µg/L	<0.20	0.27	0.21	0.19	3.62	1.21	0.61	6.17
Total Barium (Ba)	µg/L	5.7	6.6	5.6	5.6	14.2	10.4	5.6	28.4
Total Beryllium (Be)	µg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Total Bismuth (Bi)	µg/L	<1	<1	<1	<1	<1	<1	<1	<1
Total Boron (B)	µg/L	<50	<50	<50	<50	<50	<50	<50	<50
Total Cadmium (Cd)	µg/L	0.027	0.022	0.022	<0.025	0.027	0.026	0.022	<0.011
Total Chromium (Cr)	µg/L	<1	<1	<1	<1	<1	<1	<1	1.0
Total Cobalt (Co)	µg/L	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.2
Total Copper (Cu)	µg/L	14.1	10.7	14.0	13.7	1.8	0.8	7.7	2.6
Total Iron (Fe)	µg/L	<473	<36.5	<23.9	<166	<22.6	<5	<31.2	18.1
Total Lead (Pb)	µg/L	<0.85	<0.2	<0.49	<0.51	<0.2	<0.2	<0.25	<0.22
Total Manganese (Mn)	µg/L	<3.8	<1.3	<1.9	<2.1	8.0	10.0	9.5	25.3
Total Mercury (Hg)	µg/L	<0.0019	<0.0019	<0.0019	<0.0019	0.0020	<0.0019	<0.0019	<0.0019
Total Molybdenum (Mo)	µg/L	<1	<1	<1	<1	1.4	1.5	<1	<2.3
Total Nickel (Ni)	µg/L	<2.0	<1.7	<1.7	<1.7	<1	<1	<1	<1

Table 4-4 Average Water Quality of Selected Drinking Water Wells (Year 11)

Parameter	Units	Bevan #1	Bevan #2	Bevan #3	Bevan #4	Marshall #1	Marshall #3	Townline #2	McConnell
Total Selenium (Se)	µg/L	0.15	0.16	0.14	0.13	<0.1	<0.1	0.18	0.46
Total Silver (Ag)	µg/L	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Total Thallium (Tl)	µg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Total Tin (Sn)	µg/L	<5	<5	<5	<5	<5	<5	<5	<5
Total Titanium (Ti)	µg/L	<5	<5	<5	<5	<5	<5	<5	<5
Total Uranium (U)	µg/L	<0.1	<0.1	<0.1	<0.1	0.7	0.6	<0.1	0
Total Vanadium (V)	µg/L	<5	<5	<5	<5	<5	<5	<5	<5
Total Zinc (Zn)	µg/L	19.9	<7.8	<7.0	<13.0	<5.3	<5.0	<14.3	<5.8
Total Zirconium (Zr)	µg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Total Calcium (Ca)	mg/L	23.0	23.4	22.5	<22.0	41.1	37.2	20.6	37.9
Total Magnesium (Mg)	mg/L	6.36	6.57	5.86	5.54	8.68	8.73	4.52	8.41
Total Potassium (K)	mg/L	1.13	1.17	1.11	1.09	3.23	2.16	1.16	3.46
Total Silicon (Si)	mg/L	11.6	11.6	11.2	11.3	7.34	7.72	9.32	7.62
Total Sodium (Na)	mg/L	8.41	7.25	7.74	7.71	19.15	13.11	7.77	15.8

Means were calculated by setting concentrations less than the detection limit to the detection limit and showing the mean as "<" the calculated value.

N/A – Not analyzed

Table 4-5 Maximum Concentrations of Water Quality Parameters in Selected Drinking Water Wells (Year 11)

