Stormwater quality assessment and management for the Town of Jasper in Alberta, Canada

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ABSTRACT

Stormwater pollutants can have deleterious impacts on the aquatic life of receiving water bodies. This paper presents the findings of a stormwater quality monitoring program performed in the town of Jasper in Alberta, Canada. This is one of the very few studies done on a small urban settlement to identify key pollutants of concern, characterize stormwater and identify unique pollutant sources in the town. A total of 14 stormwater quality parameters were found to be of high concern to aquatic life. The most prominent pollutants were total suspended solids (TSS), metals and phosphorus which compared well with studies conducted in large urban settlements. Tourist influx contributed to high metal and petroleum hydrocarbon loads during the peak season due to high vehicular activity. Elk were found to reside in the town during summer and their fecal droppings resulted in elevated fecal coliform concentrations. It was found that winter road salting was responsible for excessive chloride concentrations observed during the spring melt. TSS concentrations were statistically correlated with various metals as well as phosphorus using Spearman’s rank correlation. It was found that the current street sweeping schedule in the town coincided with lower TSS and metal loads in stormwater.

Key words | small urban settlement, stormwater characterization, stormwater management, stormwater quality monitoring, street sweeping

HIGHLIGHTS

- This paper presents one of the very few comprehensive stormwater quality case studies conducted on a small urban settlement.
- Unique activities in the town, such as tourism and elk migration, were found to elevate stormwater pollutants.
- A strategic street sweeping route reduced pollutants.
INTRODUCTION

It has been well established that pollutants on a watershed that are washed off by runoff can cause environmental degradation in receiving water bodies (Ellis & Hvitved-Jacobsen 1996; Burton & Pitt 2002). Adequately addressing water quality concerns requires an understanding of the types of pollutants present on the watershed and their potential impacts on receiving water bodies, as well as the origins of the pollutants so that effective source controls may be applied (Adams & Papa 2000). Pollutant concentrations in runoff are highly variable in nature, and the factors that influence them are still not well understood (Adams & Papa 2000; Burton & Pitt 2002; Song et al. 2019), mostly because there are numerous pollutant buildup and wash-off mechanisms that influence pollutant mass loading in stormwater runoff. This makes it challenging to implement sustainable stormwater management strategies for the protection of aquatic life.

Pollutant buildup varies spatially and temporally depending on catchment characteristics and anthropogenic activities within the catchment. Most field studies that have attempted to characterize urban stormwater and identify pollutant sources have been conducted in major cities around the world (Marsalek et al. 1997; Wong et al. 2012; Baralkiewicz et al. 2014; Maharjan et al. 2016; Song et al. 2019). However, cities are typically made up of large, interconnected catchments where there are substantial spatial and temporal variations of pollutant mass discharge (Langeveld et al. 2012; Maharjan et al. 2016). This makes it difficult to interpret contaminant characteristics from the data. There are very few stormwater quality studies that have been conducted in small urban settlements. The ‘Central Canmore Stormwater Study’ (Mountain Engineering Ltd 2006) is a typical example of a stormwater study conducted in a small town. The study identified the pollutants that were present in stormwater; however, it lacks a systematic stormwater characterization approach in which exact pollutant sources are identified. Other small-scale stormwater studies, such as those conducted for the town of Pincher Creek (Mountain Engineering Ltd 2006) and the city of Dawson Creek (Opus International Consultants (Canada) Ltd 2017), were found to focus on flood prevention, leaving limited resources to investigate quality issues in depth. Case studies that characterize stormwater in small urban settings are needed so that representative data can be collected, and the mechanisms responsible for runoff pollutants can be accurately identified so as to ultimately facilitate the implementation of suitable quality controls.

