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ABSTRACT

Designing and sizing Low Impact Development (LID) stormwater devices to accommodate real world events and shifting hydrologic regimes can be a challenge. There is often much uncertainty regarding how a LID system will perform over time in terms of water balance, flooding, soil moisture, and clogging. Recent improvements in hydrologic models such as SWMM have attempted to address some of these challenges. SWMM is a widely-used open source, dynamic rainfall-runoff-routing simulation model capable of simulating the physical processes occurring in the individual layers of LID controls.

In this paper the LID Retrofit design project for the Mississauga Road in Ontario, Canada will be presented as an example of how modelling can be used to guide the LID design and sizing process. The retrofit project was initiated by the Region of Peel to replace the existing highway median with a series of six enhanced swales and one large bioswale. Simulation of design storms using SWMM was used to evaluate the LID system's potential runoff volume reduction as well as mitigation of peak flows for large events. Continuous modelling for the years 2004 to 2013 was used to evaluate long term water balance, identify flooding events, as well as determine the maximum duration of wilting point conditions in consideration of vegetation health. Based on the results of the modelling the design was adjusted and the models rerun in an iterative process to meet performance objectives (e.g. complete capture of a 25mm event).

INTRODUCTION

Low Impact Development (LID) practices can help mitigate the hydrologic changes associated with urbanization including reduced groundwater recharge and increased runoff volumes and peak flows (Dietz 2007). As the popularity of LID has increased in recent years, stormwater modelling tools such as SWMM (Stormwater Management Model) have evolved to incorporate various elements for the modelling of LID systems (Rossman 2010).

The number of LID installations has been increasing rapidly in the province of Ontario, Canada, especially in highly urbanized areas and new developments near sensitive waterbodies. There have been numerous LID projects in recent years including the one focused on in this paper, a retrofit design for a portion of the median on the Mississauga Road. For this retrofit project the existing grassed median will be replaced with a series of six enhanced swales and one large bioswale.

Currently the sizing of LID and other stormwater management facilities largely relies on event based sizing methods which target specific rainfall characteristics. As noted by Gregory (2015), continuous simulation offers a greater diagnostic tool for assessing LID performance as it can describe the full range of runoff response characteristics, compared to a limited snapshot view using design storm events. Although there is much knowledge that can be gained from the continuous modelling of stormwater facilities, this practice is still not commonplace, perhaps due to the required data inputs, additional effort required, and lack of clear modelling objectives.

Real world examples of LID modeling (especially continuous modelling) are now needed to serve as case studies demonstrating the input requirements, capabilities and limitations of these techniques for use in a variety of urban settings. This paper will outline the development of a SWMM model representing the proposed LID retrofit for the Mississauga Road in Ontario, Canada. A ‘dual drainage’ model approach was taken meaning that flow through the stormsewer system as well as flow on the street surface are taken into account. The model was developed with the aim of evaluating the LID system’s potential runoff volume reduction as well as mitigation of peak flows for large events. Continuous modelling was used to evaluate long term water balance, identify flooding events, and prolonged dry periods. This paper will focus on the data inputs, model development, parameterization, and data extraction from the LID model.

STUDY AREA

The model area includes a portion of the Mississauga Road in Southern Ontario, Canada, running from the Credit River to Williams Parkway (Figure 1). The total area is approximately 10 ha and is almost completely impervious. The elevation of the modeled area varies from 240 m.a.s.l. at the northwest extent to 186 m.a.s.l. in the southeast extent. The minor drainage system in the watershed consists mainly of circular concrete pipes and grassed ditches in some areas. The major drainage system consists of mostly asphalt covered roads.

Figure 1. Mississauga Road model area, Ontario, Canada (from Google Earth)

METHODS

Software

All model development was performed using PCSWMM, a GIS-based spatial decision support system for the SWMM engine. SWMM is a dynamic hydrologic and hydraulic simulation model developed by the United States Environmental Protection Agency used for single-event and continuous simulation of water quantity and quality (Rossman and Huber 2016). The ability to model LID controls was first added to SWMM in 2010 (Rossman, 2010). The current LID toolkit in SWMM allows for the simulation of the physical processes (i.e. storage, infiltration, evapotranspiration, and overflow) occurring in the individual layers of bioretention cells, infiltration trenches, vegetative swales, porous pavement, rain barrels, rain gardens and green roofs.

