Parlee Beach Water Quality :

Review of Stormwater Results 2017-2018

Approaches to Stormwater Quality Management

Data and Information Gaps

Prepared by: Robert N. Hughes

Consulting Service in Environmental Sciences
Upper Kingsclear, New Brunswick

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1. BACKGROUND AND CONTEXT

Goals and objectives

1. Review water sample results from 2017 and 2018 that follows from work carried out in the Shediac Bay watershed as part of the technical work of the Parlee Beach Water Quality Steering Committee, focusing on the stormwater results. 20%

2. Begin a review and evaluation of stormwater quality management methods used in other jurisdictions in Canada that may be relevant to the Shediac Bay watershed. 50%

3. Evaluate data and information gaps, and propose a plan that may be carried out in Phase 2 in 2019. This should include a desktop review of the stormwater infrastructure in the Shediac area as it relates to surface/stormwater monitoring results, and propose follow-up work as deemed necessary. 30%

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 abbreviations include: SWM: Stormwater management; BMP: Best management practice; LID: Low impact development; ISMP: Integrated stormwater management plan.

2. DATA REVIEW - STORMWATER SAMPLES

Stormwater samples were collected in the study area in 2017 and 2018. Samples were collected by project staff and by the Shediac Bay Watershed Association, as documented in Steering Committee for Parlee Beach Water Quality (2018), Crandall Engineering (2019) and data files supplied directly by NB ELG.

Samples were collected at a variety of additional locations across the major watersheds in the Shediac region. These samples enable the stormwater results to be put into context.

In 2017 most stormwater sites were sampled 6 times, whereas sites SW6 and 7 were sampled 3 and 4 times respectively.

In 2018 similarly, the sites were sampled 6 times except sites SW6 and 7 were sampled 3 times each and site SW2 was sampled 5 times. Although there are no field notes to verify, it is assumed that water volumes may have been lower at sites SW6 and 7 making sampling more difficult.

In 2018 an additional site was added, SW9, a stormwater outfall adjacent to John Lyons Park at the north end of Brown St, near the Shediac Marina.

The Crandall Engineering study on the Parlee Beach lagoon collected a total of seven samples in fall 2018 at locations discharging to the lagoon. Site SW6 is very close to some of the Crandall sample locations.

Discussion of results

The 2018 report of the Steering Committee for Parlee Beach Water Quality (2018), documented all the sample results from across the watershed, including the stormwater results, but contained little analysis other than comparing the results to available guidelines. These guidelines are intended for use in relation to recreational water quality and as such are not specifically designed for application to stormwater samples. A basic review of current practice suggests that few if any jurisdictions have developed stormwater quality guidelines, although there are numerous examples of management guidelines. If surface water quality guidelines are exceeded in stormwater samples or discharges this is obviously a cause for concern, as such stormwater typically discharges to surface water bodies where it can be a source of contamination.

Considering the single sample maximum guidelines for E. coli, the percentages exceeding the surface water guidelines are summarized in the following table.

Percentage of Samples of Stormwater Exceeding Surface Water Guidelines 2017-2018, Shediac Area

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

It is clear that elevated concentrations of both E. coli and Enterococcus were frequently observed in the stormwater samples. Sampling at freshwater and other types of sample sites also encountered elevated values of indicator bacteria, but at a lower frequency. Roughly half of all stormwater site water samples exceeded guidelines for E. coli and from 75-100% for Enterococcus. The total number of samples collected to date is not large, but samples were targeted at rainfall events of 10 mm or more which are unpredictable during summer. As documented in Hughes (2016) numerous investigations have found that elevated contaminant concentrations are found in runoff or surface waters following large precipitation events.

The stormwater sampling locations were selected to include a range of small natural watercourses or creeks that were receiving channels for surface stormwater. Stormwater in the Shediac region is channelled by a network of street drains and ditches into such local creeks. Some street drains discharge directly into water bodies including Shediac Bay. For example there are several direct outfalls of this type along the shoreline of Shediac Harbour both east and west of the marina. The sub-watershed catchments associated with the various SW sample sites are relatively small, such that flow in these channels is episodic. Therefore it is not possible to collect baseflow samples as can sometimes be done in larger stormwater systems.

There was a strong relationship between bacterial levels in stormwater samples and associated precipitation amounts. In 2017 the highest bacteria values were seen at sites SW 1, 3,5 and 8 (Figures 1-2), and all these occurred on September 7, when there was a two-day precipitation event totalling 65.3 mm (data from the Moncton Airport weather station), by far the wettest day during the sample period that year.

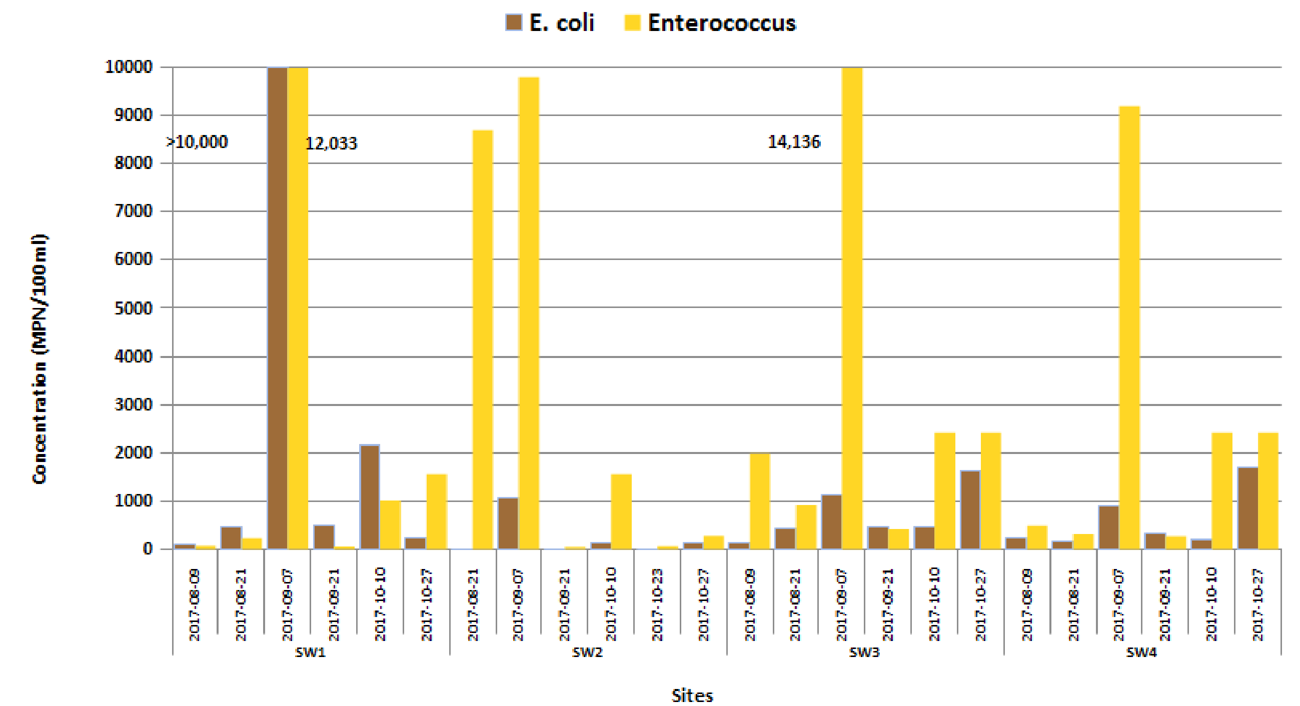


Figure 1. Stormwater site bacterial data 2017, sites SW1-SW4.

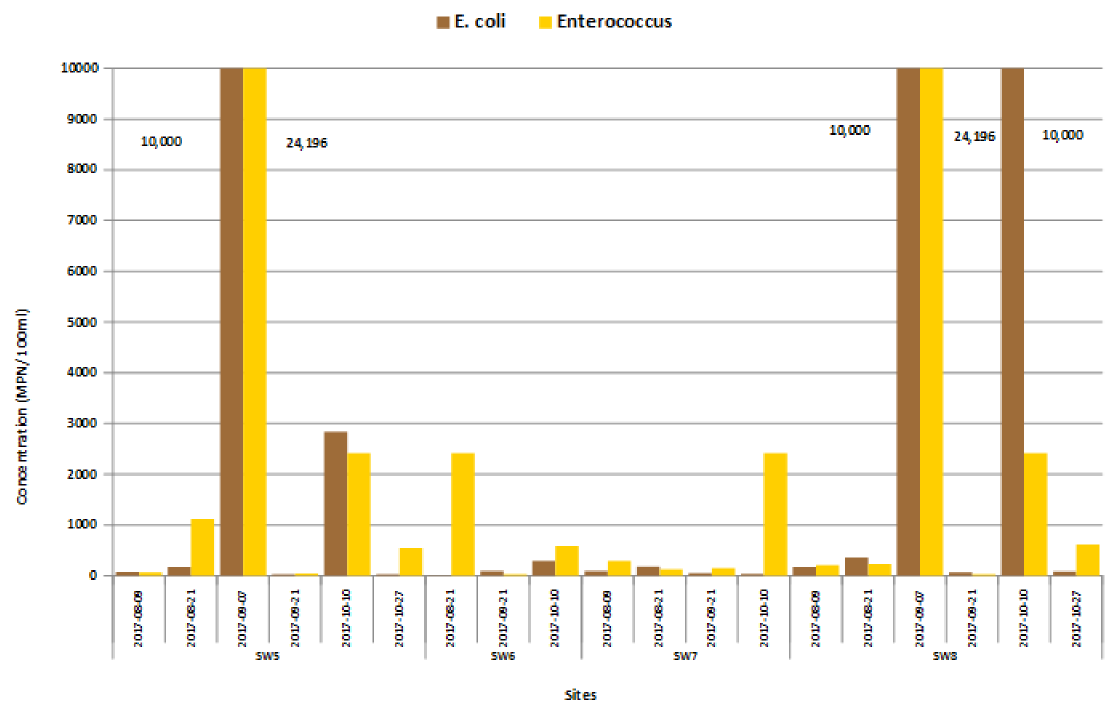


Figure 2. Stormwater site bacterial data 2017, sites SW5-SW8.

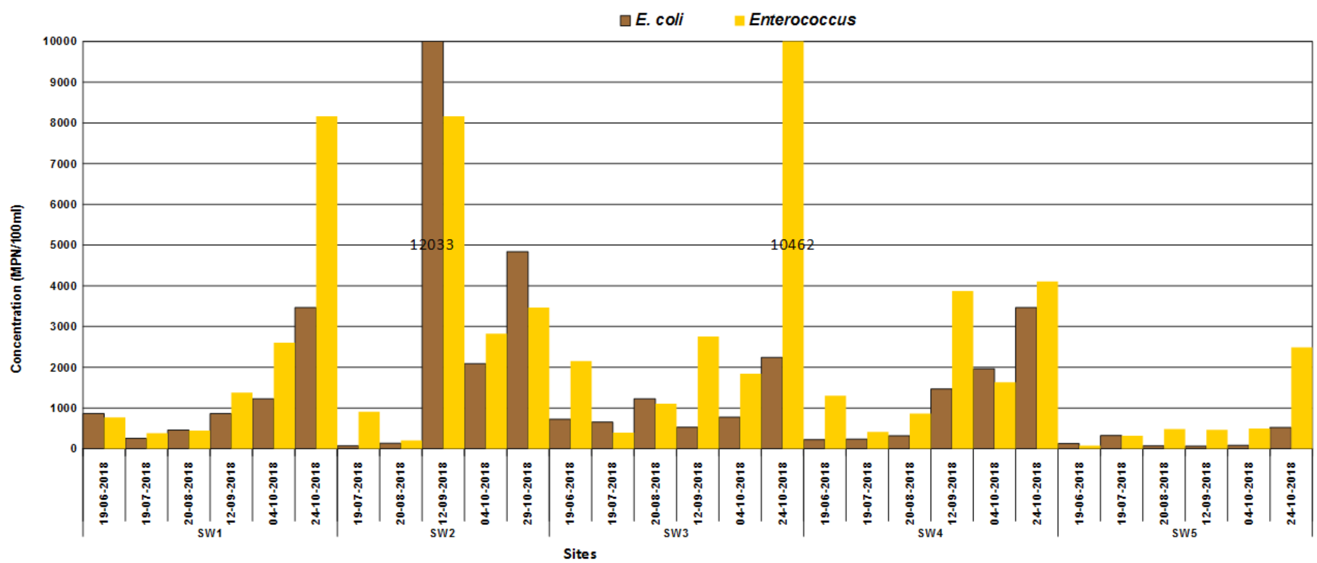


Figure 3. Stormwater sites 1-5 bacterial data 2018.

