# Oldman Watershed Council

# Lethbridge Storm Water Outfalls Monitoring Study

## Microbiological, Pesticides, and Nutrient Analysis
## (2012-2014)

City of Lethbridge

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Lethbridge College

# Acknowledgements

The following individuals from Agriculture and Agri-Food Canada contributed to the project: Greg Frick, Nathan Godfrey, Josh Koegler, Gwen Leusink measured turbidity, processed the water samples and enumerated *E. coli* and/or thermophilic coliforms; Jenny Gusse identified presumptive *E. coli* isolates through sequencing of the 16S rRNA gene; Tara Vucurevich, Ryan Kung, Monique Dawson, Kyo Farrington, Scott Spengler and Tanner Lohr processed the water samples, and Denise Nilsson analyzed the extracts by GC-MS/MS. We also wish to thank Robert Rippin (Alberta Health Services) for providing the Aquatest systems to enumerate *E. coli*, and Natalie Kromrey (Alberta Sustainable Resource Development) for providing waste water treatment information. Lethbridge College students contributing to the project included Carlee Faulbert, Elisha Jones and Kaylee Garnett. Funding for the project was provided by the City of Lethbridge and the former Alberta Environment & Sustainable Resource Development (now Alberta Environment & Parks) and supported in part by Agriculture and Agri-Food Canada and Lethbridge College. Partial funding, project coordination and dissemination was provided by the Oldman Watershed Council.

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# Executive Summary

This 3 year storm water monitoring project sought to determine water quality within Lethbridge storm water discharges and the Oldman River. Monitoring focused on measurements of turbidity, and analysis of thermophilic fecal coliforms including *Escherichia coli*, pesticides, and nutrients in storm water at eight outfalls and catchment areas, as well as three Oldman River sites and one creek site (Six Mile Coulee Creek), all within the City of Lethbridge. Sites were sampled once a month from April until September from 2012 to 2014, as well as during major rainfall events.

Turbidity in the river and creek sites was generally highest in May and decreased throughout the summer, with the exception of samples collected during rainfall events. The turbidity of Six Mile Coulee Creek was also generally greater than that of the Oldman River, which in turn was greater than that observed in storm water. With the exception of samples collected during rainfall events, turbidity values of storm water were low, and within the standards specified in the Alberta Surface Water Quality Guidelines for recreational waters. Rainfall events increased turbidity at all sites (storm water outfall sites and river), at times significantly so.

Thermophilic coliforms were detected at varying densities in storm water samples from all sites and years. For reasons unknown, but potentially linked to rainfall, coliforms were observed at higher densities in 2014 than in 2012 and 2013. Coliform counts in storm water frequently exceeded Alberta Surface Water Quality Guidelines for irrigation and recreational water, <1000 coliform CFU/dl and < 200 CFU/dl, respectively. High densities of coliforms ($\geq 4 \log_{10}$ CFU/dl) were consistently observed over the three years at sites A, C, H, and I, and exceptionally high coliform densities (exceeding $6 \log_{10}$ CFU/dl) were observed in storm water samples from sites C and H, catchments that contain the prominent reservoirs of Henderson and Nicholas Sheran Lakes. These sites, along with Sites B and D, should continue to be monitored and potential sources of fecal contamination investigated (e.g. wildlife, pets, humans, livestock, etc.). Water from Six Mile Coulee Creek consistently contained thermophilic coliforms, often exceeding the 200 coliform CFU/dl quality standard for recreational water, although densities were typically lower than was observed in some storm water samples (e.g. sites A, C, and H). Substantially higher densities of coliforms were observed in Six Mile Coulee Creek water than were observed by Saffran (2005) from 2000 to 2002. A trend for lower coliform densities was observed in river water upstream of Lethbridge (site L) relative to downstream of Lethbridge (site K). However, thermophilic coliform densities in water obtained from site M were comparable to those observed in river water collected upstream of Lethbridge suggesting that storm water contributes coliform loads in the Oldman River to a lesser degree

than does waste water from Lethbridge. No correlations were observed between turbidity and thermophilic coliform densities in storm water or river water over the three sampling years.

Since some coliforms can originate from non-fecal sources, *Escherichia coli* was measured to specifically indicate fecal contamination. In most instances, *E. coli* was the primary coliform detected, with slopes of the linear relationship between *E. coli* and thermophilic coliforms ranging from 0.80 to 0.90, and coefficients of determination ($r^2$) values from 0.61 to 0.75. As with thermophilic coliforms, storm water samples from sites A, C, H and I consistently contained high densities of *E. coli*, and densities of *E. coli* far exceeded standards for both recreational and irrigation water. It is uncertain to what degree planktonic *E. coli* which were measured in the current study, originated from environmental sources (i.e. biofilms and sediments). Additional experimentation such as detailed comparative whole genome analysis in concert with an ecological examination of *E. coli* is warranted. As with thermophilic coliforms, there was no correlation between water turbidity and *E. coli* densities.

From 2012 to 2014, a total of 27 different pesticides were detected. Of these pesticides, 2,4-D (79%), mecoprop (60%) and dicamba (54%) were those with the highest detection frequencies and concentrations. 84% of all samples analyzed over the duration of this study contained at least one pesticide. 2,4-D was the pesticide which surpassed most frequently its protection of aquatic life guideline (6.1 µg/L), with 14 samples in exceedance (mainly collected in 2013). On average, storm water samples contained 3 different pesticides each, with a maximum of 11 different pesticides detected in a single 1 L water sample. Samples collected during rain events often contained a larger number of pesticides, but their concentrations were lower than those collected during dry periods. For all other storm water sites, 9 to 12 different pesticides were detected. At least 8 pesticides were detected at least once for every year of the study: 2,4-D, dichlobenil, bromacil, bromoxynil, mecoprop, MCPA, dicamba and picloram. The average number of pesticides per sample was higher in storm water compared to river water samples. For pesticides in river water collected in 2013-2014, only 2,4-D and its metabolite 2,4-DCP were above detection levels. In Six Mile Coulee creek, a total of 11 compounds were detected, including both urban and agricultural use pesticides.

Discharge, water chemistry (temperature, oxygen, conductivity, salinity, pH), and nutrients (ammonia, nitrate, Total Nitrogen, Total Phosphorus, and Dissolved Phosphorus) were measured from 2012 to 2014. For storm water discharge, variability was demonstrated for all sites in that each outfall exceeded median values in many cases 10 fold at times over the sampling season, irrespective of rainfall. In general, water chemistry for the parameters measured did not indicate a concern. Storm water was cooler (14˚C vs. 17.6 ˚C), had similar levels of dissolved oxygen (8.3 mg/l vs. 7.9 mg/l) and pH (8.1 vs. 8.3), but had higher salinity

(0.9 ppt vs. 0.2 ppt) and Total Dissolved Solids (TDS) (median 1188 mg/l) compared to river water (median 257 mg/l).

An abundance of nutrients in aquatic systems is usually not directly toxic to organisms, but rather leads to environmental degradation through the growth of weeds and algae that alter water, habitat and aesthetic quality such that the aquatic ecosystem is compromised. For ammonia, levels in storm water increased in almost all discharges from 2012 to 2014: from a mean of 11% of samples over the Canadian Water Quality Guidelines in 2012, 43% over the guideline in 2013, and 78% of samples over the guideline in 2014. Consistent with Saffran (2005), site H (Varsity) had median ammonia concentrations substantially greater than those found at any other site. In all, ammonia levels from storm water discharges were found to be relatively high, occurring at concentrations comparable to those reported for wastewater treatment plant effluents. Median ammonia levels recorded from river waters upstream of Lethbridge (site L) and site M (Hwy 3) were also higher than previously measured by Saffran (2005).

The Canadian Water Quality Guideline for long term nitrate exposure for the protection of aquatic life is 3.0 mg $NO_3$-N per litre. Approximately 24% of all storm water samples exceeded the guideline, with sites A (Wetsminster/Winston Churchill) and H (Varsity) having up to 71% of their samples and median nitrate concentrations well above the long term guideline in 2014 and the greatest mean instantaneous loads based on flow. For tributary and river sites, most samples were below 1 mg/l with occasional nitrate exceedances of the 3 mg/l guideline recorded. Nitrate levels showed no correlation to rainfall.

Total Nitrogen (TN) constitutes ammonia, nitrite, nitrate and organic nitrogen. Site A and I had the greatest median TN (10.5 mg/L and 7 mg/L respectively), Site G (Legacy/Uplands) the greatest variability, Site I the greatest mean instantaneous load, and site E (Southgate) the lowest median TN concentration (1 mg/L), with a value similar to that of river samples. Median total nitrogen concentrations from this study were generally lower than those compared to Saffran. Rainfall events appeared to decrease TN concentrations in storm water, but increase TN levels in river water.

Dissolved Phosphorus (DP), only measured in 2013 and 2014, is often the limiting nutrient in aquatic systems and thus the most impactful. Storm water monitoring revealed that discharge from site H (Varsity) had by far (2-3 fold) the greatest median DP concentrations (1.13 mg/L in 2013 & 1.33 mg/L in 2014) and maximum DP concentrations (2.49 mg/L in 2013 & 3.12 mg/L in 2014) of all sites. In 2014, because of an increased discharge, site I had a mean instantaneous load of DP to the Oldman River similar to that contributed by site H. Sites E (Southgate), F (Tudor/Fairmont), G (Legacy/Uplands), and site B (Downtown) in 2013, all had median DP concentrations that were slightly higher, but paralleled that measured in the Oldman River. The average median DP concentration from all storm drain discharge was approximately 3 times greater than that of river water (0.32 mg/L as compared to 0.10 mg/L). The concentration of DP in river water tended to be higher in late summer (July – September) than in April to June.

Monitoring of Total Phosphorus (TP), a combined measure of all forms of phosphorus in water, found that site H (Varsity) had the greatest median TP of all storm water sites, usually being 2-4 times greater than the next highest site. Site A (Westminster/Winston Churchill) recorded the highest maximum TP (5.1 mg/L) in 2014. Storm water sites E (Southgate), F (Tudor/Fairmont), G (Legacy/Uplands), I (Heritage/Ridgewood) and B (Downtown), had TP concentrations that were lower or comparable to river water. Site A had a mean instantaneous load for TP that was five times greater than the next highest storm water site. At times, river water had median TP concentrations greater than those of storm water samples, with river site L (upriver) having the 2nd highest median TP (1.05 mg/L) of all sites sampled in 2013. No clear pattern emerged for individual sites, between sites and between years for the effect of rainfall on TP.

# 1. Introduction

The Oldman Watershed is part of the South Saskatchewan River Basin (SSRB) which extends east from the Rocky Mountains through Alberta, merging with the North Saskatchewan River Basin on the Prairies (Figure 1). The watershed and its tributaries (Castle River, Crowsnest River, Willow Creek and Pincher Creek) encompass approximately 23,000 $km^2$ in Alberta (OWC 2010). The St. Mary, Waterton, Oldman, and Twin Valley dams regulate flows to irrigation canals across southern Alberta (Derksen et al. 2012).

The Oldman River Basin (Figure 1) is considered semi-arid, receiving approximately 300-450 mm of rain per year (OWC 2005). Agriculture activities dominate the area utilizing approximately 60% of the watershed, with nearly 20% of this cultivated land being irrigated (OWC 2010). The prairie sub-basin of the watershed supports over 500 confined feeding operations (CFO) (OWC 2010). In addition, the urban population, which is most heavily concentrated within the City of Lethbridge, is home to roughly 210,000 people (OWC 2010). The growing population, intensity of land-use development, and semi-arid nature of the region is of growing concern in protecting the watershed's aquatic resources.

In 1997, a group of stakeholders formed the Oldman River Basin Water Quality Initiative (ORBWQI) and developed a five-year action plan to protect water quality within the watershed. The four main components of the action plan included (ORBWQI 1998): compiling a land-use inventory to determine the effects of various activities on water quality; assessing river water quality throughout the Oldman River Basin; developing and evaluating management practices that could benefit water quality; and promoting water quality protection through education and awareness.

In 2012, the Oldman Watershed Council (OWC) initiated the Lethbridge storm water outfalls monitoring study. The three year study (2012-2014) was designed to investigate storm water quality, and provide background data for future water monitoring purposes. Over the three years, water was collected from a total of 13 storm water outfall sites from April to September and tested for a range of bacteria, nutrients and pesticides. The bacterial component of this study involved the quantification of thermophilic fecal coliforms, as well as the determination of *E. coli*. The monitoring program also attempted to determine the quantity and source of pesticides and nutrients (ammonia, nitrate, Total Nitrogen, reactive phosphate, Total Phosphorus and Dissolved Phosphorus) present in the selected storm water outfalls. Culvert centre water depth was measured to calculate discharge as was water turbidity.

This final report 2014 is a comparative analysis of data collected from 2012 to 2014 aiming to determine if water quality has changed over the three year study. This information will help in guiding OWC's educational programs about storm water quality and water conservation initiatives.

**Figure 1.** Oldman River Basin as reported by the Oldman Watershed Council, 2013.

## 2. Materials and Methods

**Water Collection.** Selected storm water outfalls were sampled monthly in 2012 (nine sites), 2013 (12 sites) and 2014 (13 sites; Table 1, Figure 2) from April to October of each year. The City of Lethbridge comprises 18 storm water drains that deliver runoff to the Oldman River (Figure 2). The Lethbridge College has its own storm water drainage that discharges into Six Mile Coulee. Sites sampled included eight City of Lethbridge storm water outlets (A-I) and one Six Mile Coulee Creek site (site J, located upstream from where storm water outlet F joins the Creek). In addition, water samples were collected at three sites directly from the Oldman River, to determine the impact of storm water on river water quality. The Oldman River sites were situated upstream of Lethbridge (Popson Park, site L), downstream of Lethbridge storm water outlets (site M) and downstream of the waste water treatment outfall (site K; sites J, K, and L) were sampled in 2013 and 2014, while site M was added in 2014 to help separate the impact of storm water versus those of the waste water treatment plant effluent on the Oldman River water quality. All sites were sampled monthly.  In 2013 and 2014, samples were also collected after significant rainfall events. All samples were refrigerated upon collection until processed.

**Precipitation.** Daily precipitation data from April 1 to October 31 was obtained from the Lethbridge Research and Development Centre weather station. Precipitation values were obtained using an automated precipitation gauge (mm).

**Turbidity.** Water turbidity was measured with a LaMotte 2020e turbidity meter according to the manufacturer's protocol (LaMotte Company, Chestertown, MD).

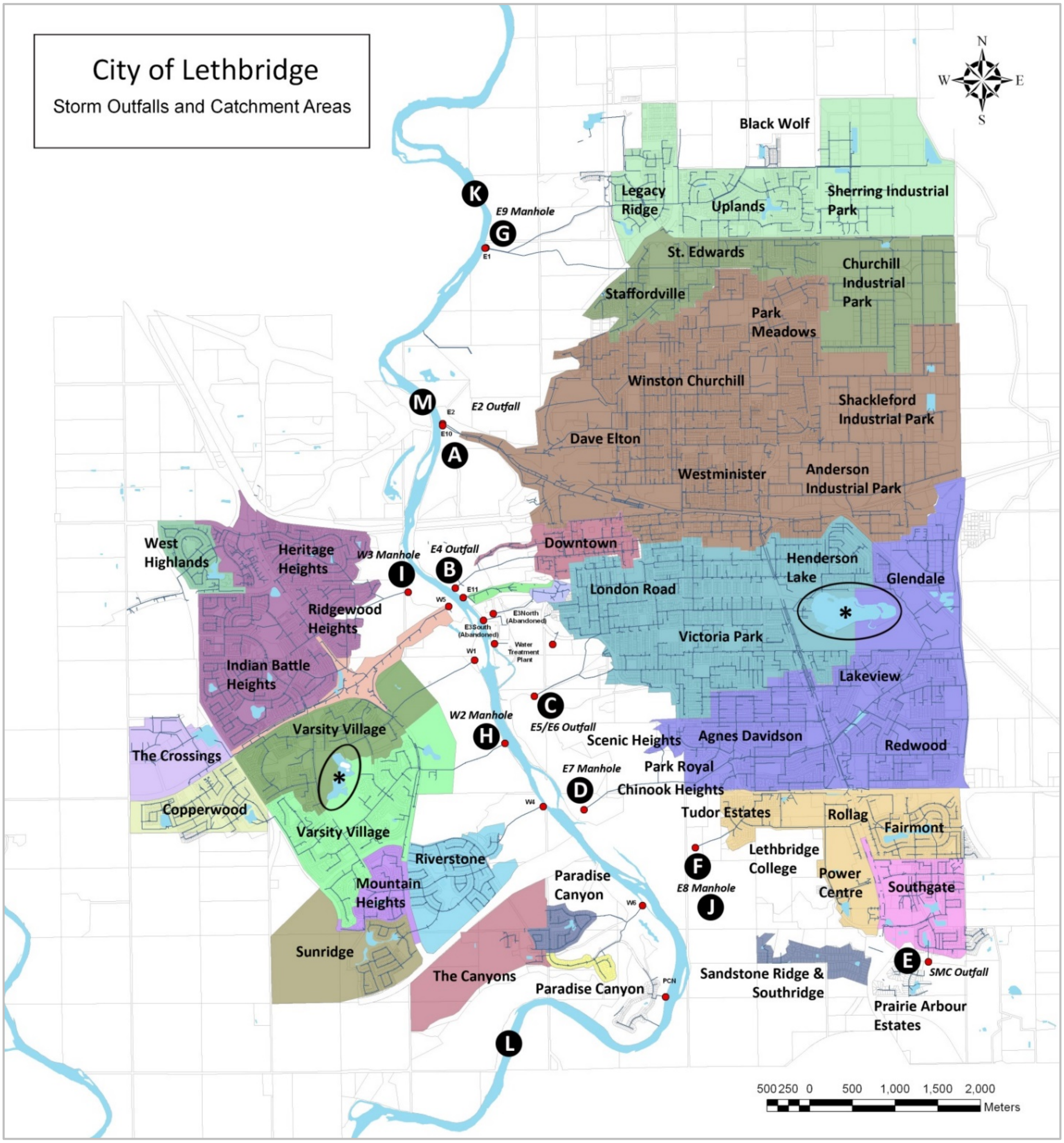


**Figure 2.** City of Lethbridge storm outfalls and catchment areas. Closed black circles with white letters correspond to the collection sites presented in Table 1. Open circles with asterisks indicate Henderson Lake and Nicholas Sheran Lake. The base map was provided by the City of Lethbridge.

**Table 1.** Lethbridge storm water and river collection sites for 2013 as indicated by map label, current site identification and past identification (brackets), and site description (e.g. associated drainage area and neighbourhoods).

| Map | Label | Description |
|---|---|---|
| **A** | E2 (N2) | Storm water drainage of Westminster/Winston Churchill/Anderson and Shackleford industrial Parks (North Lethbridge) |
| **B** | E4 (S3) | Storm water drainage of downtown |
| **C** | E5/E6 (S5/S6) | Storm water drainage of London Road/Victoria Park/Henderson Lake (South Lethbridge) |
| **D** | E7 (S7) | Storm water drainage of Park Royal/Agnes Davidson/Redwood/Lakeview/Glendale (South Lethbridge) |
| **E** | SMC | Storm water drainage of Southgate (South Lethbridge) |
| **F** | E8 (S8) | Storm water drainage of Tudor Estates/Lethbridge College/Power Storm water drainage of Centre/Rollag/Fairmont (South Lethbridge) |
| **G** | E9 (N9) | Storm water drainage of Legacy Ridge/Uplands/Sherring Industrial Park (North Lethbridge) |
| **H** | W2 (D5028418AG1) | Storm water drainage of Varsity Village (West Lethbridge) |
| **I** | W3 (W3) | Storm water drainage of Heritage Heights/Ridgewood Heights/Indian Battle Heights (West Lethbridge) |
| **J** | --- | Six Mile Coulee Creek (upstream of storm water outlet site F) |
| **K** | --- | Oldman River (downstream of storm water outfall site G) |
| **L** | --- | Oldman River (upstream of Lethbridge at Popson Park) |
| **M** | --- | Oldman River (upstream of the waste water outfall site) |

## 2.1 MICROBIOLOGY

**Water Filtration.** For each collection time, 1 L of water per site was vacuum filtered through a borosilicate glass fiber prefilter (PALL Canada Ltd, Ville St. Laurent, QC) and a 0.2 µm final filter (PALL Canada Ltd, Ville St. Laurent, QC). After filtration, each prefilter was placed in a sterile 50 ml tube containing 30 ml of Columbia broth (Oxoid Canada, Nepean ON), vortexed to release particles from the filter, and the prefilter removed. The corresponding 0.2 µm filter for each sample was then placed in the 50 ml tube containing the Columbia broth and vortexed for 3 min (high speed) to dislodge bacterial cells from the filter. The tubes were centrifuged at 14,900 x g for 10 min to pellet bacteria, and immediately after centrifugation 20 ml of the supernatant was removed. The sample was then vortexed (high speed) to re-suspend bacteria in the 10 ml of the remaining Columbia broth (concentrated suspension). The concentrated suspension was serially diluted in a 10-fold dilution series in Columbia broth.

**Enumeration of Thermophilic Coliforms.** In 2012, aliquots (100 µl) of each dilution were spread in duplicate onto mFC agar (BD Canada, Mississauga, ON); mFC agar was included as this medium was used in a previous studies that enumerated coliforms in storm water in Lethbridge (Saffran 2005). In 2013 and 2014, 100 µl of each dilution were also spread in duplicate onto Fluorocult™ LMX agar (EMD Millipore; Darmstadt, Germany). All cultures were incubated aerobically at 42°C and coliform colonies (i.e. dark blue on mFC agar and LMX agar) were counted at the dilution yielding 30 to 300 colony forming units (CFU) at 24 hr. Data were calculated as $\log_{10}$ CFU per deciliter (dl; 100 ml) of water.

**Enumeration of *Escherichia coli*.** In 2013 and 2014, *E. coli* was enumerated on Fluorocult™ LMX agar (42°C) at the dilution yielding 30 to 300 CFU at 12 to 16 hr. Of note, LMX agar is a modified lauryl sulfate tryptic agar for the simultaneous detection of coliforms and *E. coli*. This medium contains the chromogenic substrate 5-bromo-4-chloro-3-indolyl-β-D-galactopyranoside (X-GAL), which is cleaved by the β-galactosidase produced by coliforms. In addition, LMX agar contains the fluorogenic substrate, 4-methylumbelliferyl-β-D-glucuroside (MUG) which is specific for the β-glucuronidase (GUR) produced by *E. coli* (Curiale et al. 1991). In this regard, the breakdown product of MUG (4-methylumbelliferone) was detected under long-wave ultraviolet light. Representative fluorescing colonies were selected, streaked for purity, and identified by sequencing the 16S rRNA gene and comparing the resultant sequence to reference sequences present with the NBCI database using BlastN.

In 2013, *E. coli* were also enumerated using the Advanced microbial QUAlity monitoring and hygienization Techniques for Secure water Trading (Aquatest) system (http://www.aquaya.org/project/aquatest/). The Aquatest was developed as a user-friendly, low-cost water quality test that can be used on-site in developing countries. The enumeration of *E. coli* in water in the Aquatest system is accomplished using a most probable number method (0 to 210 CFU/dl).

## 2.2 PESTICIDES

**Precipitation.** Lethbridge is situated in a semi-arid ecosystem (Köppen climate classification BSk) with precipitation averaging 365 to 386 mm annually. Variable amounts of rainfall occurred during the study periods (Figure 3) with two prominent rainfall events occurring during the sample collection period in 2013 and 2014; 117 mm of rain fell from Julian day 168 to 172 in 2013, and 153 mm of rain fell from Julian day 164 to 170 in 2014.

**Sample collection.** Water samples were collected and processed on six occasions in 2012 (Julian day 109 [April 18], Julian day 136 [May 15], Julian day 164 [June 12], Julian day 199 [July 17], Julian day 227 [August 14], Julian day 255 [September 11]) and 2013 (Julian day 134 [May 14], Julian day 163 [June 12], Julian day 171 [June 20], Julian day 197 [July 16], Julian day 225 [August 13], and Julian day 260 [September 17]) (Figure 3). In 2013, there was not enough water at storm water outfall site E to obtain a sample on Julian day 134. In 2014, water samples were collected and processed on seven occasions (Julian day 106 [April 16], Julian day 135 [May 15], Julian day 150 [May 30], Julian day 169 [June 18], Julian day 197 [July 16], Julian day 227 [August 15], and Julian day 260 [September 17]) (Figure 4). Due to the prominent rainfall event on Julian day 171 in 2013 it was not possible to access the Oldman River at Site L.

**Analytical method**. Water samples were analyzed for an analytical suite of 104 pesticides. The analytical method was adapted from that of Bruns et al. (1991) and Hill et al. (2002). Briefly, water samples were filtered through glass wool, acidified with concentrated sulfuric acid to pH 2 and extracted by liquid-liquid partitioning with dichloromethane. Extracts were then dried with acidified $Na_2SO_4$, concentrated, methylated using diazomethane, transferred to hexane and adjusted to a final volume of 10 mL.

Esterified extracts were analyzed (2 µL injections) using an Agilent 7890B gas chromatograph with a 7000C QQQ mass selective detector (MSD) in MRM (multiple reaction monitoring). The column was HP-5MS UI 30m x .25mm x .25um, p/n 19091S-433UI. Temperature programming was: 70°C for 2 min, ramp of 25°C/min to 150°C then ramp 3°C/min to 200°C, then ramp of 8°C/min to 280°C for 7 min. Total analysis time was 38.867 min. One target ion and at least two qualifier ions are monitored. The limit of detection was 0.025 µg for most pesticides. Detections below these limits were outside the range of the external standard curve and were assigned values of zero (none detected). Method blanks were run with each set of groundwater samples analyzed.

## 2.3 WATER CHEMISTRY AND NUTRIENT ANALYSIS

**Water Chemistry.** Measures of pH (Horiba Laquatwin), water temperature, dissolved oxygen, conductivity, and salinity (YSI Model 85) were obtained on site at the time of collection. Calculation of discharge utilized Bentley’s Flowmaster software to solve for partially-full circular pipe flow using the Manning Formula (Manning 1891). Pipe slope and diameters were provided by the City of Lethbridge, pipe construction material (affecting roughness coefficient) was assessed on site and measurement of water depth at pipe center taken at respective sites at time of sampling. All water samples were collected in acid washed Nalgene bottles and kept cool via ice or refrigeration until analysis.

**Nutrients.** Analysis of ammonia, nitrate, Total Nitrogen (TN), Total Phosphorus (TP) and Dissolved Phosphorus (DP) were completed within 24 hours of collection, utilizing a LaMotte Smart Spectro. Prior to analysis the spectrophotometer was inspected and calibrated for accuracy by the manufacturer. The methods of analysis for each nutrient measure were as follows: ammonia - nesslerization, nitrate – zinc reduction, TN – chromotropic acid with persulfate digestion, TP and DP – ascorbic acid reduction with persulfate digestion, with DP samples prefiltered (0.45 um). In some instances samples required prefiltration or dilution prior to measurement due to high turbidity interference.

# 3. Results and Discussion

## 3.1 MICROBIOLOGY

**Sample Collection.** Water samples were collected and processed on six occasions in 2012 (Julian day 109 [April 18], Julian day 136 [May 15], Julian day 164 [June 12], Julian day 199 [July 17], Julian day 227 [August 14], Julian day 255 [September 11]) and 2013 (Julian day 134 [May 14], Julian day 163 [June 12], Julian day 171 [June 20], Julian day 197 [July 16], Julian day 225 [August 13], and Julian day 260 [September 17]) (Figure 3). In 2013, there was not enough water at storm water outfall site E to obtain a sample on Julian day 134. In 2014, water samples were collected and processed on seven occasions (Julian day 106 [April 16], Julian day 135 [May 15], Julian day 150 [May 30], Julian day 169 [June 18], Julian day 197 [July 16], Julian day 227 [August 15], and Julian day 260 [September 17]) (Figure 3). Due to the prominent rainfall event on Julian day 171 in 2013 it was not possible to access the Oldman River at Site L.

**Precipitation.** Lethbridge is situated in a semi-arid ecosystem (Köppen climate classification BSk) with precipitation averaging 365 to 386 mm annually. Variable amounts of rainfall occurred during the study periods (Figure 3) with two prominent rainfall events occurring during the sample collection period in 2013 and 2014; 117 mm of rain fell from Julian day 168 to 172 in 2013, and 153 mm of rain fell from Julian day 164 to 170 in 2014.

