KERR WOOD LEIDAL
consulting engineers

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Water Quality Assessment

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1. Introduction

This work builds on the Phase 2 IRMP results to provide a more comprehensive understanding of the water quality concerns in the City's receiving waters and drainage catchments.

This task included detailed review of the Phase 2 IRMP results and development of a plan for additional sampling and monitoring to fill gaps and increase understanding of the issues and the sources of water quality concerns. The sampling was completed and the results of previous and new monitoring were combined to better understand the status of the watersheds' quality concerns, particularly as relates to the watershed health of the receiving creeks, rivers and other water bodies.

Based on the assessment of water quality results, KWL developed a set of recommended Best Management Practices (BMPs) for water quality improvement, for consideration where water quality improvement projects can be implemented, either as pilot projects or as part of development.

2. Approach

Desktop and field studies were combined to evaluate environmental concerns associated with stormwater in the City. The desktop study involved a review of existing water quality data to identify potential water quality issues and knowledge gaps, as well as mapping of land use to investigate potential nonpoint pollutant sources. Outcomes from the desktop studies were used to develop a plan for additional sampling and monitoring to fill some of the knowledge gaps and get a better understanding of potential water quality issues in the City. The combined dataset was analyzed and compared to available water quality guidelines to identify areas where water quality is a concern. As a final step, measures to mitigate environmental impacts of stormwater were considered.

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2.1 Desktop Study

Existing Water Quality Data

Water quality monitoring was previously performed as part of Phase 2 of the City's Integrated Rainwater Management Plan (IRMP) [1]. Collected data reflect stormwater quality prior to discharge into receiving waters (i.e., not ambient water quality). The program was designed as follows:

- Five water samples collected over a period of 30 days during summer (September and October 2019) and winter (January and February 2020) to reflect low- and high-flow conditions, respectively.
- Six stormwater discharge sites, one in each of the catchments Piercy Creek, Courtenay River, Morrison Creek, Puntledge River, Glen Urquhart Creek, and Brooklyn Creek (Figure 1).
- Collected *in situ* data including pH, specific conductivity, temperature, dissolved oxygen, and turbidity, and analyzed water samples for nitrate, bacteria, and the metals cadmium, copper, iron, lead, and zinc.

Baseline water quality monitoring for the Tsolum River and its tributary Portuguese Creek was performed in 2019 for the B.C. Ministry of Environment and Climate Change Strategy (ENV) [2]. Data were analyzed to determine potential impacts associated with agricultural activity. The study concluded that water quality is generally good in the lower Tsolum River and poor in Portuguese Creek, where almost 40% of the land use is for agricultural purposes.

Land Use

Stormwater and ambient water quality is often correlated to land use. Certain activities are known for giving rise to high pollutants loads, such as metals from traffic and bacteria from agricultural land use.

Land uses within City boundaries were mapped as part of the IRMP Phase 2 Report. A review of land uses outside of City boundaries were focused on agricultural land and farm uses. Data on agricultural land use was found in the following documents:

- Comox Valley Regional District Agricultural Land Use Inventory (2013), maps B1 through B15 [3].
- Existing Farm Uses (as classified by the BC Assessment Authority) in the Comox Valley [4].

In addition to land use, lots with septic fields were mapped, using GIS data provided by the City.

[1] City of Courtenay (2020). Integrated Rainwater Management Plan: Phase 2 Report and Recommendations to Guide Next Steps.
[2] Montgomery-Stinson, T. and A. Furness. 2020. Summary of Baseline Water Quality Monitoring in Agricultural Areas of the Comox Valley. Environmental Quality Series. Prov. B.C., Victoria B.C. https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/waterquality/monitoring-water-quality/west-coast-wq-docs/comox_agricultural_area_water_quality_monitoring.pdf
[3] https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/agriculture-and-seafood/agricultural-land-and-environment/strengthening-farming/land-use-inventories/comoxvalley2013_allmaps_lowres.pdf
[4] https://www.comoxvalleyrd.ca/sites/default/files/uploads/report-study/10planning_ap_map06_existing_farm_uses.pdf

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2.2 2021 Monitoring Program

The 2021 monitoring program was partly based on the monitoring protocol outlined in the Metro Vancouver Monitoring and Adaptive Management Framework for Stormwater [5] (AMF). The AMF protocol suggests a cost-effective monitoring program that gives a good understanding of baseline water quality and watershed health.

The AMF protocol recommends water quality sampling in both the wet and the dry season, collecting 5 samples over 30 days, and analysis of 13 water quality parameters. Because previous stormwater quality monitoring was performed in line with the AMF protocol, KWL recommended a limited program for supplementary monitoring of water quality in major watercourses in the City. The objective of the additional monitoring was to get a better understanding of water quality in watercourses receiving stormwater discharges from the City and to investigate whether City discharges may negatively impact ambient water quality.

Sampling Locations

Sampling was performed on all watercourses identified in the Integrated Rainwater Management Plan, Phase 2 Report, except Brooklyn Creek and Little River, on 2021-11-24, 25 and 26. Monitored watercourses include:

- Tsolum River
- Puntledge River
- Morrison Creek
- Courtenay River
- Piercy Creek
- Glen Urquhart Creek
- Mallard Creek

Brooklyn Creek was monitored in the 2019/2020 program, and water quality was shown to be adequate, hence KWL did not recommend additional sampling of Brooklyn Creek. Water quality in Little River has not previously been monitored. Land use in the watershed is mainly agricultural and rural residential. In the IRMP Phase 2 report, it was noted that the Little River watershed has “some of the largest future development potentials within the City". Before development begins, it is recommended to determine baseline water quality so that potential changes in watershed health can be tracked over time. However, there was limited data available for the Little River watershed and KWL could not find appropriate monitoring locations in the watershed within the short time frame of the project. Monitoring of Little River should be considered in future sampling programs.

For remaining watercourses, desktop studies were performed to identify potentially accessible upstream and downstream sampling locations on each watercourse, which would allow for comparison of water quality “before” (upstream) and “after” (downstream) City inputs. Exceptions to this approach included Portuguese Creek, as only a limited reach of the creek is located within City limits, and Courtenay River, for the same reason and because the river is highly influenced by tidal waters from Comox Bay. For watercourses that run through other municipalities before reaching Courtenay (e.g., Tsolum River and Puntledge River) upstream locations were defined as the municipal border. Downstream locations were defined as either the downstream municipal border (just upstream of where the watercourse flows into another municipality), which is the case for Glenn Urquhart Creek and Portuguese River, or just upstream of where the watercourse confluences with another watercourse (e.g., Tsolum River and Puntledge River).

[5] Metro Vancouver, Monitoring and Adaptive Management Framework for Stormwater (2014): http://www.metrovancouver.org/services/liquid-waste/LiquidWastePublications/Monitoring_Adaptive_Management_Framework_for_Stormwater.pdf

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Morrison Creek and Piercy Creek have several upstream branches that converge into a main creek; for these watercourses, upstream monitoring sites were identified on each of the branches, to investigate whether sub-catchments show discrepancies in water quality.

Because sampling was limited to one multiday event, suggested water quality monitoring sites were grouped into higher and lower priority sites, where those with higher priority were monitored first and those with lower priority were monitored if time was available. Sites with no previous monitoring data were set to higher priority.

Two identified stormwater discharge sites in the Tsolum River watershed were not possible to locate in the field and hence samples were not collected; however, these sites were of lower priority because they represent small drainage areas and stormwater quality rather than ambient water quality.

Higher and lower priority monitoring sites are summarized in Table 1 and found in Figure 1. Land use and potential sources impacting water quality are indicated for each of the monitored sites.

