CSCE Annual Conference
Growing with youth – Croître avec les jeunes

Laval (Greater Montreal)
June 12 - 15, 2019

IMPACTS OF CITY OF SASKATOON'S STORMWATER RUNOFF INTO THE SOUTH SASKATCHEWAN RIVER

Al Masum, A.[†,1], McPhedran, K.N.[1,2]
[†] Deceased 3 January 2019
[1] University of Saskatchewan, Canada
[2] kerry.mcphedran@usask.ca

Abstract: Urbanization of natural areas leads to vegetation removal, replacement of pervious with impervious surfaces, and drainage channel changes leading to increased stormwater flows and pollutants from physical, chemical and biological origins flowing into receiving water bodies. Determination of these pollutant loadings can be accomplished via sampling (as part of a monitoring program) and/or model estimations. Although sampling can be the most accurate method for determination of pollutant loadings, a major issue is its accuracy relies on the need for comprehensive samples over time with substantial time and cost issues. Modeling using land-uses, rainfall, and GIS mapping can be a potential supplement for monitoring, especially for locations with numerous stormwater outfalls. For example, Saskatoon, SK, has over 100 outfalls to the South Saskatchewan River (SSR) that cannot reasonably be comprehensively monitored. Currently, we use GIS mapping and land-use based pollutant loadings to determine the stormwater loadings to the SSR including total suspended solids (TSS), chemical oxygen demand (COD), biochemical oxygen demand (BOD), nutrients, metals, and polyaromatic hydrocarbons (PAHs). The seven outfalls studied cover 36% of Saskatoon's total area with single-family residential land use found to be the most dominant across Saskatoon at 34%, followed by green, industrial and commercial with 21%, 14% and 11% respectively. The 23rd St W area was found to be primarily commercial and industrial uses with the largest predicted area loadings of: 20,000 kg/km^2 TSS, 9,500 kg/km^2 COD, 1000 kg/km^2 BOD, 225 kg/km^2 TN, 40 kg/km^2 TP, 4-26 kg/km^2 metals, 0.075 kg/km^2 PAHS.

1 INTRODUCTION

Urbanization changes existing land uses making pervious areas into impervious surfaces thus altering the natural surface runoff pollutant characteristics which impact receiving waters (Barbosa et al., 2012; Jartun & Pettersen, 2010). Urbanization also increases various anthropogenic activities on the catchment surfaces which generates pollutants of physical, chemical and biological origin that are eventually washed out to water bodies during storms (Borris et al., 2016; Goonetilleke et al., 2005; Jartun & Pettersen, 2010). These increased urban runoffs are major contributors of organics, metals, and other pollutants that can led to receiving water degradation (Järveläinen, Sillanpää, & Koivusalo, 2017). Determination and mitigation of stormwater pollutant loadings is a major area of investigation by municipalities within Canada and beyond.

Many approaches to stormwater management have been considered in Canada and worldwide, however, there is a particular issue with current conveyance systems that release stormwaters directly into waterbodies without any treatment (Burns et al. 2012). Stormwater contains numerous pollutants including total suspended solids (TSS), chemical oxygen demand (COD), biochemical oxygen demand (BOD), nutrients (total nitrogen, TN; total phosphorus, TP), metals (Pb, Zn, Cu, Cr, Ni), and polyaromatic hydrocarbons (PAHs), among others. Suspended solids affect light penetration, impact receiving habitats, and are often considered as a universal water quality parameter (Rossi et al., 2013; Rugner et al., 2013). Suspended solids originate from wear of streets and paved areas, construction sites, corrosion of vehicles and building materials, atmospheric fallout, anthropogenic wastes, and rooftops, among others. (Barbosa et al., 2012; Björklund, 2011; Goonetilleke & Thomas, 2003). BOD and COD are indicative of the degree of organic pollution in the water environment (Lee at el., 2016; Lee & Nikraz, 2015). Vegetation such as leaves and fecal matter from animals such as dogs, cats and birds are the main sources of biodegradable organic matter (Barbosa et al., 2012; Goonetilleke & Thomas, 2003). Nutrients including nitrogen and phosphorus arise from fertilizers used in many residential, commercial, and agricultural applications. Heavy metals are of concern due to their potential toxicity and their non-degradability (Goonetilleke & Thomas, 2003; Hvitved-Jacobsen et al. 2010). Heavy metal sources are vehicles, tire wear, fuel and lubricating oils, road wear, industrial processes, corrosion of road traffic signs, and road metallic structures and building materials (Björklund, 2011). PAHs originate from both anthropogenic and natural sources, although anthropogenic sources are of main concern in stormwaters (Goonetilleke & Thomas, 2003). Sources of PAHs include incomplete combustion of gasoline and diesel fuels, oil combustion, bitumen and asphalt, abrasion of tire and asphalt, urban construction plastic materials, waste incineration, and lubricating oil (Björklund, 2011; Brown & Peake, 2006). Interestingly, TSS are used as a proxy for pollutant loads as a many of the above pollutants are found adsorbed onto stormwater solids (Rossi et al., 2005; Rugner et al., 2013). Clearly, urban stormwaters are highly contaminated wastewaters that need treatment prior to their release.