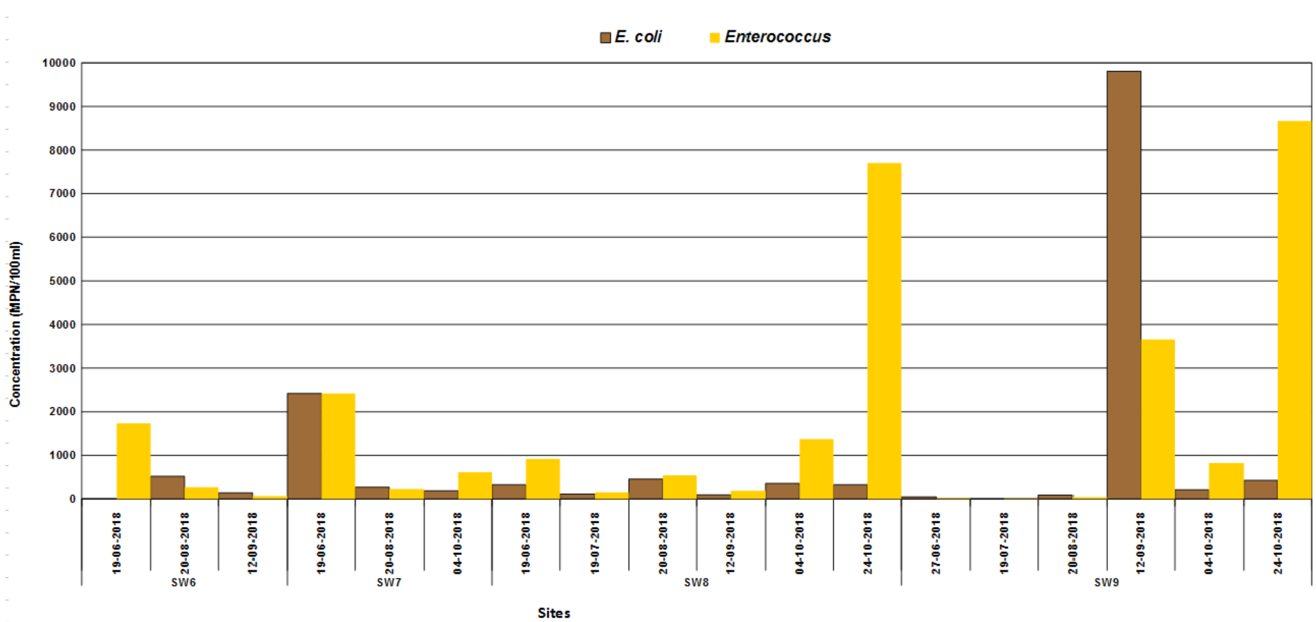


Figure 4. Stormwater sites 6-9 bacterial data 2018.

During 2018 (Figures 3-4) the wettest day during the summer period was August 18 (55.6 mm) but sampling took place two days later. The bacterial data for August 20 was unremarkable, suggesting the peak values may have been missed for that event. The highest bacterial counts for 2018 were observed on September 12 at sites SW2 and SW9, when the associated precipitation was 14 mm. These two sites are direct stormwater discharge culverts (as opposed to natural channels) and the bacteria concentrations in stormwater at these locations is probably more responsive to smaller precipitation amounts, as the proportion of discharge from impervious surfaces would be expected to be greater than at most of the other stormwater sites.

There was another notably high rainfall in 2018 on October 24 (38.3 mm) and this was associated with high bacterial results at most stormwater sample sites, especially SW 1, 3, 8 and 9. Notably for this event the results for Enterococcus were often higher than those for E. coli. This could be due to the more resilient nature of Enterococcus in the environment at lower temperatures prevailing in October.

Note: in attempting detailed analysis of the stormwater monitoring results, timing of precipitation and exact times of sample collection ideally need to be available; these details were not available for this analysis.

Considering all the bacterial results, there are several basic questions that should be addressed and (if possible) answered.

1. Are the elevated bacteria values seen in stormwater caused by sewage contamination?
2. If YES, what are the sources of this contamination?
3. If NO, what are the sources of the elevated FIB?

Considering these questions in turn, what if anything can be concluded, given the data available?

1. *Are the elevated bacteria values seen in stormwater caused by sewage contamination?*

This is perhaps the most fundamental question. The whole point of monitoring FIB is that they provide an indication of the probability that more serious bacterial pathogens may be present. In general the presence of E. coli in a water sample is a reliable indicator of recent contamination of that water by some kind of fecal source, but the E. coli or Enterococcus count alone provides no indication of what that source of contamination is. It may be from human sewage, but it could be from agricultural manure, or feces from a wide range of animal sources including wild and domesticated animals and birds. Some animal sources that have often been found associated with FIB contamination of surface and drinking water supplies include cattle, pigs, dogs, geese and gulls (Edge, and Hill, 2007; Converse et al., 2012; Pramod et al., 2014; Staley and Edge, 2016).

In a study in Tuscaloosa, Alabama, Shergill and Pitt (2004) collected hundreds of stormwater samples from many different parts of the city, including many in areas where contamination from sewage was not possible. They still found 31% of the samples for E. coli and in 74% of the samples for Enterococci exceeded the single sample maximum criteria. This showed that sources of FIB other than sewage-related sources were responsible.

The stormwater sites in the Parlee study were selected so as to provide information reflecting activities within the primary built-up area. As such agricultural effects can probably be ruled out, although no information has been collected on the presence of backyard poultry, dog pounds or kennels in the study area that could be influential sources of FIB.

More data would need to be gathered to allow this question to be answered. Cross-contamination of stormwater by sewage effluent from broken underground pipes, unidentified or unauthorized connections of sewage discharge pipes to the stormwater system, or episodic backflows/overflows of the sewage network are all common occurrences that have been identified in other studies as contributing to contamination of surface runoff or stormwater. Tracking down such sources and connections can be very time consuming and difficult. Even very thorough investigations sometimes fail to identify the source of this kind of sub-surface problem (e.g. Hyer, 2007).

To determine whether FIB in the stormwater samples is influenced by human sewage wastewater could be further investigated by tracer studies, where a trace substance (such as a fluorescent dye) is introduced into selected wastewater system elements and then tested for in the stormwater samples. It could also be further studied via chemical source tracking (CST), which involves sampling the stormwater for one or more chemical tracers known to be associated with human wastewater. Examples include caffeine, whiteners used in laundry detergents, and a number of prescription drugs, fragrances and plasticisers. Although there is no standardized approach for CST, it has been successfully used in a number of watershed-scale investigations of bacterial contamination (e.g. Standley et al., 2002; Sauvé et al., 2012). Although CST does not pinpoint the exact source of contamination (answering this question will require additional follow-up), finding a CST compound in stormwater is indicative that human-derived wastewater is contributing to the observed bacterial load which can then help focus additional work.

Microbial course tracking (MST) is also used in investigations of surface/sub surface water contamination and involves a range of molecular analytical techniques intended to identify the particular mammalian or other origins of FIB. MST is a demanding and expensive approach that requires a research-grade effort to be successful, and that potentially suffers from a range of potential confounding factors (Edge, 2017). If there is an opportunity to employ MST as part of a cooperative effort involving experienced researchers, it could be helpful. However, unless there is significant ongoing concern over bacterial contamination of water supplies or the swimming beach at Shediac, its application probably cannot be supported.

Until further information is gathered to address question 1, the relevance of question 2 will remain unknown. All that can be concluded at present is that FIB are regularly found in stormwater in the Shediac study network but that the exact sources are unknown, and could be human-related, bird/animal-related, or a combination of both.

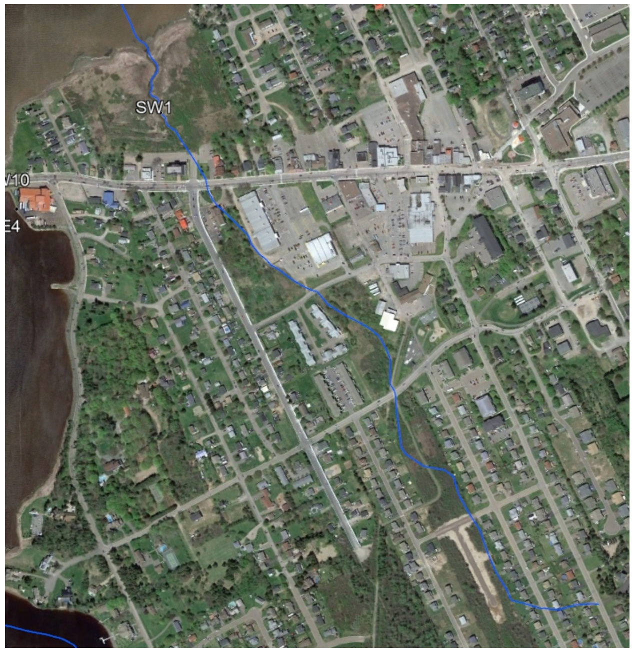
What can be said concerning question 3?

If NO, what are the sources of the elevated FIB?

If the FIB found in stormwater are determined not to be linked to sewage sources, where could it be coming from? Some alternative sources have already been mentioned – other mammals or birds, for example. From a public health point of view, fecal contamination from species other than humans is generally seen as posing a lower risk to human health than contamination from human sources (Urban Water Resources Research Council, 2014) although there could still be some cause for concern if there is significant probability of ingestion or contact.

The data gathered to date suggest that stormwater in many locations across the study region may exhibit significant levels of FIB, especially following heavy rains. The stormwater sites do not suggest any one specific 'hot spot', rather that FIB in stormwater is rather common at all locations. Some sites such as SW2, appeared to have low results in 2017, but had high results in 2018. SW5 conversely had high results in 2017 but relatively low results in 2018. There is some indication that sites SW6 and SW7 had generally lower results in both years, but the small total number of samples means this cannot be a firm conclusion. Work done by the Shediac Bay Watershed Association sampling small tributaries across a much wider area of the watershed also found occasional elevated results for FIB in widely separated locations (Shediac Bay Watershed Association, 2018). This also tends to suggest that sources of FIB are widespread in the study region. However it is not known whether the sources are of the same nature everywhere.

The summary report of the 2018 monitoring data prepared by Wood Environment & Infrastructure Solutions (2019) presented and commented on all the stormwater monitoring results. There was no discussion of or speculation on the nature of the sources of FIB beyond noting that the exceedances of standards were most likely due to runoff from streets and properties. In the following tables each stormwater site is described in detail with regard to its site characteristics to examine whether there is scope for further interpretation of the results.



Site: SW 1, Taits Creek, north of Shediac Town Hall	**Watercourse Type:** Creek
This is a small, probably seasonally intermittent stream about 1.3 km long. The surrounding land use is a mixture of low density residential housing, with a significant area of commercial development to the NE of the watercourse. There is a dog park at the southern edge of this commercial zone. Examination of the satellite image suggests that parts of the original water channel have been either diverted, buried or piped below the surface. The Shediac stormwater network map (Figure 5, next page) indicates that surface drainage from most streets in the vicinity of Taits Creek discharge to the creek.	
Potential FIB sources:	Runoff from lawns, streets, roofs, parking lots.

