2019 Intensive Stormwater Sampling Program

in the

Shediac Bay Watershed

Analysis and Interpretation of Results

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1. BACKGROUND AND CONTEXT

Work has been ongoing for several years investigating water quality in the Shediac Bay watershed. Sampling of a number of stormwater-influenced small streams has shown that these watercourses on occasion carry elevated pollutant loads, in particular having high counts of *E. coli* and enterococci bacteria. The source or sources of the coliform bacteria have remained speculative, as the types of sampling and analysis employed up to 2019 had not permitted their identification.

Recommendations were made in 2019 (Hughes, 2019) for additional sampling, specifically designed to further advance the understanding of bacterial sources impacting stormwater quality in the Shediac Bay watershed. Sampling was carried out in the fall of 2019 in accordance with this plan. This report presents an analysis and interpretation of the results.

The overarching objective of the work summarized in this report was to collect additional information that will help the Government of New Brunswick better understand the sources of fecal bacteria in stormwater in the Shediac region.

Specifically, the objectives of the current work were:

1. To interpret and report on 2019 stormwater data (i.e. tracer sampling program and routine SW sites scattered throughout the watershed);
2. To compare results with data from previous years if applicable;
3. To outline areas or issues of concern within the watershed;
4. To identify potential recommendations/mitigation measures that could be implemented by local authorities to address any issues of concern (i.e. in a stormwater By-law, through Best Management Practices, or as long-term actions that could be incorporated in the upcoming Shediac Bay watershed management plan etc.).

Terminology - bacteria

This report deals with issues relating to bacterial contamination in water, soils or sediments. Various standard measures of such bacteria are in common use including total coliforms, fecal coliforms, *E. coli* and enterococci. In this report the term *fecal indicator bacteria*, abbreviated to FIB, is used as a collective term.

Other acronyms or abbreviations used in this report:

CST	Chemical source tracking
FWA	Fluorescence whitening agent
MST	Microbial source tracking
OB	Optical brightener(s)
PPCP	Pharmaceuticals and personal care products
QA/QC	Quality assurance/quality control
ENT	Enterococci

Site identification codes:

SW	Stormwater site. Nine locations in the Shediac watershed where surface water from small creeks has been sampled since 2017.
CB	Catchbasin sampling site
GR	Grass sampling site

PBPP	Parlee Beach Lagoon sampling location
PL	Parking lot site
R	Road site
RF	Roof site
STR	Stream site

2. STORMWATER MONITORING DATA - OVERVIEW

Monitoring Locations and Sample Numbers

The monitoring network locations are shown in the following two figures.

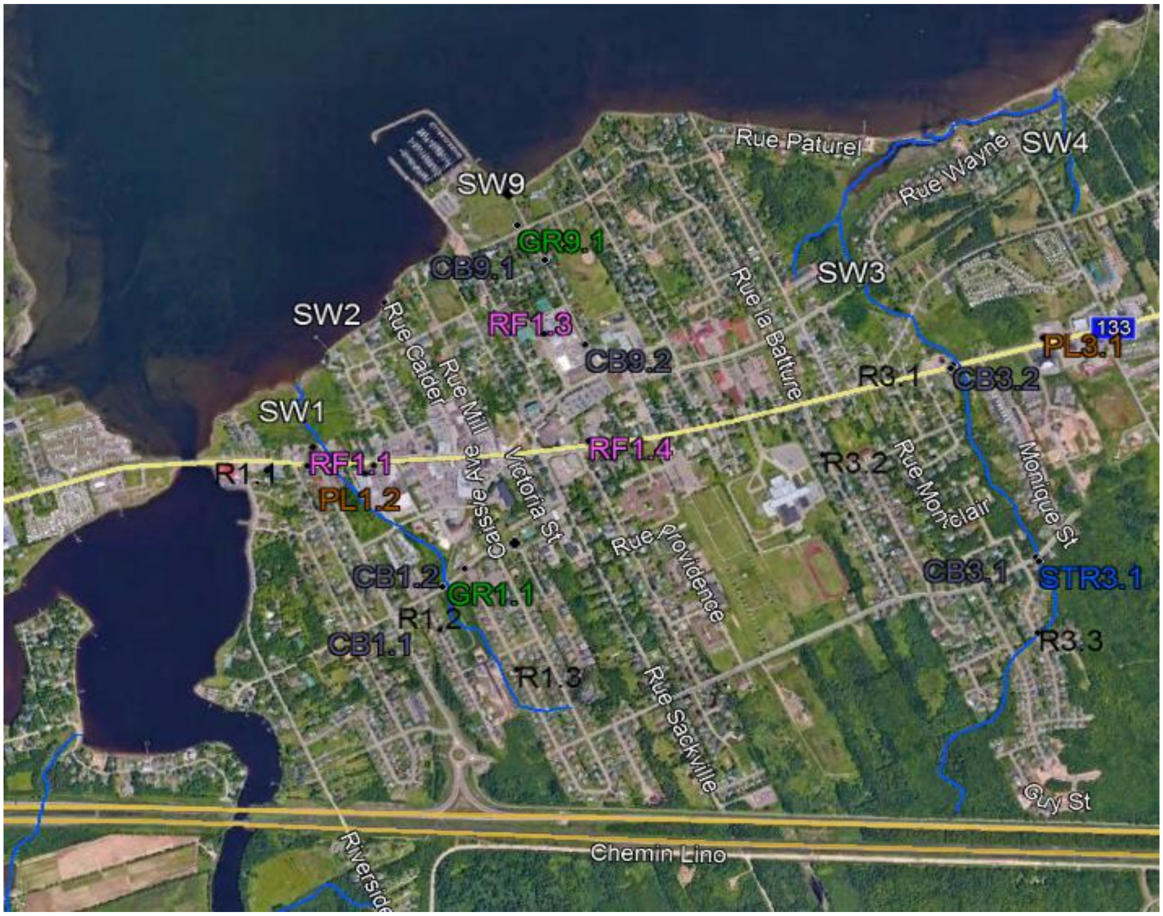

Figure 1. Monitoring site locations - Shediac west.

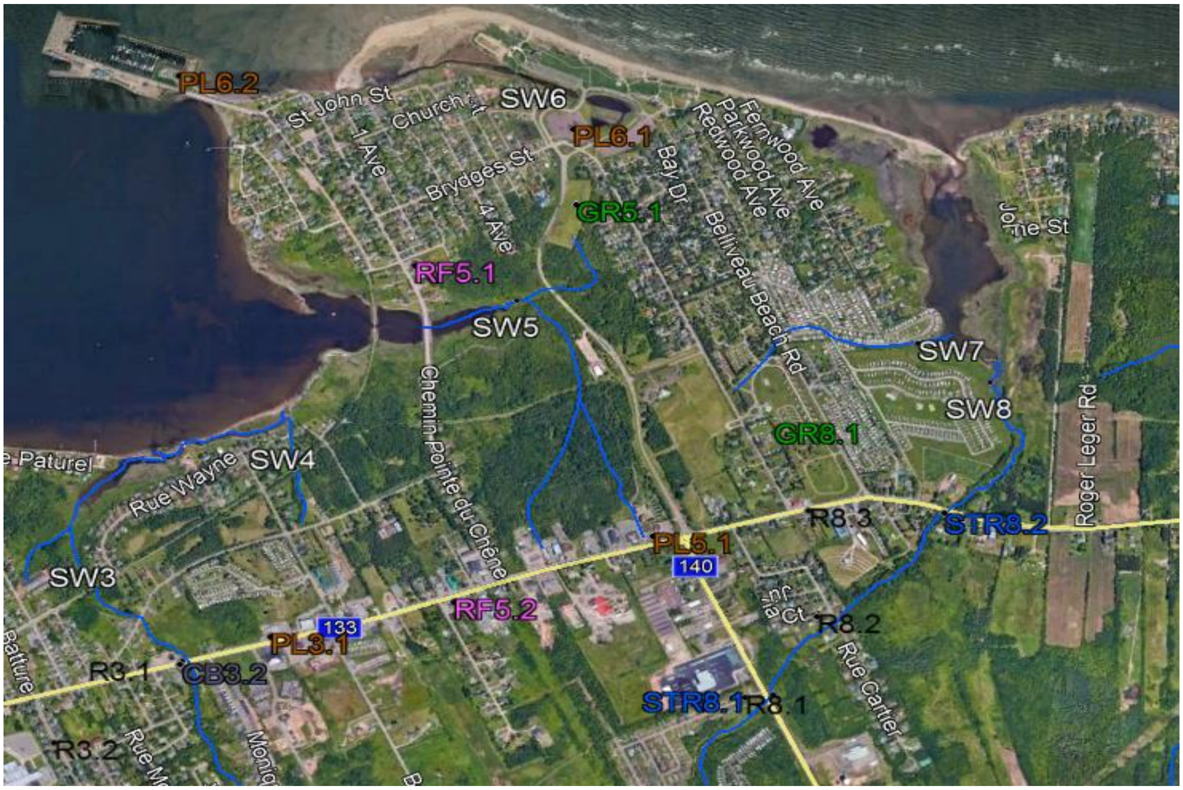

Figure 2. Monitoring site locations - Shediac east.

Samples were collected at a total of 51 different locations. Over 180 samples were collected. Sample numbers and dates are summarized in the following table.

Number of samples and dates of sampling

Site Type	Sample Dates (2019)	Number of samples	Number of sites
Stormwater network (SW)	Jun 12, Jun 19, July 15, Aug 19, Sep 25, Oct 8, Oct 18, Oct 23, Oct 24	63	9
Catch basin (CB)	Oct 2, Oct 15	12	6
Grass surface (GR)	Sep 24, Oct 17, Oct 23	12	4
Parlee Beach Lagoon (PBPP)	Oct 7, Oct 17, Oct 31	21	7
Parking lot (PL)	Sep 24, Oct 7, Oct 17	17	6
Road (R)	Sep 24, Oct 7, Oct 17	27	9
Roof (RF)	Sep 24, Oct 7, Oct 17	18	6
Stream (STR)	Oct 8, Oct 17, Oct 23	12	4
Totals		182	51

Notes: Sample number in this table refer to sampling for general chemistry and/or FIB.

The following table lists the sample dates for the stormwater (SW) sites. These sites have been sampled annually since 2017. Most sites were sampled monthly, with two samples per month collected in June, August and October at all sites.

Sample Dates and Analysis Type for Stormwater (SW) Sites (2019)									
Sample Date	SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8	SW9
Jun 12	2	2	2	2	2		2	2	2
Jun 19						2			
Jul 15	1	1	1	1	1	1	1	1	1
Aug 19	2	2	2	2	2	2	2	2	2
Sep 25	1	1	1	1	1	1	1	1	1
Oct 8	1	1	1	1	1	1	1	1	1
Oct 18	2	2	2	2	2	2	2	2	2
Oct 23	1				1	1			1
Oct 24		1	1	1			1	1	
1= analysis for FIB only; 2 = analysis for FIB and general chemistry; Blank= no sample.									

The following table lists the numbers of samples that were planned for collection under the intensive study versus what was collected. In general the targets were met for most site categories. There were no targets established for the pre-existing stormwater sites (SW) for bacteria and general chemistry as sampling was already planned for those sites during 2019. The main deviations from the intensive sampling plan was that no samples were collected for wastewater influent and effluent at the treatment plant, and seven sites were sampled around the Parlee Beach lagoon.

Number of Samples Planned versus Collected [n]				
Site Type	Bacterial	PPCP	Optical Brighteners	Chemistry
Road (R)	27 (3 areas) [27]		27 [27]	
Roof (RF)	18 (2 areas) [18]		6 total [6]	
Parking Lot (PL)	18 (2 areas) [17]		18 total [18]	
Grass (GR)	12 (4 areas) [12]		12 total [12]	
Stream (STR)	12 (2 areas) [12]	4 (2 areas) [4]	12 total [12]	12 total [0]
Catchbasin (CB)	12 (3 areas) [12]	3 (3 areas) [3]	12 total [12]	
Stormwater site (SW)	- [63]	6 total [5]	18 total [23]	- [27]
Parlee Beach Lagoon (PBPP)	- [21]	- [7]	- [21]	[7]*
Wastewater influent		4 [0]	8 [0]	
Wastewater effluent		4 [0]	8 [0]	
Notes: 'Areas' refers to different sub-watersheds within the study area. PPCP = pharmaceuticals and personal care products; Chemistry= analysis for major ions and (optionally) trace metals. * = TDS, salinity, pH and temp only. - indicates no specific target number set for the tracer study. Blank cells indicate no samples required for the intensive study.				

Precipitation Events

In all, samples were collected for chemical and/or FIB analysis on 14 different dates. The general intent when sampling for stormwater is to sample during or after recent precipitation events so as to capture the initial runoff which usually contains the highest concentrations of contaminants.

No reliable precipitation data were available collected directly in the study area. For guidance, precipitation data observed at the two closest available sites have been used. These are Bouctouche CDA, 30 km northwest of Shediac, and Moncton International Airport, 16 km southwest. In the following table daily precipitation totals at each of these sites is listed for all sample dates, plus one day prior to and one day following the sample date. It should also be noted that the day used to calculate precipitation at these sites is not the usual 24h civil day but the 24 h period ending at 0600 with the total 'thrown back' to the previous day. For example data reported against June 12 fell between 0600 June 12 and 0600 June 13.

Precipitation at Nearby Monitoring Sites on and Adjacent to Sample Dates		
Date	**Bouctouche CDA (mm)**	**Moncton Int A (mm)**
2019-06-11	9.2	5.2
2019-06-12	0	0.4
2019-06-13	14.8	19.2
2019-06-18	0	0
2019-06-19	0	0
2019-06-20	6.9	9.6
2019-06-21	38.4	43.2
2019-07-14	12.8	7.3
2019-07-15	16.6	3
2019-07-16	0.4	0.3
2019-08-18	11.9	9.9
2019-08-19	0	0.2
2019-08-20	0	0
2019-09-23	1.3	4.2
2019-09-24	38.3	40.7
2019-09-25	8.1	4.1
2019-09-26	0	0
01-10-2019	5.1	4.2
02-10-2019	0.9	0.7
03-10-2019	0	0
2019-10-06	0	0
2019-10-07	17.4	13.6
2019-10-08	0.8	1.1
2019-10-09	0	0
2019-10-16	0	0
2019-10-17	23.7	19.8
2019-10-18	4.5	8.2

Precipitation at Nearby Monitoring Sites on and Adjacent to Sample Dates		
2019-10-22	0	0
2019-10-23	20.3	0
2019-10-24	M	0
2019-10-25	M	0
2019-10-30	0	0.2
2019-10-31	16	12.9
2019-11-01	1.7	0.2

Most sample dates had significant precipitation at one or both of the two closest monitoring sites, but not in every case. It is also worth noting that a precipitation event totalling 110-120 mm occurred on September 6-7 in the study area due to the passage of hurricane Dorian. No samples were collected on that date.

3. RESULTS

Results at SW Sites

Bacteria

Bacteria results are presented in Figures 3-5 for all SW sites. As in previous seasons there were frequent positive detections of both *E. coli* and enterococci at all sites. Sites 1, 2 and 6 tended to have higher results, with generally lower values observed at sites 4 and 5.