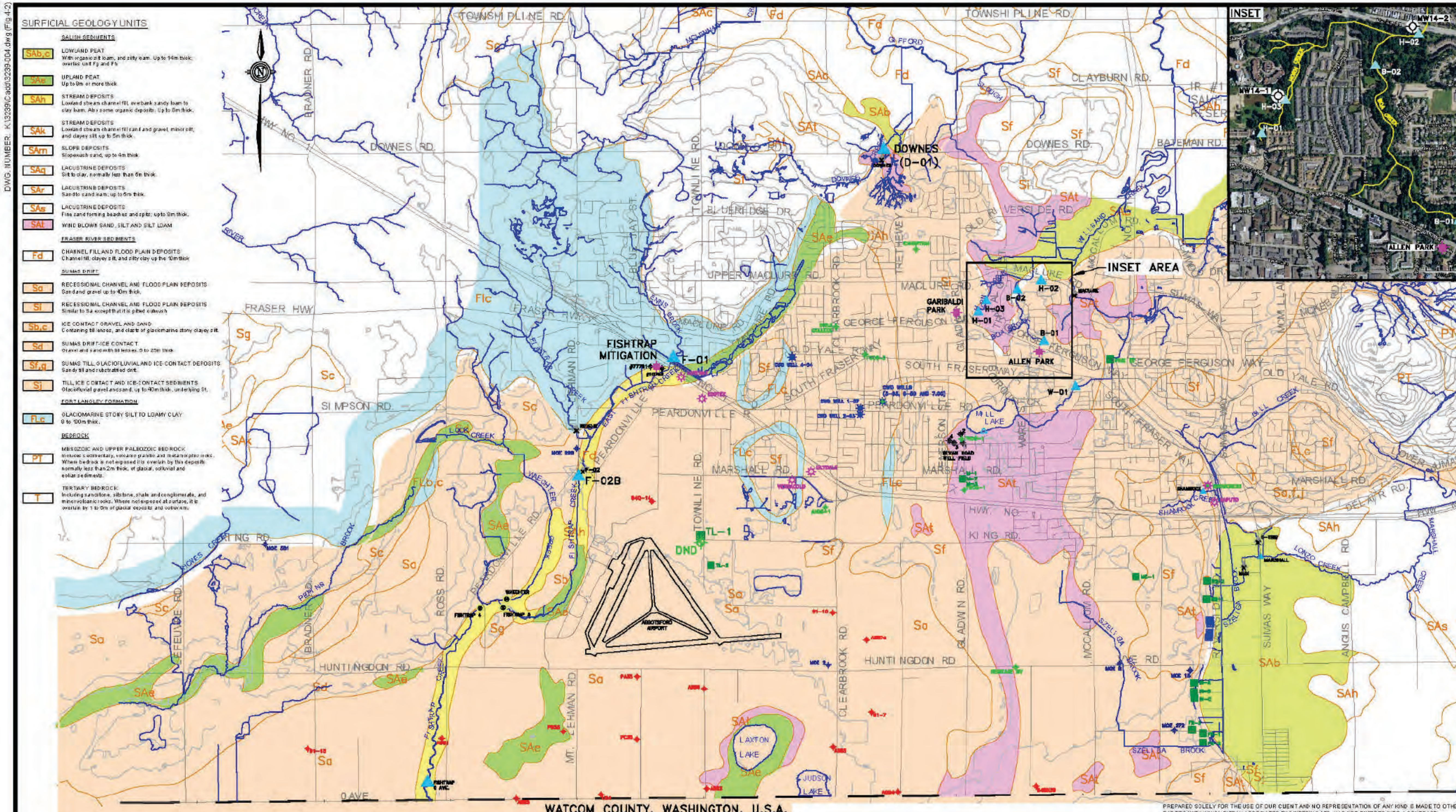
Parameter	Units	Bevan #1	Bevan #2	Bevan #3	Bevan #4	Marshall #1	Marshall #3	Townline #2	McConnell
pH	pH	6.71	6.72	6.65	6.58	7.53	7.20	6.69	7.00
Alkalinity (total, as $CaCO_3$)	mg/L	50	63	48	40	120	110	52	89
Conductivity	µS/cm	240	230	230	220	400	320	190	340
Colour	CU	<5	<5	<5	<5	<5	<5	<5	<5
Fluoride	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	0.052	<0.05	0.05
Sulphate	mg/L	16	12	13	11	43	36	15	71
Turbidity	NTU	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.38	0.1
Nitrate (as N)	mg/L	3.86	3.35	3.47	3.39	0.255	0.566	3.93	2.06
Nitrite (as N)	mg/L	0.0025	0.003	0.002	0.002	0.0212	<0.002	<0.002	0.0912
Total Aluminum (Al)	µg/L	6.6	27.7	<3	<3	7.6	<3	<3	<3
Total Antimony (Sb)	µg/L	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Total Arsenic (As)	µg/L	0.23	0.29	0.23	0.26	5.86	1.29	0.65	6.2
Total Barium (Ba)	µg/L	6.4	7.1	6	6.8	16.2	11	6.3	28.4
Total Beryllium (Be)	µg/L	<1	<1	<1	<1	<1	<1	<1	<1
Total Bismuth (Bi)	µg/L	<1	<1	<1	<1	<1	<1	<1	<1
Total Boron (B)	µg/L	<50	<50	<50	<50	<50	<50	<50	<50
Total Cadmium (Cd)	µg/L	0.038	0.027	0.024	0.033	0.033	0.029	0.026	0.012
Total Chromium (Cr)	µg/L	<1	<1	<1	<1	<1	<1	<1	<1
Total Cobalt (Co)	µg/L	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Total Copper (Cu)	µg/L	39.3	38.5	50.4	41	4.27	0.93	11.2	2.6
Total Iron (Fe)	µg/L	4750	99.4	87.2	1280	159	<5	151	19.7
Total Lead (Pb)	µg/L	7.17	<0.2	3.01	3.52	<0.2	<0.2	0.45	0.23
Total Manganese (Mn)	µg/L	13.2	2.1	4.5	3.9	10.8	13.7	11.9	28.6
Total Mercury (Hg)	µg/L	<0.0019	<0.0019	<0.0019	<0.0019	0.0031	<0.0019	<0.0019	<0.0019
Total Molybdenum (Mo)	µg/L	<1	<1	<1	<1	1.5	1.8	<1	2.3
Total Nickel (Ni)	µg/L	3.9	3.1	3.4	3.4	<1	<1	<1	<1