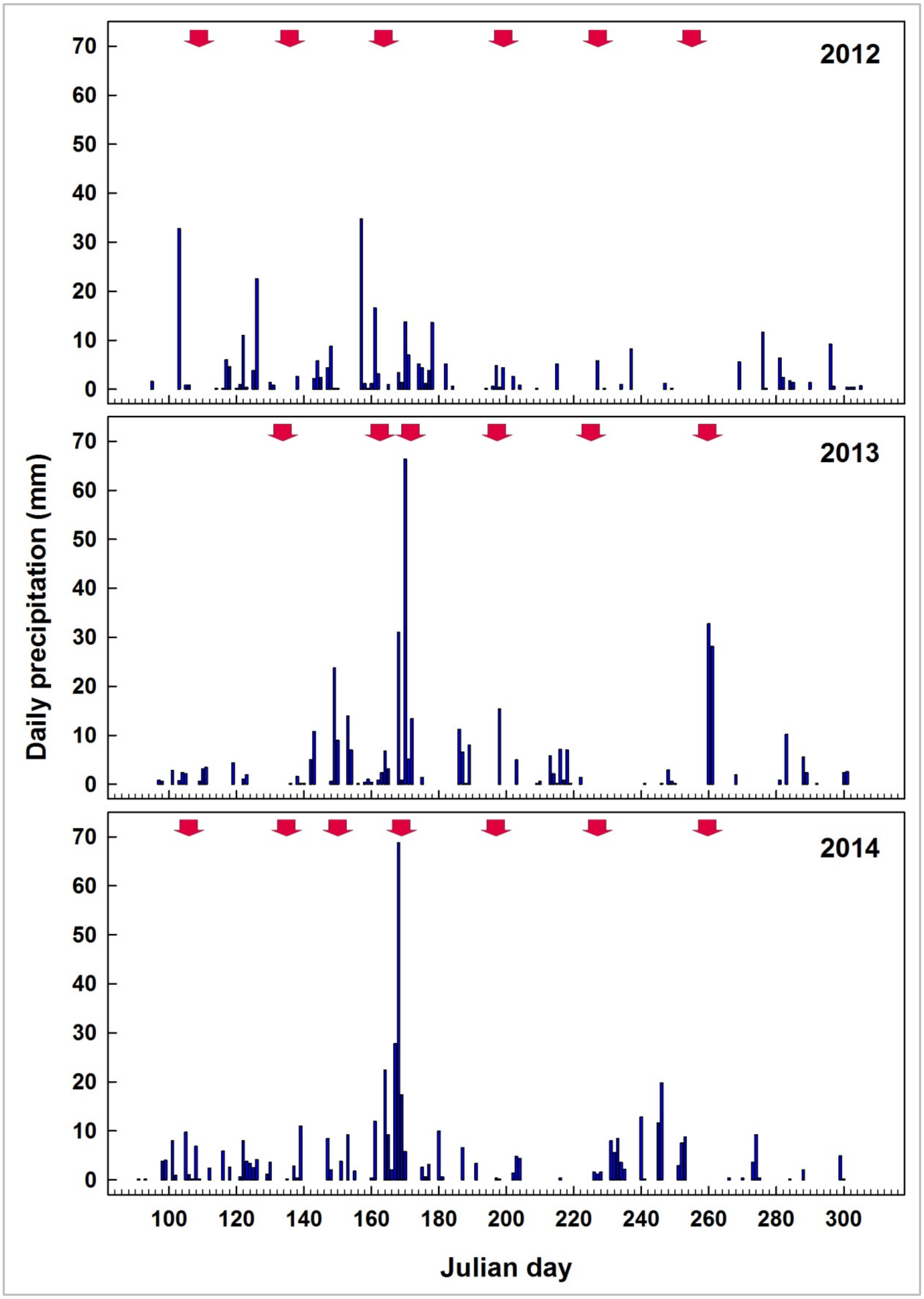


**Figure 3.** Daily precipitation events (mm) at the Lethbridge Research and Development Centre during the sample periods (2012-2014). Red arrows indicate sampling times.

**Turbidity.** With the exception of samples obtained during or after rainfall events, turbidity values of storm water were low, and within the standards specified in the Alberta Surface Water Quality Guidelines for recreational waters (i.e. the turbidity of water should not be increased more than 5.0 NTU over natural turbidity when turbidity is low [<50 NTU]) (AB Government 1999) (Figures 4-6). In many instances, the turbidity of storm water increased after rainfall events, and in some instances substantially so (e.g. Site D in 2012 on Julian day 136) (Figure 4). In 2014, elevated turbidity levels were observed in storm water from some sites following moderate levels of precipitation (e.g. Sites A, C, D, G, and I on Julian day 135) (Figure 6). A very high level of turbidity (8184 NTU) not associated with a significant rainfall event was also observed in storm water from Site A on Julian day 260; reasons for such an elevated turbidity level on this date are unknown. Turbidity levels in samples obtained from Six Mile Coulee Creek in 2013 and 2014 after major rainfall events (i.e. Julian day 171 in 2013 and Julian day 169 in 2014) were elevated and exceeded the turbidity of levels observed in the Oldman River (Figures 5-6). The turbidity of the Oldman River was generally higher than observed in storm water, and the turbidity of river water was higher in the spring and decreased over the season (Figures 5-6).

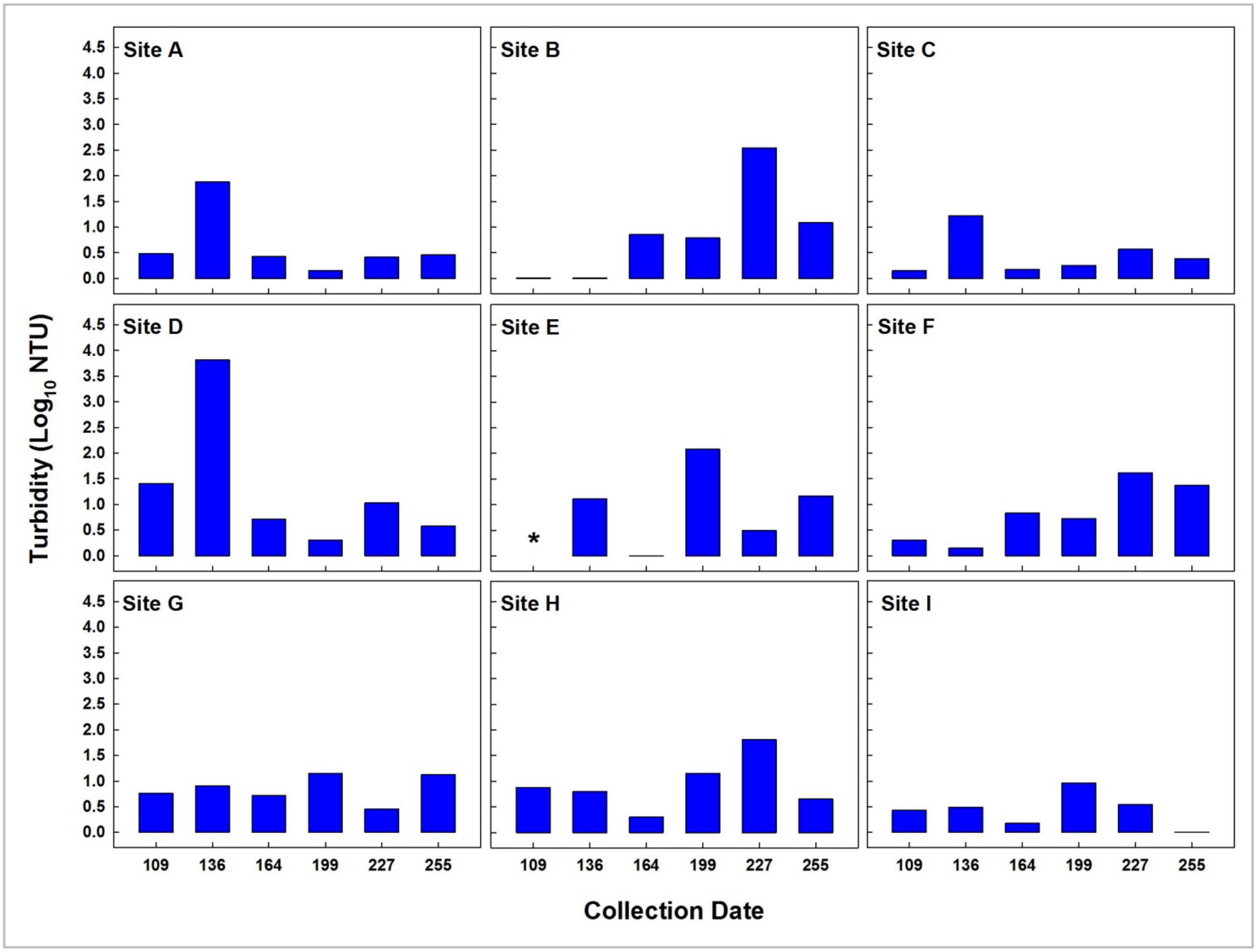


**Figure 4.** Water turbidity's ($Log_{10}$ NTU) by collection site and date in 2012. A description of sites is presented in Table 1 and Figure 2. Julian days correspond to April 18 (109), May 15 (136), June 12 (164), July 27 (199), August 14 (227), and September 11 (255). Asterisks indicate circumstances where no sample was obtained.

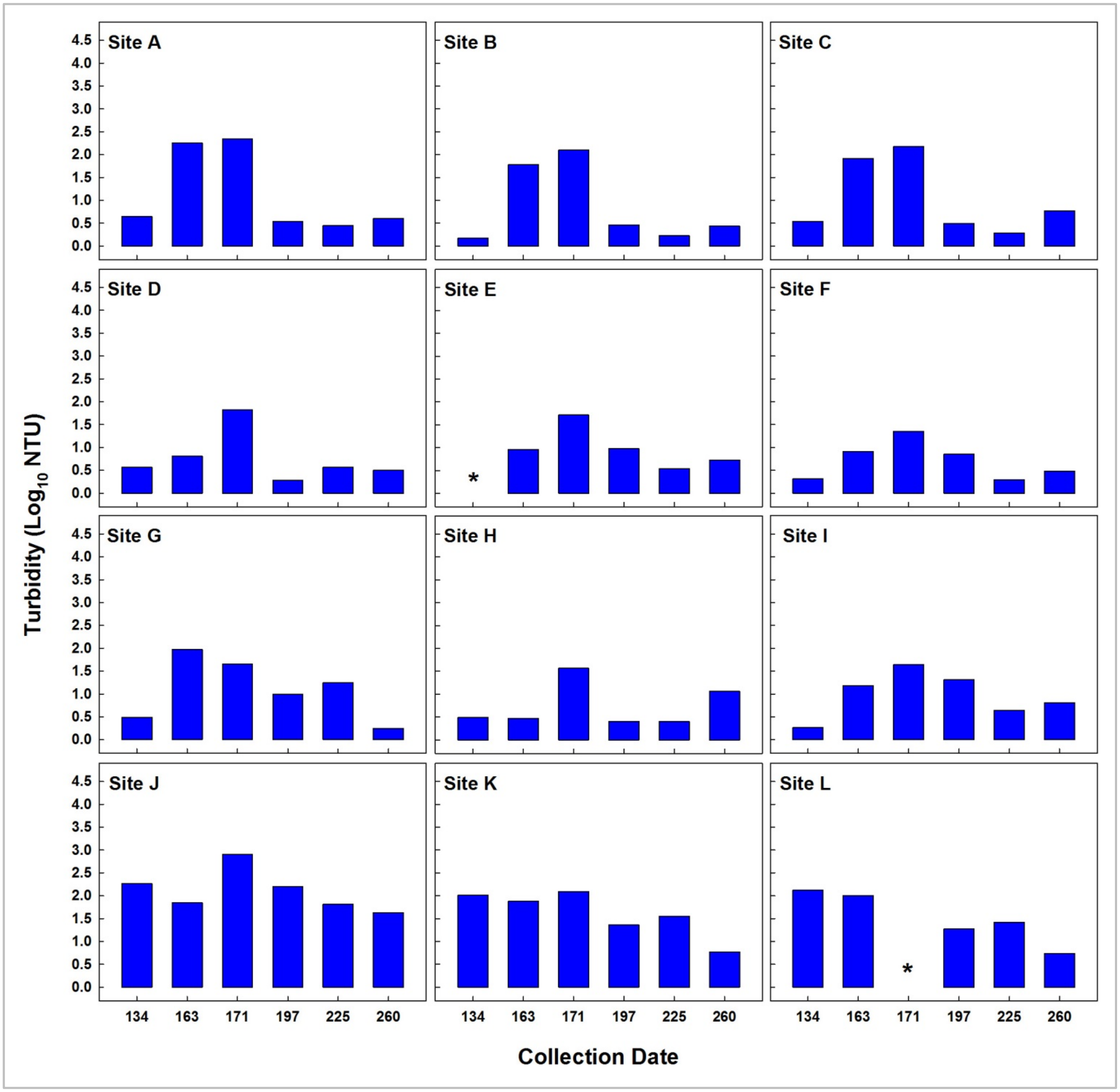


**Figure 5.** Water turbidity's ($Log_{10}$ NTU) by collection site and date in 2013. A description of sites is presented in Table 1 and Figure 2. Julian days correspond to May 14 (134), June 12 (163), June 20 (171), July 16 (197), August 13 (225), and September 17 (260) 2013. A significant rainfall event occurred from June 17th to June 21st. Asterisks indicate circumstances where no sample was obtained.

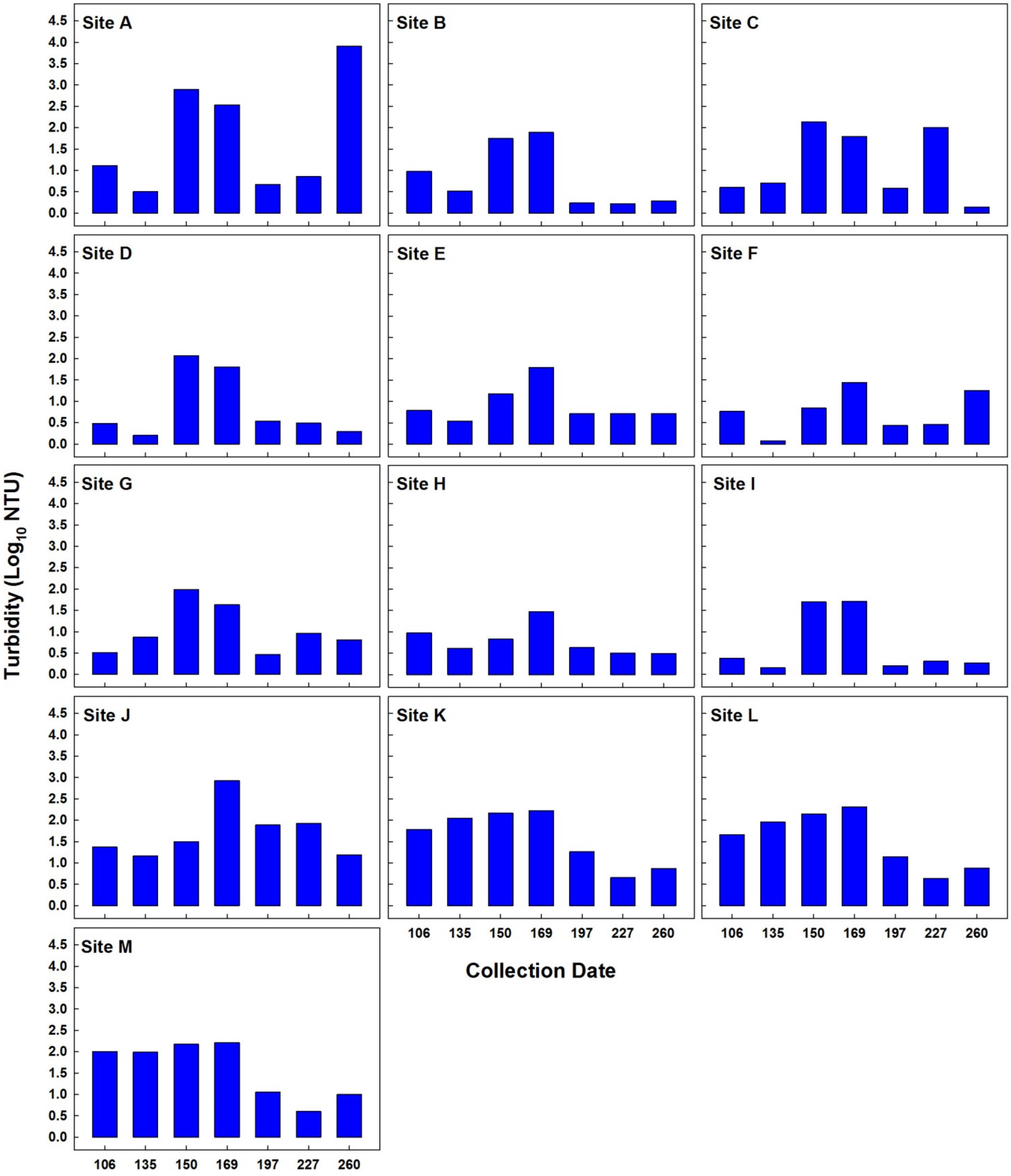


**Figure 6.** Water turbidity's (Log$_{10}$ NTU) by collection site and date in 2014. A description of sites is presented in Table 1 and Figure 2. Julian days correspond to April 16 (106), May 15 (135), May 30 (150), June 18 (169), July 16 (197), August 15 (227), and September 17 (260). A significant rainfall event occurred from June 13th to June 19th.

**Thermophilic Coliforms in Storm Water.** Coliforms were enumerated on mFC agar in all three years to facilitate comparisons with previously conducted studies (Saffran 2005) (Figures 7-9). In 2013 and 2014, coliforms were also enumerated on Fluorocult™ LMX agar. In the majority of samples, densities of coliforms corresponded between the two media (Figures 8-9). However in a few instances, coliform densities determined using mFC agar differed from than those determined by Fluorocult™ LMX agar; for example, densities were primarily but not always lower on Julian day 225 in 2013.

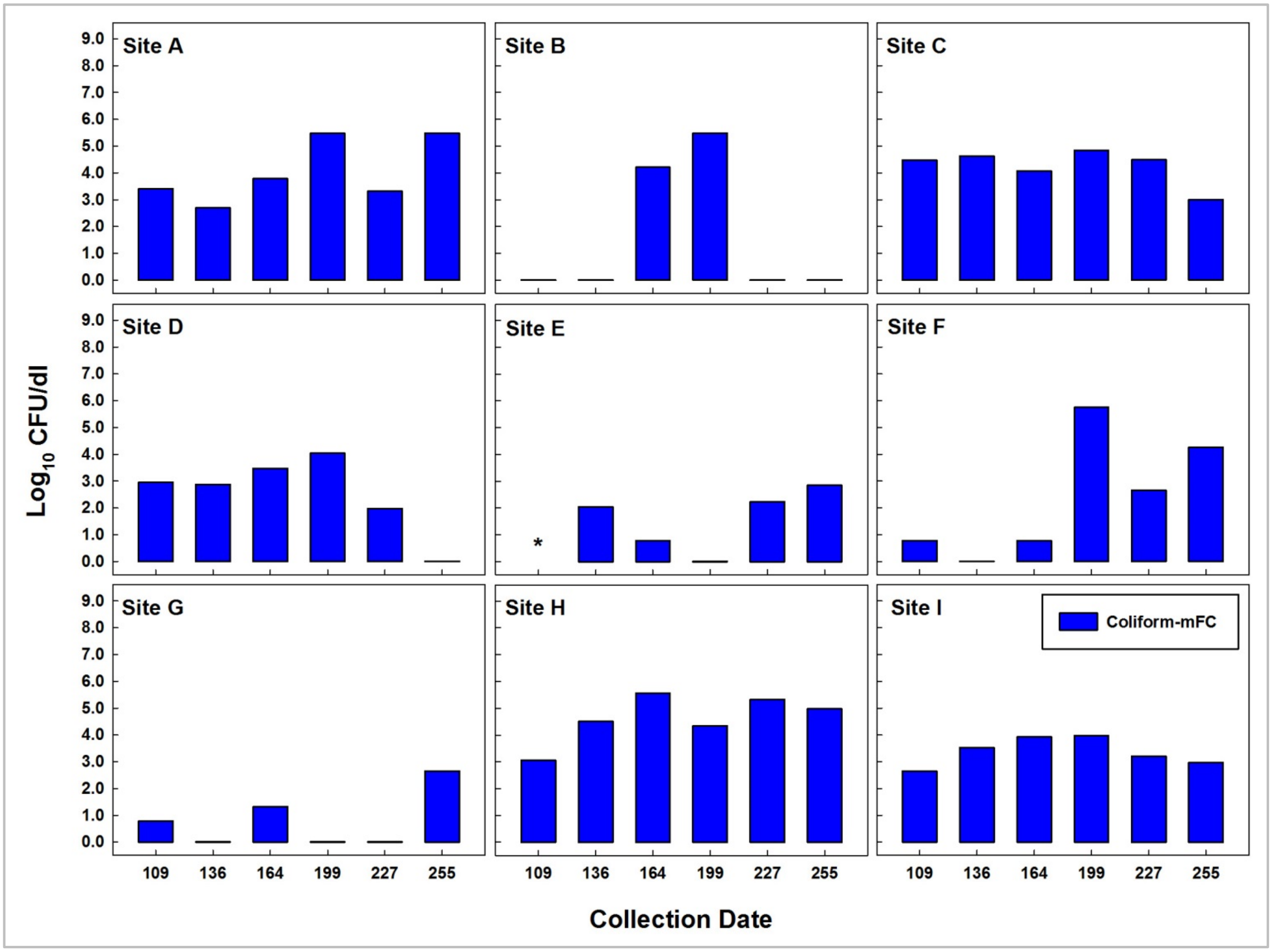


**Figure 7.** Thermophilic coliform densities ($Log_{10}$ CFU/dl) in storm water samples by collection site and date in 2012. Coliforms were enumerated on mFC agar. A description of sites is presented in Table 1 and Figure 2. Julian days correspond to April 18 (109), May 15 (136), June 12 (164), July 27 (199), August 14 (227), and September 11 (255). Asterisks indicate circumstances where no sample was obtained.

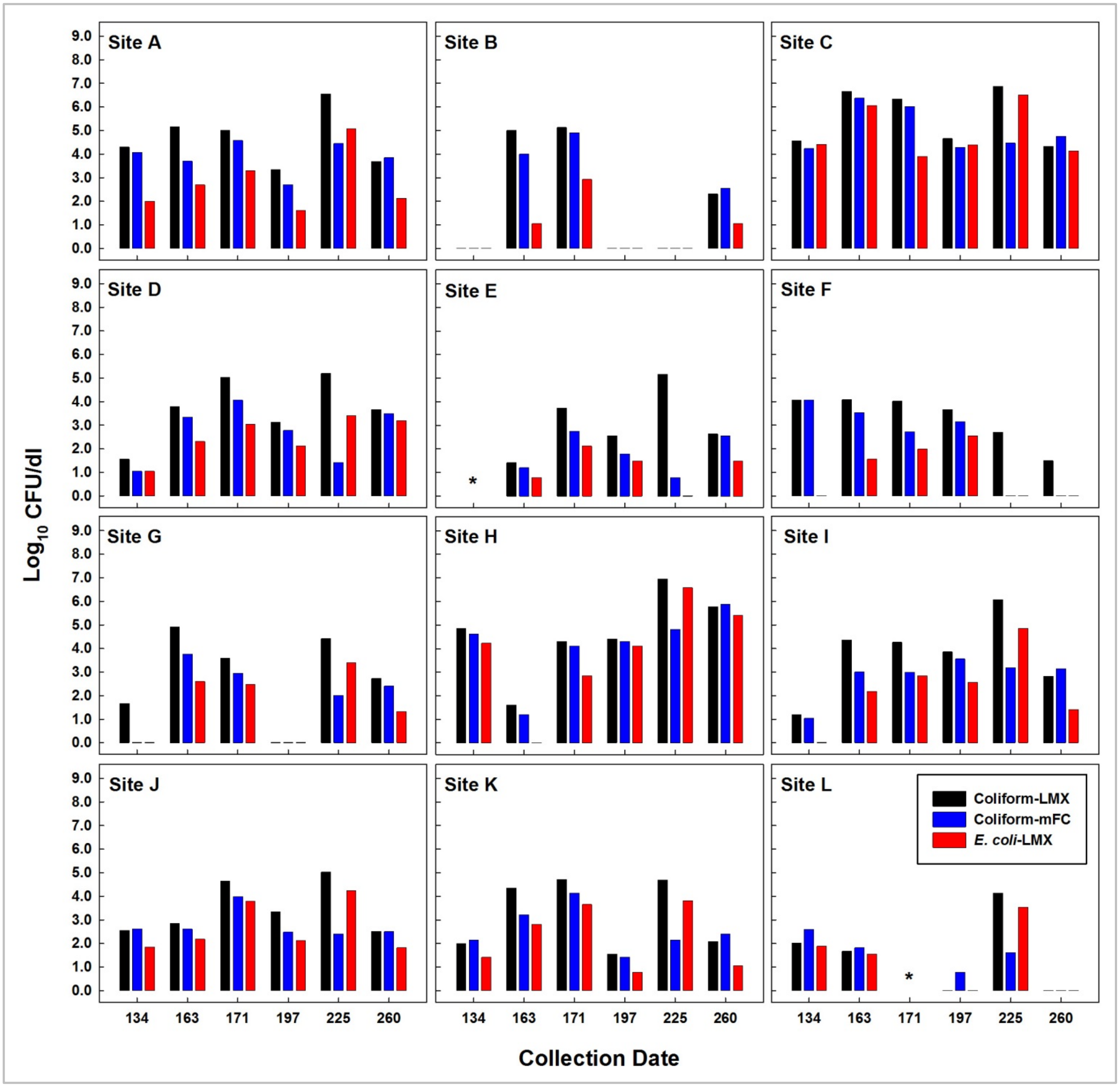


**Figure 8.** Thermophilic coliform and *Escherichia coli* densities (Log$_{10}$ CFU/dl) in storm water samples by collection site and date in 2013. Coliforms were enumerated on mFC agar (black bars) and LMX agar (blue bars). *Escherichia coli* were enumerated on LMX agar (red bars). A description of sites is presented in Table 1 and Figure 2. Julian days correspond to May 14 (134), June 12 (163), June 20 (171), July 16 (197), August 13 (225), and September 17 (260) 2013. A significant rainfall event occurred from June 17th to June 21st. Asterisks indicate circumstances where no sample was obtained.

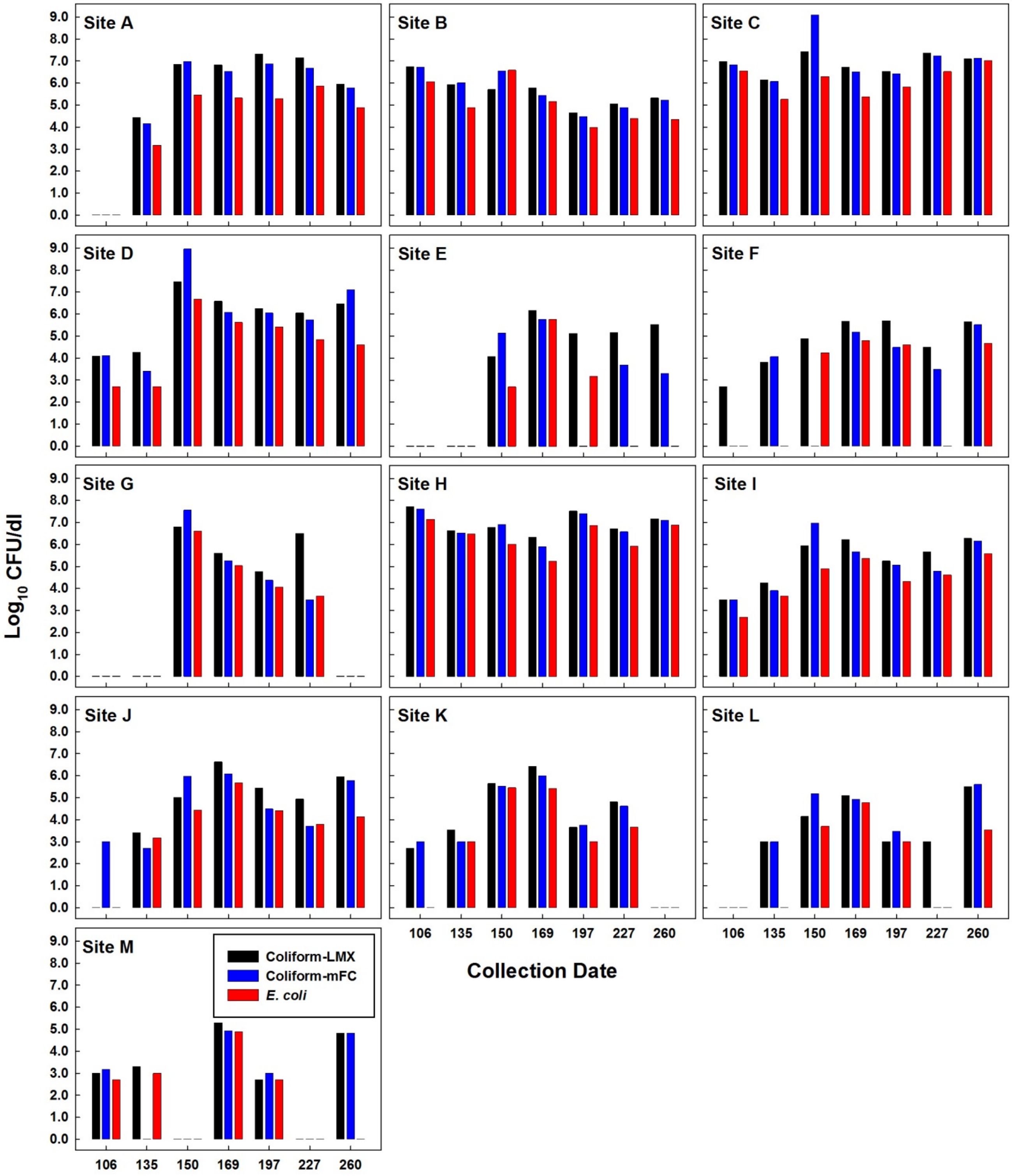


**Figure 9.** Thermophilic coliform and *Escherichia coli* densities ($Log_{10}$ CFU/dl) in storm water samples by collection site and date in 2014. Coliforms were enumerated on mFC agar (black bars) and LMX agar (blue bars). *Escherichia coli* were enumerated on LMX agar (red bars). A description of sites is presented in Table 1 and Figure 2. Julian days correspond to April 16 (106), May 15 (135), May 30 (150), June 18 (169), July 16 (197), August 15 (227), and September 17 (260). A significant rainfall event occurred from June 13th to June 19th.