Model Development

First a model representing the current conditions was developed to provide the design engineers and landscape architects with estimates of the inflows that could be expected for a variety of design storms. The developed existing conditions model is composed of subcatchments, major and minor system conduits, orifices, junctions and outfalls. An inventory of the SWMM entities used to model the drainage system in the project area is presented in Table 1.

Table 1. Inventory of SWWM5 entities

SWWM5 Entity	Count	Description
Minor System Junctions	149	manholes/catchbasins
Major System Junctions	94	inlet locations
Minor System Conduits	159	stormwater pipes and ditches
Major System Conduits	93	street flow paths
Orifices	94	controls flow between minor and major system at catchbasin locations
Subcatchments	102	drainage areas
Outfall nodes	6	locations where flow can exit the model area

The model area was discretized into 102 subcatchments (Figure 1) based on AutoCAD dxf drawings of the drainage areas imported into PCSWMM. Subcatchment flow length was assumed to be 20m for all subcatchments, the estimated average length of sheet flow along the highway. The average slope of subcatchments was assumed to be 2%, based on the average transverse slope of the road. Manning’s roughness values of 0.012 and 0.24 were assigned to impervious and pervious areas, respectively (James et al. 2010, Table 24.6). Depression storage values of 2.5 mm and 5 mm were assigned to impervious and pervious areas, respectively (James et al. 2010, Table 24.5). The percent imperviousness was assigned based on the values in the imported dxf drainage plates.

The physically based Green-Ampt method was used to model infiltration. It was assumed that all native soils in the model are silt loam with a suction head of 170 mm (James et al. 2010, Table 20-15). Saturated hydraulic conductivity was assumed to be 6mm/hr based on infiltration testing of the soil. Field capacity and wilting point were assumed to be 0.28 and 0.13, respectively (James et al. 2010, Table 24.2)

SWMM conduit links were used to represent all stormsewer pipes, roadside ditches, culverts and street flow paths in the model. Pipe locations were imported from the dxf drainage plates. Diameter, material, slope and length for minor system pipes were obtained from the original design sheets. Entrance and exit loss coefficients of 0.2 and 0.4, respectively, were assigned to all minor system conduits.

The flow on each side of the road median was modelled with a separate conduit. Each half-street cross section was assumed to be 13.5m wide and sloping at 0.02 m/m from crown to curb. A Manning’s roughness of 0.014 was assigned to all major system conduits, representing the asphalt surface. The conduits representing grassed ditch sections were added to the model manually and were assumed to be open trapezoidal conduits 1 m deep with a bottom width of 1.5m and side slopes of 1m/3m based on the road cross sections. All conduits representing grassed ditches were assigned Manning’s roughness coefficients of 0.03 (James et al. 2010, Table 24.8).

Minor system junction locations were imported from a dxf containing manhole locations provided by the consultant. Manholes invert elevations were assumed to be equal to the lowest connected pipe invert elevation at each junction. At each manhole location a second junction was created to represent the catchbasin inlet using PCSWMM's dual drainage creator. Each subcatchment drains all runoff to the most downstream major system node within its boundaries. At each of these junctions a SWMM5 orifice link was used to control flow from the major system to the minor system. Each of these links was assumed to have a side orifice opening with a width of 580 mm and a height of 127 mm.

Design Storm Scenarios

The existing conditions model was run for the 2, 5, 10, 25, 50 and 100 year Modified Chicago 3 hour design storm defined by local intensity-duration-frequency curves. As there is no Chicago design storm currently defined for a 25mm rainfall, the 25 mm event was created by adjusting the Modified Chicago design storm coefficients to give a total rainfall of 25.0 mm. A time step of 10 minutes was used for all modelled design storms so that results could be compared to the rational method calculations which assumed 10 minute intervals. Table 2 summarizes the total rainfall, peak intensity (during any 10 minute time step) and Modified Chicago Storm Coefficients specified by the City of Brampton for the design storms.