The pollutants of interest listed above are distributed differently in urban areas based on land uses. The majority of urban stormwater runoff pollutants have nonpoint sources originating from both impervious and pervious surfaces. Impervious, human-made surface sources may include paved parking lots, streets, driveways, roofs, and sidewalks. Pervious areas may include gardens, bare ground, unpaved parking areas, construction sites, and undeveloped areas which may closely mimic the natural landscape. Overall, all urban areas have the potential to contribute significant amounts of pollutants. For example, according to the Nationwide Urban Runoff Program (NURP), residential, commercial, and light industrial areas can all contribute significant amounts of pollutants to receiving waters (USEPA, 1983). More recently, these urban areas have been grouped into land use classifications including residential, commercial, roadways/highways, agricultural, undeveloped or 'green' areas, light/heavy industrial, and undeveloped areas (Järveläinen et al., 2017). These areas can be delineated in urban areas using GIS and can be coupled with measured areal pollutant loadings and rainfall data to estimate the pollutant loadings to receiving waters. Currently, areal pollutant loadings for Saskatoon catchments have not be determined; however, previous study loadings may be used as a starting point for model estimations.

Pollutant loading estimation has been one of the greatest challenges for stormwater management due to the high variability of storm events, both short-term (daily) and long-term (seasonally and yearly), and numerous potential pollutant sources (Sakson & Brzezinska, 2018). Loadings can be determined either through monitoring studies with intensive sampling and/or via modelling studies using rainfall, areal loadings, and GIS land-use classifications. Modelling pollutant loadings has been limited by low reliability when applied to larger scales as it is dependant on the variability of total rainfall, drainage area, land use and impervious area (Barbosa et al., 2012). Loadings estimation via monitoring is challenging due to inaccurate sampling, high costs for sample analysis of many constituents, and lack of resources to collect samples (personnel and/or automated sampling) (Järveläinen et al., 2017). The best approach may be to use modelling, informed by sampling regimes, to better determine pollutant loads by using climate, accurate land use, imperviousness, and surface pollutant concentration data for urban areas (Cheema et al., 2017).

The determination of impacts of stormwater runoff from the City of Saskatoon (COS), SK on the South Saskatchewan River (SSR) has been limited due to lack of comprehensive studies (McLeod et al., 2006). Clearly, there is a need to acquire a better understanding of urban runoff in the COS and its associated processes (i.e. pollutant build-up and washoff) to determine the potential impacts of pollutant loadings to the SSR. The objectives of this study are: (i) to delineate land uses for seven large stormwater catchment areas of the COS using GIS; (ii) use previous literature areal pollutant loading information and regional rainfall data (summer 2018) to estimate pollutant concentrations from each of these catchments; (iii) to estimate the total pollutant loadings and areal loadings from urban runoff of these catchments into the SSR. The pollutants estimated include total suspended solids (TSS), chemical oxygen demand (COD), biochemical oxygen demand (BOD), metals (Pb, Zn, Cu, Cr, Ni) and polyaromatic hydrocarbons (PAHs). In the future, this predictive method will be used to compare and contrast actual sampled SSR loadings.

2 METHODOLOGY

2.1 Study Area

The seven study catchment areas are located on the banks of the SSR in the COS (52° 07' N, 106° 38' W). The COS has a total area of 228.13 km^2 and a population of 246,376 making it the largest municipality in Saskatchewan, Canada (Statistics Canada, 2016). The Saskatchewan climate is continental, dry, and averages 2,268 hours of sunshine annually. The summer is the wettest season with average annual precipitation of 340 mm. The COS has high pollutant mass accumulation in catchment areas as a result of long dry periods between successive summer storms. The COS has separated stormwater sewers with over 100 outfalls, many being directed without treatment to the SSR. Of these, 14 outfalls have catchment areas greater than 100 ha (1 km^2) (Figure 1) with seven of these considered in the current study (Table 1).

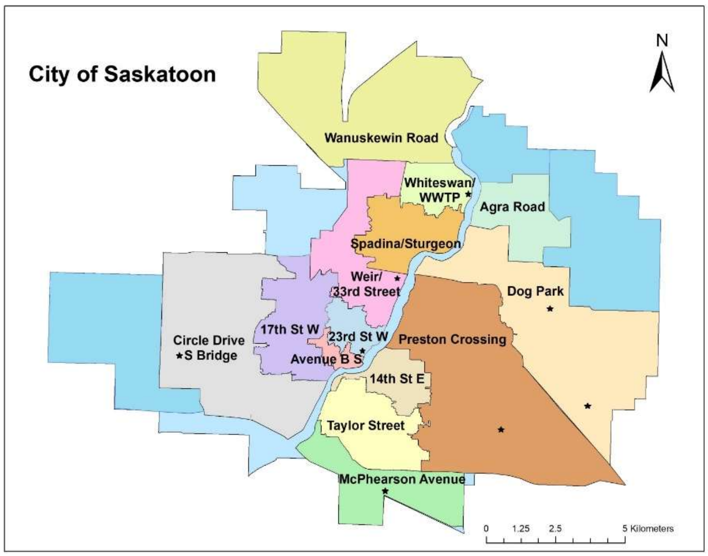


Figure 1. The fourteen major stormwater catchment areas of the City of Saskatoon (based on City of Saskatoon maps) including the seven current study areas. Stars (*) indicate rain gauge stations.