Meteorological events are the primary mechanism for pollutant wash off and they contribute to the temporal variability of pollutant concentrations in stormwater monitoring data (Kayhanian et al. 2007; Liu et al. 2012). Previous research has sampled rainfall (wet weather) events to assess the influence of storm intensity and duration as well as antecedent dry days on pollutant loading (Liu et al. 2013). Parallel to these efforts, but on a much smaller scale, the effects of urban snowmelt on runoff quality have also been addressed in colder regions. Furthermore, according to Janke et al. (2013), dry weather events, which are associated with background runoff, have been found to wash-off
substantial contaminant loads in catchments and should be monitored. Galfi et al. (2017) presented one of the few studies that characterized stormwater by sampling dry, wet and snowmelt events. More studies that monitor a range of weather events are needed to better understand how seasonal changes correlate with runoff quality variations in order to characterize and manage stormwater appropriately.

The focus of this research was to conduct a field-based investigation on stormwater quality in a small town in Jasper National Park, Alberta, Canada, called the town of Jasper. The aim was to monitor key water quality parameters (physical, chemical and biological) that may impose negative effects on sensitive ecosystems of receiving water bodies. Grab samples were collected at multiple sites and during various weather events to enable a complete characterization of the stormwater. A comprehensive approach was taken whereby the monitoring data were combined with historical reports as well as field observations and interviews, in order to understand how unique and seasonally variable activities in the town – such as tourism and animal migration – may have an impact on stormwater quality. This is a novel approach in the field of stormwater research as no other studies have investigated the effects of specific land-use activities, such as tourism, on stormwater quality. The small study site lends itself to conduct a detailed study with fewer variables at play compared to a large urban center enabling an in-depth understanding of the variables that may affect stormwater quality in the town.

**METHODS**

**Site description and historical reports**

Jasper is a small remote town located in Jasper National Park, which is situated in the Rockies mountain range in Alberta, Canada. The park is at the headwaters of some of Canada’s major river systems and has numerous pristine lakes, creeks and wetlands scattered throughout its region. Parks Canada (PC) prioritizes the conservation of these water bodies, because they sustain abundant wildlife and attract millions of tourists every year. The town of Jasper is situated at the confluence of three valleys which is a vital wildlife movement corridor for a range of animals such as elk and bears. Stormwater outfalls in the town drain runoff into local creeks and lakes, which ultimately feed into the Athabasca River, a Canadian Heritage River. Major outfalls in the town as well as the surrounding water bodies are indicated in Figure 1. These water bodies serve as habitats to sensitive aquatic ecosystems and provide drinking water for wild animals. Therefore, it is of great importance to ensure that stormwater from the town does not have a negative impact on the natural ecosystem of receiving water bodies. At the same time, it is important to preserve the aesthetic and recreational value of receiving water bodies for the residents and tourists in Jasper.

The town has a permanent resident population of only 4,700 people, but it attracts many tourists during the summer months, with a capacity to support 20,000 visitors daily during the peak season (July to October). The high influx of tourists may result in disproportionately high stormwater contamination, as studies have found that pollutant build up is largely attributed to anthropogenic sources such as population density and vehicular traffic (Adams & Papa 2000). The town of Jasper experiences small but frequent storms in the summer which are associated with high pollutant wash off (Alberta Guidelines 2013). Furthermore, winter brings sub-zero temperatures, followed by spring melt, which may result in high pollutant loading from accumulated pollutants.

The stormwater drainage system for the Municipality of Jasper is largely comprised of a conventional subsurface storm sewer collection system. This system is a complete curb-gutter system and was built for a 5-year design storm. It was established in the early 1900s after the town had developed and has expanded together with the expansion of the town. There are three main catchments, namely North, Central and Cabin Creek, and they drain runoff to the NO1, CE1 and CA2 outfalls, respectively (Figure 1). The North catchment is the largest with an area of 72 ha and a total storm sewer length of 7.5 km. All catchments have gentle grades. The average slopes of the North, Central and Cabin Creek catchments are 3.3, 2.7 and 2.5%, respectively, and the flushing conditions were assumed to be the same for all catchments. The directly connected impervious area ranges from 20% in the residential areas to 70% in the commercial areas, whereby the North catchment is a mixture of both land-use types, the Central catchment is
mostly commercial and Cabin Creek is residential only. Outfall CE1 conveys runoff into the North Twin Lake, whereas CA2 and NO1 drain stormwater to Cabin and Cottonwood creeks, respectively, which travel from high lying wetlands to the Athabasca River.

