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# PCSWMM MODELING OF STORM RUNOFF AND SEDIMENT AND NUTRIENTS LOADING TO STORMWATER WETLANDS IN CALGARY, ALBERTA

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**Abstract:** This paper presents the preliminary results of stormwater quantity and quality modeling using PCSWMM applied to two stormwater wetlands in Calgary, Alberta. Calibration and validation of hydrologic/hydraulic parameters of the Rocky Ridge wetland successfully modeled the observed flow. The most sensitive parameters were percent runoff routing from impervious to pervious areas and subcatchment width, while Horton's infiltration parameters were governed by the biggest rain event. These optimized parameters were then applied to the "ungauged" catchment of Royal Oak, which resulted in significant overestimation of the hydrograph. An exponential buildup function and EMC washoff function were used to model the water quality module for Rocky Ridge. Event-based water quality parameter calibration was conducted for TSS, TN, and TP. The maximum buildup and washoff coefficient were the most sensitive parameters. Calibrated water quality parameters for TSS and TP followed a similar trend for the events analyzed. EMCs for TSS and TP correlated with the maximum intensity and total rainfall depth.

## 1 INTRODUCTION

Urbanization has led to greater total stormwater runoff and higher peak flows, which often lead to flooding (Burton et al. 2001). Stormwater runoff quality in urbanized areas are also typically more polluted than unimpaired and rural environments (Sartor et al. 1974, Vaze and Chiew 2004). To mitigate these impacts of urbanization, stormwater ponds and wetlands are often utilized.

A comprehensive research study is being conducted to quantify the sediment and nutrient loadings into stormwater ponds and wetlands and to investigate the processes that govern their transport, deposition and cycling within these facilities. A 2-year field monitoring program during the summer season is being undertaken to monitor two wet ponds and two stormwater wetlands in Calgary, Alberta. The first year of field data was used in the development of a watershed model (PCSWMM) to investigate the suspended sediment and nutrient loads entering the ponds. Preliminary calibration and validation of the watershed model was used to predict the sediment and nutrients loadings as a function of the drainage area characteristics, land use, and storm events. The field data and PCSWMM results will also support the application of the Environmental Fluid Dynamics Code (EFDC) model to investigate the sediment transport and nutrient cycles in the ponds/wetlands. Both the field monitoring data and computer modeling will be used to improve the design and operation guidelines of stormwater facilities.

This paper presents the preliminary results from the calibration and validation of PCSWMM applied to the catchments of two stormwater wetlands using data from 2018, the first year of the field monitoring program. Measured data at the inlet of the Rocky Ridge (RR) wetland was used to calibrate the hydrologic/hydraulic and the water quality parameters. The calibration of the water quality parameters was event-based for RR, due to only one observed parameter, the event mean concentration (EMC), being available for calibration purposes. The water quality analysis focused on sediments (total suspended solids (TSS)) and nutrients, total nitrogen (TN), and total phosphorus (TP). The calibrated parameters were extrapolated to the Royal Oak (RO) wetland to determine the applicability of using these calibrated parameters on "ungauged" catchments.

## 2 STUDY AREA

The two wetlands investigated in this study were natural wetlands that were repurposed for stormwater management when this region of the city was developed. The RR and RO stormwater ponds (called 19WLA and 35WL, respectively) and their respective catchments are located in the northwest corner of Calgary. The catchments of each pond are situated in a semi-arid climate in urban, residential areas. The selection of the study sites was based on the following criteria: simple ponds/wetlands with one outlet and one or two inlets, mature catchments (i.e., five years or older without new development during the study period), and mature ponds/wetlands that have been in operation for at least five years. Figure 1 depicts the study area for RR and RO including the catchment area, percent imperviousness and slope.

Figure 1: Aerial view of the study wetlands with the catchments outlined in red [Image source: Google Earth © 2018 Google].

