Waterford River Watershed Management Plan – Draft Copy

Prepared for

Prepared by

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Executive Summary

The Waterford River Watershed Management Plan is an adaptive plan that recommends management actions under five themes involving the main issues discovered during the lifecycle of the "Waterford River Watershed Research, Restoration and Education Program". The five management themes are riparian buffer zones, stormwater management, winter maintenance, residential area and stream garbage management.

Prior to the management recommendations, important characteristics of the watershed including an assessment of the current health of the Waterford River are presented. The assessments conducted were based on data collected during stream sampling following standardized methods, visual surveys, provincial long-term water quality monitoring data and comprehensive research.

Restoration concepts that could be applicable to the impaired sites on the watershed identified during the surveys and assessments are then discussed. To adapt to the unique challenges the Waterford River faces, continued efforts should be made in a strategic manner. For that purpose, a four-year extension to the current project involving the Waterford River Watershed and the formation of a Watershed Alliance Group is proposed.

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1.0 Background

Conservation Corps Newfoundland and Labrador (CCNL) initiated the project, "Waterford River Watershed Research, Restoration and Education Program," to conserve the heavily urbanized Waterford River Watershed. This is a two-year project (2021 and 2022) funded by the Environmental Damages Fund (EDF), administered by Environment and Climate Change Canada (ECCC). To fulfill a major objective of the project, this Waterford River Watershed Management Plan is developed for the three respective municipalities within the Watershed's boundary (Town of Paradise, City of Mount Pearl and City St. John's).

1.1 Scope

This management plan is focused on providing an overview of various aspects in the Watershed, describing the assessments carried out during the lifecycle of the project, highlighting management recommendations for the major concerns in the Watershed, identifying restoration concepts and proposals for utilization in the future. The nature of the management plan is "adaptive" which means changes and amendments to recommended actions should be made as new information and knowledge is available. Also, in the face of climate change, adapting to the unique needs and challenges faced is necessary. Therefore, this adaptive management plan should be reviewed and modified as needed. Under the scope of the project, aquatic habitat was prioritized during the assessments conducted. The management recommendations will reflect the priorities and associated limits of the main project. Cost analysis for the recommended actions is not presented as it is outside the scope of the project.

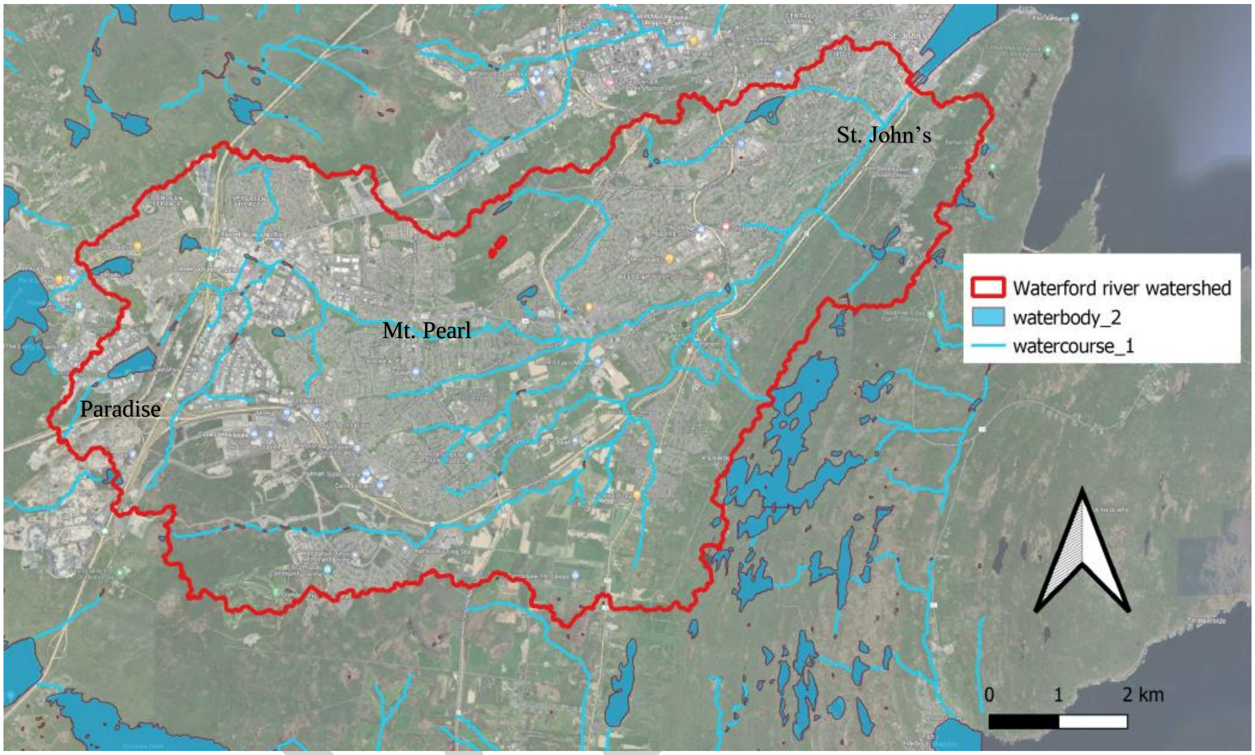
2.0 Watershed Characteristics

Location

The Waterford River Watershed is approximately 70 sq. km in area within the three major metro municipal regions on the Avalon Peninsula of the Province of Newfoundland and Labrador (Ullah, Marsalek, Hennigar, & Pollock, 1987). The river is 15 km long from its origin in the Town of Paradise. Then, it flows through the City of Mount Pearl and into the City of St. John's before discharging into the Atlantic Ocean in the western part of St. John's harbour (Wijayarathne, 2019). The EcoRegion is the Maritime Barrens EcoRegion (CANAL, 2022).

Figure 1.

Waterford River Watershed.



Hydrology

The principal sub-watersheds in the Waterford River Watershed are South Brook including Kilbride Brook (a tributary of South Brook), Flings, Tyrrwits and Kitty Gauls Brooks, and a section of Donovans Tributary (Figure 2).

The Waterford River originated from Bremigens Pond and Nevilles Pond in the town of Paradise. The headwaters begin from the wetlands above Bremigens Pond which is a man-made pond (Pomeroy & Collins, 1993). A weir structure controls the pond's water level. Downstream of the pond, the river flows through an open, flat land and then into the St. Anne's Industrial Park in Paradise. (S.Hickey & Sheppard, 2018). The main stem of the river receives flow from another tributary originating from north of Elizabeth Park (Pomeroy & Collins, 1993). This channel is straightened and confined to a narrow corridor, with no evident riffles and pools. The southern Donovan's tributary flows into the Waterford River downstream of Kentmount road. The river is again straightened and constrained into a somewhat deep valley along St. Anne's Crescent's rear. The river then turns 90 degrees south around Kinsdale Road, passes Kenmount Road, and meets Donovans Tributary (S.Hickey & Sheppard, 2018).

The Donovans tributary flows into the Waterford River downstream of Kentmount road originating in the flat, marshy wetlands to the west and south of the cloverleaf ramp system of the Trans-Canada Highway and Pitts Memorial Drive. The river then flows through Mount Pearl approximately adjacent to the Topsail Road and the Newfoundland T'railway . This section of the river adjacent to Forest Avenue (access from Newfoundland Trailway) before approaching Dunn's Road, Mount Pearl, has a flat gradient and a series of cascades and step-pools controlled by bedrock. At Dunn's Road, the Waterford River receives flow contribution from Tyrrwits and Kitty Gauls Brook. The headwaters of the Tyrrwits Brook is in Mount Pearl in the centre of a large residential subdivision, along the trail that runs parallel with Sunrise Avenue. Kitty Gauls Brook has its headwaters originating from the wetlands surrounding George's Pond (S.Hickey & Sheppard, 2018).

Directly downstream of Team Gushue Highway crossing, Flings Brook joins the river. Flings brook has headwaters in the residential area close to Old Placentia Road and Smallwood Drive. The Waterford has a variety of characteristics downstream of the highway, from flats and runs where the water flows quite slowly to riffle and pool areas where the gradient increases slightly. Upstream of Waterford Bridge Road, there is some noticeable meandering and a few good riffle-pool sequences. The river steepens as it runs through Bowring Park and crosses Waterford Bridge Road. As the river flattens out to meet the duck pond in the park, it features a wide variety of channel types through this reach, including cascades, riffles, pools, and flats. At the end of the duck pond in Bowring Park, the river is joined by its largest tributary, South Brook in St. John's. Then the river flows through a heavily urbanized narrow corridor from the Bay Bulls Road /Southside Road intersection.

The river gradient from Bay Bulls Road downstream to the Blackhead Road crossing again shows some variation of channel types, including runs, cascades, riffles, and pools. The river flattens out downstream of Blackhead Road and is impacted by backwater effects from St. John's harbour (S.Hickey & Sheppard, 2018).

The watershed channel overall is steep including the slopes in the watershed. Consequently, during rainfall events, flows concentrate rapidly in the watershed, and it is anticipated that the flood hydrographs would surge quickly to their peaks (Fenco Newfoundland Limited, 1988).

Surface water and ground water systems are closely linked (USGS, 2019). According to a study conducted on the Waterford River Watershed, the groundwater levels in the Waterford River Watershed were unlikely to be influenced by growing urban developments because of high surface runoff rates and low recharge rates even in undeveloped parts of the watershed (Ullah et al., 1987). The hydrologic soil group classification and combination of classes showcases that there is predominance of soil having moderate to high runoff potential in the basin (Fenco Newfoundland Limited, 1988). However, high level of sodium chloride because of road salting operations were detected in the groundwater that has the potential to change the chemistry of groundwater (Ullah et al., 1987).

Geology

The Waterford Watershed is generally comprised of slate, siltstone, sandstone, shale, conglomerate, granitic, and volcanic rocks (Batterson, 1984).

Bedrock geology largely controls the physiography of the basin. About 90 percent of the field area is covered by a veneer of till (King, 1984). The Appalachian Orogen makes up the bedrock and there are two types present in the basin. First one is Protorozoic III to Ordovician - subaerial and marine clastic sedimentary rocks; minor limestone. And the second one is Protorozoic III- marine and deltaic clastic sedimentary rocks. Also, there is a potential presence of some mafic and felsic volcanic and volcaniclastic rocks surrounding western Mount Pearl and Paradise. 57% of the bedrock is made up of siliciclastic sediments, and 43% is made up of turbidites (CANAL, 2022).

The overburden mantle typically functions as a filter for precipitation and creates a lag between the time that water percolates into the mantle and when it enters the stream system. The average thickness of the overburden is between 0 and 5 m and is described as extremely variable in the Waterford watershed (Batterson, 1984). The overburden is composed of 53% ablation drift, 35% undifferentiated till, 8% drift poor, 2% glaciofluvial material, and 2% alluvium. Precambrian materials, primarily of sedimentary origin but with some volcanic deposits, constitute the majority of the bedrock in the basin. Major plunge folds and fracture zones in low porosity rocks that slope towards the Waterford River are the most important geological elements affecting the river's course. In some formations, iron and manganese precipitates along the fractures (CANAL, 2022).

Soil

The soils in the watershed are formed from the underlying slate-siltstone, sandstone, conglomerate, and granite and volcanic rocks. These are generally categorized as the soils of the humoferric and ferro-humic podzol great group. Mixtures of six main soil types have previously been characterized in the watershed (Ng & Marsalek, 1987). These types are described in depth in the Newfoundland Soil Survey (Heringa, 1981). The soil types belonging to respective soil group presented in Table 2 are derived from the survey.

Table 1.

Soil types in the Waterford River basin in relation to soil groups.

Soil types in the Waterford Watershed	**Soil group**
Bauline	Shallow lithic Placic Ferro- Humic Podzol .
Cochrane	Orthic Humo-Ferric Podzol
Organic	Typic, Mesic, and Humic Fibrisols and Fibric, Typic, and Humic Mesisols.
Pouch Cove	Gleyed Humo-Ferric Podzol
Red Cove	Very shallow lithic Gleyed Ferro-Humic Podzol
Torbay	Rego Gleysol

The majority of these soils are coarse in texture, acidic and low in natural fertility. In terms of drainage capability, the soils have rapid surface drainage and poor internal drainage with the exception of Cochrane soils which are moderately well to very well internally drained (Ng & Marsalek, 1987).

Soils in the watershed also ranges from those that have significant limitations that inhibits the variety of crops or special conservation practices are required (CLI class 4) to soils which are unsuitable for arable crops or permanent pasture (CLI class 7). Stoniness, excess water, and soil depth are the key restrictions to capacity. Most fertile soils occur along Topsail Road and in the Mount Pearl-Kilbride area (CANAL, 2022).

Hydrological soil classifications collected from the United Stated Department of Agriculture (NRCS-USDA, 2016) in Table 3 describes the runoff potential of the soil. Figure 3 presents the hydrological soil groups occurring in the Waterford watershed based on the soil classification system retrieved from the Waterford River Area Flood Risk Mapping Study (CBCL Limited, 2018) . In some parts of the watershed, combination of classes (e.g., BC, CD) are showcased where combinations of soil classes were found in the area.

Table 2.

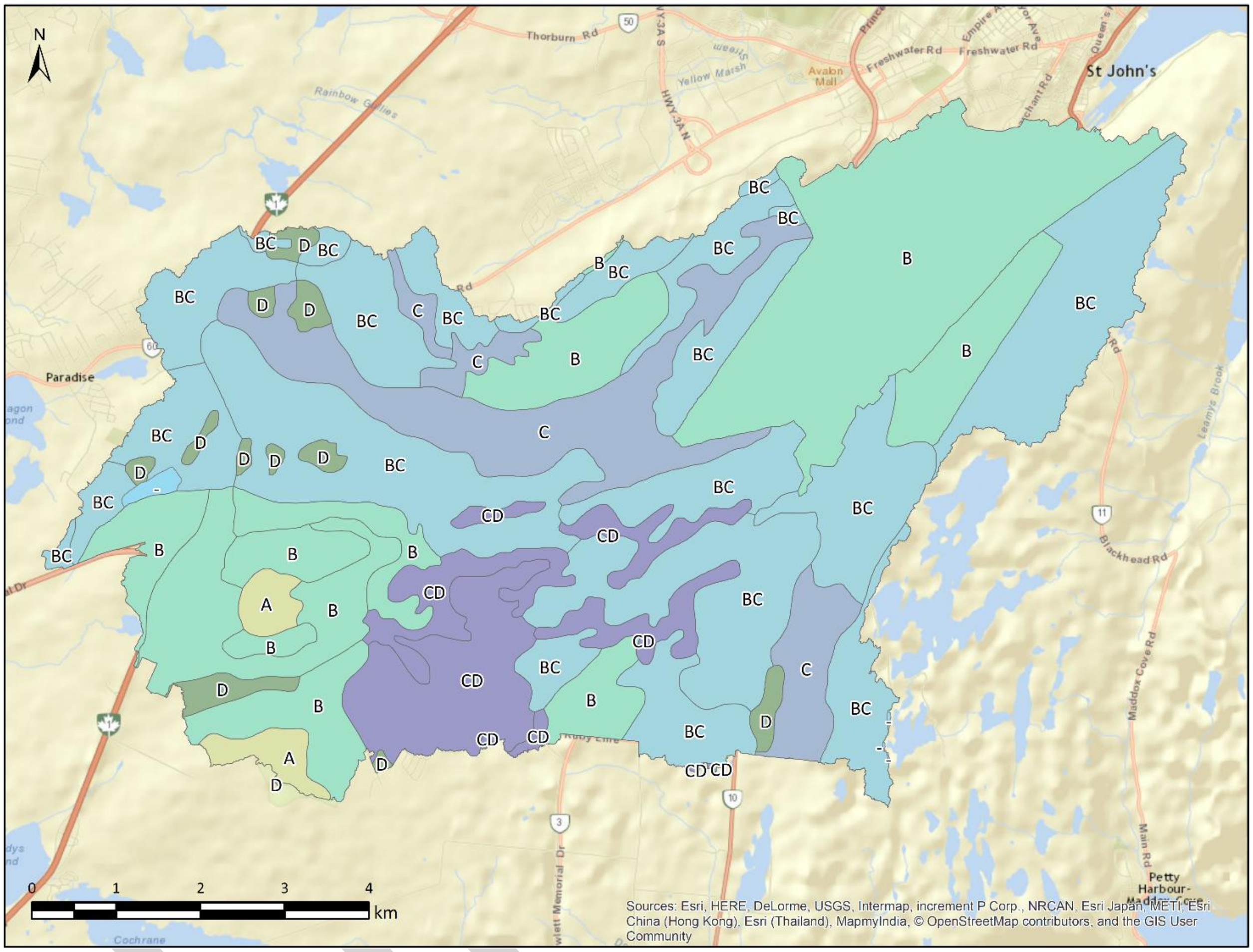
Hydrologic soil group classification

Soil group	Drainage Description
A	Soils with high infiltration rate (low runoff potential)
B	Soils with moderate infiltration rate when thoroughly wet
C	Soils with a slow infiltration rate
D	Soils with very slow infiltration rate (high runoff potential)

Note. Retrieved from (CBCL Limited, 2018)

Figure 2.

Hydrologic soil classification in the Waterford Watershed



Note. Retrieved from (CBCL Limited, 2018)

The Soil information was accessed from the National Soil Data Base in Agriculture and Agri-Foods Canada. These soil types were associated to the hydrologic soil groups based on drainage (CBCL Limited, 2018).

Climate

The climate in the Waterford Watershed is moderated by the Atlantic Ocean. Therefore, the variations in temperature contribute to the winter and summer temperatures in the region. (Ullah, Marsalek, Hennigar, & Pollock, 1987). The Kilbride Hydrometric station on the Waterford River mentions an average summer temperature of 13°C and an average winter temperature of -4°C (CANAL, 2022). On the Avalon and Burin Peninsulas, the mean annual precipitation is between 1200 mm and 1600 mm (NL, 2022). As a result of combined effect of snowmelt and rainfall, high streamflow is usually recorded in Spring whereas, the low streamflow occurs usually between June to August (Ullah, Marsalek, Hennigar, & Pollock, 1987).

Flooding

Heavy rains, sometimes in conjunction with quick snow melting, are common environmental factors that lead to flooding. Although flooding is a natural process and is required for a healthy ecology, it is detrimental to urban infrastructures and cause damages and economic loss (Government of NL, 2022). In an urban watershed, runoff from excessive rainfall can be overwhelming. The definition of urban flooding is an intersection of three components. These are 1) heavy precipitation events 2) increased level of impervious surfaces and 3) insufficient stormwater drainage capacity. With climate change, heavy precipitation is expected to be more frequent which can cause more floods in urban settings (Weber, 2019).

According to the information review presented in the Waterford River Flood Risk Study conducted by CBCL in 2018, the main causes due to which the Waterford River experienced flooding between 1934 – 2010 were mostly due to heavy precipitation events (CBCL Limited, 2018). The notable and most recent flooding event that caused damages in the watershed was in September 2022 (Hurricane Earl) 2022. The three components of urban flooding discussed above generally applies to the flooding occurrences in the Waterford River Watershed. However, each watershed is unique and hence the conclusions can not be simplified.

Figure 3.

Waterford River flooding - Symes Bridge during Hurricane Earl, 2022.

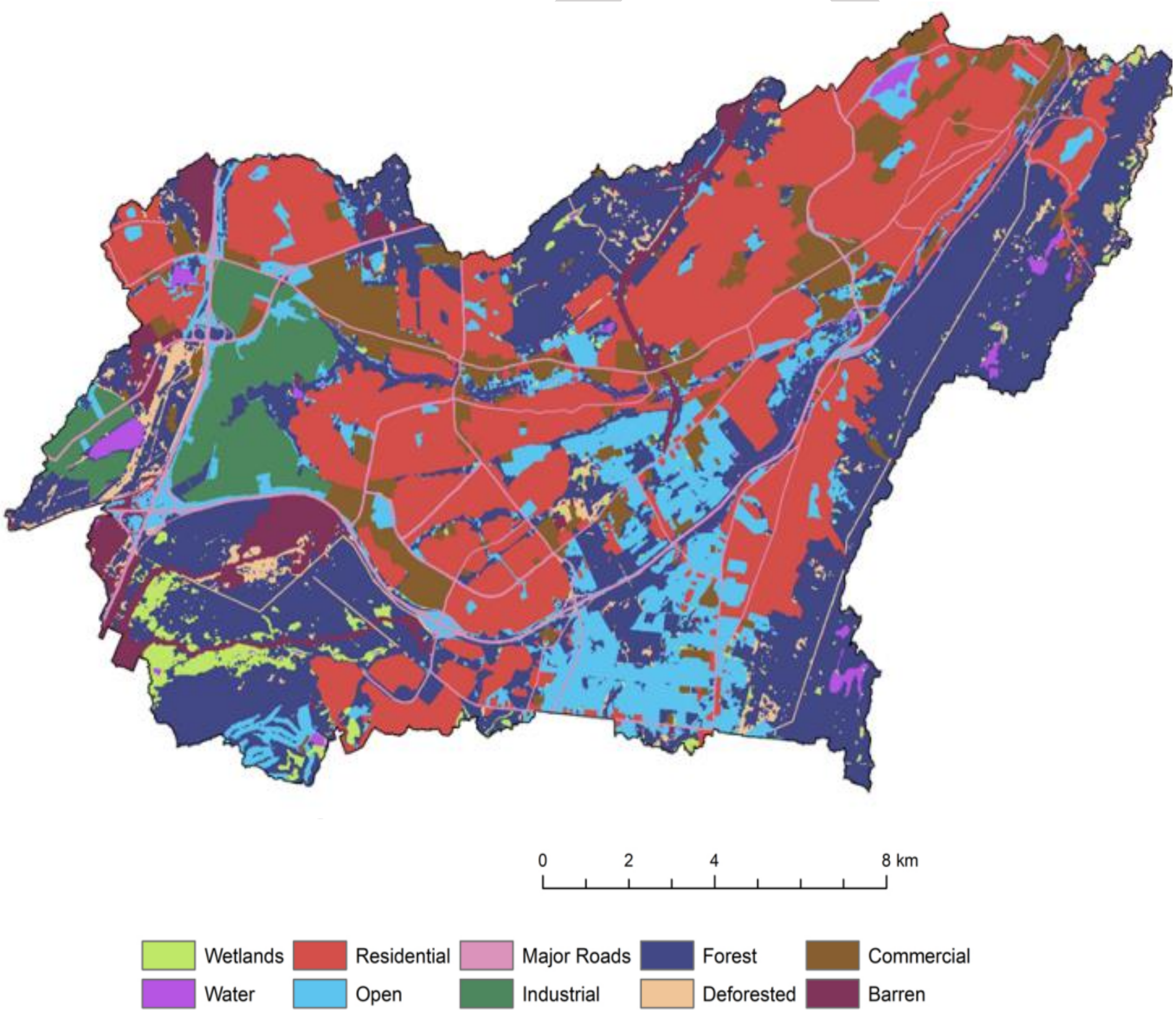
Note. From (Mike Moore, CBC News, 2022)

Watershed Uses

The urban area within the watershed comprises residential, commercial, and industrial areas and transportation passageways. Other land uses include forest, water bodies, wetlands, barren lands, deforested areas, and open areas (See Figure 2). According to a 2016 census study conducted by Statistics - Newfoundland & Labrador Statistics Agency, there were 108,860 individuals within the watershed**.**

Figure 4.