Stormwater management is a shared responsibility between PC and the Municipality of Jasper. There is little evidence of flooding or erosion damage caused by runoff because the stormwater system is well established and the soil is well drained. Street sweeping is the only form of
quality control currently applied in the town. However, the stormwater quality is largely unknown, and there is currently no management plan in place to mitigate potential stormwater impacts. Previous monitoring reports, which were provided by PC, were completed by independent consulting firms, and there lacks consistency in monitoring methods to directly compare results between studies in order to characterize stormwater. It is therefore necessary to design comprehensive, long-term studies to investigate stormwater issues.

Field sampling

A stormwater monitoring program was conducted from October 2018 to November 2019. The scope of the monitoring program was limited to sampling at the three main stormwater outfalls (CA2, CE1 and NO1 in Figure 1). Multiple outfalls were sampled to characterize stormwater quality by catchment and associated land use. Furthermore, samples were collected for dry, wet and snowmelt weather conditions to adequately characterize stormwater quality by background conditions and seasonal changes.

A PC staff member collected samples on the author’s behalf. Single grab samples were collected in the vicinity of stormwater outfall locations. A total of six sampling events were collected for dry weather, wet weather and snowmelt events and are summarized in Table 1. Samples were collected in the beginning of wet and snowmelt events to capture the ‘first flush’ runoff which is expected to be the most contaminated runoff (CCME 2016), especially in small catchments such as those in Jasper (Sansalone & Cristina 2004). Field blanks, duplicates and travel blanks were collected as quality assurance and quality control (QA/QC) samples. The overall dataset is relatively small due to limited resources available for the study.

Water samples were analyzed for a suite of physical, biological and chemical parameters. All laboratory analyses were completed by an accredited laboratory, following Standard Methods for the Analysis of Water and Wastewater, 22nd edition (Rice 2012). In addition, physical in situ parameters were collected in field studies. Water temperature, pH, turbidity and conductivity measurements were taken at each site using an OAKTON Portable pH-Conductivity Meter. Depth and velocity measurements were taken (with a Global Water Flow Probe FP211) at five equidistant points along the channel section, and a flowrate was calculated for each segment. An average flowrate was then calculated from the segments. Runoff flow was characterized as no flow, low flow or high flow based on average flowrate calculations as well as visual inspection. It should be noted that in the case of ‘no flow’, samples were collected from the runoff that had pooled at the outfall.

Table 1 shows that outfalls experienced no flow during the dry event (Event 1) on 5 October 2017, which was expected. The samples obtained during Event 1 are representative of background conditions (runoff that results from cross-connections, irrigation drainage and groundwater flow). Event 6 on 2 November 2018 was also reported as generating ‘no flow’ at outfalls (Table 1), because the storm was small. Therefore, it was assumed that surface runoff was too low to mobilize the first flush of contaminants and that observations represent background pollutant levels.

Events 2–4 in Table 1 were collected during typical rainfall and snowmelt runoff conditions in the town. The three outfalls CA2, CE1 and NO1 experienced low flows during these events. It is only during Event 5 on 2 July 2018 that