Table 2. Design storm specifications.

Event	Maximum Intensity (mm/hr)	Total Rainfall (mm)	Modified Chicago Storm Coefficient	
			A	B
25 mm	66.5	25.0	18.4	0.719
2 year	79.3	30.3	22.1	0.714
5 year	104.9	41.5	29.9	0.701
10 year	121.8	49.1	35.1	0.695
25 year	143.3	58.4	41.6	0.691
50 year	159.3	65.5	46.5	0.688
100 year	175.1	72.4	51.3	0.686

Modelling the LID Retrofit

The LID retrofit designed by the consultants includes a flow splitter upstream of the LID system which diverts a portion of the minor system flow through an orifice plate and into a newly constructed section of pipe that carries flow to the most upstream of a series of six 'enhanced swales'. An enhanced swale is a swale that includes a weir (or check dam) at the downstream end to allow ponding and sedimentation. When water ponded on the enhanced swale reaches the weir's crest elevation it begins to cascade into the next enhanced swale in the series. Weep holes located below the crest of each weir allow water to be slowly released into the next enhanced swale after ponded water has infiltrated. The sixth enhanced swale in the series overtops into a large bioswale. When the bioswale reaches capacity it begins overflowing through an overflow grate and into the existing minor drainage system.

The LID Retrofit model scenario was adapted from the model of existing conditions outlined in the Model Development section. The SWMM elements added to the base model to represent the LID elements are shown in Figure 2. Seven additional subcatchments were added to the base model to represent the six enhanced swales and one bioswale LID control. An initial saturation of 15% was assumed for the soil in each LID. Swales 1 through 6 as well as the large bioswale were each modelled as bioretentions, the only LID control in SWMM5 which includes both a storage and a soil layer. The weep holes in the weir plates were modelled as underdrains.

The outflow from the upstream stormsewer pipes flows into the most upstream LID area (i.e. Swale1) via the StormOut outfall junction. A storage node was added to each enhanced swale to represent the ponded volume above the weir crest height. When the ponded water in the enhanced swale reaches its maximum ponding depth (or 'berm height') of 0.1 m, any additional ponded volume is added to the storage node. From the storage node water can flow over the weir to an outfall node. The outfall node is assigned the next enhanced swale in the series as its outlet. This setup is repeated for each consecutive enhanced swale in the series until Swale 6, which has the bioswale subcatchment assigned as its outlet. This type of complex, inline LID system has only been possible thanks to a change made in SWMM version 5.1.008 released in April of 2015 which allowed conveyance system outfall nodes to send their outflow to a subcatchment.

When the ponded depth in the bioswale LID reaches its maximum depth of 0.3 m, any additional ponded water flows to a storage node. Outflow from this storage node into the downstream stormsewer system is controlled by an outlet link with an assigned rating curve to represent in overflow grate. Water is allowed to pile up on top of the bioswale up to a height of 0.45m (i.e. 0.15m above the overflow inlet). At surface depths greater than 0.45m overtopping onto the road will occur.

Figure 2. Mississauga Road LID retrofit SWMM model.

Model Runs and Design Adjustments
Scenarios were created and run for each of the storms previously described in the Design Storms section using PCSWMM's design storm creator tool. LID dimensions (primarily soil layer depth) were lowered incrementally and the design storm scenarios rerun until the LID system could accommodate exactly a 25 mm event without overflowing into the downstream stormsewer. The new LID specifications based on the 25 mm event were shared with the consultants and the design drawings were adjusted accordingly. Capture of the first 25mm of rainfall by the LID system ensures that the majority of highly polluted runoff will be treated as most of the rainfall comes from events of less than this size.