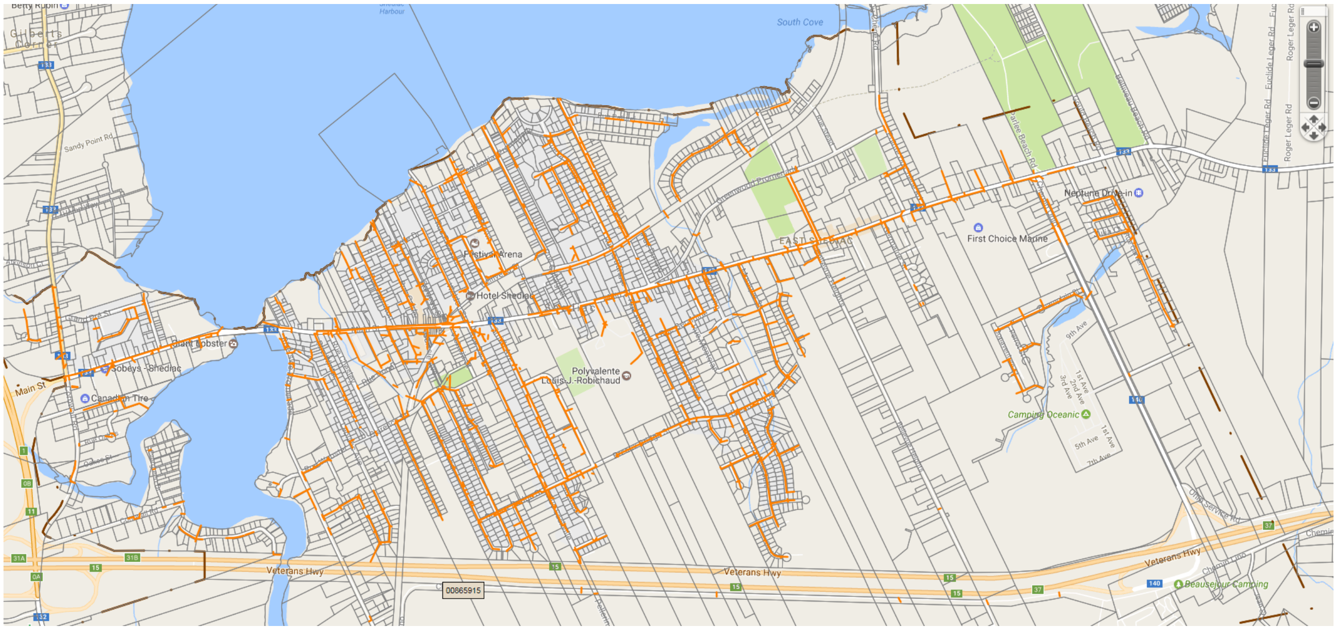
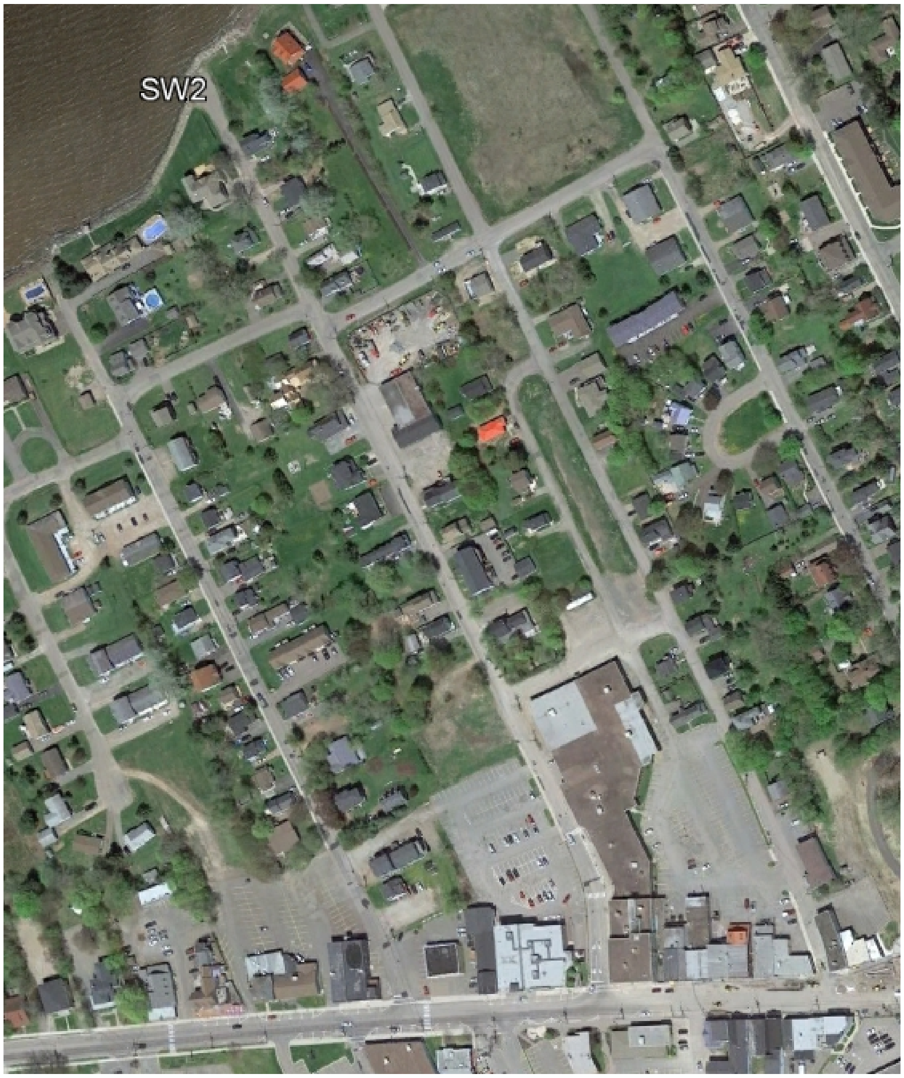
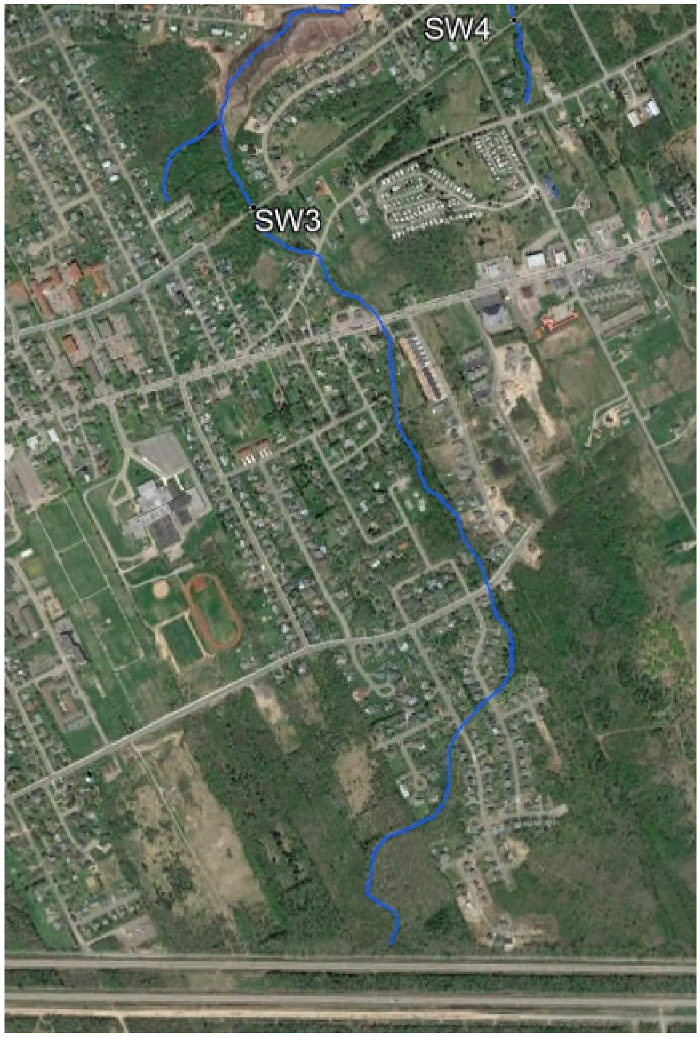


Figure 5. Shediac stormwater network.



Site: SW 2	Watercourse Type: Stormwater outfall
This sample location is the outlet of a stormwater drain that services Calder Street and immediate environs. The land use in this local drainage zone is predominant suburban residential lots, with a significant area of lawns. The southwestern end of the storm drain network adjoins the Mall Centre Ville which is an area of commercial development featuring buildings with large roofs and several parking lots.	
Potential FIB sources:	Runoff from lawns, streets, roofs, parking lots.

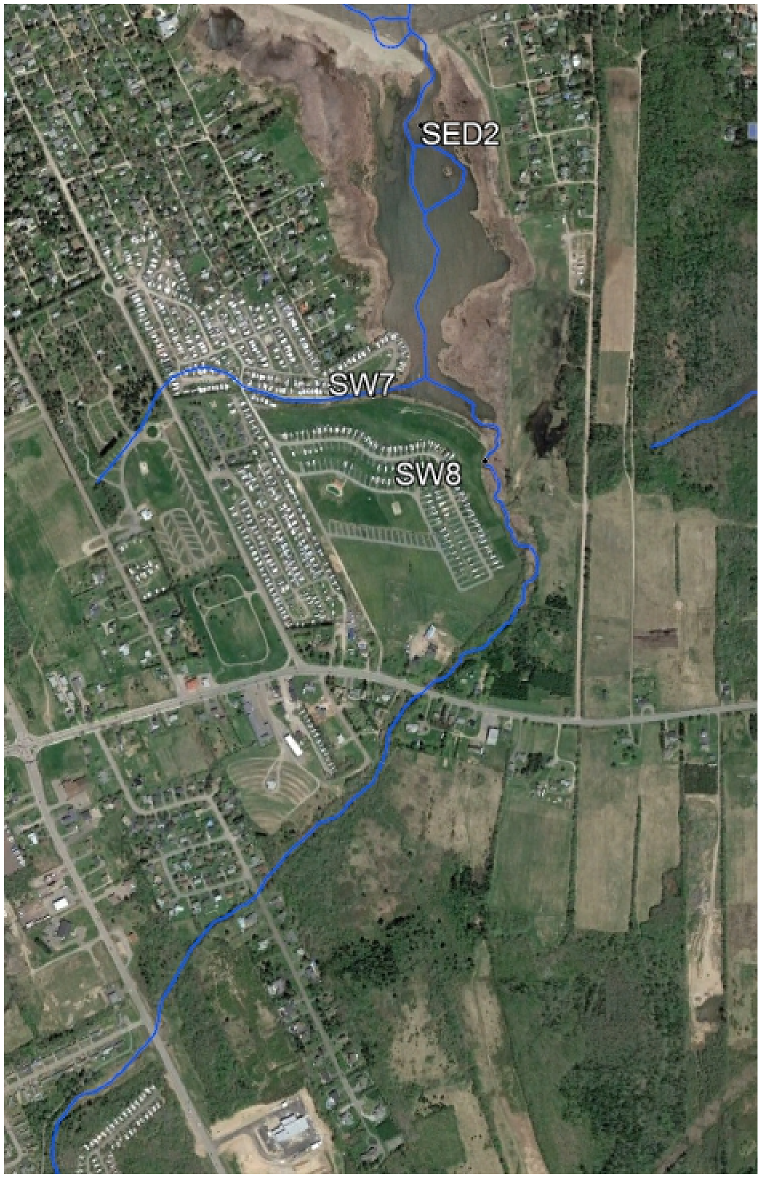


Site: SW 3	**Watercourse Type:** Creek
This watercourse is an unnamed creek approx 2 km long that discharges into a tidal marsh between Paturel and Wayne Streets. The watercourse passes through or alongside several subdivisions and the stormwater map (Fig 5) shows that numerous storm drains discharge to this creek along its course. Storm drains along Main Street also discharge to the creek.	
Potential FIB sources:	Primarily street runoff, also runoff from lawns/residential development.

Site: SW 4	**Watercourse Type:** Creek
This is a short creek only extending a few hundred metres upstream of the sample location. The majority of the creekside environment is rough open or partially tree-covered land, with a relatively small number of individual houses. There is one storm drain system from South Cove Street that discharges indirectly to this creek.	
Potential FIB sources:	Runoff from streets, lesser contribution from residential lots.

Site: SW 5	**Watercourse Type:** Creek
This sample location is at the confluence of two minor creeks, the longer southern sections about 1 km long. The surrounding land use is rough open or tree-covered, but the upper end of the creek system close to Main Street links to an area of commercial development and stormwater discharge from Main Street, plus the parking areas associated with the premises there.	
Potential FIB sources:	Runoff from streets, roofs, parking lots.