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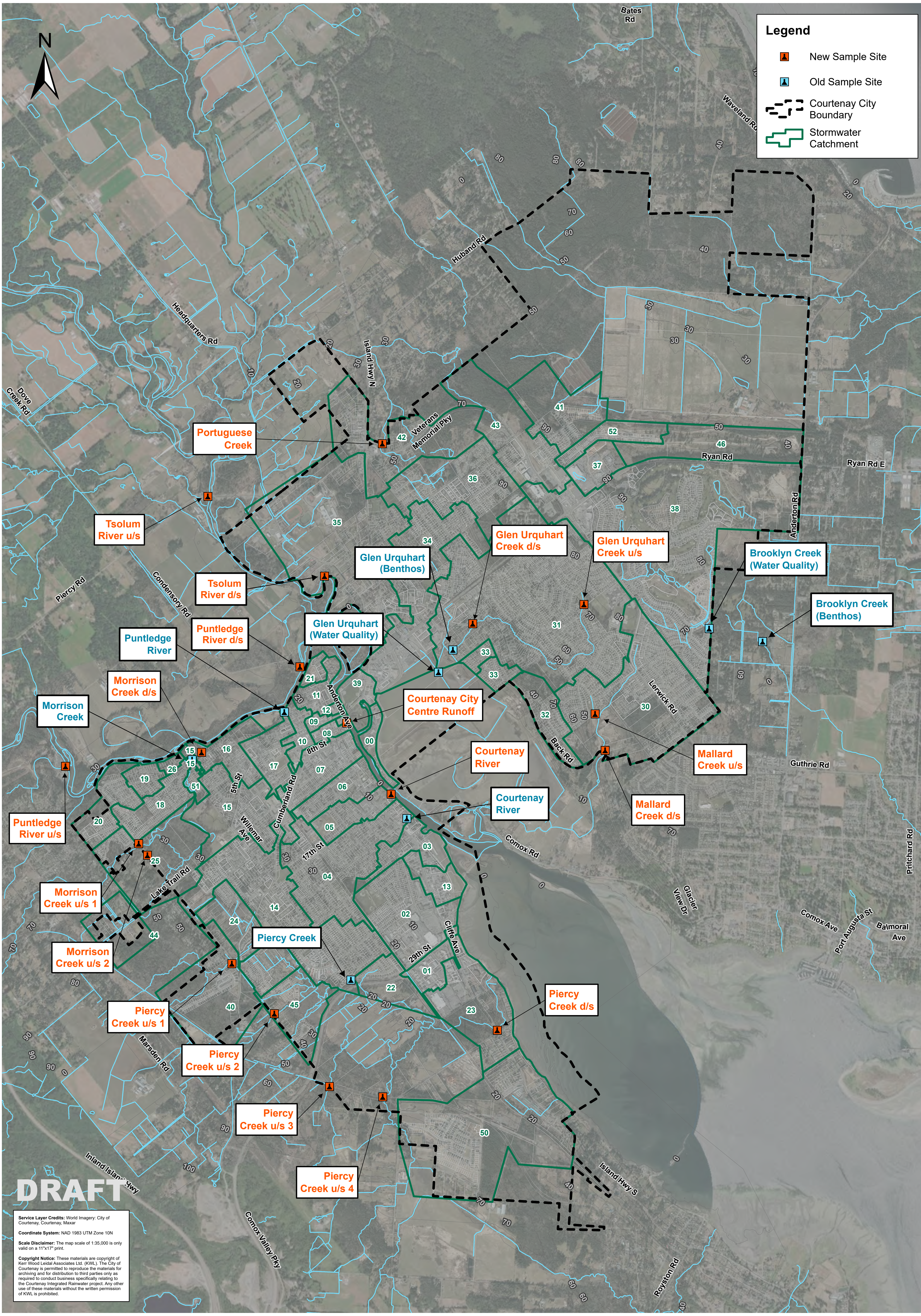
City of Courtenay

Courtenay Integrated Rainwater

KERR WOOD LEIDAL
consulting engineers



Project No. 2980-014

Date December 2021

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New and Old Sampling Locations

Figure 1

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Table 1: Higher and lower priority water quality monitoring sites located in watercourses receiving stormwater discharges from the City of Courtenay.

Site #	Monitoring location	Rationale	Location Information	Potential Impacts on Water Quality
Higher Priority				
1	Tsolum River u/s	Tsolum River upstream of City inputs – “before scenario”.	Sample collected u/s of City boundary, from Piercy Road Bridge.	• Watershed dominated by agriculture, agricultural activities are limited in the City portion of the watershed. • Land use within City boundaries dominated by rural residential. • Runoff from Highway 19A and other roads. • Water quality potentially affected by upstream, non-City related sources.
2	Tsolum River d/s	Tsolum River downstream of City inputs – “after scenario”.	Sample collected u/s of confluence with Puntledge River.	
3	Puntledge River u/s	Puntledge River upstream of City inputs – “before scenario”.	Sample collected u/s of City boundary, near Puntledge River Hatchery.	• Puntledge River drains Cumberland Lake. • Watershed dominated by natural land cover upstream of City boundary. • Considerable portion of agricultural land use on north side of river (outside City limits). • Land use within City boundaries dominated by urban and multi residential, industrial, and parks. • Water quality potentially affected by upstream, non-City related sources.
4	Puntledge River d/s	Puntledge River downstream of City inputs – “after scenario”.	Sample collected u/s of confluence with Tsolum River, near Condensory Road.	
5	Morrison Creek u/s 1	Morrison Creek upstream of City inputs – “before scenario”.	North branch of Morrison Creek in Roy Stewart Morrison Nature Park.	• Watershed dominated by residential areas upstream of City boundary, some lots with septic fields. • Land use within City boundaries dominated by parks, public/institutional areas (mainly schools), and multi residential. • Water quality potentially affected by upstream, non-City related source.
6	Morrison Creek u/s 2	Morrison Creek upstream of City inputs – “before scenario”.	South branch of Morrison Creek in Roy Stewart Morrison Nature Park.	
7	Morrison Creek d/s	Morrison Creek downstream of City inputs – “after scenario”.	Sample collected from the creek in Puntledge Park.	
8	Courtenay River	Reflects water quality right before it discharges into the ocean.	Sample collected at low tide (1 h 40 min after low tide; 6 h 20 min before high tide).	• Water quality affected by Puntledge River and Tsolum River, as well as intruding sea water from Comox Bay at high tide. • Runoff from Courtenay City centre.
9	Piercy Creek u/s 1	One of four identified upstream branches of the creek. Piercy Creek upstream of City inputs – “before scenario”.	Northernmost branch of Piercy Creek, close to Cumberland Rd and Arden Rd junction.	• Watershed dominated by rural and suburban residential, agriculture and natural land cover upstream of City boundary. • Several septic fields lots upstream of monitoring location. • Water quality potentially affected by upstream, non-City related sources.
10	Piercy Creek u/s 2	One of four identified upstream branches of the creek; Piercy Creek upstream of City inputs – “before scenario”.	Branch of Piercy Creek located close to Mabley Rd and Arden Rd junction.	• Watershed dominated by rural and suburban residential, agriculture and natural land cover upstream of City boundary. • Some septic fields lots upstream of monitoring location. • Water quality potentially affected by upstream, non-City related sources.
11	Piercy Creek u/s 3	One of four identified upstream branches of the creek. Piercy Creek upstream of City inputs – “before scenario”.	Branch of Piercy Creek located at Comox Logging Rd and Arden Rd junction.	• Watershed dominated by agriculture and natural land cover upstream of City boundary. • No identified septic field lots in catchment. • Water quality potentially affected by upstream, non-City related sources.

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Site #	Monitoring location	Rationale	Location Information	Potential Impacts on Water Quality
12	Piercy Creek u/s 4	One of four identified upstream branches of the creek. Piercy Creek upstream of City inputs – "before scenario".	Branch of Piercy Creek located at Comox Logging Rd, closer to Fraser Rd junction.	• Watershed dominated by rural and suburban residential, agriculture and natural land cover upstream of City boundary. • No identified septic field lots in catchment. • Water quality potentially affected by upstream, non-City related sources.
13	Piercy Creek d/s	Piercy Creek downstream of City inputs – "after scenario".	Sampling site located east of Highway 19A; downstream of confluence of branches.	• Land use between monitored u/s and d/s locations dominated by urban residential and industrial (mainly downstream of location #1), suburban residential, and agricultural activities including livestock. • Runoff from Highway 19A and other roads.
14	Portuguese Creek	Portuguese Creek downstream of City inputs – "after scenario".	Sample collected from creek, downstream of stormwater retention areas.	• Land use upstream of the monitoring location dominated by rural, suburban and urban residential, and parks. • Runoff from a few larger roads. • Water quality potentially affected by upstream, non-City related sources.
Lower Priority				
15	Glen Urquhart Creek u/s	Glen Urquhart upstream of City inputs – "before scenario".	Sample collected from creek, downstream of stormwater retention area; One of several upstream branches of the creek, other branches were not monitored.	• Land use dominated by multi residential, some park land; • Some agricultural land use in watershed, but located downstream of monitoring locations. • Water quality at both u/s and d/s locations impacted entirely by City-related sources as the creek has its source within City boundaries.
16	Glen Urquhart Creek d/s	Glen Urquhart Creek downstream of City inputs – "after scenario".	Suggested sampling site further downstream in the system (downstream of stormwater retention area) was not accessible, monitored site is therefore not the most downstream location of the creek.	
17	Mallard Creek u/s	Mallard Creek upstream of City inputs – "before scenario".	Sample collected downstream of Hawk Glen Park, close to downstream site, not possible to locate creek further upstream.	• Land use dominated by multi residential, park land, and public/institutional areas. • Water quality at both u/s and d/s locations impacted entirely by City-related sources as the creek has its source within City boundaries.
18	Mallard Creek d/s	Mallard Creek downstream of City inputs – "after scenario".	Sample collected from creek, downstream of stormwater retention area.	
19	Courtenay City Centre Runoff	Stormwater runoff affected by City centre activities and land use.	Sample collected at low tide from sewer outlet discharging into Courtenay River.	• City centre activities and land use.
20	Highway 19A Runoff – Tsolum River Watershed	Runoff potentially impacted by highway and traffic	Discharge point not located in field – no sample collected.	• Traffic.
21	Agricultural Runoff – Tsolum River Watershed	Runoff potentially impacted by agricultural land use	Discharge point not located in field – no sample collected.	• Agricultural activities.