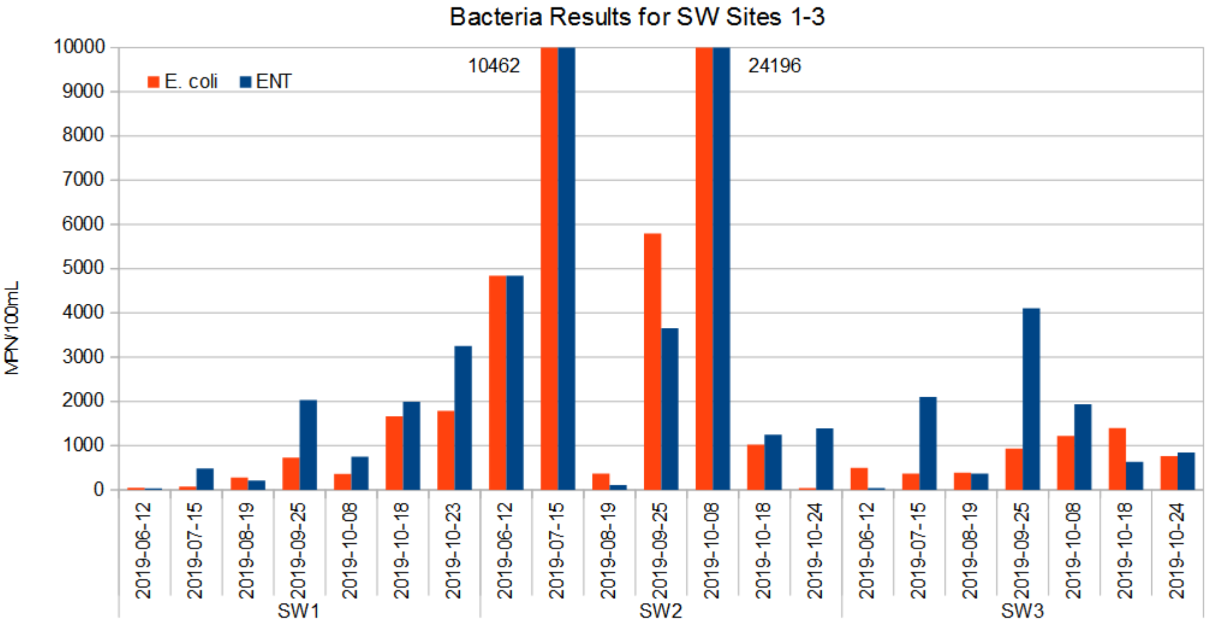

Figure 3. Bacteria results for SW sites 1-3.

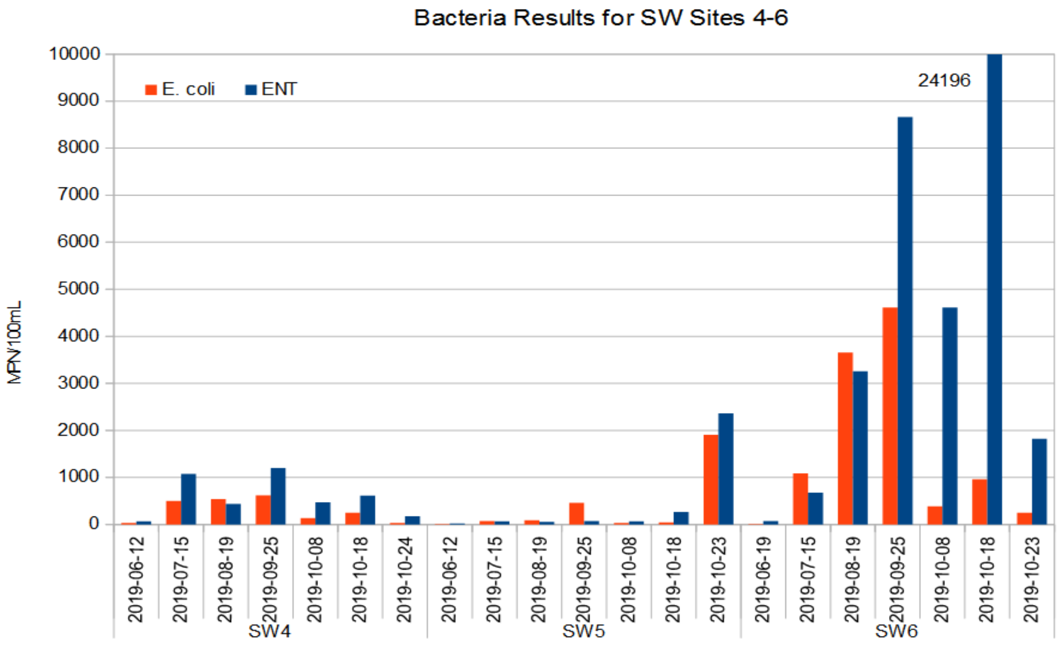

Figure 4. Bacteria results for SW sites 4-6.

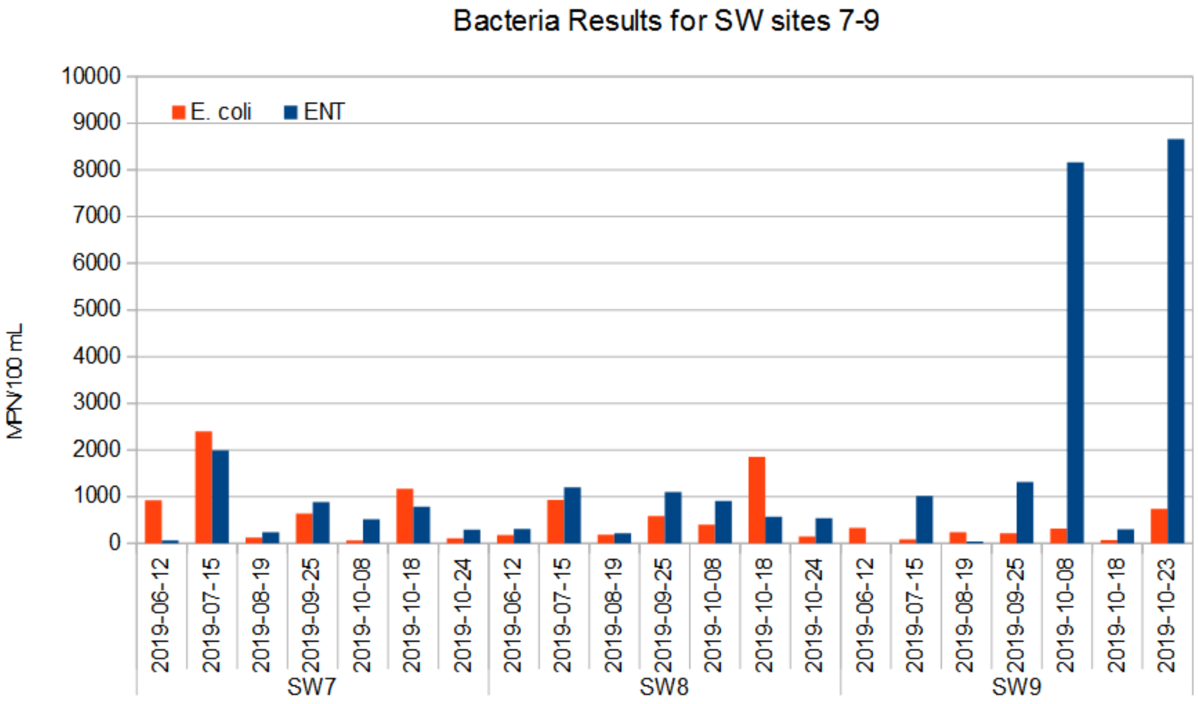

Figure 5. Bacteria results for SW sites 7-9.

Statistics on the percentage of samples exceeding guidelines for *E. coli* and entercocci are given in the following table, for 2019 and the previous two years of sampling for comparison. Results obtained in 2019 were broadly similar to those in 2017 and 2018. Data obtained by Crandall Engineering during their 2018 study of the Parlee Beach lagoon are also included (Crandall Engineering, 2019). Exceedances of guidelines for entercocci continued to be seen at a higher frequency than for *E. coli*.

Percentage of Samples of Stormwater Exceeding Surface Water Guidelines 2017-2019 (SW Sites)

	E. coli	Enterococci	Number of samples
2017	37%	77%	43
2018	49%	93%	47
2019	49%	84%	63
Crandall Lagoon sites 2018	57%	100%	7
Guidelines: *E. coli*: maximum for a single sample: 400 MPN/100mL; Enterococci: 70 MPN/100 mL			

In 2019 the geometric mean of all *E. coli* results from all nine sites was 379 MPN/100mL and for entercoccus, 631 MPN/100mL. Both results exceed the Health Canada guidelines (Health Canada, 2012) for recreational water quality for multiple samples, respectively 200 MPN/100mL for *E. coli* and 35 MPN/100mL for entercocci (geometric means). At present there are no accepted guidelines in New Brunswick specifically for stormwater quality. The Health Canada guidelines cited here are often used to provide context for surface water FIB results, despite the fact that they are designed for application to recreational waters. It is unlikely that there is much recreational contact occurring in the small streams sampled in this study. Nevertheless, the fact that these watercourses discharge in relatively close proximity to recreational waters supports the use of recreational water quality guidelines when evaluating the results.

The highest FIB results were seen on July 15 and October 8 at site SW2, September 25 at SW6, and October 8 and October 23 at SW9. September 25 featured a precipitation event of about 38-40 mm whereas the other high FIB results occurred on days with precipitation totals of 16-20 mm. The 2019 results continued to show the highest FIB values in stormwater with daily precipitation amounts of > 10-15 mm.

Other Chemical Parameters

While elevated levels of FIB in the Shediac Bay watershed and nearby swimming waters have attracted particular attention, providing the impetus for the range of monitoring and assessment work carried out in recent years, a range of other contaminants can be of concern in runoff and stormwater. Such contaminants can potentially lead to degraded quality in receiving waters, and include nutrients, suspended solids, hydrocarbons, salt, metals and a range of organic compounds ranging from pesticides to pharmaceuticals (e.g. Saskatchewan Water Security Agency, 2014).

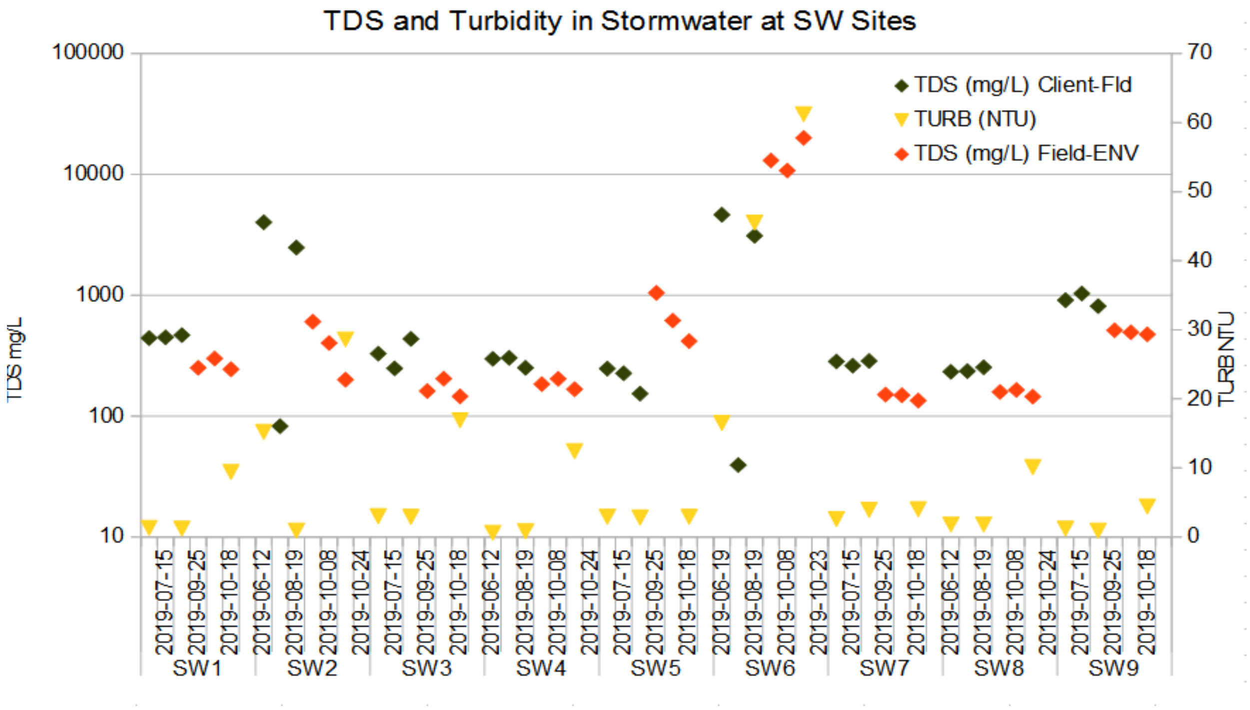

Figure 6. Turbidity and TDS at SW sites.

Figure 6 shows results at SW sites for turbidity and total dissolved solids (TDS). Turbidity is a measure of water clarity and is affected by the amount of suspended particulates whereas TDS reflects the total dissolved chemical content of the water. The highest results for TDS occurred at sites SW2, SW6 and SW9. Some high turbidity results also occurred at site SW6. It is probably significant that all these sites are piped outfalls receiving direct stormwater input from adjacent roads. SW6 discharges adjacent to the Parlee Beach lagoon and its exact watershed is unclear. Elevated TDS is not necessarily a cause for concern depending on the compounds contributing. It is possible at site SW6, due to its low elevation and susceptibility to flooding, that there could be residual marine salt in the surrounding soils that could contribute to higher TDS values. However turbidity is also high at the SW6 location which could be due to road and/or parking lot runoff influencing the results.

Considering possible additional components that could be of concern in particulates, a number of trace metals have been identified in stormwater originating from road surfaces. Known sources of such metals are particulates from motor vehicle brake pad wear and tire wear. This particulate matter is characterized by its iron, barium and copper content (brakes) and zinc, lead and copper (tires) (e.g. McKenzie et al., 2009). Figures 7-8 show results from SW sites for these metals.

In Figure 7, there is evidence for a correlation between results for all the metals, especially between iron and copper, which are highest at sites 1, 2 and 6. In Figure 8, the highest values for lead and zinc both occurred in the same samples (SW1 and SW2), although there is scatter across the rest of the results. SW1 is an open creek receiving street runoff and SW2 is a storm outfall. Given that all the SW sites are affected by stormwater contributed from street drains it is probable that all are liable to the effects of brake and tire wear, and the results for the indicator metals are consistent with this. In terms of absolute values, an examination of results for a range of rivers in New Brunswick suggests that the metal results in stormwater in this study are about 3-10 times higher than those typically seen in the lower reaches of major rivers such as the Saint John River. Smaller tributaries have much lower results for these metals, often below detection (NB Surface Water Quality Data Portal, 2020).

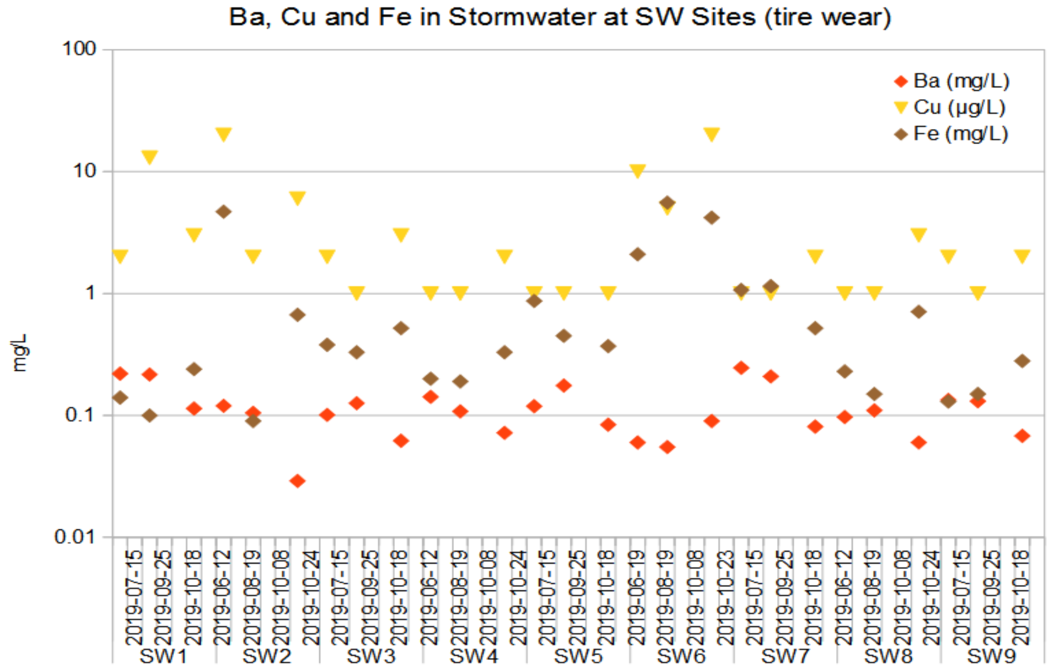

Figure 7. Barium, copper and iron in stormwater at SW sites.