Site: SW 6	**Watercourse Type:** Stormwater outfall
This sample location is the outlet of a stormwater drain discharging into the Parlee Beach Brook. The catchment region is not known in detail but is believed to include the adjacent street and residential lots.	
Potential FIB sources:	Runoff from streets and roofs, possibly the adjacent parking lot.



Site: SW 7-8	Watercourse Type: Creek
These two sample locations are on a small creek that discharges to a coastal marsh between Boudreau West and The Bluff residential areas. The creek leading to SW7 is only a few hundred meters long and it appears that the upper part of the natural channel has been diverted or buried by development. It is potentially influenced by two large trailer/RV parks. The creek leading to site SW8 is the longest of the small creeks in the sample network at about 3 km. The upper part of its drainage receives runoff from highway 15. It then flows near to the Oceanic Camping trailer park and though some areas of residential development before crossing highway 133 and passing E of the Vacation Village trailer park.	
Potential FIB sources:	Runoff from roads, lawns, residential development lots.

Site: SW 9	Watercourse Type: Stormwater outfall
This sample location is the outlet of a stormwater drain that services Calder Street and immediate environs. The land use in this local drainage zone is predominant suburban residential lots, with a significant area of lawns. The southwestern end of the storm drain network adjoins the Mall Centre Ville which is an area of commercial development featuring buildings with large roofs and several parking lots.	
Potential FIB sources:	Runoff from lawns, streets, roofs, parking lots.

Considering all the stormwater sites, they are all influenced by runoff from roads, either via a stormwater drain system or via discharge from ditches.

Sites SW1, SW2, SW9 and possibly SW5 are probably affected by runoff from the roofs of large commercial buildings. Most sites are influenced by runoff from residential lots, including lawns. The Minnesota Stormwater Manual (2019) notes that residential lawns, driveways, and streets are major source areas for bacteria. Irrigated lawns, in particular, are large contributors.

SW2, SW6 and SW9 are direct stormwater discharge points as opposed to receiving creeks. Despite this the data from these sites does not show any clearly different characteristics.

It appears that in 2017 sites SW6 and SW7 did not experience the high peaks seen at most other sites, but these two sites were not sampled on the peak rain event of September 7th, when the highest values were seen at most locations. Similarly in 2018 sites SW6 and 6 were sampled on fewer occasions. Overall there is little indication that there are systematic differences between the nature of the stormwater sampled at the different sites. This suggests that there is the potential for elevated FIB levels to be found in stormwater from most if not all parts of the study area, and that the contributing sources are broadly distributed across it. This conclusion was also reached by Schiff and Kinney (1999) following a stormwater quality study in Florida. Another large interdisciplinary team studying stormwater quality in California, reported by the Urban Water Resources Research Council (2014) came to a similar conclusion. They stated that the densities of bacteria were high throughout the watershed indicating a diffuse, widespread source.

2018 Crandall Engineering Stormwater Testing

In 2018 Crandall Engineering conducted a detailed study of the pond/lagoon at Parlee Beach Park. As part of the work, seven water quality samples were collected from stormwater pipes discharging into the lagoon. Figure 6 shows the location and numbering of the sample locations and Figure 7 the test results for the water samples.

Figure 6. Sample locations around the Parlee Beach lagoon tested by Crandall Engineering in 2018. The location of site SW6 is also shown.

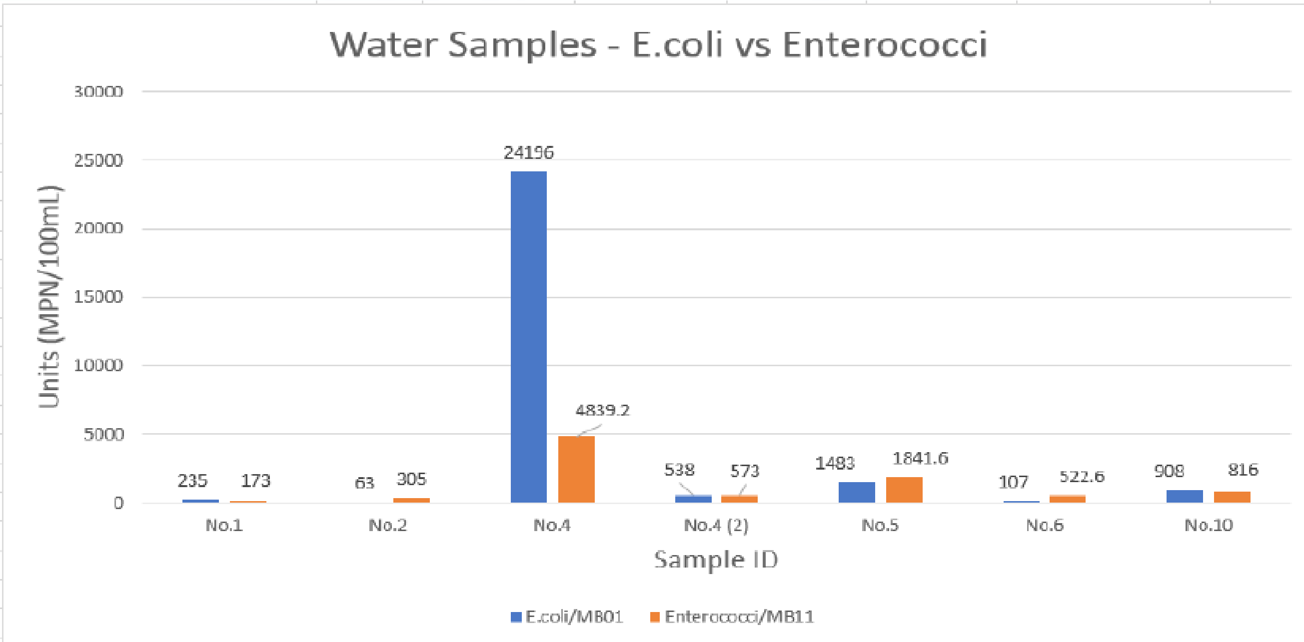


Figure 7. Results of water testing by Crandall Engineering in 2018.

Sites 3, 7 and 8 were not individually sampled as they were under water on sample days. Samples were collected on October 11, 24 and November 2, 2018. Daily precipitation exceeded 30 mm on each of these days. Four of seven samples for E. coli exceeded the single sample maximum guidelines of 400 CFU/100mL , whereas 100% of samples exceeded the equivalent guideline for Enterococcus of 70 CFU/100mL. The values from site 4 were especially high, this outfall drains water off a large adjacent parking lot, and may also be connected to stormwater drain lines that service an additional area of the nearby residential district. The Crandall report identified that the drainage area that discharges into the lagoon is about 11 ha in size and includes much of the nearby residential zone. However it can be difficult to be sure of the precise source of runoff at any discharge point in a developed environment due to the complicated nature of underground pipe connections. Detailed information on all existing piping is often lacking and the system cannot be observed from the surface.

Sediment in the lagoon tested by Crandall on October 26 2018 revealed E. coli < 1 CFU/100mL and Enterococcus of 23.3 CFU/100mL, low values. Low values were also reported from tests of the sediment done in 2017 reported by Steering Committee (2018). Very high FIB results were reported for water in the lagoon in September 2017, in excess of 10,000 CFU for E. coli and 24,196 CFU for Enterococcus, the method limits for the tests. Considered together, these results suggest that the high FIB values seen in the lagoon have their origin in the waters being discharged into it (i.e. stormwater), rather than from the sediments underlying the water.

The following table lists some typical sources of FIB that contribute to loadings in stormwater.

Potential Sources of FIB in Stormwater	
Municipal sanitary Infrastructure	Sanitary sewer overflows Combined sewer overflows Leaky sewer pipes Illicit sanitary connections
Other human sanitary sources	Porta-Potties Dumpsters (e.g., diapers, pet waste, urban wildlife) Restaurant grease bins Trash cans Garbage trucks Food processing facilities Outdoor dining Homeless encampments
Urban wildlife	Rodents, raccoons, squirrels, birds (gulls, pigeons, swallows, etc.) Skunks, foxes, beavers, muskrats.
Other urban/suburban sources	Power washing Excessive irrigation Car washing Pools/hot tubs Graywater Pet waste bins Compost piles, lawn mowings Backyard livestock (rabbits, poultry, goats etc) Biofilms/regrowth (e.g. in stormwater pipes) Decaying plant matter, litter and sediment in the storm drain system Resuspended sediments Naturalized FIB associated with plants and soil
Sources:	Schiff and Kinney (1999), Urban Water Resources Research Council, (2014), Schueler, T. (2000), Burnhart, M. (undated), Minnesota Stormwater Manual (2019).

Many of these sources could potentially contribute to the elevated FIB values seen in some of the stormwater samples obtained. The relative importance of each would be difficult to establish without considerable additional effort. Birds roosting on the flat roofs of commercial buildings could be a significant source, but would not be expected to be contributing at all the SW sites, so other factors must also be operating (since high FIB results are seen on occasion at most sites). Shergill and Pitt (2004) found that FIB levels in runoff from roofs frequently used by wildlife (including birds and squirrels) were significantly higher than those observed in samples from other roofs where wildlife was not seen.

It is possible that the mobilization of FIB from biofilms within stormwater piping could represent a significant source. This is consistent with high FIB values seen in surface waters during heavy precipitation events. Biofilms can constitute a reservoir of coliform bacteria where the bacteria persist and reproduce. This source alone could account for much of the observed pattern in FIB in stormwater in the study area, but without specific testing this explanation remains speculative.

One of the more unexpected contributors may be decomposing vegetation and in particular, grass mowings. These are ubiquitous in suburban environments. A study by Tomasko (2016) investigated the influence of several FIB sources by inoculating local lake water with them and monitoring the evolution of FIB levels over time. He found that grass clippings were a considerably more potent reservoir of FIB than dog feces or sediments, and that high values of fecal coliforms remained in the grass clippings for at least 30 days (Figure 8). Grass mowings are often dumped at or beyond suburban property lines along ravines or waterways, which could constitute a source of FIB. Suburban lawns, driveways and streets are cited as a major source of FIB by the Minnesota Stormwater Manual (2019). Pet feces (as well as that from wild animals and birds) is often deposited on lawns and the grass appears to be an ideal growth substrate based on the findings of Tomasko (2016). Lawn soils are often supplemented with fertilizers that may also support the persistence and growth of FIB.

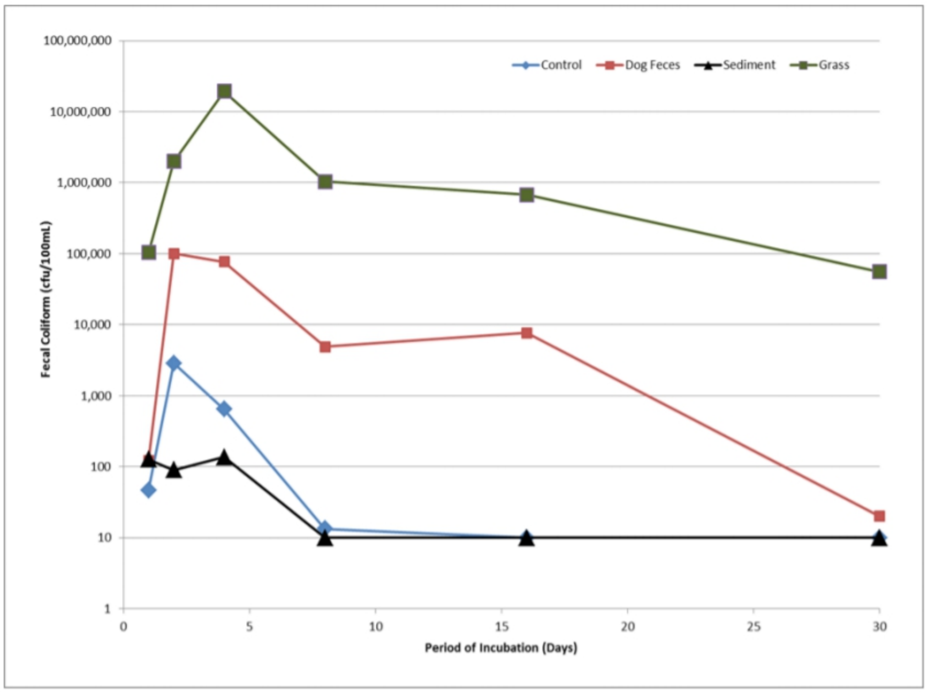


Figure 8. Fecal coliforms in various organic media following addition to local lake water and incubation at ambient temperatures.