## 3 METHODOLOGY

### 3.1 Data Collection

Weather stations were installed at each wetland to collect rainfall data for the summer of 2018. Rainfall data was recorded at 5-minute intervals using a tipping bucket with a resolution of 0.2 mm. The RO weather station ceased recording after August 12th, 2018 due to battery failure. Since the RR weather station is only 0.5 km from the RO wetland, the missing data for the rest of the monitoring season was filled in using the rainfall data from the RR site.

Wetland catchment characteristics such as land use information, topography, and minor/major drainage systems were provided by the City of Calgary. Teledyne ISCO 6712 autosamplers equipped with area velocity sensors were installed at each inlet to monitor flow rates and to collect water samples during runoff events. Composite samples from captured storm events were collected and analyzed for EMC of TSS, TN and TP. Additional details regarding wetlands catchment characteristics and data collection methods is available in Ahmed et al. (2019).

### 3.2 Model Description and Setup

The Stormwater Management Model (SWMM) is a dynamic rainfall-runoff (hydrologic-hydraulic) simulation model, developed by the USEPA, used for single-event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas. PCSWMM is a GIS-based decision support version of EPA SWMM developed by Computational Hydraulics International (CHI). SWMM tracks the quantity and quality of runoff generated within each subcatchment, and the flow rate, flow depth, and quality of water in each pipe and channel during a simulation period comprised of multiple time steps (James et al. 2010, Rossman et al. 2016).

For the model setup, the RR catchment was split into 171 sub catchments, taking into consideration the topography and distribution of the manholes. The model consists of 24 manhole junctions and 24 pipe conduits. The dynamic wave approach with a time step of 5 seconds was used for the flow routing computations. The model was setup to continuously simulate the rainfall/runoff from May 10, 2018 to October 25, 2018. Similarly, the RO catchment was divided into 181 sub catchments with 25 junctions and 27 pipe connections. A 2-second time step was used to decrease the routing error. Horton's method was applied to represent the infiltration over the pervious areas. The average slope as well as the attributes of the conduits and junctions were applied based on the original stormwater management reports provided by the City (Stantec 1999, AMEC 2000). The built-in area-weighting method was utilized to determine the imperviousness ratio of each sub catchment.

Two main components of the water quality routines in PCSWMM consist of the buildup and washoff of pollutants from a given land use category. The pollutant buildup is a function of the number of antecedent dry days (ADD) and can be modelled using either a power function, exponential function, saturation function or an external time series. ADD is defined as the duration of the dry weather period when the runoff rate is less than 0.0254 mm/hr (James et al. 2010). The pollutant washoff during rainfall events can be computed by an exponential function, rating curve function or an event mean concentration (EMC) (Rossman et al. 2016). Urban runoff pollution is heavily influenced by local site conditions (Valtanen et al. 2015). Therefore, the land use conditions were grouped into three general categories: hard surfaces (i.e., roads, driveways, streets, sidewalks), roof (i.e., building outlines), and pervious areas. The three pollutants modeled are TSS, TN and TP. The buildup and washoff of these pollutants from the different land uses were simulated using an exponential buildup function and an event mean concentration washoff. The exponential buildup function is described by Equation 1 where the buildup follows an exponential growth that asymptotically approach a maximum limit. The EMC washoff function proportional to the runoff rate is defined in Equation 2,

[1] $B = C_1(1 - e^{-C_2 t})$

[2] $W = C_w Q$

where B=buildup (kg), $C_1$=maximum buildup possible (kg/ha), $C_2$=buildup rate constant (1/day), t=buildup time interval (days), W=washoff rate (mg/sec), $C_w$=pollutant concentration (mg/L), and Q=runoff rate (L/s).

### 3.3 Storm Events for Hydrologic/Hydraulic Calibration

Twelve storm events recorded at the RR weather station were selected for calibration and validation of the hydrologic and hydraulic parameters. These events were chosen to allow for maximum variability in duration, maximum intensity and total rainfall. The main characteristics of these storm events are summarized in Table 1. Events RR1 to RR 4 were used for calibration and RR 5 to RR 12 were used for validation.