Table 1. Selected COS stormwater catchment areas and their characteristics.

Catchment Name	Area (km^2)	Relative Area (%)	Primary Type
Wanuskewin Road	25.50	11.18	Light Industrial
Circle Dr S Bridge	24.60	10.78	Residential
McPherson Avenue	9.58	4.20	Light Industrial
17th St W	9.27	4.06	Residential
Agra Road	7.20	3.16	Undeveloped
14th St E	4.27	1.87	Residential
23rd St W	2.73	1.20	Commercial & Industrial
Total	78.88	36.45	

2.2 Land Use Analysis by GIS

Geographic information system (GIS) and land use data can be used to estimate pollutant loadings coupled with rainfall-runoff models (Jato-Espino et al., 2016). Land uses characteristics can include the number of impervious surfaces, vehicles, industrial debris, leaf and animal litter, surface slopes and soils, and hydrological and meteorological characteristics of an area (Stranger et al., 2010). The seven catchment areas considered in the current study (Table 1) were divided into several land use classes following Järveläinen et al. (2017) in which the city centre was considered as commercial area. Recent land-use information from the COS and Google Earth Pro were used to classify land uses and delineated via ArcGIS. All delineated polygons of the same land use classes were summed to get the total area for that land use class. Land use by roads were estimated based on finding the percentages of roads for each class using five randomly selected areas within each catchment area.

2.3 Rainfall, Runoff Coefficients, and SMC Values

The eight rain gauges for COS (Figure 1) were used to determine the COS rainfall information for each individual catchment given rainfall depths are often localized (COS, 2016). Average pollutant concentration for each catchment was determined via the site mean concentration (SMC) which is the geometric mean of multiple rainfall's event mean concentration (EMC) over a duration (e.g., seasonally for the current study, 6 months in total) in which EMC is the total pollutant mass per event volume (Charbeneau & Barrett, 1998). For the current study catchment areas, average SMC values (Table 2) were considered based on Melanen (1981), Mitchell (2005), Nordeidet et al. (2004) and Jarvelainen et al. (2017) given the lack of available land use SMC information for the current catchments in Saskatoon. To estimate runoff during a rainfall event, runoff coefficients (CR) are required that are the ratio of total depth of runoff to total depth of rainfall (Mahmoud et al., 2014). For the current study, COS's CR values were used as shown in Table 3.

Table 2**.** Flow weighted site mean concentration (SMC) values for the different land use classes (average and standard deviation) from studies including Melanen (1981), Mitchell (2005), Nordeidet et al. (2004) and Jarvelainen et al. (2017). Note that the PAHs were only measured by Jarvelainen et al. (2017).

Class		TSS (mg/L)	COD (mg/L)	BOD (mg/L)	TN (mg/L)	TP (mg/L)	Pb (µg/L)	Zn (µg/L)	Cu (µg/L)	Cr (µg/L)	Ni (µg/L)	PAHs (µg/L)
SR	*AVG*	100	57	8.5	1.9	0.3	60	144	32	4.9	16.5	0.4
	SD	81	36	0	0.6	0.1	50	109	17.5	3.5	19	0
MR	*AVG*	118	68	8.5	2	0.3	73	252	39.5	13	21	0.6
	SD	47	45	0	.5	0.1	71	87	8	8	13	0
R	*AVG*	271	120	24	2,3	0.3	114	237	55	20	29	0.8
	SD	175	62	0	0.5	0.05	117	42	16	17	2.	0
HW	*AVG*	288	117	24	2	0.5	166	327	64	10	15	1.4
	SD	148	70	0	0.3	0,3	139	173	31	4	21	0
CM	*AVG*	194	91	10	1.9	0.3	145	260	84	14	24	0.6
	SD	160	61	0	0.3	0.05	140	136	71	9	8	0
IN	*AVG*	194	91	10	1.9	0.3	145	260	84	14	24	0.6
	SD	160	61	0	0.3	0.05	140	136	71	9	8	0
GR	*AVG*	84	38	7.9	1.8	0.3	35	116	19	7	15	0
	SD	61	2.8	0	0.2	0.1	30	110	12.5	0	0	0
AG	*AVG*	84	38	7.9	1.8	0.3	35	116	19	7	15	0
	SD	61	2.8	0	0.2	0.1	30	110	12.5	0	0	0

Table 3. The land use classification used currently based on Järveläinen et al. (2017). Runoff coefficients (CR) considered in the current study follow the COS guidelines (COS, 2018).