In terms of the influence of birds, pigeons, geese and gulls are considered particularly important contributors (Urban Water Resources Research Council, 2014) and these species are common in most parts of New Brunswick, including the study area. This study team also reported that areas having better or more habitats for urban wildlife, or where pets defecate, have higher levels of stormwater bacteria.

Sartor and Gaboury (1984) reported nearly 92 percent of the bacteria in stormwater originated from streets in residential-institutional land-use areas. Bannerman et al. (1993) reported that 78 percent of the fecal coliform bacteria load for a residential land-use study sub-basins originated from streets.

Stormwater Sampling Results - Summary

The following can be concluded in respect of the stormwater sampling results:

- High values of FIB are routinely found in stormwater at multiple sampling locations across the study region;
- The highest values for FIB in stormwater are seen following large rainfall events (especially in excess of 30 mm);
- Despite a diversity of stormwater sampling sites and variable land use and development in the associated catchments, there is apparently no major or systematic difference in results between sampling locations. A caveat is that the dataset is small, and additional sampling may reveal differences in future.
- It is not possible to determine, based on the data available, whether the FIB concentrations seen in stormwater are significantly influenced by human-related wastewater;
- Sources contributing to FIB in stormwater are probably numerous and widely distributed across the urban/suburban environment;
- Such contributing sources probably include pet and wildlife feces, biofilms in stormwater pipes, sediments and decomposing vegetation, and may include a variety of human-related sources including wastewater system overflow/leakages, garbage, and a range of other activities and discharges associated with residential living such as lawn runoff.
- It is not possible to quantify the relative contributions of these sources to the observed FIB values observed in stormwater.

3. STORMWATER QUALITY – THE MODERN CONTEXT

Introduction

Stormwater management has evolved considerably in the past 150 years. Early approaches in urban centres in the 19th century combined sanitary waste and storm runoff in storm sewer systems, discharging directly to natural waterways. It was a long time before water quality standards emerged (during the 1970s in many western countries), spurring a more comprehensive approach to environmental management. Systems separating stormwater from wastewater systems gradually became standard. Stormwater management has focussed mainly on managing water flows to prevent damage and nuisance from flooding. It is only quite recently that a fuller understanding of the impacts of stormwater on the quality of receiving waters has emerged. As such, approaches to stormwater management with the goal of ensuring surface water quality standards is, relatively speaking, in its infancy. Stormwater management is now recognised as a complex, multifaceted issue that is closely linked to development activities, land use, public safety, infrastructure costs, and environmental quality. Integrated Stormwater Management Planning (ISMP) is a term that has emerged to describe a comprehensive, ecosystem-based approach to stormwater management. Such an approach seeks to balance the needs of land use planning, stormwater engineering, flood and erosion protection as well as environmental protection.

Some of the primary reasons for managing stormwater include:

- Public safety: flood control
- Transportation
- Erosion and sediment control
- Channel protection
- Water quality (chemical and physical)
- Groundwater recharge/baseflow maintenance in waterways
- Effective management of habitat and protection of aquatic life

The field has been dominated by focus on the first three or four goals, whereas the last three have only begun to receive widespread attention more recently. Unlike drinking water and wastewater systems that operate with respect to established guidelines, stormwater management is less standardised.

Challenges where stormwater management is concerned include:

- A lack of established guidelines for stormwater quality and to a lesser extent, system design;
- Legacy infrastructure that is unsuitable if modern environmental standards are to be met;
- Inadequate funding to maintain existing infrastructure and/or build to modern standards;
- Lack of information on existing stormwater systems and their condition;
- A mixture of private (often referred to as 'lot level') and public ownership of key infrastructure components;
- Lack of familiarity on the part of design engineers and municipal operators in matters of water quality;
- Climate change, leading to a shift in baseline environmental inputs;
- The fact that effective management of stormwater involves the input and involvement of multiple government and municipal bodies (for example planning, transportation, design, environment, conservation, public safety) that often do not have a history of cooperative work (sometimes referred to as the 'silo' effect or mentality).

Despite these challenges there is a renewed focus and interest in stormwater management, in part driven by concerns over the number of costly flood-related incidents in Canada and elsewhere in the past 20 years (e.g. Moudrak, Hutter, and Feltmate, 2017). This is increasingly being considered as a consequence of climate change. As approaches to improve flood control are examined (in urban settings, especially), it is apparent that more frequent and higher energy precipitation events not only raise the flood impact hazard, they also flush more contaminants into waterways. Increased challenges in meeting standards for quality in surface waters are therefore also anticipated.

The following table contrasts modern approaches to manage stormwater to traditional methods or approaches.

Traditional versus Modern Approaches to SWM	
Traditional stormwater management approach	*Integrated stormwater management planning*
Drainage Systems	Ecosystems
Reacting to Problems	Preventing Problems
Engineer-Driven	Interdisciplinary Team-Driven
Protecting Property	Protect Property & Habitat
Pipe and Convey	Delay, Mimic Natural Processes
Unilateral Decisions	Consensus-Based Decisions
Local Government Ownership	Partnerships with Others, including property owners
Extreme Storm Focus	Management of majority of precipitation events
Peak Flow Thinking	Volume-Based Thinking
Source: Adapted from City of Surrey, 2019	

Many of the barriers to adoption of more integrated SWM methods are due to inertia or lack of familiarity within the institutions involved, as well as barriers of perception, rather than technology. This is well summarized in Traver (2009). Professor Traver is a professor of civil engineering at Villanoa University in Pennsylvania. The campus of this university is a well-known showcase for many integrated methods of SWM.

Stormwater Management and Climate Change

Climate change is expected to result in changes to a number of processes that have a direct bearing on surface water quality, and stormwater quality and characteristics.

Climate Change - Anticipated Effects on Water Quality and stormwater	
Increasing frequency of high-intensity precipitation events	More erosive runoff events, higher particulate, loads discharged to waterways, and associated higher nutrient loadings.
More winter freeze-thaw activity	Increased erosion and sediment transport.
Shorter ice season on lakes and rivers	Increased lake and river temperatures
Higher mean temperatures	Increasing temperature of water bodies, coupled with increasing nutrient cycling, higher risk of algal blooms. Lower dissolved oxygen in waters.
Source: Province of New Brunswick, Climate Change Action Plan (undated).	

The table lists just a few examples of the expected types of changes, but many involve increases in the frequency and erosive potential of runoff events and associated sediment and nutrient transport. This is expected to put additional pressure on receiving waters and will make the need to manage stormwater from a quality point of view more pressing. Municipalities are therefore faced with two related challenges where SWM is concerned: greater challenges from increasing precipitation intensity and increasing public expectations for water quality.

A previous project, *Stormwater Management in a Changing Climate* (Hughes, 2016) discussed these issues in more detail and also set out a range of options for a stormwater management manual for New Brunswick. This report will not repeat that content, but will focus on examples of approaches used elsewhere that could be considered for use in New Brunswick.

Planning and Stormwater Management

Stormwater management does not take place in isolation, it involves multiple aspects of the developed/managed environment, including important factors such as the design and layout of buildings, roads and open spaces, the management of flood hazards, and maintenance of water supplies. Effective stormwater management is difficult if not impossible to achieve outside a suitable framework of land use and development planning. Such a framework can foster uniform standards and ensure that environmental goals are met across planning districts. It is not sufficient to consider a series of small development projects individually. Collective impacts need to be considered. When considering water quantity and quality, this requires the use of watersheds as management units. In evaluating the range of management options available, this needs to be kept in mind.

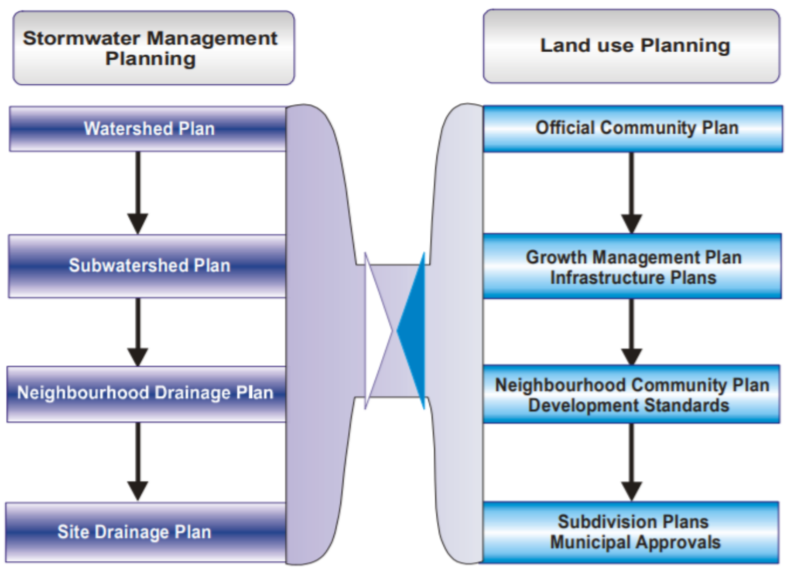


Figure 9. Relationship between land use planning and stormwater management (from NRC, 2005)

Stormwater management systems involve numerous design elements in the landscape including buildings, roads, major structures such as culverts, impoundments, bridges, modifications to the shape of the land itself and the land cover. Most of these elements are long-lived parts of the urban/suburban landscape. They are usually expensive and difficult to modify once established. This makes achieving best practice SWM challenging, as the design features of many best management practices are most easily (and at least cost) put in place when development first occurs. It is much more difficult to introduce a full range of SWM elements into an existing developed area. Although it is easiest to employ BMPs for new construction, some approaches can be 'retrofitted' when maintenance is due or as a phased approach over time.

Sources of Contaminants in Stormwater

How does stormwater become contaminated? There are many sources of pollutants in developed areas that may contaminate stormwater. Some examples are given in the following table.

Area Sources of Contaminants That May Affect Stormwater Quality	
Source of contaminant	Contaminants of concern for stormwater/water quality
Motor vehicles: Wear from tires, brakes, engine oil and lubricant drippings, combustion products.	• Heavy metals • Oil and grease, gasoline, anti freeze. • Salt (sodium, chloride) • Sediment/ particulates
Fallout of suspended particulate in the air from traffic, industrial sources and wind erosion of soils	• Pesticides • Heavy metals • Nitrogen and sulfur oxides • Hydrocarbons
Road maintenance	• Salt • Hydrocarbons • Particulates
Illicit connections of sanitary services, roof/sump drains or industrial process water to storm sewers	• Bacteria and viruses • Phosphorus • Nitrogen • Heavy metals • Pharmaceuticals • Hormone mimics/endocrine disrupters
Improper disposal of household hazardous wastes	• Oil • Paint • Solvents • Auto fluids • Pesticides
Pet and wildlife feces (on lawns, buildings, roofs, vehicles etc)	• Bacteria, viruses • Pathogens • Nitrogen • Phosphorus • Pharmaceuticals
Construction activity	• Sediment • Phosphorus • Nitrogen • Debris • Sanitary waste
Runoff from residential driveways and parking areas	• Salt • Oil and grease
Dumpsters, garbage cans, street or other dumped garbage, backyard livestock, decomposing vegetation	• BOD • Nitrogen • Phosphorus • Bacteria, viruses
Sources: Minnesota Stormwater Manual (2019); NRC 2009.	

Contaminants contained in stormwater may lead to a range of undesirable impacts in receiving waters including excessive algal growth and eutrophication/oxygen depletion (due to excess nutrients), beach closures (due to bacteria) toxicity to aquatic life (from pesticides, metals, hydrocarbons), and contamination of groundwater/drinking water supplies (metals, hydrocarbons, bacteria). Additionally, stormwater often leads to significant changes in the natural thermal environment in waterways. Elevated temperatures may have a range of adverse effects including lowering oxygen levels.