Land use- Waterford River Watershed



Note. Retrieved from (Wijayarathne & Coulibaly, 2019).

Industry - The Donovan's Industrial Park, St. Anne's Industrial Park, Kenmount Hill, Topsail Road, and a few sporadic places along Brookfield Road and Bay Bulls Road are the main industrial hubs in the watershed. These industries include construction and engineering, service garages, electrical power, materials handling, manufacturing, fabrication, wholesale, retail shops for food and beverage, recycling, liquid handling, transport and storage, security, oil and gas. On Topsail Road in Paradise, there is a feed manufacturing facility that is very close to the river's edge. Water levels and flow rates draining into South Brook, which is situated in the southwestern part of this basin, may be affected by regulated flows due to the presence of a NL Power hydro generating facility close to Petty Harbour Long Pond.

Roads and Highways: This watershed includes around 206 km of paved roads, approximately 10 km of which are the TCH. The majority of the streets and highways in the basin are centred in and around Mount Pearl in the eastern part, as well as in western St. John's. Some of the major transportation routes are the Trans Canada Highway from north to south in the western part of the basin, Pitts Memorial Drive that runs east to west in the southern part of the basin, Topsail Road and Brookfield Road runs east to west through the centre of the basin, and Bay Bulls Road runs north to south along the eastern edge of the basin. The watershed also comprises many secondary roads (CANAL, 2022).

Stream crossings and structures: Along the river, various culvert and storm sewer have been installed. The river and riverbank have been straightened, altered, and enhanced in addition to several bridges built and repaired. Gabion baskets were put in place on both sides of the river as it travels beneath the Brookfield Road bridge. The duck pond in Bowring Park has undergone renovations and repairs, as well as the removal of a dam and gravel and fishway flood control. Following Bowring Park along the river, flood control and dredging continued. After Hurricane Igor, a concrete stabilizing barrier was built on the northern side of the river, right next to the Kilbride Hydrometric station. In the direction of Blackhead Road, landscaping, bridge repair, and gabion basket installation have all been done (CANAL, 2022). A list of structures with detailed engineering assessment have been completed by CBCL and is available for review (CBCL Limited, 2018).

Sewage and waste management: The Waterford Valley trunk sewer transports sanitary and storm sewage from the basin to the Riverhead Wastewater Treatment Facility (RHWTF). The RHWTF is a primary treatment facility built to treat wastewater from the cities of St. John's, Mount Pearl, and Paradise. The plant's treated wastewater drains into St. John's Harbour, and the biosolids produced are transferred off-site to be composted. There may still be a few undocumented cross-connections between sanitary and storm sewers in Mount Pearl and neighbouring sections of St. John's that discharge sewage into the river; however, identifying and correcting these occurrences has been an ongoing undertaking for both municipalities. In addition, some homes in the basin use private septic tanks and are not connected to the public sewer system. Waste from the cities of St. John's and Mt. Pearl and from the Town of Paradise is disposed at the Robin Hood Bay Regional Waste Management Facility (CANAL, 2022).

Agriculture: Agricultural land usage is present in the eastern side of the basin and mainly concentrated near Ruby Line, Bay Bulls Road, Petty Harbour Road, and Brookfield Road. Dairy farming and vegetable gardening, particularly the production of root vegetables like potatoes, turnips, and carrots, are evident in farming operations. The Atlantic Cool Climate Crop Research Centre, located on Brookfield Road, covers roughly 61 hectares of land. In addition, there are private home gardening and hobby farms scattered throughout the watershed (CANAL, 2022).

Recreation: Bowring Park which is a major a municipal park (approximately 200 acres), is located in the eastern portion of the basin in St. John's. Also, there are a number of other small municipal parks in Mount Pearl. The three respective municipalities in the watershed are connected by a portion of the improved Provincial Trail Way Park and walking trails extending along the river. Waterford Valley Campground is situated in Mount Pearl and recreational use of ATV is present in the headwater region, downstream of Bremigans Pond in Paradise. An 18-hole golf course is located near the headwaters of the largest tributary of the Waterford River, South Brook (CANAL, 2022).

Waterford River Assessments

The assessments of the Waterford River for this section have been divided into three categories.

Category 1. Analysis on selected Water Quality parameter data collected from ECCC Open Data Portal involving six grab sampling sites on the Waterford River and one hydrometric station.

Category 2. Benthic Macroinvertebrate data analysis of test sites sampled by the WRMD, other NAACAP and CCNL on the Waterford River**.**

Category 3. Summer 2021 Waterford River assessments by CCNL.

Table 3.

Assessment categories summarized.

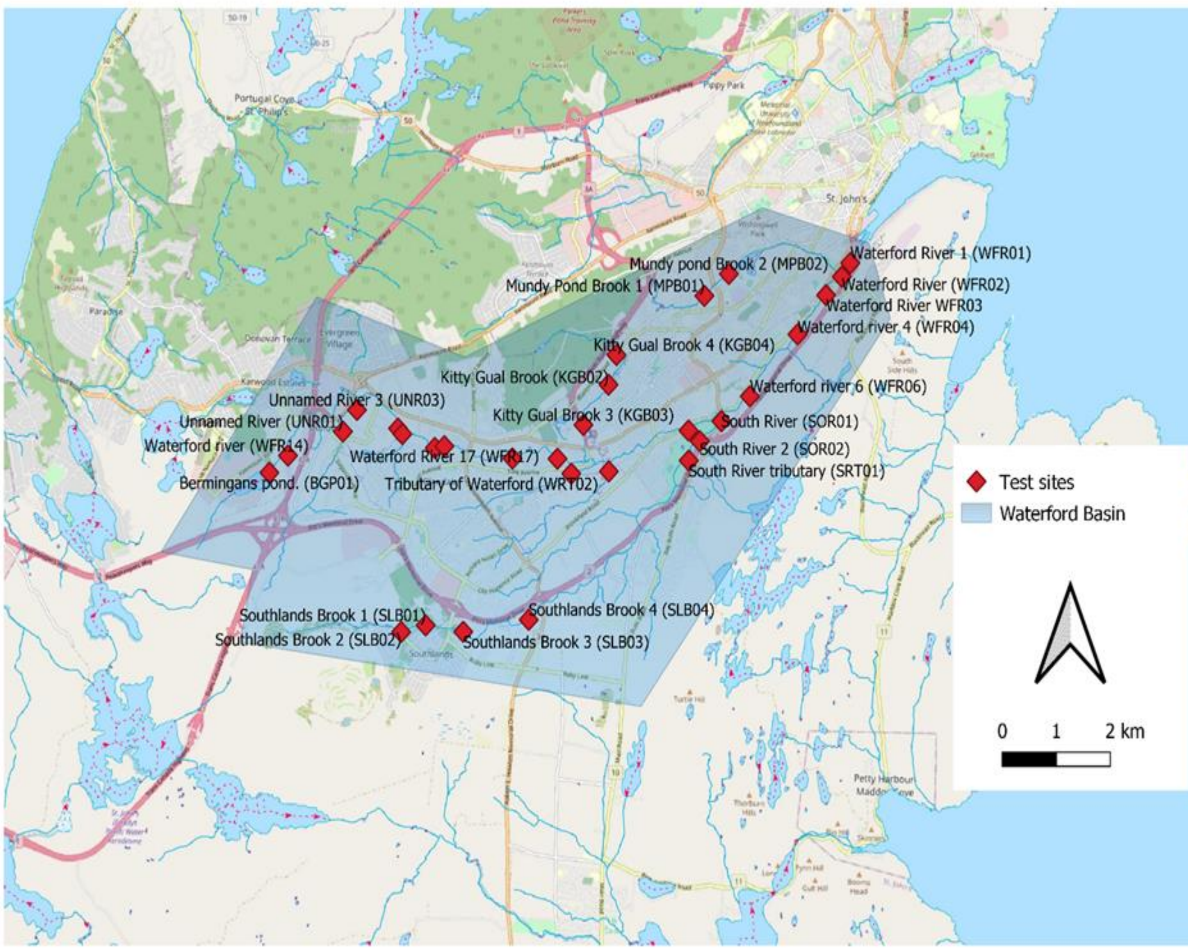
Category 1– CCNL assessments	**Category 2 –** Benthic Macroinvertebrates	**Category 3** – Water Quality assessment on long-term data	
• Twenty-four test sites on the Waterford River Watershed	Six sites: • 1 test site and 1 reference site sampled by WRMD - NL Province (2008, 2012) • 4 sites sampled by NAACAP (2014, 2015, 2016)	• Six grab sampling sites • One continuous sampling site	
Summer 2021	2008, 2012, 2014, 2015, 2016	2011 – 2022	
Parameters analyzed: • Benthic macroinvertebrates (most downstream site) • Aquatic habitat (all sites) • In-situ water quality on all site for the following: -pH, water temperature, dissolved oxygen, salinity, conductance, turbidity, total dissolved solids	Parameters analyzed: • Benthic macroinvertebrates	Parameters analyzed: • pH (field) • Water Temperature (field) • Dissolved Oxygen (field) • Conductance (field) • Turbidity (field) • Nutrient (Total Phosphorus)	

Category 1.

Twenty-four sites on the Waterford River and its tributaries were selected and assessed through one time sampling event per site following the Canadian Aquatic Biomonitoring Network (CABIIN) standardized protocols in summer 2021.

Figure 5.

Selected test sites (24) on the Waterford Watershed.



Integrated Analysis: For the purpose of interpretation, the data gathered through stream samplings will be discussed in two sections. The first section will describe the habitat suitability of fish species most commonly found in the Waterford River and its tributaries. The second section will focus on measured in-situ Water Quality parameters. The observations described in this section are based on one time data collection and thus provides a general snapshot of the condition of the streams during the time of data collection. The sites are referred to with sites codes during discussion and the raw data and site description corresponding to each site codes are included in Appendix A and Appendix B respectively.

It is to be noted that due to limited scope, benthic macroinvertebrates were sampled for the most downstream site on the Waterford River. The benthic macroinvertebrate analysis for that site is discussed in Category 2 assessments.

Habitat suitability

This section discusses the optimal habitat for the two types of trout present in the Waterford River: brook trout and brown trout. Brown trout predominate in most areas of the Waterford River, but brook trout thrive in the higher reaches of the South Brook tributary

The optimal physical habitat involving velocity, depths, substrate, and cover for different stages of life of brook trout and brown trout presented in Table 4 and 5. These were adapted from a manuscript report produced by the Department of Fisheries and Oceans Canada (DFO) on the life history characteristics of freshwater fishes occurring in NL with major emphasis on riverine habitat requirement (Grant & Lee, 2004). The raw data collected for the four physical parameters are included in Appendix B and are discussed in this section.

Table 4.

Optimal Habitat requirement for brook trout.

Habitat feature	Spawning	Young of the **Year (**YOY)	Juveniles	Adults
Velocity (m/s)	0.01-0.9	0.01-0.4	0.01-1.5	0.01-0.5
Depths	0-1 m	0-1 m	0-2 m	0-2 m
Substrate	Cobble, gravel, and sand	Boulder, rubble, cobble, and gravel	Boulder, rubble, cobble, gravel, sand, and silt	Bedrock, boulder, rubble, cobble, gravel, sand, and silt
Cover	Overhead, In-situ	Submergent, overhead and in-situ	Submergent, overhead and in-situ	Submergent, overhead and in-situ

*Overhead = Riparian cover overhanging the stream, undercut banks woody debris at the surface of the water.
*Submergent = Aquatic plants that grow entirely below the water surface and includes numerous mosses and macroalgae.
*In-situ = Cover within the stream bed in the form of fallen trees, submerged logs, rocks, boulders, undercut banks and accumulated debris.

Note. Retrieved from (Grant & Lee, 2004)

Table 5.

Optimal Habitat requirement for brown trout.

Habitat feature	Spawning	Young of the year (YOY)	Juveniles	Adults
Velocity (m/s)	0.1-0.8	0-0.2	0.05-0.8	slow-fast
Depths	0-1 m	0-1 m	0-5m	0-2 m
Substrate	Rubble, cobble, and gravel	Boulder, rubble, cobble, and gravel	Boulder, rubble, cobble, gravel	Boulder, rubble
Cover	Overhead*, In-situ*	Submergent*, overhead* and in-situ*	Submergent*, overhead*and in-situ*	Submergent*, overhead* and in-situ*

*Overhead = Riparian cover overhanging the stream, undercut banks woody debris at the surface of the water.
*Submergent = Aquatic plants that grow entirely below the water surface and include numerous mosses and macroalgae.
*In-situ = Cover within the stream bed in the form of fallen trees, submerged logs, rocks, boulders, undercut banks and accumulated debris.

Note. Retrieved from (Grant & Lee, 2004)

Substrate - Out of the 24 sites assessed, the substrate class of 13 sites in the Waterford River are gravel dominant (0.2 cm – 3 cm), 4 sites included cobble dominant substrate (3 cm – 13 cm) and the rest of the sites were dominated by rubble (14 cm – 24 cm), sand (0.2 cm – 0.006 cm) and slit (<0.006 cm). Comparison against the optimal habitat for brook trout from (Grant & Lee, 2004) highlighted that the stream sites are generally habitable for the four life stages. Brown trout habitat substrate data also seemed suitable for the first three stages of life, however only one site (WFR19) showed optimal suitability for adult life stage.

Depth - The average cross-sectional depth measured at the time of site assessments of all stream sites falls under the optimal range required for the four life stages of Brook Trout. However, only one site was suitable for all life stages of Brown Trout. One of the most downstream sites WFR01 of the Waterford River has the highest cross sectional average depth of 0.83 m. And the lowest cross sectional average depth of 0.11 m was found in three sites KGB02 (Kitty Gaul's Brook), SRT01 (South Brook Tributary), WRT01 (Waterford River Tributary).

Velocity - The comparison of optimal velocity ranges for brook trout and brown trout for the four stages of their life cycle with the collected data on the Waterford River showed that all sites were in optimal condition in terms of velocity for spawning and juvenile life stages of brook trout at the time of data collection. WRT01, WFR17, SLB01 and KGB02 were outside of the optimal range for YOY and WRT03, WFR20, WFR19, WFR18, WFR14 and SLB02 were outside of the optimal range for both YOU and adult life stages.

Cover - The standard protocols in CABIN included the collection of data of habitats present in reach (riffle, pool, straight run), canopy coverage (%), macrophyte coverage (%), dominant streamside vegetation and periphyton coverage on substrate (benthic algae). The comparison of these categories of data with the optimal habitat data for cover found in literature could not be made directly. The three types of cover mentioned in the manuscript are overhead, submergent and in-situ. Canopy coverage and dominant streamside vegetation could be related to overhead cover. Some stream sites of the Waterford River (WFR02, WFR06, WFR16, WFR17, WFR20) had canopy coverage of 1-25% and are surrounded by residential zones. WFR04 and WFR01, WFR18 and BGP01 had 0% canopy coverage. These sites had the lowest canopy coverage. Ferns and grasses were observed as the dominant streamside vegetation. Periphyton coverage was 1-5 mm thick on most sites.

To identify the suitability of each site for brook trout and brown trout in the Waterford River, collected data during site assessments for the four above mentioned physical habitat parameters were compared against the optimal physical habitat. The result of the comparison is presented in the form of a suitability matrix in Table 6. It is to be noted that brown trout and brook trout have similarity in terms of habitat and thus the suitability matrix represents both brook trout and brown trout.

Table 6.

Habitat suitability matrix – Brook Trout & Brown Trout

Habitat Parameters	Spawning	Young of the year (YOY)	Juveniles	Adults
Water velocity	*Optimal	*Optimal	*Sub-optimal	*Sub-optimal
Depth	*Optimal	*Optimal	*Optimal	*Optimal for Brook Trout *Not optimal for Brown Trout
Substrate	*Optimal	*Optimal	*Optimal	*Sub-optimal
Cover	*Sub-optimal	*Sub-optimal	*Sub-optimal	*Sub-optimal

*Optimal = collected data within the optimal ranges
*Sub-optimal = collected data marginally outside the optimal ranges
*Not optimal = collected data outside the optimal ranges to a greater extent

Note. The habitat suitability matrix is based on one-time seasonal assessment during summer and is only meant to provide an overview.

The comparison showed that the stream sites assessed are generally habitable for the four life stages except for the habitat parameter, depth, for adult Brown Trout. Only one site (WFR19) was suitable for all four stages of Brown Trout in terms of depth.

Water Quality

The measured in-situ Water Quality (WQ) parameters on the 24 sites involving Waterford River and its tributaries were pH, water temperature, dissolved oxygen, conductance, salinity, turbidity, and total dissolved solids (See Appendix C). The recommended guidelines for these parameters were adapted from various sources and described in Table 7. Sites that deviated from the recommended guideline for each WQ parameter are also presented in Table 7.

Table 7.

Summarized description of Water Quality

Water Quality parameters	**Recommended guidelines**	**Source**	**Comparison with assessed site data**
pH Unit: N/A	6.5 – 9.0	(CCME, 2022) *Water Quality Guideline for the Protection of Aquatic Life Freshwater*	All sites were within the recommended range
Dissolved Oxygen Unit: ppm	Lowest acceptable dissolved oxygen concentration (long-term) Warm water biota: early life stages = 6.0 ppm other life stages = 5.5 ppm Cold water biota: early life stages = 9.5 ppm other life stages = 6.5 ppm	(CCME, 2022) *Water Quality Guideline for the Protection of Aquatic Life Freshwater*	All sites were within the recommended range
Water Temperature Unit: (°C)	Above 22 degrees Celsius - Fish starts to show signs of stress	(Fisheries and Oceans Canada, 2022)	Temperature recorded on all sites ranged between 13 – 19.7 degrees Celsius
Conductivity Unit: µS/cm	High conductivity (1000 to 10,000 µS/cm) - indicator of saline conditions	(DataStream, 2022)	Four sites were found to have conductivity higher than 1000 µS/cm
Salinity Unit: ppt	Freshwater salinity is usually 0.5 ppt or less	(Biscayne Bay Water Watch - University of Florida, 2021)	Four sites were found to have salinity of 0.5 – 0.8 ppt
Turbidity Unit: NTU	Narrative	(CCME, 2022)	Turbidity in all sites were recorded to be 6 NTU
Total Dissolved Solids (TDS)	Maximum 1000 mg/l	(Province of BC, 1998),	The highest recorded TDS was 877 ppm and lowest 57. 9 ppm. (1ppm = 1 m/l)

			Hence, all sites were under the recommended guideline.

The WQ parameters pH, Water Temperature, TDS and DO were within the recommended guidelines. All sites were sampled during clear flow for turbidity using a turbidity tube which can be only read minimum up to 6 NTU. The recommended guideline for turbidity was narrative and required the knowledge of background level of sites to draw any conclusion.

The conductivity and salinity for four sites were higher than the recommended guidelines. Two of these sites are in the Donovan's Industrial area (UNR01, UNR02) and the conductivity recorded was 1555 µS/cm and 1530 µS/cm respectively. The corresponding salinity for both sites was 0.8 ppt. These sites indicated saline conditions and are likely receiving contamination from nearby heavy industrial activities that increased the salinity of the waterbody.

The other two sites (WFR17, WFR16) were next to the Newfoundland T'railway and surrounding land use is Urban/Residential. The conductivity recorded were 1114 µS/cm and 1122 µS/cm and corresponding salinity for both sites was 0.5 ppt. The guideline for salinity indicated that 0.5 ppt or less is considered to be freshwater, but a high conductivity above 1000 µS/cm during the summer months is indicative of contamination in the water and requires further investigation.

Category 2. Benthic macroinvertebrates

A cumulative analysis on available benthic macroinvertebrate sampling data was conducted for this section. This included data from test sites sampled by the Province of NL - Water Resources Management Division (WRMD) in 2012; sites sampled by Northeast Avalon ACAP (NAACAP) in 2014, 2015 and 2016 which involved sampling of one site consecutively for three years; and sites sampled by Conservation Corps Newfoundland and Labrador (CCNL) in 2021 following Canadian Aquatic Biomonitoring Network (CABIN) protocols. The retrieved data for the Benthic Macroinvertebrates included identification on the *Family* level. Ten indices in relation to the Benthic Macroinvertebrates were used to identify the presence of environmental stressors for a given site (See Appendix D). The indices and procedure for evaluation were retrieved from protocols developed by S.M. Mandaville (Mandaville, 2002).