Land use class	Acronym	CR	Description
Single-family Residential	SR	0.30	Single dwelling house
Multi-family Residential	MR	0.60	Multiple separate housing units within building
Roads	R	0.95	With average traffic less than 15,000 vehicles/day
Highways	HW	0.95	With average traffic more than 15,000 vehicles/day
Commercial	CM	0.60	Downtown, central business district, shopping centre, university, hospital etc.
Industrial	IN	0.60	Industrial area
Green	GR	0.10	Parks, forests, meadows and undeveloped area
Agricultural	AG	0.05	Cultivated area

2.4 Calculation of Pollutant Loads

Seasonal (summer 2018) pollutant export rates were calculated based on the following equation by Legret and Pagotto (1999) and shown as

$$L = \frac{P}{\sum P_e}\frac{V}{\sum V_e}\sum L_e \qquad (1)$$

Where, where L (kg) is the seasonal pollutant load, P (mm) represents the seasonal precipitation, P_e (mm) is the precipitation during each storm event, V (m^3) is the seasonal runoff volume, V_e (m^3) is the runoff volume computed for each storm event, and L_e is the pollutant load for each individual storm event. The pollutant load for each storm event (L_e) was calculated as

$$L_e = cV_e \qquad (2)$$

Where, c represents the mean concentration of the pollutant constituent (mg/m^3) for each runoff sample. V_e was obtained as:

$$V_e = P_e \sum (A(CR)) \qquad (3)$$

Where, A (m^2) is the measured drainage area per land use and CR represents runoff coefficient of each land use in the studied catchments.

2.5 Estimation of Pollutant Loads

Pollutant export rates for Summer 2018 were calculated for individual pollutants for each of the land use classes within all catchments areas following Novotny (2003). Briefly, equations (4) and (5) were used to determine monthly pollutant loads calculations as follows:

$$L_{ua} = (CR)P(SMC) \qquad (4)$$

Where, L_{ua} (kg/km^2) is the monthly unit area load, CR (dimensionless) is the runoff coefficient as presented in Table 3, P (mm) is the monthly precipitation depth, and SMC (mg/L) is the characteristic event-volume-weighted SMC.

$$L_{tot} = L_{ua}A \qquad (5)$$

Where L_{tot} (kg) is the monthly pollutant export rate, and A (km^2) is the total area occupied by the individual land use class.

3 RESULTS AND DISCUSSION

3.1 Land Use Analysis

The seven catchment areas were divided into the various land use classifications are shown in Figure 2. Overall, except for the Wanuskewin Road catchment, all the catchments areas have significant amounts of single-family residential areas (SR: 20-54%) (Figure 3a). Wanuskewin Road is comprised of mostly green (GR: 55%) and industrial (IN: 37%) area with a small percentage of roads and highways. The majority of Agra Road is green (GR: 60%) and single-family residential area (SR: 25%). The 17th St W and Agra Road are the only two catchment areas with agricultural (AG) land use. The 14th St E catchment is commercial (CM) and industrial (IN) land use dominated with over 50%. Roads (R) and highways (HW) are found in each catchment but at low areas, while multiple-family residential (MR) areas are found in five catchment areas but in low areas. Clearly, each catchment has significantly different area usages and, by inference, will have variability in expected pollutant loadings to the SSR.