Table 1: Characteristics of rainfall events for Rocky Ridge

| Event | Date | Duration (hr) | Maximum Rainfall (mm/hr) | Total Rainfall (mm) | ADD (days) |
|---|---|---|---|---|---|
| RR 1 | 06/16/18 | 1.75 | 7.2 | 4.8 | 1 |
| RR 2 | 06/23/18 | 7.33 | 21.6 | 33.2 | 0.5 |
| RR 3 | 06/28/18 | 3.83 | 4.8 | 7.2 | 5.4 |
| RR 4 | 07/14/18 | 6.08 | 4.8 | 2.4 | 3.4 |
| RR 5 | 07/18/18 | 0.83 | 19.2 | 2.6 | 4.4 |
| RR 6 | 07/24/18 | 4.5 | 12 | 6.6 | 0.3 |
| RR 7 | 08/01/18 | 2.75 | 7.2 | 2.0 | 0.5 |
| RR 8 | 08/03/18 | 4.83 | 9.6 | 6.1 | 0.3 |
| RR 9 | 08/04/18 | 3.5 | 2.4 | 1.2 | 0.45 |
| RR 10 | 08/26/18 | 5.33 | 7.2 | 8.2 | 2.2 |
| RR 11 | 09/10/18 | 1.5 | 4.8 | 2.4 | 7.1 |
| RR 12 | 09/20/18 | 11.58 | 4.8 | 6.8 | 1.8 |

### 3.4 Goodness of Fit Criteria

To evaluate the model performance during calibration and validation, goodness of fit criteria were applied. The Nash-Sutcliffe efficiency (NSE) and coefficient of determination ($R^2$) are commonly used to evaluate model performance. They are given by Equations 3 and 4:

$$[3]\ NSE = 1 - \frac{\sum_{i=1}^{n}\left(y^{i}{}_{obs} - y^{i}{}_{comp}\right)^2}{\sum_{i=1}^{n}\left(y^{i}{}_{obs} - \overline{y_{obs}}\right)^2}$$

$$[4]\ R^2 = \left(\frac{\sum_{i=1}^{n}\left(y^{i}{}_{obs} - \overline{y_{obs}}\right)\left(y^{i}{}_{comp} - \overline{y_{comp}}\right)}{\sqrt{\sum_{i=1}^{n}\left(y^{i}{}_{obs} - \overline{y^{\iota}{}_{obs}}\right)^2 \sum_{i=1}^{n}\left(y^{i}{}_{comp} - \overline{y_{comp}}\right)^2}}\right)^2$$

Where $y^{i}{}_{obs}$= $i^{th}$ observed value, $y^{i}{}_{comp}$= $i^{th}$ computed/simulated value, $\overline{y_{obs}}$ = the mean of the observed values, $\overline{y_{comp}}$= the mean of the computed values, and n is the number of computed/observed values.

NSE is defined as a normalized statistic that determines the relative magnitude of the residual variance (noise) compared to the measured data variance (signal). It determines the goodness of fit by comparing both the volume and shape of the discharge profile. NSE indicates how well the plot of observed versus simulated data fits the 1:1 line. $R^2$ describes the proportion of the variance between the measured values and the simulation (Nash et al. 1970, James 2005, chiwater.com).

## 4 RESULTS AND DISCUSSION

PCSWMM is equipped with a Sensitivity-based Radio Tuning Calibration (SRTC) Tool to calibrate the model against observed data. The user inputs a percentage of estimated uncertainty (e.g. +/- 30%) for each parameter that is considered for calibration based on the accuracy and source of the initial input. This gives a low end value and a high end value for each parameter. The SRTC tool executes a SWMM5 run by using both the high and low values of the designated uncertainty range generating sensitivity gradients for each parameter defined for calibration. The sensitivity analysis can be performed with the SRTC tool before calibration.