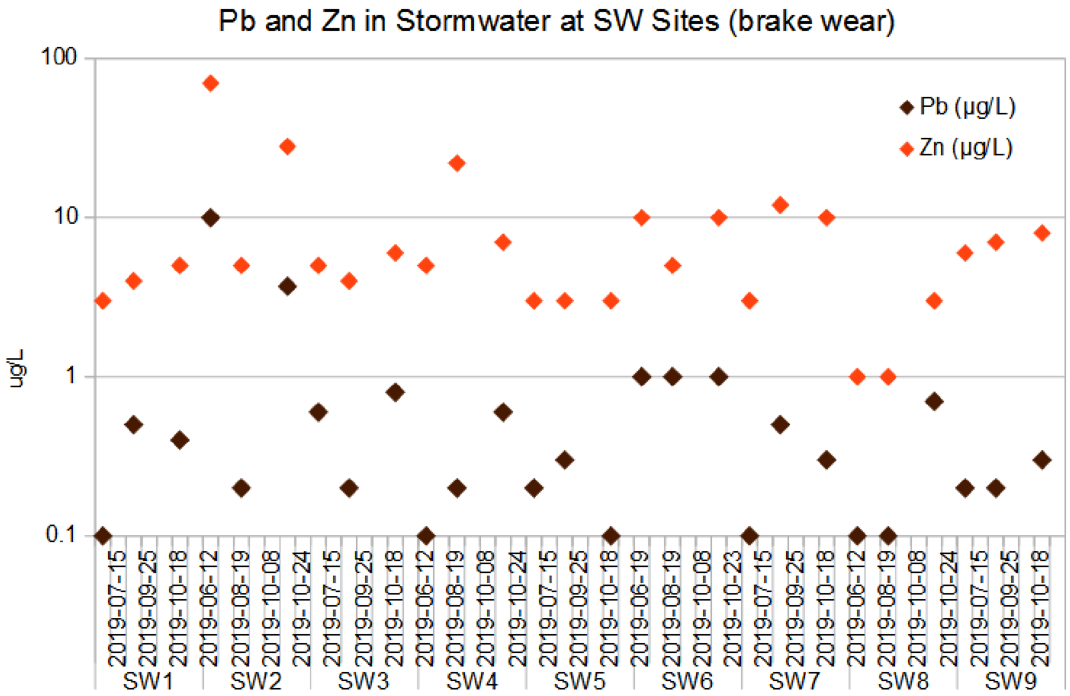

Figure 8. Lead and zinc in stormwater at SW sites.

Results at Surface Sites

As part of the 2019 stormwater sampling plan, samples were collected at a range of sites to investigate the FIB profile associated with a number of different ground surface types across the watershed. These samples were collected between September 24 and October 23, as detailed in tables in the preceding section. Samples were analyzed for FIB and a subset of samples was also tested for optical brighteners and PPCP.

FIB Results

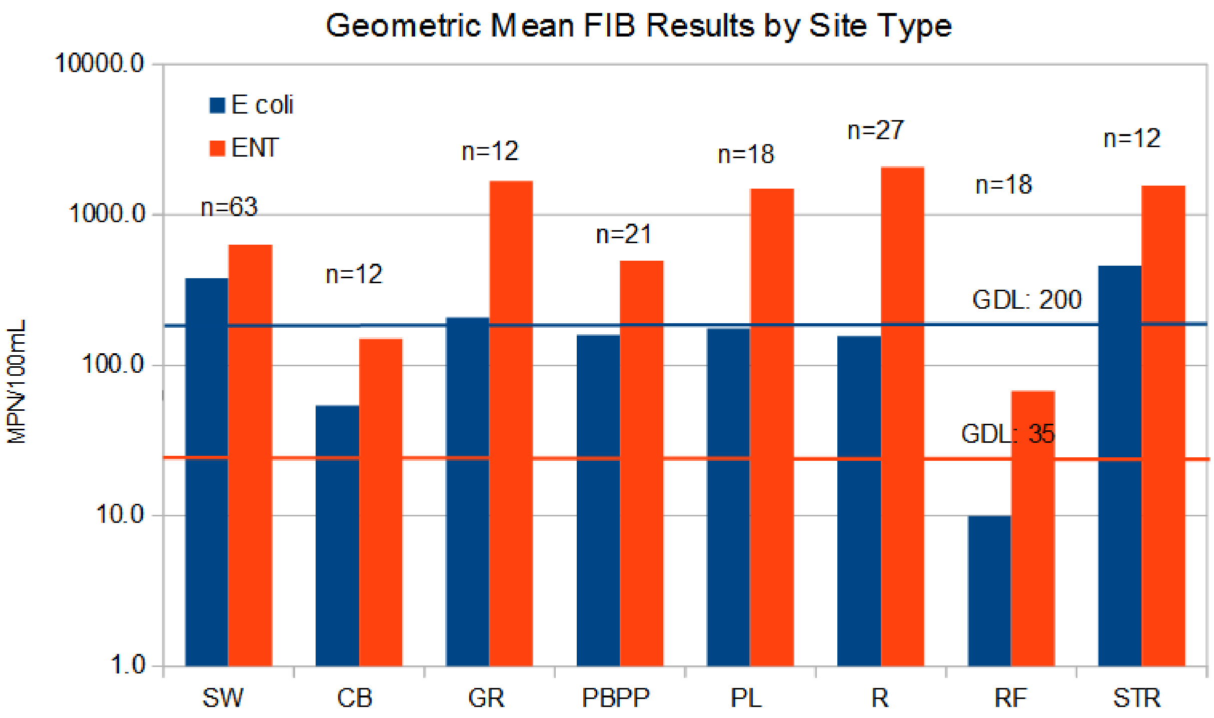

Figure 9. Geometric means for FIB by site type.

Geometric mean values for FIB for each site type is summarized in Figure 9. Note the log scale for the Y axis. Sample numbers (n) and the recreational surface water quality guidelines for multiple samples are indicated. Geometric mean FIB values exceeded the *E. coli* guideline at the SW, GR (grass) and STR (stream) sites, and was close to the guideline at several of the other site categories. Means were lower for the CB (catchbasin) and RF (roof) sites. The multiple sample guideline for entercocci was exceeded at all site types.

Results for the SW sites were summarized in the previous section. The stream sites added for the intensive sampling study are additional sites of the same type, so it is not surprising that the results for the STR sites are similar to those found at the SW locations.

Catchbasin (CB) Sites

There were three pairs of catchbasin sites sampled, one pair in each of the sub-watersheds associated with SW1, SW3 and SW9. The CB sites were sampled twice, on October 2 and October 15. The intent with these sites was to check for FIB presence and persistence in the stormwater system between precipitation events. However there was 4-5 mm recorded at the two reference precipitation stations on October 1, and 2-4 mm on October 15 itself, so the results are more representative of what is found during or within 24 hrs of precipitation occurring.

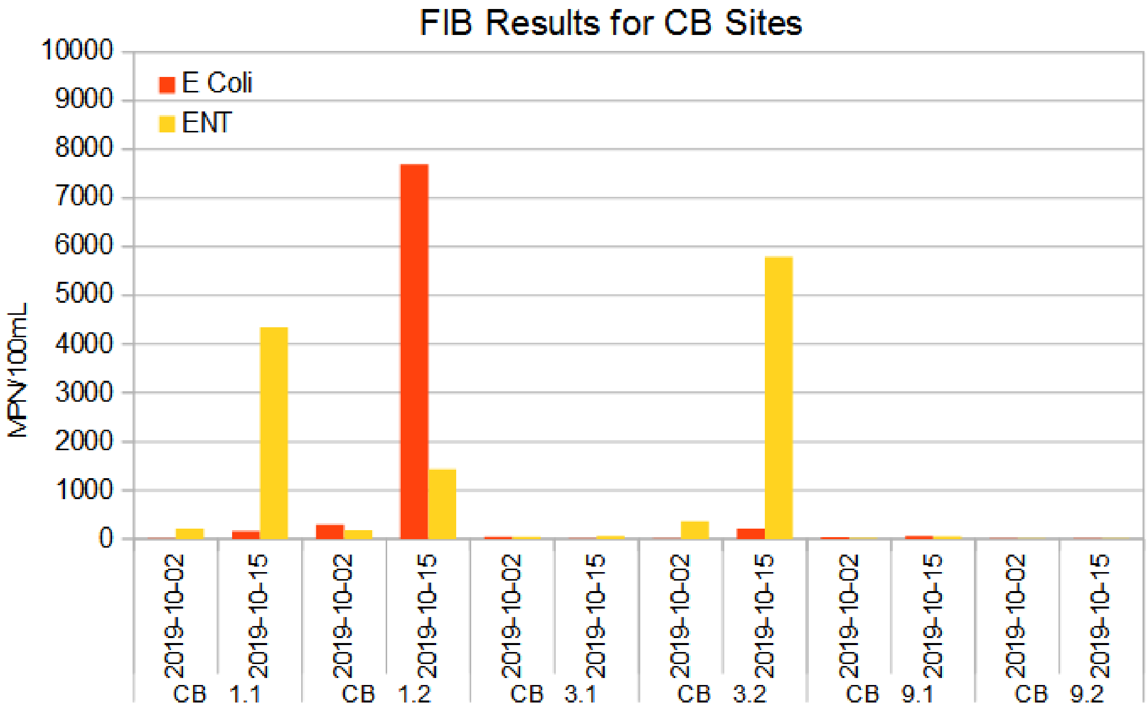

Figure 10. FIB results for catchbasin (CB) sites.

Results for FIB are shown in Figure 10. There were positive FIB detections at all locations, but considerable variation between sites. CB 1.2, on the northeastern side of Taits Brook, had higher values, especially on October 15. This date had higher results at all sites which may be due to the greater precipitation on that date. Site CB1.2 is less than 100m and down gradient from a dog park on Rachel Street, which may have influenced the results at that location. Site CB3.2 (on Main Street) had higher results than CB3.1 (on a smaller suburban street). This could be due to the greater extent of paved surfaces adjacent to CB3.2 and might suggest a greater influence from local FIB sources in the vicinity of CB3.2. However other factors could also be at work, for instance the nature of the sub-surface drainage pipework, its age and the presence or absence of biofilms.

The sites CB9.1 and CB9.2 on Brown Street had low FIB levels on both sample dates. CB9.1 is downstream of CB9.2 in the same drainage network and might be expected to show higher FIB levels, which was in fact what was observed, although the difference was slight.

Grass Surface (GR) Sites

There were four grass surface sites, one each in the sub-watersheds associated with sites SW1, SW5, SW8 and SW9. Sites GR1.1 and GR9.1 can be located in Figure 1 and GR5.1 and 8.1 in Figure 2. All were sampled three times, on September 24, October 17 and October 23. Results are summarized graphically in Figure 11.

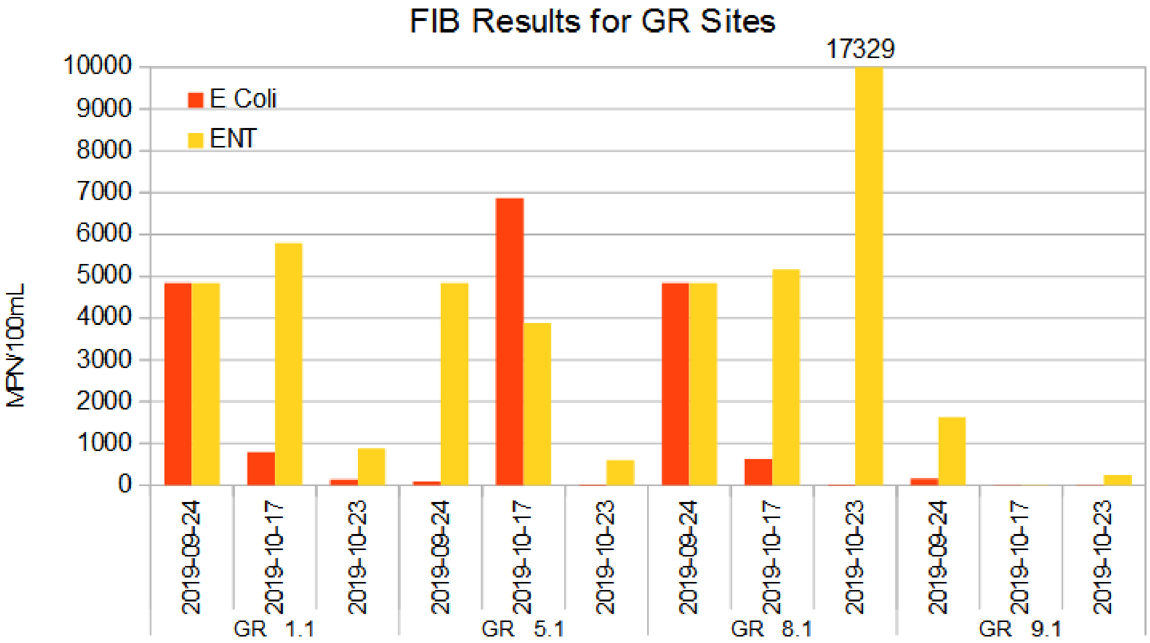

Figure 11. FIB results for grass surface (GR) sites.

Positive results for FIB were found at these sites on all sample occasions. All sample dates featured significant precipitation (> 20 mm). At each location sampling was carried out in swales or low points where water would pond on the surface. All sites are adjacent to areas of mown, short grass. The GR9.1 site had lower FIB results on each occasion. Sites 1.1, 8.1 and 9.1 are all associated with small parks featuring walking trails whereas 5.1 is a large area of mown grass next to Parlee Beach Road with no obvious use as a recreational area. Dog walking might be expected at 1, 8 and 9, however site 5 had higher FIB results than site 9. Site 1 is close to a dog park. Without more detail on the actual activities taking place around these sites it is not possible to make firm conclusions regarding the sources of FIB contributing to the results. However it is not feasible for the wastewater system to have influenced the results and so other sources must be responsible. This would include wildlife (birds, rodents, other mammals) and domestic animals.

Other investigations have found that grass is an excellent substrate for the growth and sustenance of FIB. For example Tomasko (2016) found that after dog feces is mixed with grass cuttings high FIB concentrations can persist for at least 30 days.

Parlee Beach Lagoon Sites

Samples were collected at seven locations around the Parlee Beach Lagoon, where different pipes discharge into the lagoon. Sample locations are shown in Figure 12. Note that PPPB 2 is in the same gully that is sampled as site SW6. These outfalls were also investigated by Crandall Engineering as part of their 2018 study of the lagoon (Crandall Engineering, 2019). The numbering system used by Crandall in their study has been carried over to the sites sampled in 2019 in this study. Crandall (2019) found that the pipes discharging at PPPB 3,4,5,7 and 8 all convey water drained from adjacent parking lots into the lagoon. PBPP1 is a culvert connecting the lagoon to its discharge channel towards Shediac Bay. PPPB 2 is the same swale sampled as site SW6 and was sampled a short distance to the NE by Crandall. Previously there was a sewage lift station overflow discharging to the lagoon at its easterly end, but this has been removed.

Figure 12. Sample site locations around the Parlee Beach lagoon.

Results for FIB are shown in Figure 13. The sites were each sampled three times, on October 7th, 17th and 31st. All occasions featured precipitation in excess of 10 mm with >20 mm on October 17th.

Positive results for FIB were found on most sample days with the highest values seen at site 4. Site 4 receives runoff from a large adjacent parking lot, but so does site 5. There is a lot of recreational activity in the area all around the sampling locations and presumably abundant wildlife sources of FIB as well (especially birds), given the close location to the ocean front. In their report Crandall Engineering recommended a detailed stormwater study of all the pipes discharging to the lagoon, including video inspection and smoke testing. There appears to be a lack of detail on the origin of water discharging to the gully sampled at site SW6, which appears to be connected by a short underground pipe to location 2 as identified in the Crandall study.