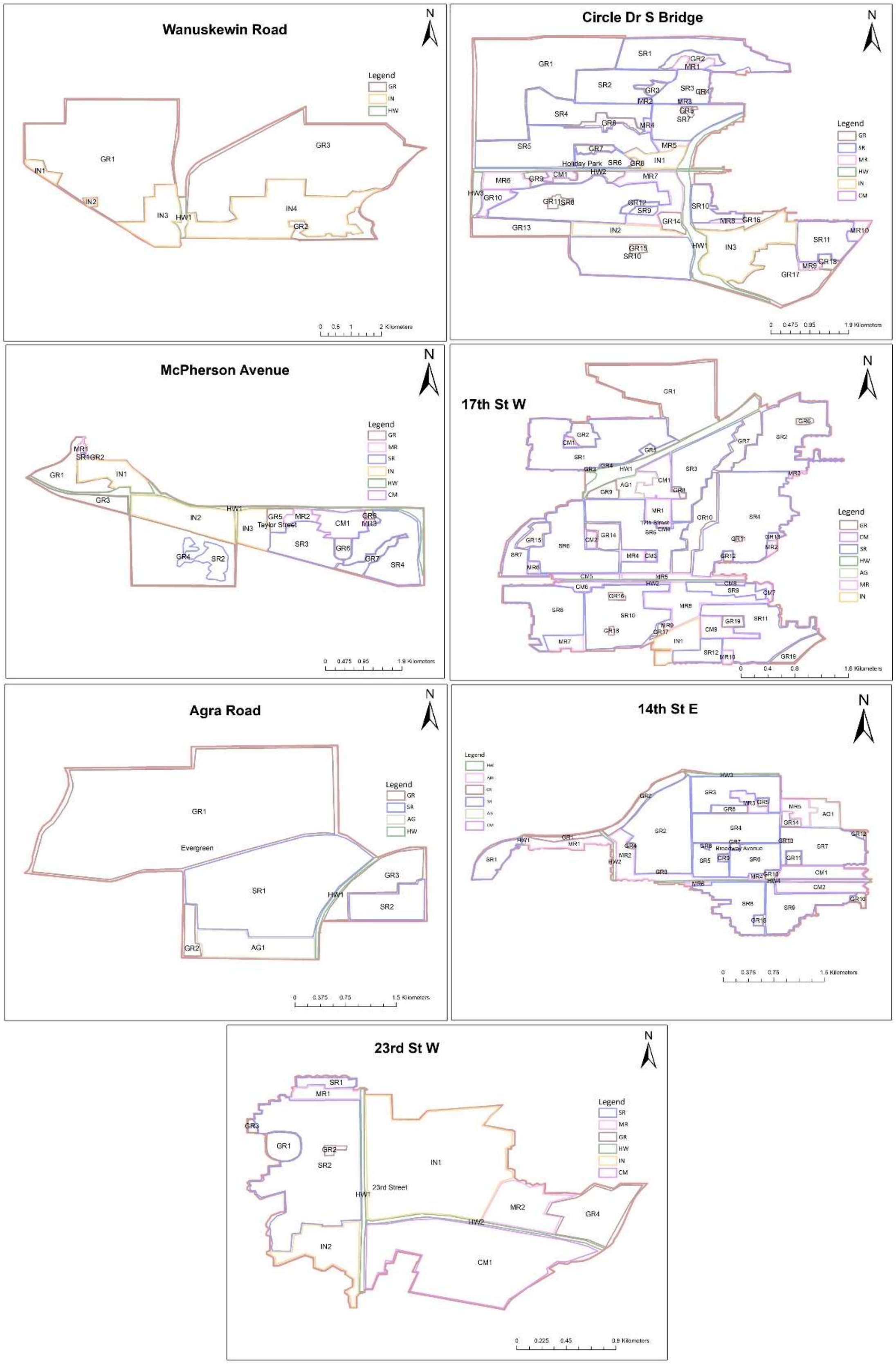
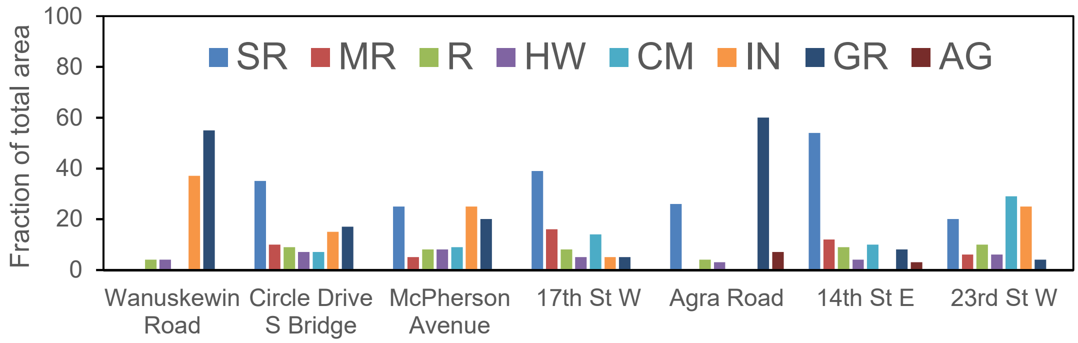
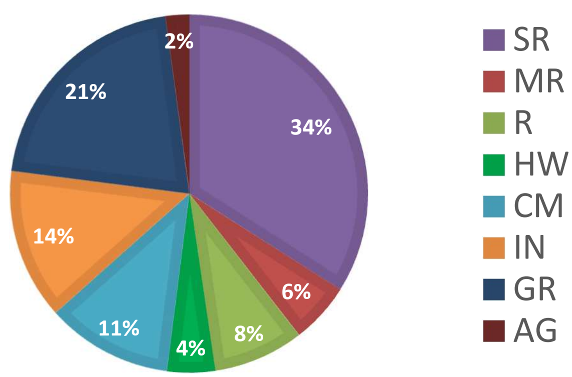


Figure 2. Land use analysis of the studied catchment areas. Legend areas acronyms are in Table 3.

Figure 3b represents overall land uses for the seven catchment areas that make up 36% of the COS total area. Single-family residential (SR) land use is the most dominant across the COS comprising 34%, followed by green (GR), industrial (IN), and commercial (CM) with 21%, 14% and 11% respectively. Land use by roads (R) are less than 10% of COS total area. The lowest land use in COS is the agricultural (AG) at 2% as it is found in few catchments, whereas highways (HW) and multi-family residential (MR) represent 4% and 6% of the overall area. For comparison, Bannerman et al. (1996) found 47% residential area, 8% commercial area, 6% industrial area, and 20% of combined green and agricultural area in Milwaukee, Wisconsin, USA. Additionally, Luck and Wu (2002) found residential areas dominated within the city of Arizona, NV, USA comprising 35% overall area. In contrast, study areas of Lahti and Espoo in Finland determined by Järveläinen et al. (2017) were dominated by agricultural (58%).