From the analysis, only two notable indicators to describe the impairment in the sites are discussed here. It was found that out of the six sites, four sites were dominated by the Chironomidae (non-biting midges or lake flies). In the presence of environmental stressors, the percentage of this taxa group increases. The four sites are South Brook at the mouth (sampled in 2015), Waterford River downstream of Corisande Drive in Mount Pearl (sampled in 2014, 2015 and 2016), Waterford River downstream of the waterfall near Park Avenue (sampled in 2015), and Waterford River downstream of Blackhead Road (sampled in 2015). The site that was consecutively sampled for three years by NAACAP indicated increase in % Chironomidae consistently. Another notable indicator for the presence of environmental stressor is cumulative % of Ephemeroptera, Plecoptera and Tricoptera taxa(%EPT). In the presence of any stressor, the %EPT decreases in a site since these are very sensitive to pollution. The four sites which had an increase in % Chironomidae, had decreased %EPT.

It is worth mentioning that the most downstream site of the Waterford River (lower reaches) sampled by CCNL in 2021 did not show any impairment through the Benthic Macroinvertebrate analysis.

Category 3. Water Quality monitoring data WQMA

As part of an effort operated by the Department of Municipal Affairs and Environment, Water Resources Management Division, water quality sampling has been performed within the Waterford River watershed for many years under Canada - Newfoundland and Labrador Water Quality Monitoring Agreement, (WQMA). There are six grab sampling sites and one continuous station in the basin (See Table 8). All data were retrieved from Environment and Climate Change Canada's open portal.

Table 8.

WQMA Sampling Stations.

Site ID	Sampling station type	Description
NF02ZM0182	Grab	Bremigans Pond Dam (Waterford River Headwaters region)
NF02ZM0185	Grab	South Brook Headwaters (Largest tributary of the Waterford River)
NF02ZM0004	Grab	Waterford River at Commonwealth Avenue
NF02ZM0175	Grab	Waterford River at Brookfield Road
NF02ZM0176	Grab	South Brook at Mouth
NF02ZM0009	Continuous	Waterford River at Kilbride
NF02ZM0181	Grab	Waterford River at Blackhead Road

These seven sites have been sampled for various Water Quality parameters however, there is inconsistency in both the number of samples taken annually and the dates on which those samples are taken from year to year. Therefore, it was very hard to discover trends in the data. Nevertheless, five Water Quality parameters for each of the stations were analyzed by sorting the respective data seasonally for Winter (January, February March) and Summer (July, August, September) for the years 2011 to 2022. The sorted data were graphed (boxplots) and analyzed which are included in Appendix E. These five WQ parameters were selected because the recommended guidelines for these parameters could be gathered. Only the summarized observations are reported for the purpose of this section.

Table 9.

Summary of the WQ parameters with respect to the seven Sites on the Waterford River Watershed.

Water Quality parameters	**Recommended guidelines**	**Notes on compared Sites**
pH Unit: N/A	6.5 – 9.0 Source: (CCME, 2022)	Sites NF02ZM0182 and NF02ZM0185 deviated from the guidelines during **winter** months and indicated acidic conditions. Site NF02ZM0185 deviated from the guidelines during **summer** months.
Dissolved Oxygen Unit: ppm	Lowest acceptable dissolved oxygen concentration (long-term) Warm water biota: early life stages = 6.0 ppm other life stages = 5.5 ppm Cold water biota: early life stages = 9.5 ppm other life stages = 6.5 ppm Source: (CCME, 2022)	All Sites met recommended guidelines. Exception: Few outlier events
Water Temperature Unit: (°C)	Above 22 degrees Celsius - Fish starts to show signs of stress. Source: (Fisheries and Oceans Canada, 2022)	All Sites met recommended guidelines

Conductivity Unit: µS/cm	High conductivity (1000 to 10,000 µS/cm) - indicator of saline conditions Source: (DataStream, 2022)	Sites NF02ZM0004, NF02ZM0009, NF02ZM0175 and NF02ZM0181 exceeded recommended guidelines for the **winter** months that indicated saline conditions.
Nutrient (Total Phosphorus) Unit: mg/l	• Hyper-eutrophic >0.10 mg/l • Eutrophic, between 0.035 – 0.1 mg/l • Meso- eutrophic, between 0.02 – 0.035 mg/l Source: (CCME, 2022)	Site NF02ZM0009, and NF02ZM0181 showcased trigger ranges for meso-eutrophic states in the summer months. Site NF02ZM0176 showcased trigger ranges for eutrophic in the summer months. Exception: Few outlier events

Discussion

The WQ parameter data for pH, Conductivity and Total Phosphorous of some sites were outside the recommended guidelines. Out of the seven sites, Bremigens pond Dam Site which is the headwater regions of the Waterford River and the South Brook tributary headwaters in the Watershed showed acidic conditions in the winter months. South brook tributary headwaters also tend to be acidic during the summer months as well. One of the reasons of the sites being acidic could be rapid snowmelt in winter seasons. Rainwater and snow are slightly acidic in nature and when snow melts rapidly, the water may become runoff and not percolate through the soil before reaching the stream. This may not give the soil time to buffer the water, causing the pH to be slightly acidic (Mesner & Geiger, 2010). Also, presence of organic material, increased carbon di oxide concentration in water and temperature can also affect the pH.

Certain substances such as chloride, nitrate, sulphate, phosphate, sodium, magnesium, calcium, and iron dissolved in water influences the conductivity. Road salts which typically includes Sodium Chloride, Calcium Chloride, Potassium Chloride and Magnesium Chloride used in the winter months can get deposited in the nearby waterbodies through runoff. The Waterford River Sites at Commonwealth Avenue, Kilbride, Brookfield Road and Blackhead Road exceeded the maximum recommended guideline for conductivity in freshwater and indicated saline conditions. This could be due to road salting operation since the high conductivity was recorded to be high during the winter months.

The Canadian Guidance Framework for nutrient includes Total Phosphorus Trigger Ranges to develop guidelines for Phosphorus. It does not provide guidance for other freshwater nutrients. The trigger range for meso-eutrophic, eutrophic and hyper eutrophic conditions in relation to total phosphorus data is considered for this section. Waterford River site in Kilbride and Blackhead Road showed tendency to be meso- eutrophic during the summer months. Runoff input from surrounding urbanized areas such as lawns could have affected the Total phosphorous levels in these sites The South Brook Site at the mouth closer to the Duck Pond in the Bowring Park fell within the trigger ranges for eutrophic conditions in the summer months. This could be due to the excrements of ducks that inhabit in the area.

3.0 Management Themes and Recommended Actions

This Section discusses five main management themes in addition to recommended actions under each of those themes for the Waterford River Watershed. The five themes were carefully selected after analyzing collected data, research, surveys, and interactions with the residents of the Watershed throughout the duration of the Waterford River Conservation Project by CCNL. Recommended actions involve tackling the issues related to the conservation of the Waterford River and are presented under each of those five management themes. The themes are

3.1 Maintenance of a healthy riparian zone
3.2 Integrated stormwater management
3.3 Maintenance of roads and paved areas in winter
3.4 Residential area management
3.5 Stream garbage management

The summary tables under each theme highlights recommendations, timeframe, and deliverables. Additional information and considerations that can help in executing the actions are also mentioned under some themes.

3.1 Maintenance of healthy riparian buffer zones

A process-based actionable step in terms of management strategy that could be applied to improve the water quality and maintain a good aquatic habitat for fish in the Waterford River and its tributaries is to maintain (where impaired) a healthy riparian buffer zone. It is to be noted that all water quality impairment might not be rectified through the implementation of this one management strategy, but it has the potential to mitigate the adverse affects of non-point source pollution to a greater extent. A functional riparian zone can provide the benefits (Nova Scotia Environmental Farm Plan, 2021) that includes:

- Maintaining and strengthening stream banks naturally
- Protecting stream bank erosion
- The shading of the watercourse to maintain a cooler water temperature (improvin)
- Sedimentation and nutrient filtration from urban runoff (improving water quality)
- Flood control
- Sequestering carbon

Given the importance of riparian zones to watersheds, it is recommended that riparian zone management be integrated whenever possible into watershed management plans (National Research Council, 2002).

The Waterford River flows through varied land use zones in the three respective municipalities. The land use adjacent to the Waterford River and its tributaries in most cases are heavily urbanized and are residential, commercial and industrial in nature. The ideal riparian buffer zone that can provide all the beneficial ecological functions mentioned earlier are not present in all parts of the basin. The stream reaches in many places have become separated from its floodplain or has developed unstable channel conditions due to changing stream flow regimes or channel alterations.

Recommended action:

- **Designing a riparian zone assessment and restoration program for the Waterford Watershed**

Overview: The program will identify the priority areas for restoration on Municipal owned properties based on the assessments of links and functions of adjacent land use, slope, stream bank conditions, channel conditions hydrologic flow regime, sediment dynamics, and vegetative growth. After establishing the areas in need of restoration, suitable techniques will be selected depending on the need of each impaired site. A budget analysis will need to be completed following funding securement for the work including labour, materials, transportation, and permit costs. Identifying the respective jurisdictions (federal, municipal, and private land) and compliance with associated regulations is important before implementing any restoration work.

- **Building connections with landowners (residential, commercial, and industrial) as some of the riparian zones of the river channels are adjacent to their properties.**

Overview: Reaching out to respective landowners and receiving their cooperation prior to beginning any restoration work is very important. This is to ensure that no disruptions to the enjoyment of their respective private properties takes place. In this case, providing them a schedule and scope of the work in addition to highlighting the importance of the work to conserve the water quality and fish habitat in streams can be effective.

- **Maintaining vegetation in the riparian zone**

Overview: To ensure that the riparian zone continues to provide the important ecological functions throughout the year, it is necessary to incorporate varieties of native plants and trees that can withstand different weather conditions and climate change. Selection of plant materials will be conducted after consultation with a horticulturist and botanist. In addition, identification and removal of invasive species should be conducted.

- **Development and implementation of a monitoring and maintenance schedule**

Overview: A seasonal monitoring schedule will need to be developed to maintain the riparian zone vegetation and look for any damage. In a changing climate, urbanization impact and frequent storm events, monitoring and maintenance of the riparian zone is required. The maintenance will also include management of fallen trees after storm events and planting more trees where requires. Where possible woody debris should be left in the stream to promote habitat complexity in stream considering it will be not pose any sort of risk to nearby infrastructures.

Table 10.
Maintenance of healthy riparian buffer zone recommendation summaries.

Actions	Timeframe	Deliverables
Designing a riparian zone assessment and restoration program	2-3 years	-Inventory of impaired riparian areas in each municipality -Restoration work projects for the impaired areas
Building connections with landowners (residential, commercial and industrial)	Periodical check-ins	Create awareness of the negative impacts of industrial and commercial activities to the waterbody.
Maintaining vegetation in the riparian zone	Seasonal every year	Healthy, well vegetated riparian zones.
Monitoring and maintenance schedule	Yearly	Well structured monitoring program

Buffer zone considerations

The ideal buffer zone width determination depends on many factors. These factors are slopes, soil type and vegetation mix. With increase in slope, the speed of water flow over and through the buffer also increases. Thus, the buffer must be wider for steeper slopes to provide enough time to slow the water flow and promote absorbance of pollutants and sediments. Steep slope definition varies from over 10% to over 40 %. Type of soil has an affect on the absorbency potential of the runoff and a riparian buffer that is structurally diversified, or one that has a mix of trees, shrubs, and grasses, is significantly more effective at removing a variety of pollutants than one that is only grass or trees (Hawes & Smith, 2005). The table below mentions the removal efficiency of plant types corresponding to functions.

Table 11

Removal efficiency of different types of plants corresponding to riparian zone functions.

Function	**Grass**	**Shrubs**	**Trees**
Sediment trapping	High	Medium	Low
Filtration of Sediment born Nutrients, Microbe and Pesticides	High	Low	Low
Soluble forms of Nutrients and Pesticides	Medium	Low	Medium
Flood Conveyance	High	Low	Low
Reduce Stream Bank Erosion	Medium	High	High

Note. Retrieved from (Hawes & Smith, 2005).

To maintain an effective riparian zone, the recommended width depending on the intended function of the riparian zones should be considered. Sometimes it will not be possible to create an ideal buffer zone because of existing land use in the Waterford Basin. In those cases, ensuring the existing buffer zone is well vegetated is the key for management. The riparian buffer zone can be divided in to five planting zones in relation to the waterline for vegetation. Knowledge of these zones will help in determining the type of plants that should be used. The five-planting zone from (Hawes & Smith, 2005) are described briefly below.

Toe zone - The toe zone, or baseflow is below the average water elevation and at a level where water is moving throughout the summer. Since it's flooded most of the year, the toe zone rarely has dense vegetation.

Bank zone - The bank zone lies between the average water elevation and bankfull discharge. Flexible stemmed willows, and low shrub species will typically cover the bank zone. It usually floods less often than the toe zone and after spring runoff, this zone's soil moisture drops.

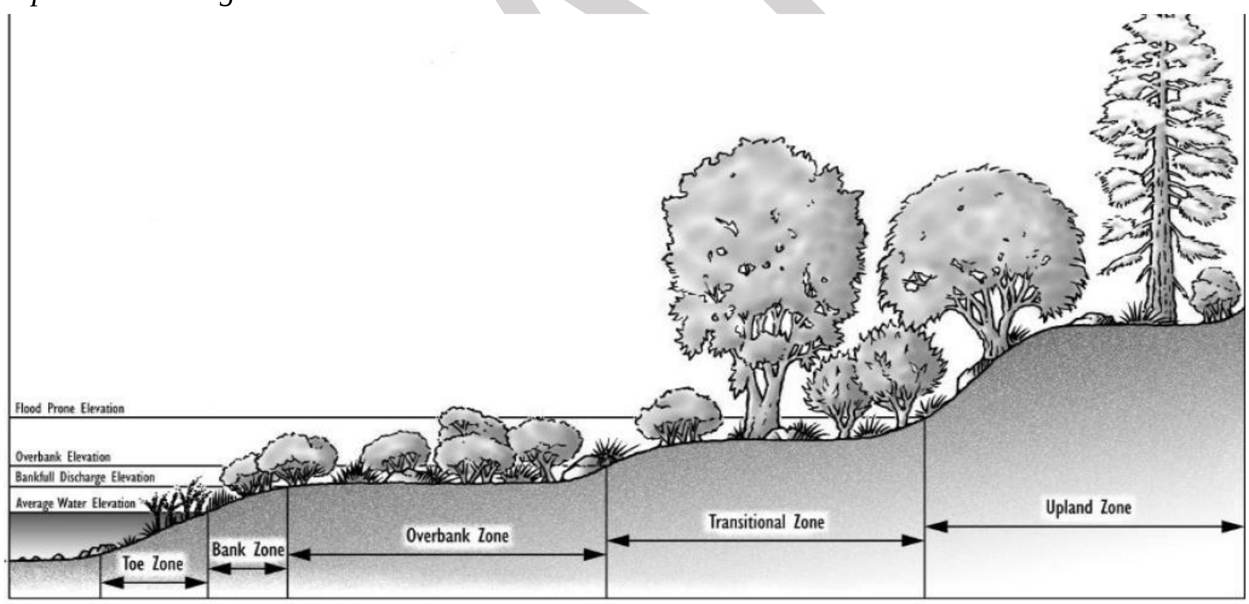
Overbank zone - Overbank zone is between bankfull discharge elevation and overbank elevation. It is flat and occasionally flooded. The vegetation in this zone should be flood tolerant and about 50% hydrophytic. Dogwoods, alder, birch, and shrubby willows with flexible stems will be the most common trees in this area.

Transitional zone - The transitional zone is between the overbank and flood-prone elevations. Most species in this zone cannot tolerate flooding. The largest tree species are often found in this area.

Upland zone - The upland zone is located above the flood-prone elevation. This zone's vegetation is dominated by upland species.

Figure 6.

Riparian Planting Zones



Note. Retrieved from (Hawes & Smith, 2005).

The Provincial legislation/guidelines for Buffer zones in Newfoundland and Labrador (Island Nature Trust, 2005) and general buffer zone width recommendations based on research are also included which can help in planning for an ideal riparian buffer zone. However, there are exceptions, and the *Lands Act*, SNL 2002, and the *Water Resources Act*, SNL 2022, should be consulted in addition to the following guideline.

Newfoundland and Labrador - legislations/guidelines for Buffer zones

- Crown land reserve of 15 meters along all water represented on a 1:50,000 NTS topographic map
- Buffer zone is measured from the high-water mark and is required to be forested.
- 15-meter buffer zone requirement on all watercourses larger than 1 meter wide not represented on a 1:50,000 NTS topographic map
- When the slope of the land exceeds 30% the width of the buffer zone is required to be 15 meters plus 1.5 times the slope (%)
- Depending on the land use or practices (including pesticide use, pesticide storage, or maintenance buildings) occurring adjacent to the watercourse the buffer zone width requirement could be as wide as 400 meters

There might be exceptions to the 15 m Crown land reserve, and the *Lands Act*, SNL 2002, and the Water Resources Act, SNL 2022, should be consulted in that case.

Table 12

General recommended width for buffer zones.

Function	Explanation	Optimal width (both banks)
Water Quality Protection	Overland runoff is intercepted by buffers, particularly dense grassy or herbaceous buffers on sloping slopes, which also trap sediment, remove contaminants, and encourage ground water recharge. Runoff filtration capability: • low to moderate slope – first 10 m • steeper slopes comprised of shrubs and trees with low soil permeability and high pollutant load – 30 m	5 – 30 m

Stream Stabilization	Buffers including diverse stands of shrubs and trees. Roots from riparian plants add tensile strength to the soil matrix and help keep streambanks from eroding by regulating soil moisture.	10-20 m
Riparian Habitat	In the absence of active bank erosion, a buffer of merely the width of the bank may be necessary for effective erosion management. Additional bioengineering methods might be needed to address severe bank erosion.	30 – 500 m
Flood Accumulation	Flood peaks are mitigated by riparian buffers because they improve floodplain storage via backwater effects, intercept overland flow, and increases travel time of water flow.	20 – 150 m
Detrital Input	Streams receive valuable nutrients and habitat from the leaves, twigs, and branches that fall from riparian forest canopies.	3 – 10 m

Note. Retrieved from (Hawes & Smith, 2005).

3.2 Integrated Stormwater Management

Universally, there has been a gradual expansion in the scope of urban water management's traditional objectives. While flood mitigation remains crucial in urban areas, preserving aquatic habitats in waterbodies flowing through cities is also being prioritized. Integrated stormwater management can incorporate an ecosystem-based approach. In addition to focusing on multifunctionality, an integrated stormwater management system can emphasize building partnerships, collaborating with interdisciplinary teams, exploring innovative techniques, identifying gaps, and modifying existing policies where necessary.

The three respective municipalities within the Waterford River Watershed have policies and regulations in place to address stormwater management. Robust policies are evident for new developments prioritizing the ecosystem function of the waterbodies within each municipal jurisdiction. Some prominent objectives and policies concerning stormwater management from the respective Municipal Plans are stated below.

Town of Paradise –Section 6.4.1 of the current Town of Paradise Municipal plan (2016) mentions policies regarding stormwater management. These include:

- *Ensuring new development in the town is planned designed and constructed to adequately manage stormwater in accordance with the Town's engineering design standards.*
- *Development in areas identified in the Town's Stormwater Management Plan as having insufficient capacity in the stormwater system to handle current and predicted future stormwater flows, shall not be permitted unless infrastructure is upgraded.*
- *Ensure that development sites have adequate erosion and sediment control measures in place to prevent pollution of the Town's ponds and waterways.*
- *Require measures to reduce stormwater runoff in site designs in accordance with the Town's Urban Design Guidelines.*
- *When completed, incorporate the recommendations of a Waterford River Floodplain Study into the Municipal Plan and Development Regulations*

One of the strategic objectives in the Chapter 7 of the Infrastructure Systems is the *upgrade of stormwater system to reduce flooding risks*. The stormwater policies in section 7.2.3 associated with the objectives are:

- *Continue to improve stormwater management in the Town through the implementation of the Town's Stormwater Management Plan, taking into account increased stormwater flows that are predicted as a result of climate change.*
- *Incorporate an integrated design approach and use of best practices for stormwater management as part of Town infrastructure projects.*

- *Encourage on-site management of stormwater in the design of new developments consistent with the Town's Urban Design Guidelines.*

Limitation to development in the policy section 8.1.3 of the municipal that mentions, development may be refused where one or more of certain conditions exits. With regards to stormwater management, one of the conditions is - *There is insufficient capacity in the stormwater system to accommodate predicted increases in stormwater runoff volumes as a result of the development. Note that these conditions are notwithstanding the conformity of a proposed development with this Plan and the Development Regulations*.

Currently, there is no policy in the municipal plan regarding zero-net runoff for development to handle stormwater on site. Amongst other recommendations, the implementation of zero-net runoff policy in the municipal plan was mentioned in the Paradise Storm Water Management Plan Final Report by CBCL (CBCL, 2020).

City of Mount Pearl – The current municipal plan (2010) comprises several objectives and policies specific to the Waterford River Watershed area. On of the objective in relation to stormwater management in section 4.2.7 of the Environment Objectives in the municipal plan is - *To direct stormwater management practices that reduce the impact of stormwater entering the Waterford River system during peak rain events*. The specific Stormwater Management policies in section 7.4 are:

- *Council will encourage sustainable storm water management practices and will investigate multiple strategies that meet or exceed predevelopment conditions including such measures as low impact development practices, permeable pavement, exfiltration trenches and stormwater harvesting.*
- *Council shall make every effort to ensure the preservation of the Waterford River, its tributaries, and other watercourses in their natural state. Vegetation along the banks of watercourses shall be preserved to a distance specified by the Development Regulations and shall be enhanced where necessary to ensure that slopes are stabilized. Development that may impact a watercourse or waterbody shall not proceed unless it receives the approval and meets the conditions of the provincial Department of Environment and Conservation and the federal Department of Fisheries and Oceans.*
- *Where storm water discharges into a wetland, water body, or watercourse, through a sewer line or engineered drainage ditch, Council shall require the sewer line and its outfall to be designed so as to minimize any detrimental effects on the receiving water or a watercourse, such as destruction of streambank vegetation, increase in water speed, streambank erosion, or decrease in water quality.*
- *The City shall review the storm water management measures proposed for new development to ensure that the development does not create negative downstream impacts within the Waterford River watershed.*
- *All land use and development proposals shall contain and manage all storm water on site within the limits of the subdivision development and shall design the developments storm water drainage system to attain or approach as close as possible to "zero net runoff".*

- *All land use and development proposals shall be designed in such a manner to minimize silt runoff. This will also include construction practices during the various stages of development. Appropriate environmental measures shall be implemented to eliminate or minimize silt runoff*.