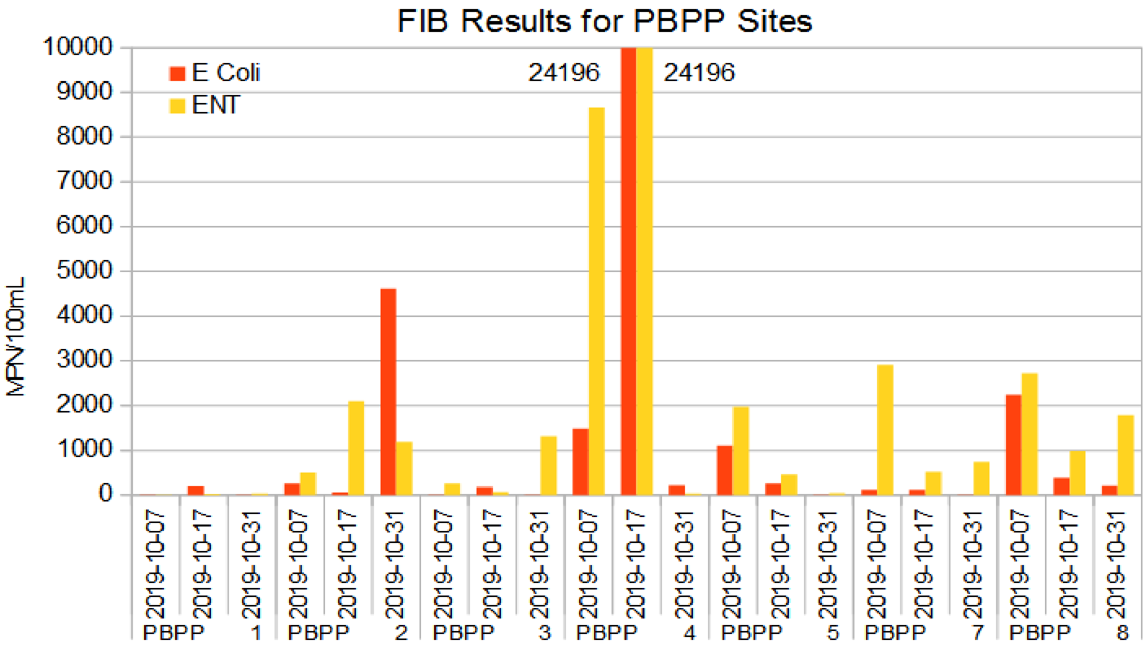

Figure 13. FIB results at Parlee Beach lagoon sampling sites.

Parking Lot (PL) Sites

There were six parking lot sampling sites in the study, in sub-watersheds 1, 3, 5 and 6. Site locations are shown in Figures 1 and 2. These sites were sampled three times, on September 24, and October 7 and 17th. FIB results are summarized in Figure 14.

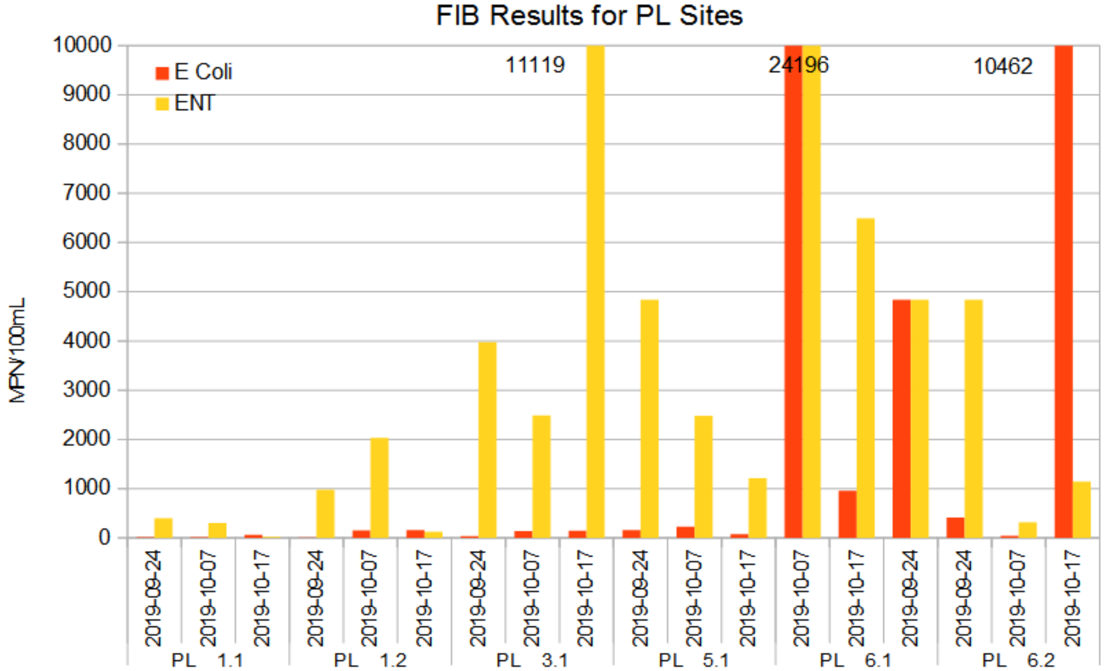

Figure 14. FIB results at parking lot (PL) sites.

FIB were detected on all sample dates at all sites, although the results were variable, with the highest values seen at sites 3.1, 5.1, 7.1 and 6.2. Results from sites 1.1 and 1.2 were lower. Sites 3.1 and 5.1 were especially high in entercocci, whereas high *E. coli* results were seen at sites 6.1 and 6.2. The latter two sites are close to the ocean, 6.1 is the parking lot at the Pointe-du-Chene wharf and 6.1 is a main parking lot for Parlee Beach itself. High sea bird numbers would be expected to influence these locations. Also note that runoff from PL6.1 ends up at location PPPB 4, which had the highest FIB results in the locations sampled around the lagoon. Site 3.1 is a Main Street Tim Hortons parking lot. It is not clear why the results would be much higher there for entercocci than for coliforms, but much the same profile of results was seen at site 5.1, an Ultramar parking lot also on Main Street.

As for the grass sampling sites there is no realistic way that human wastewater could be affecting the results at the PL sites, so other sources have to be considered, most probably wildlife once again, plus domestic animals.

Road (R) Sites

There were nine road site locations in the study, each sampled three times, on September 24, and October 7 and 17th. Road site results are summarized in Figure 15. Road sites were located in sub-watersheds 1, 3 and 8.

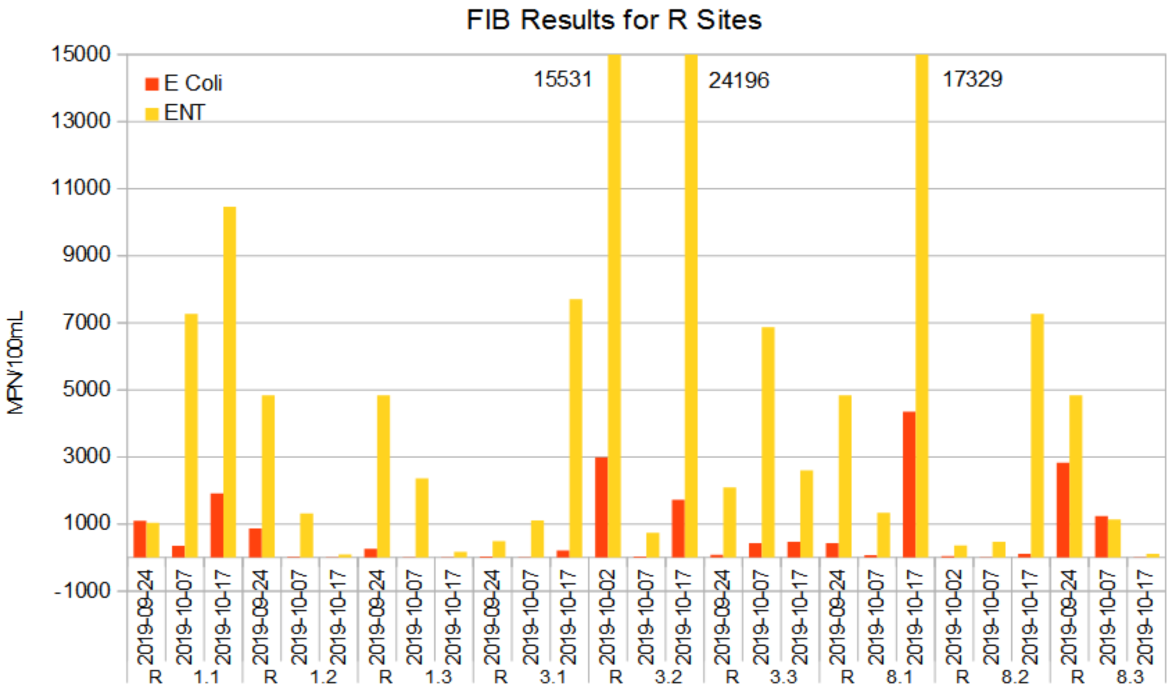

Figure 15. FIB results at road (R) sites.

Results were similar to those found at parking lot sites, with somewhat lower *E. coli* values, but frequent high values for entercocci. Some road sites were on main roads (1.1, 3.1, 8.3) and others on suburban roads (1.2, 1.3, 3.2, 3.3, 8.1, 8.2). There was no clear pattern in the results indicating any difference between FIB results seen at these different road types. Sites 1.1, 3.2 and 8.3 had higher coliform results. Sites 1.1 and 8.3 are at opposite ends of Main Street, whereas site 3.2 is in a much lower traffic area on suburban Rue Alphonse.

All the sites with higher *E. coli* results are roads with walking paths along them, whereas sites 1.2, 1.3

and 8.2, which had the lowest coliform results, do not have walking paths. As walking paths are potential deposition zones for pet feces, this might explain these differences, but since the total sample numbers are low, this must remain speculative. As for parking lot and grass locations, there is no realistic way for wastewater to be responsible for the observed positive FIB results, so other sources must be responsible. Again, wildlife and domestic animals are the probable sources.

Although the greatest precipitation of the three sampling dates occurred on September 24, FIB results were not uniformly higher on this date.

Roof (RF) Sites

There were six roof sites in the study, four in sub-watershed 1, and two in sub-watershed 5. Each was sampled three times, on September 24, and October 7 and 17th. Roofs cannot be influenced by wastewater, and they are also physically separated from other potential FIB sources that are active at ground level such as pet waste and some wildlife activity, with the important exception of birds. Results are shown in Figure 16.

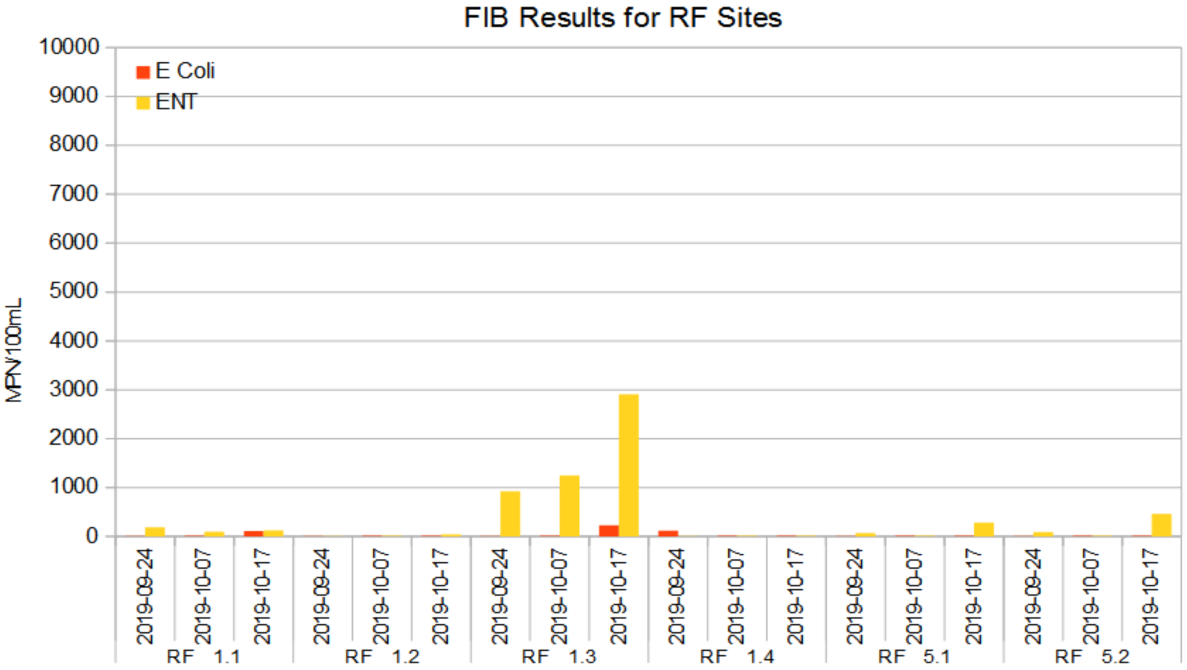

Figure 16. FIB results at roof (RF) sites.

Although there were FIB detections at these sampling locations, results were much lower than for all the other surface types examined. Results for *E. coli* and entercocci were both low. The roofs sampled were on a range of buildings of different sizes. Site 1.3 stands out as having consistently higher results. This roof is a large one, on the arena building on Festival Street. It is likely that the positive FIB results on the roofs originate from bird feces. The arena building is relatively close to the shore and could be a favourite roosting spot for sea birds and/or pigeons, which also congregate on roofs.

Stream (STR) Sites

There were two pairs of stream sampling sites in the study, one pair on the stream leading to site SW3, and the other pair on the stream leading to site SW8. Sites STR3.1 and STR3.2 and STR8.1 and STR8.2 are respectively about 600m and 800m apart. Each pair of sites was sampled three times, on October 8, October 17 and October 23. Between the two sample sites on stream 3 there are stormwater discharges from Monique Street and other adjacent suburbans streets. On stream 8, the stream crosses Rue Cartier between the two sample points, and the municipal stormwater drainage map indicates that the stream receives stormwater from Rue Cartier as well as the Julia Court subdivision in this middle section. The sample locations were chosen to investigate whether there would be a significant difference in upstream/downstream sampling points, possibly due to a variety of sources between them. Results are shown in Figures 17-19. Precipitation totals for each event are indicated in the figures.

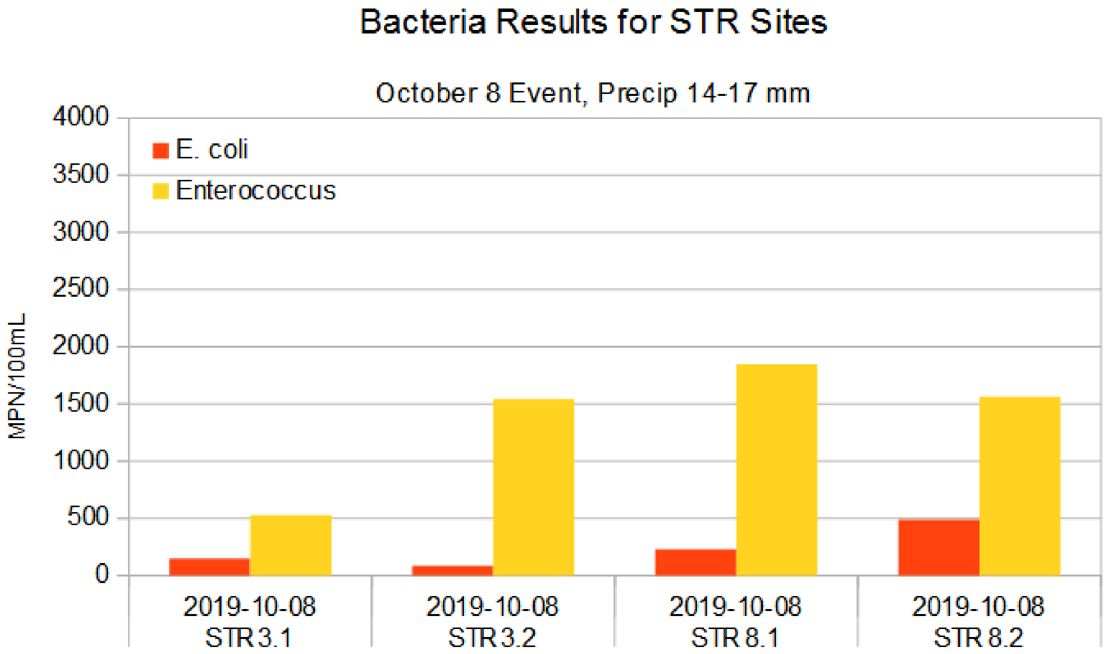

Figure 17. Bacteria results at stream (STR) sites on October 8, 2019.