### Table 1 | Summary of sampling events collected from October 2017 to November 2018

| Event | Date          | Weather classification | Rainfall         | Runoff flow at outfalls | Notes                                      |
|-------|---------------|------------------------|------------------|-------------------------|--------------------------------------------|
| 1     | 5 October 2017| Dry                    | No rainfall      | No flow                 | No notes recorded                         |
| 2     | 17 October 2017| Wet                    | 8.6 mm over 24 h | Low flow                | No notes recorded                         |
| 3     | 23 November 2017| Snow melt             | No rainfall      | Low flow                | Varsol odor at NO1                         |
| 4     | 14 March 2018 | Snow melt             | No rainfall      | Low flow                | Visible hydrocarbon sheen at NO1           |
| 5     | 2 July 2018   | Wet                    | 56.9 mm over 48 h| High flow               | Visible hydrocarbon sheen and varsol odor at CE1 |
| 6     | 2 November 2018| Wet                    | 6.6 mm over 24 h | No flow                 | Visible hydrocarbon sheen at NO1           |
the outfalls experienced high flows since the rainfall intensity was high during the storm. In fact, Event 5 was the largest volume of rainfall recorded over 48 h in the past decade when compared to the historical precipitation data from the Jasper Warden Station (station no. 3053635). Event 5 was the only event collected during the summer and, thus, will help characterize the effects of tourist activities on stormwater quality. Finally, notes in Table 1 indicate that there was an evidence of petroleum hydrocarbons (PHCs) observed during Events 3–6.

Two follow-up field visits were conducted in the town of Jasper (1 July 2018 and 4 May 2019) in order to collect relevant information from the Municipality, such as Geographic Information System (GIS) data, land-use maps and drainage system maps for the town, as well as make detailed field observations that would assist in the interpretation of the sampling results. Meetings and personal communications were conducted with relevant PC personnel, including environmental management specialists and ecologists. In addition, the operations and utilities staff at the Municipality were consulted about potential stormwater issues in the town.

**Identification of parameters of interest**

Parameters of interest (POIs) are critical pollutants identified with the help of PC Leadership Targets (PCLT) for Wastewater Effluent Discharged to Water Bodies provided by the Municipality, as well as the Canadian Water Quality Guidelines (CWQGs) established by the Canadian Council of Ministers of the Environment (CCME) (2016) for the protection of freshwater aquatic life. The CWQGs were used in addition to PCLTs so that a wide range of parameters could be evaluated.

Analytical parameters that exceeded either PCLT or CWQG guidelines for two or more sampling events during the course of the test period were considered POIs. Parameters that exceeded guidelines on one occasion were isolated loading cases and were not considered POIs, unless they were a cause for concern in previous studies.

**Analysis methods**

The magnitude and frequency of POI exceedances were assessed to determine whether they are a cause for concern for the health of aquatic life. This was done by visually inspecting concentration graphs for each POI. Furthermore, POI concentration patterns were compared to identify potential correlations and relevant relationships (Burton & Pitt 2002). Apparent correlations between pollutants were subject to statistical hypothesis testing with a Spearman rank-order correlation, performed with the XLSTAT software. Finally, spatial and temporal concentration patterns of POIs were evaluated to characterize stormwater and determine potential POI sources.