The New Brunswick Context

Stormwater management is of increasing importance as the proportion of impervious surfaces in an area increases, in other words, with increasing urbanization. At one extreme is a natural environment with no man-made impervious surfaces and at the other is a completely urbanized situation with almost no natural cover remaining. In New Brunswick there are only a few cities of any size and even in those cities the area of intense urbanization is fairly small. Most 'urban' development in New Brunswick would be considered suburban in more populated parts of the world. Low-density housing development is the norm for most of the municipal area even in New Brunswick cities, with most residential lots having some surrounding vegetated surface. This should mean that stormwater management pressures in New Brunswick may be lower than in some larger centres. Conversely, bedrock is often close to the surface in New Brunswick, precipitation is relatively high, and there are unique features of the water cycle such as the intense spring runoff peak, or freshet, that pose special challenges when managing stormwater flow and quality.

Bearing in mind the typical development patterns in the province, some approaches to stormwater management that are suited to highly urbanized settings may not be appropriate in New Brunswick. In preparing the following list of examples, those selected appear to align best with the New Brunswick situation.

Prioritizing Actions

In selecting possible actions to manage stormwater it makes sense (if possible) to choose those that provide benefits in other respects. For example in terms of water quality management, drinking water source protection, habitat conservation, preserving or enhancing public amenities or providing additional resilience to climate change.   Fortunately, many actions that assist in one or more of these areas also provides help towards the others. In general, measures that slow and minimize runoff help reduce flood hazard. The same activities also reduce the amount of contaminated stormwater generated and reduce erosion, suspended solids and nutrient transport into watercourses. Actions that provide multiple benefits should be prioritized.

4. PRINCIPLES OF INNOVATIVE STORMWATER QUALITY MANAGEMENT

As a preamble to considering a number of examples of SWM approaches used in different municipalities or water planning districts, it is useful to consider some of the common basic principles. For the Shediac region or any other watershed, building a practical plan will involve selecting features and omitting others. Appreciation of the principles is useful, as in some respects current best practice is rather contrary to traditional civil engineering methods that have become standardized (if not ingrained) over past generations.

SWM efforts need to be delivered on three scales: the site or individual property level, the neighbourhood level, and the watershed level. The following table sets out what has to date been the traditional approach to SWM, compared with more innovative methods that would be considered best practice today.

Property Level Actions	
Traditional	**Innovative**
Convey roof runoff to storm drains	Green roof, or convey roof runoff to infiltration trench or storage barrels
Pave driveways and paths	Use pervious paving materials and route runoff to swales for infiltration
Strip topsoil, ignore compaction during construction, and add turf when finished	Prevent soil compaction during construction or remediate after, and ensure 30 cm of topsoil before seeding
Use drinking water for irrigation on lawns and gardens	Use collected rainwater for irrigation or use drought resistant landscaping plants
Remove trees and all vegetation cover before development	Retain as much natural cover as possible
Neighbourhood Level Actions	
Pave all roads and sidewalks, runoff directed to storm drains via curb and gutter system	Minimize paved road area, remove or omit curbs, route runoff to roadside swales; use pervious pavement
Using a network of storm drains, direct stormwater into local streams	Use distributed stormwater detention ponds and constructed wetlands to detain runoff and provide settling/filtration of sediments and pollutants
Build impervious parking lots and direct runoff to storm drains	Use pervious paving of parking lots and direct runoff to infiltration swales or detention ponds/ constructed wetlands
Contaminants allowed to build up on streets and parking lots then washed into storm drains and watercourses	Pollution prevention used to minimize contaminant loadings, street sweeping to remove remainder, treatment of residual runoff in swales, ponds and wetlands
Watershed scale actions	
Stormwater passes via storm drains through riparian zones and is discharged to local streams	Wide riparian zones protected and constructed wetlands used to detail/filter discharges; direct discharges of stormwater to streams eliminated
Urban streams piped or channelized to stop bank erosion and speed up drainage	Natural river channels and overflow zones maintained to allow floodwater storage in riparian zone
Development is permitted in flood plains as well as infill and road construction in floodways	Floodplain areas protected from development to serve as temporary water storage during floods
Stormwater system is fully interconnected, outlets become point sources of pollution entering local streams	Distributed design of detention and infiltration features avoids cumulative effects and minimizes contaminated discharges
Source: adapted from Marsalek and Schreier, 2009.	

The approach of focussing on lot-level actions is often referred to as “source control”. As noted in the table, source control uses infiltration, reuse and evapotranspiration methods, as well as storage and treatment. Source control places strong emphasis on landscape or vegetation based methods (incorporating both infiltration and evapotranspiration). Source control is also viewed as a pollution prevention approach by reducing the magnitude of the pollution source at the origin.

An important concept stressed in many references is the “treatment train”, where a linked series of design elements plus community actions together manage the flow of water through the environment.

The "treatment train" is designed to ensure that:

•Groundwater and baseflow characteristics are preserved;
•Water quality will be protected;
•Watercourses will not undergo undesirable geomorphic change;
•There will not be any increase in flood damage potential; and ultimately
•That an appropriate diversity of aquatic life and opportunities for human uses will be maintained.

5. EXAMPLES OF APPROACHES TO STORMWATER QUALITY MANAGEMENT

This section lists a range of information resources on SWM with an emphasis on Canadian sources. Some US sources are also included. Where possible, the most recently published or updated references have been selected. The list is not exhaustive. There is no lack of information available, but the format and content of many documents with similar titles is quite variable. Published references on this topic tend to fall into one of several categories:

1. Detailed, technically complex documents with a lot of engineering design detail, with an emphasis on traditional engineering solutions and a relatively small proportion of content on low impact design principles, with the major content specific to a given location. These tend to be produced by mainstream engineering consulting companies for larger municipalities.
2. More generic, descriptive details of projects in suburbs of cities or in smaller municipalities, with the main emphasis on integrated stormwater management and environmental principles. These usually have a smaller proportion of content on engineering design, and more focus on environmental impacts.
3. References that set out basic principles, and sets of best management practices, often with descriptions of case studies.
4. Web resources of various kinds that are often aimed at facilitating community actions relating to stormwater.

All of these information sources contain valuable information that can help inform planning for new work in a watershed or municipal region. For Shediac in particular, references in categories 2-4 are probably most useful, and these offer the best scope for addressing water quality in stormwater in particular. The references found in the present study are listed in the following table, with some commentary on each. Those that are considered of most use or relevance are identified with highlighting. This does not mean the other references are not helpful, it is an attempt to prioritise the references that may be most useful in the New Brunswick context and for Shediac in particular.

<table>
<tr><th colspan="2">Examples and Reference Sources on Stormwater Quality Management</th></tr>
<tr><td>Urban Stormwater Management in the United States (2009) National Research Council 2009.</td><td>https://doi.org/10.17226/12465.</td></tr>
<tr><td colspan="2">This is a complete text on the subject of SWM. It is comprehensive, and at 600 pages is not a quick read, but worthwhile for its depth and breadth of coverage of the issues. The content contains contributions from a long list of experts. The summary section contains a great deal of information on its own. The whole book is available for free download.

Main chapters in the publication include:
1. INTRODUCTION
2. THE CHALLENGE OF REGULATING STORMWATER
3. HYDROLOGIC, GEOMORPHIC, AND BIOLOGICAL EFFECTS OF URBANIZATION ON WATERSHEDS
4. MONITORING AND MODELING
5. STORMWATER MANAGEMENT APPROACHES
6. INNOVATIVE STORMWATER MANAGEMENT AND REGULATORY PERMITTING</td></tr>
<tr><td>Ontario Stormwater Planning and Design Manual</td><td>https://www.ontario.ca/document/stormwater-management-planning-and-design-manual-0</td></tr>
<tr><td colspan="2">Not for a specific municipality, but a modern generic reference that includes many innovative approaches to SWM. A comprehensive reference comprising a large body of information. This reference has undergone input and updating from many involved parties since the 1990s and was fully updated after 2003. Includes useful content on system maintenance and inspection, as well as addressing the organizational features of an effective management system.

Of particular interest:

•incorporating water quantity, erosion control, water quality protection, and water balance principles into the selection and design of Stormwater Management Practices (SWMPs);

•incorporating design considerations for cold climate conditions for SWMPs;

“sewer system maintenance and operation program. • inspection (closed circuit television, CCTV) and repair, • sewer flushing, • pumping station inspection, • emergency response system”
“a strong, long-term municipal staff commitment especially as a leader or co-ordinator; • sufficient financial resources to provide this support and create/distribute promotional materials; • a reasonable number of clearly defined objectives that are practical, environmentally sound and attainable; • policy or by-law support, which also implies strong political support; • public support fostered by education and some involvement in the program development or implementation; • recognition and use of community resources, such as the use of community contractors and suppliers where possible to provide services and materials, linkages to watershed studies, management plans and larger scenarios (e.g. RAP) as a basis for justifying the program”.</td></tr>
<tr><td>Stratford, PEI, Town of Stratford Zoning and Development Bylaw # 45, Sep 2018</td><td>http://www.townofstratford.ca/wp-content/uploads/Zoning-and-Development-Bylaw-No.-45-FINAL-11.22.18.pdf</td></tr>
<tr><td colspan="2">The municipality of Stratford has adopted a range of innovative planning policies. Among these is its</td></tr>
</table>

approach to SWM. “8.6.2. All stormwater management plans shall include low impact management practices that minimize alteration of drainage patterns, enhance existing Wetland and Watercourses and retain existing vegetative cover during and following construction. The stormwater management plan must address: (a) surface drainage patterns; (b) material storage locations and protection measures; (c) construction phasing; (d) runoff quantity and quality control measures during construction or any required earthworks; (e) a stormwater management plan approved as part of any approved Subdivision; and (f) Climate change”.	
Stratford, PEI. 5. Sustainable Subdivision Overlay Application Process 5.1.	http://www.townofstratford.ca/wp-content/uploads/Zoning-and-Development-Bylaw-No.-45-FINAL-11.22.18.pdf
“This part of the planning framework in Stratford assesses and scores developments with the aim of improving their sustainability performance. It seems complicated, but is an interesting example of an applied management tool in action and is worthy of further study. It promotes the use of low impact development and land conservation. The intent of this overlay zone is an approval and performance-based scoring criteria to encourage a holistic site design and development standards, including consideration of environmental sustainability, pedestrian needs, efficient servicing, access to public and private amenities and land use diversity 5.1.2. The aim of a sustainable subdivision is to preserve the natural environment and ecology; improve social amenities and cultural inclusion; increase energy efficiency and reduce fossil fuel energy consumption; improve the Town’s active transportation network and reduce the cost of building and maintaining the Town’s infrastructure. This Appendix contains two parts: (a) The Evaluation Criteria and Indicators; and (b) The Scoring System Applications made under this subsection shall provide a report showing the extent of any Wetland and Watercourse on the site as well as the ecological functions, including: water quality maintenance, wildlife habitat protection, and hydrologic function maintenance. ii. Assign appropriate buffers (not less than 30 meters for water bodies and 15 meters for wetlands) based on a site assessment conducted by a qualified professional. Proposed development shall not disturb wetlands, water bodies, or buffers; and shall protect them from development in perpetuity, with points obtained as outlined in Table 2. Employ a low impact development approach to the development of the required Stormwater Management plan for the project. The Development Officer shall grant 10 points if the proposed development based on comments from the provincial department responsible for the Roads Act maintains the maximum volume water flow rate to the downstream in predevelopment conditions”.	
City of Chilliwack, BC. Policy and Design Criteria Manual for Surface Water Management 2002	https://www.chilliwack.com/main/attachments/files/658/Surface_Water_Management.pdf
Not one of the latest plans, but still contains many progressive ideas. Includes a comprehensive 5 year plan for developing improved SWM.	
City of Edmonton Stormwater Quality Control Strategy & Action Plan, 2008.	https://www.edmonton.ca/city_government/documents/PDF/SWQStrategyActionPlan.pdf
A plan for a large city, but of interest due to its specific focus on stormwater quality.	