## 4.1 Hydrologic/Hydraulic Calibration and Validation of Rocky Ridge

The sensitivity analysis showed that (a) the percent routed (i.e., percent of runoff routed from impervious to pervious subareas), (b) characteristic width, (c) percent imperviousness and (d) slope are the most sensitive parameters for calibration. In highly urbanized areas, it is to be expected that the parameters related to the impervious elements of the catchment will control the hydrograph modeling since the impervious surfaces generate most of the runoff. The roughness coefficients (n) affected the peaks and troughs of the hydrograph, while the depression storage and Horton parameters affected the latter part of the storm. The most sensitive parameters were calibrated first, followed by the parameters with lesser sensitivity. Table 2 lists the initial and calibrated parameters.

Table 2: Initial and calibrated hydrologic/hydraulic parameters for Rocky Ridge

| Parameters | Initial | Calibrated | % Change |
|---|---|---|---|
| Average subcatchment area (ha) | 0.09284 | 0.09284 | - |
| Average width (m) | 30.98 | 41.92 | 35.3 |
| Average slope (%) | 2.35 | 2.35 | 0 |
| Imperviousness ratio (%) | 50 | 49.4219 | -1.2 |
| n Impervious | 0.0125 | 0.0146 | 16.6 |
| n Pervious | 0.15 | 0.1196 | -20.2 |
| Depression Storage (Impervious) | 1.85 | 2.2759 | 23.0 |
| Depression Storage (Pervious) | 7.5 | 11.025 | 47.0 |
| Percent Routed | 50 | 61 | 22.0 |
| Max. Infiltration (mm/hr) | 75 | 118.8 | 58.4 |
| Min. Infiltration (mm/hr) | 7.5 | 1.2 | -84.0 |
| Decay Constant (1/day) | 4.14 | 2.76 | -33.3 |
| Drying Time (day) | 7 | 3.333 | -52.4 |
| PVC Pipe Roughness | 0.011 | 0.011 | 0 |
| Concrete Pipe Roughness | 0.013 | 0.013 | 0 |

Table 3: Simulated versus observed of maximum and total flow for Rocky Ridge

| | Maximum Flow (L/s) | | | Total Flow (L) | | | | |
|---|---|---|---|---|---|---|---|---|
| Event | Simulated | Observed | %Error | Simulated | Observed | %Error | NSE | $R^2$ |
| RR 1 | 44.7 | 47.95 | -6.8 | 158500 | 141300 | 12.2 | 0.951 | 0.959 |
| RR 2 | 115.4 | 124.6 | -7.4 | 1207000 | 1403000 | -14.0 | 0.938 | 0.951 |
| RR 3 | 28.31 | 35.97 | -21.3 | 234200 | 267000 | -12.3 | 0.921 | 0.949 |
| RR 4 | 16.89 | 14.52 | 16.3 | 78990 | 62570 | 26.2 | 0.809 | 0.879 |
| RR 5 | 69.37 | 81.85 | -15.2 | 85610 | 73830 | 16.0 | 0.903 | 0.907 |
| RR 6 | 66.8 | 77.86 | -14.2 | 222800 | 216400 | 3.0 | 0.953 | 0.955 |
| RR 7 | 36.01 | 38.85 | -7.3 | 65760 | 60700 | 8.3 | 0.945 | 0.948 |
| RR 8 | 52.75 | 55.44 | -4.9 | 200500 | 204400 | -1.9 | 0.938 | 0.939 |
| RR 9 | 7.422 | 9.488 | -21.8 | 39790 | 33720 | 18.0 | 0.844 | 0.853 |
| RR 10 | 41.65 | 35.88 | 16.1 | 271600 | 245000 | 10.9 | 0.919 | 0.931 |
| RR 11 | 31.19 | 31.79 | -1.9 | 76770 | 81060 | -5.3 | 0.965 | 0.967 |
| RR 12 | 23.88 | 30.33 | -21.3 | 223900 | 217800 | 2.8 | 0.944 | 0.947 |

The parameters for RR were optimized to obtain the closest accuracy to the observed flow. The calibration and validation of the hydrological parameters gave very good results. Results for NSE and $R^2$ are typically rated “excellent” for values greater than 0.85 and “very good” for values ranging from 0.65-0.85 (Kabbani 2015). Using the validated model parameters resulted in a minimum NSE of 0.809 and minimum $R^2$ of 0.853 for the 12 storm events used in this study. The overall NSE is 0.773 and $R^2$ is 0.815 for the whole time series. The NSE and $R^2$ for the maximum flow are 0.935 and 0.968 and for the total flow 0.982 and 0.997, respectively. Therefore, the model gave very good to excellent results.