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Parameters

A combination of *in situ* measurements and water samples for laboratory analysis were collected at each sampling location. Water quality parameters measured in field and by the analyzing laboratory are presented in Table 2.

Table 2: Monitored water quality parameters

In situ measurements	Laboratory analysis
pH	Nitrogen as Nitrate
Water temperature	*E. coli*
Conductivity	Fecal Coliforms
Dissolved oxygen (DO)	Total cadmium
Turbidity	Total copper
	Total iron
	Total lead
	Total zinc

Physical Water Quality Parameters

Physical water quality parameters are general water quality indicators that help with interpretation of results for other water quality parameters, such as metals and solids, and are useful when trying to determine the cause of an impact:

- Low dissolved oxygen levels can indicate low flow/still waters, as well as organic matter, including bacteria and plant debris, that can consume oxygen as it decays.
- Changes in pH can indicate the presence of particular discharges such as road runoff or spill.
- Increased water temperature is a potential indicator of loss of riparian habitat upstream, leading to reduced shading, or increased water retention, for example, due to an increase in number and size of stormwater ponds.
- Conductivity is a measure of ions. Urban runoff typically shows higher conductivity that natural forested streams with similar geology and groundwater inputs. Large fluctuations in conductivity can be an indication of wastewater discharge.
- Turbidity is a measure of water clarity and is affected by solids and coloured dissolved material such as humic acids. Increased turbidity could indicate upstream erosion.

Metals

The occurrence of many metals in stormwater is often related to traffic and building materials. Traffic-related sources to metals include both vehicle parts such as body, tires, brake pads, and exhaust, and leaching from materials used for street furniture such as traffic barriers, lamp posts, and traffic signs. The most common metals emitted from traffic are zinc, released with tire wear and from galvanized surfaces, and copper, emitted during brake wear and with exhaust. Traffic is also a major source to many other common stormwater pollutants, including solids and polycyclic aromatic hydrocarbons (PAHs).

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Metal leaching from construction materials is very common: important sources are roofs, including HVAC and ductwork and gutters, which mainly leach zinc but also copper; zinc, copper, and arsenic leaching from wood preservatives; and copper and lead from paint.

Nitrogen

Nitrogen exists in many forms in water (e.g., nitrite, nitrate, ammonia, organic nitrogen, and particulate nitrogen). Nitrate (NO_3^-) is frequently detected in stormwater. High nitrate concentrations may indicate pollution from septic system leakage, fertilizers, garden waste, waste from pets and wildlife, as atmospheric deposition from, for example, vehicle exhaust. Nitrate is directly toxic to some aquatic species.

Bacteria

E. coli and fecal coliforms are common in stormwater from populated areas and may come from waste from humans, dogs and other domestic animals, and wildlife. Urban surfaces such as roofs, streets, and driveways contribute considerably to bacteria levels in stormwater. Fecal matter from urban wildlife, for example birds including waterfowl, squirrels, rats, and racoons, is deposited on urban surfaces or in storm sewers. Irrigated lawns attract birds and mammals, and over-watering has been shown to be an important source of bacteria in stormwater.

High bacteria concentrations in ambient water and stormwater can indicate sanitary issues such as cross-connections and failing septic fields. *E. coli* and fecal coliform bacteria counts in stormwater typically range from 10^3 and 10^4 units per 100 mL. Considerably higher counts, $\geq 10^5$ units/100 mL, indicate the presence of cross-connections with sanitary sewers[6].

Sampling Methodology

Samples were collected according to the Ministry of Environment BC Field Sampling Manual (2013)[7] (BCFSM) methodologies and methodologies described in Section 6 (Water Quality Sampling Methodology) of the *Metro Vancouver Monitoring and Adaptive Management Framework for Stormwater* (2014)[8].

In situ water quality was measure using a handheld ProDSS Multiparameter Digital Water Quality Meter with GPS from YSI.

The water quality indicator parameters nitrate, bacteria, and total metals were submitted to CARO Analytical Services (CARO), a CALA accredited lab, in Richmond. At the end of each sampling day, the samples were dropped off at Harbour Air in Nanaimo, for air transport to Vancouver and CARO's laboratory drop off in Richmond. On the last day of sampling, samples were dropped off by KWL staff in Richmond.

[6] Marsalek, J. and Rochfort Q. (2004). Urban wet-weather flows: sources of fecal contamination impacting on recreational waters and threatening drinking-water sources. Journal of Toxicology and Environmental Health, Part A. 67(20-22):1765-77. doi: 10.1080/15287390490492430.
[7] https://www2.gov.bc.ca/gov/content/environment/research-monitoring-reporting/monitoring/laboratory-standards-quality-assurance/bc-field-sampling-manual
[8] http://www.metrovancouver.org/services/liquid-waste/LiquidWastePublications/Monitoring_Adaptive_Management_Framework_for_Stormwater.pdf

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Quality Assurance/Quality Control Program

Sampling Methods

Field sampling was conducted following:

- Ministry of Environment *BC Field Sampling Manual* (2013) (BCFSM) methodologies
- *Metro Vancouver Monitoring and Adaptive Management Framework for Stormwater* (2014) section 6 (Water Quality Sampling Methodology)

Equipment Calibrations

The ProDSS Multiparameter Digital Water Quality Meter was calibrated by Hosking Scientific Ltd. on 2021-11-21. Calibration values were recorded and filed for record keeping.

Holding Times

Holding times are the length of time a sample can be stored after collection and before analysis without significantly affecting the analytical results. Samples were analyzed within recommended holding time except for bacteria samples collected on 2021-11-25. Because of cancelled flights between Nanaimo and Vancouver on that day, collected samples were delayed until the next day and microbiological analyses were therefore initiated beyond the recommended maximum holding time of 30 hours. The quality of other analyzed parameters is not expected to have been compromised because of the delayed sample delivery.

Field QC Sampling

Field duplicates (replicates) are two samples collected at the same location, using the same equipment, and submitted to the lab for analysis. Duplicates are used to estimate sampling and laboratory analysis precision. Because of the size of the monitored watercourses, temporal variability duplicates were collected at most locations. These samples are collected from the same sampling location, using the same techniques and the same type of equipment, but at a time different from the original sample, to understand if measurable variations in water quality occur within short periods.

The BCFSM states that for field duplicates/replicates "It should be expected that the Relative Percent Difference (RPD) is somewhat greater than that for laboratory duplicates. If one of a set of duplicate values is at or greater than five times the Method Detection Limit (MDL), then RPD values >20% indicate a possible problem, and > 50% indicate a definite problem, most likely either contamination or lack of sample representativeness" (*BC Field Sampling Manual (2013): Part A Appendix 3*).

Many bacteria duplicates showed RPDs between 20 and 50%. This is commonly observed for samples with low bacteria counts, which is the case for most collected samples. Samples collected from Piercy Creek d/s on 2021-11-25 showed high RPDs (47% for fecal coliforms, and 56% for *E. coli*) even though bacteria levels were high; fecal coliforms and *E. coli* were both at 613 MPN/100 mL compared to <100 MPN/100 mL in most other samples. The high bacteria RPDs may be a result of long holding times due to the delayed delivery of the Piercy Creek samples.