City of St. John's – One of the strategic objectives in relation to stormwater management in the Chapter 3 of the Environmental Systems in the current municipal plan (2021) is - *Protect the hydrologic functions of waterways and wetlands as a critical component of the city's stormwater management system*. Lands required for storm water management is included in the Environmentally Valuable Areas under section 3.1 Protecting Natural Areas.

The specific Stormwater policies under section 3.2 Water Systems are:

- *Ensure that new development in the city is planned, designed, and constructed in accordance with the City's Policy on Stormwater Detention.*
- *Ensure that development sites have adequate erosion and sediment control measures in place to prevent pollution of the city's waterways.*

City of St. John's has a separate Stormwater Detention Policy, and it applies to all new developments within the City with few exceptions. Also, the strategic objectives of Chapter 7 Transportation and Infrastructure includes - *Focus infrastructure investment on the upgrading and replacement of aging infrastructure including water (potable water, wastewater, stormwater), recreation and streets*. Section 7.5 Water and Wastewater Servicing includes - *Incorporate an integrated design approach and use of best practices for stormwater management as part of City infrastructure projects*.

Stormwater management is complex and has multiple layers, especially for highly urbanized areas. Although the scope of this management plan did not allow for an in-depth analysis of all current stormwater management practices, it is concluded that stormwater management for existing infrastructures and their effects can be addressed further with the integrated stormwater management approach. The recommended actions described below acknowledge the existing policies. These recommendations highlight management suggestions that can be applied to existing developed urban infrastructures.

Recommended actions:

- **Create an education and outreach program targeting the commercial and industrial property owners in each municipality**

Overview: Current developed properties with impervious parking lots are sources of surface stormwater runoff. If net zero runoff goal is to be achieved, it is important that the property owners understand the risk and negative effects of stormwater runoff entering waterbodies. The program will focus on presenting and educating the benefits of Low Impact Development, Green Infrastructure, and on-site stormwater retention/detention techniques. The initiative can be carried out in collaboration with Conservation Corp NL (CCNL).

- **Conduct one pilot project in each municipality to set example of Low Impact Development (LID) and Green Infrastructure's (GI) efficacy in addressing stormwater issues**

Overview: Pilot projects are a good way to set examples of LID and GI which can encourage other property owners to follow. This will require strong partnership, approval, and collaboration with the selected property owner. Potential areas for such pilot projects can be in St. Anne's Industrial Park in the Town of Paradise, Donnovan's Industrial Park in the City of Mount Pearl, and the commercial/industrial area close to the harbour in the City of St. John's. One property from the three mentioned areas will be selected for the pilot project. The selection process should be considered based on the proximity of the property to the Waterford River and runoff volume potential. The stormwater runoff volume for the selected area for the pilot project will be assessed before and after the project has been completed. This will promote a result-oriented approach.

- **Create a monitoring program to evaluate the performance of existing stormwater management systems in each municipality.**

Overview: Establishing a monitoring program under stormwater management on a municipal level will allow for a feedback mechanism that will enable the assessment of existing stormwater management practices and help in identifying gaps. Routine monitoring should be conducted to cover three aspects which are performance, compliance, and environmental effects. In this case, making a stormwater outfall mapping and inventory can be a part of the monitoring program.

- **Establish non-stormwater discharges (illicit discharges) detection and elimination program**

Overview: Stormwater is discharged untreated into waterbodies. It is considered that Mount Pearl and St. John's may still have some unidentified cross-connections between sanitary and storm sewers that feed raw sewage into the river but locating and fixing these problems has been an ongoing effort for both cities. Identification and elimination of non-stormwater discharges (such as sanitary sewer cross connections, industrial and commercial wastes, effluent from septic tanks) to stormwater systems can be established to reduce the contaminant load from stormwater. Municipalities can also develop an action plan to ensure compliance with a regulatory mechanism that prohibits the disposal of non-stormwater discharges into stormwater systems. Particular attention should be paid to areas that have a significant concentration of industrial or commercial land uses.

Table 13

Integrated Stormwater Management Recommendation summaries.

Actions	Timeframe	Deliverables
Create an education and outreach program targeting the commercial and industrial property owners in each municipality	3 years (Every summer season)	-Strategic outreach plan for individual property owners in the commercial and industrial zones and building good communication -List of willing participants (property owners) -Educational presentation delivery for each industrial and commercial zones in respective municipalities for three years.
Conduct one pilot project in each municipality	1 year	Design and installation of on-site runoff control techniques (LIDs) Plan and measure runoff volume pre-installation and post-installation
Create a monitoring program to evaluate the performance of existing stormwater management systems		Well structured monitoring program
Establish non-stormwater discharges (illicit discharges) detection and elimination program	Yearly	Illicit discharges detection and elimination program

3.3 Maintenance of roads and paved areas in winter

The Eastern Canada faces sub zero conditions during the winter months. Removal of snow and ice is necessary to keep the roads and paved areas functional and safe. However, the public works crew in the Avalon peninsula of Newfoundland are regularly challenged with winter maintenance since the accumulated snowfall that turns to ice go through a cycle of partial thawing followed by a refreezing period. Municipalities in the heavily urbanized regions utilizes salt and sand as the primary means of de-icing to keep the roadways and paved areas clear (Ficken, 2008).

However, road salt has adverse effects on the environment. A comprehensive 5-year scientific assessment of road salts beginning in 1995 under the Canadian Environmental Protection Act, 1999 established that road salts constitute a threat to plants, animals, and the aquatic environment in sufficient concentrations (Environment and Climate Change Canada, 2022).

Road salts can get released into the environment from roadway splashes, runoff from salt storage facilities, and snow disposal sites. Also, snowbanks on the side of parking lots or roads eventually melts and the resulting runoff containing road salt and other contaminants gets into freshwater bodies and groundwater systems. A salt loading study (Ficken, 2008) on the three urban rivers in the Avalon Peninsula concluded that Waterford River receives high level of salt contents in the winter months in relation to road salt application. Another study published in 1987 on the Effects of Urbanization on Water Resources in the Waterford River Basin included that there is readily detectable increase in sodium and chloride concentration in the groundwater chemistry caused by road salting operations (Ullah, Marsalek, Hennigar, & Pollock, 1987). In addition, after analyzing the six grab sampling sites and one hydrometric station data from 2011 - 2022 on the Waterford River basin, it was found that the conductance and salinity on four of the sites exceeded the recommended guidelines in the winter months (See Chapter 2, Category 3 Assessments).

Some of the recommended actions below to manage salt applications in winter might draw parallels with the current municipal salt management plans.

Recommended actions:

- **Identify environmentally vulnerable areas in the Waterford River Watershed with regards to salt application during winter.**

Overview: Sites that directly drains into waterbodies especially located near high density network of paved roads and parking lots in the watershed should be considered while identifying vulnerable areas. The list of those areas should be available to all personnel involved in winter maintenance. More environmentally safe, technically, and economically feasible alternatives should be explored for those areas.

- **Establish a systematic procedure before undertaking winter maintenance on identified environmentally vulnerable areas.**

Overview: A systematic procedure can include the following:

- Prepare site plans for the vulnerable areas that work crews can refer to. These site plans can primarily include – area measurements, pedestrian paths, entrance and exit points, vegetation cover, loading zones, distance of the nearest waterbody, runoff drainage direction from the site, snow storage areas and a safe distance from waterbodies.
- Determine surface temperature
- Choose suitable de-icing materials
- Post cleanup plans for over salt application and snowbanks removal.

- **Adapt strong winter maintenance practices for parking lots.**

Overview: Locate parking lot snow storage in the site's low region to avoid melt water from rushing across the property and refreezing on surfaces that still have frost on them. Determine and standardize salt application rate for parking lots close to waterbodies to avoid over application of salt. Restrict on-site snowbank accumulation (for municipally owned areas) close to waterbodies and plan for immediate disposal. Improve the efficiency of winter maintenance by utilizing new maintenance techniques, equipment, and optimal technologies.

- **Introduce living snow fences where possible in the vulnerable areas.**

Overview: Living snow fences are vegetation which are planted in a strategic manner to function as windbreakers and designed to reduce blowing and drifting snow. Living fences can work as structural barriers and cause blowing snow to settle in a designated area.

- **Consult the Code of Practice for Salt Management by ECCC** to **develop, implement and update the Salt Management Plans.**

Overview: To assist municipalities and other road authorities in properly managing their use of road salts in a way that minimizes any potential environmental damage while preserving road safety, the Canadian government released the Code of Practice for the Environmental Management of Road Salts in collaboration Multistakeholder Working Group. Parallel to these efforts, the Transportation Association of Canada (TAC) compiled a Syntheses of Best Practices that provide comprehensive information on winter maintenance procedures and add to the Code's suggested practices. Although the code does not apply to road salts used for households, private or institutional uses, it can still be consulted to develop a Salt Management Plan that will have minimal environmental negative impacts. Organizations are encouraged under the Code of Practice to create and implement a salt management plan (SMP) that includes best management practices intended to address salt storage, salt application, and the disposal of snow containing road salts.

- **Adapt strong salt storage practices**

Overview: Road salt should be kept indoors on an impermeable pad that won't let water through. The pad needs to be sloped away from the storage building, be free of any drainage escape routes, and equipped with mechanisms to manage any spills or drainage. Maximum effort should be made to keep the salt storage dry and covered. Also, brine tanks need to be placed on a waterproof pad with walls that are high enough to catch any overflow.

- **Monitor and update the salt management plan as new technologies and equipment become available.**

- **Provide training to operators and facilities manager on a yearly basis.**

- **Educate businesses (industrial/commercial) and residents regarding harmful impacts of salt use on freshwater systems, groundwater and provide management guidelines.**

Table 14

Recommended action summaries for winter maintenance.

Actions	**Timeframe**	**Deliverables**
Identify vulnerable areas in relating to salt loading in the Waterford River Watershed	2 years	Map of environmentally vulnerable areas and locations
Establish a systematic procedure before undertaking winter maintenance on identified environmentally vulnerable areas	1 year	Well defined list of the systematic procedure handed to winter maintenance crew
Adaptation of a strong salt management plan that prioritizes the protection of environment.	2 years	- Good winter maintenance practices for parking lots. - Introduction of living fences. - Good salt storage practices. - Adaptation of new available technologies
Education and outreach programs for businesses (industrial/commercial) and residents	2 – 4 Years (Once every year)	- Door to door outreach and distribution of educational materials

3.4 Residential area management

The Waterford River and its tributaries flows through high to mid density residential areas. The impact of homeowners and how their properties close to the river and streams are managed is significant in managing the health of the Waterford River Watershed. Encouraging management practices to the homeowners, renters and property managers need to be visually pleasing, fit into the ease of the property use, and cost-effective. Therefore, conducting outreach and education to describe the importance of their roles in conserving the Waterford River can be the first strategy. The second strategy would be to recommend Green Infrastructure (GI) and Low-Impact Development (LID). Techniques that are generally cost-effective and raises the overall value of the property should be investigated which will incentivise the homeowners to adapt the LIDs and GI

Recommended actions:

- **Provide yearly free educational workshops to residents.**

Overview: Organize two yearly free educational workshops in each municipal region to educate residents about everyday water conservation techniques and green infrastructure. Stream assessment data can be presented during the seminars on the Waterford River in an understandable way and show reference photos that indicate visible impairment (where possible). Environmental stressors from residential sources should also be explained in detail. The seminar can deliver examples from other urban watersheds where homeowners have implemented nature-based solutions to mitigate any adverse effects resulting from the property use on the adjacent waterbodies. Keep an average cost of materials for the presented nature-based project and sources of the materials ready. Inform the participants that these materials would be provided to those who are interested. It is important to promote the seminar in an effective way to get as many participants as possible. Partnerships with non-governmental organizations can be established to arrange the seminars.

- **Identify the residential properties closest to the waterways and survey the buffer zone conditions.**

Overview: The survey and identification will result in creating a personalized outreach plan to property owners/managers where appropriate buffer zone conditions and an adequate distance from the waterbody is not maintained. The outreach plan will involve providing suitable restoration plans and assistance with cost analysis. It is important to encourage the property owner to adapt the restoration plans and highlight how it could raise the property value or add to keeping the property safe (where applicable).

- **Encourage regular inspection, pumping, maintenance, and upgrades/repairs to septic systems to prevent septic leaching.**

Overview: Municipal social media posts and the planned workshops can be utilized to encourage homeowners to conduct maintenance on private septic systems and share techniques on how to identify malfunctioning septic systems.

- **Monitor and manage septic leakage**

<u>Overview</u>: Map the locations where there is a concentration of septic systems close to water bodies Review system performance records on a yearly basis to identify areas with a high risk for leaching. Set strategic stream assessment test location for those areas. Indicators of leaching will be reflected on the water quality monitoring data. Conduct testing depending on the risk factor of leaching.

Table 15

Residential area management recommendation summaries.

Actions	Timeframe	Deliverables
Educational workshops delivery to residents	2 years	- Publicity, arrangement, and delivery of workshops
Survey of buffer zone conditions of properties close to the river	1 year	- List identifying areas with inadequate buffer zones
Monitoring and management of sewage leakage	Once every two years	- Outlining and establishment of monitoring program

3.5 Stream garbage management

Rivers and Streams in most urbanized watersheds are usually vulnerable to garbage accumulation. Waterford River and its tributaries faces the same issue. Trash from sidewalks, roads garbage bins and improper disposal of garbage from various sources finds its way into waterways. Also, after sever weather events, washed up garbage settles into the floodplains, banks, and streams. Many organizations including non-government groups such as Conservation Corps NL (CCNL), Northeast Avalon ACAP and the Waterford Valley Rotary Club have been taking on clean up events for many years now and are continuing to do so to keep the streams free from garbage input. Through multiple stream clean-up events during summer 2021 and 2022, CCNL have removed approximately 1950 lbs of garbage and debris from the Waterford River and its tributaries. While it is relatively easy to organize clean up events and get youth volunteers and community volunteers involved in a meaningful way, it is not easy to manage the source of garbage build up in rivers. Continuous efforts are already being made to mitigate this issue. But a systematic and consistent approach has the potential to significantly reduce garbage accumulation in rivers.

Recommended actions:

- **Identify high density areas (commercial. Industrial, residential) and road networks.**

Overview: Locate the sites which are more prone to garbage accumulation in the Waterford Watershed. Compile information through community surveys to know about the areas that are usually seen to have lot of trash.

- **Make seasonal stream cleanup plans for the identified sites.**

Overview: Maintain seasonal stream clean up schedules, once at the start of the season and once at the end of the season (total 8 yearly). Also, after severe weather events (high wind, storms, hurricane, and rainfall), organize clean ups. Reach out to organizations and volunteer groups and establish partnership to gather helping hands for the clean ups. Seasonal partnerships could be formed with a particular organization or volunteer groups so that multiple groups are contributing to the stream clean ups in a given year. Review the plan and schedule on a yearly basis and contact the volunteer groups to finalize a schedule for the upcoming year.

- **Conduct outreach and education through various platforms**

Overview: Deliver educational materials to community members including businesses (commercial and industrial) to address waste disposal management. Inform the residents on the detrimental impacts of littering and trash in their waterways. Take advantage of the social media platforms, community newsletters and email subscriptions to deliver educational material and to spread information.

Table 16.

Stream garbage management recommendation summaries.

Actions	Timeframe	Who	Deliverables
Identification of high-density areas and road networks	1 year	CCNL in collaboration with Municipalities	- Map defining the high-density areas and -Compilation and distribution of community surveys
Seasonal stream clean ups	Seasonal (Once every Year)	CCNL, Municipalities and other volunteer groups	-List identifying areas during each clean up -Arrangement, distribution of information and publicity for stream clean ups.
Outreach and Education	Summer season Yearly	CCNL, Municipalities and other volunteer groups	-surveys, social media engagement and distribution of educational materials

Note. The parties outlined in the column "Who" are mentioned only to showcase examples of collaboration. Commitment to carry out the above "Actions" will be determined in the future if the Watershed Management Plan is formally adapted.

4.0 Site Applicable Restoration Concepts

Hard engineering approaches have been traditionally used in river restoration projects in urbanized areas with the primary goal of providing protection to urban infrastructures. Depending on the objective of the restoration work, certain techniques are generally adapted. However, with the increasingly damaging impacts of urban landscape uses on the waterbodies, the shift to make the protection of river health and aquatic environment has become the primary objective, in addition to the protection of infrastructures. Stream restorations in an urbanized watershed such as the Waterford River Watershed will require in depth analysis of each site condition and creative approaches. Sustainable solution in the face of climate is to engineer with nature and provide necessary conditions for it to repair and manage itself. That is why, process-based, bio-engineered, and nature-based restoration projects have become widely explored options to restore the ecological habitat of waterbodies. In addition, Low-Impact Developments (LID) and Green Infrastructures (GI) have been incorporated in many urban landscapes.

Through the assessments, site walks and satellite imagery (where site-walks were not possible) of the Waterford River Watershed under the scope of the parent project, this section will emphasize on some specific sites that need attention and restoration focusing mainly on buffer zone elements. Stabilizing riverbanks and vegetation cover in an urban setting can be the first actionable step to conserve the Waterford River (See Section 3.1). This will provide protection against urban runoff to some degree which seemed to be a major stressor for the river system. In addition, creating complexity in the straightened channelized streams will provide good aquatic habitat. Some restoration concepts that could be applied to the Waterford River Watershed are described below. The restoration concepts are adapted from various management manuals and practical implementations. The Department of Fisheries and Oceans Canada (DFO) Restoration Unit should also be consulted before planning restoration work as they can provide necessary advice and information on the most recently published guidance materials.

4.1 Structural and non-structural LID concepts

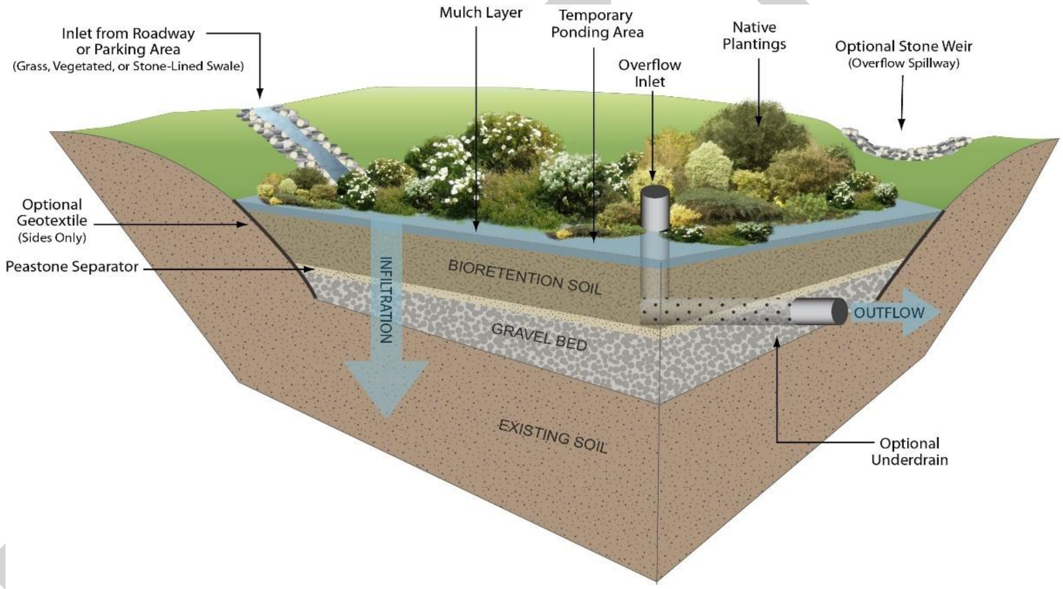
Structural and non-structural Low Impact development (LID) would be suitable for some industrial areas in the watershed. The most detrimental impact to the channel in this type of areas are industrial runoff. Recommending any particular type of LID measures for these areas is outside the scope of this management plan. However, two example concepts of a runoff reduction framework with regards to structural and non-structural LIDs are mentioned below. It is to be noted that, the selection, implementation, monitoring and maintenance of any type of measure would require time, adequate funding, and high degree of collaboration. But it is important to address the issue at hand and take actionable initiative.

Runoff reduction is a strategy mainly used for managing stormwater runoff that focuses on preventing pollutant export, peak flows, and runoff volumes from urban landscapes by using practices that encourage infiltration, reuse, or evaporation of runoff (Vermont Agency of Natural Resources, 2017).

Bioretention (Structural) – Bioretention techniques catch and treat runoff from impermeable areas by passing it through a vegetated filter bed with a sand, soil, and organic matter filter mixture. Runoff that has been filtered is either redirected to a conveyance system or absorbed into the surrounding soil (Vermont Agency of Natural Resources, 2017). Bioretention is a multipurpose technique that can be easily adapted for new and redevelopment applications, for practically any land use. Bioretention can be applied as concave parking lot islands, linear roadway or median filters, terraced slope practices, residential cul-de-sac islands, and ultra-urban planter boxes. Most importantly, this technique provides water quality treatment and adds aesthetic value to urban landscapes (Massachusetts Department of Environmental Protection, n.d.).

Figure 7

Schematic of a typical bioretention structure.