Table 3 shows the observed versus simulated maximum flow and total flow of the 12 RR events after calibration and validation. Their goodness of fit results and % relative errors, all within 30%, are also included. Figure 2 shows the simulated and observed hydrographs for two of the storm events (June 23 and August 26), showing how well the model captures the shape of the hydrograph, and the maximum and total flow for the 12 storm events.

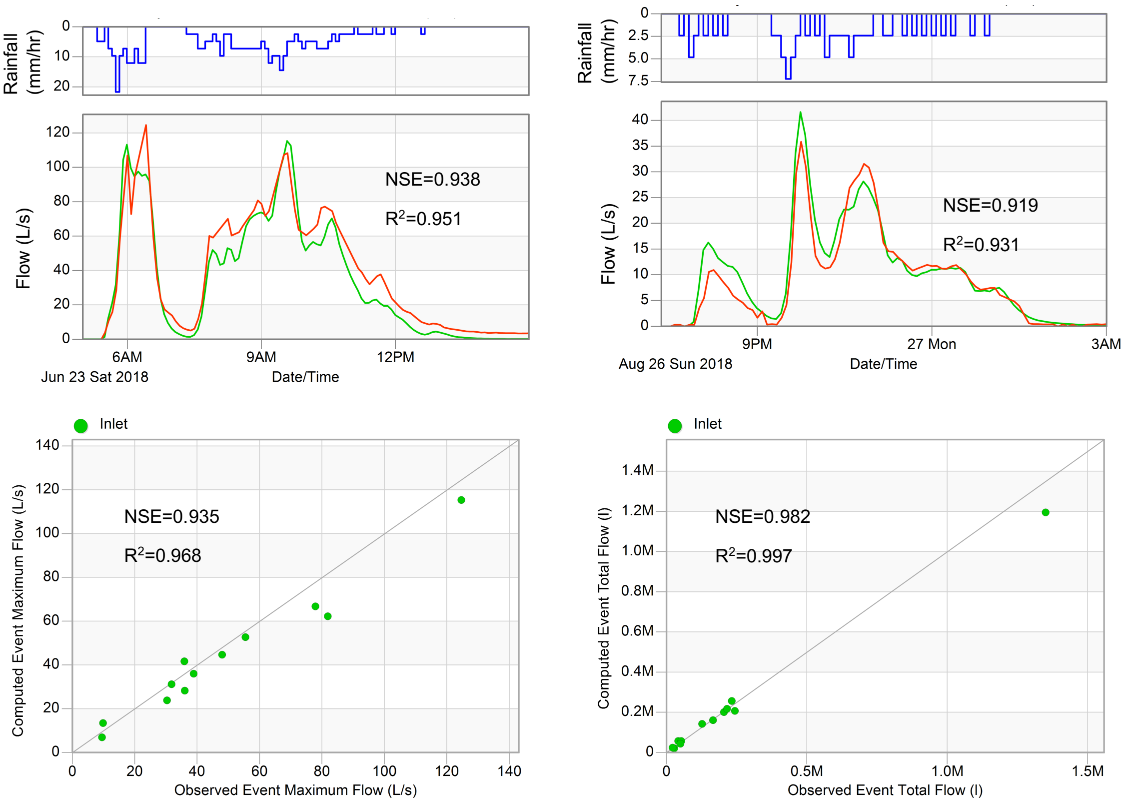

Figure 2: Observed versus simulated flow for Rocky Ridge at the pipe inlet. The green and red hydrograph represents the simulated and observed flow, respectively. Events RR2 and RR10 are shown plotted on the left and right, respectively.