Laboratory QA/QC

CARO conducts internal QA/QC protocols to meet the CALA certification requirements. This includes running internal blanks, duplicates, and matrix spike analysis.

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Water Quality Assessment Guidelines

Collected water quality data have been evaluated according to the system proposed in the AMF, which was developed based on Provincial water quality guidelines. The AMF water quality assessment approach was developed to provide a simplified system to help municipalities identify where water quality conditions are good and where concerns exist. Water quality is interpreted as follows:

- **Good Priority Indicator:** Suggests that water quality for this parameter is good. No further monitoring for this parameter is required in the drainage system for 5 years and no adaptive management is required.
- **Satisfactory Priority Indicator:** Suggests that water quality is either closely approaching a level of concern for this parameter or is already in non-attainment with Provincial Water Quality guidelines.
- **Need Attention Priority Indicator:** Suggests that water quality is in non-attainment with Provincial Water Quality guidelines.

Parameter-specific thresholds for the 'good', 'satisfactory' and 'need attention' classifications are found in Table 3. In watersheds with all good priority water quality indicators, further monitoring is not required for 5 years, and adaptive management is not needed. In watersheds with single or multiple satisfactory and/or need attention priority indicators, actions to address water quality issues should be considered. The level of water quality relative to guidelines and the incidence of additional priority indicators of concern should be considered in the development of the city-wide adaptive management plan. Also, supplemental water quality monitoring and/or adaptive management actions should be considered.

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Table 3. Classification of Water Quality Results According to the Metro Vancouver AMF Evaluation System.

Parameter (Unit)	Good Level	Satisfactory Level	Need Attention Level
Physical Water Quality Parameters			
Dissolved Oxygen (mg/L)	≥11	<11 to 6.5	<6.5
pH	6.5 to 9.0	<6.5 to 6.0 or >9.0 to 9.5	<6 or >9.5
Water Temperature (wet season) (°C)	7 to 12	5 to <7 or >12 to 14	<5 or >14
Conductivity (mS/cm)	<0.050	0.050-0.200	>0.200
Turbidity (NTU)	0 to 5	5 to 25	>25
Nutrients			
Nitrate, N-NO_3 (mg/L)	<2	2-5	>5
Microbiological			
E. coli (MPN/100 mL)	Geomean ≤77	Geomean 78-385	Geomean >385
Fecal Coliforms (MPN/100 mL)	Geomean ≤200	Geomean 201-1000	Geomean >1000
Metals			
Cadmium, total (mg/L)	<0.00006	0.00006-0.00034	>0.00034
Copper, total (mg/L)	<0.003	0.003-0.011	>0.011
Iron, total (mg/L)	<0.8	0.8-5	>5
Lead, total (mg/L)	<0.005	0.005-0.03	>0.03
Zinc, total (mg/L)	<0.006	0.006-0.04	>0.04

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3. Water Quality Analysis

Results from the stormwater monitoring program in 2019/2020 are summarized in Section 3.1 and the ambient water quality data collected in 2021 are discussed more in detail in Section 3.2.

3.1 2019/2020 Stormwater Quality Monitoring

Averaged (5 samples) stormwater quality data collected in 2019 and 2020 are found in Table 4. Data in Table 4 are compared to the AMF 'good', 'satisfactory', and 'need attention' thresholds, as the AMF framework provides a simplified water quality assessment approach for identifying water quality issues.

In the IRMP Phase 2 Report, water quality data were compared to the Provincial 2019 Working Water Quality Guidelines (WQGs) for metals, and the 2017 Recreational WQGs for bacteria and nitrate, but those have since then been replaced by updated and approved guidelines.

Water quality data in Table 4 were discussed in detail in the IRMP Phase 2 Report; some of the key takeaways are as follows:

- Conductivity was exceeding the 'satisfactory' threshold at all sites and in the summer, the 'need attention' threshold was also exceeded in samples from Courtenay River, Morrison Creek, and Puntledge River. High conductivity is a general indication of potential water quality impacts.
- Consistent high turbidity conditions were found at the stormwater outlet into Morrison Creek while elevated temperature and turbidity events were observed periodically at all sites except for Piercy Creek.
- Except for Puntledge River, nitrate concentrations were within the AMF 'good' level at all locations, which indicates limited nutrient contamination.
- Bacteria concentrations were elevated at most monitored locations, with *E. coli* in Brooklyn Creek being the exception. Fecal coliform concentrations exceeded the 'need attention' level at all locations during both summer and winter conditions. Bacteria concentrations were generally higher in the summer than in the winter samples. Fecal coliform concentrations were very high in the samples from Courtenay River, Morrison Creek, and Puntledge River in the winter. These data suggest that there are chronic issues with elevated bacteria levels in City stormwater discharges.
- At all locations except Brooklyn Creek, copper and zinc concentrations exceeded the 'satisfactory' level. Zinc concentrations in Piercy Creek also exceeded the 'need attention' level. Some locations also exhibited 'satisfactory' iron concentrations and samples from the Courtenay River outlet exceeded the 'need attention' level for iron. These results indicate that there are chronic issues with elevated metal concentrations in City stormwater.
- Brooklyn Creek showed the fewest exceedances of water quality thresholds. Averaged stormwater quality data from Courtenay River and Morrison Creek showed the highest frequency of threshold exceedances.

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Table 4: Water quality in 2019/2020 monitoring of stormwater discharges. Data represent the mean of five samples collected during winter (January and February 2020) and summer (September and October 2019) conditions.

Parameter (Unit)	Piercy Creek		Courtenay River		Morrison Creek		Puntledge River		Glen Urquhart Creek		Brooklyn Creek	
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
Physical Water Quality Parameters												
pH	7.3	7.7	7.6	7.7	7.0	7.5	7.5	8.0	7.4	7.7	7.2	7.5
Water Temperature (°C)	6.2	15.7	6.9	16.1	5.6	16.0	7.1	15.6	6.6	14.3	6.7	15.2
Conductivity (mS/cm)	140	172	129	224	189	218	155	254	151	151	112	176
Turbidity (NTU)	9.8	2.4	9.3	6.6	12	41	14	6.4	7.1	3.3	7.4	1.2
Dissolved Oxygen (mg/L)	9.7	7.5	10.2	8.0	10.1	8.3	10.4	8.5	9.6	7.2	9.7	6.3
Nutrients												
Nitrate (mg/L)	1.3	1.6	1.0	0.8	0.8	1.1	1.3	3.0	1.1	1.3	0.9	0.2
Bacteria												
Fecal Coliforms (MPN/100 mL)	2,647	7,934	1,595	246,004	3,739	162,825	3,800	131,964	14,000	10,541	366	16,446
E. coli (MPN/100 mL)	219	113	128	662	155	6,357	310	803	1,672	159	26	41
Total Metals												
Cadmium, total (mg/L)	0.00001	0.00003	0.00004	0.00001	0.00001	0.00002	0.00002	0.00001	0.00001	0.00001	0.00001	0.00001
Copper, total (mg/L)	0.0041	0.0059	0.0045	0.047	0.0051	0.0054	0.0053	0.0042	0.0046	0.0042	0.0055	0.0014
Iron, total (mg/L)	0.5	0.8	0.5	5.5	0.9	1.0	0.9	0.5	0.5	0.4	0.5	0.2
Lead, total (mg/L)	0.0004	0.0009	0.0015	0.0008	0.0005	0.0009	0.0011	0.0005	0.0005	0.0003	0.0002	0.0001
Zinc, total (mg/L)	0.033	0.080	0.025	0.010	0.013	0.016	0.021	0.018	0.020	0.008	0.008	0.004

Cell colour indicates the classification of water quality results according to the Metro Vancouver Monitoring and Adaptive Management Framework for Stormwater; green = ‘good’ level, yellow = ‘satisfactory’ level, red = ‘need attention’ level.
Mean values are averaged over 5 samples; the geomean was calculated for microbial parameters.
Data in this table were copied from the Integrated Rainwater Management Plan Phase 2 Report and have not been checked against raw data.