**RESULTS AND DISCUSSION**

**Identifying and analyzing POIs**

The results from the analytical testing of samples were evaluated, and a total of 14 parameters were identified as POIs. Graphical comparisons of POIs and their respective guidelines are presented in Figure 2. They are presented in order of parameters with a high frequency of exceedances at the top and a low frequency of exceedances at the bottom. The graphs show the POI concentration (y-axis) for each event (x-axis) at the outfalls CA2 (green), CE1 (blue) and NO1 (red). The horizontal dashed line in each graph delineates the applicable CWQG or PCLT threshold limit, and the concentration value of the threshold limit is marked in the upper right corner of the graph. POIs that exceeded guidelines significantly and frequently were judged to be of greater concern to the health of aquatic life than marginal and occasional exceedances. A qualitative evaluation of the analytical results in Figure 2 shows that POIs of highest concern are phosphorus, total suspended solids (TSS) and metals. These findings compare well with the literature which was conducted for large urban areas. A comprehensive literature review was compiled by Gobel et al. (2007) which found that the most common types of stormwater pollutants in cities are nutrients (such as phosphorus), TSS and heavy metals (cadmium, copper, lead and zinc). According to Burton & Pitt (2002), sediment (on a mass basis) is the greatest pollutant of water resources in the USA. Furthermore, Marsalek et al. (1997) found that metals such as Zn and Cu are the most prevalent toxic contaminants found in an urban runoff in Canada.
Figure 2 | Concentration graphs for 14 POIs identified from sampling stormwater in the town of Jasper, namely TP, TSS, Al, Zn, Fe, Cu, fecal coliforms, Cl, Co, Mn, Cd, Pb, Cr and PHC-F2. Please refer to the online version of this paper to see this figure in colour: http://dx.doi.org/10.2166/wqrj.2021.012.
Total phosphorus (TP) was deemed to be a parameter of high concern because concentrations exceeded both CWQG and PCLT guidelines by a significant magnitude and frequency at all outfalls. CWQG, the more conservative guideline, is 0.01 mg/L for phosphorus and was exceeded more than 100 times at CA2 during a snowmelt event. Phosphorus also exceeded both guidelines for background flows at NO1.

TSS exceeded the PCLT of 10 mg/L by a factor of 45 and exceedances occurred for Events 1–6. Particularly high concentrations were observed during high flow (Event 5), which resulted in a high mass loading. TSS also exceeded stormwater background flows, and studies have found that long-term exposures of TSS may have a significant impact on aquatic life (Burton & Pitt 2002).

A total of nine inorganic elements were identified as POIs. Aluminum (Al), iron (Fe), zinc (Zn) and copper (Cu) in particular are of high concern because they occur at high concentration levels. Al and Fe exceeded CWQG by a factor of 44 and 27, respectively, and exceedances occurred for Events 1–6. Zn and Cu exceeded guidelines by a factor of 20 and 7, respectively, and exceedances occurred for almost every event. These metals were generally found at their highest concentrations during Event 5 when outfalls experienced high flow rates. Exceedances even occurred during baseflow conditions. Furthermore, previous studies dating back to 2001 show that Al, Zn and Cu concentrations exceeded guidelines in surface water samples taken at outfall CE1, confirming that these parameters are a recurring concern in Jasper stormwater. Other inorganic POIs are cobalt (Co), manganese (Mn), cadmium (Cd), lead (Pb) and chromium (Cr). They generally showed lower exceedance magnitudes and frequencies, and had a lower presence in background flows. However, Co, Mn, Cd, Pb and Cr were also classified as being of high concern.

The impact of fecal coliforms on aquatic environments is of high concern, because analysis of the samples showed that they exceeded water quality guidelines (PCLT) by the highest magnitude (up to 240 times at CE1) during the highest flow event. Chloride (Cl) exceeded guidelines (CWQG) for only Events 3 and 4 which induced low-flow conditions at the outfalls CA2, CE1 and NO1. The results were consistent with previous monitoring results, and thus chlorides are of high concern.

PHC fraction 2 (PHC-F2) only exceeded guidelines during Event 5 at the NO1 outfall; however, it is included as a POI because it was identified as a cause for concern in previous studies at the same location. Exceedance of PHC-F2 was significant, reaching almost 12 times more than the guideline, and occurred during the event of highest flow. In addition, a hydrocarbon sheen and odor were occasionally observed at either CE1 or NO1 during Events 3–6.

Metal concentrations were found to have a statistically significant correlation with TSS concentrations using Spearman’s rank correlation at a 95% confidence level. Fe and Al were found to have the strongest correlation to TSS, with correlation coefficients of 0.963 and 0.954, respectively, followed by Pb, Zn, Co, Cu, Cr, Mn and Cd in descending order. These are strong correlations which suggest that the metal POIs are linked to the same source. Furthermore, TP showed to have a strong positive correlation with TSS (correlation coefficient of 0.563) which suggests that they likely originate from the same source.