Continuous modelling for the years 2004 to 2013 was used to evaluate long term water balance, identify flooding events, and determine the maximum duration of wilting point conditions in the soil layer of the LID devices. Each year was simulated as a separate model event running from approximately the beginning of April to the beginning of November. Simulations periods for some years have shorter durations due to gaps in the available data. Rainfall input for the continuous modelling was based on 15 minute interval data from a rain gauge located at a nearby firehall. Evaporation was calculated by SWMM using Hargreave's method (Rossman and Huber, 2016) throughout the simulations based on the minimum and maximum daily temperatures measured at the nearby Pearson Airport.

RESULTS

The results tables in this section provide an example of the type of flow and volume data that can be extracted from a SWMM model. Data from the SWMM output file and the detailed LID reports from each individual LID catchment were required to complete the tables. Results of the design storm scenario modelling runs are shown in Tables 3 and 4 and results from the continuous modelling runs are presented in Tables 5 to 6. The results for Swales 2 to 5 were omitted, as maximum flows over the weirs decrease gradually from Swale 1 to Swale 6, while the time to drain the surface increases gradually from Swale 1 to Swale 6.

Table 3. Design Storm results from flow splitter to Swale 6

Storm	Total Rainfall (mm)	Peak 10 Minute Intensity (mm/hr)	From Flow Splitter to StormOut Outfall		Weir at Flow Splitter		Swale 1		Swale 6	
			Max Flow (l/s)	Volume Through (m^3)	Max Flow (l/s)	Volume Over (m^3)	Max Outflow (l/s)	Time to Drain Surface (hours)	Max Overflow (l/s)	Time to Drain Surface (hours)
25 mm	25	66.5	250	560	0	0	242	17	189	21
2 year	30.3	79.3	263	710	62	30	260	17	228	21
5 year	41.5	104.9	280	950	250	204	278	17	258	21
10 year	49.1	121.8	289	1090	386	356	286	17	268	21
25 year	58.4	143.3	298	1270	538	557	295	17	276	21
50 year	65.5	159.3	301	1400	601	710	299	17	280	21
100 year	72.4	175.1	303	1530	636	862	301	18	284	21

Table 4. Design Storm results from Bioswale to outfall (OF2)

Storm	Bioswale							Total Volume Retained in whole LID System (m^3)
	Max Overflow (l/s)	Overflow Volume (m^3)	Underdrained Volume (m3)	Max Surface Depth (mm)	Time to Drain Surface (hours)	Time to Drain Soil to Field Capacity (hours)	Volume Retained (m^3)	
25 mm	0	0	290	320	15	22	232	295
2 year	70	119	326	350	16	23	233	295
5 year	145	331	363	400	16	23	234	296
10 year	172	470	375	420	16	23	235	298
25 year	188	639	390	450	16	23	236	299
50 year	200	767	400	460	16	23	236	300
100 year	210	896	410	480	16	23	236	301

Table 5. Continuous modelling results from flow splitter and Swale 1

Start Date	Duration (days)	Total Rainfall (mm)	Peak 15 Minute Intensity (mm/hr)	Flow Splitter Orifice Plate (towards LID system)		Flow Splitter Weir (towards outfall at Adamsville Road)			Swale 1	
				Maximum Flow (L/s)	Volume Through (ML)	Maximum Flow (L/s)	Volume Over (ML)	Number of times crest overtopped	Max Outflow (L/s)	Volume Retained (ML)
05/06/2004	127	244	28	138	3.1	0	0	0	134	0.3
07/08/2005	74	410	180	309	8.6	770	2.7	5	309	0.1
05/11/2006	175	540	76	287	10.1	358	0.4	3	285	0.2
4/23/2007	193	266	47.2	263	4.1	64	0.1	2	263	0.1
4/28/2008	188	578	35.2	258	11.3	25	0	1	256	0.2
05/07/2009	179	458	86.9	282	8.3	272	0.7	4	281	0.2
6/22/2010	133	392	56.2	279	8.6	228	0.2	4	278	0.2
4/16/2011	200	592	34.4	160	9.5	0	0	0	152	0.3
4/15/2012	201	529	34	264	9	67	0.1	2	261	0.2
4/17/2013	56	174	43.9	242	3	0	0	0	236	0.1
Total	1526	4184	-	-	75.5	-	4.2	21	-	2