(a)



(b)

Figure 3. Distribution of land use classes for the individual study catchments (a) and overall COS (b).

3.2 Pollutant Export Estimates for Summer 2018

Predicted loadings of the seven catchment areas were determined using SMC concentrations and 2018 rainfall data (Figure 4). Overall, Circle Drive S Bridge and Wanuskewin Road catchment areas had the highest predicted loadings for all pollutants as expected based on their larger areas (25.5 and 24.6 km^2, respectively). These two catchments account for approximately 70% of all pollutants into the SSR. The Agra Road catchment produced the lowest projected loadings given it has a large amount of green (GR) area which would be anticipated to have less available pollutants as well as less runoff based on a low CR (0.1 from Table 3). The remaining catchments show that 14th St E and 23rd St W contributed less pollutant loadings as compared to McPherson Avenue and 17th St W, and these are generally proportional on the total areas for each of these catchment areas.

The approximate pollutant loadings from all catchments into the SSR over 2018 are: 1,230,000 kg TSS, 571,000 kg COD, 88,300 kg BOD, 13,000 kg TN, 2,100 kg TP, metals ranging from 80 to 1,500 kg, and 4.3

kg PAHs. These loadings would be scattered throughout the year due to various rainfall events. For future consideration, the pollutant loadings per unit area will be useful to extrapolate the impacts of land uses of catchment areas on pollutant loadings, as well as to predict the impacts of changes in land uses within catchment areas. In addition, these values can more readily be compared to previous studies as shown below. As a commercial and industrial dominated area, the 23rd St W catchment contributed the largest amount of all pollutants based on area with: 20,000 kg/km^2 TSS, 9,500 kg/km^2 COD, 1,000 kg/km^2 BOD, 225 kg/km^2 TN, 40 kg/km^2 TP, metals ranging from 4-26 kg/km^2, and 0.075 kg/km^2 PAHs. The Agra Road