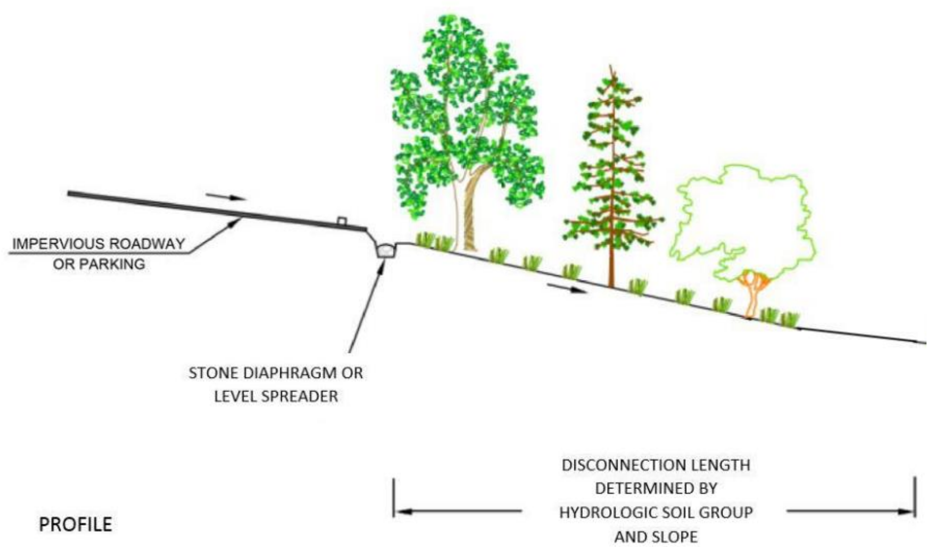
Note. Retrieved from (Massachusetts Department of Environmental Protection, n.d.)

Disconnection to Filter Strip or Vegetated Buffer (Non- Structural) - Disconnection is a design where filter strips or vegetated buffers collect runoff from nearby impermeable surfaces and allow the runoff to be filtered and slowed down by vegetation and soil before entering the ground. It can be used to replenish groundwater, minimize runoff from the site, lower pollutant and sediment loads, and slow down or stop peak flows. Based on site variables including the drainage area, slope and site grading, as well as the size and infiltration capacity, the efficiency of disconnection varies greatly. The most efficient planted filters have dense vegetal cover, long disconnection lengths, and low surface slopes. There are two general configurations of the design to direct runoff from ground-level impervious surfaces to filter strips or planted buffer areas

- A stone diaphragm or similar pre-treatment practice serves as a non-erosive transition between the impervious surface and the filter strip or vegetated buffer when runoff uniformly enters along a linear edge, such as at the edge of a road or parking lot and drains down-slope across the length of the filter strip or vegetated buffer.
- An engineered level spreader will have to be included in the design if the runoff is directed in the form of a concentrated flow from a pipe or channel. The level spreader will convert the concentrated flow back to a sheet flow.

Figure 8

Simple Schematic of Disconnection to Filter Strips and Vegetated Buffer Design.



Note. Retrieved from (Vermont Agency of Natural Resources, 2017)

4.2 Bio-engineered and nature-based restoration concepts

Structural Earth Wall (SEW) - The SEW consists of a number of soil wraps arranged in a stair-like pattern from the waterline to the top of the bank. Each step is created by laying down a 13-ft wide roll of geogrid fabric The grids are supported by layers of compacted gravel-borrow (natural bank-run sand and gravel). The geo-grid is then folded over, and an additional layer of gravel is applied to further weigh it down. As each wrap is completed, the next one is spaced by at least one foot to create the appearance of steps. The exterior surface of the wall is covered with a layer of heavy coir fabric and topsoil, which is then hydroseeded. This enables the geogrid to lock in place and secure the slope without the risk of deterioration from exposure to ultraviolet light. The entire slope is then planted with live willow cuttings that eventually take root. As the trees mature, their root systems contribute to the stability of the bank. On the toe of the SEW, continuous rows of logs are anchored with attached root wads. During high water surge, the logs can offer migratory fish with the necessary shelter. They also serve as a barrier, keeping larger woody debris from penetrating the base of the soil wraps during periods of high surge or flooding. Over time, logs recruits more woody debris into the shoreline and improves the fish habitat on site further. Also, the hydroseeded grass and other vegetation eventually covers the coir fabric entirely and the structural earth wall itself (FEMA, 2009).

Figure 9.

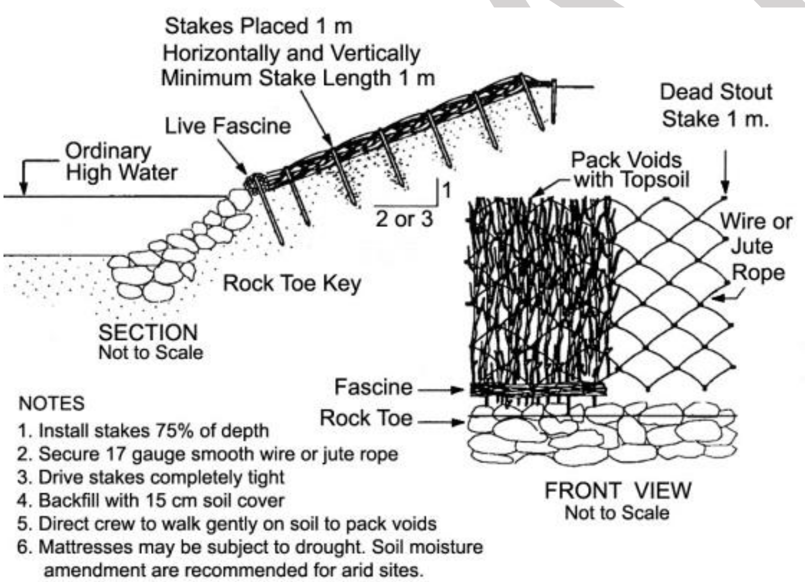
Structural Earth Wall (SEW).

Note. Retrieved from (FEMA, 2009)

Brush Mattress - A brush mattress is a layer of live, intertwined branches placed on the bank and secured in place with live or dead stakes and untreated twine. Brush mattresses are often used with techniques like wattles, tree or rock revetments that protect the toe of the streambank slope from undercutting and keeps the bank more stable in the long run. This method slows the flow of water and is effective in providing immediate stream bank protection from scouring. Once the vegetation on the mattress is established, it can offer fish habitat, shading, and the ability to catch sediments from overland flow. Mattresses can only be used on slopes that are 3H:1V or shallower. In this case, some banks will have to be graded first to meet the slope requirement for installation. To allow the branches to grow roots, it is crucial to maintain moisture at the bottom of the branches. The mattress needs to be put in place over the high mark of water and while the plants are dormant. While the plant material established roots on the banks, the mat material overtime will degrade (Ministry of Agriculture, Food and Fisheres BC, 2004). A limitation of this method is that it is mostly effective on wider waterways. In smaller streams, this type of structure usually directs the flow to the opposite bank and thus can cause erosion. However, in wider streams, re-direction of flow can be absorbed by the system.

Figure 10.

Simple schematic of Brush Mattress.



Note. Retrieved from (Ministry of Agriculture, Food and Fisheres BC, 2004).

Live willow staking (nature-based technique) - The utilization of live willow stakes is one of the easiest and cheapest way to restore banks and provide vegetation cover. This technique works best in moist soil and will need to be combined with bank toe protection techniques if there is a likelihood of scour at the bank toe until the vegetation root takes place. To provide a firm hold, the stake should be pushed into the ground to a depth of at least two-thirds of its total length. Stakes should be hammered into the bank face, with an additional line hammered into the bank toe (if visible) around every 0.5m. As the willow grows, a root network should form in the bank material, strengthening it. Eventually, the branches will grow to produce flexible stems, which will enhance the roughness, disperse more energy, and prevent the bank from eroding (Scottish Environment Protection Agency, 2020).

Deflector structures – Channelized rivers flowing through urbanized areas often lack complexity in stream which is necessary for aquatic habitat. Deflector structures have gained recognition as an approach used for river restorations to generate varying flow conditions, narrow flow routes, deepen mid-channel flow for navigation, increase bank protection, and provide an area of refuge for fish. Flow heterogeneity is important for fish species to develop and spawn. These structures, occasionally comprised of logs or rocks, are useful for producing natural pool and riffle sequences, including mid-channel scour pools, and for diverting water energy away from the banks (NSSA Adopt A Stream, n.d.).

4.3 Road management and restoration concepts

The natural drainage pattern of a watershed is somewhat altered due to road functions. The road network also functions as an additional drainage system in the watershed, influencing the drainage pattern of the watershed. Roads in urban watersheds mainly affects the waterbodies by increasing the concentration and volume of urban runoff. This can lead to flooding, transport of contaminants to waterbodies, and increase in sedimentation and erosion. Road infrastructures are highly significant public asset. Therefore, investigating various ways in which roads can be managed to reduce the negative impacts on the aquatic environment will provide benefits to both the society and the natural environment (Steenbergen, et al., 2021).

Road drainage improvement - The road network and its drainage should have limited hydrological connectivity. In this case, hydrological connectivity means, that road drainage diverting large volumes of water to watercourses at an increased speed. This type of increased hydrological connectivity along a road network will concentrate water volume transport, intensify flood peaks, and restrict infiltration. Well designed culverts are important structures in road-water management. Culvert designs can be used to gain control of water discharge rate and directing runoff. For highly concentrate road network sites in the watershed, culverts can be equipped with diversion canals for downstream side of the culverts that will direct runoff to dense vegetated areas or bio-engineered retention structures. This approach will also reduce sediment deposition in the streams (Steenbergen, et al., 2021).

Road embankment slope – Steep slopes of road networks parallel to waterbodies can be graded or bioengineered to gentler slopes. Measures should be taken to then plant deep rooted native plant species and grasses along the contours of the slope. Spraying hydroseeds on the slopes is a cost-effective and faster way to establish vegetation. Post-maintenance measures should be taken until the vegetation has taken its roots. This will help in stabilizing the slopes, reduce erosion and sediment transport, provide some degree of filtration to runoff containing contaminants from roads and highways.

Figure 11

Vegetated road embankment slopes.

Note. Retrieved from (Green Roads for Water Learning Alliance, 2022)

4.4 Recommended Sites in need of attention and restoration

1. St. Anne's Industrial Park: The part of the river channelized and flows through St. Anne's Industrial Park in the Town of Paradise downstream of the highway is very similar to a conveyance feature. The channel is susceptible to sands and silts from the surrounding lots and lacking in riparian buffer zone for the most part. The water quality of the channel is expected to be degraded because of industrial runoff (CBCL, 2018).

Figure 12.

Stream channel entering St. Anne's Industrial Park.

Note. *From ESRI ArcGIS World Imagery Web map*

Figure 13

Channel flowing in the rear area of St. Anne Industrial Park.

Note. *From ESRI ArcGIS World Imagery Web map*

Figure 14.

Channel flowing in the rear area of St. Anne Industrial Park (continued)

Note. *From ESRI ArcGIS World Imagery Web map*

2. Donovan's Industrial Park: The Unnamed River known as the Donovan's tributary flows through Donovan's Industrial Park before meeting the Waterford River. The riparian buffer zone conditions in some parts of the river are degraded and the waterbody is highly susceptible to industrial runoff. The river channel is typical of other industrial areas and is channelized. Also, during winter, snowbanks from parking lot snow clearing activities were noticed to be stored very close to the streams. The snowmelt likely carries road salts and gets deposited in the form of runoff to the streams which can have negative impact on the aquatic habitat.

Figure 15.

Section of Donovan's tributary (access from Bruce Street, Mount Pearl).

Figure 16.

Snowbank accumulation on the edge of the parking lots in Donovan's Industrial area, Winter 2022.

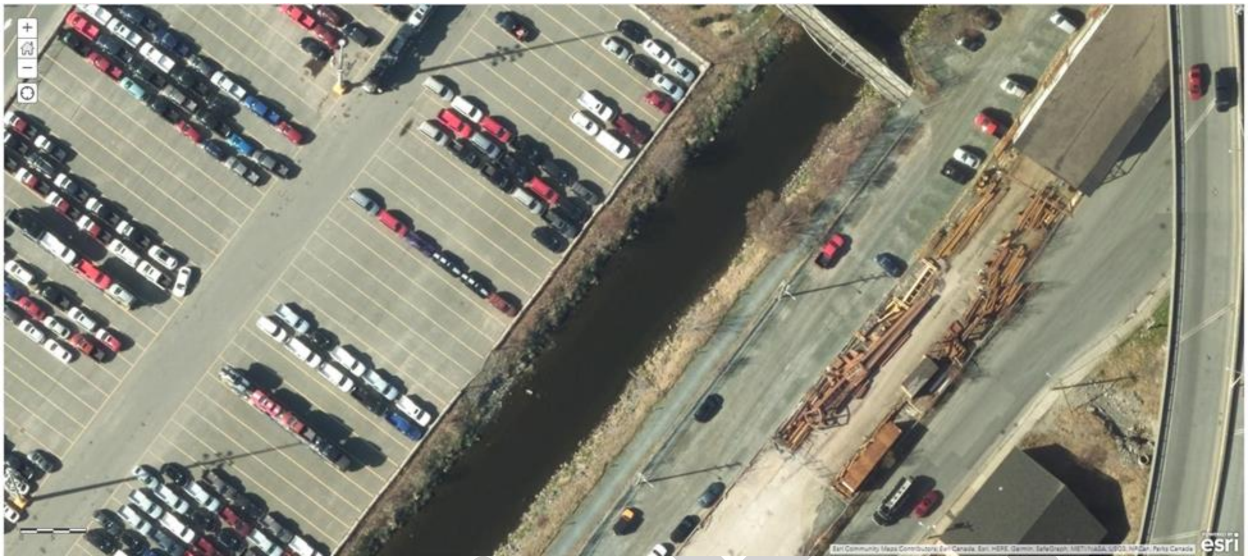
Parking lots near the river: Parking lots in close proximity to the river exists throughout all three municipal regions. Industries in St. John's concentrated near the harbour (mouth of the river) in some parts lacks adequate riparian zones. Runoff from these lots can easily enter the river and adversely effect the water quality.

Figure 17.

Parking lot close to the Waterford River lower reaches, St. John's Harbour area.

Figure 18.

Parking lots in close proximity to the Waterford River lower reaches, St. John's Harbour area.

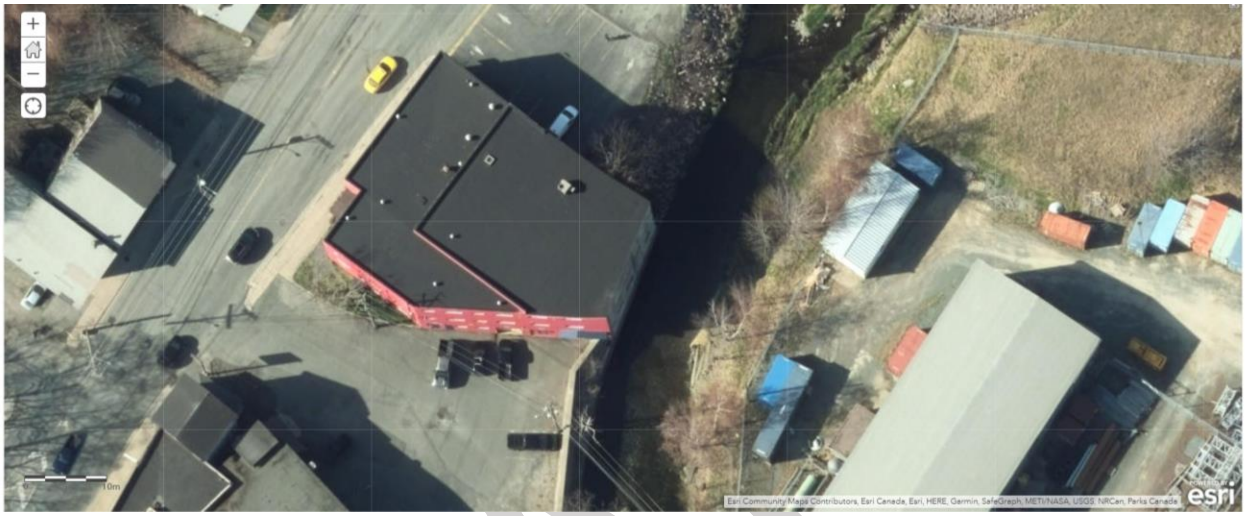


Note. *From ESRI ArcGIS World Imagery Web map*

Properties on the Floodplains: Some buildings in the Watershed were noticed to be very close to the river's edge leaving no room for any buffer zones. Two such infrastructures in the City of St. John's are highlighted in Figure 18 and 19 below.

Figure 19.

A commercial building in the Water Street leaving no room for buffer zone.



Note. *From ESRI ArcGIS World Imagery Web map*

Figure 20

A building in Brookfield Road leaving no room for buffer zone.

5.0 Proposals

This Management Plan has been developed under the parent project "Waterford River Watershed Research, Restoration and Education Program (2021-2022)". There are many aspects of the watershed which could not be studied in-depth or considered due to the limited scope of the project. This management plan is an "Adaptive Management Plan" and needs to be revised periodically going forward to adapt to the unique challenges the Waterford River faces. Hence, going forward, a well-structured research and monitoring program needs to be established which will enable the effective management of the Waterford River Watershed. In addition, development of a strong partnership of stakeholders is essential. To achieve these objectives, the following proposals are presented. The proposals mentioned here are summaries only and if these were to be furthered considered then detailed proposals will be submitted.

5.1 Waterford River Watershed Conservation Project (2023 – 2026)

The next phase in the conservation of the Waterford River Watershed should involve a comprehensive and well-designed study and monitoring program, restoration work, community engagement and collaboration. After analyzing the past projects and study programs carried out on the Waterford River, a few potential gaps were identified which could be addressed through a future conservation project. The design and elements of the project is described below.

Scientific Assessments – Taking inspiration from the previous studies and the identified gaps in monitoring, it was concluded that the scientific assessments of the Waterford River and its tributaries will have to be conducted on a long - term basis and include sites which will provide a good reflection of the watershed's impairments. Assessments of Water Quality, sediments, aquatic habitat, and riparian buffer zone conditions will need to be carried for three years (2023 – 2025).

- Assessment timeline – The Water Quality, sediments, aquatic habitat at each site will be assessed based on a well-defined methodology already outlined by CCNL and available for review upon request. The sites will be assessed four times in two seasons – Winter (Jan, Feb, March) and Summer (Jul, Aug, Sep) for three consecutive years.

- Riparian buffer zone – Through visual assessments, the condition of the riparian zone will be studied for the entire length of the river accessible on foot during summer seasons. The riparian buffer zone assessments will identify invasive species, condition of the vegetation and identify sites for nature-based restoration techniques. In addition, where site walks are not possible, the use of Drone technology could be implemented.

Collaboration and Community Engagement –

- Commercial/Industrial Businesses: Reach out to the commercial and industrial area businesses to propose the idea of an education workshop. The workshop will showcase how the industrial/commercial business operations can affect the waterbodies negatively and the roles these businesses can play to minimize the negative impact. Green Infrastructures (GI), Low Impact Development (LID) and other daily practices that can contribute to the conservation of the Waterford River and its tributaries will also be presented during the workshop. The objective of these outreach work will be to first educate the businesses and second share the idea of LIDs and GIs. The outreach activities will take place during the summer seasons yearly for the duration of the project. Three major industrial/commercial business areas will be targeted in each year in the three respective municipalities.

5.2 Watershed Alliance Committee

Across Canada and globally, Watershed Groups have been contributing significantly to the conservation and management of regional and local watersheds. Some of the notable ones in Canada are Prince Edward Island (PEI) Watershed Alliance, North Saskatchewan Watershed Alliance, Southeast Alberta Watershed Alliance, and Greater Sudbury Watershed Alliance. Until now, numerous conservation efforts have been made for the Waterford River Watershed. However, if the Waterford River Watershed is to be restored and managed to a degree where the ecosystem health will be maintained in addition to providing positive benefits to the communities, a long-term, systematic approach with strong collaboration is required. Therefore, the formation of a Watershed Alliance Committee NL is proposed.

The ideal structure, objective and role of the committee are summarized below.

- One representative from each municipality and the province Water Resource Management Division and CCNL will be the primary members.
- Secondary members will be experts specialized in Ecology, Hydrology, Civil Engineering and Environmental studies. In this case, Professors from the Memorial University and Marine Institute.
- The tertiary members will be guest members who will be approached for advice, funding opportunities and collaboration when the need arises. These members are Environment and Climate Change Canada (ECCC), Department of Fisheries and Oceans Canada (DFO), other local environmental groups, volunteer groups such as Waterford Valley Rotary Club and like-minded community members. The tertiary members are important to build community engagement.

- The primary members of the committee will be required to meet annually at the start of a fiscal year to approve and finalize the plans for each yearly tasks, and commit to providing support where needed (e.g., permits for restoration, municipal funding etc.)

- The secondary members of the committee will be approached to get advice on scientific assessments monitoring programs and restoration work before they are carried out each year.
- The tertiary members will be approached for developing community engagement plans and collaborative work such as community environmental education workshops, distribution of outreach materials, carrying out stream clean up events and restoration work. The meetings with the tertiary members will be called upon when the necessity arises.
- CCNL will manage all communication, planning, initiation of tasks and responsible for development of yearly reports on all works carried out under the Watershed Alliance Committee. The progress and impact of each year's work will be evaluated to set targets for the next year. The Adaptive Management Plan under the supervision of the Primary and Secondary members of the Committee will be revised annually, updated when required and will go through an approval process for implementation.

Note. The structure and roles outlined for the committee in this section are mentioned just to provide an idea about what the Watershed Alliance Committee can look like. The parties mentioned here have not been approaches or agreed to any roles.

References

Batterson, M. J. (1984). *Surficial and Glacial Geology of the Waterford River Basin* . St. John's: Government of Newfoundland and Labrador.