Thermophilic coliforms were detected at varying densities in storm water samples from all sites and years (Figures 7-9). In 2014, coliforms were observed at higher densities than in 2012 and 2013. Reasons for this are unknown, but may be the result of the greater precipitation that occurred in 2014; 413.2 mm of rain fell from April 1st to September 17th in 2014, compared to 268.4 mm and 339.1 mm of rain during the same period in 2012 and 2013, respectively. The Alberta Surface Water Quality Guidelines (AB Government 1999) and/or British Columbia Water Quality Criteria for Microbiological Indicators (BC Government 2001) indicate a limit of ≤ 1000 coliform CFU/dl (geometric mean) in irrigation water (i.e. ≤ $10^3$ CFU/dl) and a limit ≤ 200 coliform CFU/dl (geometric mean) in recreational water. At times during all three sample years, coliform counts in storm water frequently exceeded this level, and in many cases, substantially so. High densities of coliforms (≥ 4 $\log_{10}$ CFU/dl) were consistently observed at sites A, C, H, and I, and exceptionally high coliform densities (exceeding 6 $\log_{10}$ CFU/dl) were observed in storm water samples from sites C and H in all three years. High densities of coliforms were also observed in storm water samples for site B and D in 2014. Site C encompasses a catchment area for the residential communities of Henderson Lake, London Road, and Victoria Park, and site H encompasses a catchment area for the residential community of Varsity Village. Of note, sites C and H contain the prominent reservoirs Henderson Lake and Nicholas Sheran Lake, respectively (Figure 2; open circles with asterisks). Wild birds and pets are known to readily shed thermophilic coliforms, including *E. coli* in their feces, and the degree to which these animals contribute to the coliform loads in site C and H catchment water is speculative at present. Furthermore, the degree to which industrial activities (e.g. livestock processing) affects coliform numbers in storm water from the Andersen and Shackleford Industrial Parks is not known. No correlations were observed between thermophilic coliform densities and turbidity in storm water over the three sampling years (Figures 10-12).

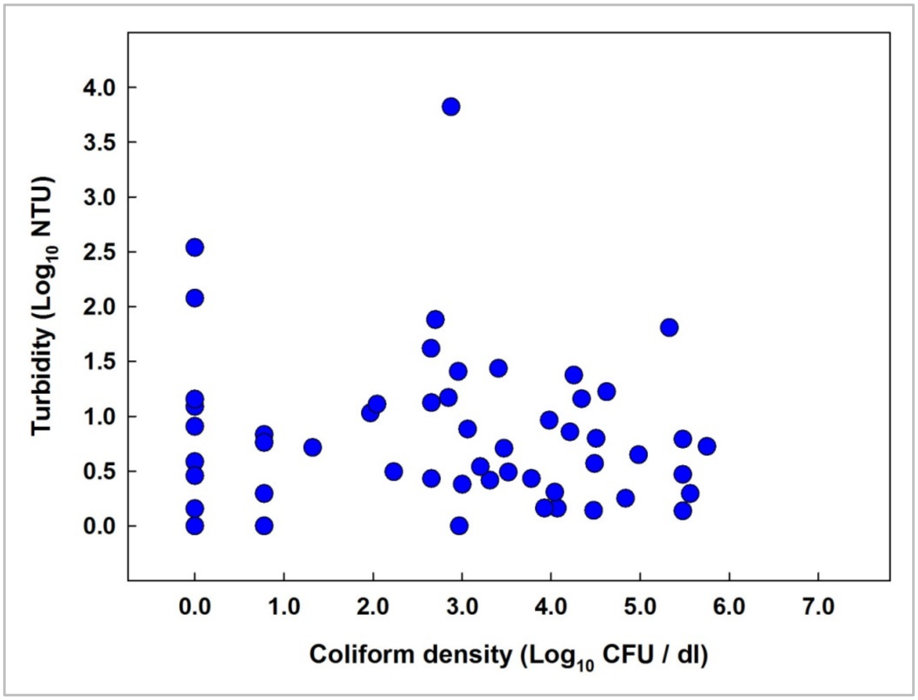


**Figure 10.** Relationship between storm water sample turbidity (log$_{10}$ NTU) and thermophilic coliform densities (log$_{10}$ CFU/dl) in 2012.

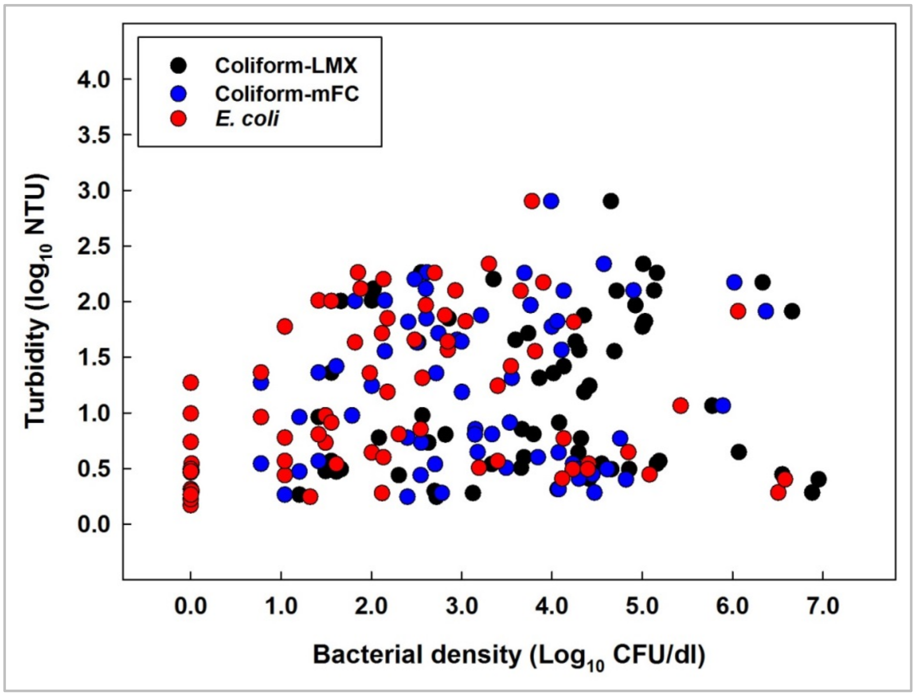


**Figure 11.** Relationship between storm water sample turbidity (log$_{10}$ NTU) and thermophilic coliform and *Escherichia coli* densities (log$_{10}$ CFU/dl) in 2013.

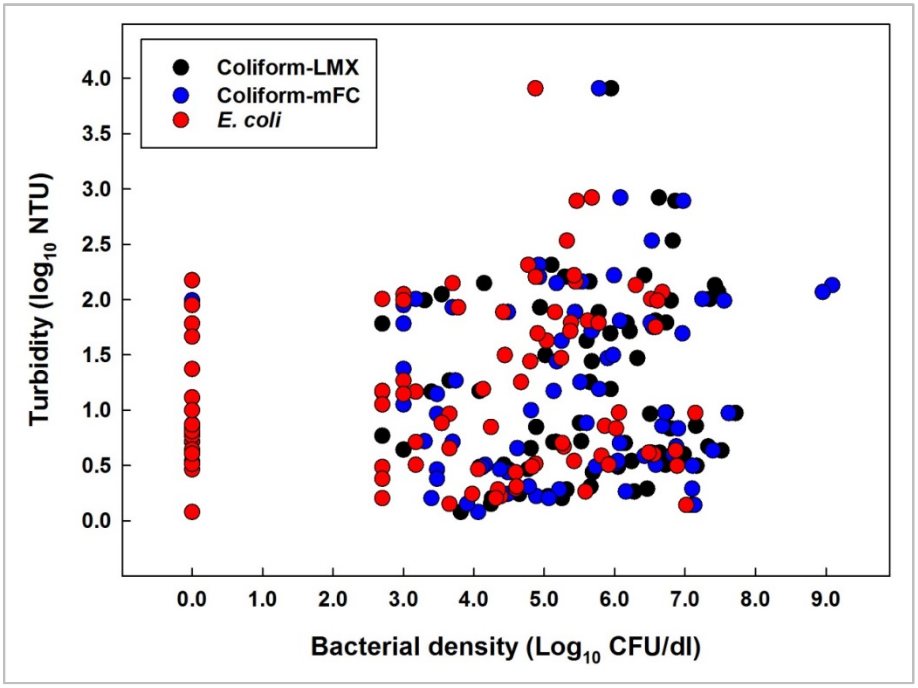
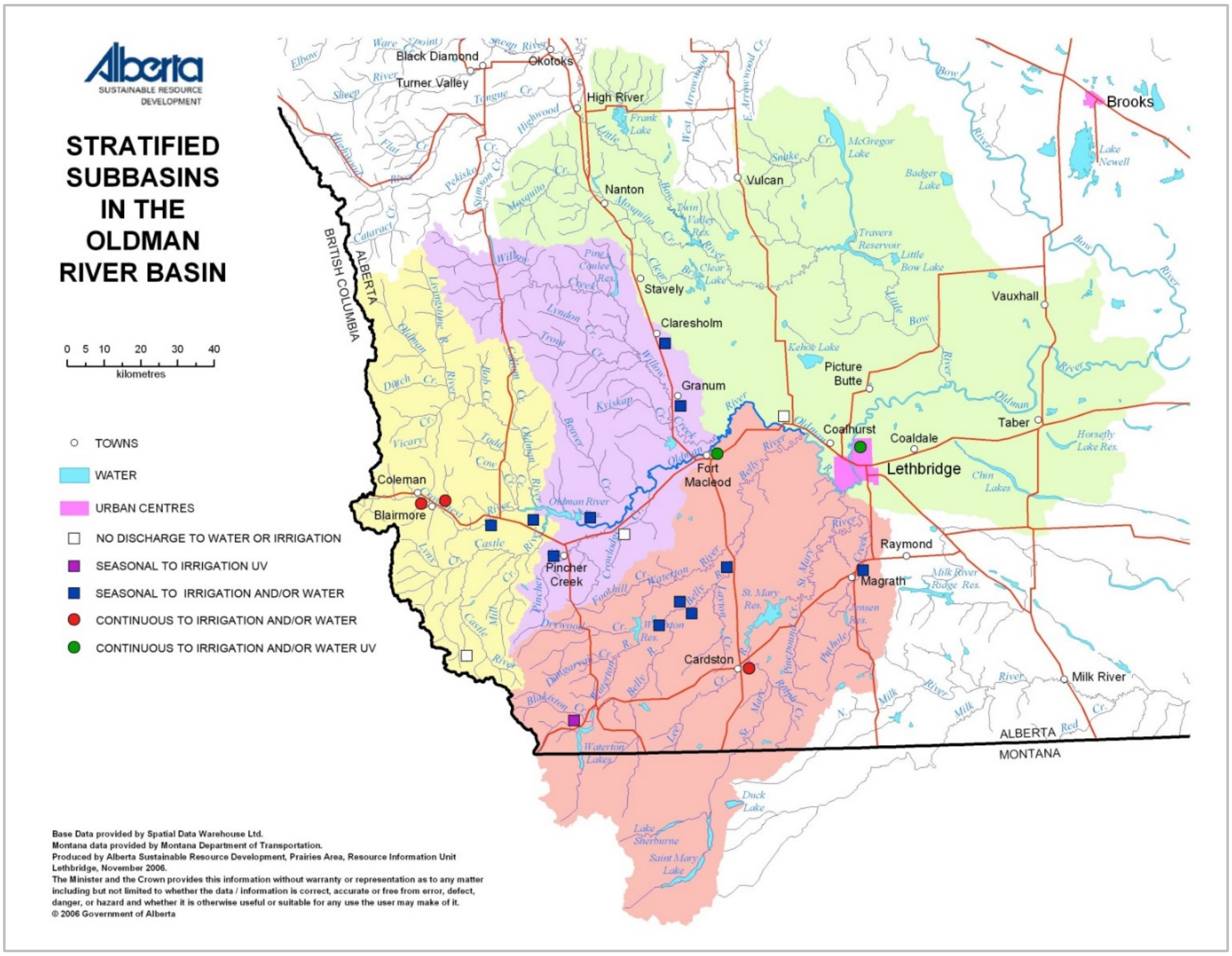


**Figure 12.** Relationship between storm water sample turbidity ($\log_{10}$ NTU) and thermophilic coliform and *Escherichia coli* densities ($\log_{10}$ CFU/dl) in 2014.

Densities of thermophilic coliforms detected in the current study were generally higher than observed previously (Saffran 2005). Nonetheless, our findings correspond with those of Saffran (2005) in that storm water samples from sites A, C, and H tended to contain high densities of thermophilic coliforms. Our study design involved more intensive intra-year sampling relative to that of Saffran (2005). However, we similarly noted a periodicity of coliforms in storm water from some sites. For example, water samples collected from site B contained very high thermophilic coliform counts at two sample times during late spring in 2012 and 2013. However, coliform densities below the detection threshold were observed at other times at site B. In conclusion, storm water from all catchment areas in Lethbridge contained thermophilic coliforms, and in many instances densities exceeded recognized surface water quality limits (AB Government 1999; ORBWQI 2005). Storm water outlet sites of particular concern were site A (Westminster/Winston Churchill/Anderson and Shackleford Industrial Parks), site B (downtown), site C (London Road/Victoria Park/Henderson Lake), site D (Park Royal/Agnes), and site H (Varsity Park) (Table 1; Figure 2). These sites should continue to be monitored and potential sources of fecal contamination investigated (e.g. wildlife, pets, humans, livestock, etc.).

**Thermophilic Coliforms in Six Mile Coulee Creek.** Six Mile Coulee Creek (site J) was sampled in 2013 and 2014. Water from Six Mile Coulee Creek consistently contained thermophilic coliforms (Figures 8-9), although densities were typically lower than was observed in some storm water samples (e.g. sites A, C, and H). The Six Mile Coulee watershed covers an area of about 175 km$^2$, 89% of which contributes to runoff (ORBWQI 2005). The Coulee receives runoff from both rural and urban sources; although it is a natural channel, it is part of the St. Mary River Irrigation District distribution system which is responsible for its relatively consistent flow throughout the season. Saffran (2005) concluded that water quality in Six Mile Coulee Creek is adversely affected by both urban and rural influences. We consistently observed substantially higher densities of coliforms in Six Mile Coulee Creek water than did Saffran in 2000 to 2002 (Saffran 2005). Whether the intensified urban activities since 2002 in this area are responsible is uncertain. The Six Mile Coulee Creek watershed contains intensive agriculture including beef cattle feedlots and cereal cropping. Furthermore, the watershed is home to a significant number of people (i.e. neighborhoods of Southgate, Prairie Arbor Estates, Sandstone Ridge, Southridge, Power Centre, and Lethbridge College). Two storm drains, one from the City of Lethbridge (site E) and one from the Lethbridge College (site F) empty into Six Mile Coulee Creek. Although the relative contributors of fecal pollution to Six Mile Coulee Creek was beyond the scope of the current project, circumstantial evidence suggested that non-City sources are contributing a high fecal bacterial load to the creek; relatively low flow and densities of thermophilic coliforms were observed in storm water from site E, and the Creek was sampled before the Lethbridge College storm water outfall. Regardless of the source of contamination, the evidence is unequivocal that the Six Mile Coulee Creek water contains high densities of thermophilic coliforms throughout the non-winter season, and densities often exceed the 200 coliform CFU/dl quality standard for recreational water (BC Government 2001).

**Thermophilic Coliforms in the Oldman River.** The Oldman River was sampled in 2013 and 2014. With the exception of day 106 in 204, and day 260 in 2013, thermophilic coliforms at varying densities were observed in river water sampled upstream of Lethbridge (site L). The sources of thermophilic coliforms in the Oldman River upstream of Lethbridge are uncertain. However, it is likely that a diversity of sources are responsible including human beings, livestock, and wildlife. There are a number of sources of treated waste water that enter the Oldman River or its tributaries upstream of Lethbridge (Figure 13). Alberta Environment and Sustainable Resource Development (AESRD) specify limits on coliforms allowed to enter the Oldman watershed in treated waste water (http://environment.alberta.ca/01248.html) with the exception of waste water treatment plants located in Waterton Lakes National Park, and on the Blood and Peigan First Nations which are under Federal jurisdiction. It is noteworthy that treated waste water in Waterton Lakes National Park is UV irradiated and used to irrigate the Waterton Lakes Golf Course; no effluent is released directly into the Waterton River (Layton Banack, pers. comm.). Waste water treatment on the Blood Tribe First Nation is treated in lagoon stabilization ponds (multiple storage cells ± anaerobic cells) and effluent release is seasonal (once per year) into “dry ditches” or “unnamed creeks” (http://www.cbc.ca/slowboil/pdfs/ab/Blood_Tribe_first_nation.pdf); the degree to which enteric bacteria and nutrients enter the Belly River or St. Mary River from these locations is unknown. The only waste water treatment plant located on the Peigan First Nation consists of lagoon stabilization ponds with



Base Data provided by Spatial Data Warehouse Ltd.
Montana data provided by Montana Department of Transportation.
Produced by Alberta Sustainable Resource Development, Prairies Area, Resource Information Unit Lethbridge, November 2006.
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**Figure 13.** Map of the Oldman River basin showing waste water input sites and types upstream of Lethbridge. The base map was prepared by Alberta Environment and Sustainable Resource Development and provided by the Oldman Watershed Council.

no discharge (i.e. evaporation) (http://www.cbc.ca/slowboil/pdfs/ab/Peigan_first_nation.pdf). The degree to which other waste water treatment plants collectively contribute enteric bacteria to the Oldman River is not known, however, water quality (nutrients and thermophilic coliforms) upstream of Fort Macleod was deemed excellent in 1998 and 2002 (OWC 2005). The Oldman River (downstream of the Crowsnest and Castle Rivers) and the St. Mary River are dammed; there are a number of waste water treatment locations upstream of the Oldman and St. Mary River dams (i.e. Blairmore, Cardston). As enteric bacteria are known to sediment in lakes (Brettar and Hofle 1992), it is likely that the reservoirs created by the dams act as buffers for enteric bacteria. Downstream of the St. Mary River dam, there are two waste water seasonal input sites, one on the Blood Tribe nation and one discharging into Pothole Creek, a tributary of the St. Mary River. Willow Creek water quality was rated as excellent to moderate (OWC 2005), and there are two waste water sites on Willow Creek (i.e. Claresholm and Granum) (Figure 13); however, treated waste water from these two communities is released seasonally (once per year) and typically for short periods of time. The Willow Creek watershed drains an area of cropping and livestock production, primarily beef cattle (AB Government 2001). There is one waste water treatment site on Pincher Creek and five waste water treatment sites on the Belly River (Figure 13); water quality of the Belly River was rated as moderate in 1998 (OWC 2005). Fort Macleod is a significant potential source of enteric bacteria entering the Oldman River upstream of Lethbridge. Fort Macleod has a new waste water treatment plant with discharge limits of <1000 total coliforms/dl and <200 coliforms/dl set by AESRD (http://envext02.env.gov.ab.ca/pdf/00000686-02-01.pdf). However, discharge of viable coliforms from the Fort MacLeod waste water treatment plant are substantially less than the limits specified by AESRD since the installation of a UV irradiation discharge system (Robert Rippin, pers. comm.). The extent to which human fecal effluent enters the Oldman River watershed from non-urban sources (i.e. farms, acreages, recreational sites in riparian zones) is currently unknown.

In addition to site L located upstream of Lethbridge, a site located downstream of Lethbridge (site K) was sampled in 2013 and 2014. An additional site located just upstream of the Lethbridge waste water outfall was sampled in 2014 (Figure 2). With the exception of day 150 and day 227 in 2014 (site M), and day 260 in 2014 (site K), thermophilic coliforms were detected in river samples downstream of Lethbridge (Figures 8-9). A trend for lower coliform densities was observed in river water upstream of Lethbridge (site L) relative to downstream of Lethbridge (site K). However, thermophilic coliform densities in water obtained from site M were comparable to those observed in river water collected upstream of Lethbridge (Figure 9) suggesting that storm water contributes coliform loads in the Oldman River to a lesser degree than does waste water from Lethbridge. Significantly, the waste water treatment facility in Lethbridge is a continuous to river treatment facility; the city's facility possesses the capacity to treat 80 million litres of waste water per day, and consists of primary (i.e. primary clarification), secondary (biodigestors and secondary clarification), tertiary (lagooning), and ultraviolet treatment steps before liquid effluent is discharged into the Oldman River (http://www.lethbridge.ca/living-here/water-wastewater/Pages/Wastewater.aspx).

***Escherichia coli* in Lethbridge storm water, Six Mile Coulee Creek, and the Oldman River.** Thermophilic coliforms have been traditionally used as an indicator of fecal contamination in recreational waters, but coliforms such as *Klebsiella* species may originate from non-fecal sources (Huntley et al. 1976; Dufour and Cabelli 1976). Thus, the Guidelines for Canadian Recreational Water Quality (GCRWQ) (GCRWQ 2012) recommends that *E. coli* be specifically targeted as an indicator of fecal contamination. In 2013 and 2014 *E. coli* was enumerated on LMX agar. In most instances, *E. coli* was the primary coliform detected (Figures 9-10), but coliform densities often overestimated *E. coli* abundance (Figures 14-15); slopes of the linear relationship between *E. coli* and thermophilic coliforms ranged from 0.80 to 0.90, and coefficients of determination ($r^2$) values ranged from 0.61 to 0.75. As with thermophilic coliforms, storm water samples from sites A, C, H and I consistently contained high densities of *E. coli*, and densities of *E. coli* far exceeded standards for both recreational and irrigation water. See above for discussion on the possible reasons for the very high densities of *E. coli* in storm water from these sites C and H. There was no correlation between water turbidity and densities of *E. coli* in storm water or river water (Figures 11-12).

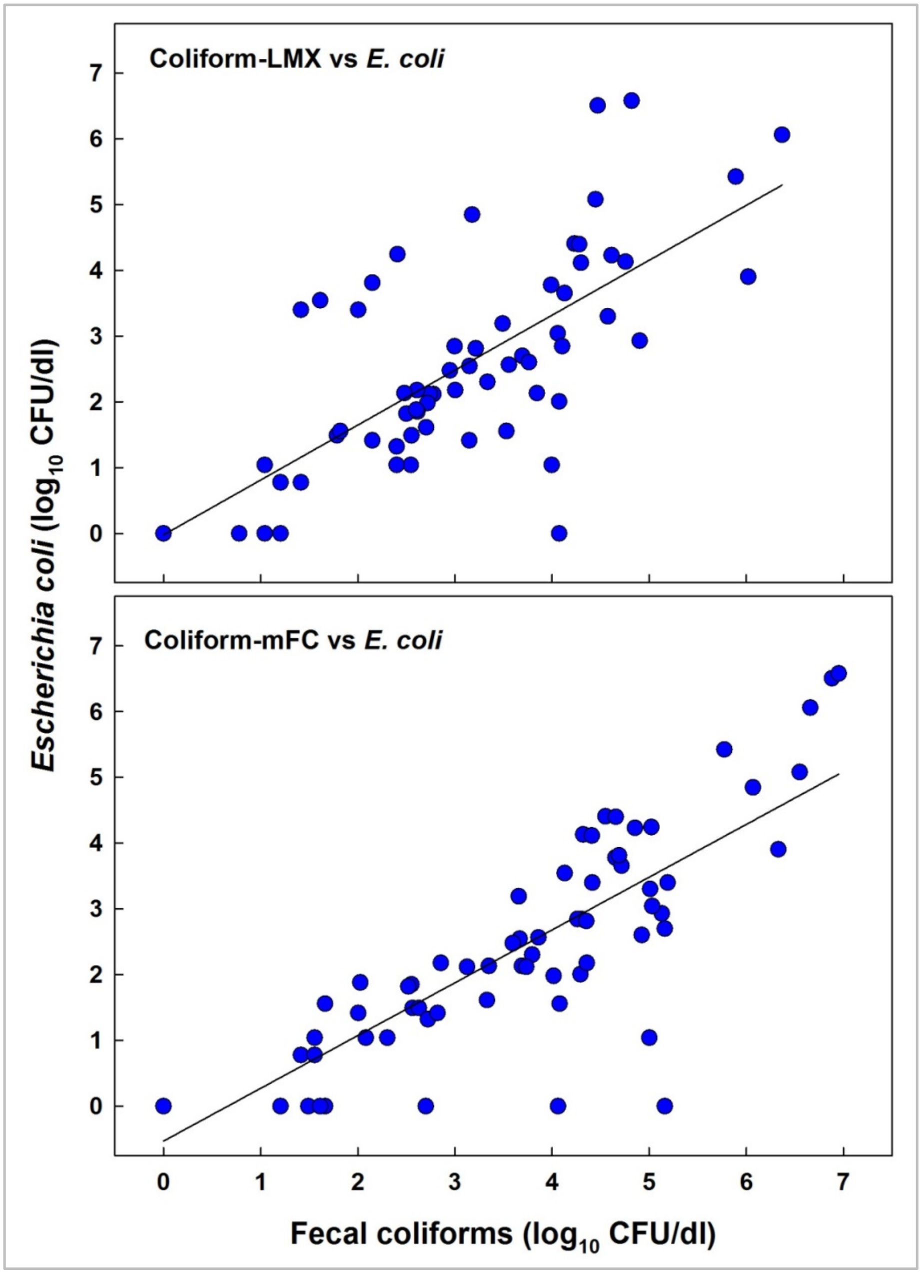

**Figure 14.** Relationship between thermophilic coliform and *Escherichia coli* densities ($\log_{10}$ CFU/dl) in storm water in 2013. Coefficients of determination were 0.71 and 0.60 for coliform-LMX and coliform-mFC, respectively.

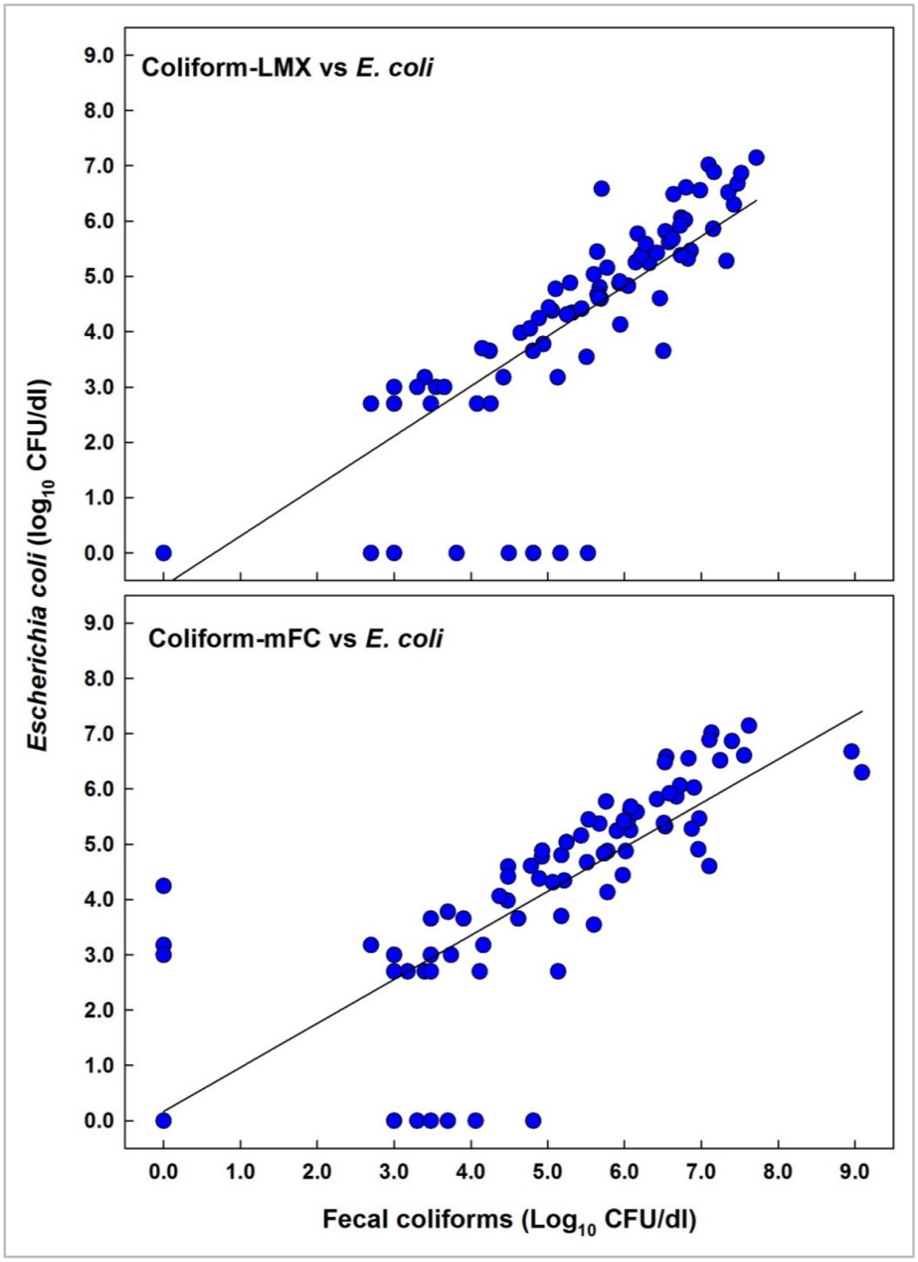

**Figure 15.** Relationship between thermophilic coliform and *Escherichia coli* densities ($\log_{10}$ CFU/dl) in storm water in 2014. Coefficients of determination were 0.75 and 0.71 for coliform-LMX and coliform-mFC, respectively.