Stormwater characterization

The spatial and temporal concentration patterns of POIs were evaluated to characterize stormwater and determine potential POI sources. Figure 3(a) is a land-use map of Jasper and Figure 3(b) is a map that indicates road features in Jasper which may be responsible for certain pollutant loading.

TSS concentrations were generally lower for low-flow and dry events and highest during Event 5 (the major storm event). Further inspection of the data reveals that TSS concentrations tend to be higher at the CE1 and NO1 outfalls compared to the CA2 outfall. However, TSS concentrations were unexpectedly lower (especially at CE1) during Event 5 – the same period when street sweeping was implemented in Jasper. In communication with the Municipality maintenance staff, it was determined that street sweeping was implemented frequently (on a weekly basis) during the summer season, predominantly in the central catchment (Figure 3(b)). This corresponds to the particularly low TSS at the CE1 outfall. It is thus likely that the sweeping was responsible for TSS reductions at the CE1 and NO1 outfalls in the summer. There is substantial literature which supports the environmental benefits associated with street sweeping. For example, Rochfort et al. (2009) conducted...
comprehensive tests to show that sweeping significantly reduces road debris, especially when applied in urban areas with high solid deposits. Furthermore, Sartor & Gaboury (1984) reported that a mechanical broom sweeper (the same technology adopted in Jasper) can provide a 30% reduction in end-of-pipe sediment loads. Street sweeping is common practice in small urban settlements, as illustrated in the ‘Central Canmore Stormwater Study’ (Mountain Engineering Ltd 2006). This study shows that regular street sweeping is an effective means of source control in small towns where resources are limited to invest in costly low impact developments (LIDs) that need to be retrofitted and regularly maintained. Street sweeping efficacy can be maximized with strategic changes in sweeping route and frequency, to target areas of highest pollutant loading.

Metal concentrations were generally high at all outfalls around Jasper. Al, Zn, Cu and Fe were present in background levels which may indicate that they are inherent to the site soil composition. However, low extractable Al and Fe values in the soil type found at the Jasper townsite indicate a weak weathering environment, and thus it is unlikely that the soil contributed metal loadings to runoff. It is unlikely that rusting gutters and galvanized steel pipes are a major source of metals in Jasper’s stormwater because the buildings drain rainfall into the surrounding yard, where it infiltrates in the rapidly draining soil (Burton & Pitt 2002). Hence, the streets may be a major source of metal contaminants. Previous studies such as Callahan et al. (1979) have also reported that a large portion of dissolved metal concentrations are attributed to traffic-related runoff. Furthermore, Qin et al. (2010) proved that 50% of Cu and 70% of Zn burdens in runoff were from traffic-related activities. The U.S. Department of Transport (D.O.T. 1987) found that Pb and Zn in stormwater are from tire wear and Cu, Cd, Cr and Mn are from moving engine parts.

The data show that metal concentrations are generally higher at outfalls CE1 and NO1 than CA2. This corresponds well with land-use activities (i.e. vehicular activity) because the North (NO1) and Central (CE1) catchments include commercial zoning areas which are associated with high vehicular activity, whereas the Cabin Creek (CA2) catchment is a residential area (Figure 3(a)) with low traffic volumes. Event 5 shows particularly high metal loadings at the CE1 and NO1 outfalls which are indicative of the influx of tourist vehicles in the summer, as they mostly populate the commercial zones in Jasper.

Similar to metals, PHC occurrence may be related to vehicular activities that are associated with land use because...
PHCs were only detected at outfalls CE1 and NO1. Previous studies have shown that oil leaks from vehicles are the primary source of PHCs in stormwater (D.O.T. 1987). The main thoroughfare in Jasper passes through the Central and North catchment and provides direct access from the highway to the town (Figure 3(b)). The data findings suggest that the vehicles on this road are a significant contributor to oil leaks in Jasper because the road provides ample parking and primary access to the commercial center, and has four gas stations along with it where vehicular oil leaks were frequently observed (Figure 3(b)). The road has especially high volumes of traffic during the tourist season, and this is reflected in the data which show that PHC-F2 concentration spiked during Event 5.