Biscayne Bay Water Watch - University of Florida. (2021). Retrieved from University of Florida: https://sfyl.ifas.ufl.edu/media/sfylifasufledu/miami-dade/documents/sea-grant/Temperature,-Salinity-and-pH.pdf

CANAL, C.-N. a. (2022). Water Quality Station Profile. St. John's, NL, Canada.

CBCL Limited. (2018). *Waterford River Area Flood Risk Study.* St. John's: Department of Municial Affairs and Environment, Government of NL.

CCME. (2022). *Canadian Council of Ministers of Environment*. Retrieved from Summary Table : https://ccme.ca/en/summary-table

City of St. John's . (2005). *City of St. John's Salt Management Plan.* St John's: Department of Public Works and Parks - City of St. John's.

Conservation Ontario. (2018). *Good Practices for Winter Maintenance in Salt Vulnerable Areas.* Retrieved from Conservation Ontario: https://conservationontario.ca/fileadmin/pdf/conservation_authorities_section/SWP_Good_Practices_Salt_Vulnerable_Areas_2018.pdf

Credit Valley Conservation. (2010). *Low Impact Development Stromwater Management Planning and Design Guide.* Toronto: Toronto and Region Conservation for the LIving City.

Credit Valley Conservation. (2022). *Stromwater Management Guideline.* Retrieved from Credit Valley Conservation: https://cvc.ca/wp-content/uploads/2012/01/CVC-SWM-Guide_f_20220720-1.pdf

DataStream. (2022). *A Monitor's Guide to Water Quality*. Retrieved from Data Stream: https://datastream.org/en/guide/conductivity

Engineers Canada. (2018). *Publications.* Retrieved from Standards Council of Canada: https://www.scc.ca/en/system/files/publications/SCC_RPT_SW-QMS_EN.pdf

Environment and Climate Change Canada. (2022). *Code of practice for the environmental management of road salts*. Retrieved from Environment Canada: https://www.canada.ca/en/environment-climate-change/services/pollutants/road-salts/code-practice-environmental-management.html#s08

Fay, L., Honarvarnazari, M., Jungwirth, S., Muthumani, A., Cui, N., Shi, X., . . . Venner, M. (2015). *Clear Roads Manual.* Retrieved from Clear Roads Program - Minnesota Department of Transportation : http://clearroads.org/wp-content/uploads/dlm_uploads/Manual_ClearRoads_13-01_FINAL.pdf

FEMA. (2009, January). Retrieved from U.S. Federal Emergency Management Agency: https://www.fema.gov/pdf/about/regions/regionx/Engineering_With_Nature_Web.pdf

Fenco Newfoundland Limited. (1988). *Waterford River Area- Hydrotechnical Study.* St. John's: Water Resources Management Division .

Ficken, D. (2008). *Road Salt Loadings Study.* St. John's: Northeast Avalon Atlantic Coastal Action Program.

Fisheries and Oceans Canada. (2022). Best Management Practices for the Protection of Freshwater Fish Habitat in Newfoundland and Labrador. St. John's, NL, Canada.

Fisheries and Oceans Canada. (2022). *Best Management Practices for the Protection of Freshwater Fish Habitat in Newfoundland and Labrador.* St. John's, NL: Fisheries and Oceans Canada.

Fleenor, R., & Gaines, C. (2017). *Trees and Shrubs for Riparian Plantings.* Washington: USDA-Natural Resources Conservation Service.

Gibb, A., Kelly, H., Horner, R., Schueler, T., Simmler, J., & Knutson, J. (1999). *Publications.* Retrieved from Metro Vancouver: http://www.metrovancouver.org/services/liquid-waste/LiquidWastePublications/BMPVol1a.pdf

Gov. of Massachusetts. (1997). *Stormwater Parctices.* Retrieved from Government of Massachusetts: https://www.mass.gov/doc/massachusetts-stormwater-handbook-vol-2-ch-2-stormwater-best-management-practices/download

Government of NL. (2022). *Flooding in Newfoundland and Labrador*. Retrieved from Environment and Climate Change : https://www.gov.nl.ca/ecc/waterres/flooding/flooding/#causes

Grant, C., & Lee, E. (2004, March). Life History Characteristics of Freshwater Fishes Occurring in Newfoundland and Labrador, with Major Emphasis on Riverine Habitat Requirements. St. John's, Newfoundland and Labrador, Canada.

Green Roads for Water Learning Alliance. (2022). *Bio-engineering measures for road side-slope stabilization*. Retrieved from Roads for Water: https://roadsforwater.org/guideline/conclusions-it-pays-off/1-bio-engineering-measures-for-road-side-slope-stabilization/

Harris, P. (n.d.). *Beneficial Management Practices fpr Riparian Zones in Atlantic Canada.* Agriculture and Agri-Food Canada.

Hawes, E., & Smith, M. (2005). *Riparian Buffer Zones: Functions and Recommended Widths.* New Haven: Yale School of Forestry and Environmental Studies.

Heringa, P. K. (1981). *Soils of the Avalon Peninsula, Newfoundland.* St. John's: Agriculture Canada.

Island Nature Trust. (2005). *Beneficial Management Practices for Riparian Zones in Atlantic Canada.* Ottawa: Agriculture and Agri-Food Canada. Retrieved from https://www.gov.nl.ca/ffa/files/publications-pdf-riparian-zones.pdf

King, A. F. (1984). *Geology - Urban Hydrology Study of the Waterford River Basin* . St. John's: Government of Newfoundland and Labrador.

Mandaville, S. M. (2002). *Benthic Macroinvertebrates in Freshwaters-Taxa Tolerance Values, Metrics, and Protocols.* Halifax: Soil & Water Conservation Society of Metro Halifax.

Massachusetts Department of Environmental Protection. (n.d.). *Bioretention Areas & Rain Gardens* . Retrieved from Massachusetts Clea Water Toolkit: https://megamanual.geosyntec.com/npsmanual/bioretentionareasandraingardens.aspx

Massachusetts Department of Environmental Protection. (Retrieved: 2022). *Masachusetts clean water toolkit*. Retrieved from Toolkit topics: https://megamanual.geosyntec.com/npsmanual/bioretentionareasandraingardens.aspx

Mike Moore, CBC News. (2022). Retrieved from CBC News: https://www.cbc.ca/news/canada/newfoundland-labrador/rain-flooding-stjohns-1.6579647

Ministry of Agriculture, Food and Fisheres BC. (2004). *Drainage Maagaement Guide - Bioengineering Techniques.* Retrieved from Govrnment of British Columbia: https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/agriculture-and-seafood/agricultural-land-and-environment/water/drainage-management-guide/533431-1_bio-engineering_techniques-drainage_guide_factsheet_no13.pdf

National Research Council. (2002). *Riparian Areas: Functions and Strategies for Management.* Washington DC: The National Academy Press.

Ng, H., & Marsalek, J. (1987). *Streamflow Modeling in the Waterford River Basin.* St. John's: Government of Canada; Government of Newfoundland and Labrador.

NL, G. o. (2022). *Hydrology and Climate of Newfoundland*. Retrieved from Municipal and Provincial Affairs: https://www.gov.nl.ca/mpa/nl/

Nova Scotia Environmental Farm Plan. (2021). *Riparian Zones*. Retrieved from Nova Scotia Environmental Farm Plan: https://nsefp.ca/riparian-zones-little-areas-with-big-benefits/

NRCS-USDA. (2016, January 19). *NRCS Consumption.* Retrieved from Natural Resources Conservation Service-United Stated Department of Agriculture: https://www.nrcs.usda.gov/wps/PA_NRCSConsumption/download?cid=nrcseprd1296623&ext=pdf

NSSA Adopt A Stream. (n.d.). Retrieved from Adopt A Stream: http://adoptastream.ca/sites/default/files/Deflectors%202014.pdf

Pomeroy, J. H., & Collins, G. (1993). *Waterford River and Quidi Vidi Watershed Intensive Survey Report.* St. John's; Moncton: Government of NL Environment and Climate Change; Environment Canada.

S.Hickey, & Sheppard, G. (2018). *Waterford River Watershed Study.* St. John's: CBCL Limited.

Saldi-Caromile, K., Bates, P., Skidmore, J., & Barenti, D. P. (2004). *Stream Habitat Restoration Guidelines.* Olympia, Washington: Washington Departments of Fish and Wildlife and Ecology and the U.S. Fish and Wildlife Service.

Scottish Environment Protection Agency. (2020, August). *Bank Protection Guidance.* Retrieved from SEPA: Scottish Environment Protection Agency: https://www.sepa.org.uk/media/219450/bank_protection_guidance.pdf

Steenbergen, F. v., Arroyo-Arroyo, F., Rao, K., Hulluka, T. A., Woldearegay, K., & Deligianni, A. (2021). *Green Roads for Water - Guidelines for Road Infrastructure in Support of Water Management and Climate Resilience.* Washington: International Bank for Reconstruction and Development - The World Bank Group.

Transportation Association of Canada. (2013). *Syntheses of Best Practices- Road Salt Management.* Retrieved from Transportation Association of Canada: https://www.tac-atc.ca/sites/tac-atc.ca/files/site/doc/resources/roadsalt-1.pdf

Ullah, W., Marsalek, J., Hennigar, T., & Pollock, T. (1987). *Effects of Urbanization on Water Resources in the Waterford River Basin.* St. John's; Dartmouth; Burlington; Moncton: Government of Canada Publications.

USGS. (2019, March 2). *Water Resources: The United States Geological Survey*. Retrieved from USGS: https://www.usgs.gov/mission-areas/water-resources/science/groundwatersurface-water-interaction

Vermont Agency of Natural Resources. (2017). *Vermont Stormwater Management Manual Rule and Design Guidance.* Retrieved from Stromwater: https://dec.vermont.gov/sites/dec/files/wsm/stormwater/docs/Permitinformation/2017%20VSMM_Rule_and_Design_Guidance_04172017.pdf

Weber, A. (2019). *Expert Blog*. Retrieved from U.S. Natural Resources Defense Council: https://www.nrdc.org/experts/anna-weber/what-urban-flooding

Wijayarathne, D. B., & Coulibaly, P. (2019). Identification of hydrological models for operational flood forecasting in St. John’s, Newfoundland, Canada. *Journal of Hydrology: Regional Studies 27,* 1-16.

Appendices

Appendix A

Site Codes and Description – Twenty-Four Test Sites – Sampled by CCNL in 2021

Sampling Date	Site Code	Site name	Dominant land use	Geographical description
13-Jul-21	WFR04	Waterford River	Residential /Urban	Study area consists of wide section of the river. Consistent straight runs with few rapids. Substrate mostly cobbles and sand. Scattered boulders. Riparian area dominated by grass. Zero capopy coverage. Far bank is large flat flood plain.
13-Jul-21	WFR01	Waterford River	Commercial/Industrial	Wide & heavily channelized section of the river. Relatively deep (about 1 m). Riparian zone heavily modified and dominated by grass. Has zero canopy coverage. Runs between main road and large parking lot. Eroding banks
13-Jul-21	WFR02	Waterford River	Residential /Urban	Shallow, fast moving section of river. Wide with presence of straight runs and riffle habitats. Deciduous trees planted on banks but very little canopy cover. Substrate is mostly bedrock with boulders and sand in between.
13-Jul-21	WFR06	Waterford River	Forest	Heavy bedrock with loose gravel and cobble. Banks have lots of trees. The river forks downstream creating lot of pool areas.
15-Jul-21	WFR17	Waterford River	Forest	This section of the river runs over a steep slope with a multi-level drop before flattening out into a section characterized by boulders, cobbles, riffles, and pools. Riparian area consisting of trees that partially shade both edges of river.

15-Jul-21	WFR16	Waterford River	Residential /Urban	Long straight run without many features. Substrate heavily covered in periphyton and exclusively cobbles. Not much aquatic habitats and few riffles. Riparian zone dominated by tall grasses
16-Jul-21	WFR20	Waterford River	Residential /Urban	Two large drops in the river over a foot in height. Substrate is mostly bedrock, cobble and boulders. Small riparian habitat zone dominated by grass.
16-Jul-21	SOR01	South River	Residential /Urban	Slow moving. Shallow water. Loosely packed cobble and pebble substrate. Very little canopy coverage. Banks dominated by grass.
16-Jul-21	SOR02	South River	Forest	Shallow straight run section of south brook. Not much variety of aquatic habitat but dozens of small trout observed. In cut of banks provides shade near brook edges.
19-Jul-21	UNR01	Unnaemd River (Donnovan's tributary)	Commercial/Industrial	Decaying evergreen/coniferous on both banks. Eroding banks. Good canopy coverage. Big obstruction/boulders/log on the stream.
19-Jul-21	UNR02	Unnaemd River (Donnovan's tributary)	Commercial/Industrial	Lots of algae in the stream. Good canopy coverage obstruction / logs / boulders on the stream. Some undercut banks. Dead fishes were noticed and some alive fishes on the stream
20-Jul-21	KGB02	Kitty Gaul Brook	Residential /Urban	Urbanized brook running through a park. The riparian zone is intact and the sourcewater is approximately <5 km away. Riffles and straight run present.

20-Jul-21	SRT01	South River Tributary	Residential /Urban	Small tributary from south brook. It runs quickly from southside hills, under Pitts memorial highway and into south brook. 1 km below highway. Canopy coverage is thick.
21-Jul-21	WRT01	Waterford River Tributary	Residential /Urban	Small tributary of Waterford in mount pearl. Substrate is very rocky. Filled with cobbles and gravel. Riparian area mixes of trees and grasses. Straight runs and riffle habitat
21-Jul-21	WRT03	Waterford River Tributary	Residential /Urban	Heavily forested section but also close to a residential area. Lots of woody debris in river channel. Some drops are greater that 1 foot. Runs into concrete panels downstream which passes under a constructed highway.
21-Jul-21	WRT02	Waterford River Tributary	Residential /Urban	Small tributary with large flood plain covered in grass. Canopy coverage mostly from coniferous trees. Runs into a concrete tunnel downstream. Banks are littered with wastes.
22-Jul-21	WFR18	Waterford River	Residential /Urban	Straight section of river running through a marshland.Zero canopy coverage. Stream side vegetation dominated by grass. Substrate composed of cobble and sand mostly.
22-Jul-21	WFR19	Waterford River	Residential /Urban	steep section of the river with numerous >1ft drops. Substrate is composed of mostly bedrock and boulders. Banks were undercut and eroding. No canopy coverage. Banks mostly consistent of grass
22-Jul-21	WFR14	Waterford River	Residential /Urban	Section of the river is 2 km downstream of Donovans industrial yard. 50 m upstream of a campground. Banks are reinforced with steel walls. Substrate is

				cobbles and pebbles with small riffles.
23-Jul-21	SLB01	South Lands	Residential /Urban	slow moving sectionof the river that meets an artificial barrier to become a series of riffles. Substrate primarily cobbles with low algal cover. Bank is eroding with many loose stones, but roots from trees provide stability. Dense coniferous forest runs along bank, providing riparian vegetation. Some aquatic plants and fish present.
23-Jul-21	SLB02	South Lands	Residential /Urban	Narrow section of south brook running through southlands. Several boulders block streamflow and divert riffles. Moderate streamflow moves downstream on reaching a section of rapids and drops until the section meets a large culvert. Banks are surrounded by mossy coniferous forest, which is surrounded by urban development. Section meets a gravel roadway downstream,
23-Jul-21	SLB04	South Lands	Agriculture	Mostly riffles and few undercut banks. Pebbles and cobble covered in heavy algae. Medium canopy coverage and fishes were noticed on the stream. Eroding bank from the major roadside bank.
26-Jul-21	BGP01	Immediate downstream of Bremigens Pond (Head waters of Waterford River)	Residential /Urban	Very narrow stream of Bermigans pond which is the headwater of Waterford River. The stream immediately turns into a marshland approximately 100 m away form the pond

26-Jul-21	MPB01	Mundy Pond Brook	Residential /Urban	Narrow gently sloped stream, running through suburbs. Substrate composed of cobble and sand. Riparian zone alternates between tree cover and grass covers.

Appendix B

Test Site Data - Fish Habitat – Sampled by CCNL in 2021

Site Code	Average cross-sectional depth (m)	Substrate size class	Interstitial material	Brook Trout	Brown Trout
WFR04	0.19	0.1 - 0.2 cm	sand	S, J,A	
WFR01	0.83		Water level was too high for pebble counts	–	–
WFR02	0.28	0.1 - 0.2 cm	sand	S, J,A	
WFR06	0.40	0.2 - 1.6 cm	gravel	S, YOY, J, A	S, YOY, J
WFR17	0.22	1.6 - 3.2 cm	pebble	S, YOY, J, A	S, YOY, J
WFR16	0.26	3.2 - 6.4 cm	pebble	S, YOY, J, A	S, YOY, J
WFR20	0.19	0.2 - 1.6 cm	gravel	S, YOY, J, A	S, YOY, J
SOR01	0.23	3.2 - 6.4 cm	pebble	S, YOY, J, A	S, YOY, J
SOR02	0.34	3.2 - 6.4 cm	pebble	S, YOY, J, A	S, YOY, J
UNR01	0.06	1.6 - 3.2 cm	pebble	S, YOY, J, A	S, YOY, J
UNR02	0.12	0.2 - 1.6 cm	gravel	S, YOY, J, A	S, YOY, J
KGB02	0.11	3.2 - 6.4 cm	pebble	S, YOY, J, A	S, YOY, J
SRT01	0.11	1.6 - 3.2 cm	pebble	S, YOY, J, A	S, YOY, J
WRT01	0.11	0.2 - 1.6 cm	gravel	S, YOY, J, A	S, YOY, J
WRT03	0.19	0.2 - 1.6 cm	gravel	S, YOY, J, A	S, YOY, J
WRT02	0.27	0.2 - 1.6 cm	gravel	S, YOY, J, A	S, YOY, J
WFR18	0.27	0.1 - 0.2 cm	sand	S, J,A	
WFR19	0.28	6.4 - 12.8 cm	cobble	S, YOY, J, A	S, YOY, J, A
WFR14	0.20	1.6 - 3.2 cm	pebble	S, YOY, J, A	S, YOY, J
SLB01	0.12	3.2 - 6.4 cm	pebble	S, YOY, J, A	S, YOY, J
SLB02	0.15	3.2 - 6.4 cm	pebble	S, YOY, J, A	S, YOY, J
SLB04	0.15	3.2 - 6.4 cm	pebble	S, YOY, J, A	S, YOY, J
BGP01	0.13	<0.1 cm	(sand/silt/clay)	J, A	
MPB01	0.08	0.1 - 0.2 cm	sand	S, J,A	

Note. S = Spawning,
YOY = Young of the Year
J= Juvenile
A= Adult

Site code	Dominant land use	Habitat present in reach	Canopy Coverage	Macrophyte Coverage	Streamside Vegetation	Dominant Streamside Vegetation	Periphyton Coverage
WFR04	Residential /Urban	Rapids, Straight run	0%	0%	Ferns/grasses, deciduous trees	Ferns/grasses	1
WFR01	Commercial/Industrial	Straight run	0%	0%	Ferns/grasses, deciduous trees, coniferous trees	Ferns/grasses	1
WFR02	Residential /Urban	Riffle, Rapids, Pool	1-25%	1-25%	Ferns/grasses, deciduous trees	Ferns/grasses	1
WFR06	Forest	Riffle, Rapids, Straight run, Pool	1-25%	0%	Ferns/grasses, deciduous trees	Ferns/grasses	4
WFR17	Forest	Riffle, Rapids, Pool	1-25%	0%	Ferns/grasses, deciduous trees, coniferous trees	deciduous trees	4
WFR16	Residential /Urban	Riffle, Straight run	1-25%	0%	Ferns/grasses, shrubs, deciduous trees, coniferous trees	Ferns/grasses	5
WFR20	Residential /Urban	Riffle, Rapids, Pool	1-25%	0%	Ferns/grasses, shrubs, deciduous trees, coniferous trees	Ferns/grasses	5
SOR01	Residential /Urban	Straight run	1-25%	0%	Ferns/grasses, shrubs, deciduous trees, coniferous trees	Ferns/grasses	1
SOR02	Forest	Straight run, Pool	1-25%	0%	Ferns/grasses, shrubs, deciduous trees, coniferous trees	Ferns/grasses	4
UNR01	Commercial/Industrial	Straight run, Riffle	76-100%	0%	Ferns/grasses, shrubs, coniferous trees	Coniferous trees	1
UNR02	Commercial/Industrial	Riffle, Straight run, Pool	76-100%	0%	Ferns/grasses, shrubs, coniferous trees	Ferns/grasses	5
KGB02	Residential /Urban	Straight run, Riffle	1-25%	1-25%	Ferns/grasses, shrubs, deciduous trees, coniferous trees	Ferns/grasses	4
SRT01							
WRT01	Residential /Urban	Riffle, Straight run	1-25%	0%	Ferns/grasses, deciduous trees, coniferous trees	Ferns/grasses	5
WRT03	Residential /Urban	Riffle	26-50%	0%	Ferns/grasses, deciduous trees, coniferous trees	Ferns/grasses	2
WRT02							
WFR18	Residential /Urban	Riffle, Straight run	0%	0%	Ferns/grasses	Ferns/grasses	5
WFR19							
WFR14	Residential /Urban	Riffle, Straight run	1-25%	0%	Ferns/grasses, deciduous trees, coniferous trees	Coniferous trees	5
SLB01	Residential /Urban	Riffle, Straight run	76-100 %	0%	Ferns/grasses, deciduous trees, coniferous trees	deciduous trees	2

SLB02	Residential /Urban	Riffle, Straight run, Pool	1-25 ~~%~~	0%	Ferns/grasses, shrubs, deciduous trees, coniferous trees	ferns/grasses	4
SLB04	Agriculture	Riffle, Straight Run	51-75%	0%	Ferns/grasses, shrubs, deciduous trees, coniferous trees	deciduous trees	5
BGP01	Residential /Urban	Straight run	0%	0%	Ferns/grasses, shrubs	Ferns/grasses	2
MPB01	Residential /Urban	Riffle, Straight Run	51-75%	0%	Ferns/grasses, shrubs, deciduous trees, coniferous trees	Coniferous trees	3