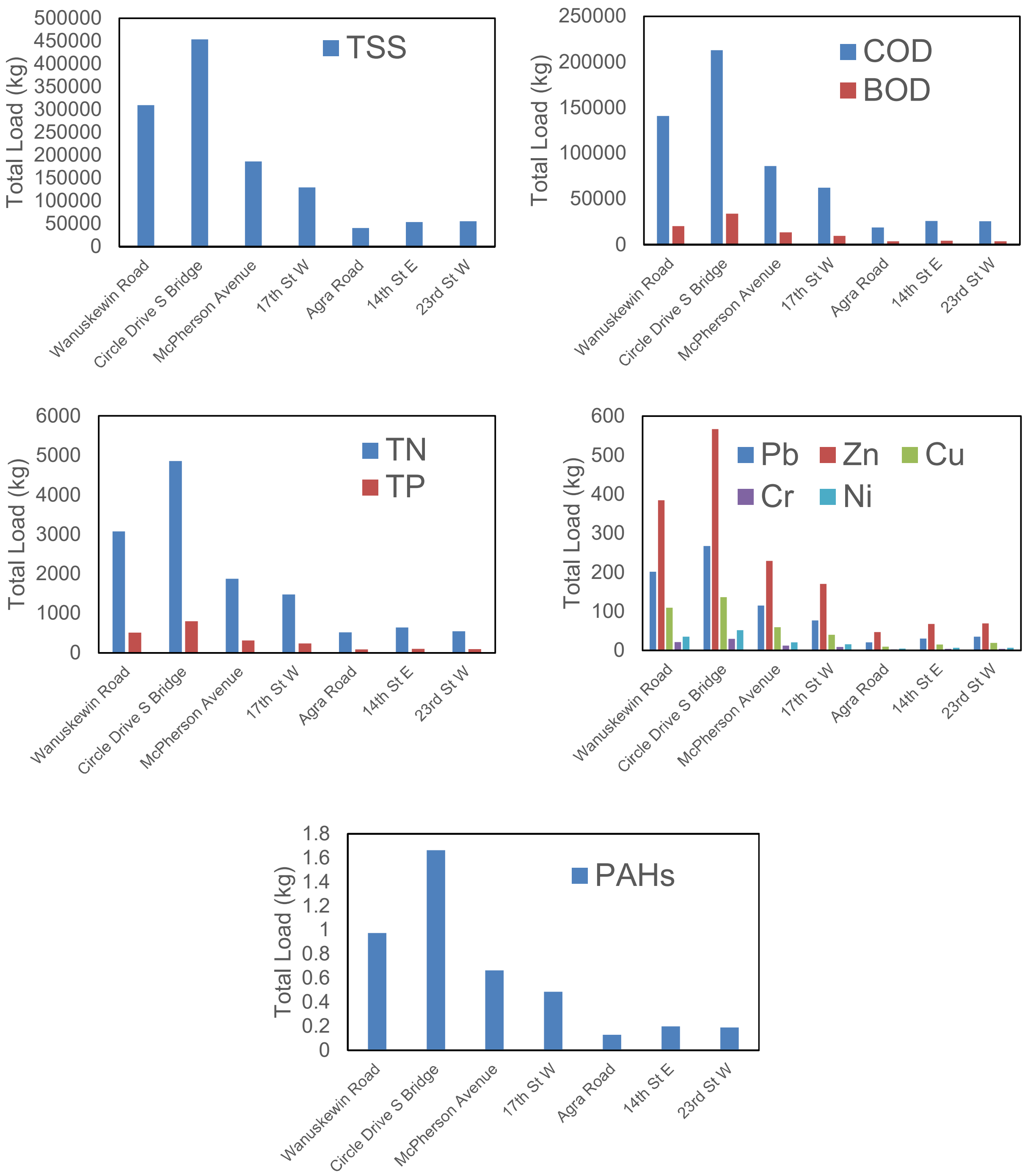


Figure 4. Total estimated pollutant loads to the South Saskatchewan River.

and Wanuskewin Road areas produced the least amount of pollutants per unit area because of their large green land uses, despite Wanuskewin Road having a relatively large area making it a higher total contributor to loadings. For comparison, Sillanpää (2013) estimated loadings for urban developed areas in the City of Espoo, Finland and found similar yearly loading ranges of TSS (12,900-54,800 kg/km^2), COD (2,670-4,700 kg/km^2), TN (560-2,290 kg/km^2), and TP (26-65 kg/km^2). Additionally, Melanen (1981) studied three different types of residential area, commercial area and driveways and found TSS (10,000-100,000 kg/km^2), COD (10,000-50,000 kg/km^2), BOD (1,000-10,000 kg/km^2), TN (200-1,000 kg/km^2), and TP (20-200 kg/km^2). For the COS, McLeod et al. (2006) studied Avenue B S, Taylor Street and Silverwood catchment areas for a period of two years study and found: TSS: 21,200 kg/km^2 for Avenue B S, 5,700 kg/km^2 for Taylor Street, 7,100 5,700 kg/km^2 for Silverwood; COD: 7,300 kg/km^2 for Avenue B S, 2,400 kg/km^2 for Taylor Street, 1,000 kg/km^2 for Silverwood; TN: 218 kg/km^2 for Avenue B S, 79 kg/km^2 for Taylor Street, 17 kg/km^2 for Silverwood; and TP: 48 kg/km^2 for Avenue B S, 24 kg/km^2 for Taylor Street, 5 kg/km^2 for Silverwood. Despite similarities, each catchment area and region will be expected to have different loadings based on land usage, catchment topography, and rainfall event timing, durations, and volumes.

4 CONCLUSIONS

The current study predicted the loadings for seven different COS stormwater outfalls into SSR during summer of 2018. The seven catchment areas were dominated by single-family residential (SR) land use at 34%, with smaller amounts of green (GR), industrial (IN) and commercial (CM) land uses with 21%, 14% and 11% respectively. Pollutants considered were total suspended solids (TSS), chemical oxygen demand (COD), biochemical oxygen demand (BOD), nutrients (TN, TP), metals (Pb, Zn, Cu, Cr, Ni) and polyaromatic hydrocarbons (PAHs).These seven catchments accounted for 36.5% of the total land area in the COS and contributed estimated loadings in 2018 of 1,230,000 kg TSS, 571,000 kg COD, 88,300 kg BOD, 13,000 kg TN, 2,100 kg TP, metals ranging from 80 to 1,500 kg, and 4.3 kg PAHs. These loadings are distributed throughout the rainfall season (approximately 6 months), thus it is difficult to determine if the loadings would result in exceedances of CCME (Canadian Council of Ministers of the Environment) (CCME, 2011) guidelines. Further research is being conducted to assess actual samples as part of a monitoring program to determine how the actual samples compare to these GIS-based model estimations. This work will include 14 catchment areas of the COS and will be presented as a continuation of this study.

Acknowledgements

The authors would like to acknowledge funding through the NSERC Discovery Grant (K.M) program and the assistance of partners at the City of Saskatoon for providing stormwater catchment area information.

References

Barbosa, A.E., Fernandes, J.N., and David, L.M. 2012. Key issues for sustainable urban stormwater management. *Water Research*, **46**(20), 6787–6798.

Bannerman, R.T., Legg, A.D., and Greb, S.R. 1996. Quality of Wisconsin stormwater, 1989-94. (No. 96-458). US Geological Survey.

Björklund, K. 2011. Sources and fluxes of organic contaminants in urban runoff. *PhD Thesis.* Chalmers University of Technology, Gothenburg, Sweden.

Borris, M., Leonhardt, G., Marsalek, J., Österlund, H., and Viklander, M. 2016. Source-based modeling of urban stormwater quality response to the selected scenarios combining future changes in climate and socio-economic factors. *Environmental Management*, **58**(2), 223–237.

Burns, M.J., Fletcher, T.D., Walsh, C.J., Ladson, A.R. and Hatt, B.E. 2012. Hydrologic shortcomings of conventional urban stormwater management and opportunities for reform. *Landscape and Urban Planning*, **105**(3), 230-240.