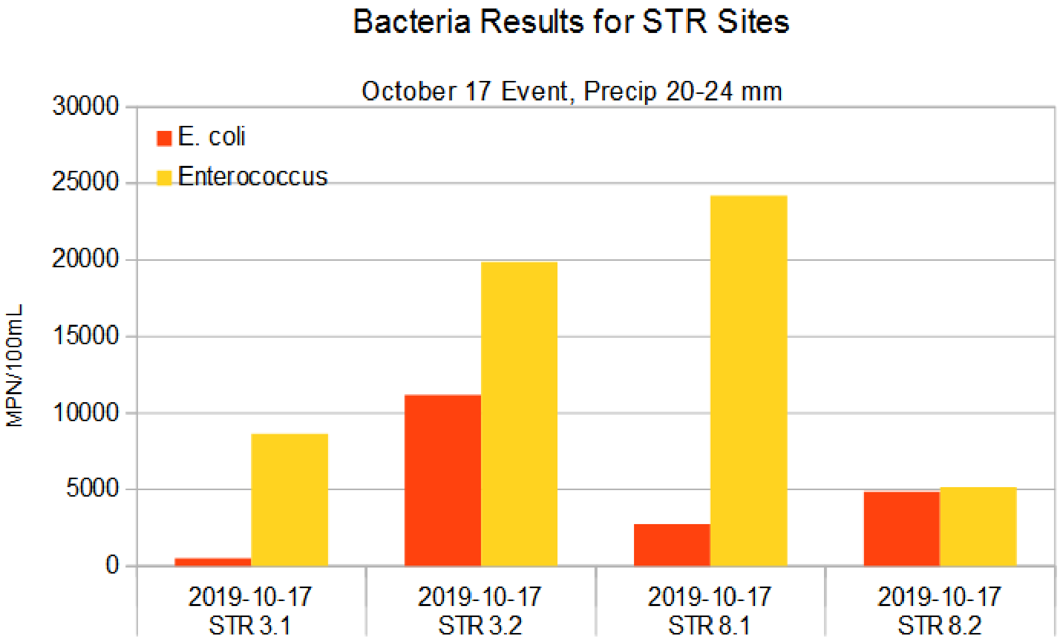

Figure 18. Bacteria results at stream (STR) sites on October 17, 2019.

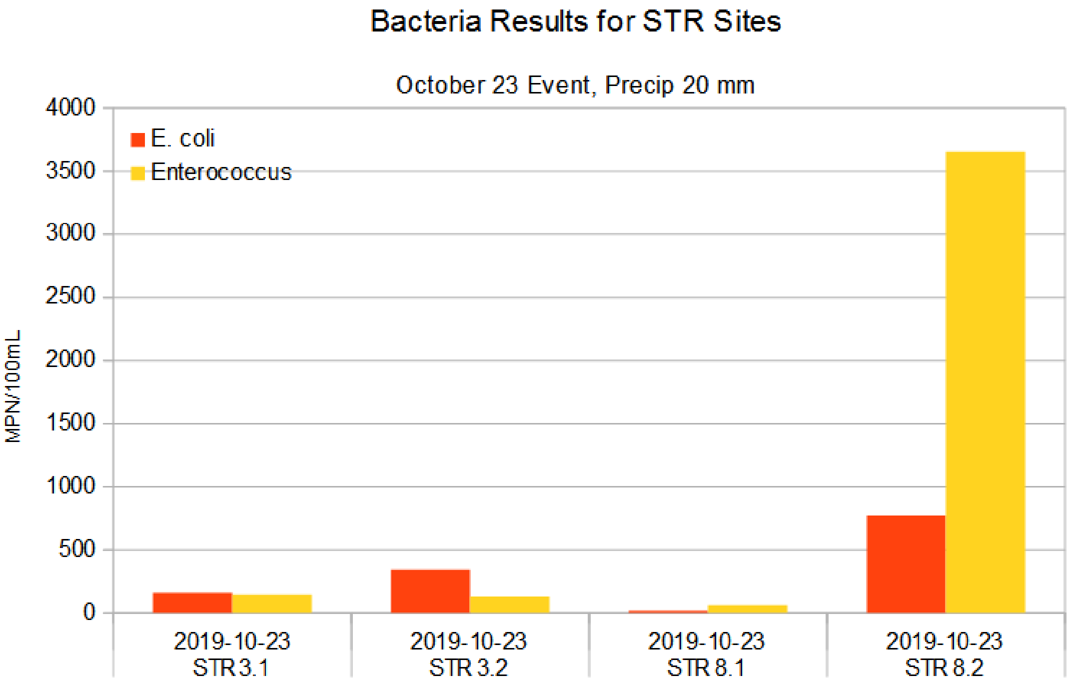

Figure 19. Bacteria results at stream (STR) sites on October 23, 2019.

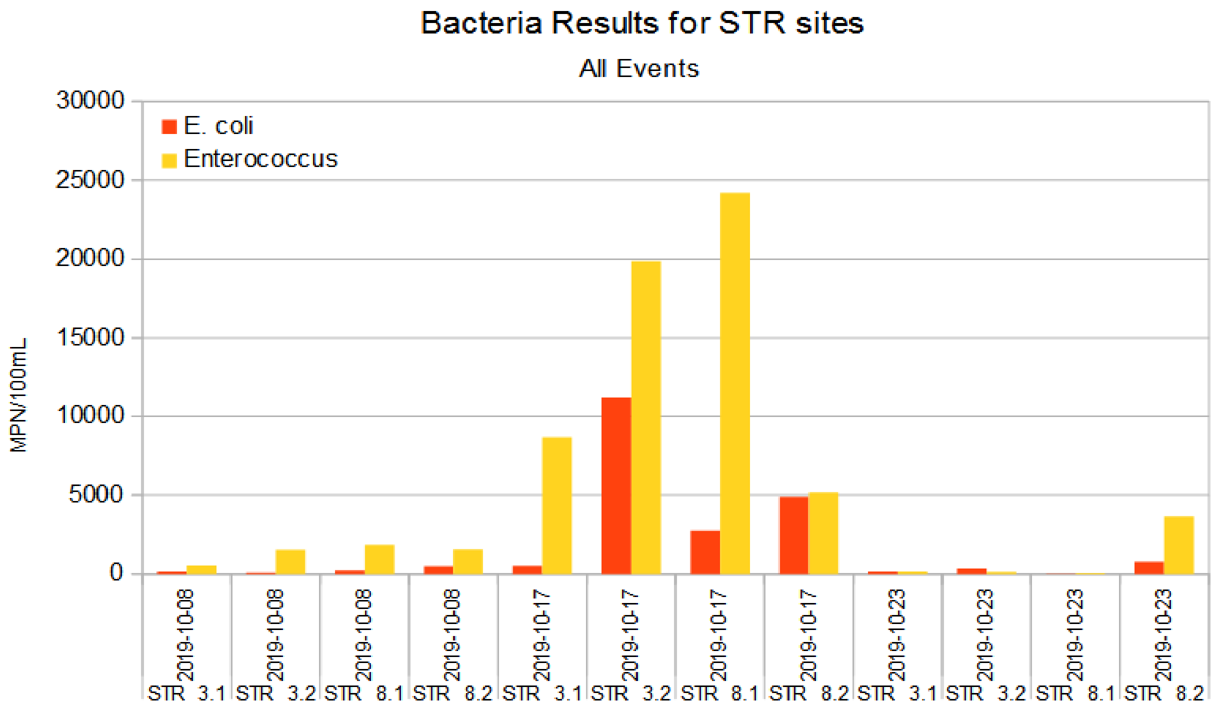

Figure 20. Bacteria results at all stream (STR) sites (3 events).

All the stream results are shown in Figure 20 for comparison between events. The results on October 17 were much higher than the other two sample dates. Precipitation was similar on October 17 and October 23 at the two reference weather station sites used, but it is possible that the study location received more precipitation on October 17. Precipitation intensity is also important to consider, as this is critical in terms of runoff and mobilization of particulates on the surface. Considering the events individually, there was no clear tendency for FIB results to be higher at the downstream locations. The largest downstream differential was seen on October 23 between sites STR8.1 and STR8.2, but this was not the case for the earlier events. Overall, all the stream locations were found to have variable but relatively high FIB results, often exceeding the Health Canada guidelines for contact activities.

Pharmaceuticals and Personal Care Product (PPCP) Results

As part of the study a total of 20 samples were tested for pharmaceuticals and personal care products (PPCP), plus caffeine. Four samples were from stream sites (STR), six from stormwater sites (SW), seven from outfalls leading into the Parlee Beach lagoon (PBPP) and three from catch basins (CB). Most samples were collected on either October 7 or October 8, either during or following a precipitation event of about 13-17 mm. One SW site was collected on October 15 (precipitation 2-4 mm) and the catch basin sites on October 2 (precipitation < 1mm, but 4-5 mm on October 1).

The substances tested for as part of this analysis are listed in the table below. Many of these compounds are useful indicators of contamination by human wastewater due to the fact that natural sources are usually zero or insignificant. They are widely used in studies of environmental contamination of surface waters.

Chemical Tracer Compounds Sampled in Stormwater	
Substance	**Notes**
Caffeine	Sources include coffee, tea and cocoa-containing products.
3,4,4-Trichlorocarbanilide	Triclocarban, antimicrobial agent in soaps, cosmetics and other personal care products.
Acetylsalicylic acid	Widely used pharmaceutical (aspirin).
Bezafibrate	Drug used to manage cholesterol.
Carbamazepine	Widely used anti-seizure drug.
Clofibric acid	Metabolite of the cholesterol-lowering pharmaceutical drug clofibrate.
Diclofenac	Anti-inflammatory drug.
Fenoprofen	Anti-inflammatory drug.
Gemfibrozil	Drug used to manage cholesterol.
Ibuprofen	Anti-inflammatory drug.
Indomethacin	Anti-inflammatory drug.
Ketoprofen	Anti-inflammatory drug.
Meclofenamic acid	Anti-inflammatory drug.
Methyl Triclosan	Bactericide.
N,N-diethyl-m-toluamide	DEET, commonly used insect repellent.
Naproxen	Widely used anti-inflammatory medication.
Salicylic acid	Used as a skin exfoliant and acne treatment. Metabolite of acetylsalicylic acid.
Tolfenamic acid	Anti-inflammatory drug.
Triclosan	Antibacterial compound used in many consumer products.
Notes: Analyses were performed by the Innotech laboratory in Vegreville, Alberta.	

The majority of results for all compounds at all sites were below detection. However there were some positive results for a small number of substances at some sites. Given the small number of positive results, these are summarized in the following table.

Positive Detections for PPCP Compounds plus Caffeine at Study Locations			
Site	**Sample Date**	**Compounds Detected**	**Result (µg/L)**
SW1	Oct 15	DEET Caffeine	0.063 0.020
SW3	Oct 8	DEET Ibuprofen	0.027 0.030
SW5	Oct 8	DEET Salicylic acid	0.045 0.176
SW6	Oct 8	None	-
SW8	Oct 8	None	-

Positive Detections for PPCP Compounds plus Caffeine at Study Locations			
Site	**Sample Date**	**Compounds Detected**	**Result (µg/L)**
SW9	Oct 8	DEET	0.014
STR8.1	Oct 8	DEET Salicylic acid	0.036 0.140
STR8.2	Oct 8	DEET	0.024
STR3.1	Oct 8	DEET	0.016
STR3.2	Oct 8	DEET Ibuprofen	0.011 0.026
PBPP1	Oct 7	DEET	0.108
PBPP2	Oct 7	None	-
PBPP3	Oct 7	DEET	0.158
PBPP4	Oct 7	DEET	0.080
PBPP5	Oct 7	DEET	0.092
PBPP7	Oct 7	DEET	0.272
PBPP8	Oct 7	DEET	0.595
CB1.2	Oct 2	DEET	0.044
CB3.2	Oct 2	DEET Salicylic acid Caffeine	0.138 0.147 0.510
CB9.1	Oct 2	DEET Salicylic acid	0.047 0.258

The most widely detected compound was N,N-diethyl-m-toluamide, more commonly known as DEET. This widely used insect repellent was detected in samples from 17 of the 20 samples collected. This substance was not specifically selected as a wastewater tracer in the study design but was included as part of the standard PPCP analysis package offered by the testing laboratory. DEET is known to be widely distributed in the environment and moderately persistent. Weeks et al. (2012) reported that DEET enters the environment through several pathways: directly into air during spray application, to surface waters from overspray and indirectly via wastewater treatment plant (WTTP) discharges (as a result of washing of skin and laundering of clothing). In surface waters and soil, DEET degrades at a moderate to rapid rate (its half-life is measured in days to weeks). As such this suggests that the DEET detected in this study was probably released into the surrounding environment during the same season. Weeks et al. (2012) noted that the bioaccumulation potential of DEET is low; it is not considered a persistent, bioaccumulative toxicant nor a persistent organic pollutant. Among aquatic species, acute effect concentrations range between 4 and 388 mg/L. The observed values across all sites were all more than1000 times lower than this range.

Clarke et al. (2015) in a study of landfill leachate from five sites in the United States found that DEET was one of ten trace organic pollutants commonly detected in surface and municipal wastewater effluents. Their study reported that the contaminants found in the highest concentrations were DEET (6900–143 000 ng /L) and sucralose (<10–621 000 ng/ L). The DEET values are about 10 or more times higher than the values seen in the Shediac results, but this is not surprising as landfill leachate and wastewater would be expected to be more highly contaminated than surface waters.

Costanzo et al. (2007) reported that DEET has commonly been detected in aquatic water samples from around the world, indicating that it is both mobile and persistent, despite earlier assumptions that DEET was unlikely to enter aquatic ecosystems.

Because DEET is often applied outdoors it can enter the environment from a range of locations separate from the wastewater stream. As such it is not (on its own) a reliable indicator of wastewater contamination of surface waters or stormwater. While the literature does not suggest any special concern over the toxicity of DEET in the environment (as noted in Costanzo et al., 2007), its detection in multiple locations across the study area provides confirmation that some personal care products do become widely distributed in surface waters.