### 4.2 Water Quality Parameter Calibration for Rocky Ridge

Calibration of the water quality parameters was conducted following the hydraulic parameter calibration. Six events captured by the RR autosampler were considered for water quality calibration. Aliquots were mixed to obtain composite samples, which resulted in EMC of the pollutants for each sampling event. Because of this, the actual shape of the pollutograph was not captured. Therefore, the water quality parameters were calibrated using the EMC for the individual storm events. The sensitivity analysis found that the washoff coefficient ($C_w$) is the most sensitive parameter followed by the maximum buildup coefficient ($C_1$). Therefore the calibrated water quality parameters for these two coefficients are presented in Table 4 for the 6 events. The simulated and observed mean concentrations are within 10% of each other, as shown in Table 5.

Table 4: Event-based calibrated $C_1$ and $C_w$ parameters for Rocky Ridge

| Date | | 06/22/18 | 06/28/18 | 08/24/18 | 08/26/18 | 09/10/18 | 09/26/18 |
|---|---|---|---|---|---|---|---|
| Max. Intensity (mm/hr) | | 21.6 | 4.8 | 14.4 | 7.2 | 4.8 | 7.2 |
| Total Rainfall (mm) | | 34.6 | 7.2 | 9.8 | 8.2 | 2.4 | 11.6 |
| Duration (hh) | | 22.2 | 3.9 | 5.3 | 5.4 | 1.5 | 15.5 |
| ADD (days) | | 5.8 | 5.4 | 4.2 | 2.2 | 7.1 | 2.2 |
| Total Suspended Solids | | | | | | | |
| Hard surface | $C_1$ | 90.509 | 24.368 | 50.685 | 29.815 | 25.860 | 48.736 |
| | $C_w$ | 144.000 | 7.169 | 24.194 | 14.232 | 12.733 | 8.961 |
| Pervious | $C_1$ | 24.462 | 6.586 | 13.699 | 8.058 | 6.989 | 13.172 |
| | $C_w$ | 21.333 | 1.062 | 3.584 | 2.108 | 1.886 | 1.327 |
| Roof | $C_1$ | 73.386 | 19.758 | 41.096 | 24.174 | 20.967 | 39.515 |
| | $C_w$ | 58.667 | 2.921 | 9.857 | 5.798 | 5.188 | 3.651 |
| Total Nitrogen | | | | | | | |
| Hard surface | $C_1$ | 1.552 | 0.672 | 1.040 | 0.672 | 0.672 | 0.196 |
| | $C_w$ | 0.789 | 0.503 | 2.394 | 0.503 | 0.503 | 0.352 |
| Pervious | $C_1$ | 3.492 | 1.512 | 2.340 | 1.512 | 1.512 | 0.441 |
| | $C_w$ | 0.358 | 0.229 | 1.088 | 0.229 | 0.229 | 0.160 |
| Roof | $C_1$ | 0.776 | 0.336 | 0.520 | 0.336 | 0.336 | 0.098 |
| | $C_w$ | 0.573 | 0.366 | 1.741 | 0.366 | 0.366 | 0.256 |
| Total Phosphorus | | | | | | | |
| Hard surface | $C_1$ | 0.100 | 0.012 | 0.044 | 0.052 | 0.032 | 0.036 |
| | $C_w$ | 0.307 | 0.026 | 0.081 | 0.034 | 0.031 | 0.026 |
| Pervious | $C_1$ | 0.200 | 0.023 | 0.088 | 0.104 | 0.064 | 0.072 |
| | $C_w$ | 0.087 | 0.007 | 0.023 | 0.010 | 0.009 | 0.007 |
| Roof | $C_1$ | 0.070 | 0.008 | 0.031 | 0.036 | 0.022 | 0.025 |
| | $C_w$ | 0.175 | 0.015 | 0.046 | 0.020 | 0.018 | 0.015 |