Note. Periphyton Coverage

1= Rocks not slippery, no obvious color (thin layer < 0.5 mm thick)

2= Rocks lightly slippery, yellow brown to light green colour (0.5 - 1 mm thick)

3= Rocks have a noticeable slippery feel (foot slippery), with patches of thicker green to brown algae (1-5 mm thick)

4= Rocks are very slippery (algae can be removed with thumbnail), numerous large clumps of green

5= Rocks mostly obscured by algal mat, extensive green, brown to black algal mass

Appendix C

Test Site Data – Water Quality – Sampled by CCNL in 2021

Site Code	Sampling Date	Air Temp (°C)	Conductance µS/cm	Water Temp (°C)	pH	TDS (Total Dissolved Solids) (ppm)	Salinity (ppt)	Dissolved Oxygen (ppm)	Dissolved Oxygen-Saturation concentration (%)	Turbidity (NTU)	Slope	Velocity (m/s)
WFR04	13-Jul-21	15.6	830	15	8.14	646	0.4	9.3	93.1	6	0.013	0.1555
WFR01	13-Jul-21	12.2	842	13.4	7.94	655	0.4	7.29	78.5	6	0.011	0.049
WFR02	13-Jul-21	13.7	814	13	7.96	633	0.3	7.85	73.8	6	0.013	0.4
WFR06	13-Jul-21	13.7	853	16.2	8.56	663	0.4	8.28	81.3	6	0.0089	0.34
WFR17	15-Jul-21	14.4	1114	13.8	7.35	877	0.5	11.81	118.6	6	0.0182	0.46
WFR16	15-Jul-21	16.1	1122	15.6	7.81	869	0.5	10.29	103.2	6	0.0039	0.262
WFR20	16-Jul-21	16.3	1007	15.6	7.24	788	0.5	8.6	87.5	6	0.067	0.614
SOR01	16-Jul-21	18.9	465	16.8	7.27	365	0.2	10.42	98.7	6	0.012	0.21
SOR02	16-Jul-21	23	448	19.7	7.38	349	0.2	10.38	106.5	6	0.0038	0.21
UNR01	19-Jul-21	21	1555	18.2	7.07	121	0.8	11.41	111.9	6	0.029	0.269
UNR02	19-Jul-21	19.8	1530	18	7.12	122	0.8	11.24	110.7	6	0.0018	0.243
KGB02	20-Jul-21	18.8	363	14.5	6.89	282	0.2	11.33	118.6	6	0.0503	0.479
SRT01	20-Jul-21	21.3	292	16.5	6.96	228	0.1	9.97	104.7	6	0.138	0.14
WRT01	21-Jul-21	14.6	976	14.8	7.21	726	0.5	10.24	102.2	6	0.0426	0.36
WRT03	21-Jul-21	17	607	17.1	7.18	472	0.2	10.98	109	6	0.058	0.7
WRT02	21-Jul-21	19.7	316	16.8	7.09	246	0.1	10.39	108.3	6	0.054	0.427
WFR18	22-Jul-21	12.8	920	13.4	7.16	716	0.4	10.01	96.1	6	0.024	0.626
WFR19	22-Jul-21	13.5	898	13.8	7.11	672	0.4	9.6	93.3	6	0.058	0.65
WFR14	22-Jul-21	14.8	967	14.6	7.32	752	0.5	10.82	106.8	6	0.005	0.7
SLB01	23-Jul-21	13.8	101.6	14.4	6.99	85.3	0	9.7	94.8	6	0.0113	0.443

SLB02	23-Jul-21	13.6	74.7	13.5	7.18	57.9	0	9.14	87.9	6	0.018	0.7
SLB04	23-Jul-21	17.4	257	14.5	7.11	200	0.1	9.71	95.3	6	0.02	0.3
BGP01	26-Jul-21	16.7	692	17.9	6.86	537	0.2	8.45	85.8	6	0.01	0.18
MPB01	26-Jul-21	16	680	15.9	7.12	529	0.3	8.55	86.3	6	0.038	0.115

Appendix D

Benthic Macroinvertebrate Analysis Data

Table D1

Site ID and Description

Benthic Macroinvertebrate sample Site ID	Description
NF02ZM0367_2012	Accessed 15m downstream of bridge at intersection of Bay Bulls Road and Waterford Bridge Rd.
STH01_2015	This site is in Bowring Park, in St. John's, NL, near the mouth of South Brook. The sample site is located downstream of the bridge for the walking trail which was the old railway track.
WFD01_2014*	Located on the Waterford River in Mount Pearl, NL. Accessed via t-rail linear trail. Sample site is located upstream of the inflow from Powers Pond, and downstream of Corisande Drive.
WFD01_2015*	Located on the Waterford River in Mount Pearl, NL. Accessed via t-rail linear trail. Sample site is located upstream of the inflow from Powers Pond, and downstream of Corisande Drive.
WFD01_2016*	Located on the Waterford River in Mount Pearl, NL. Accessed via t-rail linear trail. Sample site is located upstream of the inflow from Powers Pond, and downstream of Corisande Drive.
WFD02_2015	This sample site is located on the Waterford River in Mount Pearl, NL. It was accessed by walking west along the T-rail trail from Park Avenue and is located downstream of the waterfall located behind the Greenwood Motel and Lodge.
WFD03_2015	This sample site is located on the Waterford River in St. John's, NL. This site is near the mouth of the river, downstream of Blackhead Road.
WFR03_2021	This site is in St. John’s about 4 m away from a Waterford River walking trail (near southside road) on one side of the bank and about 15 m away from residential houses on the other bank.

*WFD01 (same site) sampled in the year 2014, 2015, and 2016

Table D2

Benthic Macroinvertebrate indices with response to environmental stressors.

Indices	**In the presence of environmental stressors**
Family richness	Decreases
*EPT family richness	Decreases
Ephemeroptera family richness (e.g., mayflies)	Decreases
Plecoptera family richness (e.g., stoneflies)	Decreases
Trichoptera family richness (e.g., caddisflies)	Decreases
% EPT	Decreases
% Chironomidae (e.g., nonbiting midges, or lake flies)	Increases
% Oligochaeta (e.g., aquatic and terrestrial worms)	Increases
% Dominant family	Increases

*EPT = Ephemeroptera, Plecoptera, Trichoptera

Table D3

Calculated benthic macroinvertebrate indices

Indices	NF02ZM0367_2012 (WRMD, NL)	STH01_2015 (NAACAP)	WFD01_2014 (NAACAP)	WFD01_2015 (NAACAP)	WFD01_2016 (NAACAP)	WFD02_2015 (NAACAP)	WFD03_2015 (NAACAP)	WFR03_2021 (CCNL)
Individuals #	4200	6780	5100	2431	3655	2791	4443	639
Family richness	20	18	19	23	25	24	19	24
#EPT families	8	8	5	7	9	8	7	9
#Ephemeroptera families	4	3	2	2	3	3	3	3
#Plecoptera families	0	2	0	0	1	1	1	2
#Trichoptera families	4	3	3	5	5	4	3	4
%EPT	42.0	45.4	28.1	47.2	38.9	35.2	12.2	60.5
%Chironomidae	26.2	21.5	47.4	31.6	36.5	22.2	52.0	11.2
%Oligochaeta	0	0	0	0	0	0	0	4.3
%DF*	33.3	21.5	47.4	31.6	36.5	22.2	52.0	47.7
DF	Baetidae	Chironomidae	Chironomidae	Chironomidae	Chironomidae	Chironomidae	Chironomidae	Baetidae

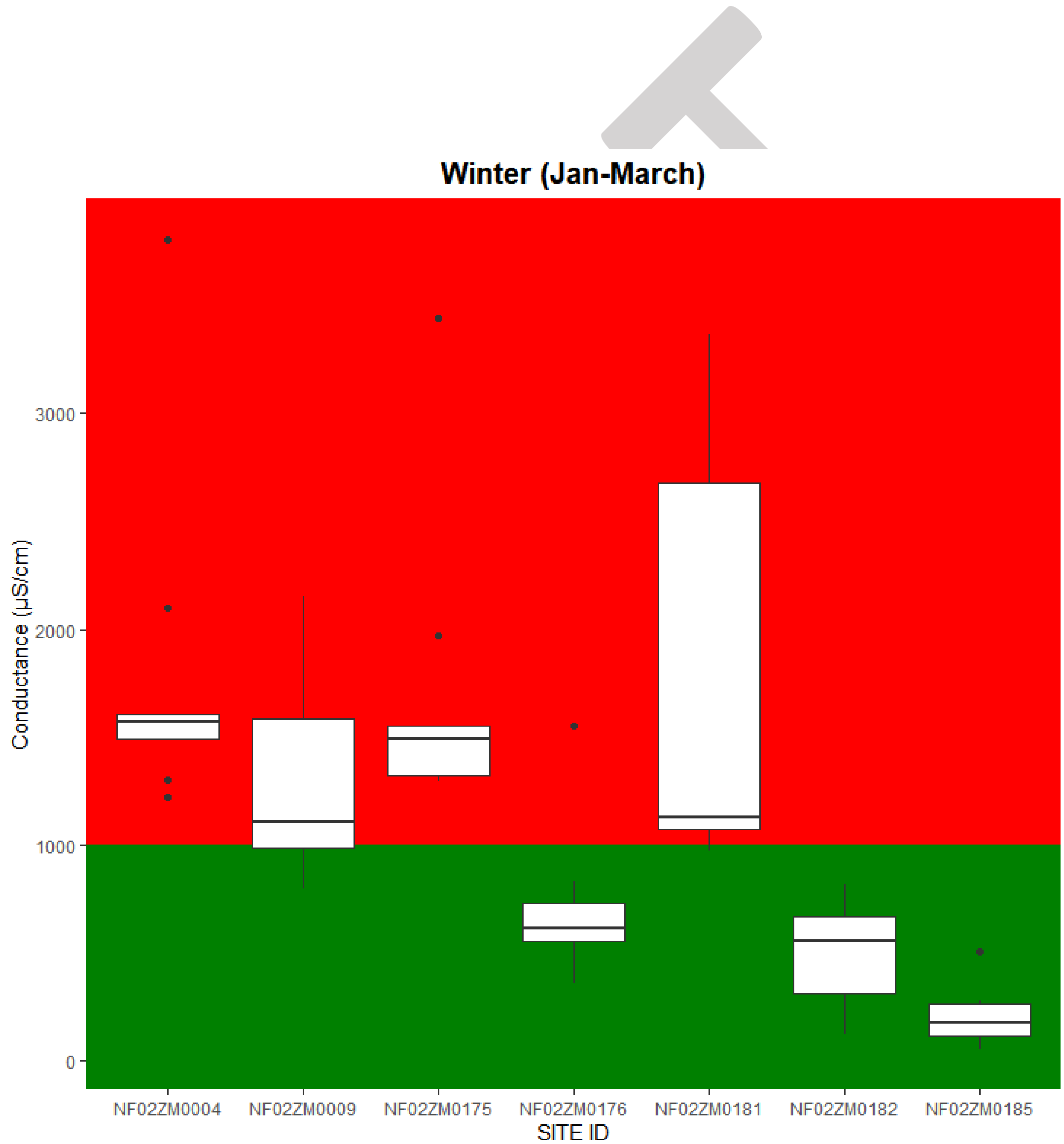
*DF = Dominant Families

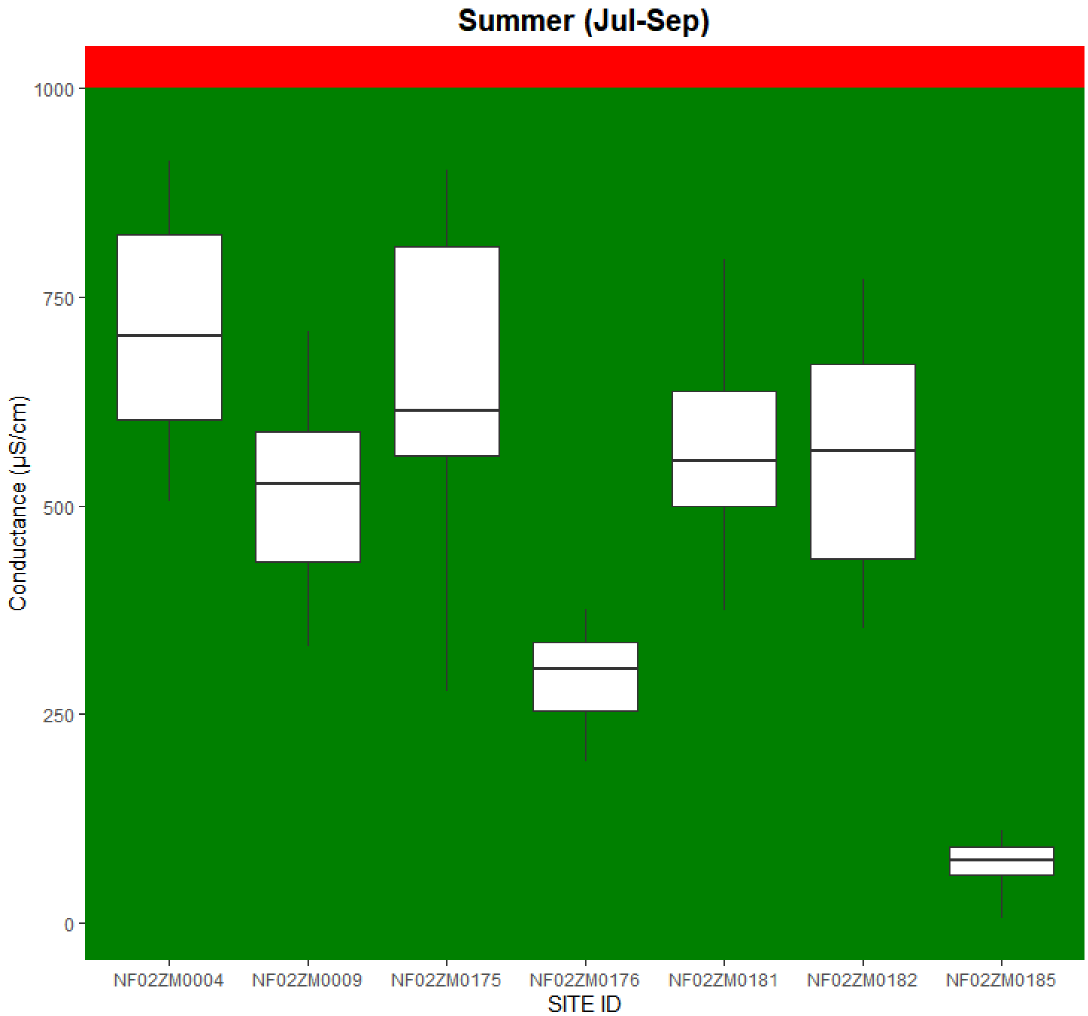
Appendix E

Boxplots of selected Water Quality Parameter data – Sampled under WQMA program (2011-2022)

Conductivity - six grab sample sites and one hydrometric station on the Waterford River (2011-2022)

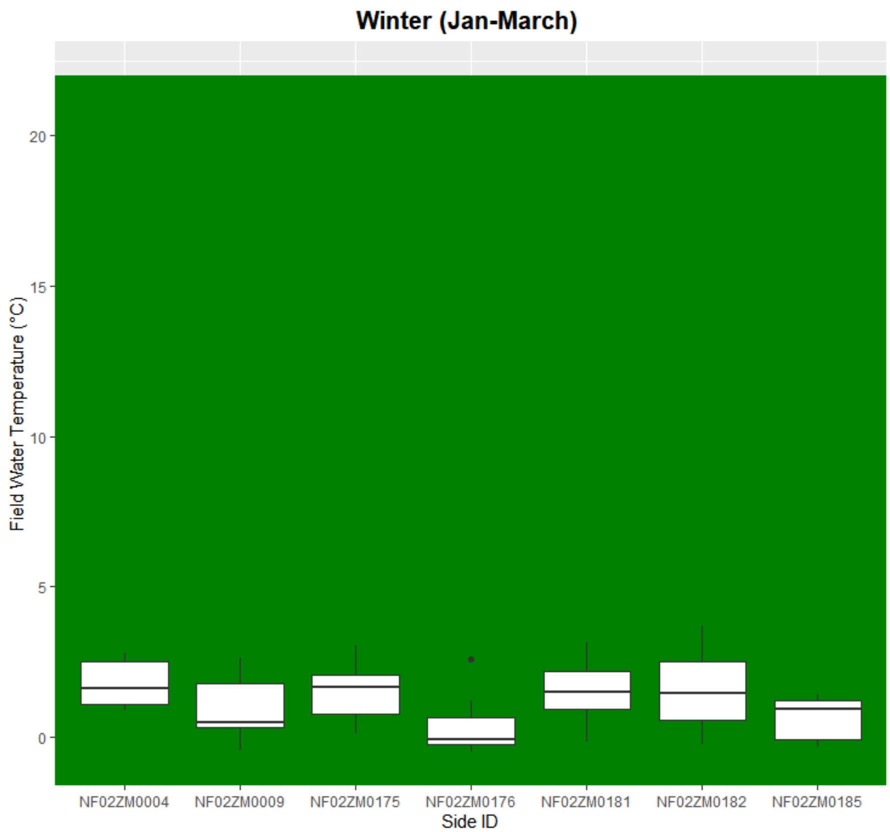
Note. High conductivity (1000 to 10,000 µS/cm) - indicator of saline conditions
Source: (DataStream, 2022)

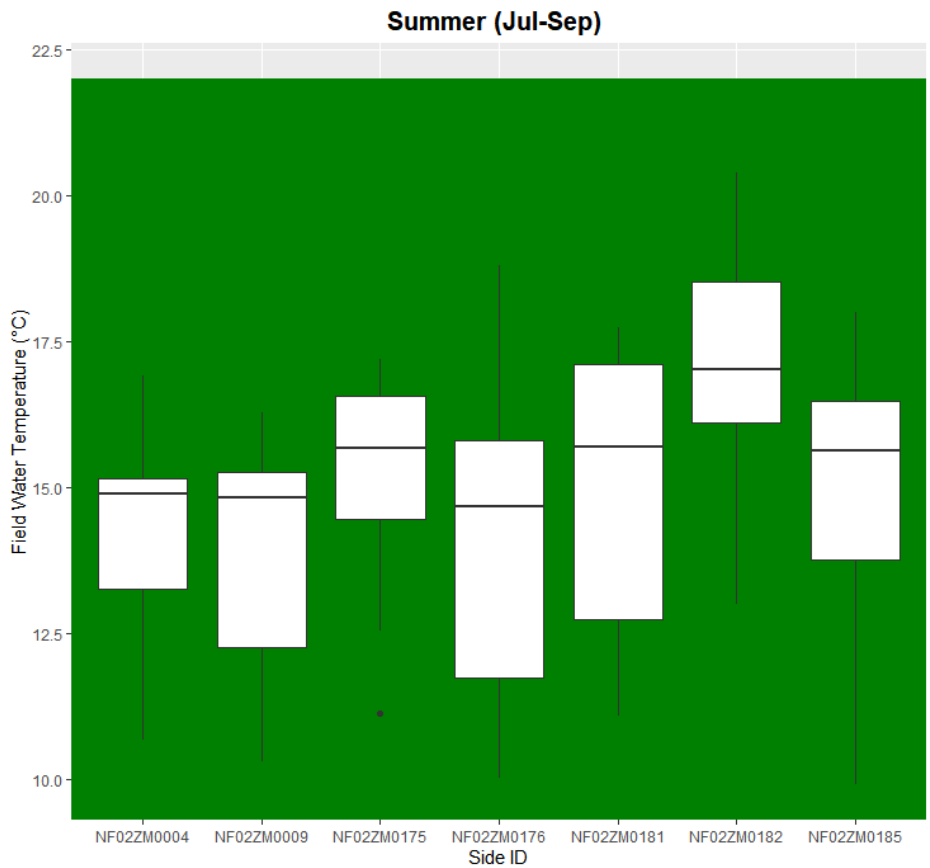



Summer (Jul-Sep)
1000
750
500
250
0
Conductance (µS/cm)
NF02ZM0004
NF02ZM0009
NF02ZM0175
NF02ZM0176
NF02ZM0181
NF02ZM0182
NF02ZM0185
SITE ID

Temperature - six grab sample sites and one hydrometric station on the Waterford River (2011-2022)

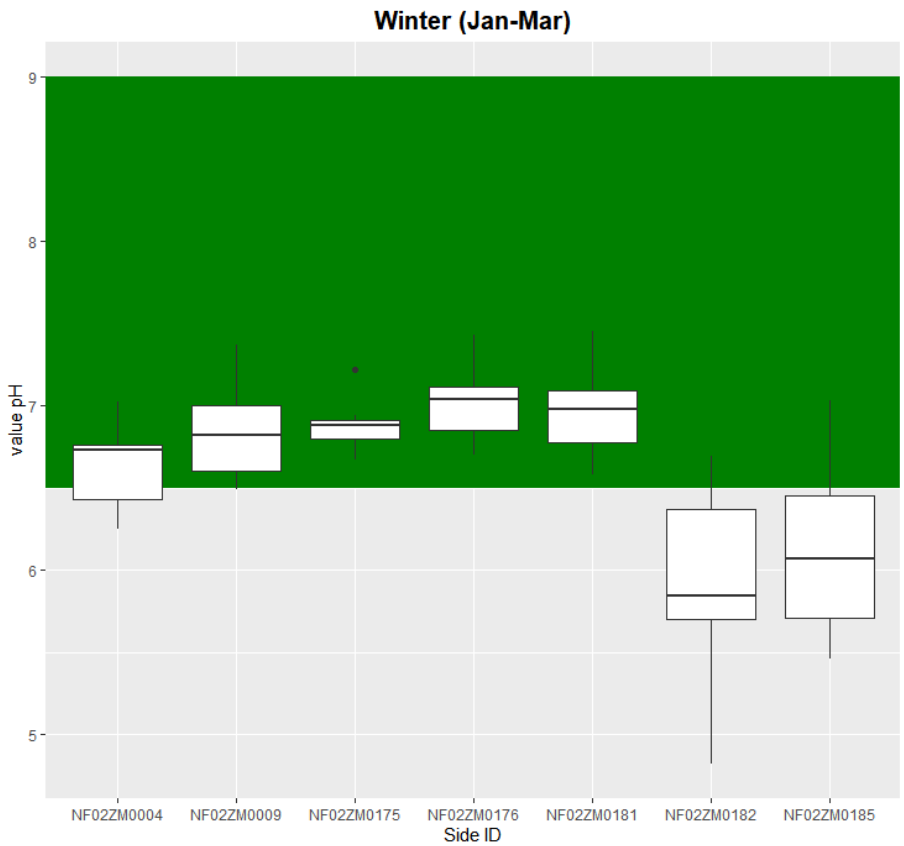
Note. Above 22 degrees Celsius - Fish start to show signs of stress.
Source: (Fisheries and Oceans Canada, 2022)