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3.2 2021 Receiving Water Quality Monitoring

Water quality data collected from receiving waters in November 2021 are summarized in Table 2 and exceedances of AMF thresholds are discussed below. Figure 1 shows AMF exceedances in samples of both ambient water and stormwater. Water quality data collected in 2021 were not compared to data collected in 2019/2020, as 2021 data reflect ambient water quality, and 2019/2020 data mostly reflect stormwater quality.

Tsolum River

Water quality data collected from Tsolum River show few exceedances of the AMF thresholds. Low pH was measured at both the upstream (5.7) and downstream (4.7) locations. These pH levels are lower than those found in the Provincial study (2020) of the Tsolum River watershed, where pH ranged from 7.1 to 7.7. The Provincial study further concluded that agriculture is a large contributor to negative impacts on water quality in Tsolum River; however, the current monitoring showed low nitrate concentrations at 0.2 mg/L.

Exceedances of AMF thresholds include conductivity at the downstream location, which is at 'satisfactory' level, and water temperature around 4°C ('need attention' level). Except for mentioned exceedances, there are no other signs of contamination in Tsolum River. In addition, there were no measurable impacts of City inputs on water quality at the time of sampling apart from an increase in conductivity from the upstream to the downstream monitoring location; hence City discharges are assumed to have a negligible impact on the measured water quality in Tsolum River. Only a short reach, approximately 2 km, of Tsolum River runs through the City and City discharges are assumed to be limited compared to the total discharge of the river.

Portuguese Creek

Water quality in Portuguese Creek showed exceedances of the AMF 'satisfactory' thresholds for pH, water temperature, conductivity, dissolved oxygen, and zinc. Monitoring was performed downstream of stormwater retention areas but also downstream of a major road, which may impact water quality. Stormwater retention may improve water quality through particle removal, which generally leads to lower metal concentrations, whereas traffic usually leads to increased metal loads in stormwater.

The Provincial study (2020) concluded that water quality in Portuguese Creek, which is a tributary to Tsolum River, is generally poor. It was suggested that agricultural land use, which is found downstream of City boundaries in the Portuguese Creek watershed, is a large contributor to negative impacts on water quality.

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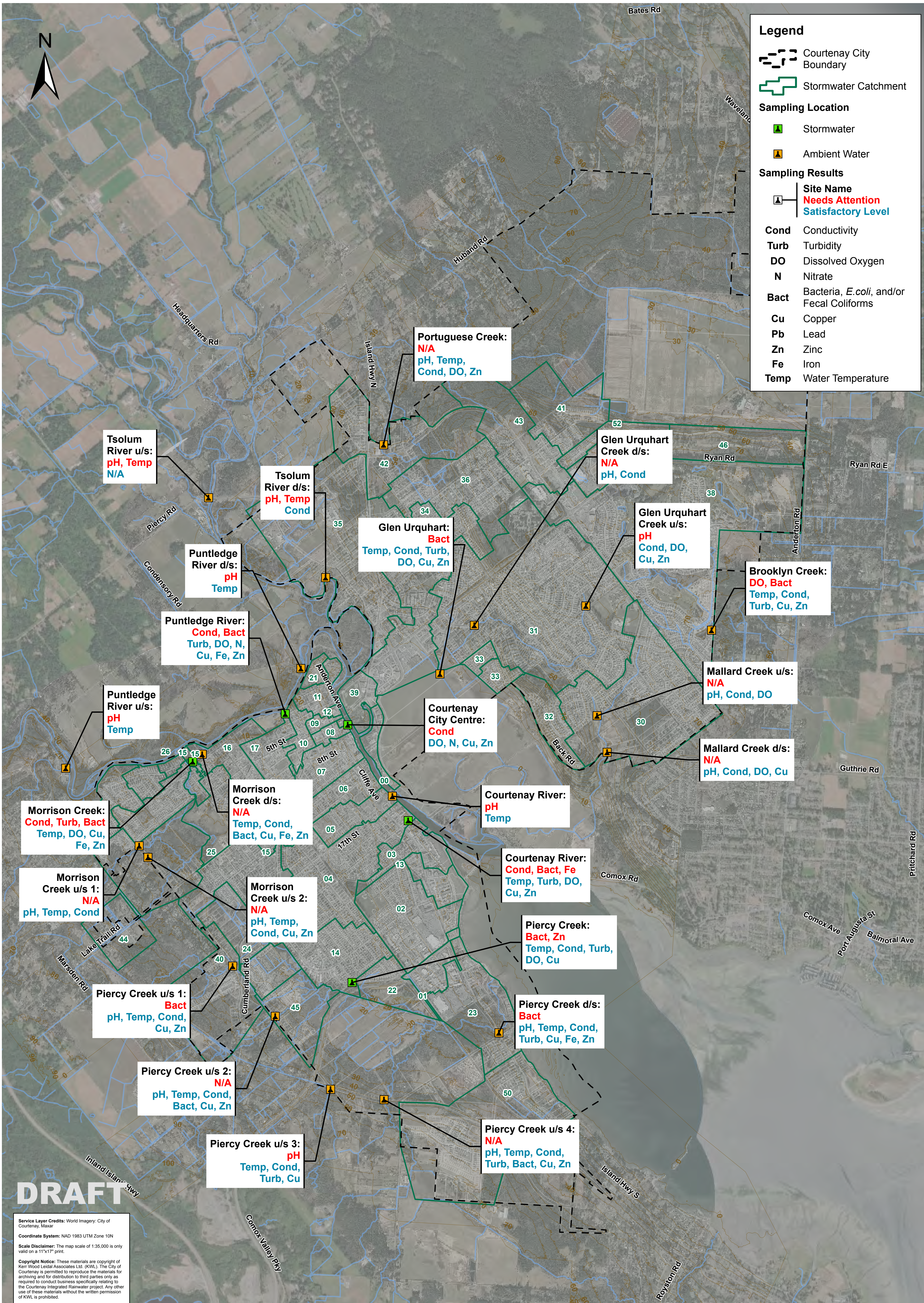
City of Courtenay

Courtenay Integrated Rainwater

KERR WOOD LEIDAL
consulting engineers



Project No. 2980-014

Date March 2022

Scale 1:35,000

0 250 500 1,000 Metres

Observed Water Quality Threshold Exceedances in Stormwater and Ambient Water

Figure 2

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Table 5: Water Quality Data

Parameter	Unit	Tsolum River u/s	Tsolum River d/s	Portuguese Creek	Puntledge River u/s	Puntledge River d/s	Morrison Creek u/s 1	Morrison Creek u/s 2	Morrison Creek d/s	Glen Urquhart Creek u/s	Glen Urquhart Creek d/s	Mallard Creek u/s	Mallard Creek d/s	Courtenay River	Courtenay River stormwater	Piercy Creek u/s 1	Piercy Creek u/s 2	Piercy Creek u/s 3	Piercy Creek u/s 4	Piercy Creek d/s
pH		5.7	4.7	6.1	5.3	5.6	6.4	6.3	7.0	6.0	6.3	6.3	6.2	5.9	6.7	6.2	6.0	5.9	6.0	6.0
Water Temperature	°C	3.9	4.2	6.8	7.0	6.8	5.2	6.1	6.4	9.0	9.6	9.3	7.3	6.7	11.6	6.5	6.6	5.9	6.3	7.0
Conductivity	uS/cm	28	73	91	27	26	171	85.3	132	93	121	136	110	26	404	87.4	68.3	60.3	81.5	70
Turbidity, Field	NTU	1.4	1.8	4.9	0.8	1.3	1.6	1.7	9.8	3.6	1.6	1.7	4.0	2.4	3.3	8.1	5.8	5.9	10.3	15.9
Turbidity, Lab	NTU			4.1					3.8	2.6	1.0	0.9	3.0	1.6	3.0	4.4	4.9	5.4	8.1	12.0
Dissolved Oxygen	mg/L	12.7	12.7	10.6	12.5	12.3	12.7	12.0	11.8	10.5	11.2	10.5	10.7	12.2	10.7	12.0	12.0	12.4	12.3	11.8
Anions																				
Nitrogen, Nitrate as N	mg/L	0.20	0.21	0.59	0.04	0.04	0.26	0.35	0.29	0.99	1.4	1.8	1.1	0.08	2.6	1.1	0.30	0.07	0.23	0.40
Microbiological Parameters																				
Coliforms, Fecal	MPN / 100 mL	31	28	68	2	6	53	43	268	45	61	31	45	39	71	1,410	194	50	219	481
E. coli	MPN / 100 mL	27	33	62	2	5	48	10	236	45	30	26	40	36	71	1,300	144	38	219	459
Total Metals																				
Cadmium, total	mg/L	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	0.0000105	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	0.000013	<0.000010	0.000011	<0.000010	0.000014	0.0000175
Copper, total	mg/L	0.00211	0.00198	0.00275	0.00053	0.00059	0.00098	0.00310	0.00319	0.00632	0.00245	0.00282	0.00765	0.00127	0.00356	0.00600	0.00479	0.00319	0.00781	0.00657
Iron, total	mg/L	0.154	0.184	0.599	0.038	0.055	0.190	0.202	0.946	0.477	0.140	0.169	0.340	0.191	0.460	0.574	0.451	0.551	0.721	1.300
Lead, total	mg/L	<0.00020	<0.00020	0.0006	<0.00020	<0.00020	<0.00020	<0.00020	0.0003	<0.00020	<0.00020	<0.00020	<0.00020	<0.00020	<0.00020	<0.00020	0.0003	<0.00020	0.0005	0.0005
Zinc, total	mg/L	<0.0040	0.0054	0.0093	<0.0040	<0.0040	<0.0040	0.0065	0.0066	0.0158	0.0051	0.0054	<0.0040	<0.0040	0.0203	0.0124	0.0070	<0.0040	0.0072	0.0145