In 2013, *Escherichia coli* was enumerated using two methods, a dilution spread-plate method on LMX agar and using the Aquatest MPN system. Based on detection, the two methods were in agreement 91.7% of the time. In six instances (Figure 16; arrows), *E. coli* was detected using the Aquatest, and not by the dilution spread-plate method on LMX.

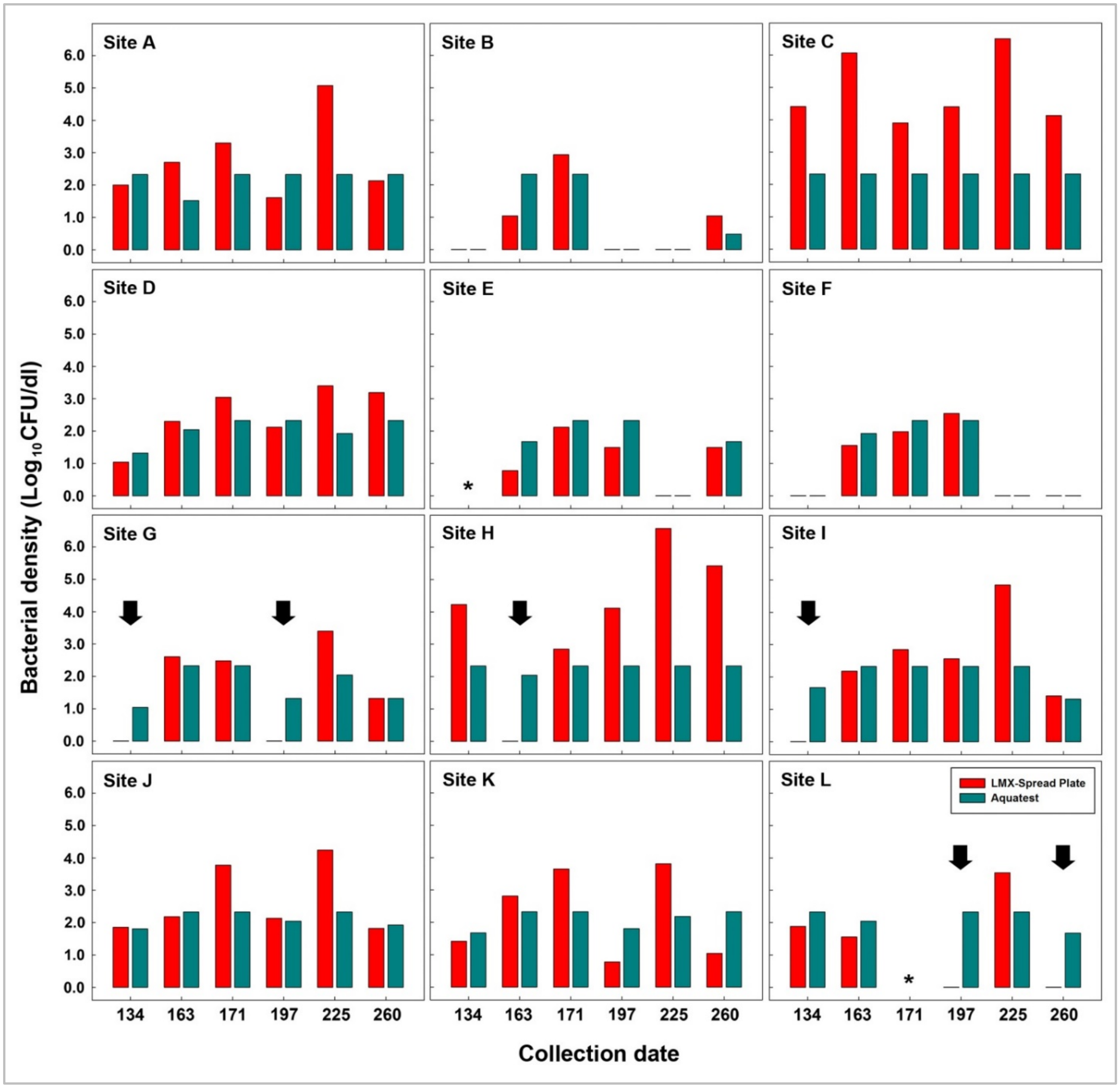

**Figure 16.** *Escherichia coli* densities (Log$_{10}$ CFU/dl) in storm water samples by collection site and date in 2013 determined using the dilution spread-plate method on LMX agar (red bars) and the Aquatest (green bars). A description of sites is presented in Table 1 and Figure 2. Julian days correspond to April 16 (106), May 15 (135), May 30 (150), June 18 (169), July 16 (197), August 15 (227), and September 17 (260). Arrows indicate results where the Aquatest was positive, but the dilution spread-plate method on LMX agar was negative. A significant rainfall event occurred from June 13th to June 19th.

Whether these represent true or false positive results are uncertain. Of note, all of the presumptive *E. coli* that were isolated on LMX agar and sequenced were confirmed to be *E. coli* (*data not presented*). Furthermore, no coliforms were isolated on LMX or mFC from two samples (i.e. site G on day 197, and site L on day 260) that were positive for Aquatest suggesting that the Aquatest may provide false positives in some instances. The Aquatest is a user-friendly system designed to detect low densities of *E. coli* in drinking water, and a limitation of the Aquatest system for quantifying *E. coli* in environmental samples is the relative low upper limit of quantification (i.e. 210 CFU/dl). In numerous instances, *E. coli* densities estimated by Aquatest underestimated true densities by many orders of magnitude (i.e. at site C and site H). In conclusion, the Aquatest and dilution spread-plate method were in concordance for detecting *E. coli* and also for determining quantities of the bacterium at low densities. However, the dilution spread-plate method on LMX was found to be superior to the Aquatest for quantifying *E. coli* at densities typically encountered in storm water and river water samples. A salient advantage of the Aquatest is that minimal expertise and infrastructure were required, whereas the dilution spread-plate method required both specialized infrastructure, as well as microbiological expertise.

Although *E. coli* is an intestinal bacterium, a growing body of literature indicates that *E. coli* is able to persist and even replicate in water (e.g. in biofilms and sediments) and in soil in tropical, subtropical, and temperate climates (Ishii and Sadowsky 2008). This has led some to question the legitimacy of using total *E. coli* as a fecal indicator, and the validity of national and provincial water quality standards currently in place. However, it is unclear to what extent the 'environmental' *E. coli* that exist in storm water in Lethbridge (i.e. retention ponds and distribution systems) and within the Oldman River originated from environmental reservoirs of the bacterium instead of from feces directly. Furthermore, it is uncertain to what degree planktonic *E. coli* which were measured in the current study, originate from environmental sources (i.e. biofilms and sediments). Additional experimentation such as detailed comparative whole genome analysis in concert with an ecological examination of E. coli is warranted. Whether genetic lineages of environmental *E. coli* can be linked to phenotypic adaptation in extra-intestinal niches is currently unknown. It is highly unlikely that any biological indicator of fecal contamination will be absolute.

## 3.2 PESTICIDES

**Pesticides in storm water.** A range of pesticides was measured in all samples (215) collected over the three years to facilitate comparisons with previously conducted studies. In 2012, a total of 101 pesticides were included in the analytical suite. That number increased to 104 pesticides in 2013 and 2014. From 2012 to 2014, for all sampling sites combined, a total of 27 different pesticides were detected including 22 herbicides, one herbicide degradation product and 3 insecticides (Figure 17). 2,4-D (79%), mecoprop

(60%) and dicamba (54%) were the pesticides with the highest detection frequencies.

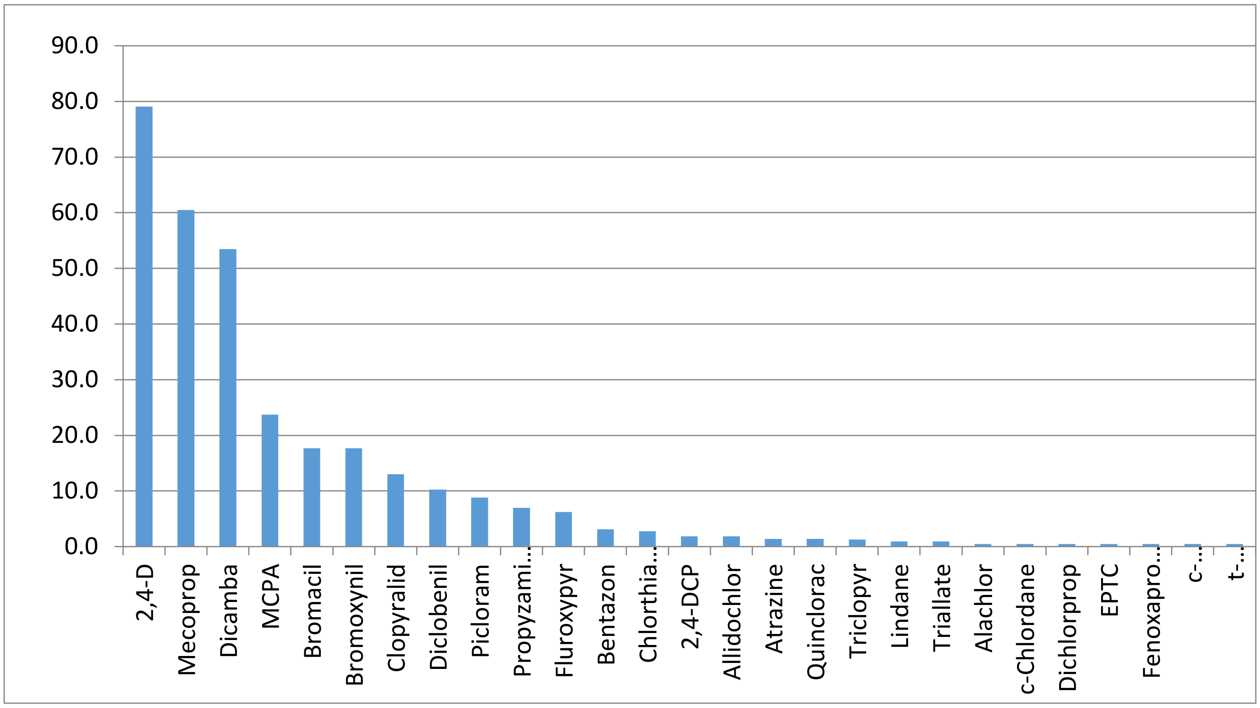

**Figure 17.** Frequency (%) of pesticides detected during the sample periods (2012-2014).

These same pesticide active ingredients were also those detected at the highest concentrations observed throughout the study, with 2,4-D once being detected at 345 µg/L, mecoprop at 45 µg/L and dicamba at 9 µg/L (Figure 18). It should be noted, however, that all of these high concentrations were found in a single sample collected from site C (London Road, Victoria and Henderson Lake Park) on September 17, 2014. On the same day, the storm water sample collected at site D (a site adjacent to site C, encompassing storm water drainage from Park Royal/Agnes Davidson area) also contained some of the highest concentrations of these three compounds, in roughly the same ratios, with very little other pesticide detected at both locations. This rare occurrence of high concentrations of the same three pesticide active ingredients at two adjacent locations at such a late date (September) in the season might be linked to a rain event which occurred the day before sampling took place. Interestingly, major rain events as outlined above which occurred in June 2013 and 2014 did not seem to cause as significant an increase in pesticide concentrations including those of 2,4-D, mecoprop and dicamba. In fact, for both rain events, concentrations of these pesticides were higher in samples collected earlier in June compared to that of samples collected during the rain events. Moreover, it should be noted that samples collected from sites other than C and D did not show pesticide concentrations higher than average on September 17, 2013. Activities disturbing soil and sediments could potentially release accumulated pesticides into urban drainages, but the concentrations observed indicate that a pesticide spill or inadequate pesticide disposal are likely responsible for this unusual event.

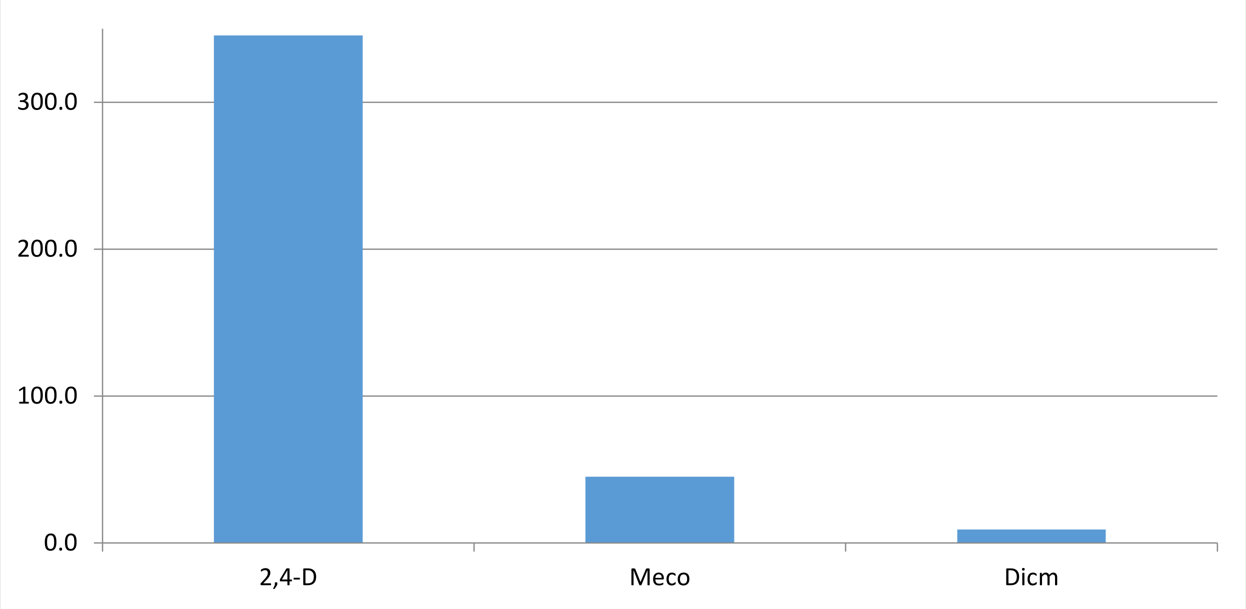

**Figure 18.** Maximum pesticide concentrations (µg/L) detected during the sample periods (2012-2014).

All pesticides other than 2,4-D, mecoprop and dicamba had a maximum detected concentration below 3 µg/L (Figure 19).

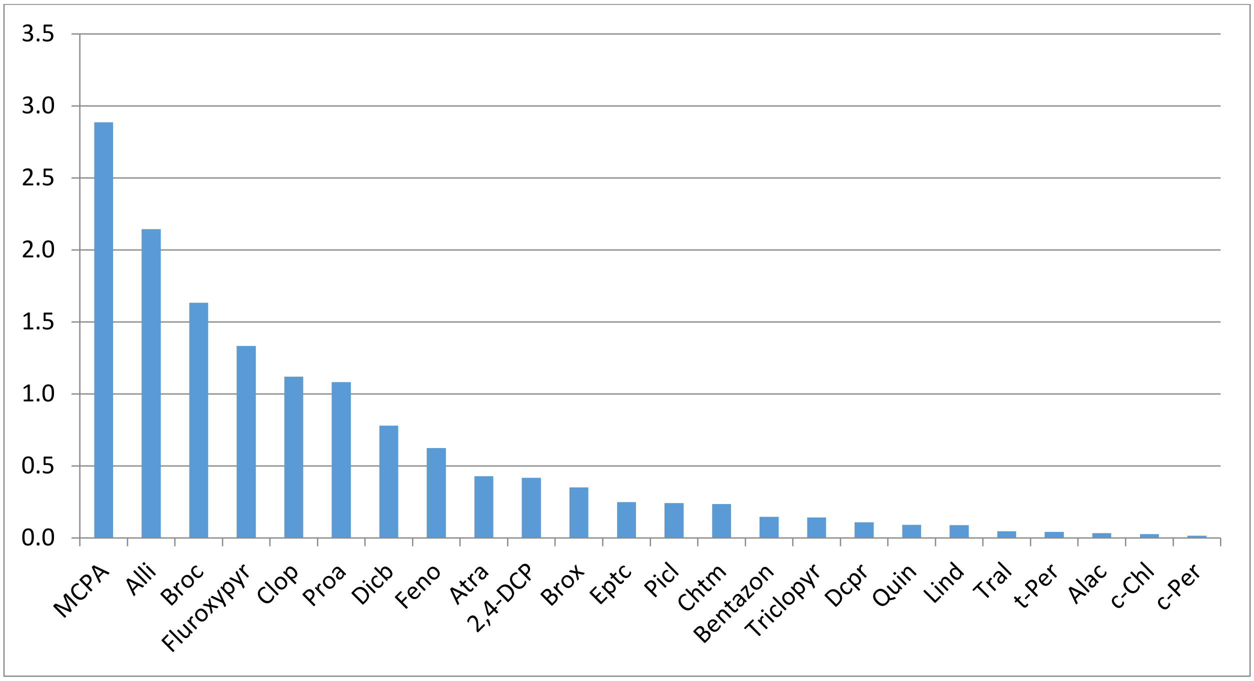

**Figure 19.** Pesticide concentrations (µg/L) detected during the sample periods (2012-2014).

Overall pesticide detection frequency from 2012 to 2014 was 84% (84% of all samples analyzed contained at least one pesticide), with the annual detection frequency ranging from 74% in 2012 to 90% in 2013 (Table 2).

**Table 2.** Water Collection Sites Sampled for Pesticides Over 2012-2014.

| | 2012 | 2013 | 2014 |
|---|---|---|---|
| **Number of Samples Analyzed** | 54 | 70 | 90 |
| **Detection Frequency (%)** | 74 | 90 | 82.2 |
| **Number of Pesticides Detected** | 10 | 16 | 22 |
| **Site with Highest Number of Detections** | A | H | A |
| **Average Number Pesticides per Sample** | 2 | 3.9 | 3.3 |

On average, storm water samples contained 3 different pesticides each, with a maximum of 11 different pesticides detected in a single 1 L water sample (Site H - June 2013 and site A - August 2014). Samples collected during rain events often contained a larger number of different pesticides, but at lower concentrations compared to those collected during dry periods. The sample collected at site H in June 2013 was a rain event sample, while there was no rain event in August 2014. There is therefore no clear rationale to explain the high number of pesticides in the latter. 73% of the samples (158 samples) contained 4 or less pesticides, with a fairly equal distribution (about 15% each) among the 0-4 pesticide(s) per sample categories (Figure 20). Compared to river waters such as rivers, streams and irrigation, the average number of pesticides per sample is higher in the urban storm water samples. This can be observed both as part of this study as well as in Saffran (2005), pond water quality studies (City of Lethbridge 2013) and Charest and Sheedy (2012, 2013).

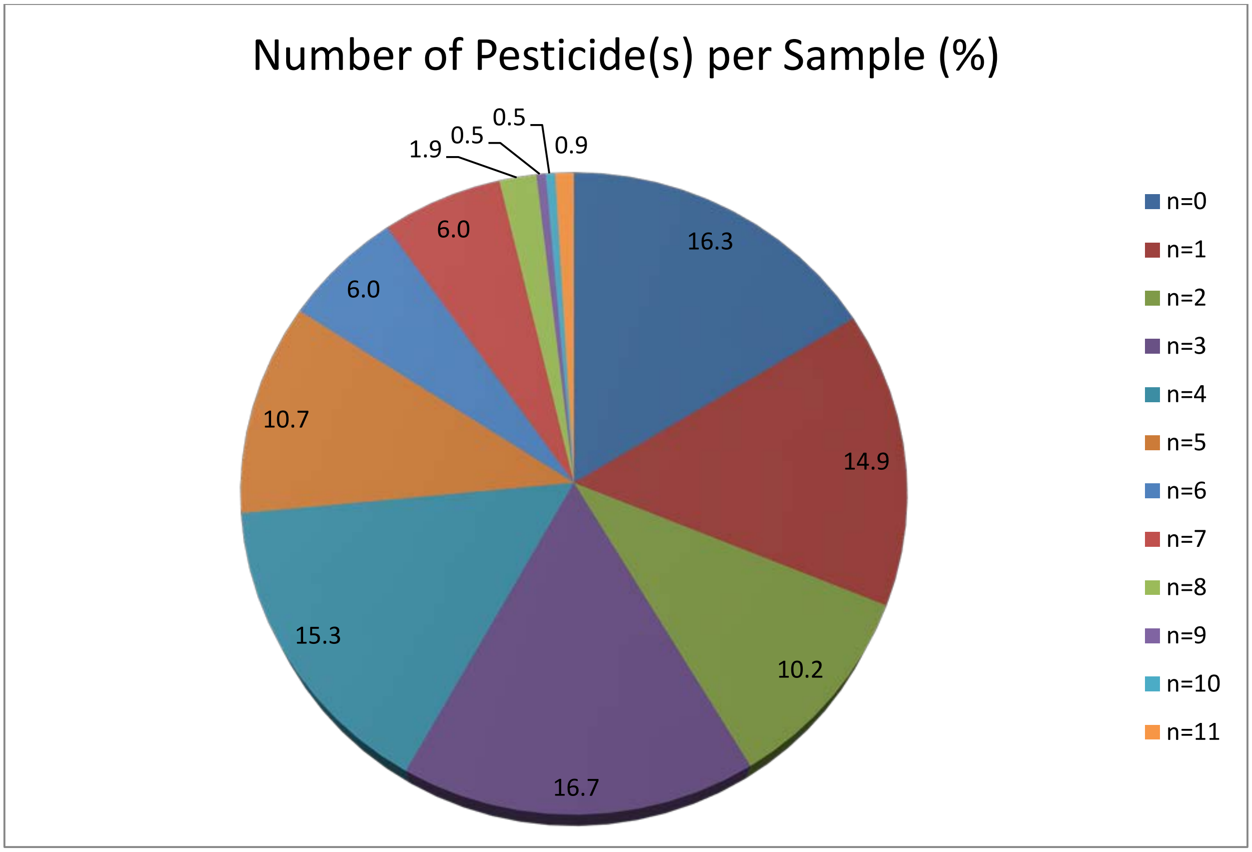

**Figure 20.** Percentage of samples with "n" number of different pesticides for 2012-2014 period.

Site A is the site for which the highest number of different pesticides was detected since 2012 (19 pesticides), followed by site H (15 pesticides). For all other storm water outfalls, 9 to 12 different pesticides were detected over the duration of this study (Figure 21).

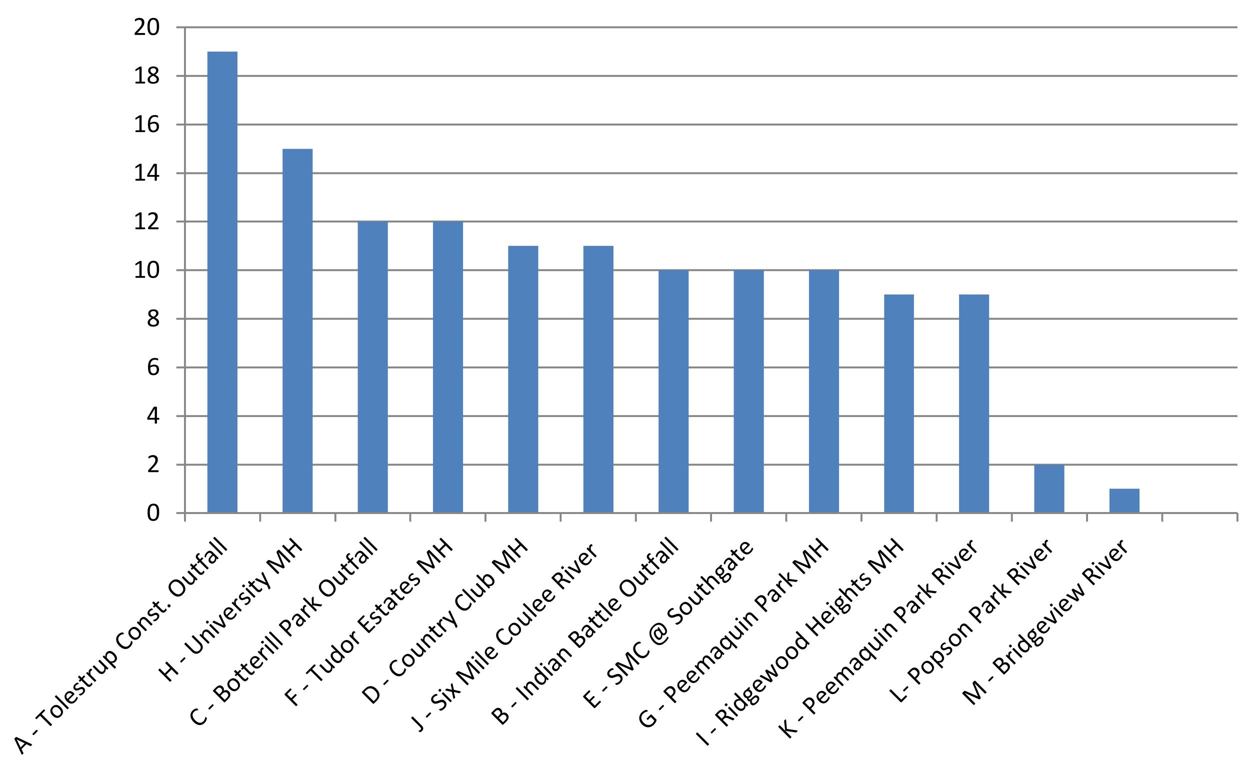

**Figure 21.** Number of Pesticides detected per site from 2012-2014.

Samples collected directly from the Oldman river contained fewer pesticides (one or two) compared to those collected from storm water outfalls, except for site K (Oldman river at Peenaquim park), whose samples were very similar to the storm water ones (Figure 21). On a yearly basis, site A was the site with the highest number of pesticides detected in 2012 and 2014, while site H was the highest in 2013 (although closely followed by site A). Based on a separate GIS study, site A drains water from a fairly equal ratio of commercial, industrial, park and residential areas, whereas site H mainly drains a residential area and one park. Both sites have a similar number of different pesticides detected, although site A has a much higher detection frequency compared to site H. A high number of detections for the typical lawn care products which often include the herbicides 2,4-D, mecoprop and dicamba was observed at both sites. However, site A also showed a number of herbicides such as bromoxynil, picloram, dichlobenil, bromacil, and MCPA which were not frequently detected at site H. This difference in the detection frequencies is likely a consequence of the differential land use for each drainage, which is more diverse at site A compared to site H.

In 2013, the overall detection frequency (number of samples containing one or more pesticide(s) divided by the total number of samples) was of 90%, the highest detection frequency of the entire study period (Table 2). For most pesticides, the average detected concentration was highest in 2013. The maximum concentrations for each pesticide and the highest detection frequencies were also observed in 2013. This is likely due to the samples collected on September 17th 2013, which contained the highest detected concentrations of 2,4-D, mecoprop and dicamba of the whole study duration. Moreover, 2013 and 2014 were similar with regards to overall meteorological conditions and rainfall events volume and timing during the summer, whereas fall precipitation consisted in one main event in September 2013 compared to several smaller rain events in September 2014.

Eight (8) pesticides were detected at least once for every year of the study: 2,4-D, dichlobenil, bromacil, bromoxynil, mecoprop, MCPA, dicamba and picloram. 2,4-D, mecoprop and dicamba are lawn care products frequently used on golf courses, and in parks and residential areas. Dichlobenil, picloram and bromacil are mainly used for the control of weeds in non-crop vegetation whereas bromoxynil and MCPA are herbicides used for the control of annual broadleaf weeds. Most if not all of these pesticides are used by the City of Lethbridge Pesticide Crew to control weeds in parks and along roads.

On a yearly basis, results are similar to the overall (all years combined) results. Results are tabulated in Table 2. Year 2012 seemed better with regards to pesticides, with a lower detection frequency, lower number of pesticides detected and lower average number of pesticides per sample. Results for years 2013 and 2014 were very similar, with 2013 having highest detection frequency and number of pesticides per sample but 2014 providing a higher number of different pesticides detected (22 in 2014, compared to 16 in 2013, and 10 in 2012).

2,4-D was the only pesticide detected at all sampling sites throughout the study. Mecoprop, MCPA, bromoxynil and dicamba were detected at 11 sampling sites. Several pesticides were single occurrences for the 2012-2014 period, including alachlor, permethrin (cis and trans), fenoxaprop, dichlorprop, atrazine, triallate, EPTC and cis-chlordane. These pesticides were detected at sites A (4 detections), H (3 detections), G and K (1 detection each). Fenoxaprop and triallate are herbicides used regularly across the Canadian Prairies and are frequently detected in river waters of southern Alberta. Fenoxaprop is used in a variety of crops such as soybeans, potatoes and sugar beets, while triallate is a pre-emergence herbicide used for the control of annual broad-leaved weeds in cereal crops. Dichlorprop is a herbicide used in post-emergence for the control of broad-leaved weeds in a variety of crops. EPTC is a herbicide used pre-emergence and soil-incorporated for the control of in grasses and broad-leaved weeds in non-crop vegetation such as orchards. Alachlor (herbicide), permethrin (insecticide) and chlordane (insecticide) are products currently without registration for use in Canada. It is unclear why pesticides registered solely for agricultural uses (fenoxaprop, triallate, dichlorprop, EPTC) have been detected in an urban catchment such as Lethbridge, although it is possible that some drainages include agricultural runoff from nearby areas. As for products not registered for use such as alachlor, permethrin and chlordane, their persistence in the environment might explain why they have been detected unfrequently during the study. Those pesticides are also infrequently detected in surface and ground waters of southern Alberta.