The POI concentration graphs in Figure 2 suggest that TP, fecal coliforms and Cl concentrations respond to meteorological events. For example, TP concentrations steadily increased until they peaked during Event 4—a major snowmelt event. In fact, TP loading is generally highest for all outfalls during the spring melt events (Events 3 and 4). Studies completed by Noton et al. (1989) and Riemersma et al. (2006) also found higher TP values during spring flows. Furthermore, Timmons & Holt (1977) found that, on an unimproved grassland, more than 80% of phosphorus runoff losses occurred during spring melt. This suggests that previous areas are a major source of phosphorus during snowmelt events; in these cases, TP may originate from decaying organic debris in the soil.

Fecal coliform concentrations increased significantly during the summer which was expected since warmer temperatures promote higher microbial activity. Fecal droppings from roaming animals also contribute to the increase in fecal coliforms (Galfi et al. 2016), and field observations revealed that elk are a prominent source of fecal droppings in Jasper. Elk contribute significant amounts of fecal droppings in the summer as large herds reside in the town to graze on lush vegetation. PC staff push the elk to the fringes of the town for the safety of the residents and tourists. Hence, they were generally observed around the NO1 and CE1 outfalls, and there was evidence of elk tracks in the NO1 outfall channel as well as evidence of elk droppings near a catch basin (Figure 3(b)) which leads directly to NO1. This is reflected in the data which show the highest coliform concentrations at the CE1 and NO1 outfalls during Event 5.

Chloride was only detected in runoff during snowmelt events (Events 3 and 4) and so the likeliest source is winter road salting. These findings are supported by numerous studies conducted in large urban settlements (Guevara-Riba et al. 2005; Galfi et al. 2016).

**CONCLUSIONS**

Overall, this study has successfully identified the stormwater quality issues present in the town of Jasper. The monitoring data revealed a total of 14 POIs in Jasper stormwater, namely TSS, metals (Al, Zn, Fe, Cu, Co, Mn, Cd, Pb and Cr), TP, Cl, fecal coliforms and PHCs. TSS, metals and TP concentrations exhibited the highest frequency and magnitude of exceedance of local and federal thresholds. This compares well with studies done in large urban settlements, which found that TSS, metals and TP were the most common pollutants found in stormwater.

It was found that the prominent source of metal and PHC loading was from vehicular traffic in commercial areas. Furthermore, these parameters were present in significantly higher concentrations during Event 5, which was attributed to the high influx of tourists in the summer months. Fecal coliforms were present in significant magnitude in the summer which was indicative of, amongst other things, the presence of fecal droppings from the resident elk population which is unique to the town of Jasper.

TSS and metal concentrations were statistically correlated whereby Fe showed the closest correlation to TSS, followed by Al, Pb, Zn, Co, Cu, Cr, Mn and Cd. Furthermore, it was found that street sweeping in the town coincided with reduced TSS and metal loads at the Central and North outfalls. The concentration patterns of TP and Cl were found to respond to meteorological events, with similar findings in the literature for large catchments. TSS concentrations were statistically correlated with TP concentrations, and thus, the source of TP was linked to soil features (organic debris). Chloride was detected during spring melt events, and the source was presumed to be road salting.

The overall findings from this study are based on limited data, and thus, it is recommended that future sampling programs focus on capturing additional sampling events to reduce uncertainty. Nevertheless, the findings from this
study provide a platform for future stormwater research in the field of small urban studies.

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**CONFLICT OF INTERESTS**

The authors declare that they have no conflict of interests.

**DATA AVAILABILITY STATEMENT**

All relevant data are included in the paper or its Supplementary Information.

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