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Puntledge River Watershed

Like Tsolum River, pH levels in Puntledge River were low (5.3 and 5.6 at the upstream and downstream locations, respectively) and at the ‘need attention’ AMF level and water temperatures were at the ‘satisfactory’ level.

All other monitored water quality parameters were within the AMF ‘good’ threshold in Puntledge River and there were few measurable signs of water contamination in Puntledge River. Among the monitored water quality parameters, there was only a noticeable increase in fecal coliform concentrations from the upstream (2 MPN/mL) to the downstream (6 MPN/mL) monitoring location. However, such low bacteria concentrations are uncertain, which was confirmed by the RPD of duplicate samples, and it cannot be concluded that bacteria concentrations were increased in the downstream location.

Morrison Creek Watershed

The two upstream branches of Morrison Creek showed pH, water temperature, and conductivity at the ‘satisfactory’ level. The south branch also showed exceedances in copper and zinc concentrations, which were both at the ‘satisfactory’ level. In general, water quality appears to be slightly poorer in the south upstream branch of Morrison Creek, although differences were small.

At the downstream location, water quality was more impacted and showed concentrations at the ‘satisfactory’ level for water temperature, conductivity, turbidity, fecal coliforms and *E. coli*, and copper, iron, and zinc. Compared to the upstream samples, the downstream sample showed higher conductivity, bacteria count, and concentrations of several metals. It should be noted that upstream and downstream samples were collected on different days due to logistical issues and are not directly comparable. However, the data suggest that Morrison Creek is impacted by metals and bacteria. Among the previously monitored stormwater discharges, the Morrison Creek location showed some of the highest conductivity, turbidity, and bacteria concentrations, as well as elevated concentrations of several metals. These observations suggest that stormwater may contribute to the observed water quality issues in Morrison Creek.

Piercy Creek

Piercy Creek has several upstream branches and four of these branches were monitored for water quality. A fifth branch, highly impacted by urban runoff from the central parts of the City, was monitored as part of the 2019/2020 program. Data collected from all sampling locations indicate that water quality in Piercy Creek is impacted by bacteria and metals.

Water quality at location #1 showed elevated bacteria and metal concentrations. Fecal coliforms and *E. coli* were at the ‘need attention’ level and pH, water temperature, conductivity, turbidity, copper, and zinc were all at the ‘satisfactory’ level.

Water quality at location #2 was also impacted by bacteria and metals, although at a lower degree than at location #1. *E. coli*, pH, water temperature, conductivity, turbidity, copper, and zinc were all at the ‘satisfactory’ level at location #2.

Water quality at location #3 was less affected by bacteria and metals than at locations #1 and 2, although exceedances of the AMF thresholds were observed. pH was at ‘need attention’ level whereas water temperature, conductivity, turbidity, and copper were at the ‘satisfactory’ level.

Water quality at location #4 was affected by bacteria and metals. Fecal coliforms, *E. coli*, pH, water temperature, conductivity, turbidity, copper, and zinc were all at the ‘satisfactory’ level at location #4.

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At the downstream location in Piercy Creek, the AMF 'satisfactory' thresholds were exceeded for pH, water temperature, conductivity, fecal coliforms, copper, iron, and zinc, and *E. coli* concentrations exceeded the 'need attention' threshold.

Glen Urquhart Creek

Water quality in Glen Urquhart Creek showed low pH at 6.0 and 6.3 at the upstream and downstream locations, respectively, conductivity at the 'satisfactory' level at both locations, as well as copper and zinc concentrations at the 'satisfactory' level at the upstream location. It should be noted that upstream and downstream samples were collected on different days due to logistical issues and are not directly comparable. Previous sampling also showed conductivity, copper, and zinc concentrations at 'satisfactory' levels during both summer and winter flow conditions, as well as high bacteria concentration exceeding the 'need attention' level for fecal coliforms during both seasons.

Data collected during both monitoring programs suggest that water quality in Glen Urquhart Creek is impacted by City discharges. Because Glen Urquhart is a smaller creek, it can be expected to be proportionally more impacted by City discharges than (e.g., Tsolum River). The stormwater retention areas located in the downstream reach of the creek could potentially improve water quality, but this has not been investigated.

Mallard Creek

Water quality in Mallard Creek showed 'satisfactory' levels of pH, conductivity, and dissolved oxygen at both the upstream and downstream locations, as well as copper at the downstream location. The upstream and the downstream sampling locations are located close to each other, but there is a stormwater retention area in-between these locations that could potentially affect water quality. Concentrations of several measured water quality parameters, such as nitrate, iron, and zinc, were lower in the downstream location, whereas concentrations of bacteria and copper were higher downstream. It is therefore not possible to draw any conclusions on whether the stormwater retention area influences water quality in Mallard Creek. Collected data suggest that water quality in Mallard Creek is slightly impacted by City discharges.

Courtenay River Ambient Water and Stormwater

Water quality in Courtenay River shows few exceedances of the AMF thresholds; pH was low (5.9) and at 'need' attention' level and water temperature was at the 'satisfactory' level. Water quality in Courtenay River is affected by both Puntledge River and Tsolum River, which also showed pH and water temperatures exceeding the AMF thresholds. Water quality in Courtenay River is affected by intrusion of seawater from Comox Bay at high tide, but the low conductivity (26 µm/cm) confirms that salt water was not affecting water quality at the time of sampling.

The stormwater outfall sample collected before discharge into Courtenay River showed more exceedances of AMF thresholds than the river water sample. Conductivity was at the 'need attention' level and dissolved oxygen, nitrate, copper, and zinc were at the 'satisfactory' level. The stormwater sample also showed higher concentrations of bacteria, cadmium, and zinc than the river water sample. Elevated concentrations of conductivity, bacteria and metals are commonly seen in urban runoff and was also observed in previous monitoring of stormwater quality in the Courtenay River watershed.

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4. City-Wide Adaptive Management Plan

Monitoring data collected in 2019/2020 indicate that stormwater quality at all locations in the City is impacted by high bacteria and metal concentrations. Monitoring data collected in 2021 indicate that water quality in larger watercourses, such as Tsolum River, Puntledge River and Courtenay River, is adequate, but that smaller watercourses, such as Morrison Creek and Piercy Creek show more exceedances of water quality guidelines. Smaller urban watercourses may be proportionally more impacted by polluted stormwater inputs because of the higher stormwater volume to total discharge ratio.

The collected water quality data provide key information to help identify whether adaptive management is needed and to help prioritize where to focus management resources to gain the most benefit for identified water quality issues.

4.1 Priority Areas for Adaptive Management Based on Observed Water Quality

As part of a city-wide adaptive management plan, priority areas where mitigations are warranted to improve watershed health should be identified. Priority should be given to areas with relatively higher exceedances of water quality objectives. Based on performed water quality monitoring (see Figure 2), watersheds in the City were categorized into areas of higher and lower priority for adaptive management, presented in Table 6.