<table>
<tr><td colspan="2">The goal of the work was to:
“better manage the impact of stormwater discharges ...to protect water quality in the river.” This means enacting programs and policies that will limit the release of pollutants from the storm sewer system to the river. The SWQS supports the larger strategic City goal of total loads management from all pipe discharges and non-point sources.

“The traditional focus of stormwater management has been flood protection and system operation and maintenance. Stormwater management has been evolving for some years and to be considered innovative it must now also address quantity and quality issues, total loadings, runoff volume, and the impacts of runoff on watershed ecology”.</td></tr>
<tr><td>City of Peterborough
Stormwater Quality Management Master Plan Final Project Report, 2014.</td><td>https://www.peterborough.ca/Assets/City+Assets/Engineering/Documents/Stormwater+Master+Plan/Reports/Stormwater+Quality+Management+Master+Plan+Final+Draft+(Report+Only).pdf</td></tr>
<tr><td colspan="2">Useful, as it examines the need to find ways of adapting a traditional stormwater systems so as to progressively reduce direct discharges of stormwater to receiving streams.

“Need for the project:
The project included a water sampling program within local creeks and at the storm ponds. Results indicate that stormwater discharges are partly or possibly wholly responsible for pollutant concentrations in local creeks rising above accepted objectives (e.g. MOE's Provincial Water Quality Objectives) during wet weather.

As in many municipalities, older portions of the City do not have any direct form of stormwater treatment built into the drainage system; stormwater discharges untreated into local creeks or the river. The project has addressed this issue by looking at various short-term and long-term options for reducing the volume and contamination of stormwater across the City. As well, the project has examined opportunities for retrofit improvement of existing drainage systems, to identify locations where it may be feasible to install new and innovative forms of stormwater treatment.

• Update to the City’s engineering design standards to promote or require site design approaches such as "Low Impact Design" (LID) to minimize stormwater volume and pollutant runoff, while maintaining good property drainage”.</td></tr>
<tr><td>City of Guelph Stormwater Management Master Plan, 2016.</td><td>https://guelph.ca/plans-and-strategies/stormwater-management/</td></tr>
<tr><td colspan="2">Very comprehensive plan that explores many options for quantity and quality management and includes detail on monitoring and evaluation. The SWM Master Plan approach is to integrate flood control and stormwater drainage with opportunities to improve and protect groundwater and surface water quality and the natural environment.</td></tr>
<tr><td>Halifax/Halifax Water Integrated Stormwater Management Policy Draft Framework, 2017</td><td>https://www.halifax.ca/sites/default/files/documents/city-hall/standing-committees/171207essc1213.pdf</td></tr>
<tr><td colspan="2">In 2007, Halifax’s utility services were merged and Halifax Water became the first regulated water, wastewater, and stormwater utility in Canada. This created a unique opportunity to provide integrated, cost-effective, and environmentally sound services across the full urban water cycle. Among various actions, Halifax has adopted separated stormwater handling fees.</td></tr>
</table>

Notes the following problems:
“Private property flooding; • Street flooding and icing in the street; • Sewer backups; • Excessive stormwater in the wastewater system; and, • Degradation in receiving water quality”.

Impetus for the plan was:
“Poor site grading and lack of proper site drainage; • Informal (no) major stormwater or overland flow routes; • Poor street grading and drainage; and • Deficient stormwater systems”.

Notes also:
“There is growing evidence to suggest that a stormwater by-law which regulates site design features promote control of stormwater at source is more effective than public infrastructure at protecting water resources”.

Strathcona County Best Management Practices for Stormwater Management Facilities. 2016 (Alberta)	https://www.strathcona.ca/files/files/ut-best-management-practices-guidebook-june2016.pdf

Takes explicit note of Alberta's Water for Life Strategy. Clearly presented and easy to follow. Good section on pollution prevention BMPs. Good content on responsibilities and maintenance. Lots of good ideas.

Principles:
“Stormwater in Strathcona County will be managed using a watershed approach. The County’s watershed planning approach involves: • Taking into account the natural characteristics of the watershed to ensure that stormwater discharges cause the least impact possible on our natural drainage systems • Considering past, present and future land use to increase the quality of water flowing to receiving waters

The County’s watershed planning approach involves: • looking at the natural characteristics of the watershed • taking into account past, present and future land use • conservation of watershed components • integration of natural systems into SWMF • considering all of the past, present, and future water use • working to ensure that stormwater discharges cause the least impact possible on our natural drainage systems • taking a proactive role in stormwater management to increase the quality of water flowing to the receiving waters”.

Also notable is the Strathcona Yellow Fish Road Program, designed to raise awareness of the effects of stormwater on water quality.

https://www.strathcona.ca/agriculture-environment/environment-and-conservation/environmental-initiatives/yellow-fish-road/

Integrated Stormwater Management Plans, City of Surrey, BC. Web resource.	https://www.surrey.ca/city-services/3661.aspx

This resource from the City of Surrey is valuable in several respects, most importantly, it embodies a genuinely integrated approach to SWM. This is lacking on many other plans that retain a piecemeal approach still dominated by traditional thinking even when there are attempts being made to 'modernize' the systems.

Surrey has developed ISMPs for over 20 discrete sub watersheds. Although these have many common elements, a lot can be learned not only from the content of each of these plans but also

<table>
<tr><td colspan="2">from the process that was followed to develop them. In addition there are about 100 other drainage plans on file via their web site.

The Surrey approach has lot to commend it. It puts specific emphasis on catchment/watershed management, conservation principles, environmental goals, and quite unusually, an ongoing monitoring and assessment component to 'stay on track'. This latter element is missing in most SWM efforts even in larger municipalities.   The Surrey management planning takes place under a top-level Sustainability Charter, which was enacted in 2008.</td></tr>
<tr><td>Sustainable Prosperity, 2016. New Solutions for Sustainable Stormwater Management in Canada</td><td>https://institute.smartprosperity.ca/sites/default/files/stormwaterreport.pdf</td></tr>
<tr><td colspan="2">Explores BMPs for SWM, notably the issue of user fees as a means to drive activities to reduce runoff at the lot level. 21 municipalities in Canada have implemented this approach and 1,500 in the US. Contains details of example projects with detailed analysis of costs/benefits of the user fee system.

Contains case study details for projects in Philadelphia, PA , Mississauga, ON, Victoria, BC, Kitchener, ON, Washington, DC and Prince George's County, MD.</td></tr>
<tr><td>City of Airdrie, 2015. Master Stormwater Drainage Plan.</td><td>https://www.airdrie.ca/index.cfm?serviceID=1029</td></tr>
<tr><td colspan="2">The City of Airdie, Alberta acquired a large area of land for new development, planned to occur over the next 50 years. The Master Stormwater Drainage Plan is designed to guide stormwater management and is itself guided by the AirdrieONE Sustainability Plan.

The main aims of the new drainage plan are to :

• Accommodate the projected growth in a logical and orderly fashion
•Prevent flooding
•Protect water quality in the receiving streams/creeks
•Work with the natural topography
•Respect land ownership to the extent possible
•Protect the riparian environment and unique characteristics of the Nose Creek watershed

The plan is a good example of a process for greenfield development sites.</td></tr>
<tr><td>City of Calgary 2011 Stormwater Management & Design Manual.</td><td>http://www.calgary.ca/_layouts/cocis/DirectDownload.aspx?target=http%3a%2f%2fwww.calgary.ca%2fPDA%2fpd%2fDocuments%2furban_development%2fbulletins%2f2011-stormwater-management-and-Design.pdf&noredirect=1&sf=1</td></tr>
<tr><td colspan="2">Very large and detailed document resulting from the input of teams of consultants, engineers, architect, developers and other stakeholders. Full of technical design details. The abbreviations alone used in the document take up five pages.

Like many similar documents that have a predominantly technical flavour, this one touches on source control but does not give it particular prominence. Helpful for cross checking technical details but not so good where community-based actions/pollution prevention are the main focus.</td></tr>
</table>

City of Calgary, Low Impact Development.	http://www.calgary.ca/UEP/Water/Pages/Watersheds-and-rivers/Erosion-and-sediment-control/Low-Impact-Development.aspx
Specific information relating to Low Impact Development projects in Calgary. Basic information, plus some examples of projects actually carried out.	
Depave Paradise. Peterborough, Ontario based organization.	http://depaveparadise.ca/
Web resource, for coordinating and supporting depaving projects across Canada. Details of projects carried out in a number of areas. The aim is to involve community members directly in the projects, to build commitment and interest and to educate on the benefits of replacing impervious surfaces with vegetated areas.	
Federation of Canadian Municipalities, 2005. Stormwater Management Planning : A Best Practice by The National Guide to Sustainable Municipal Infrastructure.	https://data.fcm.ca/documents/reports/Infraguide/Stormwater_Management_Planning_EN.pdf
A useful basic reference, but starting to look dated compared with some other more recent publications.	
Innovative Stormwater Management Practices. Web Resource.	http://www.iswm.ca/index.php
Web resource, comprising a database and showcase listing of low impact development projects in Ontario. Features an interactive map where projects can be selected and detials viewed according to the type of low impact development used, e.g. green roof, permeable pavement etc.	
Peeling back the Pavement: A Blueprint for Reinventing Rainwater Management in Canada's Communities. Susanne Porter-Bopp et al. 2011.	https://poliswaterproject.org/files/2011/10/Peeling-Back-the-Pavement-A-Blueprint-for-Reinventing-Rainwater-Management-in-Canadas-Communities.pdf
Reference publication explaining basic principles of modern SWM, including numerous examples form across North America and elsewhere in the world. Details of case studies. and very clear 'how to do it 'section. Clearly written and set out. Notes: "Three design principles are crucial for moving from a stormwater paradigm to a rainwater paradigm in our urban communities: 1. Reduce the amount of impermeable surfaces by changing the way we build and retrofit our communities 2. Use rain as a resource and as a viable decentralized source of water for non-potable needs 3. Integrate decision making on a watershed scale".	
Green Communities Canada, RAIN Community Solutions.	http://www.raincommunitysolutions.ca/en/for-municipalities/services/
Useful resource that includes a range of information for property owners, municipalities and community groups that support a range of actions. RAIN Community Solutions states: "We work with municipalities, environmental groups, and property owners to reduce runoff and protect water quality by managing rain where it falls". "In 2009, recognizing the growing impacts of urban stormwater runoff – flooding, erosion, nutrient	

loadings, thermal pollution, infrastructure deficits and more – we initiated a program to help implement positive solutions. In 2010, after several years of research and testing, we launched RAIN to promote green stormwater infrastructure, also known as low impact development". This website also has a link to raingardentour.ca, http://www.raingardentour.ca/ ...which contains details of rain garden projects from across Canada. The site also has a useful list of how-to references for both homeowners and municipalities, with videos, reference manuals and fact sheets.	
Rooftops to Rivers: Green Strategies for Controlling Stormwater and Combined Sewer Overflows. Christopher Kloss, Crystal Calarusse, NRDC 2006.	https://www.nrdc.org/sites/default/files/rooftops.pdf
Peer-reviewed overview of SWM focussing on green infrastructure, and including nine case studies, two in Canada. The main focus is on large cities, but the content is useful as a general reference.	
EPA Facility Stormwater Management.	https://www.epa.gov/greeningepa/epa-facility-stormwater-management
USEPA reference site on stormwater management. US context, but a good reference.	
Sackville-Tantramar regions Rain Gardens Project. 2014, ongoing. EOS Eco Energy, Sackville, NB.	https://eosecoenergy.com/en/projects/climate-change-adaptation/rain-gardens/
EOS has developed and implemented a program for building rain gardens in Sackville and across the Tantramar region. The project is supported via the New Brunswick Environmental Trust Fund and by the municipality and local suppliers of materials. Some rain barrels also supplied as part of the program. The program is focussed on stormwater/flood abatement, but also offers potential water quality benefits. The program has been well planned and implemented and could be replicated elsewhere. Note also work begun by the Shediac Bay Watershed Association on this same topic: http://www.shediacbayassociation.org/current-projects/	
Conservation Subdivision Design (CSD), Manitoba.	https://www.gov.mb.ca/mr/land_use_dev/manualforconservationsubdivisiondesign.html
There appears to be is no single central reference for CSD, but here are numerous sources on the web discussing its application. The Manitoba example here (link above) is a good one, clearly set out. Intended for application for new developments, usually in greenfield sites, this approach aims to preserve at least 50% of a development site with natural cover, resulting in major benefits in terms of runoff and water quality control. There is substantial overlap between many LID principles and those of the CSD approach. Although not applicable for actions in existing developed areas the CSD method should be considered for use in watersheds where new developments are being considered and water quality management is a core goal.	