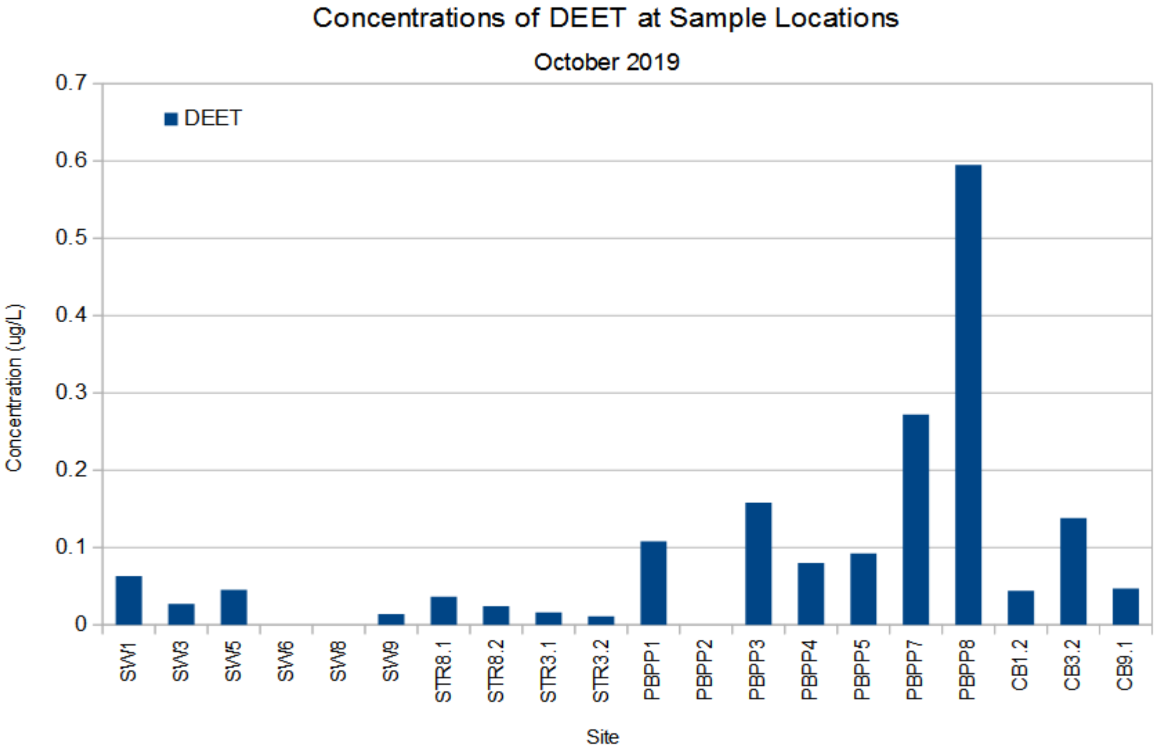

Figure 21. DEET results at all sample locations.

Figure 21 shows the range of DEET concentrations across the different study sites. Values at SW and STR sites were relatively low and in a similar range. Values at the Parlee Beach lagoon outfall and catch basin locations were higher, but as noted above, not especially high in relation to acute effect concentration values. Higher values might be expected in the Parlee Beach location where large numbers of people can be expected to be using insect repellents.

Caffeine

This substance was detected at two sites. Although there are some plant-based sources of caffeine in the environment, background levels are usually negligible and can be disregarded (Sauvé et al., 2011).

Caffeine Detections in the Shediac Bay Watershed			
Site	*Caffeine (µg/L)*	*E. coli (MPN/100 mL)*	Enterococci *(MPN/100 mL)*
SW1	0.020	NA	NA
CB3.2	0.510	10	364

The result of 0.020 µg/L for site SW1 is equal to the reporting limit for the analysis used. As such it is not possible to conclude with high confidence that this may indicate wastewater contamination. On the other hand, almost all the other samples returned results below detection. This suggests a possible flag against this location warranting further testing or investigation to see if there are additional indications of wastewater impacts.

The result of 0.510 µg/L from site CB3.2 appears more significant. Sauvé et al. (2011) suggest (based on their investigations in Montreal) that a water sample shown to contain more than 400 ng /L of caffeine, has a 100% chance of being contaminated with more than 200 cfu/ 100 mL of FIB. This CB3.2 sample equates to 510 ng/L of caffeine. The bacteria results for the same site and sample date were: *E. coli* 10 MPN/100 mL and enterococci 364 MPN/100 mL, relatively unremarkable compared to many other results that were much higher, for example from catch basin sites 1.1 and 1.2, but still indicative of bacterial impacts.

Caffeine-free sources of FIB include wildlife and cattle. If FIB are found in a water sample but little or no caffeine, it suggests wildlife as the source of the FIB. This is probably the case at most of the sample sites tested during this study, when FIB were often found, but caffeine seldom. When caffeine and FIB are found together this implies a human source or a mixture of human and wildlife-influenced waste.

Salicylic Acid

When aspirin (acetylsalicylic acid) is ingested, it is quickly hydrolyzed to the major excretion product, salicylic acid (Khamis et al. (2011). Salicylic acid was found at four sites in the study network, as follows.

Salicylic Acid Detections in the Shediac Bay Watershed			
Site	*Salicylic acid (µg/L)*	*E. coli (MPN/100 mL)*	Enterococci *(MPN/100 mL)*
SW5	0.176	30	63
STR8.1	0.140	228	1850
CB3.2	0.147	10	364
CB9.1	0.258	31	20

You et al. (2015) studied urban surface waters of Singapore for PPCP and related compounds over a 16-month period and found that all sites had measurable PPCP and EDC concentrations, with caffeine (33.9–2980 ng/L), salicylic acid (5–838 ng/L), acetaminophen (< 4–485.5 ng/L), BPA (< 2–919.5 ng/L) and DEET (13–270 ng/L) being the most abundant. The results for salicylic acid in this Shediac study fall into the same range as that reported by You et al.

Khamis et al. (2011) reported that influent concentrations of salicylic acid in wastewater in Palestine were found to be 54 µg/L whereas the concentration in treated effluents was around 0.5 µg/L. The values seen in this study were much lower than these influent values, but this is to be expected as the

Shediac samples were not sampled directly in the wastewater system.

Carmona et al. (2014) in a study of the Turia River, Spain found concentrations of salicylic acid of 70 ng/L in river water (n=22) compared with 295 ng/L in wastewater treatment plant influent (n=21). The Shediac study results are all greater than the Turia River values, as such they could be considered elevated above background when compared with the Turia River results, although they are of the same order of magnitude.

Comeau et al. (2008) studied pharmaceuticals in wastewater and surface waters at three locations in Atlantic Canada. In their review they noted that drug residue concentrations in receiving waters generally fall in the low ng/L to low µg/L range. Again this would suggest the Shediac salicylic acid results are elevated with respect to background. As part of the Comeau et al. study (2008), samples were taken in the Cocagne estuary area (near Surette Island). No pharmaceuticals were detected in their survey, but salicylic acid and caffeine were found, in the ranges 15-36 ng/L and 15-18 ng/L respectively. The authors concluded that this was an indication of organic pollution in the area, probably from leaking/failing domestic septic systems. The salicylic acid results in the present study were about 10 times those reported by Comeau et al. Is this clear evidence of contamination by wastewater? While all the samples that were positive for salicylic acid also had positive results for FIB, the values were not especially high compared with other results at the same sites. However, the small number of results for PPCP and caffeine testing limits interpretation. It is possible that values for PPCP and caffeine were also above detection on other occasions when higher FIB values were found.

Perhaps the most interesting is the sample of October 2 at site CB 3.2, which had positive detections for both caffeine and salicylic acid, plus DEET. This profile of results suggests the impact of human wastewater at this location. Further on-site investigations to check for possible contamination sources would be useful. Underground cross-contamination between the wastewater and stormwater systems could explain the results seen at this site, unless the caffeine and salicylic acid originated from non-wastewater sources, for example discarded caffeinated drinks and pharmaceuticals.

Ibuprofen

This pharmaceutical was detected in two samples, as follows.

Ibuprofen Detections in the Shediac Bay Watershed

Site	*Ibuprofen (µg/L)*	*E. coli (MPN/100 mL)*	Enterococci *(MPN/100 mL)*
SW3	0.030	1223	1935
STR3.2	0.026	86	1541

Like many other pharmaceuticals used as environmental tracers, ibuprofen has no natural sources and its presence is generally held to indicate the impact of human-generated wastewater (e.g. Buser et al., 1999). Buser et al. reported values of ibuprofen from lakes and rivers in Switzerland in the range 1-3 ug/L. Bendz et al. (2005) reported influent concentrations of ibuprofen in the Hoje river, southern Sweden, of 3.6 ug/L. In their study Comeau et al. (2008) found ibuprofen concentrations of 13-22 ng/L in the Pictou watershed, and 6-230 ng/L in the Halifax study location. Much higher values of 140-6300 ng/L were found in wastewater treatment plant effluents.

The values seen in the current study are about 100 times lower than those reported in the Swiss and Swedish studies cited above (for surface waters, not effluents), but similar to those found by Comeau et al. (2008). As the Shediac results are above detection, they still constitute a flag against these locations. How did this substance arrive in the samples? As both sample locations are influenced by a significant catchment above the collection point, there could be numerous possible locations where wastewater contamination may have occurred. As for the caffeine and salicylic acid results, the very small sample numbers limit interpretation. All samples obtained at sites SW3 and STR3.2 were positive for both *E. coli* and enterococci, which suggests significant FIB sources influencing those sites, although not necessarily those originating from wastes of human origin. Furthermore, samples at a range of other sites had high FIB values but no detections for ibuprofen or other pharmaceuticals.

Optical Brighteners

As part of the chemical source tracking approach employed in this study, a range of samples were tested for optical brighteners (OB). Also known as fluorescence whitening agents, these substances are found in many commercial cleaning products, and make the products being cleaned look brighter with more intense colours. These compounds are not found in nature, so if they are detected in the environment they came from a human-related source. The largest volume of optical brighteners is used in laundry detergents. Accordingly, their presence in water in the environment implies contamination with human-generated wastewater. As well as in sanitary wastewater, optical brighteners can also be found in other products containing detergents that may be used to wash cars, house siding, or outdoor furniture. As such it could be present in runoff in urban areas from residential or commercial lots. Any detection of optical brighteners in stormwater would be a flag that further investigation would be indicated to identify the source(s) of contamination.

Testing for optical brighteners was carried out using a Turner Designs Aquafluor fluorimeter. A total of 131 samples were tested from a subset of all surface site types, as well as SW sites. Although fluorimetric testing for optical brighteners has been used by many researchers investigating water contamination, there are no formally standardized methods. The procedures documented by Burres (2011) were used in the present study.

Overall, the results for optical brightener analysis were negative. Across all the site types examined there were no results with a result of 5 ppm or more, the suggested cutoff for concluding that the sample contains optical brighteners according to the Burres (2011) procedure. A further test as part of the evaluation process is to irradiate the samples with ultraviolet light to check for a reduction of the optical brightener value. A reduction of 30% or more is considered positive for optical brighteners, assuming the concentration was > 5 ppm. Although none of the samples tested above 5 ppm, they were irradiated anyway to check for the result. An average reduction in the optical brightener reading of > 30% was seen for 10% of the total 131 samples tested. There was no apparent relationship between the OB values and FIB results in any samples, suggesting that wastewater was not contributing significantly to the FIB results at any sample site.

For example Figure 22 is a plot of reduction in OB value versus entercocci values across all sites. High enterococci values occur across a wide range of OB reduction results (many near zero) and conversely a significant number of high results for OB reduction are associated with low entercoccus numbers.

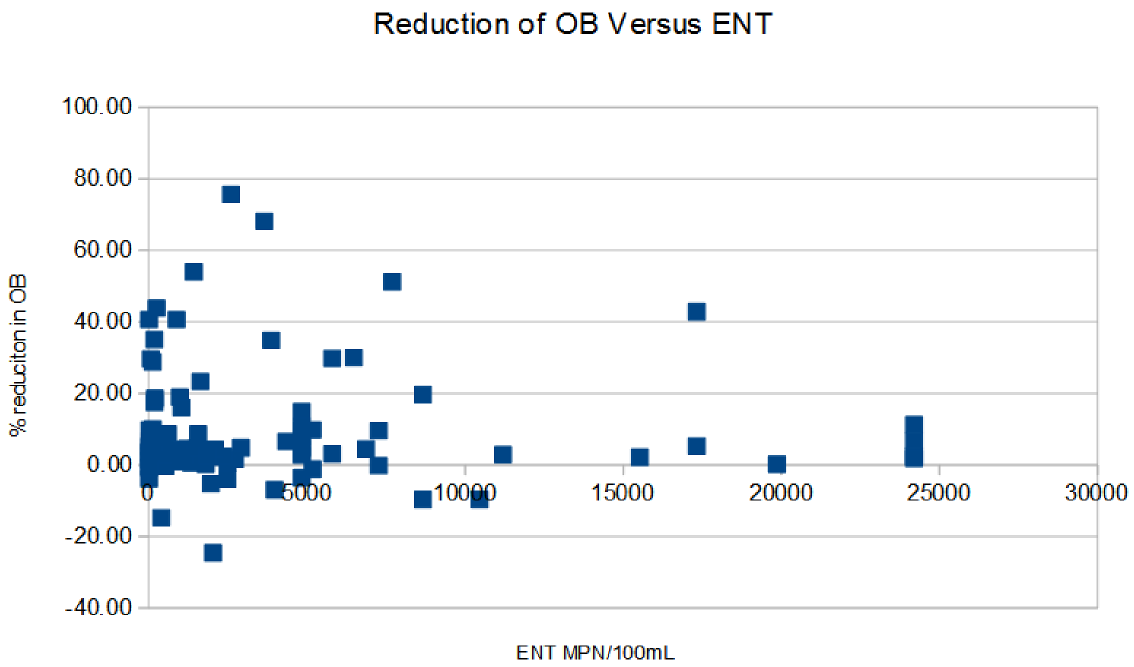

Figure 22. Reduction in OB result following irradiation versus enterococci.

One pattern was evident when considering the OB reduction results. The values obtained at the grass sampling locations were significantly higher than any other class of site. The data are summarized in the following table. At the grass location samples 75% (n=12) showed an OB reduction of 10% or more. This was more than three times the frequency seen at any other site type. Perhaps also of note was that none of the SW sites showed a >10% reduction in OB. The source of fluorescence in the grass site samples could be chlorophyll from the grass itself. Wastewater can be ruled out. Chlorophyll is a naturally fluorescent molecule which ultraviolet irradiation may degrade over time during the testing process. An effect of this kind was found by Nassour et al. (2017) investigating the effects of ultraviolet light on algae.

Percentage of Samples with OB Reduction of > 10% by Site Type	
Site Type	% of Samples > 10% reduction
CB	25.0
GR	75.0
Lagoon (PPPB)	9.5
PL	11.1
R	18.5
RF	16.6
STR	16.6
SW	0.0

4. STORMWATER WATERSHED MAPPING

A Stormwater Watershed Map

An exercise was undertaken to define the stormwater watersheds across the municipal area serviced by the Shediac municipal stormwater system. Knowing the area of influence associated with each sampling location offers the possibility of enhanced data interpretation. This information may also be used to guide and optimize the location and types of pollution prevention actions, as well as planning infrastructure changes or enhancements. This work required calculations of water flow based on the land surface elevation profile, carried out using specialized geographic information system (GIS) tools. The resulting sub-basin boundaries then had to be checked against and adjusted taking into account flow paths determined by the stormwater pipe system. This work was carried out by staff of the New Brunswick Department of Environment and Local Government (Water Sciences and Geographical Information Systems Sections). Full details of the methodology used to calculate the watersheds is contained in Appendix A.

Figure 23. Stormwater watersheds in the Shediac municipal area. Credit: New Brunswick Department of Environment and Local Government. See Appendix A for methodology.

The stormwater watershed boundaries obtained from this exercise are shown in Figure 23. Each stormwater watershed has a defined discharge (outlet) location. Some of these are stormwater outfall pipes, for example, discharges from watersheds 16-18 are released from outfalls directly into Shediac Bay. Other discharge points are locations where one sub-watershed discharges into another, usually along a watercourse, with a few discharging into ditches that subsequently convey stormwater to a watercourse.

As can be seen in Figure 23, some parts of the municipal area are not served with the piped underground stormwater network (notably Pointe-du-Chene). Stormwater in these areas is managed via roadside ditches and culverts. These areas were not included in the stormwater watershed mapping exercise.

Characteristics of the Stormwater Watersheds

Figure 24 shows the mapped stormwater watersheds in relation to the stormwater monitoring site locations which provided data for this report.