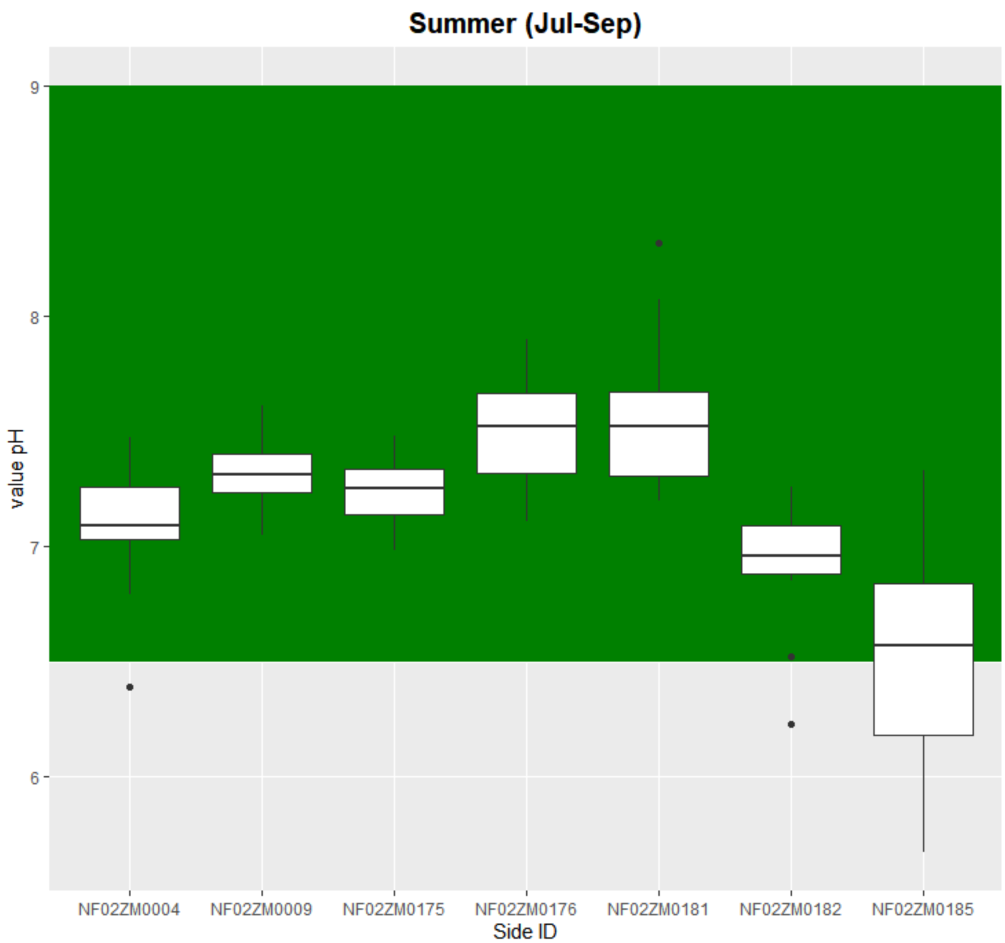



Summer (Jul-Sep)
22.5
20.0
17.5
15.0
12.5
10.0
Field Water Temperature (°C)
NF02ZM0004
NF02ZM0009
NF02ZM0175
NF02ZM0176
NF02ZM0181
NF02ZM0182
NF02ZM0185
Side ID

PH- six grab sample sites and one hydrometric station on the Waterford River (2011-2022)

Note. Ideal pH for freshwater 6.5 – 9.0
Source: (CCME, 2022)




Summer (Jul-Sep)
9
8
7
6
value pH
NF02ZM0004
NF02ZM0009
NF02ZM0175
NF02ZM0176
NF02ZM0181
NF02ZM0182
NF02ZM0185
Side ID

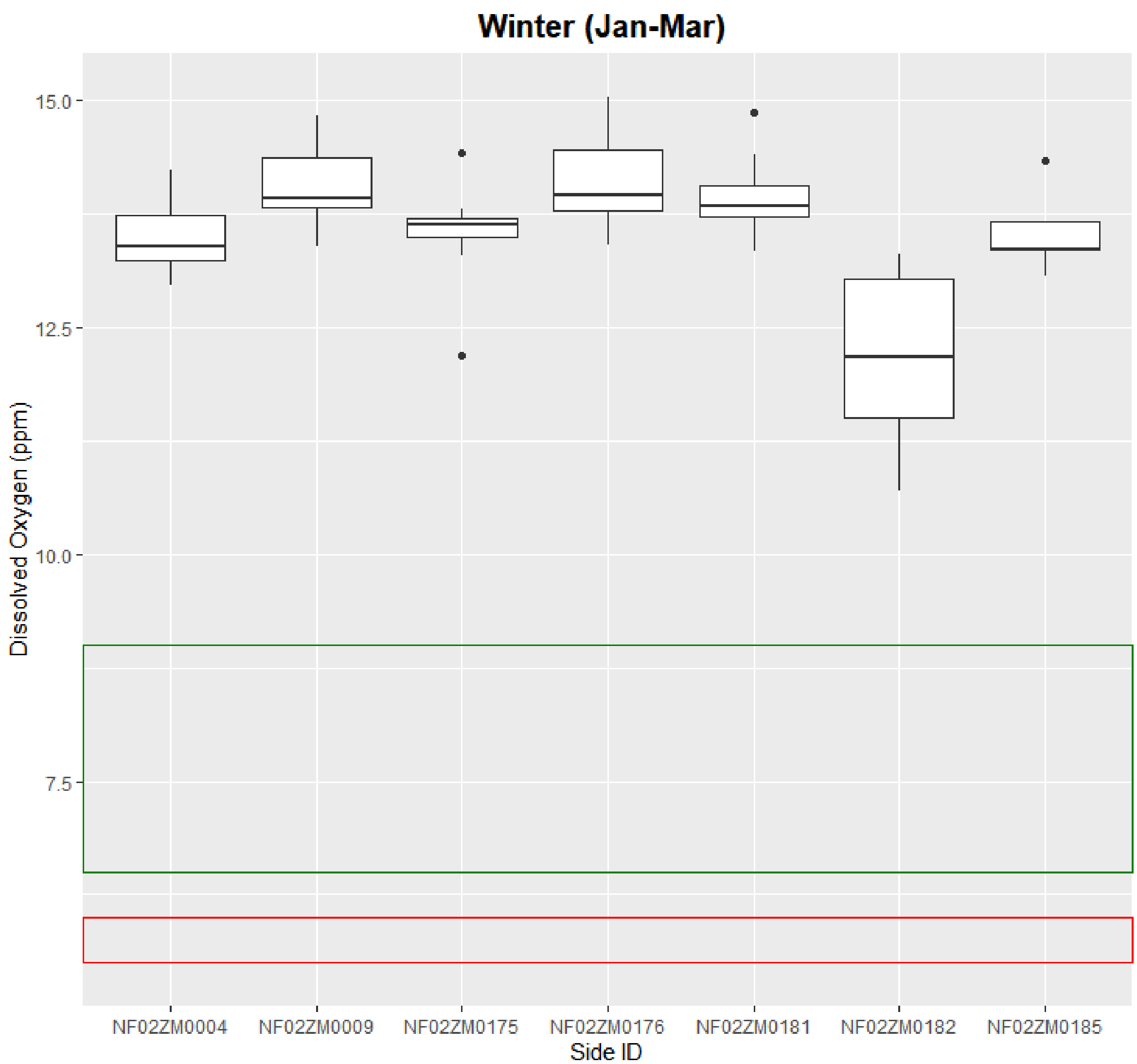
Dissolved Oxygen- six grab sample sites and one hydrometric station on the Waterford River (2011-2022)

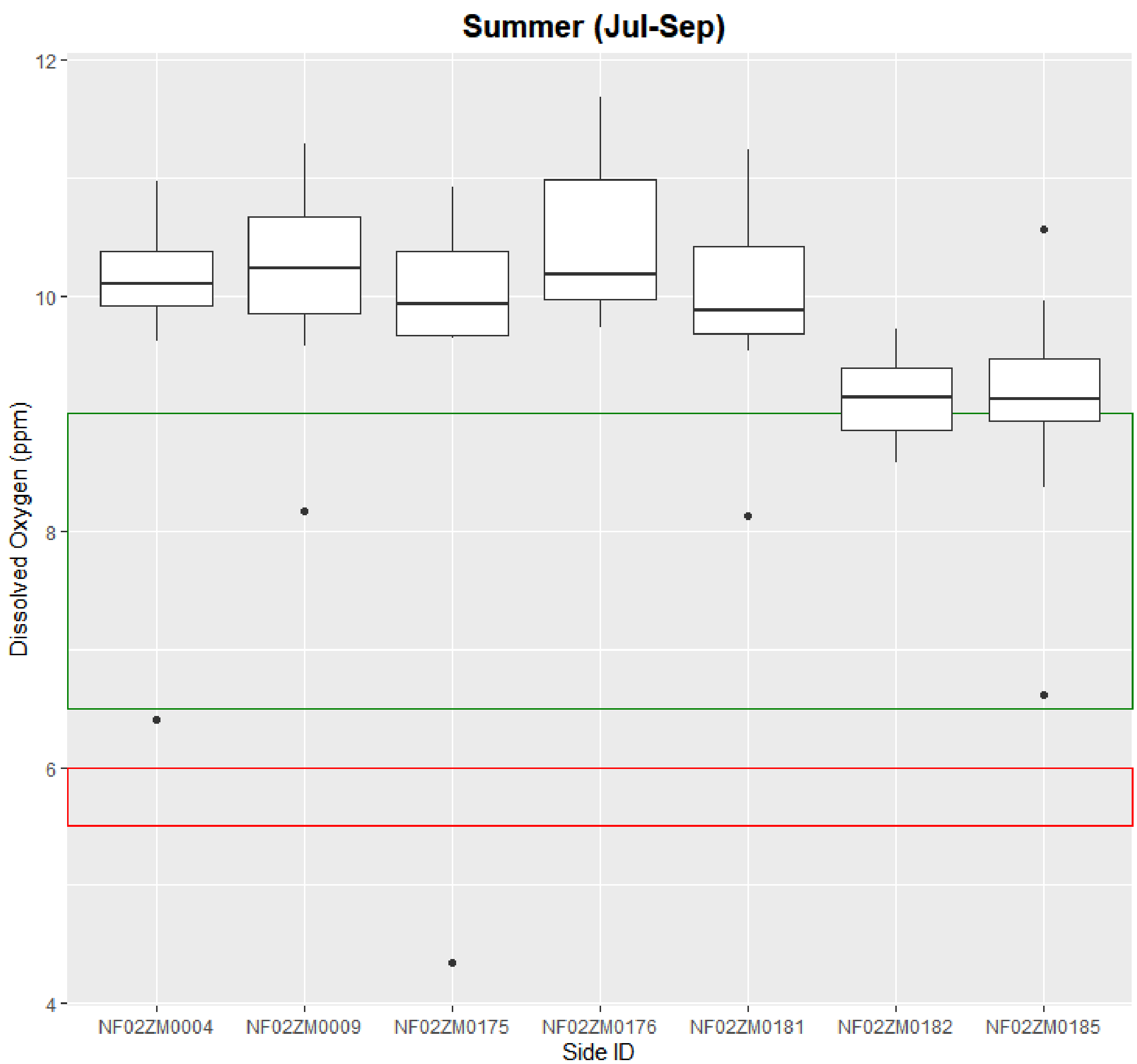
Note. Lowest acceptable dissolved oxygen concentration (long-term)

Warm water biota:
early life stages = 6.0 ppm
other life stages = 5.5 ppm

Cold water biota:
early life stages = 9.5 ppm
other life stages = 6.5 ppm

Source: (CCME, 2022)

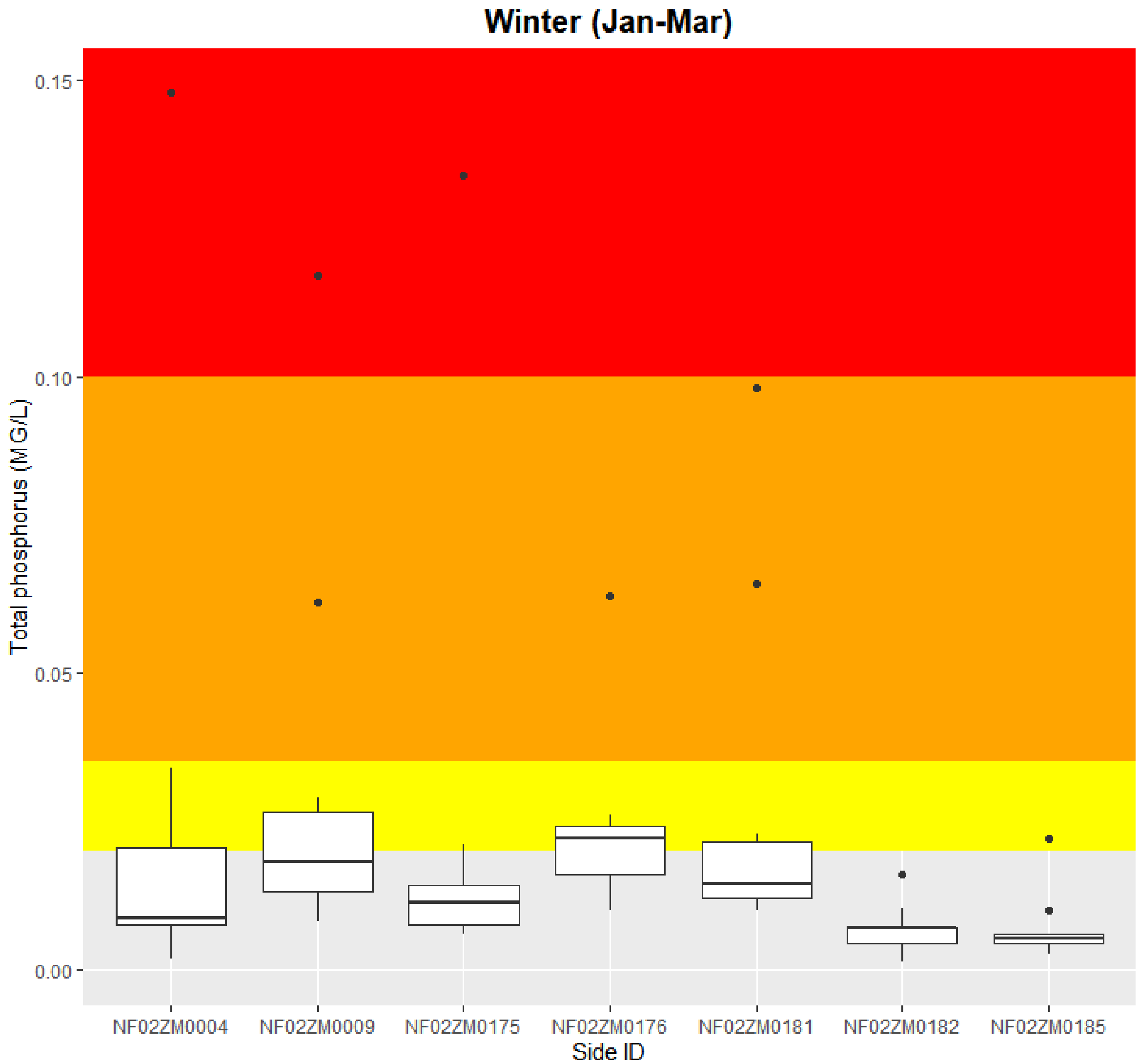

Winter (Jan-Mar)
15.0
12.5
10.0
7.5
Dissolved Oxygen (ppm)
NF02ZM0004
NF02ZM0009
NF02ZM0175
NF02ZM0176
NF02ZM0181
NF02ZM0182
NF02ZM0185
Side ID

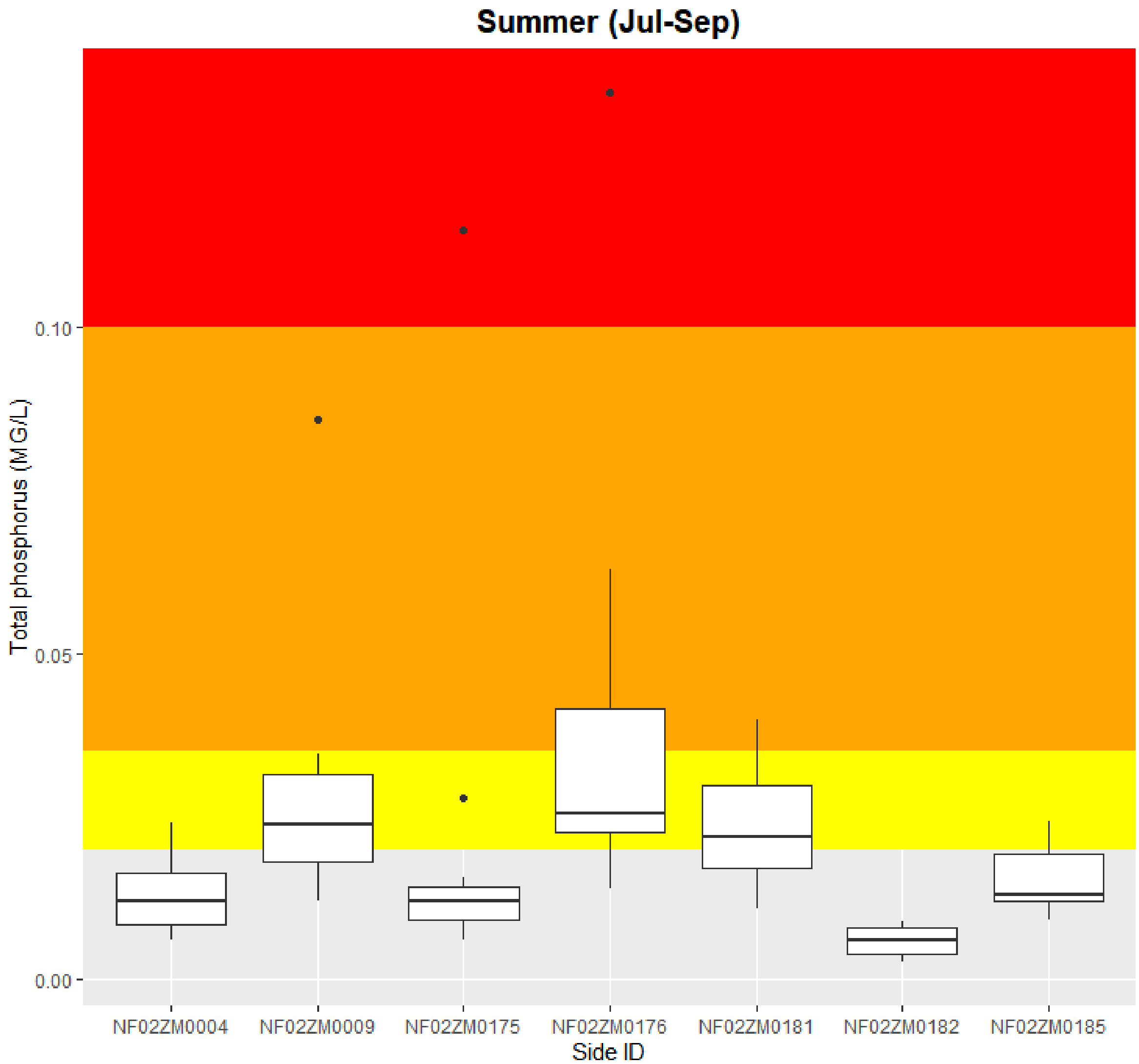

Summer (Jul-Sep)
Dissolved Oxygen (ppm)
12
10
8
6
4
NF02ZM0004
NF02ZM0009
NF02ZM0175
NF02ZM0176
NF02ZM0181
NF02ZM0182
NF02ZM0185
Side ID

Phosphorous (Nutrient) - six grab sample sites and one hydrometric station on the Waterford River (2011-2022)

Note. Phosphorous guideline Source: (CCME, 2022)

- Hyper-eutrophic >0.10 mg/l (Indicated in color red)
- Eutrophic, between 0.035 – 0.1 mg/l (Indicated in color orange)
- Meso- eutrophic, between 0.02 – 0.035 mg/l (Indicated in color yellow)


Winter (Jan-Mar)
0.15
0.10
0.05
0.00
Total phosphorus (MG/L)
NF02ZM0004
NF02ZM0009
NF02ZM0175
NF02ZM0176
NF02ZM0181
NF02ZM0182
NF02ZM0185
Side ID


Summer (Jul-Sep)
Total phosphorus (MG/L)
0.10
0.05
0.00
NF02ZM0004
NF02ZM0009
NF02ZM0175
NF02ZM0176
NF02ZM0181
NF02ZM0182
NF02ZM0185
Side ID