Table 6: Prioritization of Watersheds for Adaptive Management Based on Observed Water Quality

Watershed	Rationale
Higher Priority	
Morrison Creek	**Stormwater:** • Exceedances of the AMF 'need attention' level for conductivity, turbidity, and bacteria. • Exceedances of the AMF 'satisfactory' level for several of the metals. **Receiving water:** • Exceedances of the AMF 'satisfactory' level for conductivity, turbidity, bacteria, and several metals.
Piercy Creek	**Stormwater:** • Exceedances of the AMF 'need attention' level for zinc and fecal coliforms. • Exceedances of the AMF 'satisfactory' level for conductivity, *E. coli* and metals. **Receiving water:** • Bacteria levels vary between the 'good' and 'need attention' threshold. • Exceedances of the AMF 'satisfactory' level for conductivity, turbidity, and several metals.
Courtenay River	**Stormwater:** • Exceedances of the AMF 'need attention' level for conductivity, bacteria, and iron. • Exceedances of the AMF 'satisfactory' level for copper and zinc. **Receiving water:** • Adequate water quality.

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Watershed	Rationale
Puntledge River	**Stormwater:** • Exceedances of the AMF ‘need attention’ level for conductivity and bacteria. • Exceedances of the AMF ‘satisfactory’ level for copper, iron, and zinc. **Receiving water:** • Adequate water quality.
Lower Priority	
Glen Urquhart	**Stormwater:** • Not monitored. **Receiving water:** • Exceedances of the AMF ‘need attention’ level for bacteria. • Exceedances of the AMF ‘satisfactory’ level for conductivity, dissolved oxygen, copper, and zinc.
Brooklyn Creek	**Stormwater:** • Not monitored. **Receiving water:** • Exceedances of the AMF ‘need attention’ level for fecal coliforms and dissolved oxygen. • Exceedances of the AMF ‘satisfactory’ level for conductivity, copper, and zinc.
Mallard Creek	**Stormwater:** • Not monitored. **Receiving water:** • Limited data. • Exceedances of the AMF ‘satisfactory’ level for conductivity, dissolved oxygen, and zinc.
Portuguese Creek	**Stormwater:** • Not monitored. **Receiving water:** • Limited data. • Exceedances of the AMF ‘satisfactory’ level for conductivity, dissolved oxygen, and zinc.
Tsolum River	**Stormwater:** • Not monitored. **Receiving water:** • Limited data. • Adequate water quality.
Little River	Not monitored.

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Watersheds with higher priority for adaptive management are some of the most urbanized areas of the City. Urbanization generally leads to increased pollutants loads in stormwater and receiving waters compared to pristine areas.

Because there are many potential and diffuse sources of metals in urban areas, specific sources of elevated metal concentrations in stormwater and ambient water in the City have not been identified. Areas with high traffic counts (e.g., next to Highway 19A and in City centre) could potentially receive higher loads of metals than comparable areas where traffic is limited (e.g., residential areas). With the currently available data (one stormwater location monitored in each watershed), it is not possible to draw any conclusions on impacts from road runoff on observed stormwater quality. Elevated concentrations of copper and zinc were observed in ambient water samples collected from Morrison Creek and Piercy Creek; however, as stormwater and ambient water quality monitoring were performed in different years, the relationship between these remain unknown.

It is currently not known whether the elevated concentrations of bacteria observed in samples of stormwater and ambient waters in the City are caused by humans or animals. Failure of existing septic fields could potentially affect water quality in several of the investigated watersheds, particularly in Piercy Creek (see Table 1 for potential impacts on water quality at each monitoring location). However, septic field lots are generally not occurring within City limits and stormwater quality should therefore not be affected by failing septic fields, although ambient water quality could be affected by upstream fields. Only samples collected from Piercy Creek watershed showed elevated bacteria concentrations in ambient water, which may be a sign of contamination from septic fields located upstream in the watershed.

High bacteria concentrations are also common in areas with agricultural land use. In Courtenay, livestock such as poultry, equine, and dairy cattle may contribute to bacterial contamination of ambient water as agricultural land use exists within several of the investigated watersheds (Table 1). However, as agricultural land use is limited within City limits, bacteria from livestock are more likely to affect ambient rather than stormwater quality. Ambient water quality in watersheds with existing agricultural land use (e.g., Tsolum River and Puntledge River) did not show exceedances of bacteria thresholds.

Bacteria counts $\geq 10^5$ units/100 mL were observed in stormwater samples from Courtenay River, Puntledge River, and Morrison Creek, and may indicate that cross-connections with sanitary sewers occur at these locations.

4.2 Recommended Further Water Quality Monitoring

It is currently unknown where in the prioritized catchments (Table 6) sources to pollutants may be located. Stormwater monitoring performed so far has focused on water quality at the end-of-pipe, right before or at the point where stormwater is discharging into ambient water. By monitoring water quality at additional locations in the prioritized storm catchments, specific sources may be identified. Identifying and quantifying the correct source help target appropriate and cost-effective mitigations to eliminate or reduce important sources of bacteria and metals in stormwater and ambient water. Further monitoring of water quality is therefore recommended in the prioritized watershed.

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Bacteria Source Identification

Stormwater samples collected in the watersheds Courtenay River, Puntledge River, and Morrison Creek showed such bacteria concentrations (≥ 10^5 units / 100 mL) that cross-connections cannot be ruled out. It is recommended to perform further water quality monitoring at several upstream locations in these watersheds to identify specific locations or areas in the system where bacteria levels are high. When bacteria hot spots have been identified, **microbial source tracking** (MST) can be used to discriminate between sources of bacterial contamination (e.g., human, gull, and dog fecal sources).

Metals and Other Water Quality Parameters

To identify areas with potentially high metal loads, monitoring may focus on traffic areas where metal exceedances are an issue (i.e., Courtenay River, Puntledge River, Morrison Creek, and Piercy Creek). As traffic count is often related to metal and particle pollution of stormwater, it is recommended to perform further water quality monitoring at locations in mentioned watershed, focusing on areas around roads with higher daily traffic counts.

4.3 Adaptive Management Practices

Point and nonpoint source pollution can be controlled through pollution prevention actions and operational measures, as well as best management practices including both source controls and end-of-pipe facilities.

Pollution Prevention

Non-structural measures to prevent or reduce bacteria, metals and other common pollutants in urban stormwater include for example:

- Pet waste control: In areas with pet waste ordinances and education, pet wastes are less likely to contribute to bacteria in stormwater.
- Bird and mammal control: Animal control can include modifying habitat and reducing urban food sources, including trash; preventing rodents from entering drainage infrastructure; and relocating wildlife.
- Garden, lawn, and park maintenance, such as:
    - prevent garden waste from entering storm systems as it contributes to higher bacteria and nutrient levels in stormwater; and
    - repair exposed soils to reduce solids and bacteria loads in stormwater.
- Street sweeping: Reduces washed off loads of solids and attached pollutants, including bacteria, metals, and hydrocarbons.
- Storm and sanitary system maintenance, such as:
    - septic field maintenance;
    - investigate leaks and function of the sanitary system;
    - repair aging infrastructure, correct illicit connections and cross connections;

- vacuum catch basins to remove sediments with high concentrations of metals, bacteria, and other pollutants; and
- remove trash and sediments from stormwater control practices to reduce the potential for bacterial growth.

- Vehicle maintenance: Maintenance and washing of vehicles should be avoided in impervious areas because of the potential for the release of metals, hydrocarbons, and other pollutants.
- Construction materials: Avoid using galvanized materials on roofs, for downspouts, in storm sewer culverts, etc. because of the potential for leaching of zinc. Copper should also be avoided in outdoor applications that may lead to contamination of runoff (e.g., roofs).

Several non-structural measures to prevent stormwater pollution would need involvement from the public, including pet waste control, garden and lawn maintenance, proper vehicle maintenance, septic field maintenance, and water-wise material choices for outdoor applications. Such measures may be promoted through City-administered education and outreach programs.