Table 5: Simulated versus observed event mean concentration for Rocky Ridge

| | TSS (mg/L) | | TN (mg/L) | | TP (mg/L) | |
|---|---|---|---|---|---|---|
| Event | Observed | Simulated | Observed | Simulated | Observed | Simulated |
| E1 | 144 | 149.6 | 1.21 | 1.099 | 0.178 | 0.181 |
| E2 | 13 | 13.19 | 0.96 | 0.984 | 0.034 | 0.035 |
| E3 | 50 | 49.41 | 3.65 | 3.742 | 0.108 | 0.111 |
| E4 | 28 | 27.26 | 1.07 | 1.031 | 0.0632 | 0.061 |
| E5 | 22 | 22.89 | 0.95 | 0.972 | 0.057 | 0.058 |
| E6 | 17 | 17.43 | 0.655 | 0.626 | 0.04475 | 0.042 |

### 4.3 Model Validation for "Ungauged" Catchment – Royal Oak

In stormwater management modelling, it is common practice to extrapolate calibrated parameters from a "gauged" catchment and apply it to other catchments. The calibrated parameters from RR were therefore applied to RO to evaluate to what extent these parameters can be applied to other "ungauged" catchments. The RO wetland is located approximately 500 m away from the Rocky Ridge wetland and the catchments are similar in size.

Applying the hydrological parameters to RO gave an overall NSE of 0.19 and $R^2$ of 0.723 for the time series evaluated. Table 6 below shows the percent errors between simulated and observed maximum flow values and total flow volumes. The model overpredicted the total flow volume significantly, by more than a factor of two in some cases. Due to the poor performance of the model in predicting the hydrographs, no comparison was conducted for the water quality parameters at RO.

Table 6: Simulated versus observed maximum and total flow for Royal Oak using Rocky Ridge calibrated parameters

| | | Total Flow (L) | | | Maximum Flow (L/s) | | | Max. Intensity (mm/hr) | Total Rainfall (mm) |
|---|---|---|---|---|---|---|---|---|---|
| Event | Date | Simulated | Observed | %Error | Simulated | Observed | %Error | | |
| RO 1 | 8/24/18 | 381500 | 155100 | 146.0 | 95.47 | 65.3 | 46.2 | 14.4 | 9.8 |
| RO 2 | 8/26/18 | 330500 | 206600 | 60.0 | 40.61 | 39.95 | 1.7 | 7.2 | 8.4 |
| RO 3 | 9/03/18 | 113000 | 70410 | 60.5 | 37.04 | 37.98 | -2.5 | 7.2 | 3 |
| RO 4 | 9/10/18 | 89290 | 69810 | 27.9 | 30.97 | 32.54 | -4.8 | 4.8 | 2.4 |
| RO 5 | 9/19/18 | 45080 | 32470 | 38.8 | 8.826 | 8.991 | -1.8 | 2.4 | 1.2 |
| RO 6 | 9/20/18 | 264000 | 213100 | 23.9 | 25.89 | 29.49 | -12.2 | 4.8 | 6.8 |
| RO 7 | 9/23/18 | 46400 | 31640 | 46.6 | 6.48 | 3.272 | 98.0 | 2.4 | 1.2 |
| RO 8 | 9/26/18 | 462500 | 240500 | 92.3 | 35.07 | 19.64 | 78.6 | 7.2 | 11.6 |

### 4.4 Discussion

During the hydrological calibration, the percent of runoff routed from impervious to pervious areas and subcatchment width were the most sensitive parameters for all events. However, the infiltration parameters were governed by the June 23 event, which had the greatest maximum intensity and rainfall total. This is a reflection of the impervious surfaces contributing most of the runoff for the smaller events, while the contribution of the pervious areas only becomes pronounced during the larger events. Burton and Pitt (2001) state that pervious areas are not active runoff contributors for rain events lesser than 5 to 10 mm.

About 80% of Calgary's historical storm events are less than approximately 5 mm in depth (Westhoff Engineering 2007). For these small events, the directly connected paved surfaces typically contribute most of the runoff and pollutants (Burton and Pitt 2001). However, an analysis of the representation of the pervious areas is still needed for water quality modeling to determine the extent of their contribution. This emphasizes the importance of defining appropriate values for the different land surface characteristics (e.g., hard surface area) within a catchment and not lumping them under one land use activity (e.g., residential).