Learnings / Indications from the References

Some basic issues are apparent from reviewing the references in the preceding table. These are presented in no particular order.

- Fully integrated SWM plans are still relatively uncommon, although there is a trend in this direction;

- Effective management of water quantity and especially quality in a community/municipality requires the active involvement of residents, since both these objectives require actions at the lot level;
- Pollution prevention initiatives are essential to support the achievement of stringent water quality objectives;

- In addition to residents, effective SWM efforts require the active involvement of managers in all key areas of responsibility across levels of government, capturing planning, environment, water supply, wastewater and stormwater. Achieving the necessary integration and cooperation across responsibility areas is a significant barrier to effective development and implementation of ISMPs;

- Another important barrier has to do with established practice and attitudes in the civil engineering and municipal infrastructure management fields. Modern integrated SWM requires an approach to many fundamental design features that is quite different to that which has been established for many years;

- Effective stormwater quality management relies on a supportive framework of planning, community and environmental objectives;

- The more comprehensive approaches that fully address water quality in stormwater have usually been developed within a broader framework that features an overarching sustainability or environmental charter (or equivalent);

- The planning and management units that should be used to design and implement effective stormwater quality management efforts are watersheds and sub-watersheds;

- Although it is easiest to implement effective stormwater quality controls during the initial phases of development, retrofitting is possible and can also be effective.

- Two important features that are often given little attention in SWM plans are inspection and maintenance, and monitoring.

6. DATA/INFORMATION GAPS AND NEXT STEPS PLANNING

Considering the Shediac area watersheds overall, a range of monitoring has been carried out over many years under numerous programs, these were listed and discussed in the monitoring plan report (Hughes, 2017). Attention has been focussed in recent years on issues relating to bacterial contamination and in particular, possible sources of bacterial pollution that could be contributing to elevated bacteria counts observed at times in seawater at the Parlee Beach swimming beach. Reports by the Steering Committee for Parlee Beach Water Quality (2018) and Wood Environment & Infrastructure Solutions (2019) have summarized the 2017 and 2018 monitoring data in detail.

In terms of the regional water quality monitoring, mostly carried out by provincial staff or by the Shediac Bay Watershed Association, water quality has been found to meet provincial or national objectives with relatively few exceptions, although elevated results for FIB have been found frequently in sites established for more detailed monitoring in 2017-2018.

Some additional studies, such as that by Crandall Engineering on the Parlee Beach Lagoon have been completed more recently. While account is taken of all these studies, for the purposes of this report, primary attention will be paid to the stormwater results.

Detecting exceedances of standards or objectives in samples is relatively straightforward, but determining their primary cause or source is often a lot more difficult. This has proven the case in the Shediac studies. Periodic exceedances of bacterial standards have been observed at widely scattered locations across the watershed, as well as within the denser monitoring networks within the municipal region. In some cases (for example the sites set up to examine agricultural impacts) the sources responsible for elevated bacterial results can be identified with some degree of certainty, but this is the exception. For most of the monitoring results where FIB guidelines have been exceeded the source(s) of contamination remain speculative. Being able to link results in watercourses unequivocally to specific sources of contamination (especially non-point sources) requires a lot of forensic monitoring and related investigations that are time consuming and can be difficult and costly. Where runoff process are dominant, sampling is also at the mercy of the weather, as results can only be obtained during significant precipitation episodes.

Results of some of the special studies suggest that a few possible FIB sources can be downgraded in significance, if not ruled out. The report by Stantec (2017) on bacteria in sand and shallow groundwater suggest that there are no major FIB sources in the shallow groundwater and sand at Parlee Beach. The 2019 Crandall Engineering Report on the Parlee Beach lagoon found that sediments in the lagoon contained low levels of FIB. Both these sets of results in turn support the concept that inputs of FIB in runoff are responsible for observed elevated levels of FIB in various parts of the Shediac Bay watershed, including streams and the nearshore marine environment and that reservoirs of bacteria in sand and sediments bacteria are of lesser importance. However the studies completed to date still do not fully confirm and/or pinpoint the nature and location of the originating bacterial sources.

Stormwater: Information Gaps and Options to Address

The stormwater bacterial results are relatively high compared to samples gathered at other locations, which makes gaining a clear understanding of the sources and processes contributing to the results especially desirable. The 2017-2018 data were reviewed in the first part of this report. While some insights can be gained from the data so far, there is still a lack of certainty regarding bacterial sources influencing the results in stormwater. The outstanding knowledge gaps could be addressed via future work, discussed in the following sections.

Information gaps/questions: Stormwater Monitoring Results		
	Question/knowledge gap	*Options to address*
1	Are the elevated bacteria values seen in stormwater caused by sewage contamination?	1. Sample stormwater for chemical tracers of sewage. 2. Optionally, carry out tracer studies, introducing tracer compounds into the wastewater system

		and testing for the tracers in stormwater in streams/outfalls.
2	If YES, what are the sources of this contamination?	1. Use the first CST results to focus attention on sub-basins of concern. 2. Gather additional details from municipal officials regarding the stormwater infrastructure in Shediac. Input to item 4.2.
3	If NO, what are the sources of the elevated FIB?	1. Perform targetted sampling of runoff during precipitation events within sub-basins.
4	What are the precise spatial extents of the sub-watersheds for the creeks/outfalls receiving stormwater in Shediac?	1. Perform detailed watershed delineation using LIDAR digital elevation data. 2. Supplement with municipal data to account for any inter-basin transfers via drainage system. 3. Use the information to support detailed sub-basin water quality studies.
5	Wildlife monitoring	1. Monitor the presence of birds and other wildlife at selected locations.
6	Flow from wastewater network to surface	1. Investigate, using the drainage surface data obtained in item 4, possible locations where wastewater could be released (e.g. manholes) during episodes of extreme precipitation and if so, its destination.
7	Are exceedances of FIB standards caused by urban wildlife sources a cause of concern for human health?	1. Commission a review of studies by a suitable environmental health expert or consultancy.

Discussion of proposed additional stormwater actions
(numbers refer to the proposed actions in the above table)

Note: the following proposals are in outline only. Prioritizing and finalizing the detail of each action item requires more consultation and planning, which would take place in Phase 2. It is also important to stress that these proposed actions need to be evaluated within the context of environmental quality within the Shediac region (including Parlee Beach) as well as the larger Shediac Bay environment. Are environmental guidelines being met sufficiently? Is water quality acceptable in all parts of the watershed? The answers to these questions are important to help decide the level of effort that is appropriate for further investigations.

1.1 and 1.2

These options, while offering good potential to answer the questions concerning potential sewage cross-contamination into stormwater lines or discharge channels, are likely to be expensive, and so should first be costed out. Sites SW1, SW3 and SW6 would be logical candidate sites at which to investigate using CST or tracer techniques. The Crandall study has proposed a study of all seven pipes discharging into the Parlee Beach lagoon. Tracer studies could reduce the need to examine all the discharges if it can be shown which sources are of concern. This would take a minimum of one full additional season of monitoring, capturing at least 6-8 precipitation events (but see below).

2.1

If evidence of sewage contamination is found based on chemical tracer methods, further testing and investigation at additional points within the stormwater system will be needed to pinpoint the location of the contamination (probably during a subsequent year of work). This could possibly be accomplished in the first year if there is the capacity to rapidly review results as they come in and adapt the monitoring program.

2.2

The existing stormwater map (Figure 5) provides some detail on the location of stormwater pipework in relation to the natural drainage network. To improve the ability to interpret results there is a need to confirm drainage direction and interconnectivity in many of the mapped sections. This information can be combined with the mapping data obtained under items 4.1-4.2. Together this will provide firm information on what surface water is draining where. Obtaining this information will require a combination of liaison with municipal engineers, field checking, and mapping the results. With this information it will be possible to narrow down the range of potential influences on the stormwater results obtained at the established monitoring sites with more confidence.

3.1

This proposal would be cheaper to implement than 1.1. and 1.2 but would offer the opportunity to prove that observed FIB results at stormwater sites are definitely due in part to non-human waste sources. While there is an assumption that this is the case, for most of the stormwater sites there is at least some possibility that sewage effluent could be entirely responsible. This action item involves directly sampling surface runoff at a number of locations during significant precipitation events. The sample locations are chosen so that there is no possibility of sewage waste impact. If FIB are then found, then they have to originate from non-wastewater sources.

The sampling design is designed to test the runoff from several potential FIB source categories;

1. Roofs of large commercial buildings, via sampling of water from downspouts/discharge pipes.
2. Parking lots, via surface sampling of runoff from downstream edges or water about to enter surface drains within paved parking areas.
3. Roads, from curbside gutters prior to entering drains.
4. Lawns/grassed areas, at the downslope edge of such areas adjoining an impermeable surface such as a curb, road, driveway etc.

There is a requirement for permission/access involved with item 1 and possibly 4, although edges of communal grassed areas, parkland or other non-private land could be used. It may be difficult to find sufficient runoff from grass unless there is intense precipitation, but this will also depend on soil permeability so is hard to predict. Samples can be collected directly using bottles (downspouts) or large syringes (hard surfaces). Ideally at least three locations of each source category should be tested at least 3-6 times. For roads, both major and minor sealed roads should be sampled. Site selection will involve walking potential sites and in some cases obtaining prior permissions.

4.1 - 4.3

LIDAR data are available for the Shediac area and can be used to calculate local micro-watersheds for each of the creek systems forming part of the stormwater sampling network. Some experimentation is needed to obtain the drainage pattern at the desired scale. The derived watersheds then need to be compared to municipal data from the stormwater system to check for potential cross-basin movement of stormwater, which can then be recorded and mapped. Additionally, the locations of all points where storm drains pass over or under wastewater forcemains should also be identified. These would be sites where cross-contamination might be most likely to occur. The resulting mapping data can be used to support revised data analysis with improved confidence concerning which sources would be influencing results at each stormwater monitoring site. This information will supplement any chemical tracer studies under items 1.1-1.2.

5.1

Wildlife monitoring. This item supplements and potentially enhances item 3. In the case of large rooftops discharging stormwater there is the possibility that such water becomes contaminated with FIB from wildlife, such as birds, squirrels, raccoons and rodents spending time on the roofs. This would be investigated using a wildlife/trail camera set up at a suitable location, which could record either by time lapse or by motion detection. Replication would be advantageous if possible. Site permission would be required. Action 3.1 can potentially prove the existence of non sewage FIB sources in runoff. This action item (5.1) would provide hard evidence of the sources of the FIB in this runoff category.

6.1

Wastewater flow to surface, potentially during episodes of high precipitation. This may have been investigated but if not, is worth pursuing to determine whether such flow is likely and if so, where and under what conditions. Will require hydraulic analysis and input for the Wastewater Commission. If flow from the wastewater system to surface occurs, such as via manholes, then this contaminated water will enter the stormwater system. Mapping data from item 4.1 will enable surface flow predictions to be made.

7.1

This appears to be a gap in knowledge based on a review of the published reports to date. Exceedances of FIB standards may be caused by human or animal sources. Although some molecular testing has been done, it cannot be considered conclusive regarding the relative contributions of each source category. It seems likely that a significant proportion of exceedances could be due entirely to wildlife sources. If this is the case, are further source control measures warranted? In general it appears that health concerns are lower where wildlife sources are implicated but this should be more definitively investigated by qualified authorities. A report published by the Urban Water Resources Research Council (2014) entitled Pathogens in Urban Stormwater Systems is a good reference on this subject. It appears in general that an equivalency between human/wildlife FIB sources is generally assumed for the purposes of environmental and human health management. The reference cited notes two literature reviews sponsored by the USEPA, “Review of Published Studies to Characterize Relative Risks from Different Sources of Fecal Contamination in Recreational Waters (EPA 2009b)” and “Review of Zoonotic Pathogens in Ambient Waters (EPA 2009a)”.

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