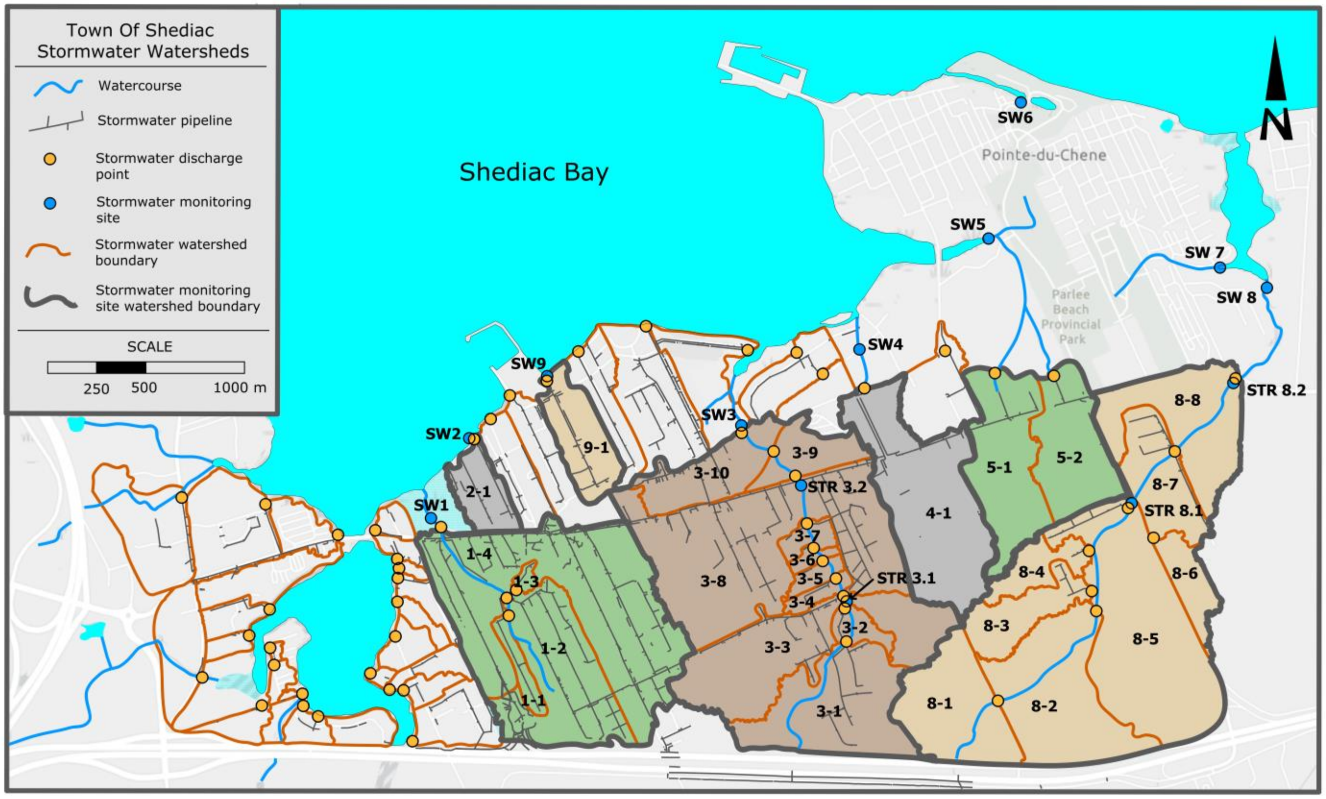

Figure 24. Stormwater watersheds in the Shediac municipal area associated with monitoring site locations.

Shown in the figure are the locations of stormwater sites SW1-SW9 plus the additional stream sites STR 3.1, STR 3.2, STR 8.1 and STR 8.2. For each of these sample locations, all the sub watersheds have been delineated.

Beginning on the western side of the area, there are four sub-basins that contribute to site SW1 (numbered 1-1 to 1-4). This site is in a small creek (Taits Creek) that discharges to the Bay behind the City Hall building. Runoff at site SW1 will be heavily influenced by stormwater collected via the stormwater system along Main Street and a number of adjoining suburban streets.

In contrast, site SW2 is served by a much smaller watershed containing just a couple of residential streets. Site SW9 is similar in terms of the size of the watershed and land use type.

Site SW3 is in a small, northward-flowing watercourse in the centre of the municipal area. There are 10 defined sub-watersheds (3-1 to 3-10) that contribute water to this monitoring location. Note that the watersheds to the north of site SW3 (22, 23 and 24 in Figure 23) do not contribute to discharge at this monitoring site location.

Site SW4 is fed by watershed 4-1 in Figure 24, which contains a mix of low density development and rough open land in its upper (most southerly) part. In the central and northern parts of this catchment, stormwater is contributed from a section of Main Street. Within the watershed boundaries there are areas of typical suburban density housing development, as well as part of a campground.

Site SW5 is just downstream of the confluence of two small watercourses, one originating to the north of the monitoring site, in an area of open land south of Parlee Beach Provincial Park. The other, more significant watercourses begin just north of Main Street/ highway 133. Watersheds 5-1 and 5-2 discharge into these watercourses and contain mostly commercial premises, with very little residential housing. It is notable that developments such as a new building supply store on Ohio Street constitute significant areas of impermeable surface. This development is in sub-watershed 5-2 (number 30 in Figure 23) and occupies about 15% of the total area of this watershed.

Site SW6 is in Pointe-du-Chene and is located in a surface ditch that receives runoff from adjacent streets and probably parking lots. As this area was not mapped in detail there are no sub-watershed boundaries available to consider. The adjacent land use type is residential, with low-density housing.

Site SW7 is on a small watercourse. As this location was also outside the piped stormwater network the detailed stormwater watersheds were not mapped in its vicinity. Adjacent land use includes the Parlee Beach campground and two large trailer/RV parks.

Site SW8 is on a watercourse that has its origin in swamplands south of highway 15. From there it flows in a northeasterly direction, receiving water from sub-watersheds 8-1 to 8-8. Watershed 8-1 is largely wooded; watershed 8-2 also has a significant forest cover, but also a large RV park. Watersheds 8-3 to 8-5 all discharge stormwater to the watercourse from streets within a modular home development. Runoff from 8-6 is released to a ditch at the mapped discharge point; from this location it flows northwestwards about 200m before finally entering the main watercourse. Land use in 8-6 is commercial/industrial. Watershed 8-7 contributes stormwater via the piped system from suburban streets. Watershed 8-8 is different in nature as it is on the fringes of the piped stormwater network and has almost no piped stormwater infrastructure. Aerial imagery shows that street runoff from route 133 enters stream 8 after flowing along the roadside shoulders. There are also some roadside ditches. Land use in 8-7 is low-density residential / commercial north of the watercourse and almost all undeveloped, rough open or wooded land to the south.

The surface areas of each of the stormwater watersheds that discharge to monitoring site locations are listed in the following table. The data are incomplete in that the watersheds associated with some sites were not determined (for SW6 and SW7). Some of the monitoring site locations are also not located at the boundary of the mapped watersheds, they therefore receive some water from additional areas not included in the totals shown in the table. Nevertheless several things are clear: watersheds for sites SW1, SW3 and SW8 are the largest, with those for sites SW2 and SW9 being much smaller and SW4 and SW5 intermediate in area.

Areas of Watersheds Associated with Stormwater Monitoring Sites

Sample Site	Watershed Area (000s of square metres)
SW1	1132
SW2	100
SW3	1923
SW4*	480
SW5*	539
SW6	N/A
SW7	N/A
SW8*	2050
SW9	153

Notes: * The monitoring sites in these watersheds also receive water from areas outside the mapped watershed.

The area of each stormwater watershed is important, as a larger watershed captures more precipitation, and would be expected to generate a larger flow in its watercourses. However, given the objectives of this monitoring study, the most important features are the proportion of impervious surfaces in each stormwater watershed, and the strength of the pollution sources within them. A greater proportion of impermeable surface will result in greater volumes of runoff. In general, runoff from man-made surfaces will be contaminated with pollutants associated with human activity and development noted in earlier sections of this report.

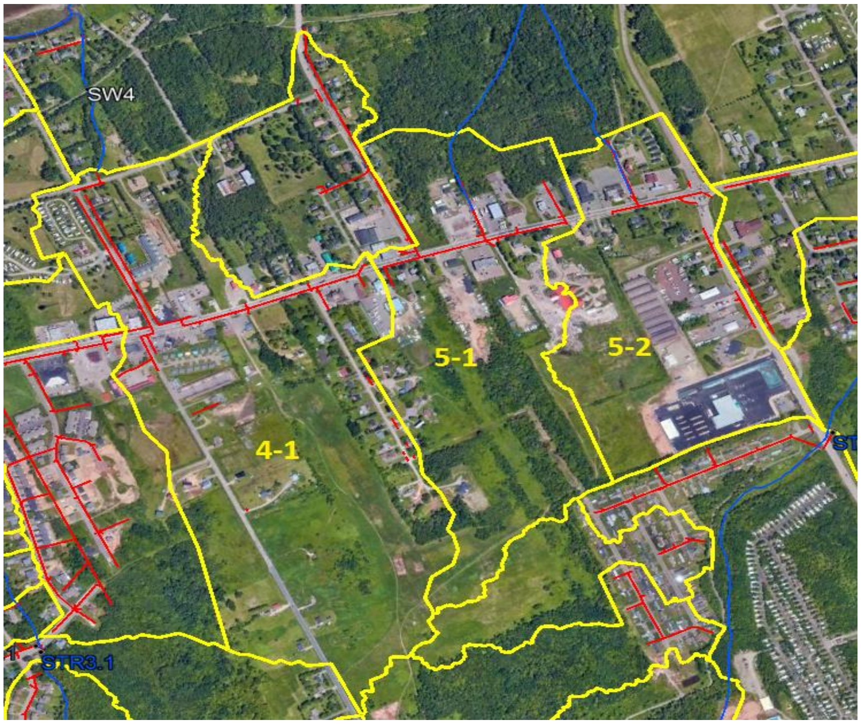

Figure 25. Example watersheds showing relative extent of development and impervious cover. Watershed boundaries in yellow, stormwater pipes in red.

Inspection of aerial imagery shows that the SW1 watershed has the greatest proportion of impervious surface - parking lots, roads and housing development (roughly 50%). The SW3 watershed has considerably less impervious cover, and the SW8 watershed a still lower level. For SW4, watershed 4-1 has less than 50% impervious cover. Watershed 5-1 has less than 50%, but 5-2 appears to be slightly over 50%. This can be seen in Figure 25. Watershed 5-2 is quite small and recent development at its southeastern end covers a significant area.

As the area of impervious surfaces increases so will the proportion of runoff for each unit of precipitation, but if this runoff is clean, it will not have adverse effects on water quality. As this study is concerned primarily with water quality, it is the pollution source strength that is of major importance, the worst scenario being extensive impervious surfaces that are also contaminated with pollutants that can impair water quality. Roads and parking lots are likely to be the biggest contributors to polluted runoff from of vehicle-related pollutants such as oil, grease, metals from brake and tire wear, and deposition of exhaust particulates. In practice there is no 100% clean runoff from impervious surfaces in municipal environments.

Considering FIB, animal feces on impervious surfaces is an especially undesirable combination as the fecal material can then be rapidly mobilized by runoff and conveyed to storm drains. Pet waste on sidewalks, roads, parking lots and driveways is an obvious example of this problem, and excrement from wildlife is also deposited on these surfaces. Sea birds often congregate in significant numbers on flat roofs and parking lots and these are both surfaces that enable rapid entry of runoff to the stormwater system. As the map data in this report show, all principal storm drains eventually discharge to surface water channels or direct to Shediac Bay. In areas without storm drains, where street runoff is conveyed by ditches, there may be some possibility for filtration and amelioration of water quality if the ditch is covered with grass, reeds, shrubs or other vegetation.

Considering the possible impacts of stormwater discharges on the receiving waters of Shediac Bay, the most important factor is likely to be the total mass of pollutants (organic and inorganic) input to the Bay. This depends on stormwater volume as well as pollutant concentration. Stormwater sampled at some of the smaller stormwater outfalls (such as at SW9 or SW2) at times show elevated levels of contaminants. However the small area of their contributing watersheds limits the total mass of pollutants that can be discharged. The larger volumes of stormwater that will be generated by the larger stormwater watersheds (such as SW1, SW3 and SW8) suggest that these areas are likely to have a greater impact on the water quality in Shediac Bay.

Data Interpretation Considering Stormwater Watersheds

Knowledge of the watershed boundaries can assist with interpreting some aspects of the monitoring results. The sub-watershed detail is relevant for the results obtained at the main stormwater monitoring locations (SW1-SW9), the stream monitoring sites, and the catchbasin sites. It is not relevant for the samples obtained on roads, parking lots, grass surfaces and roofs, as the water sampled at these locations is not influenced by hydrological processes across the wider watershed but instead reflects conditions immediately local to the sample point.

Stormwater sites

Referring to Figures 3, 4 and 5 for FIB results at these sites, the highest peak results were seen at sites 2, 6 and 9. While there is no detailed watershed boundary detail available for site 6, sites 2 and 9 are similar in that they are both small catchments where the discharge is conveyed by storm drains direct to the monitoring point. Both sites are adjacent to the coastline and there are large parking lots located at the southern extent of both watersheds. Transit times in the storm drains are probably quite short as the total length in each case is about 400-500m. Although the concentrations of FIB seen at both sites SW2 and SW9 were high, the watershed sizes are among the smallest in the whole area and this will limit the total mass of pollutants discharged to the Bay. As such these outfalls, although contributing to the overall pollutant load, are almost certainly less important than the other discharges from mapped watercourses.

Considering the trace metals associated with vehicle tire and brake wear (Figures 7 and 8), highest values were seen at sites 1, 2 and 6. Considering the relative proportions of land cover discussed above, site SW1 would be expected to have higher results given the large area of road and parking lots in its watershed. Taits Creek, as represented by the data at site SW1, can be expected to have a more significant impact on the receiving environment given the much greater discharge at this location compared to discharge at sites SW2 or SW9.

Catchbasin Sites

Further to the discussion of these results on page 15 and presented in Figure 10, the elevated FIB values at site 1.2 are consistent with the indications of the watershed mapping data; this shows that a total of over 3.5 km of storm drains servicing McQueen Street, Caissie Avenue and Rachel Street converge at the sampling location. Catchbasin site 1.1 is located in watershed 1-1 in Figure 24 and can be seen to have a much smaller area. It is possible that there are differences in FIB sources in each of these catchments that could explain the differences in results, although there are no field data available to confirm this. The number of samples is small which also puts limits on interpretation of the results.

Considering catchbasin sites CB3.1 and 3.2, these are both at the end of storm drain networks of similar lengths, about 1.5 km, although the drains ending at CB3.2 service a much busier road (Main

Street), which may explain the higher FIB results at that site.

Catchbasin sites sampled in watershed SW9 had lower FIB results although this is probably a reflection of the specific dates when sample were obtained, as the larger number of samples obtained for waters monitored at site SW9 showed relatively high results compare to other sites.

Stream Sites

There were two pairs of stream sites, located on streams in watersheds 3 and 8. Within the area serviced by the municipal stormwater system watershed 3 has an area of 1.92 km^2 and watershed 8 2.05 km$^{2.}$ However while the watershed areas are quite similar, examination of Figure 24 shows that stream 3.2 has a much greater total length of storm drains that discharge into the main watercourse. Despite this apparently significant difference, the results as summarized in Figures 17-20 showed no systematic tendency for the FIB data from stream 3 to be higher than those in stream 8. The more extensive greater storm drain network for stream 3 would be expected to make discharge more rapidly responsive to precipitation events than stream 8, and total discharge per event may also be higher. As such, the impacts of discharge from stream 3 to the receiving waters would be greater.

PPCP Results

Results for these substances are discussed on pages 23-29. The number of positive detections was low, but there are some potentially useful observations that can be made. Ibuprofen was detected at sites SW3, STR 3.2 and CB 3.2. These sites are all in the same stormwater watershed. Furthermore the positive ibuprofen results at SW3 and STR3.2 were observed on the same day, October 8. Sites CB3.2 and STR 3.2 are very close together where stream 3 crosses Main Street. This suggests a common factor and that the ibuprofen was in the stormwater discharged to stream 3 by the storm drain network at Main Street. In that location there are storm drains that drain towards the watercourse from both east and west. It is possible that potential sources of PPCP could be identified by field work in this area. Any checks on possible crossover points between the wastewater system and stormwater system should also focus on the area bounded by the stream 3 watershed in this area. High FIB was also observed at site SW3 on October 8.