**Pesticides in Six Mile Coulee Creek and the Oldman River.** Six Mile Coulee Creek (site J) was only sampled in 2013 and 2014. A total of 11 pesticides were detected at this site, including both urban use (2,4-D, mecoprop and dicamba) and agricultural use (MCPA, bromoxynil, propyzamide, picloram, clopyralid, bentazon and fluroxypyr) pesticides. Since Six Mile Coulee receives runoff from both rural and urban sources, the variety of pesticides detected in storm water samples collected at site J is not surprising. However, all pesticides detected at site J had 4 or less detections for 2013 and 2014 combined (except for 2,4-D with 11 occurrences); this detection frequency is less than what could be anticipated considering the potential and diverse sources of pesticides draining into that site.

The Oldman River was sampled in 2013 and 2014 (sites K, L and M). Only 2,4-D and its metabolite 2,4-DCP (3 detections in total) were above detection levels in river water sampled upstream of Lethbridge (site L). Similarly, only 2,4-D was detected in the river samples collected at Bridgeview, and only once in 2014. However, site K (Peenaquim Park at the river) showed 11 pesticides. The pesticide profile detected in the Oldman river at site K is very similar to that of site G (Peenaquim Park manhole), a storm water sewer site located adjacent to Peenaquim Park. Site K is located downstream from the City of Lethbridge wastewater treatment plant; a water sample collected from the wastewater treatment plant final effluent in August 2014 showed the presence of five pesticides including 2,4-D, dicamba, mecoprop, chlorthiamid and dichlobenil. All of the latter were detected in the Oldman river at Peenaquim Park except for chlorthiamid. The sources of these pesticides is therefore unclear at this time, but likely multiple. There are a number of waste water treatment plant effluents that enter the Oldman River or its tributaries upstream of Lethbridge (Figure 13). The overall contribution of pesticides to the Oldman River was estimated in August 2014, and revealed that very few pesticides were present in the Oldman river upstream of Lethbridge although the waste water treatment plant in Fort McLeod did contribute 2,4-D and fluroxypyr. Tributaries and effluents to the Oldman River watershed sampled in August 2014 including non-urban sources (i.e. creeks, spillways, rivers) indicated that very few pesticides make their way to the Oldman river upstream of Lethbridge for any length of time.

In addition to site L located upstream of Lethbridge, a site located downstream of Lethbridge (site K) was sampled in 2013 and 2014. An additional site located just upstream of the Lethbridge waste water outfall was sampled in 2014 (site M, Bridgeview). Very few pesticides were detected in river water upstream of Lethbridge (site L) relative to downstream of Lethbridge (site K). However, pesticides in water obtained from site M were comparable to those observed in river water collected upstream of Lethbridge suggesting that storm water contributes pesticides in the Oldman River to a lesser degree than possibly treated waste water effluents from Lethbridge and site G.

**Pesticides in Lethbridge storm water, Six Mile Coulee Creek, and the Oldman River.** Pesticides can impact water quality for irrigation, recreation, drinking and livestock watering. Canadian and Alberta guidelines for water quality have been developed to assess water quality (CCME 1999, Government of Alberta 1999). It should be noted however that most pesticides do not have guidelines, and for those who do, the guidelines are typically incomplete with only one or two guidelines. Guidelines for both recreational and irrigation water were those exceeded most frequently. Only 2,4-D surpassed its drinking water guideline (100 µg/L), livestock watering guideline (100 µg/L) in addition to its protection of aquatic life guideline (6.1 µg/L) all at once in September 2013 at site C. Similarly, MCPA exceeded its protection of aquatic life (2.6 µg/L, livestock watering (25 µg/L) and irrigation (0.25 µg/L) guidelines all at once in the same sample as the aforementioned 2,4-D exceedance. However, it should be pointed out that urban storm waters are not used directly as a source of drinking water for humans and livestock. In addition, the storm water is diluted considerably once it reaches the Oldman river main stem. Nonetheless, such high concentrations of pesticides in one sample and therefore one drainage are not desirable and may impact water quality downstream. Overall, 2,4-D was the pesticide which surpassed most frequently its protection of aquatic life guideline (6.1 µg/L), with 14 samples collected mainly in 2013 in exceedance. Dicamba and MCPA consistently exceeded their respective irrigation guidelines (0,006 and 0.025 µg/L), since the latter are low and close to our analytical limit of detection for these pesticides. Bromacil and bromoxynil exceeded infrequently their respective irrigation guidelines (0.2 and 0.33 µg/L).

## 3.3 WATER CHEMISTRY AND NUTRIENT ANALYSIS

Water quality naturally varies from site to site and from year to year, such that water quality may appear better in drier years, since dry conditions cause less surface runoff and fewer contaminants coming from the land to the river. However, most persistent trends can be linked to human influence. Any activity that alters water quantity or affects inputs from point sources (e.g., storm water outfalls) or non-point sources (e.g., agricultural run-off) has the potential to influence water quality (http://esrd.alberta.ca/water/reports-data/alberta-river-water-quality-index.aspx). For total nutrients, most guideline protocols to protect aquatic life cannot be directly applied as with those of pesticides or metals, because not all nutrients are directly toxic. Nutrients however can have considerable detrimental effects, which include undesirable algae and plant growth impairing aesthetic and recreational use, outbreaks of toxic cyanobacteria, shifts in species assemblages, and ultimately, a reduction in dissolved oxygen levels and biodiversity (EQGASW 2014).

**Discharge.** In the three year period from 2012-2014, 2013 had the greatest median storm water discharge (Figure 22), although the maximum individual site discharges were measured in 2014 (Figure 23). This was more a function that two of the monthly samplings occurred on rainfall events in 2014 and only one did in 2013. From April 1st to September 17th 413.2 mm of rain fell in 2014, compared to 268.4 mm and 339.1 mm of rain during the same period in 2012 and 2013, respectively. Storm water discharge was measured more for estimating instantaneous load of nutrients, pesticides or bacterial loading to the Oldman River than estimating patterns in flow, since sampling once per month frequency would be inadequate for this level of discrepancy. Outfall discharge variability was demonstrated for all sites in that each outfall exceeded median values in many cases 10 fold at some point(s) over the sampling season. The respective discharge for storm water outfalls were shown to vary dramatically, irrespective of rainfall, since industrial, residential, lake and storm water pond discharges can all either increase, delay, or in other ways influence outfall discharge. These storm drains often flow without precipitation or snow-melt, where watering of lawns, infiltration of groundwater, cross-connections with sanitary sewers are other possible sources of flow (Saffran 2005). This was demonstrated both within and between years, where some sites experienced increased discharges while others decreased, at times significantly. Even during sampling events, pulses of flow were often experienced.

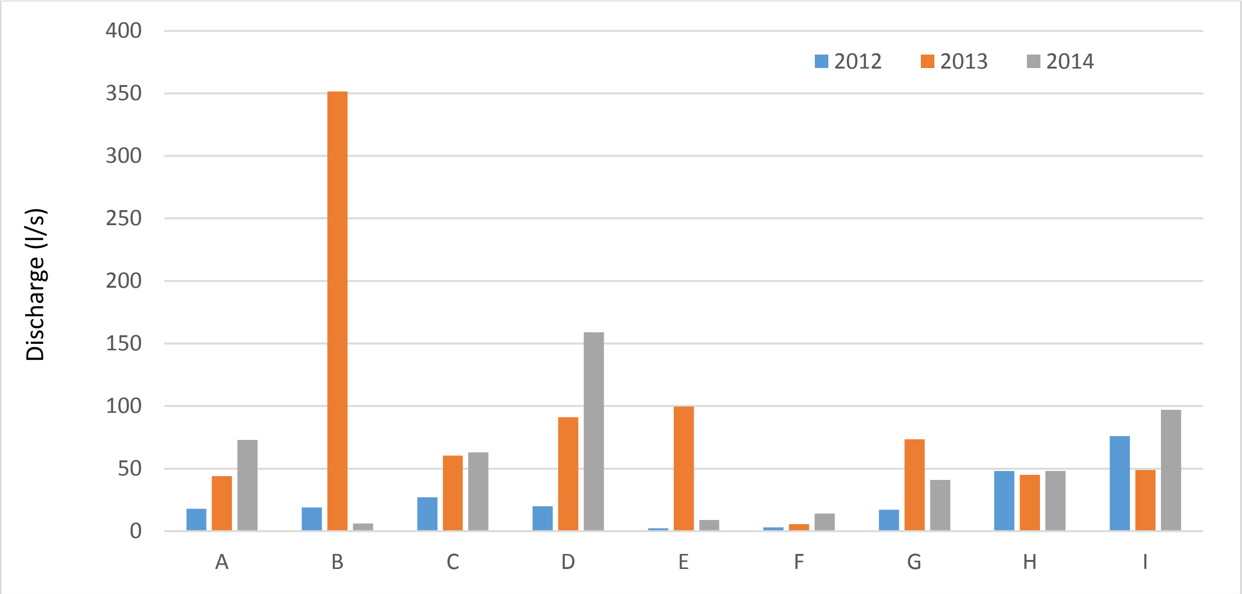

Figure 22. Median storm discharge in L/sec at each storm water site as measured at time of sampling for 2012 to 2014. Calculation of discharge based on pipe material, slope and diameter, and depth of flow as determined by the Manning formula using Bentleys Flowmaster Software. Median discharge calculated with rainfall event(s) included except for 2012 when no sampling was associated with a rainfall event.

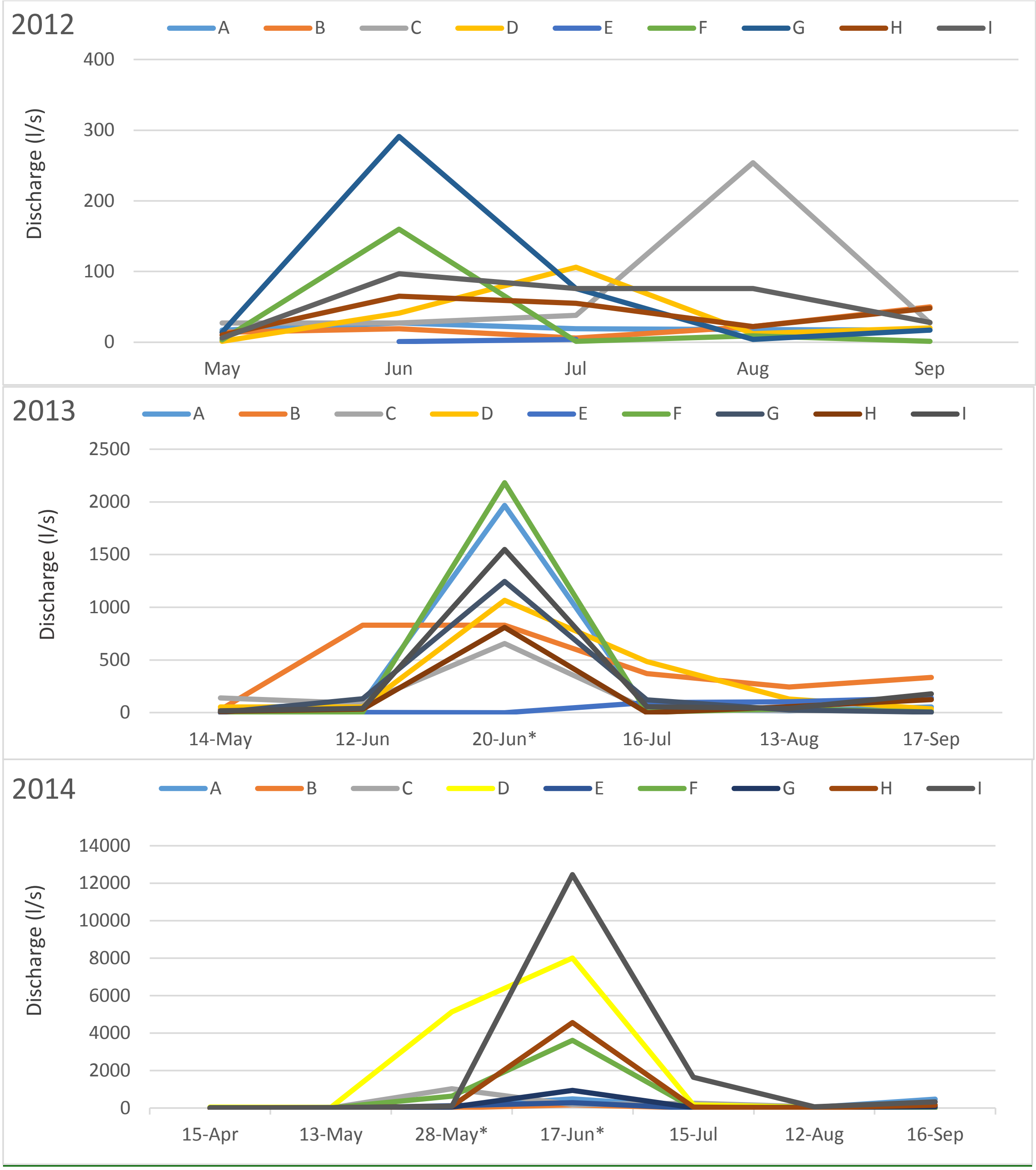

**Figure 23.** Monthly storm water outfall discharges for respective sample sites (A-I) based on single measures taken once per month between April and September for sampling year indicated.
* Denotes date of rainfall events

**Water Chemistry.** The parameters of temperature, dissolved oxygen, electrical conductivity (specific conductance), salinity and pH were tested for storm water from 2012 to 2014 and for river water for 2013 and 2014. For comparison, Site L was chosen as the river site because it represented river water quality upstream of Lethbridge. In general, storm water was cooler then river water (14 C vs. 17.6 C), had similar dissolved oxygen (8.3 mg/l vs. 7.9 mg/L) and pH (8.1 vs. 8.3) as river water, but had higher salinity (0.9 ppt vs. 0.2 ppt) (Figure 24). In comparing these results to the Saffran study from 2000-2002 (Saffran 2005), although temperature was not monitored, pH and oxygen were similar in storm water and sodium levels measured in storm waters were greater than those found in the Oldman River.

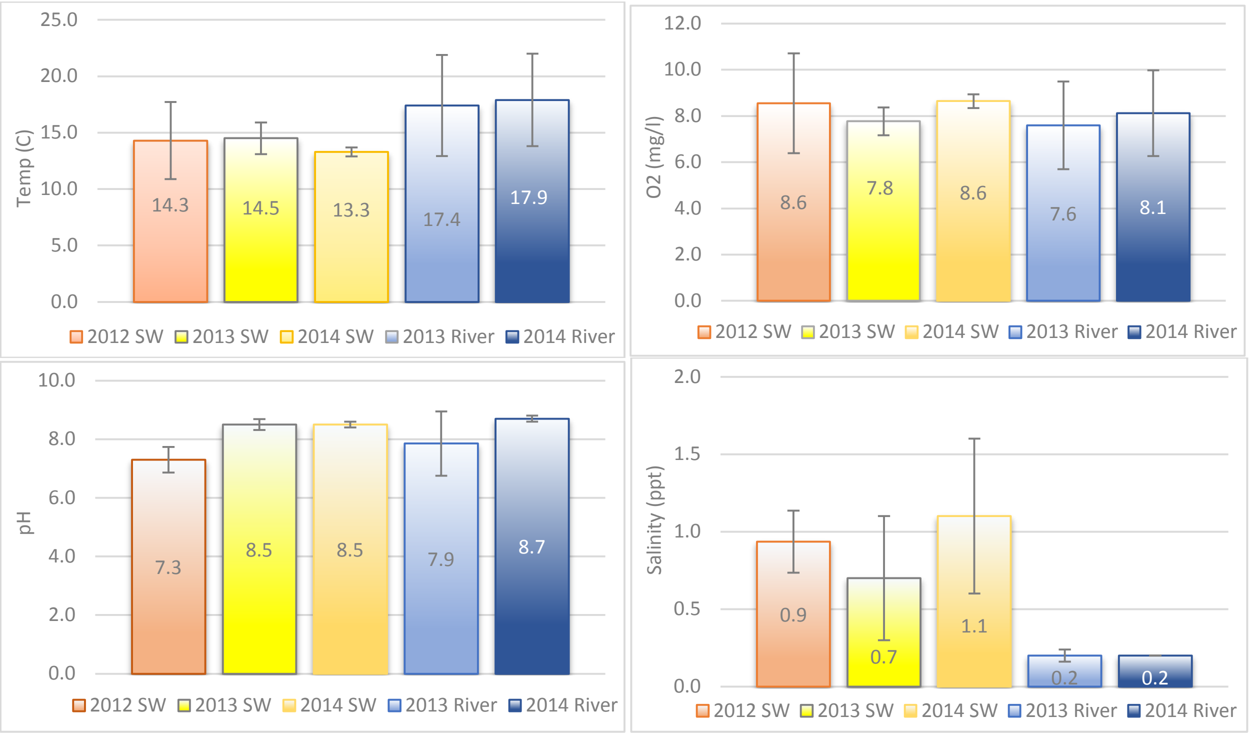

**Figure 24.** Median water chemistry (water temperature, dissolved oxygen, pH and salinity) for Lethbridge storm water outfall sites (SW) from 2012-2014 and river location (Site L) for 2013-2014 as measured from respective (April – September) monthly water samples. Error bars represent standard deviation.

Salinity is part of the Total Dissolved Solids and contributes to the overall conductivity. Conductivity, or specific conductance provides a simple, inexpensive measure of Total Dissolved Solids (TDS) that can be determined precisely and accurately in the field. The specific conductance and conversely TDS were also found to be higher in storm water discharge (median 1188 mg/L) compared to river water (median 257 mg/L) (Figure 25). The amount of dissolved solids can vary dramatically in natural water bodies and in a water course throughout the year. Although there are no guidelines for the parameters of conductivity, salinity or TDS for the protection of aquatic life, and storm water is not likely to be used as an irrigation source, for the sake of comparison the Alberta TDS guideline for agricultural use is in the range of 500 to 3500 mg/L (crop dependent) (ESRD 2014). The results of TDS values from storm water samples collected in this study compared closely to those of Saffran (2005), where median concentrations of TDS in storm water were 1127, but the TDS concentrations in the Oldman River at Lethbridge were greater (median 195 mg/L).

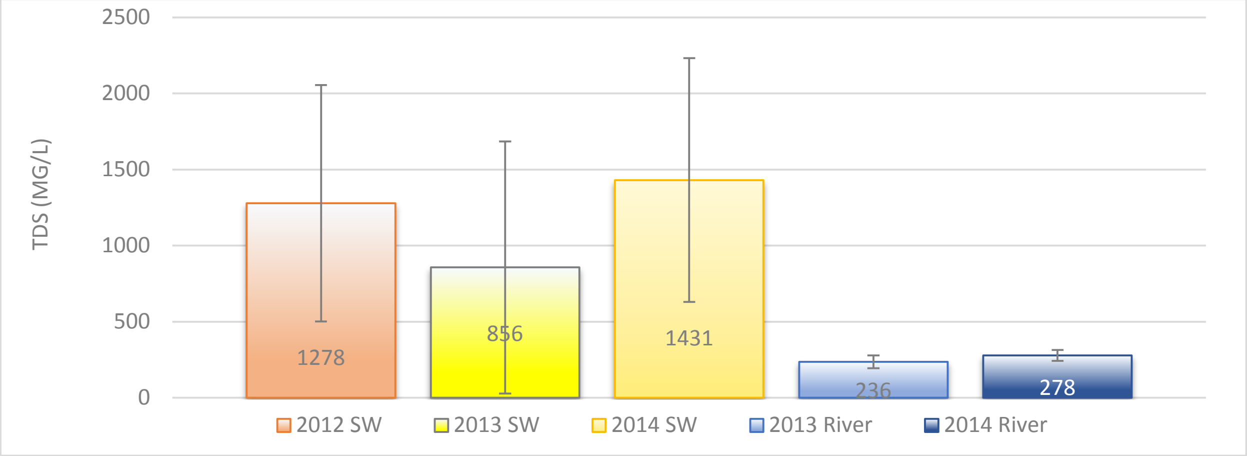

**Figure 25.** Median total dissolved solids (TDS) for Lethbridge storm water sites (SW) from 2012-2014 and river (Site L) for 2013-2014 as measured from respective (April – September) monthly water samples. Error bars represent standard deviation. TDS estimated by multiplying specific conductance (uS/cm) by 0.67.

**Ammonia ($NH_3$-N).** The nitrogen nutrients; ammonia, nitrate and Total Nitrogen were measured in 2012-2014 storm water samples. Nitrogen nutrients provide the basis of amino acids (proteins) and abundance can cause increased production of vegetation and algae in aquatic systems. Ammonia being highly soluble in water exists as two species; ionized ($NH_4$+) and unionized ($NH_3$); where the abundance of each species is determined principally by the water pH and temperature. Because these water quality parameters naturally fluctuate, the guideline value for ammonia ($NH_3$) for the protection of freshwater aquatic life is somewhat of a moving target. Over the course of sampling (April – September) the pH and water temperature varied and ammonia guidelines were calculated respectively using spreadsheet software from Alberta Environment. The actual ammonia concentrations for storm water at each site and the number of site samples surpassing the Canadian Water Quality Guidelines (CEQG 2010) was calculated (Table 3).

**Table 3.** Ammonia ($NH_3$-N) in (mg/L) for Lethbridge storm drains (A – I) and stream/river sites (J -M), for 2012 to 2014. Specific samples exceeding the guideline for surface water (Canadian Water Quality for the Protection of Aquatic Life) are shaded, with rainfall event dates highlighted in yellow. No river sites were sampled in 2012.

| **(2012)** | **Ammonia-N (mg/L)** | | | | | | **Min.** | **Median** | **Max.** | **Date of Min.** | **Date of Max.** | **# & % of sites over guideline** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Site** | **17-Apr** | **15-May** | **12-Jun** | **17-Jul** | **14-Aug** | **11-Sep** | | | | | | | |
| **A** | 0.59 | 0.05 | 0.44 | 0.77 | 0.86 | 0.16 | 0.05 | 0.52 | 0.86 | 15-May | 14-Aug | 2 | 33% |
| **B** | 0.33 | 0.34 | 0.64 | 2.25 | 0.24 | 4.0 | 0.24 | 0.49 | 4 | 14-Aug | 11-Sep | 0 | 0% |
| **C** | 0.86 | 0.39 | 0.33 | 0.29 | 0.44 | 0.4 | 0.29 | 0.4 | 0.86 | 17-Jul | 17-Apr | 0 | 0% |
| **D** | 0.08 | 0.13 | 0.06 | 0.24 | 0.22 | 0.22 | 0.06 | 0.18 | 0.24 | 12-Jun | 17-Jul | 0 | 0% |
| **E** | - | 0.22 | 0.23 | 0.38 | 0.04 | 0.1 | 0.04 | 0.22 | 0.38 | 14-Aug | 17-Jul | 0 | 0% |
| **F** | 0.17 | 0.48 | 0.06 | 0.21 | 0.21 | 0.11 | 0.06 | 0.19 | 0.48 | 12-Jun | 15-May | 0 | 0% |
| **G** | 0.16 | 0.36 | 0.1 | 0.28 | 0.26 | 0.25 | 0.1 | 0.26 | 0.36 | 12-Jun | 15-May | 0 | 0% |
| **H** | 0.86 | 1.6 | 2.82 | 3.36 | 4.0 | 0.03 | 0.03 | 2.21 | 4 | 11-Sep | 14-Aug | 3 | 50% |
| **I** | 0.15 | 0.25 | 0.14 | 0.12 | 0.53 | 0.34 | 0.12 | 0.2 | 0.53 | 17-Jul | 14-Aug | 1 | 17% |
| **Mean** | **0.4** | **0.42** | **0.54** | **0.88** | **0.76** | **0.62** | | | | | | **0.67** | **11%** |

| **(2013)** | **Ammonia-N (mg/L)** | | | | | | **Min.** | **Median** | **Max.** | **Date of Min.** | **Date of Max.** | **# & % of sites over guideline** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2013 Site** | **14-May** | **12-Jun** | **20-Jun** | **16-Jul** | **13-Aug** | **17-Sep** | | | | | | | |
| **A** | 0.43 | 1.12 | 0.39 | 1.2 | 0.92 | 0.41 | 0.39 | 0.68 | 1.2 | 20-Jun | 16-Jul | 4 | 67% |
| **B** | 0.32 | 1.47 | 0.41 | 0.36 | 0.16 | 0.21 | 0.16 | 0.34 | 1.47 | 13-Aug | 12-Jun | 2 | 33% |
| **C** | 0.29 | 1.92 | 0.35 | 0.48 | 0.35 | 0.17 | 0.17 | 0.35 | 1.92 | 17-Sep | 12-Jun | 3 | 50% |
| **D** | 0.1 | 0.4 | 0.65 | 0.37 | 0.56 | 0.31 | 0.1 | 0.39 | 0.65 | 14-May | 20-Jun | 4 | 67% |
| **E** | - | 0.11 | 0.35 | 0.12 | 0.27 | 0.18 | 0.11 | 0.18 | 0.35 | 12-Jun | 20-Jun | 2 | 40% |
| **F** | 0.26 | 0.83 | 0.23 | 0.19 | 0.21 | 0.22 | 0.19 | 0.23 | 0.83 | 16-Jul | 12-Jun | 0 | 0% |
| **G** | 0.69 | 1.03 | 0.52 | 0.34 | 0.19 | 0.11 | 0.11 | 0.43 | 1.03 | 17-Sep | 12-Jun | 3 | 50% |
| **H** | 5.64 | 0.45 | 0.24 | 6.2 | 3.35 | 8.25 | 0.24 | 4.5 | 8.25 | 20-Jun | 17-Sep | 4 | 67% |
| **I** | 0.16 | 0.41 | 0.16 | 0.16 | 0.2 | 0.22 | 0.16 | 0.18 | 0.41 | May, Jun, Jul | 12-Jun | 1 | 17% |
| **Mean** | **0.99** | **0.86** | **0.37** | **1.05** | **0.69** | **1.12** | | | | | **Mean** | **2.44** | **43%** |
| **J** | 0.24 | 0.1 | 0.29 | 0.1 | 0.15 | 0.04 | 0.04 | 0.13 | 0.29 | 17-Sep | 20-Jun | 1 | 17% |
| **K** | 0.1 | 0.21 | 0.18 | 0.23 | 0.19 | 0.07 | 0.07 | 0.19 | 0.23 | 17-Sep | 16-Jul | 3 | 50% |
| **L** | 0.5 | 0.18 | - | 0.26 | 0.15 | 0.02 | 0.02 | 0.18 | 0.5 | 17-Sep | 14-May | 2 | 40% |

| **(2014)** | **Ammonia-N (mg/L)** | | | | | | | **Min.** | **Median** | **Max.** | **Date of Min.** | **Date of Max.** | **# & % above guideline** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Site** | **15-Apr** | **13-May** | **28-May** | **17-Jun** | **15-Jul** | **12-Aug** | **16-Sep** | | | | | | | |
| **A** | 0.50 | 0.38 | 0.77* | 0.67 | 0.42 | 1.36 | 0.41 | 0.38 | 0.50 | 1.36 | 13-May | 12-Aug | 6 | 86% |
| **B** | 2.13 | 0.51 | 0.82 | 0.81 | 0.32 | 0.47 | 0.28 | 0.28 | 0.51 | 2.13 | 16-Sep | 15-Apr | 7 | 100% |
| **C** | 1.93 | 0.22 | 0.81 | 0.64 | 0.37 | 0.29 | 0.48 | 0.22 | 0.48 | 1.93 | 13-May | 15-Apr | 6 | 86% |
| **D** | 0.23 | 0.22 | 0.93 | 0.44 | 0.34 | 0.29 | 0.34 | 0.22 | 0.34 | 0.93 | 13-May | 28-May | 4 | 57% |
| **E** | 0.39 | 0.27 | 0.28 | 0.29 | 0.28 | 0.42 | 0.19 | 0.19 | 0.28 | 0.42 | 16-Sep | 12-Aug | 5 | 71% |
| **F** | 0.21 | 0.18 | 0.51 | 0.37 | 0.33 | 0.70 | 0.33 | 0.18 | 0.33 | 0.70 | 13-May | 12-Aug | 4 | 57% |
| **G** | 0.49 | 0.21 | 0.57 | 0.39 | 0.36 | 0.54 | 0.25 | 0.21 | 0.39 | 0.57 | 13-May | 28-May | 6 | 86% |
| **H** | 4.20 | 6.40 | 0.69 | 0.35 | 9.05 | 7.34 | 2.98 | 0.35 | 4.20 | 9.05 | 17-Jun | 15-Jul | 7 | 100% |
| **I** | 0.34 | 0.35 | 0.48 | 0.37 | 0.18 | 0.35 | 0.18 | 0.18 | 0.35 | 0.48 | 16-Sep,15-Jul | 28-May | 4 | 57% |
| **Mean** | **1.16** | **0.97** | **0.65** | **0.48** | **1.29** | **1.31** | **0.60** | | | | | | **5.4** | **78%** |
| **J** | 0.24 | 0.21 | 0.38 | 0.35 | 0.18 | 0.46 | 0.23 | 0.18 | 0.24 | 0.46 | 15-Jul | 12-Aug | 5 | 71% |
| **K** | 0.34 | 0.17 | 0.21 | 0.38 | 0.27 | 0.42 | 0.30 | 0.17 | 0.30 | 0.42 | 13-May | 12-Aug | 4 | 57% |
| **L** | 0.11 | 0.27 | 0.17 | 0.24 | 0.21 | 0.31 | 0.37 | 0.11 | 0.24 | 0.37 | 15-Apr | 16-Sep | 5 | 71% |
| **M** | 0.20 | 0.15 | 0.19 | 0.37 | 0.28 | 0.12 | 0.05 | 0.05 | 0.19 | 0.37 | 16-Sep | 17-Jun | 3 | 43% |

Ammonia concentrations in water vary seasonally and regionally, but in natural waters are generally less than 0.1 mg/L. Higher levels of ammonia are generally indicative of organic pollution (McNeely et al. 1979). Ammonia levels increased in almost all storm water discharges from 2012 to 2014, demonstrated by the increase in the maximum ammonia recorded (4 mg/L in 2012 to 9.05 mg/L in 2014) (Table 3), by the increase in the number of sites and percentage of samples from each site that were over the recommended guideline (3 of 9 sites and 11% of samples over guideline in 2012, 8 of 9 sites with 43% of samples over the guideline in 2013, and 9 of 9 sites with 78% of samples over the guideline in 2014) and in the increase in median ammonia measured at virtually all sites (Figure 26). This trend also appeared consistent in levels of ammonia in river water, where although no river samples were collected in 2012, in 2013 36% of river samples were above the guideline, and in 2014 61% of samples were above. Samples taken in the spring were also less likely to be over the guideline vs. those samples taken in June through to September, with July and August usually having the highest mean ammonia concentrations. The amount of precipitation would also have an influence on water quality in storm and river water and for ammonia, a high percentage of samples (93%) collected during or after rainfall events exceeded the recommended guideline. Comparing between all storm water drains, water from site H (Varsity) had median ammonia concentrations that were from 6 to 15 times greater than those concentrations recorded at any other site (Figure 26). This site also had the greatest mean instantaneous load from any storm water site in each of the three years of monitoring (Figure 26).