Table 4-5 Maximum Concentrations of Water Quality Parameters in Selected Drinking Water Wells (Year 11)

Parameter	Units	Bevan #1	Bevan #2	Bevan #3	Bevan #4	Marshall #1	Marshall #3	Townline #2	McConnell
Total Selenium (Se)	µg/L	0.22	0.21	0.21	0.17	<0.1	<0.1	0.28	0.5
Total Silver (Ag)	µg/L	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Total Thallium (Tl)	µg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Total Tin (Sn)	µg/L	<5	<5	<5	<5	<5	<5	<5	<5
Total Titanium (Ti)	µg/L	<5	<5	<5	<5	<5	<5	<5	<5
Total Uranium (U)	µg/L	<0.1	<0.1	<0.1	<0.1	0.83	0.62	<0.1	0.52
Total Vanadium (V)	µg/L	<5	<5	<5	<5	<5	<5	<5	<5
Total Zinc (Zn)	µg/L	72.7	14.3	10.6	49.3	7.9	5.0	26.9	6.6
Total Zirconium (Zr)	µg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Total Calcium (Ca)	mg/L	25.5	25.3	24.3	23.3	44.8	39.7	21.6	38.8
Total Magnesium (Mg)	mg/L	6.87	7.32	6.28	6.34	9.01	9.02	4.77	8.56
Total Potassium (K)	mg/L	1.18	1.20	1.16	1.18	3.59	2.24	1.25	3.46
Total Silicon (Si)	mg/L	13.7	12.9	12.3	13.0	8.63	8.51	9.92	7.92
Total Sodium (Na)	mg/L	9.33	7.82	8.10	8.36	22.4	13.7	8.89	16.0

Table 4-6 Groundwater Monitoring Sites

Site ID	Description	Type	UTM Northing	UTM Easting
TW06-1	Gladwin and Bevan Avenue, Bevan Avenue Wells site in Centennial Park.	Monitoring well	5432370	549965
M14-2 (H-02 Monitoring Well)	Maclure Road, in center of path where Horn Creek meets Maclure Road	Monitoring well	5434385	550857
M14-1 (H-03 Monitoring Well)	In path directly beside H-03 monitoring site.	Monitoring well	5434038	550246
Exhibition Park	Trethewey and Maclure, Exhibition Park in southeast corner of parking lot 1, near washrooms.	Monitoring well	5434623	549342
Columbia Bible College	2940 Clearbrook Road, at George Ferguson Way. Well is in basement of the dormitory.	Monitoring well	5433888	548408
Heritage RV	33120 Huntington Road. Well is flush-mounted in front yard.	Monitoring well	5429553	550705
DND	Townline and King, just inside fence in clump of trees. Well is about a 0.5 m stickup. Climate control transducer is located here as well.	Monitoring well	5431067	546765
Bevan Avenue Wells	Gladwin and Bevan Avenue, Bevan Avenue Wells site in Centennial Park.	SCADA	5432370	549965
Boa Brook mitigation well	Allan Park, George Ferguson Way and Fuller Street	SCADA	5433505	550917
Horn Creek mitigation well	Garibaldi Park, Gladwin and Dahlstrom Place	SCADA	5433976	549978
Fishtrap Creek Mitigation Well	West side of Deacon Street between 2669 and2595 and above the north bank of Fishtrap Creek.	SCADA	5433235	546217



LEGEND

- B.C. MINISTRY OF ENVIRONMENT OBSERVATION WELL
- MONITORING WELL MONITORED BY COA
- ENVIRONMENT CANADA MONITORING WELL
- PRIVATE WELL IDENTIFIED BY WELL TAG No.
- CITY OF ABBOTSFORD PRODUCTION WELL
- FRASER VALLEY TROUT HATCHERY WELL
- CLEARBROOK WATER DISTRICT PRODUCTION WELL
- PRIVATE INDUSTRY PRODUCTION WELL
- BEVAN ROAD WELL
- MONITORING WELL INSTALLED BY PITEAU
- MITIGATION WELL
- LOCATION OF SPOT-MEASUREMENT OF SURFACE WATER FLOWS (SEP. 2009)
- MILL LAKE MONITORING STATION
- CREEK MONITORING STATION
- HISTORICAL CREEK MONITORING STATION
- ABBOTSFORD SUMAS AQUIFER (CANADIAN PORTION)

NOTES:

1. SURFICIAL GEOLOGY FROM ARMSTRONG ET. AL., 1976.
2. SURFICIAL GEOLOGY UNITS OUTSIDE LIMITS OF AQUIFER DEPICTED WITHOUT COLOUR.

0 400 800 1200 1600 2000m

SCALE 1:45,000

CITY OF ABBOTSFORD
UPDATED HYDROGEOLOGICAL ASSESSMENT
BEVAN WELLS PROJECT

PITEAU ASSOCIATES
GEOTECHNICAL AND WATER MANAGEMENT CONSULTANTS

AQUIFER LEVEL AND SURFACE WATER MONITORING STATIONS WITH SURFICIAL GEOLOGY

BY:	DATE:
SC/sl	NOV 21
APPROVED:	FIG:
DJT	4-2