The other positive PPCP results appear to offer less scope for further interpretation. Caffeine was found at sites SW1 and CB 3.2. Considering site CB3.2, there is a Tim Hortons store about 330 m east of the sample point and down gradient along the stormwater line that leads to CB 3.2. Possibly discarded coffee and/or coffee cups could prove to be the source: this could be investigated by some forensic testing.

For other results, the appropriate stormwater watershed boundaries can be used to focus any investigations of possible sources, although in some cases this still leaves significant areas to be examined.

5. SUMMARY OF RESULTS

The 2019 stormwater sampling study provided a significant amount of information additional to that obtained in earlier investigations. The following are the main findings:

- Results for FIB in stormwater as sampled at small stream sites in the Shediac watershed (SW sites) were similar to those found in 2017 and 2018. Fifty-seven percent of samples exceeded single sample guidelines for *E. coli*, and 84% for entercocci. The geometric mean for *E. coli* and enterococci across all SW site samples also exceeded the Health Canada guidelines

(Health Canada, 2012) for recreational water quality for multiple samples.

- As seen in previous years, FIB concentrations in stormwater were higher when sampled during or shortly after larger precipitation events (> 10-15 mm).

- Trace metals in stormwater at SW sites such as lead, zinc and copper were found to be present at levels elevated in comparison to those seen in many larger rivers across New Brunswick. Such metals are suspected of being associated with emissions from motor vehicles that are deposited on roads and parking lots.

- Runoff samples collected at a variety of surface types across the municipal area including catchbasins, roads, parking lots, grass areas, roofs and intermediate streams were also frequently found to contain elevated concentrations of FIB. Samples collected from roads, parking lots and grass areas had the highest concentrations of FIB, whereas those from roofs and catchbasins had lower values, although positive results were found at all sample locations.

- Considering the Health Canada guidelines for multiple samples, geometric mean FIB results for *E. coli* exceeded the guidelines at the SW, GR and STR sites, whereas the guideline for entercoccus was exceeded at all site types (SW, CB, PL, R, RF, PPPB and STR).

- Some positive results for FIB were found in samples collected at seven sites discharging to the Parlee Beach lagoon, although values were unremarkable in comparison to other stream and surface sites sampled during the study. Most of these sites receive runoff from adjacent parking lots.
- There was no systematic tendency for downstream values of FIB to be higher than upstream locations in two streams sampled in sub watersheds 3 and 8, although most of the results obtained revealed elevated FIB concentrations.

- Stormwater and runoff samples tested for a range of commonly used pharmaceuticals and personal care products plus caffeine, commonly used chemical tracers of wastewater impacts, were found to be mostly below detection. Exceptions were two samples positive for caffeine, four for salicylic acid, and two for ibuprofen. All the sites with positive results were stream (STR or SW) or catchbasin sites. Associated FIB results were positive but not remarkably high.

- Testing for optical brighteners in a range of surface water and runoff samples, a chemical tracer of human wastewater, produced negative results. There was no apparent relationship between optical brightener values or reduction in OB results following sample irradiation and FIB results.

- Detailed mapping of stormwater watersheds revealed that the watersheds for streams discharging at sites SW1, SW3 and SW8 are largest and may be expected to contribute the greatest quantities of stormwater to Shediac Bay.

- Stormwater watersheds 1 and 3 have the greatest extent of impervious cover and length of stormwater pipe infrastructure.

6. CONCLUSIONS

Testing small streams for FIB in 2017 and 2018 (8-9 SW sites) revealed that FIB were often found in these watercourses, sometimes at high concentrations, often highest following larger precipitation events. Sampling in 2019 found the same pattern at those sites. More significantly, testing discrete runoff samples collected from a range of land surface types found that FIB were to be found in the majority of these samples. One of the principal concerns when FIB are found in surface waters is that the contamination may have originated from human-generated wastewater. Wastewater could find its way into streams and stormwater via leaking underground wastewater pipework, cross connections between the wastewater and stormwater conveyance systems, overflows to the surface from the wastewater system, or failing septic systems.

There is no realistic way for any human-generated wastewater to have influenced the FIB results at any of the grass surface, parking lot, road or roof sites sampled during this study. The fact that positive FIB results were found at all these site types is conclusive evidence that other bacterial sources must be responsible. The most likely sources are wildlife and domestic animals. The fact that similar FIB results were found at well-separated locations across the municipal area on all the surface types suggests that the sources responsible are widely distributed.

Lower (but still positive) FIB test results from roofs suggests that bird feces are highly likely to be contributing on roof surfaces, and that hard surfaces at lower elevations such as roads and parking lots are accumulating higher loadings of FIB, probably also from birds, plus other wild animals and pets. Cumulative effects, as roof runoff adds to pet and wild animal feces on grass and asphalt surfaces, plus possible persistence and establishment of FIB in soils and vegetation (e.g. Minnesota Stormwater Manual (2019), Tomasko (2016)) can probably explain the higher results observed in samples collected from roads and parking lots.

When mobilized from these impervious surfaces during significant precipitation events, dissolved and particulate matter in surface runoff can pass with minimal holding times via storm drains and enter the small stream network. The final runoff feeding these streams has by this time accumulated a range of contaminants (including FIB). Perhaps not surprisingly the results showed that geometric mean FIB levels in the SW and STR sites were the highest of all (Figure 9), exceeding established guidelines for recreational water contact.

The Parlee Beach lagoon has been the focus of a range of earlier testing for FIB in both water and sediment (e.g. Crandall Engineering, 2019). Testing in the present study revealed generally unremarkable FIB results and bearing in mind that the discharges to the lagoon appear to be mainly from adjacent parking lot surfaces it should not be surprising that the bacterial results were in the same range as other parking lot sites tested. These parking lots will receive fecal deposits from birds and other wildlife plus (probably) dogs.

Recent analysis of the use of entercocci as a water quality indicator published by Health Canada is relevant in helping understand both the usefulness of this indicator and its limitations (Health Canada, 2019). This reference notes that standard test methods used for enterococci (and coliforms) do not resolve specific fecal species, only the genus level, and that species found naturally in the environment are detected by these methods. Enterococci have been detected in a range of environmental habitats including plants, flowers, vegetables, cereals and grasses, freshwater and marine water, sand, soil and sediments. This has complicated interpretation of FIB results as it can no longer be assumed that any one genus is exclusively associated with fecal wastes. Moore et al. (2008) reported that the largely environment-associated species *E. casseliflavus* was the dominant species in urban runoff, while *E. faecium, E. faecalis* and *E. hirae* were dominant in sewage samples. It is quite likely that many of the Shediac samples were similarly influenced by non-fecal enterococci species, although the standard test methods do not provide this detail.

The small number of positive results for PPCP compounds plus caffeine (indicators of wastewater influence), is interesting. For the roof, grass, road and parking lot sites there should be no way for wastewater to have had any effect on the results, barring a major flood/overflow situation, for which there was no evidence during the study. And indeed there were no detections of PPCP or caffeine at any of those sites. The only positive results were from stream and catchbasin locations, where the potential does exist for wastewater influence if there were leaking wastewater pipes or effluent crossovers taking place. The values for caffeine, salicylic acid and ibuprofen that were found were low, but may be indicative of locations where wastewater impacts or the impact of other wastes warrants further investigation. The fact that the associated FIB values were fairly low suggests that there was no major wastewater crossover taking place at the sample locations.

One associated finding of the PPCP testing was the widespread occurrence of the synthetic insect repellent DEET in many of the stormwater and runoff samples. Levels detected were highest at the Parlee Beach lagoon sites which is in accordance with the intensive use of that area for human recreation. There is no indication, based on a review of the literature, that the levels of DEET detected would pose any environmental or human health risk (e.g. Weeks et al., 2012, Costanzo et al., 2007).

The results of optical brightener analysis did not indicate the existence of any contamination of the wide range of surface water and runoff samples tested with human-generated wastewater. Given the widespread use of products that use optical brighteners, it would not be surprising to detect them, especially in the stream sites that have accumulated runoff from many source locations. The test method used may be considered somewhat experimental and its sensitivity is probably not sufficient to reliably detect very low optical brightener concentrations, but the results suggest that no major wastewater contamination was present. The fact that this is in agreement with the PPCP results adds weight to the conclusion.

7. AREAS OR ISSUES OF CONCERN

The principal finding of the sampling conducted in 2019 was that there was no evidence of significant wastewater impacts on observed FIB levels in the samples. The study did not identify particular hotspots or areas of concern of that kind. This finding must be qualified in that there were some positive detections of chemical wastewater tracers at a few locations. The associated FIB results were not high, but these locations warrant ongoing assessment.

While the lack of evidence for human-generated wastewater impacts is reassuring, the fact remains that elevated FIB were found to be widely distributed across the watershed in water samples of many kinds. The small streams that accumulate contaminants in runoff discharge to Shediac Bay, and this runoff has the potential to affect marine water quality. While existing guidelines for recreational water contact remain framed as they do, any discharges of FIB, whatever the sources, are significant, as they may result in the guidelines being exceeded.

Fecal bacteria, although attracting a good deal of attention in the study area, are not the only contaminants contained in stormwater. Other substances such as trace metals, nutrients, suspended and dissolved solids and hydrocarbons are found at elevated concentrations in this kind of runoff and have the potential to degrade receiving environments. To date these additional components of stormwater have not received as much focus, but it would be instructive to examine these contaminants in greater depth.

8. RECOMMENDATIONS AND MITIGATION MEASURES

Stormwater Impacts and Water Quality

Based on what has been learned to date there are a number of follow-up actions that could be considered. These would provide useful additional information that would guide future efforts to improve stormwater management in the watershed.

1. Precipitation monitoring. Given the importance of precipitation amount, timing and intensity to the understanding and management of runoff and stormwater, both in relation to environmental quality and flooding and erosion, consideration should be given to establishing a reliable precipitation recording station at a suitable location within the Shediac municipal area. Ideally this would use a recording gauge that will provide precipitation intensity measurements. The site should use standard instrumentation and the site chosen and operated so the results are acceptable for use in national climatological databases and studies.

2. Additional analysis of stormwater chemical parameters should be undertaken. This would be helpful to put into context the impacts of inputs of trace metals, nutrients and particulates into the receiving environment. Additional analyses would be needed for associated parameters of potential concern such as hydrocarbons.

3. Follow-up monitoring and assessment of potential wastewater impacts is indicated in the areas surrounding the locations where positive detections occurred for PPCP and caffeine (sites CB3.2, CB9.1, SW3, SW5 and STR 3.1 and STR 8.1).

4. Associated with the previous recommendation, influent entering the Cap Pele wastewater treatment facility should be tested for PPCP and caffeine to verify that this waste stream contains these compounds, and if so at what concentrations.

5. In the Crandall Engineering report (Crandall Engineering, 2019) further investigations of the internal condition and the existence of possible lack of integrity of pipes discharging to the Parlee Beach lagoon was recommended. This recommendation should be considered for action, and any testing should include any pipes discharging into the SW6 sample location gully.

6. Efforts should be directed to support and where possible expand existing work aimed at reducing the amount of pet waste everywhere within the municipality. An ongoing educational aspect is required to ensure pet owners are aware of the impacts of pet waste, not only on walking trails but on residential lots and all recreational areas. Pet waste is likely to have a significant impact on FIB counts in runoff no matter where it is deposited, if left outdoors and not disposed of in a controlled manner.

7. Bird behaviour across the municipality should be studied. This would improve understanding of how birds may be influencing water quality in terms of FIB levels. Identifying patterns of congregation and roosting behaviour may identify 'hot spots'. Bird control measures on the beach should also be considered. Efforts elsewhere have found positive effects in reducing FIB levels in beach environments when measures to deter birds were adopted. For example Converse et al. (2012) in a study of water quality at a beach in Lake Michigan, showed that *E. coli* and enterococci in the bathing waters decreased dramatically when gulls were chased from the beach. Pandey et al. (2014) also found that birds were a significant source of FIB found on beaches.

8. If resources permit, testing of enterococci FIB in stormwater samples should be carried out using methods that can identify the bacteria present to species level.

Regulatory Management

1. Municipal bylaws for Shediac that influence any aspect of stormwater management, both in terms of volume and water quality, should be reviewed for opportunities for improvement. This exercise should be guided by a clear framework of objectives which should include human health, environmental quality, recreational amenity and public safety. A consultation exercise may be required to develop these objectives.

2. The development of a stormwater design manual for the municipality should be considered, which would provide technical guidance on the planning, design and construction details of all components of the drainage and water control infrastructure. This should include all current recommended best practice designs for stormwater management.

3. An integrated planning and management approach for stormwater should be used to guide ongoing efforts to improve outcomes, wherein a multi-disciplinary team is involved in prioritizing activities.

Long Term Planning and Actions

Efforts to work toward continued improvement in the management of surface water in the region should be coordinated and assessed within the framework of a watershed-wide plan that is reviewed and updated every 10 years. Actions to support the use of a range of low impact design (LID) approaches should be approached as incremental, long term goals, where facilities or installations are upgraded to improved design standards when in need of major maintenance or replacement.

Use of detailed stormwater watershed mapping

The detailed map of stormwater watersheds may be used in a variety of ways. If additional measures to improve water quality in Shediac Bay are pursued, the map data provide useful boundaries that can focus attention on where improvement activities should be carried out. Considering the impacts of runoff and stormwater, it would be logical to prioritize actions (for example expanded pet waste cleanup or the use of stormwater best management practices (BMPs)) within the watersheds of streams 1, 3 and 8.

Knowledge of the watershed areas can also be used to guide engineering design of BMPs as it can provide detail on expected runoff volumes. The map may help with flood risk planning. The application of planning objectives, for example areas where impervious surfaces for new developments should meet specific targets, can also be designed taking into account the defined stormwater watersheds. Conservation goals, such as preserving a minimum proportion of natural vegetation cover, could also be planned using the map information.

If spills of contaminants occur on roads, parking lots or anywhere that they can enter the storm drain system, the map can provide strategic guidance on the flow destination of the contaminant, which can speed up and optimize any containment response measures.

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APPENDIX A: METHODOLOGY FOR MAPPING STORMWATER WATERSHEDS

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The process described below was used to generate the boundaries for the stormwater drainage areas in the Shediac municipal area. This methodology, fundamentals and concepts, are similar to the delineation of natural watersheds, essentially determining the area that drains water to a common outlet. However, to accomplish the delineation of the stormwater areas, most of the drainage points were structures (outlets or outfalls), from the stormwater infrastructure. These features were used as the locations with the highest flow accumulation (pour points). The GIS location data for the stormwater infrastructure (i.e. pipes, outlets, manholes) was provided by the Town of Shediac.

Initially a high-resolution Digital Elevation Model (30 cm resolution) was the groundwork for analysis and modeling. ArcMap version 10.8 and the Spatial Analyst extension were used to prepare the data for digitizing the stormwater drainage areas. The following describes the relevant steps in the methodology:

1) Reconditioning the DEM based on a 30 cm resolution LiDAR: the digital terrain model was prepared by lowering by 10 m the elevation of a total of 34 culverts, this was accomplished by using the raster calculator. This is relevant for areas with little topographic relief similar to the Town of Shediac.

2) Watershed (Spatial Analyst Tools): these are the set of tools and the sequence that were applied to determine the watershed boundaries:
    1. Fill sinks (corrects imperfections in the DEM)
    2. Calculation of the Flow Direction
    3. Calculation of the Flow Accumulation
    4. Snap Pour Point (Stormwater-outlets)
    5. Calculation of the watershed boundaries (Raster format)
    6. Conversion of the watershed boundaries (Vector format)

3) Overlay analysis of watershed boundaries and stormwater structures: the GIS layer created in step 6 was used as a reference to digitize the new boundaries, and to be able to incorporate and integrate the stormwater infrastructures (pipes, inlets, manholes). Other GIS data was also included during this analysis, including a hillshade raster, roads, New Brunswick Hydrographic Network data, and imagery.

4) Review and inputs: the watershed boundaries were reviewed by technicians and specialists from the Town of Shediac and their observations were incorporated into the final version.

5) Correction and observations: watershed boundaries were adjusted or modified where required to include the stormwater structures (outlets and pipelines).

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