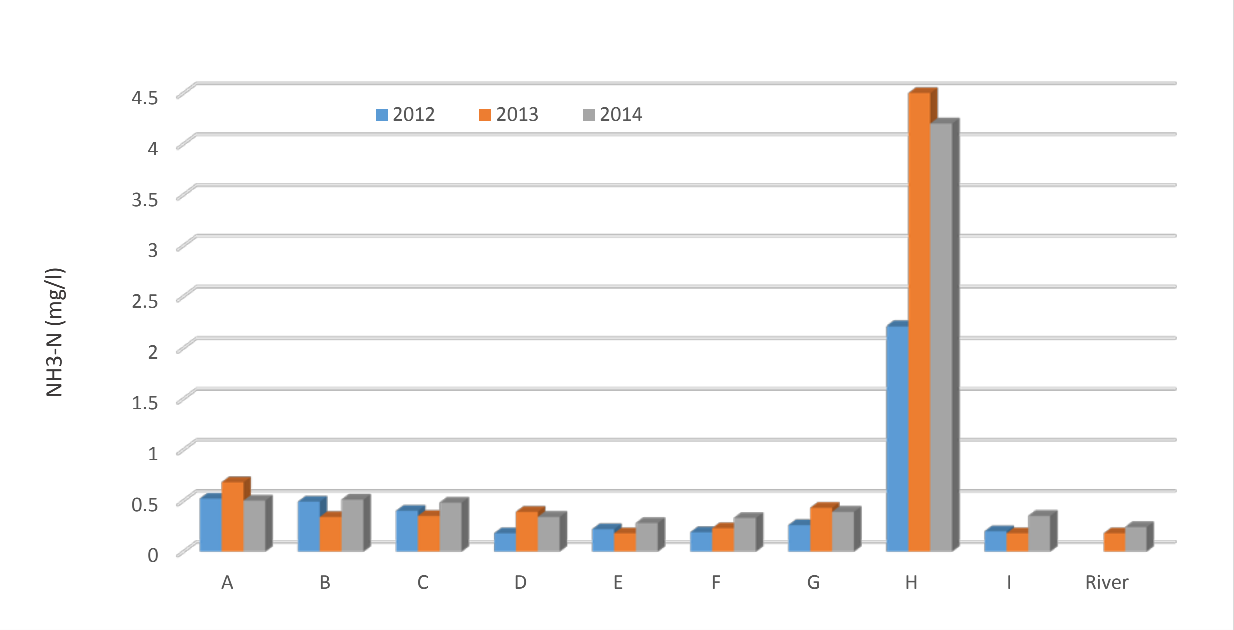

**Figure 26.** Median storm water ammonia (NH3-N) concentrations at outfall sites (A-I) from 2012 to 2014 and the Oldman River site upstream of Lethbridge (L) from 2013-2014.

In looking back a decade at the Saffran study (2005), it was the same storm drain (Site H) that showed elevated ammonia concentrations. Compared to these past monitoring results the present study showed elevated minimum ammonia nitrogen levels for all drain sites, elevated median levels in 8 out of 10 sites, an increase from only 50% of the sites having samples over the recommended guideline to all sites having samples over the guidelines, and the number of samples over the guideline went from an average of 8.3% per site to approximately 46% per site (Table 4). In all, ammonia levels from storm water discharges were found to be relatively high, occurring at concentrations comparable to those recorded from wastewater treatment plant effluent. For river samples, Saffran (2005) found ammonia nitrogen concentrations in the Oldman River were low; with median values no greater than 0.02 mg/L, and no guidelines exceedances. Between 2013 and 2014 median $NH_3$-N levels from sites M (Hwy 3) and L (Popson Park) had increased from historically 0.01 mg/L to 0.19 mg/L and 0.24 mg/L respectively. The results from the present study also had 51% of all river samples exceeding the guidelines. Table 4 summarizes the ammonia nitrogen results for 3 years of storm and river water monitoring. It should be noted that the results from the present study and the Saffran study on guideline exceedances may not be directly comparable in that in the present study guidelines were calculated for each sample based on sample pH and temperature at the time of sampling, whereas in the Saffran study exceedances were based on sample pH and a mean temperature of 10 C.

**Table 4.** Summary of ammonia ($NH_3$-N) in (mg/L) for Lethbridge storm drains (A – I) and stream/river sites (J -M), for April to September 2012 to 2014. Total samples and percentage of samples exceeding the guideline for surface water (Canadian Water Quality for the Protection of Aquatic Life) as calculated for pH and temperature of each sample. No river sites were sampled in 2012.

| Site | Years Sampled | # of Samples | Min | Median | Max | Date of Min | Date of Max | # & % above guideline | |
|---|---|---|---|---|---|---|---|---|---|
| **A** | 3 | 19 | 0.05 | 0.5 | 1.36 | May-12 | Aug-14 | 12 | 63% |
| **B** | 3 | 19 | 0.16 | 0.41 | 4 | Aug-13 | Sep-14 | 9 | 47% |
| **C** | 3 | 19 | 0.17 | 0.39 | 1.93 | Sep-13 | Apr-14 | 9 | 47% |
| **D** | 3 | 19 | 0.06 | 0.29 | 0.93 | Jun-12 | May-14 | 8 | 42% |
| **E** | 3 | 17 | 0.04 | 0.27 | 0.42 | Aug-12 | Aug-14 | 7 | 41% |
| **F** | 3 | 19 | 0.06 | 0.22 | 0.83 | Jun-12 | Jun-13 | 4 | 21% |
| **G** | 3 | 19 | 0.1 | 0.34 | 1.03 | Jun-12 | Jun-13 | 9 | 47% |
| **H** | 3 | 19 | 0.03 | 3.35 | 9.05 | Sep-12 | Jul-14 | 14 | 74% |
| **I** | 3 | 19 | 0.12 | 0.22 | 0.53 | Jul-12 | Aug-12 | 6 | 32% |
| **J** | 2 | 13 | 0.04 | 0.23 | 0.46 | Sep-13 | Aug-14 | 6 | 46% |
| **K** | 2 | 13 | 0.07 | 0.21 | 0.42 | Sep-13 | Aug-14 | 7 | 54% |
| **L** | 2 | 12 | 0.02 | 0.24 | 0.5 | Sep-13 | May-13 | 7 | 58% |
| **M** | 1 | 7 | 0.05 | 0.19 | 0.37 | Sep-14 | Jun-14 | 3 | 43% |

Storm water discharge was calculated in order to determine mean instantaneous load to the Oldman River. Instantaneous load is the quantity of a compound being introduced to a water body based on the rate of release (discharge) and concentration of the compound in discharged water. In 2012 and 2013, site H had the greatest instantaneous load of ammonia to the Oldman River over any other storm drain site, but in 2014, because of the greater discharge by sites D and I, these sites contributed more ammonia load to the Oldman River then did Site H (Figure 27).

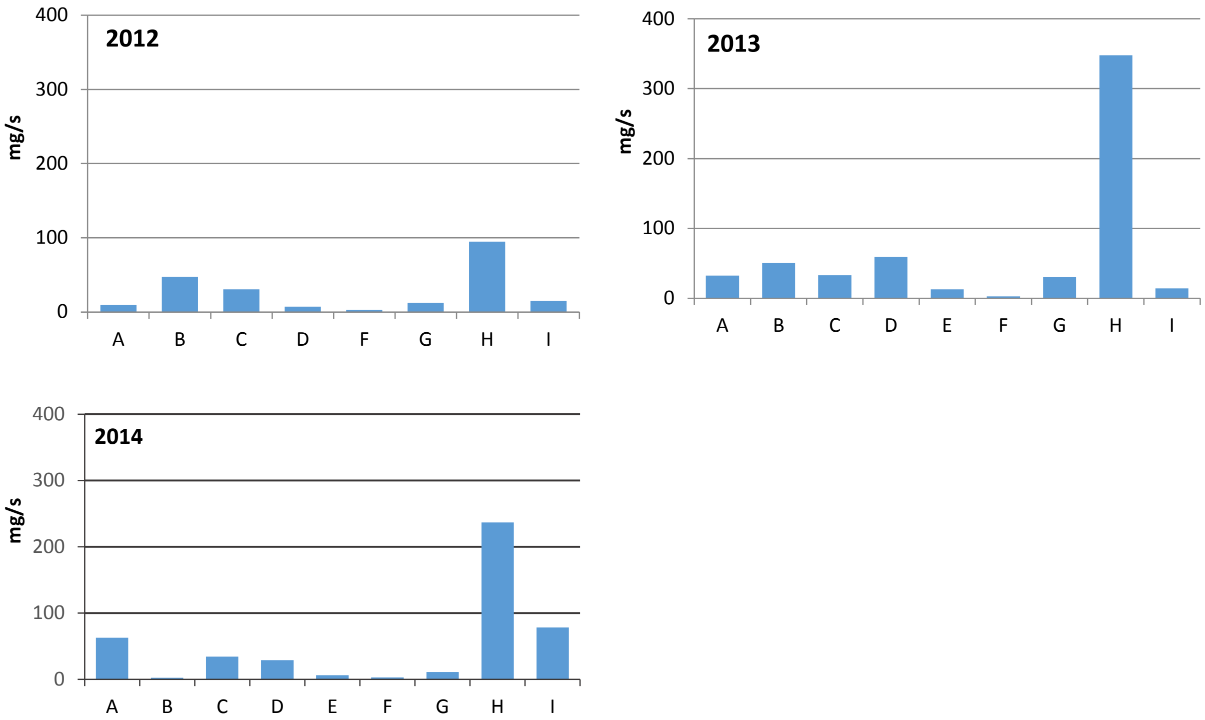

**Figure 27.** Mean instantaneous load of ammonia nitrogen ($NH_3$-N in mg/s) for storm water sites based on flows (excluding rainfall events) and ammonia levels recorded at time of sampling. Samples collected monthly from April to September 2012 to 2014.

**Nitrate ($NO_3$-N).** All forms of inorganic nitrogen, ammonia ($NH_3$), ammonium ($NH_4$+), released into river waters have the potential to undergo nitrification to nitrate ($NO_3$), which is the most oxidized form of nitrogen in the environment. Naturally occurring nitrate levels in Canadian lakes and rivers rarely exceed 4 mg $NO_3$-/L (CEQG 2012), and levels above this value are often considered the result of anthropogenic inputs and are associated with eutrophic conditions (NRC 1978, USGS 1999). Although not directly toxic to freshwater aquatic life, nitrate serves as the primary source of nitrogen for aquatic plants in well oxygenated systems (Nordin and Pommen 1986).

The Canadian water quality guideline for long term nitrate exposure for the protection of aquatic life is 3.0 mg $NO_3$-N per litre, with the short-term benchmark concentration indicating the potential for severe effects (e.g. lethality or immobilization) being 124 mg $NO_3$-N/L (CEQG 2012). The highlights from three years of monitoring storm drains for $NO_3$-N: there appeared to be no correlation of nitrate with rainfall, sites D (Park Royal/Lakeview), E (Southgate) and F (Tudor/Fairmont) had no samples that exceeded guidelines, while sites A (Westminster/Winston Churchill) and H (Varsity) had up to 71% of their samples and their median nitrate values well above the long term guideline (6 & 7 mg/L respectively) in 2014, with the maximum recorded nitrate concentration (26 mg/L) coming from site A, again in 2014 (Tables 5-6). Although previously, Saffran reported a much higher nitrate nitrogen concentration (51 mg/L), coming from storm drain I, site E similarly had no sample exceedances for nitrate. An average of 44% of the storm water samples in this earlier study exceeded guidelines, similar to the 43% of samples doing the same in 2014, however averaged over three years 2012-2014, only approximately 24% of samples exceeded water quality guidelines for long term nitrate exposure.

For tributary and river samples the results of the present study also represent a very similar picture to the Saffran (2005) findings. Where Saffran reported occasional nitrate exceedances of the 3 mg/L guideline in lower Six Mile Coulee, all samples from the main stem Oldman River were below this level and most below 1 mg/L. However, both the Hwy 3 (Site M) and Popson Park (Site L) median $NO_3$-N site values had increased (0.052 mg/L vs. 1 mg/L and .03 mg/L vs. 1 mg/L respectively). In the present study, 15% of the Six Mile Coulee samples (Site J) exceeded guidelines, and from all samples collected from the Oldman River only a single sample from Site K (downstream of Lethbridge) resulted in any nitrate exceedance, otherwise most samples were below 1 mg/L (Table 6, Figure 28). For mean instantaneous loads to the Oldman River from storm discharges, the highest loads from 2012 to 2014 were recorded in 2014, substantially so, with sites A and H having the greatest contributions (435 and 459 mg/s) (Figure 29).

**Table 5.** Summary of nitrate ($NO_3$-N) in (mg/L) for Lethbridge storm drains (A – I) and stream/river sites (J -M), for 2012 to 2014. Specific samples exceeding the guideline for surface water (Canadian Water Quality for the Protection of Aquatic Life) are shaded, with rainfall event dates highlighted in yellow. No river sites were sampled in 2012.

| (2012) | Nitrate-N (mg/L) | | | | | | Min. | Median | Max. | Date of | Date of | Guideline >3 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site | 17-Apr | 15-May | 12-Jun | 17-Jul | 14-Aug | 11-Sep | | | | Min. | Max. | | |
| A | 4.3 | 1.1 | 1.8 | 1.6 | 1.6 | 5.9 | 1.14 | 1.7 | 5.91 | 15-May | 11-Sep | 2 | 33% |
| B | 1.4 | 0.9 | 10 | 1.6 | 1.4 | 0.7 | 0.68 | 1.36 | 10 | 11-Sep | 12-Jun | 1 | 17% |
| C | 1.1 | 1.6 | 1.1 | 0.2 | 2.7 | 0.7 | 0.23 | 1.14 | 2.73 | 17-Jul | 14-Aug | 0 | 0% |
| D | 0.9 | 0.9 | 0.9 | 0.7 | 0.7 | 2 | 0.68 | 0.91 | 2.05 | 17-Jul | 11-Sep | 0 | 0% |
| E | - | 1.1 | 0.7 | 0.5 | 0.7 | 0.5 | 0.45 | 0.68 | 1.14 | 17-Jul | 15-May | 0 | 0% |
| F | 1.1 | 2 | 0.7 | 0.5 | 1.1 | 1.6 | 0.45 | 1.14 | 2.05 | 17-Jul | 15-May | 0 | 0% |
| G | 2 | 3 | 0.7 | 4.1 | 8.6 | 0.5 | 0.45 | 2.5 | 8.64 | 11-Sep | 14-Aug | 2 | 33% |
| H | 2.5 | 1.1 | 2 | 2.7 | 1.4 | 3.4 | 1.14 | 2.27 | 3.41 | 15-May | 11-Sep | 1 | 17% |
| I | 0.9 | 1.4 | 5 | 9.1 | 1.8 | 0.9 | 0.91 | 1.59 | 9.09 | 17-Apr | 17-Jul | 2 | 33% |
| **Mean** | **1.79** | **1.46** | **2.55** | **2.32** | **2.22** | **1.79** | | | | | | **0.9** | **15%** |

| (2013) | Nitrate-N (mg/L) | | | | | | Min. | Median | Max. | Date of Min. | Date of Max. | Guideline >3 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site | 14-May | 12-Jun | 20-Jun | 16-Jul | 13-Aug | 17-Sep | | | | | | | |
| A | 1.1 | 1.6 | 1.4 | 0.9 | 2.7 | 1.6 | 0.9 | 1.5 | 2.7 | 16-Jul | 13-Aug | 0 | 0% |
| B | 1.8 | 1.6 | 4.1 | 0.7 | 0.2 | 0.5 | 0.2 | 1.1 | 4.1 | 13-Aug | 20-Jun | 1 | 17% |
| C | 0.9 | 4.8 | 3.2 | 2.7 | 0.5 | 0.2 | 0.2 | 1.8 | 4.8 | 17-Sep | 12-Jun | 2 | 33% |
| D | 1.1 | 1.4 | 2.5 | 0.9 | 0.7 | 0.5 | 0.5 | 1 | 2.5 | 17-Sep | 20-Jun | 0 | 0% |
| E | - | 0.9 | 1.8 | 0.5 | 0.2 | 0.2 | 0.2 | 0.5 | 1.8 | Aug, Sep | 20-Jun | 0 | 0% |
| F | 0.7 | 1.6 | 0.9 | 0.2 | 0.5 | 0.2 | 0.2 | 0.6 | 1.6 | Jul, Sep | 12-Jun | 0 | 0% |
| G | 0.9 | 3.9 | 1.8 | 3.4 | 2.7 | 0.2 | 0.2 | 2.3 | 3.9 | 17-Sep | 12-Jun | 2 | 33% |
| H | 0.9 | 0.7 | 1.6 | 3.4 | 0.5 | 0.5 | 0.5 | 0.8 | 3.4 | 17-Sep | 16-Jul | 1 | 17% |
| I | 1.1 | 3.2 | 1.8 | 1.4 | 0.5 | 0.2 | 0.2 | 1.3 | 3.2 | 17-Sep | 12-Jun | 1 | 17% |
| **Mean** | **1.08** | **2.17** | **2.12** | **1.57** | **0.93** | **0.45** | | | | | **Mean** | **0.8** | **13%** |
| J | 0 | 3.2 | 0.2 | 2 | 0.5 | 0.2 | 0 | 0.3 | 3.2 | 14-May | 12-Jun | 1 | 17% |
| K | 0.9 | 0.5 | 0.5 | 0.9 | 0.2 | 0.2 | 0.2 | 0.5 | 0.5 | Aug, Sep | 12/20 -Jun | 0 | 0% |
| L | 0 | 1.8 | - | 0 | 0.5 | 0 | 0 | 0.2 | 1.8 | May, Jul, Sep | 12-Jun | 0 | 0% |

| (2014) | Nitrate-N (mg/L) | | | | | | | Min. | Median | Max. | Date of Min. | Date of Max. | Guideline >3 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site | 15-Apr | 13-May | 28-May | 17-Jun | 15-Jul | 12-Aug | 16-Sep | | | | | | | |
| A | 26.0 | 21.0 | 6.0 | 1.0 | 6.0 | 7.0 | 1.0 | 1.0 | 6.0 | 26.0 | June/Sept. | 15 Apr. | 5 | 71% |
| B | 2.0 | 1.0 | 4.0 | 1.0 | 2.0 | 3.0 | 2.0 | 1.0 | 2.0 | 4.0 | May/ June | 28-May | 1 | 14% |
| C | 3.0 | 2.0 | 2.0 | 1.0 | 0.0 | 4.0 | 2.0 | 0.0 | 2.0 | 4.0 | July | 2 Aug. | 1 | 14% |
| D | 2.0 | 1.0 | 2.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 2.0 | multiple | Apr./ May | 0 | 0% |
| E | 1.0 | 3.0 | 1.0 | 0.0 | 1.0 | 1.0 | 1.0 | 0.0 | 1.0 | 3.0 | 17-Jun | 13-May | 0 | 0% |
| F | 1.0 | 0.0 | 2.0 | 0.0 | 1.0 | 1.0 | 3.0 | 0.0 | 1.0 | 3.0 | May/June | Sept. | 0 | 0% |
| G | 5.0 | 14.0 | 1.0 | 1.0 | 1.0 | 8.0 | 0.0 | 0.0 | 1.0 | 14.0 | Sept. | 13-May | 3 | 43% |
| H | 6.0 | 12.0 | 2.0 | 3.0 | 10.0 | 7.0 | 9.0 | 2.0 | 7.0 | 12.0 | 28-May | 13-May | 5 | 71% |
| I | 1.0 | 2.0 | 5.0 | 1.0 | 0.0 | 2.0 | 2.0 | 0.0 | 2.0 | 5.0 | 15-Jul | 28-May | 1 | 14% |
| **Mean** | **5.22** | **6.22** | **2.78** | **1.00** | **2.44** | **3.78** | **2.33** | | | | | **Mean** | **3** | **43%** |
| J | 8.0 | 1.0 | 2.0 | 3.0 | 3.0 | 0.0 | 1.0 | 0.0 | 2.0 | 8.0 | 12-Aug | Apr. | 1 | 14% |
| K | 6.0 | 0.0 | 1.0 | 0.0 | 0.0 | 1.0 | 2.0 | 0.0 | 1.0 | 6.0 | multiple | Apr. | 1 | 14% |
| L | 3.0 | 0.0 | 1.0 | 1.0 | 1.0 | 1.0 | 2.0 | 0.0 | 1.0 | 3.0 | 13-May | Apr. | 0 | 0% |
| M | 3.0 | 1.0 | 0.0 | 1.0 | 0.0 | 1.0 | 1.0 | 0.0 | 1.0 | 3.0 | May/ July | Apr. | 0 | 0% |

**Table 6.** Summary of nitrate ($NO_3$-N) in (mg/L) for Lethbridge storm drains (A – I) and stream/river sites (J -M), for April to September 2012 to 2014. Total samples and percentage of samples exceeding the guideline for surface water (Canadian Water Quality for the Protection of Aquatic Life). No river sites were sampled in 2012.

| Site | Years Sampled | # of Samples | Min | Median | Max | Date of Min | Date of Max | # & % above Guideline | |
|---|---|---|---|---|---|---|---|---|---|
| A | 3 | 19 | 0.9 | 1.6 | 26 | Jul-13 | Jun-14 | 7 | 37% |
| B | 3 | 19 | 0.2 | 1.6 | 10 | Aug-13 | Jun-12 | 3 | 16% |
| C | 3 | 19 | 0 | 1.6 | 4.8 | Jul-14 | Jun-13 | 3 | 16% |
| D | 3 | 19 | 0.5 | 1 | 2.5 | Sep-13 | Jun-13 | 0 | 0% |
| E | 3 | 17 | 0 | 0.9 | 3 | Jun-14 | May-14 | 0 | 0% |
| F | 3 | 19 | 0 | 1 | 3 | May-14 | Sep-14 | 0 | 0% |
| G | 3 | 19 | 0 | 2 | 14 | Sep-14 | May-14 | 7 | 37% |
| H | 3 | 19 | 0.5 | 2.5 | 12 | Sep-13 | May-14 | 7 | 37% |
| I | 3 | 19 | 0 | 1.4 | 9.09 | Jul-14 | Jul-12 | 4 | 21% |
| J | 2 | 13 | 0 | 1 | 8 | Aug-14 | Apr-14 | 2 | 15% |
| K | 2 | 13 | 0 | 0.5 | 6 | Multiple 2014 | Apr-14 | 1 | 8% |
| L | 2 | 12 | 0 | 1 | 3 | May-14 | Apr-14 | 0 | 0% |
| M | 1 | 7 | 0 | 1 | 3 | May-14 | Apr-14 | 0 | 0% |

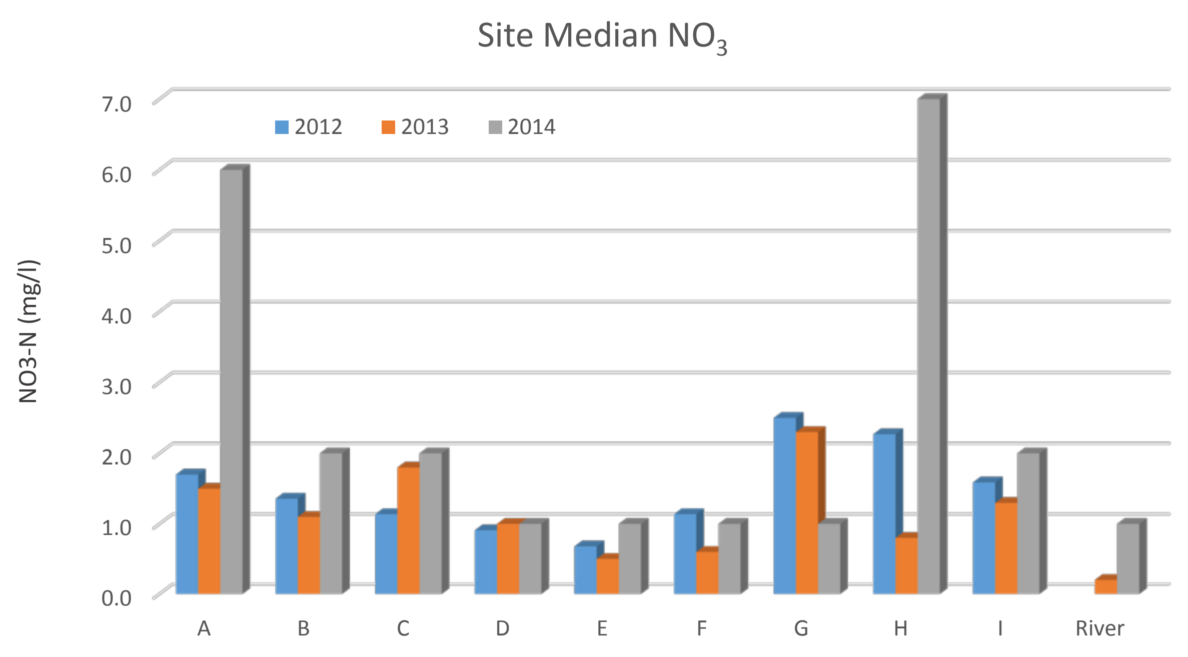

**Figure 28.** Median storm water nitrate ($NO_3$-N) concentrations at outfall sites (A-I) from 2012 to 2014 and the Oldman River site upstream of Lethbridge (L) from 2013-2014.

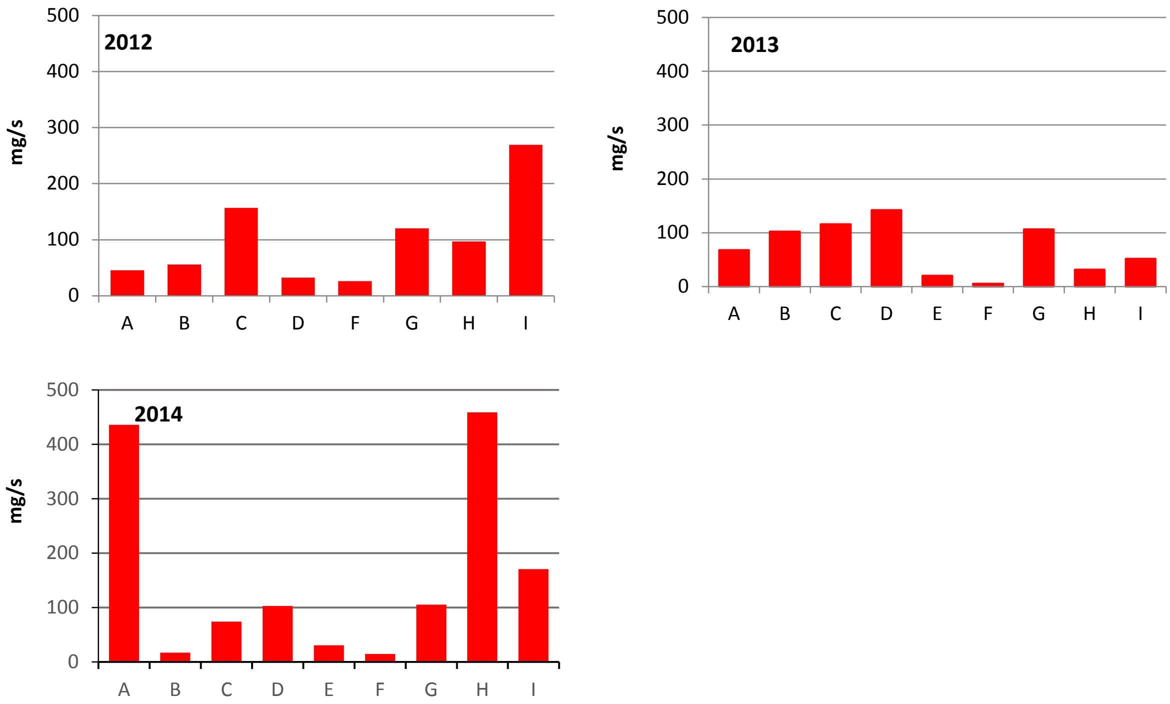

**Figure 29.** Mean instantaneous load of nitrate nitrogen ($NO_3$-N in mg/s) for storm water sites based on flows (excluding rainfall events) and nitrate levels recorded at time of sampling. Samples collected monthly from April to September 2012 to 2014.