Table 6. Continuous modelling results from Swale 6 and Bioswale

Start Date	Swale 6		Bioswale							Whole System
	Max Outflow (L/s)	Volume Retained (ML)	Max Overflow (L/s)	Overflow Volume (ML)	Volume Underdrained (ML)	Volume Retained (ML)	Max Ponded Depth (mm)	Days <= Field Capacity	Days at Wilting Point	Volume Retained (ML)
05/06/2004	111	0.2	16	0	0.5	1.5	310	124	0	3.2
07/08/2005	303	0.2	260	3.7	2.5	2.6	580	70	2.8	3.5
05/11/2006	270	0.4	201	1.7	2.9	3.9	470	166	0	6
4/23/2007	251	0.2	188	0.8	0.7	1.7	450	189	0	2.9
4/28/2008	229	0.5	152	1.3	3.9	4.4	410	179	0	6.6
05/07/2009	269	0.4	221	1.6	1.9	3.4	500	173	0	5.3
6/22/2010	269	0.3	194	1.9	2.4	3.2	460	124	0	4.7
4/16/2011	134	0.5	104	0.7	2.1	4.9	370	192	3.1	7.3
4/15/2012	249	0.4	191	1	2.3	4.1	450	193	16.1	6.2
4/17/2013	205	0.2	78	0.3	1	1.1	360	54	0	1.8
Total	-	3.4	-	13	20.3	30.9	-	1465	21.9	47.5

DISCUSSION

Design storm modelling based on the final design specifications indicated that there will be no overflow at the flow splitter or from the bioswale during the 25mm event. For events larger than the 25 mm event, there will be overflow at both the flow splitter and the bioswale's overflow grate. The maximum computed depth of ponded water on the bioswale varied from 300 mm for the 25 mm storm to 480mm for the 100 year storm. Modelling of design storms also provided an estimate of the reduction in peak flows from the flow splitter to the outfall at Adamsville Road. For the 25 mm event, all of the flow into the flow splitter is diverted to the LID system (Table 3).

Results from the continuous modelling indicated that for all years simulated, with the exception of 2005, the LID system would be able to retain more than half of the flow volume entering the flow splitter. As the year 2005 had several large events and a relatively short simulation duration, only 3.5 ML of total 11.3 ML entering the flow splitter was retained in the LID system (Table 6). Continuous simulation also indicated that from 2004-2013, the bioswale would have had a ponded depth exceeding 450 mm once in 2005, 2006, and 2010 and twice in 2009. Two other years (2007 and 2012) had maximum ponded depths of 450mm and therefore would have been close to overtopping the bioswale.

Continuous modelling results shown in Table 6 indicated that the bioswale soil moisture would be equal to or less than field capacity for 1465 of the 1526 days simulated. Wilting point was reached for an equivalent of 31 days, or approximately 1.4% of the 1526 days simulated. The longest continuous period the bioswale soil was at the wilting point was 14 days.

CONCLUSION

This paper has outlined how hydrologic and hydraulic modelling was used to aid in the design and sizing of a new LID System planned for a section of the median on the Mississauga Road. Modelling of design storms was undertaken to compare the LID system performance to the existing condition in terms of water balance, runoff volume, and peak flows. Design storm modelling also ensured that the water quality objective was achieved (i.e. treatment of the 25 mm event). Continuous modelling of the system provided an estimate of long term water balance, determined frequency of potential flooding events, and the historic maximum duration of wilting point conditions.

The most recent version of SWMM allows many configurations that were not possible just one year ago. For example, the modelling of LID systems with many inline elements separated by weirs or those receiving inflow from a pipe network can now be modelled by allowing an outfall node to flow to an LID subcatchment. Models like SWMM are becoming increasingly versatile and can be a valuable tool to aid in the design, sizing, and planning of LID systems. Continuous modelling based on historic local rainfall and temperature data can be used to evaluate LID systems and better understand how they will perform during real world wet and dry periods. This information can be valuable to managers who have an interest in how often water may overflow onto the road and how often vegetation will require irrigation.

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