Pollution Control – Source Control and End-of-Pipe Practices

Structural measures are most often needed to further reduce pollution of stormwater when preventive measures have been implemented. Stormwater source controls are commonly recommended for stormwater management to maintain and improve watershed health. They are designed to prevent or mitigate the impacts of stormwater at or near its source by using engineered infrastructure or natural features to reduce stormwater volumes and rates as well as improve its quality. Examples of source controls include:

- Absorbent landscape: Designed to increase infiltration, filtration, and evapotranspiration of rainfall and runoff by using leafy greens and soils with high infiltration capacity.
- Bioretention: Captures, infiltrates, and treats runoff from impervious surfaces by using the natural properties of soil and vegetation. Bioretention practices are commonly designed as shallow depressions with engineered soils and resilient vegetation that can tolerate both wet and dry weather. Bioretention practices include rain gardens, bioswales, bioretention cells and planters, and tree trenches.
- Permeable pavement: Allows stormwater to drain through the surface and infiltrate into the subsoil, which reduces runoff volumes and improve water quality. Permeable paving techniques include porous asphalt, pervious concrete, paving stones, and grass pavers made of concrete. Generally, permeable pavements are used on surfaces with low traffic volumes, such as walkways, plazas, driveways, and parking areas.
- Infiltration practices: Provide storage and infiltration of stormwater in infiltration beds of varying types. Infiltration practices reduce stormwater volumes, provide pollutant removal through soil filtration, and help recharge groundwater. Dry wells, infiltration trenches, and sumps are underground excavations with level or gently sloping bottom grade that are filled with clean stone or other void-forming structures for temporary storage of water before infiltration into the underlying soil. Infiltration chambers with permeable bottom or perforated pipes are below-ground containers that create large space for temporary storage of stormwater before infiltration. Infiltration chambers and perforated pipes can generally support vehicular loading and can be placed under parking or landscaped areas to maximize land use.

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- Green roofs: Roof with growing media and vegetation that enable infiltration and evapotranspiration of rainwater and help reduce stormwater peak flows and volume. Intensive green roofs with thick layers of soil are more effective for water storage than extensive roofs with thinner layers of soil.

Source controls have the potential to improve watershed health and are generally more cost-effective than end-of-pipe measures. Structural end-of-pipe practices, for example ponds and wetlands, may be employed to treat the residual stormwater impacts that cannot be controlled at source.

Source controls with soils and vegetation generally employ several different processes to reduce pollutant loads, for example ponding, which leads to settling of solids and particle-bound pollutants as well as volatilization of (e.g., petroleum hydrocarbons, filtration through soil, plant uptake, microbial degradation, and sorption to soil particles). Preferred control measures to reduce bacteria and metals in stormwater include sources controls such as bioretention, sand filters, permeable pavement, infiltration basins or trenches, and tree trenches. End-of-pipe solutions based on particle settling and filtration through vegetation for pollutant removal (e.g., retention ponds and wetlands) are also efficient for reducing bacteria and total metal concentrations in stormwater but are not effective for removing dissolved pollutants. In addition, these measures should be designed to avoid attracting wildlife including birds to effectively reduce bacteria levels. Swales and detention ponds are two examples of measures that have been proven less effective for removal of pollutants in stormwater.

Source controls are more or less suitable for different contexts because of factors such as expected pollutant load and available land. Table 7 summarizes how well-suited source controls and end-of-pipe practices are for various types of land use.

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Table 7: Suitability and potential use of source control and end-of-pipe stormwater management practices for different land uses

Land Use Type	Absorbent Landscape	Bioretention	Permeable Pavement	Infiltration Practices	Green Roofs	End-of-Pipe Practices
Dense Urban	Limited to certain land uses, (e.g., institutional and parks).	Potential for bioretention practices with small footprints (e.g., tree trenches and stormwater planters along streets, greenways, and bike lanes) as well as bioswales and bioretention cells installed as parking lot islands, median strips, and traffic islands.	Can be used on sidewalks and walkways, bike lanes, parking lanes and lots, laneways, plazas, etc.	Potential for underground infiltration chambers and perforated pipes to manage roof, walkway, parking lot and road runoff; can be installed underneath parking or landscaped areas such as lawns and planting beds to maximize land use.	Well suited for dense urban environments (e.g., office, retail, and institutional buildings) as well as multi-unit residential buildings.	Limited potential.
Commercial and Light Industrial	Limited potential	Potential for bioswales and bioretention cells installed as parking lot islands and medians as well as along roads. Limited potential for rain gardens to manage roof runoff.	Can be used on sidewalks, parking areas and driveways; however, should not be applied at stormwater pollution "hot spots" such as recycling facilities, industrial storage and loading facilities, work yards, and vehicle service and maintenance areas.	Potential for underground infiltration chambers installed underneath (e.g., parking areas) should not be applied at stormwater pollution "hot spots".	Well suited for many retail, office, and light industrial buildings.	Limited potential.
Residential Urban	Limited potential to retrofit gutters, downspouts, and driveways to discharge onto grassy areas.	Potential for bioswales and bioretention cells installed in traffic calming bulges/curb extensions, along greenways, bike lanes, local streets, and parks. Limited potential for rain gardens to manage roof runoff.	Can be used on sidewalks, bike lanes, parking lanes and lots, laneways, and low-traffic streets.	Potential for underground infiltration chambers installed underneath landscaped areas or pathways.	Well-suited for institutional and multi-unit residential buildings.	Some potential. (e.g., detention basins, ponds, and wetlands in large public spaces such as parks).
Suburban	Large potential to retrofit gutters, downspouts, driveways, patios, etc. to discharge onto grassy areas and use leafy greens to enhance interception	Potential for bioswales and bioretention cells installed in traffic calming bulges/curb extensions, along greenways, bike lanes, local streets, and parks. Large potential for rain gardens to manage roof and driveway runoff.	Can be used on sidewalks, bike lanes, and low-traffic streets. Large potential for permeable pavement on driveways.	Large potential for dry wells and other types of soakaways to manage roof and walkway runoff on individual lots. Infiltration trenches are useful in narrow strips of land between buildings or properties or along road rights-of-way. Underground infiltration chambers and perforated pipes can be used (e.g., in laneways).	Absorbent landscape can replace the need for green roofs.	Some potential. (e.g., detention basins, ponds, and wetlands in large public spaces such as parks).
Rural	Large potential to retrofit gutters, downspouts, driveways, patios, etc. to discharge onto grassy areas and use leafy greens to enhance interception	Large potential for bioswales along roads and many types of bioretention on individual lots.	Can be used on driveways, sidewalks and low-traffic roads.	Large potential for soakaways and infiltration trenches on individual lots.	Absorbent landscape can replace the need for green roofs.	Large potential for ponds and wetlands.

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Cost-Effectiveness of Stormwater Management Practices

The cost-effectiveness of stormwater management practices is often expressed as an annualized cost to remove a specified quantity (e.g., 1 kg of an unwanted pollutant) for example, nitrogen, phosphorous, or solids, per unit (e.g., m^2/m^3). The most cost-effective practices are the ones that remove the greatest quantity of a specified pollutant for the least annual cost. Alternatively, the cost-effectiveness of management practices designed for runoff control can be expressed as a cost per reduced runoff volume or reduction in peak flows.

Cost-effectiveness estimations are not standardized and can be estimated by including or excluding costs related to land acquisition, construction, design, engineering and permit fees, geological testing, contingencies, or operation and management (O&M). Stormwater management practices may also provide benefits beyond pollutant removal and runoff control, for example, improve public health, neighbourhood beautification, and heat island reduction, which may or may not be included in the estimation of cost-effectiveness.

The cost-effectiveness of stormwater management practices can vary widely because of large variations in performance between practices and pollutants, or large variations in achieved runoff control. Also, factors such as geographic location and land value, required site preparation, and influent water quality or volume/flow rate have a large impact on the estimated annual cost. O&M costs also show large variations depending on (e.g., type of practice, frequency and complexity of inspection and maintenance, rainfall patterns and climate).

There are numerous cost-effectiveness studies of stormwater management practices, although few studies are based on Canadian conditions or include both pollution prevention and pollution control measures. A study of the relative costs and pollutant removal effectiveness of 33 strategies to treat stormwater found that pollution preventative measures such as pet waste programs, sewer repair, and correction of cross-connections were the most cost-effective measures to reduce nitrogen, phosphorous, and solids loads [9]. Structural practices were consistently estimated least cost-effective due to their low water quality benefit (e.g., dry detention ponds and hydrodynamic structures) or high cost (e.g., permeable pavement) or high O&M costs (e.g., bioretention, infiltration practices).

[9] Swann, C. (2016). Cost-Effectiveness Study of Urban Stormwater BMPs in the James River Basin. The Center for Watershed Protection, Ellicott City, MD. https://owl.cwp.org/mdocs-posts/jra-cost-memo-june-update/