**Total Nitrogen (TN).** Total Nitrogen (TN) constitutes ammonia, nitrite, nitrate and organic nitrogen (Clesceri et al. 1998), of which nitrate typically constitutes 67% to 80% of the total available nitrogen in river waters (Crouzet et al. 1999). The chronic guideline of 1.0 mg/L that was in place for TN has now been withdrawn and replaced with narrative statements, which for major rivers, Total Nitrogen and Phosphorus concentrations should be maintained so as to prevent detrimental changes to algal and aquatic plant communities, aquatic biodiversity, oxygen levels, and recreational quality (EQGASW 2014). Different waterways and waterbodies have natural variation and background nutrient levels so a single numeric guideline is not desirable. Numeric guidelines have not been abandoned for these nutrients, but work is presently ongoing to establish realistic and beneficial ones for Alberta's major rivers.

Despite not having a site specific guideline to compare to yet, TN median levels between tested sites were still of value. For storm water sites, Site A (Westminster/Winston Churchill) had the greatest maximum TN recorded (25 mg/L), plus the greatest maximum in 2 of the 3 years of sampling (25 mg/L in

2012 and 20 mg/L in 2014) (Table 7). Where in 2012 Site A had a median TN concentration of 15 mg/l, significantly higher than the next highest site (Site I and C: Heritage/Ridgewood and London road/Victoria Park) at 8.5 mg/l, consistent and dramatic improvements (decreases) in median TN were seen at this site, decreasing to 11 mg/L and then 6 mg/L respectively in 2013 and 2014. Over 3 years, site A and I had the greatest median TN (10.5 mg/L and 7 mg/L respectively), Site G (Legacy/Uplands) had the greatest variability in TN readings, and site E (Southgate) had the lowest median TN concentration (1 mg/L), which were median values that approached that of river samples (Table 8). Rainfall events appeared to decrease TN concentrations in storm water, but increase TN in river water. Cumulatively, storm water TN concentrations ranged from 0 mg/L to 25 mg/L, with a median concentration of 4.67 mg/L (Table 8). On average, the highest TN concentrations were recorded in 2012 and the lowest in 2013 (Figure 30). Comparing the mean instantaneous load of TN in storm water, site I was consistently one of the highest sites each year, but especially in 2014 where this site contributed more than 5x the TN than the next highest site (A) (Figure 31). River water did have some samples with TN as high as 3 mg/L, but as a whole river water had much lower median TN than the water from all but 2 or 3 storm drains. Six mile coulee water (Site J) had the highest TN (4 mg/L) of all non-storm water sites (Table 7).

In comparing the results to that of Saffran (2005), the present study still saw similar low median TN levels in the Oldman River at Popson Park (Site L), but median TN at Hwy 3 (Site M) increased (0.3 mg/L to 1 mg/l). For the Six Mile Coulee (Site J), the maximum TN of 4 mg/l in 2012-2104 was similar to that found by Saffran (2005) where TN concentrations ranged from 0.2 mg/L to 3.9 mg/L for this site. In storm drain discharge there was an overall reduction in TN from the previous monitoring study (Saffran 2005) with 4 of the previous 8 sites having reduced median TN values, 1 site showing no change between the two studies, and 2 sites with only marginal increases in median TN, and finally the maximum TN concentration measured (25 mg/L) was 50% of what was previously recorded (52.9 mg/L). With regards to rainfall, Saffran (2005) found the same trends as with the present study, that the highest TN levels in river and tributary samples occurred during rainfall events and the highest concentrations in storm drains occurred during dry periods. When nitrate makes up the majority of this TN rather than other sources, it indicates that the source is inorganic fertilizer and/or fecal matter (Saffran 2005), but this was not the case with most storm drain discharges other than with site B (Downtown). This contrasted to Saffran (2005) where the majority of storm drains had nitrate making up the majority of TN.

**Table 7.** Summary of Total Nitrogen (mg/l) for Lethbridge storm drains (A – I) and stream/river sites (J -M), for 2012 to 2014. Rainfall event dates highlighted in yellow. No river sites were sampled in 2012.

| (2012) | Total Nitrogen (mg/L) | | | | | | Min. | Median | Max. | Date of Min. | Date of Max. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Site | 17-Apr | 15-May | 12-Jun | 17-Jul | 14-Aug | 11-Sep | | | | | |
| A | 10 | 25 | 19 | 15 | 15 | 5 | 5 | 15 | 25 | 11-Sep | 15-May |
| B | 1 | 1 | 11 | 4 | 1 | 6 | 1 | 2.5 | 11 | 17-Apr | 12-Jun |
| C | 11 | 11 | 19 | 6 | 2 | 1 | 1 | 8.5 | 19 | 11-Sep | 12-Jun |
| D | 8 | 10 | 19 | 5 | 6 | 3 | 3 | 7 | 19 | 11-Sep | 12-Jun |
| E | - | 1 | 4 | 2 | 1 | 3 | 1 | 2 | 4 | 15-May | 12-Jun |
| F | 12 | 3 | 16 | 9 | 2 | 7 | 2 | 8 | 16 | 14-Aug | 12-Jun |
| G | 25 | 25 | 4 | 7 | 3 | 7 | 3 | 7 | 25 | 14-Aug | 17-Apr |
| H | 7 | 1 | 4 | 8 | 6 | 9 | 1 | 6.5 | 9 | 15-May | 11-Sep |
| I | 19 | 4 | 13 | 10 | 7 | 3 | 3 | 8.5 | 19 | 11-Sep | 17-Apr |
| **Mean** | **11.6** | **9** | **12.1** | **7.3** | **4.8** | **4.9** | | | | | |

| (2013) | Total Nitrogen (mg/L) | | | | | | Min. | Median | Max. | Date of Min. | Date of Max. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Site | 14-May | 12-Jun | 20-Jun | 16-Jul | 13-Aug | 17-Sep | | | | | |
| A | - | 0 | 2 | 13 | 11 | 12 | 0 | 11 | 13 | 12-Jun | 16-Jul |
| B | - | 6 | 6 | 1 | 1 | 0 | 0 | 1 | 6 | 17-Sep | Jun, Jun |
| C | - | 15 | 1 | 2 | 2 | 1 | 1 | 2 | 15 | Jun, Sep | 12-Jun |
| D | - | 4 | 3 | 5 | 1 | 4 | 1 | 4 | 5 | 13-Aug | 16-Jul |
| E | - | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | multiple | 20-Jun |
| F | - | 2 | 1 | 4 | 4 | 4 | 1 | 4 | 4 | 20-Jun | multiple |
| G | 24 | 3 | 1 | 2 | 5 | 23 | 1 | 4 | 24 | 20-Jun | 14-May |
| H | 4 | 2 | 2 | 2 | 1 | 0 | 0 | 2 | 4 | 17-Sep | 14-May |
| I | - | 5 | 4 | 8 | 7 | 5 | 4 | 5 | 8 | 20-Jun | 16-Jul |
| Mean | 14 | 4.1 | 2.3 | 4.1 | 3.6 | 5.4 | | | | | Mean |
| J | - | 1 | 2 | 0 | 1 | 0 | 0 | 1 | 2 | Jul, Sep | 20-Jun |
| K | - | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | multiple | Jun, Sep |
| L | - | 0 | - | 0 | 0 | 0 | 0 | 0 | 0 | multiple | multiple |

| (2014) | Total Nitrogen (mg/L) | | | | | | Min. | Median | Max. | Date of Min. | Date of Max. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Site | 15-Apr | 13-May | 28-May | 17-Jun | 15-Jul | 12-Aug | 16-Sep | | | | | |
| A | 4 | 10 | 6 | 3 | 20 | 18 | 5 | 3 | 6 | 20 | June | July |
| B | 3 | 1 | 3 | 1 | 1 | 5 | 3 | 1 | 3 | 5 | multiple | August |
| C | 4 | 5 | 4 | 3 | 5 | 8 | 7 | 3 | 5 | 8 | June | August |
| D | 8 | 4 | 1 | 0 | 7 | 8 | 5 | 0 | 5 | 8 | June | August |
| E | 1 | 1 | 1 | 3 | 2 | 0 | 1 | 0 | 1 | 3 | August | June |
| F | 4 | 7 | 0 | 16 | 7 | 9 | 1 | 0 | 7 | 16 | 28-May | June |
| G | 2 | 14 | 6 | 1 | 10 | 7 | 2 | 1 | 6 | 14 | June | 13-May |
| H | 1 | 2 | 0 | 0 | 16 | 10 | 2 | 0 | 2 | 16 | May/June | July |
| I | 7 | 6 | 3 | 2 | 14 | 8 | 7 | 2 | 7 | 14 | June | July |
| **Mean** | **3.8** | **5.6** | **2.7** | **3.2** | **9.1** | **8.1** | **3.7** | | | | | |
| J | 2 | 2 | 3 | 3 | 4 | 1 | 1 | 1 | 2 | 4 | Aug./Sept. | July |
| K | 0 | 0 | 0 | 0 | 3 | 0 | 2 | 0 | 0 | 3 | multiple | July |
| L | 0 | 0 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 3 | multiple | 28-May |
| M | 0 | 0 | 2 | 2 | 1 | 1 | 0 | 0 | 1 | 2 | multiple | May/June |

**Table 8.** Summary of Total Nitrogen (TN) in (mg/l) for Lethbridge storm drains (A-I) and stream/river sites (J -M), for April to September 2012 to 2014. No river sites were sampled in 2012.

| Site | Years Sampled | # of Samples | Min | Median | Max | Date of Min | Date of Max |
|---|---|---|---|---|---|---|---|
| **A** | 3 | 18 | 0 | 10.5 | 25 | Jun-13 | May-12 |
| **B** | 3 | 18 | 0 | 2 | 11 | Sep-13 | Jun-12 |
| **C** | 3 | 18 | 1 | 4.5 | 19 | Sep 2012/2013 | Jun-12 |
| **D** | 3 | 18 | 0 | 5 | 19 | Jun-14 | Jun-12 |
| **E** | 3 | 16 | 0 | 1 | 4 | multiple 2013/2014 | Jun-12 |
| **F** | 3 | 18 | 0 | 4 | 16 | May-14 | June 2012/2014 |
| **G** | 3 | 19 | 1 | 6 | 25 | June 2013/2014 | Apr-12 |
| **H** | 3 | 19 | 0 | 2 | 16 | multiple 2013/2014 | Jul-14 |
| **I** | 3 | 18 | 2 | 7 | 19 | Jun-14 | Apr-12 |
| **J** | 2 | 12 | 0 | 1.5 | 4 | Jul-13 | Jul-14 |
| **K** | 2 | 12 | 0 | 0 | 3 | multiple 2013/2014 | Jul-14 |
| **L** | 2 | 11 | 0 | 0 | 3 | multiple 2013/2014 | May-14 |
| **M** | 1 | 7 | 0 | 1 | 2 | multiple 2014 | May-14 |

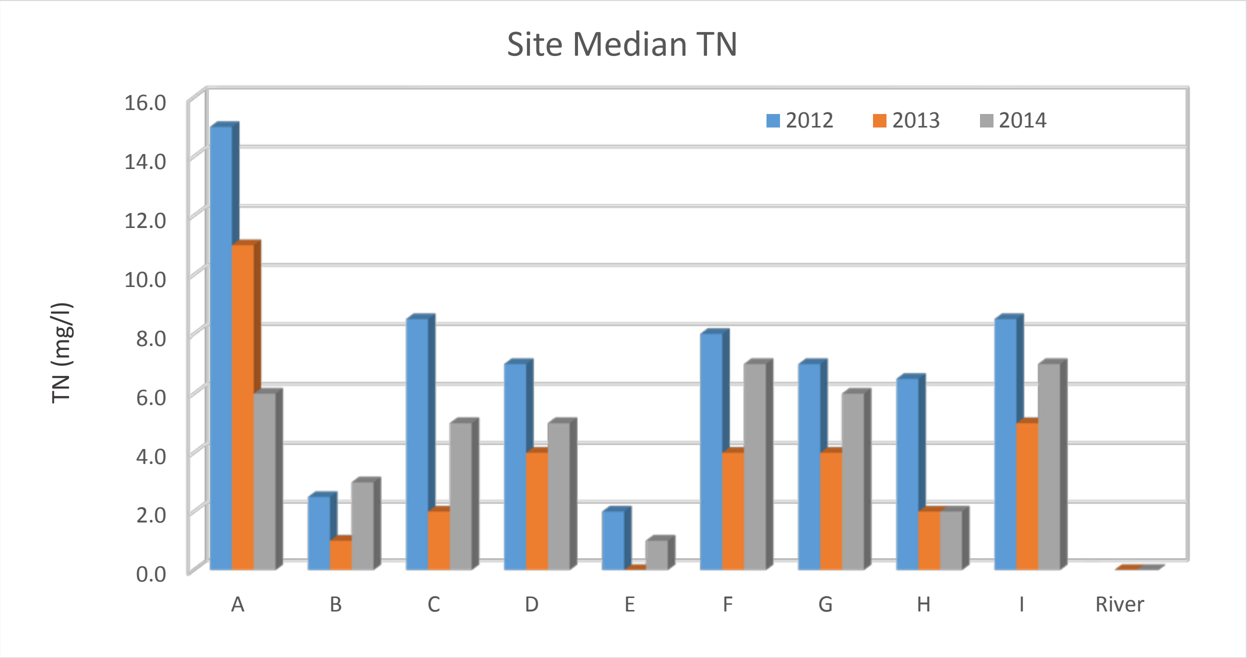

**Figure 30.** Median storm water Total Nitrogen (TN) concentrations at outfall sites (A-I) from 2012 to 2014 and the Oldman River site upstream of Lethbridge (L) from 2013-2014.

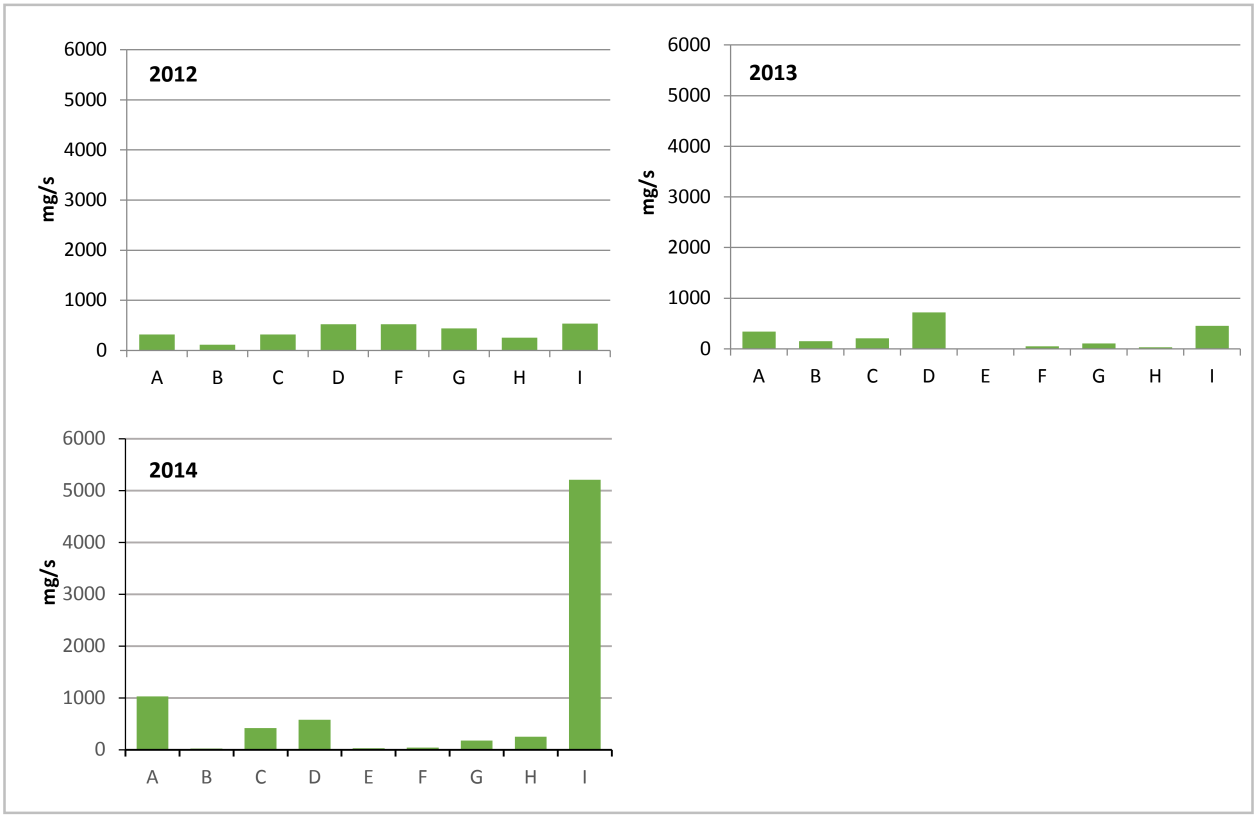

**Figure 31.** Mean instantaneous load of Total Nitrogen (mg/s) for storm water sites based on flows (excluding rainfall events) and Total Nitrogen levels recorded at time of sampling. Samples collected monthly from April to September 2012 to 2014.

**Dissolved Phosphorus (DP).** Phosphorus plays a major role in biological metabolism, and when compared to other macronutrients, phosphorus is the least abundant, and often the first nutrient to limit biological productivity (Wetzel 2001). Therefore, the first response of an aquatic system to the addition of phosphorus is increased plant, algal and microbial productivity and biomass (CEQG 2004). Phosphorus in aquatic systems occurs in three forms: inorganic phosphorus, particulate organic phosphorus, and dissolved (soluble) organic phosphorus. Inorganic phosphate (orthophosphate PO43-), or reactive phosphorus, is the only form of inorganic phosphorus that can be directly used by aquatic plants and bacteria, which is transferred to consumers and decomposers as organic phosphate. The majority of phosphorus in fresh water (up to 95%) occurs as organic phosphates, cellular constituents of organisms, and within or adsorbed to inorganic and dead particulate organic matter (Wetzel 2001). Dissolved Phosphorus (DP) is that component of phosphorus not adsorbed to suspended matter, or in particulate form, and thus directly available to plants and algae in aquatic systems. To measure only the fraction of phosphorus that is in solution (Dissolved Phosphorus) the sample must first be filtered before analysis.

Like for Total Nitrogen, since phosphorus is not directly toxic to aquatic systems and different aquatic systems have natural variability in nutrient levels, no phosphorus guideline values (dissolved or total) are applicable for all waters, so rather a trigger range must be established for each water body. Specific trigger concentrations have not yet been established for the Oldman River.

For the current study Dissolved Phosphorus was only measured in 2013 and 2014. Results from this monitoring revealed that storm water discharge from Site H (Varsity) had by far (2-3x) the greatest median DP concentrations (1.13 mg/L in 2013 & 1.33 mg/L in 2014) and maximum DP concentrations (2.49 mg/L in 2013 & 3.12 mg/L in 2014) of any site sampled (Table 9-10). Even though Site H had a median DP concentration that was 6x greater than that of Site I (Heritage/Ridgewood), Site I had an increased discharge in 2014 and so had a mean instantaneous load of DP to the Oldman River similar to Site H (Figure 33). Sites E (Southgate), F (Tudor/Fairmont), G (Legacy/Uplands), and Site B (Downtown) in 2013, all had median DP concentrations that were slightly higher, but paralleled that measured in the Oldman River (Figure 32). The average median DP concentration from all storm drain discharge was approximately 3 times greater than that of river water (Sites K, L, M) (0.32 mg/L as compared to 0.10 mg/L). The concentration of DP in river water tended to be higher in later summer (July – September) then earlier (April – June) with rainfall appearing to have a variable effect, causing reduced DP concentrations in 2014, but not in 2013.

In comparison to the Saffran (2005), higher concentrations of DP were often, but not always, associated with wetter conditions in storm water discharge. For storm water discharges, although Saffran also found storm drain water from Site H to have the highest median and maximum concentrations from all sites tested, the DP concentrations were less than that found in the present study (median: 0.268 mg/L vs. 1.12 mg/L, max: 2.12 mg/L vs. 3.12 mg/L). The storm sites that had the lowest DP medians in the present study (B, E, F and G) were also the sites with the lowest DP medians from the Saffron study, however like that of DP levels from Site H, the current DP concentrations for these sites were also elevated (approximately 2 – 3 x) from previous levels (Site B: 0.067 vs. 0.20 mg/L, Site E: 0.051 vs. 0.13 mg/L, Site F: 0.68 vs. 0.16 mg/L, Site G: 0.28 vs. 0.11 mg/L). The concentration of DP in river water Site M (Hwy 3) and Site L (Popson Park) also increased, with a median DP of 0.09 mg/L for both sites in the present study vs. a median of 0.03 mg/L for both sites recorded from a decade ago.

**Table 9.** Summary of Dissolved Phosphorus (mg/l) for Lethbridge storm drains (A – I) and stream/river sites (J -M), for 2013 to 2014. Rainfall event dates highlighted in yellow. No Dissolved Phosphorus was measured in 2012.

| (2013) | Dissolved Phosphorus (mg/L) | | | | | Min. | Median | Max. | Date of Min. | Date of Max. |
|---|---|---|---|---|---|---|---|---|---|---|
| Site | 12-Jun | 20-Jun | 16-Jul | 13-Aug | 17-Sep | | | | | |
| A | 0.17 | 1.03 | 0.49 | 0.39 | 0.46 | 0.17 | 0.46 | 1.03 | 12-Jun | 20-Jun |
| B | 0.79 | 0.26 | 0.14 | 0.16 | 0.16 | 0.14 | 0.16 | 0.79 | 16-Jul | 12-Jun |
| C | 0.31 | 0.35 | 0.13 | 0.20 | 0.19 | 0.13 | 0.20 | 0.35 | 16-Jul | 20-Jun |
| D | 0.29 | 0.85 | 0.32 | 0.60 | 0.27 | 0.32 | 0.32 | 0.85 | 16-Jul | 20-Jun |
| E | 0.25 | 0.06 | 0.17 | 0.13 | 0.27 | 0.06 | 0.17 | 0.27 | 20-Jun | 17-Sep |
| F | 0.42 | 0.19 | 0.33 | 0.18 | 0.16 | 0.16 | 0.19 | 0.42 | 17-Sep | 12-Jun |
| G | 0.14 | 0.13 | 0.25 | 0.08 | 0.10 | 0.08 | 0.13 | 0.25 | 13-Aug | 16-Jul |
| H | 0.31 | 0.36 | 2.00 | 1.13 | 2.49 | 0.31 | 1.13 | 2.49 | 12-Jun | 17-Sep |
| I | 0.17 | 0.42 | 0.23 | 0.20 | 0.21 | 0.17 | 0.21 | 0.42 | 12-Jun | 20-Jun |
| Mean | **0.32** | **0.41** | **0.45** | **0.34** | **0.48** | | | | | |
| J | 0.12 | 0.52 | 0.20 | 0.12 | 0.19 | 0.12 | 0.19 | 0.52 | 12-Jun, Aug | 20-Jun |
| K | 0.21 | 0.18 | 0.16 | 0.12 | 0.09 | 0.09 | 0.16 | 0.21 | 17-Sep | 12-Jun |
| L | 0.11 | N/A | 0.10 | 0.08 | 0.13 | 0.08 | 0.11 | 0.13 | 13-Aug | 17-Sep |

| (2014) | Dissolved Phosphorus (mg/L) | | | | | | | Min. | Median | Max. | Date of Min. | Date of Max. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site | 15-Apr | 13-May | 28-May | 17-Jun | 15-Jul | 12-Aug | 16-Sep | | | | | |
| A | 0.23 | 0.17 | 0.59 | 0.63 | 0.23 | 0.44 | 0.13 | 0.13 | 0.23 | 0.63 | Sept. | June |
| B | 0.22 | 0.18 | 0.29 | 0.16 | 0.09 | 0.39 | 1.16 | 0.09 | 0.22 | 1.16 | July | Sept. |
| C | 0.77 | 0.31 | 0.55 | 0.21 | 0.22 | 0.21 | 0.55 | 0.21 | 0.31 | 0.77 | August | April |
| D | 0.25 | 0.19 | 0.28 | 0.21 | 0.54 | 0.48 | 0.20 | 0.19 | 0.25 | 0.54 | 13-May | July |
| E | 0.13 | 0.09 | 0.10 | 0.17 | 0.23 | 0.07 | 0.09 | 0.07 | 0.10 | 0.23 | August | July |
| F | 0.10 | 0.11 | 0.15 | 0.31 | 0.14 | 0.09 | 0.08 | 0.08 | 0.11 | 0.31 | Sept. | June |
| G | 0.11 | 0.10 | 0.17 | 0.14 | 0.10 | 0.07 | 0.11 | 0.07 | 0.11 | 0.17 | August | 28-May |
| H | 1.11 | 1.78 | 0.16 | 0.40 | 3.12 | 2.02 | 0.88 | 0.16 | 1.11 | 3.12 | 28-May | July |
| I | 0.15 | 0.15 | 0.21 | 0.62 | 0.20 | 0.17 | 0.18 | 0.15 | 0.18 | 0.62 | 13-May | June |
| Mean | **0.34** | **0.34** | **0.28** | **0.32** | **0.54** | **0.44** | **0.38** | | | | | |
| J | 0.13 | 0.09 | 0.11 | 0.16 | 0.43 | 2.82 | 0.04 | 0.04 | 0.13 | 2.82 | Sept. | August |
| K | 0.10 | 0.09 | 0.09 | 0.19 | 0.08 | 0.17 | 0.09 | 0.08 | 0.09 | 0.19 | July | June |
| L | 0.11 | 0.09 | 0.08 | 0.11 | 0.06 | 0.04 | 0.08 | 0.04 | 0.08 | 0.11 | August | Apr./June |
| M | 0.09 | 0.09 | 0.09 | 0.09 | 0.07 | 0.04 | 0.06 | 0.04 | 0.09 | 0.09 | August | multiple |

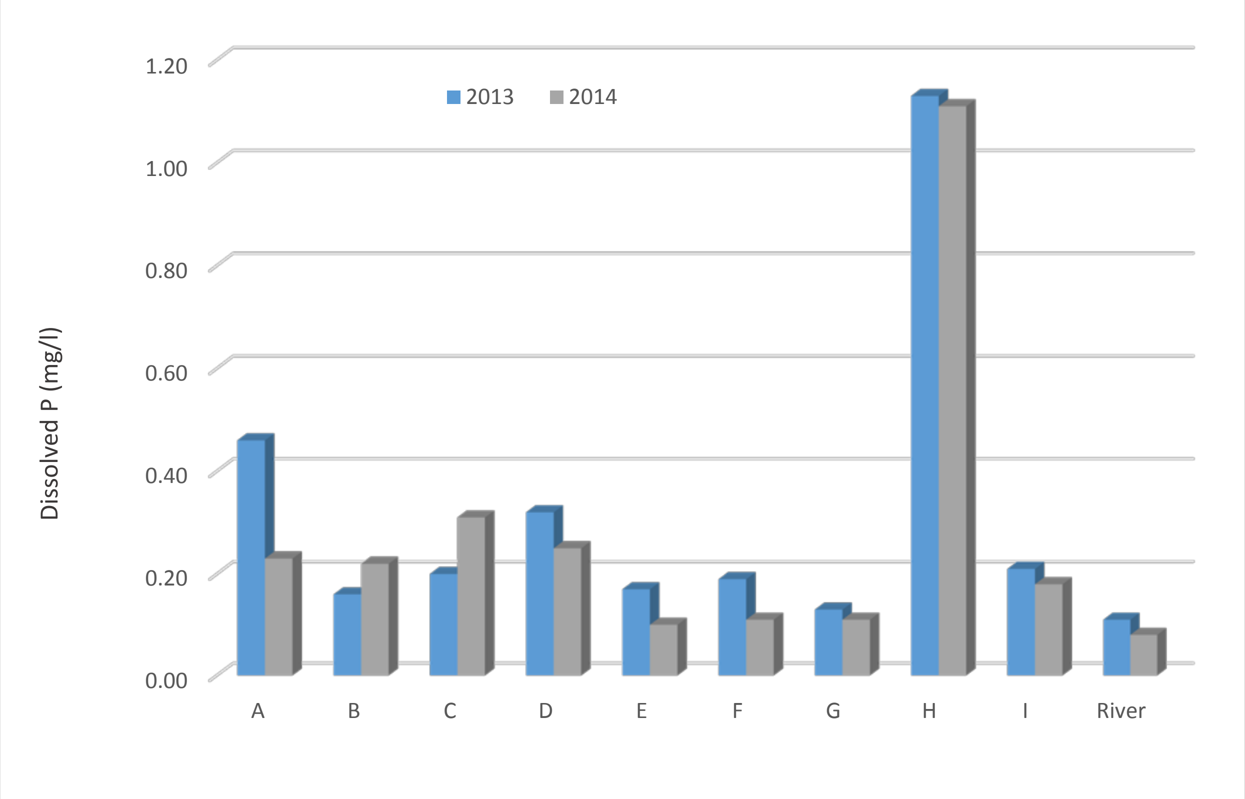

**Figure 32.** Median storm water Dissolved Phosphorus concentrations at outfall sites (A-I) for 2013 to 2014 and the Oldman River site upstream of Lethbridge (Site L) from 2013-2014.