CCME (Canadian Council of Ministers of the Environment) 2011. Protocols manual for water quality sampling in Canada. PN 1461. ISBN 978-1-896997-7-0

Charbeneau, R.J. and Barrett, M.E. 1998. Evaluation of methods for estimating stormwater pollutant loads. *Water Environment Research*, **70**(7), 1295–1302.

Cheema, P.P.S., Reddy, A.S. and Kaur, S. 2017. Characterization and prediction of stormwater runoff quality in sub-tropical rural catchments. *Water Resources*, **44**(2), 331–341.

COS (City of Saskatoon) 2016. 2016 Annual Rainfall Report: Monitoring and Modeling. Saskatoon Water Transportation & Utilities Department.
COS (City of Saskatoon) 2016. 2016 Outfall Evaluation Storm Water Management. Saskatoon Water Transportation & Utilities Department.
Goonetilleke, A., Thomas, E., Ginn, S. and Gilbert, D. 2005. Understanding the role of land use in urban stormwater quality management. *Journal of Environmental Management*, **74**(1), 31–42.
Goonetilleke, A. and Thomas, E.C. 2003. Water quality impacts of urbanisation: Evaluation of current research. *Technical Report*, Centre for Built Environment and Engineering Research, Faculty of Built Environment and Engineering. Queensland University, Brisbane City, Australia.
Jartun, M. and Pettersen, A. 2010. Contaminants in urban runoff to Norwegian fjords. *Journal of Soils and Sediments,* **10**(2), 155–161.
Järveläinen, J., Sillanpää, N. and Koivusalo, H. 2017. Land-use based stormwater pollutant load estimation and monitoring system design. *Urban Water Journal*, **14**(3), 223–236.
Jato-Espino, D., Sillanpää, N., Charlesworth, S.M. and Andrés-Doménech, I. 2016. Coupling GIS with stormwater modelling for the location prioritization and hydrological simulation of permeable pavements in urban catchments. *Water*, **8**(10), 451.
Lee, A. H. and Nikraz, H. 2015. BOD:COD Ratio as an indicator for river pollution. *International Proceedings of Chemical, Biological and Environmental Engineering*, **51**(26), 139–142.
Lee, J., Lee, S., Yu, S. and Rhew, D. 2016. Relationships between water quality parameters in rivers and lakes: BOD5, COD, NBOPs, and TOC. *Environmental Monitoring and Assessment*, **188**(4), 1–8.
Legret, M. and C. Pagotto 1999. Evaluation of pollutant loadings in the runoff waters from a major rural highway. *Science of the Total Environment*, **235**, 143-150.
Luck, M. and Wu, J. 2002. A gradient analysis of urban landscape pattern: A case study from the Phoenix metropolitan region, Arizona, USA. *Landscape Ecology*, **17**(4), 327-339.
Mahmoud, S.H., Mohammad, F.S. and Alazba, A.A. 2014. Determination of potential runoff coefficient for Al-Baha Region, Saudi Arabia using GIS. *Arabian Journal of Geosciences*, **7**(5), 2041–2057.
McLeod, S.M., Kells, J. and Putz, G.J. 2006. Urban runoff quality characterization and load estimation in Saskatoon, Canada. *Journal of Environmental Engineering*, **132**(11), 1470–1481.
Mitchell, G. 2005. Explaining variations in public acceptability of road pricing schemes. *Journal of Environmental Management*, **74**, 1–9.
Nordeidet, B., Nordeide, T., Åstebøl, S. and Hvitved-Jacobsen, T. 2004. Prioritising and planning of urban stormwater treatment in the Alna watercourse in Oslo. *Science of the Total Environment*, **334**, 231–238.
Novotny, V. 2003. Water quality: Diffuse pollution and watershed management. 2nd Ed. *John Wiley & Sons.*
Rossi, L., Chevre, N., Fankhauser, R., Margot, J., Curdy, R., Babut, M., Andrew Barry, D.A. 2013. Sediment contamination assessment in urban areas based on total suspended solids. *Water Research*, **47**, 339-350.
Rugner, H., Schwientek, M., Beckingham, B., Kuch, B. and Grathwohl, P. 2013. Turbidity as a proxy for total suspended solids (TSS) and particle facilitated pollutant transport in catchments. *Environmental and Earth Sciences*, **69**, 373–380.
Sakson, G. and Brzezinska, A. 2018. Emission of heavy metals from an urban catchment into receiving water and possibility of its limitation on the example of Lodz city. *Environmental Monitoring & Assessment*, **190**: 281.
Statistic Canada 2016, Science and Economic Development 2016. Statistics Canada: Report on Plans and Priorities, Ottawa, ON, Canada.
Sillanpää, N. 2013. Effects of suburban development on runoff generation and water quality. *PhD thesis*, Aalto University, Helsinki, Finland.
U.S. Environmental Protection Agency 1983. Results of the Nationwide Urban Runoff Program: Volume 1 – Final Report, Water Planning Division, Washington, DC, USA.