Pollutants from pervious areas are mobilized through an erosion process by the kinetic energy of rain drops removing soil from the surface (Burton and Pitt 2001, Murphy et al. 2015). This may explain why the June 23 event, compared to the much smaller events, had the biggest EMC for TSS and TP. However, for smaller rain depths, plants in pervious areas actually act as filters for pollutants. More data is needed to determine the contributions of the smaller events to the overall runoff volume and pollutant loading on an annual basis.

The event-based water quality calibration showed that the maximum buildup and washoff coefficient govern the event mean concentration simulation. The buildup rate constant was not sensitive and stayed consistent for all pollutants since only the EMC was used for calibration of the water quality parameters. Table 5 shows that TSS and TP follow a similar trend for all parameters across the 6 events. The EMCs for TSS and TP were also correlated with the maximum intensity and rainfall depth. This relationship between TSS and TP indicates that the main form of phosphorus is associated with particulate matter in stormwater runoff (Arias et al. 2013, Song et al. 2017). However, a more detailed analysis of the forms of phosphorus is needed to confirm this finding.

A study by He et al. (2010) analyzed the relationship between event mean concentrations in stormwater and rainfall characteristics in the 150 ha residential development Inverness area (southeast Calgary). Their conclusion that the TSS EMC strongly correlated with rainfall depth and intensity is consistent with the findings of this study. Their EMC for TSS ranged from 20 – 342 mg/L compared to 13 – 144 mg/L for the current study. The smaller values for RR might be attributed to RR not featuring any lanes and Inverness still being under active residential development.

The exponential buildup function, which is usually paired with the exponential washoff function, is widely used in watershed models such as SWMM due to their ability to best replicate the real-life buildup and washoff of pollutants over a catchment area (Kabanni 2015, Xi et al. 2018). In the current study, the exponential buildup and EMC washoff function was used. It was found that the washoff coefficient dominated the pollutant loading. The range of the calibrated buildup parameters agree with buildup parameters from previous studies, although the latter are located in humid climates (Chow et al. 2012, Li et al. 2016).

It was expected that the calibrated parameters from RR would be applicable to RO because of similar catchment characteristics and their closeness in proximity. The maximum flow rate was captured well for 5 out of 8 events but it was overestimated for the other events (i.e., RO1, RO 7 and RO 8). However, the total flow volume was overestimated for all events. Although the Rocky Ridge weather station is close to the Royal Oak wetland, the rain intensity can still differ between the two catchments, which could have contributed to the large errors.

During the RR hydrologic/hydraulic calibration, it was observed that the measured hydrograph showed flow data in the absence of rainfall events. These readings might be caused by potential landscape watering (e.g. lawn watering) and car washing. This is one component in urban drainage modeling that is typically overlooked but can have a substantial impact on the total volume. Evaluation of this component is recommended for future work to determine the effects of watering practices on the modeling results.

## 5 CONCLUSION AND FUTURE WORK

Calibration and validation of a watershed model can be a useful and cost-effective tool for predicting sediment and nutrient loadings into stormwater ponds. PCSWMM was able to successfully model the RR catchment. However, some challenges were observed for watershed modeling. Extrapolation of the calibrated results from RR to RO gave a significant overestimation of the total runoff volume. The calibration of the RR water quality parameters showed that the washoff coefficient and maximum buildup governed the pollutant loading. The EMCs showed a strong correlation with the maximum intensity and total rainfall for TSS and TP. Year 2 of field monitoring will provide more data to serve as verification of Year 1 results. A separate calibration for RO is needed to determine the difference in other calibration parameters. Discretized water quality samples are needed for the second year of field monitoring to capture the shape of the pollutograph. Subsequently, quantity and quality modeling will be applied to the two wet ponds with a similar approach used in this study.

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