**Table 10.** Summary of Dissolved Phosphorus (DP) in (mg/L) for Lethbridge storm drains (A-I) and stream/river sites (J -M), for April to September 2013 to 2014. No Dissolved Phosphorus was measured in 2012.

| Site | Years Sampled | # of Samples | Min | Median | Max | Date of Min | Date of Max |
|---|---|---|---|---|---|---|---|
| **A** | 2 | 12 | 0.13 | 0.42 | 1.03 | Sep-14 | Jun-13 |
| **B** | 2 | 12 | 0.09 | 0.20 | 1.16 | Jul-14 | Sep-14 |
| **C** | 2 | 12 | 0.13 | 0.27 | 0.77 | Jul-13 | Apr-14 |
| **D** | 2 | 12 | 0.19 | 0.29 | 0.85 | May-14 | Jun-13 |
| **E** | 2 | 12 | 0.06 | 0.13 | 0.27 | Jun-13 | Sep-13 |
| **F** | 2 | 12 | 0.08 | 0.16 | 0.42 | Sep-14 | Jun-13 |
| **G** | 2 | 12 | 0.07 | 0.11 | 0.25 | Aug-14 | Jul-13 |
| **H** | 2 | 12 | 0.16 | 1.12 | 3.12 | May-14 | Jul-14 |
| **I** | 2 | 12 | 0.15 | 0.20 | 0.62 | May-14 | Jun-14 |
| **J** | 2 | 12 | 0.04 | 0.15 | 2.82 | Sep-14 | Aug-14 |
| **K** | 2 | 12 | 0.08 | 0.11 | 0.21 | Jul-14 | May-13 |
| **L** | 2 | 11 | 0.04 | 0.09 | 0.13 | Aug-14 | May-13 |
| **M** | 1 | 7 | 0.04 | 0.09 | 0.09 | Aug-14 | Multiple 2014 |

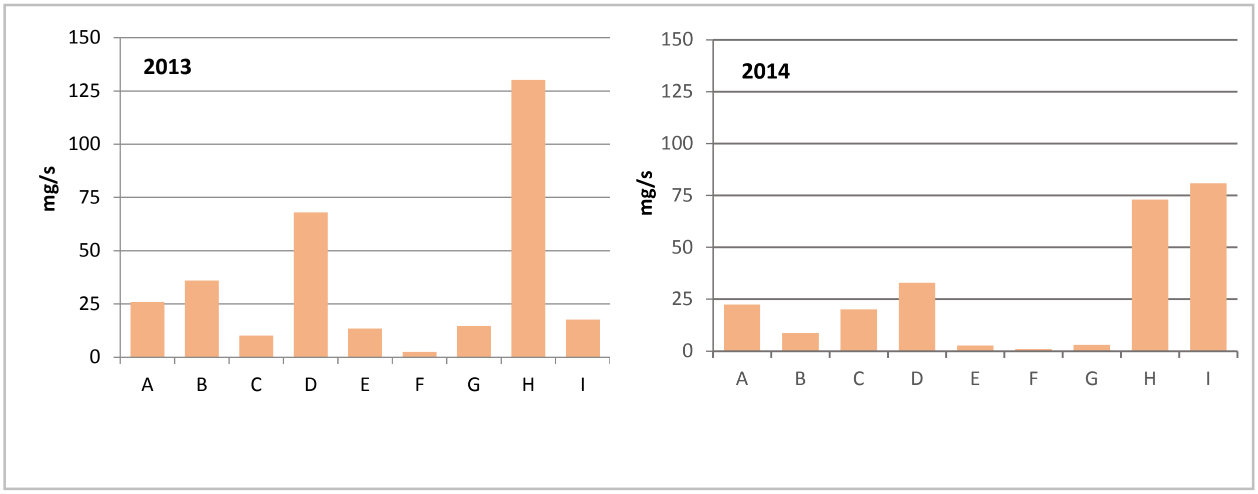

**Figure 33.** Mean instantaneous load of Dissolved Phosphorus (mg/s) for storm water sites based on flows (excluding rainfall events) and Dissolved Phosphorus concentrations recorded at time of sampling. Samples collected monthly from April to September 2013 to 2014. No Dissolved Phosphorus was measured in 2012.

**Total Phosphorus (TP).** Phosphorus usually exists as part of a phosphate molecule ($PO_4$) and in aquatic systems occurs as organic phosphate and inorganic phosphate. Organic phosphate consists of a phosphate molecule associated with a carbon-based molecule, as in plant or animal tissue. Inorganic phosphate, not associated with organic material, is the form required by plants. Animals can use either organic or inorganic phosphate (http://water.epa.gov/type/rsl/monitoring/vms56.cfm). The turnover rate of orthophosphate ($PO_4^{3-}$) in phosphorus limited systems is extremely rapid, making its accurate measurement difficult. As a result, measuring TP is generally recommended as a meaningful measurement of phosphorus in water (Wetzel 2001). In water, both organic and inorganic phosphorus can be dissolved or suspended (attached to particles in the water column). Total Phosphorus (TP) measures all the forms of phosphorus in the sample (orthophosphate, condensed phosphate, and organic phosphate) (http://water.epa.gov/type/rsl/monitoring/vms56.cfm).

TP concentrations in non-polluted natural waters extend over a wide range from <0.001 mg/L in ultra, nutrient poor waters to >0.2 mg/L in highly productive waters; however, most uncontaminated freshwaters contain between 0.01 and 0.05 mg/L of TP (Wetzel 2001). This upper value is usually considered the chronic water quality guideline for the protection of freshwater aquatic life in Alberta (AENV 1999). However, because of the variability of this nutrient in different aquatic systems recent government wide applicable guidelines have been removed and site specific normal ranges are presently being established (EQGASW 2014).

Monitoring for TP found that Site H (Varsity) had the greatest median TP of all storm water sites for all three years, usually being 2-4x greater than the next highest site (Table 11, Figure 34). Site A however recorded the highest maximum TP from 2012-2014 with a concentration of 5.1 mg/L in 2014. Storm water showing the lowest median concentrations came from Sites E (Southgate), F (Tudor/Fairmont), G (Legacy/Uplands), I (Heritage/Ridgewood) and B (Downtown), which were lower or comparable to the TP concentrations measured in river water (Sites K ,L, M) (Table 11, Figure 34). At times river water samples had median TP concentrations greater than storm water samples, with river site L (upriver) having the 2nd highest median TP (1.05 mg/L) in 2013 of all sampled sites (Figure 34). Although the majority of higher TP recordings came from samples taken in May and June, this was not consistent for individual sites, between sites or between years and where the rainfall event in 2013 led to an increase in mean storm water TP, in 2014 it did not (Table 11, Table 12). For mean instantaneous load, site A contributed 5x greater TP to the Oldman River then the next highest storm water site (Figure 35).

From Saffran (2005), storm water samples were often higher in TP when conditions were wetter, which held true in the present study, but only for 2013, the 2014 samples had greater TP concentrations during dry periods. When comparing median TP concentrations for storm drains, all but 3 sites showed an increase in the present study as compared to Saffran (2005). Sites A (Westminster/Winston Churchill) and I (Heritage/Ridgewood) had comparable TP between the two studies, Site D (Park Royal/Lakeview) had reduced TP in the present study, but all the remaining storm water sites showed increased median levels in TP, sometimes by as high as 5x (site H: 0.324 mg/L vs. 1.64 mg/L) to 7 x greater (site G: 0.039 mg/L vs. 0.29 mg/L). The same trend held true for TP concentrations in the Oldman River at Lethbridge. Median TP increased from 0.008 mg/L at Hwy 3 and from 0.12 mg/L at Popson Park in the Saffran study, to 0.3 mg/L (Site M) and 0.24 mg/L respectively, in the current study.

**Table 11.** Summary of Total Phosphorus (mg/l) for Lethbridge storm drains (A – I) and stream/river sites (J -M), for 2012 to 2014. Rainfall event dates highlighted in yellow.

| (2012) | Total Phosphorus LR (mg/L) | | | | | Min. | Median | Max. | Date of | Date of |
|---|---|---|---|---|---|---|---|---|---|---|
| **Site** | **15-May** | **12-Jun** | **17-Jul** | **14-Aug** | **11-Sep** | | | | **Min.** | **Max.** |
| **A** | 0.04 | 0.19 | 0.7 | 0.9 | 0.24 | 0.04 | 0.24 | 0.9 | 15-May | 14-Aug |
| **B** | 0.25 | 0.14 | 0.4 | 0.09 | 3.18 | 0.09 | 0.25 | 3.18 | 14-Aug | 11-Sep |
| **C** | 0.36 | 0.23 | 0.59 | 1.01 | 0.25 | 0.23 | 0.36 | 1.01 | 12-Jun | 14-Aug |
| **D** | - | 0.29 | 0.26 | 0.22 | 0.24 | 0.22 | 0.25 | 0.29 | 14-Aug | 12-Jun |
| **E** | 0.08 | 0.1 | 0.12 | 0.23 | 1.83 | 0.08 | 0.12 | 1.83 | 15-May | 11-Sep |
| **F** | 0.05 | 0.17 | 0.13 | 0.15 | 0.1 | 0.05 | 0.13 | 0.17 | 15-May | 12-Jun |
| **G** | 0.36 | 0.17 | 0.23 | 0.41 | 0.24 | 0.17 | 0.24 | 0.41 | 12-Jun | 14-Aug |
| **H** | - | 1.07 | 1.77 | 2.9 | 0.16 | 0.16 | 1.42 | 2.9 | 11-Sep | 14-Aug |
| **I** | 0.01 | 0.16 | 0.22 | 0.32 | 0.76 | 0.01 | 0.22 | 0.76 | 15-May | 11-Sep |
| **Mean** | **0.16** | **0.28** | **0.49** | **0.69** | **0.78** | | | | | |

| (2013) | Total Phosphorus (mg/L) | | | | | | Min. | Median | Max. | Date of Min. | Date of Max. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Site** | **14-May** | **12-Jun** | **20-Jun** | **16-Jul** | **13-Aug** | **17-Sep** | | | | | |
| **A** | 0.38 | 1.26 | 2.22 | 0.65 | 0.62 | 0.6 | 0.38 | 0.64 | 2.22 | 14-May | 20-Jun |
| **B** | 0.11 | - | 0.67 | 0.12 | 0.17 | 0.21 | 0.11 | 0.17 | 0.67 | 14-May | 20-Jun |
| **C** | 0.55 | - | 1.2 | 0.47 | 0.35 | 0.46 | 0.35 | 0.47 | 1.2 | 13-Aug | 20-Jun |
| **D** | 0.11 | - | 1.78 | 0.38 | 0.93 | 0.32 | 0.11 | 0.38 | 1.78 | 14-May | 20-Jun |
| **E** | - | - | 0.39 | 0.28 | 0.16 | 0.33 | 0.16 | 0.31 | 0.39 | 13-Aug | 20-Jun |
| **F** | 0.1 | - | 0.43 | 0.41 | 0.17 | 0.16 | 0.1 | 0.17 | 0.43 | 14-May | 20-Jun |
| **G** | 0.19 | 0.73 | 0.39 | 0.34 | 0.48 | 0.12 | 0.12 | 0.37 | 0.73 | 17-Sep | 12-Jun |
| **H** | 2.13 | - | 0.59 | 2.35 | 1.37 | 3.49 | 0.59 | 2.13 | 3.49 | 20-Jun | 17-Sep |
| **I** | 0.13 | 0.3 | 0.95 | 0.29 | 0.2 | 0.25 | 0.13 | 0.27 | 0.95 | 14-May | 20-Jun |
| **Mean** | **0.46** | **0.76** | **0.96** | **0.59** | **0.49** | **0.66** | | | | | |
| **J** | 1.69 | - | 3.5 | 0.74 | 0.4 | 0.44 | 0.4 | 0.74 | 3.5 | 13-Aug | 20-Jun |
| **K** | 0.79 | - | 0.95 | 0.26 | 0.22 | 0.15 | 0.15 | 0.26 | 0.95 | 17-Sep | 20-Jun |
| **L** | 1.91 | - | - | 0.19 | 0.14 | 2.96 | 0.14 | 1.05 | 2.96 | 13-Aug | 17-Sep |

| (2014) | Total Phosphorus (mg/L) | | | | | | | Min. | Median | Max. | Date of Min. | Date of Max. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Site** | **15-Apr** | **13-May** | **28-May** | **17-Jun** | **15-Jul** | **12-Aug** | **16-Sep** | | | | | |
| **A** | 0.25 | 0.20 | 1.98 | 1.91 | 0.33 | 0.90 | *5.10 | 0.20 | 0.90 | 5.10 | 13-May | Sept. |
| **B** | 0.33 | 0.20 | 0.50 | 0.48 | 0.10 | 0.53 | 1.20 | 0.10 | 0.48 | 1.20 | July | Sept. |
| **C** | 0.87 | 0.36 | 1.32 | 0.60 | 0.26 | 1.59 | 0.62 | 0.26 | 0.62 | 1.59 | July | Aug. |
| **D** | 0.26 | 0.20 | 0.88 | 0.36 | 0.67 | 0.58 | 0.22 | 0.20 | 0.36 | 0.88 | 13-May | 28-May |
| **E** | 0.16 | 0.15 | 0.16 | 0.44 | 0.34 | 0.20 | 0.12 | 0.12 | 0.16 | 0.44 | Sept. | June |
| **F** | 0.15 | 0.11 | 0.21 | 0.68 | 0.20 | 0.10 | 0.22 | 0.10 | 0.20 | 0.68 | August | June |
| **G** | 0.11 | 0.11 | 0.51 | 0.53 | 0.13 | 0.46 | 0.21 | 0.11 | 0.21 | 0.53 | 13-May | June |
| **H** | 1.51 | 2.10 | 0.40 | 0.55 | 3.80 | 3.27 | 1.03 | 0.40 | 1.51 | 3.80 | 28-May | July |
| **I** | 0.12 | 0.15 | 0.31 | 0.79 | 0.22 | 0.20 | 0.29 | 0.12 | 0.22 | 0.79 | April | June |
| **Mean** | **0.42** | **0.40** | **0.70** | **0.70** | **0.67** | **0.87** | **1.00** | | | | | |
| **J** | 0.51 | 0.16 | 0.27 | 2.02 | 0.79 | 3.46 | 0.23 | 0.16 | 0.51 | 3.46 | 13-May | Aug. |
| **K** | 0.27 | 0.37 | 0.72 | 0.59 | 0.12 | 0.22 | 0.15 | 0.12 | 0.27 | 0.72 | July | 28-May |
| **L** | 0.24 | 0.32 | 0.60 | 1.03 | 0.09 | 0.09 | 0.10 | 0.09 | 0.24 | 1.03 | July/Aug. | June |
| **M** | 0.31 | 0.30 | 0.67 | 1.02 | 0.11 | 0.08 | 0.10 | 0.08 | 0.30 | 1.02 | Aug. | June |

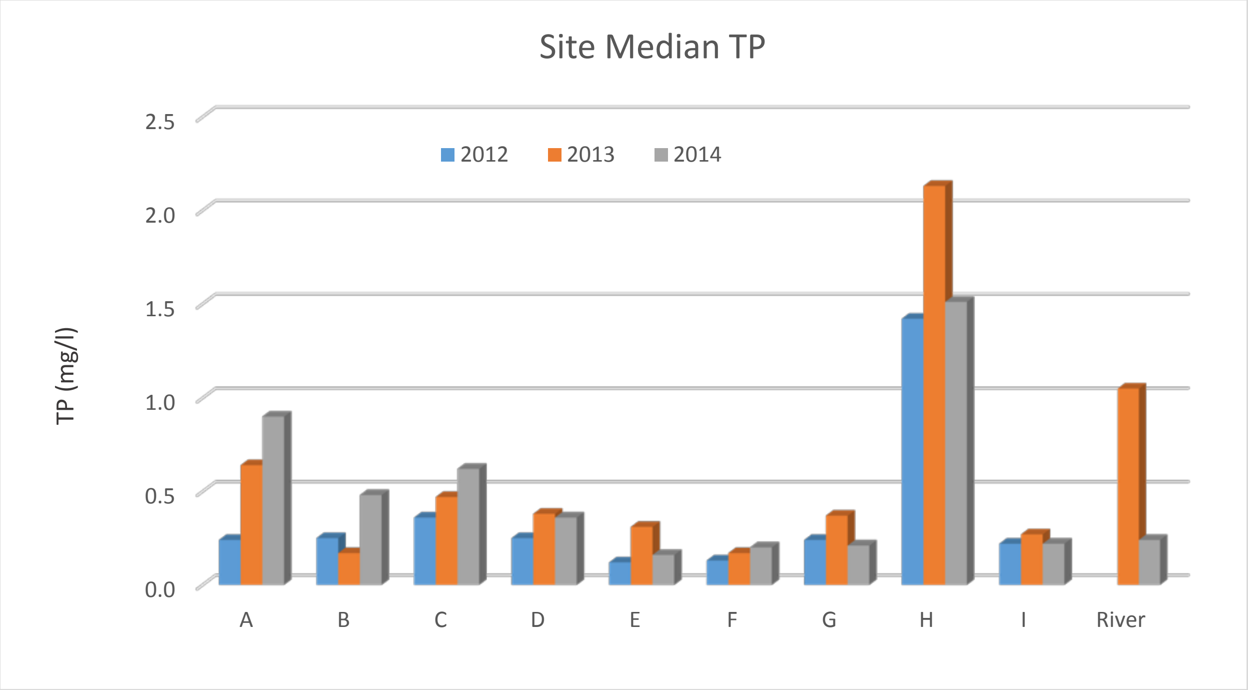

**Figure 34.** Median storm water Total Phosphorus concentrations at outfall sites (A-I) from 2012 to 2014 and the Oldman River site upstream of Lethbridge (L) from 2013-2014.

**Table 12.** Summary of Total Phosphorus (TP) in (mg/L) for Lethbridge storm drains (A-I) and stream/river sites (J -M), for April to September 2012 to 2014.

| Site | Years Sampled | # of Samples | Min | Median | Max | Date of Min | Date of Max |
|---|---|---|---|---|---|---|---|
| A | 3 | 18 | 0.04 | 0.635 | 5.1 | May-12 | Sep-14 |
| B | 3 | 17 | 0.09 | 0.25 | 3.18 | Aug-12 | Sep-12 |
| C | 3 | 17 | 0.23 | 0.55 | 1.59 | Jun-12 | Aug-14 |
| D | 3 | 16 | 0.11 | 0.305 | 1.78 | May-13 | Jun-13 |
| E | 3 | 16 | 0.08 | 0.18 | 1.83 | May-12 | Sep-12 |
| F | 3 | 17 | 0.05 | 0.16 | 0.68 | May-12 | Jun-14 |
| G | 3 | 18 | 0.11 | 0.29 | 0.73 | May-14 | Jun-13 |
| H | 3 | 16 | 0.16 | 1.64 | 3.8 | Sep-12 | Jul-14 |
| I | 3 | 18 | 0.01 | 0.235 | 0.95 | May-12 | Jun-13 |
| J | 2 | 12 | 0.4 | 0.625 | 3.5 | Aug-13 | Jun-13 |
| K | 2 | 12 | 0.12 | 0.25 | 0.95 | Jul-14 | Jun-13 |
| L | 2 | 11 | 0.09 | 0.24 | 2.96 | Jul-14 | Sep-13 |
| M | 1 | 7 | 0.08 | 0.3 | 1.02 | Aug-14 | Jun-14 |

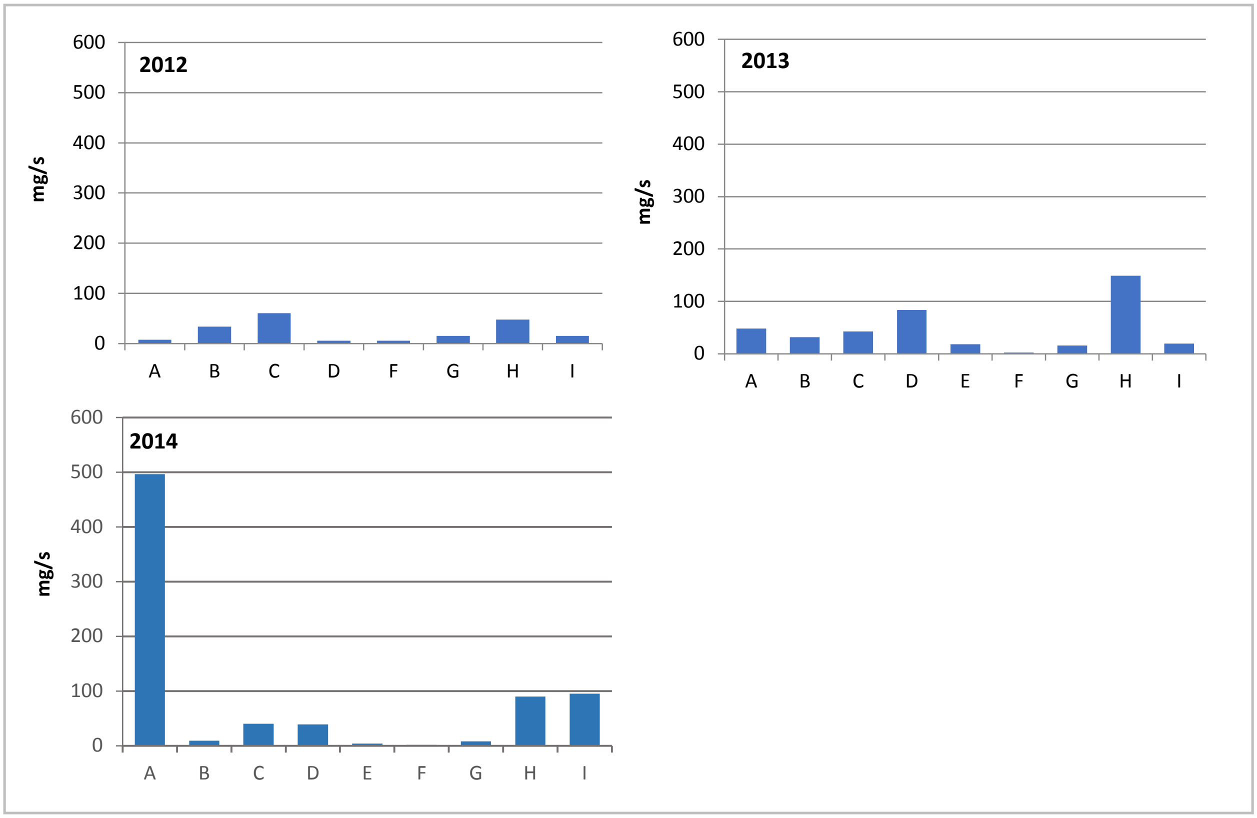

**Figure 35.** Mean instantaneous load of Total Phosphorus (mg/s) for storm water sites based on flows and Total Phosphorus levels recorded at time of sampling. Samples collected monthly from April to September 2012 to 2014.

# 4. Summary

## 4.1 MICROBIOLOGY

**Summary of Microbiology.** Thermophilic coliforms were detected at varying densities in storm water samples from all sites and years.

- Coliforms were observed at higher densities in 2014 than in 2012 and 2013.
- Escherichia coli was the primary thermophilic coliform detected.
- Coliform counts in storm water frequently exceeded Alberta Surface Water Quality Guidelines for irrigation and recreational water, and were as high, or higher than observed in 2000 to 2002.
- High densities of coliforms (≥ 4 log10 CFU/dl) were consistently observed over the three years at sites A (Westminster/Winston Churchill/Anderson, and Shackleford industrial Parks), C (London

Road/Victoria Park), H (Varsity Village), and I (Heritage Heights/Ridgewood Heights/Indian Battle Heights).

- Exceptionally high coliform densities (exceeding 6 log10 CFU/dl) were observed in storm water samples from sites C and H, catchments that contain the prominent reservoirs of Henderson and Nicholas Sheran Lakes.
- Water from Six Mile Coulee Creek consistently contained coliforms that exceeded the quality standard for recreational water, and densities were higher than observed in 2000 to 2002.
- A trend for lower coliform densities was observed in river water upstream of Lethbridge relative to downstream of Lethbridge.
- No correlations were observed between turbidity and coliform densities in storm water or river water over the three sampling years.

**Future Work.** Continuation of storm water monitoring with identification and monitoring of alternate fecal indicators and/or enteric pathogens (opposed to surrogates). Future studies would benefit from the inclusion of determination of the relative inputs of fecal bacteria to the Oldman River from storm water versus treated wastewater as well as the determination of the relative inputs of fecal bacteria to the Oldman River from storm water versus treated wastewater. The establishment and validation of model mitigation strategies (e.g. artificial wetlands) would be of benefit in studying microbiology for Storm Water in future studies.

## 4.2 PESTICIDES

**Summary of Pesticides.** This study was undertaken in part to determine whether Lethbridge storm water quality had changed since 2000-2002, when a similar study was conducted by Saffran et al. (2005). With regards to the storm water drains, both studies were conducted over three years and included roughly the same sites. However, the 2012-2014 study included a much larger number of pesticides (101-104 pesticides versus 39-62 compounds in 2000-2002) and a larger number of samples (215 versus 145) due to a higher frequency of sampling. 27 pesticides were detected in this study, compared to 20 compounds in 2000-2002, a result likely due to the larger pesticide suite analyzed. However, as in 2000-2002, the pesticides most frequently detected in 2012-2014 and at the highest concentrations were 2,4-D, mecoprop and dicamba. These compounds and others detected in both studies were at higher concentrations in storm drains compared to surface waters of the Oldman river and tributaries. Site A and I were the drainages with the highest detection frequencies in 2000-2002, compared to A and H in 2012-2014. The maximum pesticide concentrations detected in 2012-2014 and detection frequencies were lower compared to those obtained by Saffran et al. (2005), but in both studies results did not appear to be impacted directly by wet and dry weather. In addition, several pesticides detected in 2000-2002 were not detected in samples collected from 2012 to 2014, although they were all included in the analytical suite of 2012-2014. This could be a reflection of changes in pesticide use, as well as phasing out of pesticides de-registered for use in Canada including lindane and methoxychlor.

Overall, we can conclude that, from a pesticide perspective, water quality in Lethbridge storm water drainages has not changed significantly over the last 15 years. A large number of pesticides are being detected, sometimes at fairly high concentrations. Pesticides used in lawn care products are the most prevalent pesticides in storm water, and educating the population of Lethbridge about proper pesticide use and disposal is crucial to improve the quality of the storm waters discharged by Lethbridge into the Oldman River.

## 4.3 WATER CHEMISTRY AND NUTRIENT ANALYSIS

**Summary of Water Chemistry and Nutrient Analysis.** Evaluating the quality of aquatic habitats with regards to nutrients is not easily accomplished. Nutrients act in concert with one another, have concentrations that are naturally variable over time and change form in response to changing water quality parameters (temperature, oxygen, pH). As all ecosystems, aquatic systems need nutrients, but it comes down to the scope (number and variety of nutrients present), frequency (the temporal availability of nutrients) and amplitude (the concentration of each nutrient) of the particular nutrients which determines whether aquatic systems are getting too much of a good thing. Some aquatic systems have naturally high nutrient levels and these are usually abundant in algae and/or aquatic plants (e.g. sloughs, marshes). Some are low in nutrients and this may be reflected in clear waters with little to no plant or algae growth (e.g. foothill streams, high mountain lakes). It is the natural progression of lakes to become more nutrient rich with time as it is for nutrients to increase the further downstream you go in a watershed. The natural rate of this nutrification in lakes, a process referred to as eutrophication, is usually very slow, often taking tens of thousands to millions of years, but the activities of man can have significant impacts on expediting this natural rate. In a similar manner our activities of lawn fertilizer misuse, car washing and discharging of chemical and organic waste into our storm water systems contribute to polluting and nutrifying our aquatic systems to an extent that far exceeds nature’s natural range. Lawn fertilizer applications can release nutrients into aquatic systems that are 10 to 20 thousand times more concentrated then would be naturally available. In monitoring the physical, chemical and biological parameters of storm waters we get a barometer of residential, industrial and commercial activities in our community.

Some storm drains have high median concentrations for some nutrients, which is important to know, but the other factor to consider in total nutrient impact to nutrient enrichment to the Oldman is the total discharge of each drain. Some drains may have high nutrient concentrations, but low discharge volumes, or low nutrient concentrations but high discharges, which in either case would moderate their overall enrichment potentials. Specific to the nutrients monitored, with regards to phosphorus, determining the percentage of Total Phosphorus (TP) that is in the Dissolved Phosphorus (DP) form, can indicate the direct impact this nutrient can have on the aquatic system, since DP measures what is directly available to plants and algae and TP is a measure of the amount of phosphorus that is both available (unbound) and unavailable (bound or adsorbed). When comparing storm water discharge the percentage of TP in the dissolved form averaged about 72% as compared to 34% for river water. This indicates that there is more than twice the concentration of primary productivity promoting phosphorus (stimulates the growth of aquatic plants and algae) available in storm water than in the Oldman River water which it discharges into. With respect to nutrients and the quality of Oldman River water, it appears that in a little more than a decade since the Saffran study monitored water quality, the concentrations of all nutrients tested in this study increased in the Oldman River in Lethbridge and all nutrients but nitrate and TN increased in storm water. What will the consequence be for the aquatic system in way of aesthetics (smell, off flavour, recreational use, beauty), human health (bacteria, algae toxins), and biology (fish and organismal diversity) if this rate continues?

The process of accurately monitoring and safeguarding the integrity of our aquatic systems is undergoing an overhaul both nationally and provincially. Developing guidance or trigger concentrations for nutrients like Total Nitrogen and Total Phosphorus for the Oldman River are in the process of being assessed and applied once natural baseline concentrations are established. Although in most cases guideline exceedances were not able to be used to compare nutrient conditions, the resultant nutrient concentrations measured from river sites from this study can be used towards development of establishing baseline nutrient guidelines for the Oldman River at Lethbridge so that future monitoring can better gauge environmental impact and change and determine whether our practices are improving or declining the quality of our watershed.

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