2013

Showcasing Water Innovation: Stormwater Performance Monitoring Report

Lake Simcoe Region conservation authority

Background

Stormwater management ponds are widely used in Ontario to provide quantity and quality control of surface runoff prior to entering watercourses. Over time, however, excessive deposition of silt, sand and other materials in the ponds can compromise their performance. Previous research by the Lake Simcoe Region Conservation Authority (LSRCA) has shown that traditional stormwater management ponds accumulate particulate phosphorus (P) and, under anoxic conditions, may become a source of soluble phosphorus, a biologically available form of this nutrient, which contributes to excess plant and algae growth, eutrophication, and loss of cold water fish habitat downstream. As a result, there is a need to retrofit stormwater management ponds in a cost-effective manner that addresses performance concerns (e.g. water quality) and accounts for existing site-constraints.

LSRCA identified three facilities to be retrofitted in this project. These ponds were originally constructed to meet local water quantity management objectives as part of urban development in their respective communities. Additionally, these ponds no longer met the minimum stormwater quality performance standards, and were providing little, if any, water quality improvement benefits. The retrofit approaches undertaken employed technologies designed to remove a portion of both particulate and soluble phosphorus, prior to release into the receiving watercourse.

The objective of this project was to compare and contrast the efficiency and efficacy of three innovative technology approaches to retrofitting stormwater management ponds, each designed to decrease the level of phosphorous and other pollutants discharged to the receiving water body. The implementation of three different technologies will not only assess the technologies individually, but also comparatively, in order to demonstrate how each approach may be best-suited to similar catchment areas province-wide.

This report covers the results of the monitoring work conducted at each facility in order to determine the efficacy of the retrofit facility.

Retrofit 1: The George Richardson Pond is located in Newmarket and services a 155 ha catchment with, primarily, residential land use. The design for the retrofit project included a typical forebay and main cell with the installation of an oil/grit separator and a red sand filter media chamber. The treatment train approach is intended to first capture the larger sediment particles and then the suspended particles and soluble material as the water travels through the system. The red sand filter media chamber is designed to capture soluble phosphorus that generally passes through a typical stormwater management pond. The footprint of the existing facility has minimal elevation changes making for some challenges in conveying water through the full treatment train. The original concept design looked at installing a pumping system to assist in conveying flows through the treatment train. Due to the potential costs and maintenance issues, the solution was to extend the outfall pipe to extend the fall and allow the system to function by gravity alone.

Retrofit 2: The Colony Trail retrofit is located in East Gwillimbury and services an 18 ha residential catchment. The design of the project included a typical forebay with the installation of several wetland cells and a "Sorbtive media" chamber. The treatment train approach is similar to the above noted project with the "Sorbtive" media" media chamber being the last stop to capture the soluble phosphorus prior to entering the receiving waters. This project included a mixture of using natural plant life in the wetland cells and innovative media materials to improve water quality.

Retrofit 3: The Lincoln pond retrofit is located in Uxbridge and services an 18 ha residential catchment. This retrofit project included an engineered wetland component in the design. Similar to the above projects, the Lincoln pond included a forebay and main cell with a clear aggregate added in part of the treatment train. The clear aggregate provides an area of voids that allows for vegetation root systems and bacteria to grow and capture additional soluble material.

Performance Monitoring Program Design

In order to determine the efficiency of each facility or feature, a water and chemical mass balance is conducted on representative precipitation events. This is achieved through the installation of automated monitoring equipment at the primary inlet(s) and primary outlet, consisting of flow loggers and autosamplers. Flow data was logged at 15 minute intervals (or shorter depending on flow characteristics) with the resulting data used to calculate a water balance. A water level logger was placed in the pond to help account for water loss (negative water balance) due to infiltration and evaporation.

Figure 1 - Monitoring equipment setup at Colony Trail facility

Autosamples were used to collect water samples during storm events. Samples were combined to represent the rising limb, peak and falling limb of the event hydrograph if sufficient sample water was available. The samples were analyzed for total phosphorus (TP), orthophosphate, chloride (Cl^-), and total suspended solids (TSS) for each event captured. The resulting concentrations when combined with the water balance yield a mass balance for each parameter for each captured event. The reduction of a given parameter at the outlet, compared to the inlet, was considered the efficiency of the facility for that event.

Rainfall duration and intensity for monitored events was also recorded from the nearest suitable gauge. As some of the gauges were located some distance from the facility, standard gauges (to record precipitation volume) were installed. Standard gauge data could then be used to calibrate proximal gauges. Rainfall data was used to examine the performance of the facility under different precipitation conditions.

When possible, monitoring was conducted pre -and post-construction in order to more reliably assess the improvement the retrofit facility had on the water quality to the receiving water body. Pre-construction monitoring of Lincoln Pond followed the monitoring design described above. Based on the configuration of the Colony Trail pond, namely minimal attenuation of flows from inlet to outlet, pre-construction monitoring only captured outlet flows and concentrations to represent impacts to the receiving watercourse. The George Richardson pond, being an online facility with a relatively large catchment (155 ha), is subject to large flow volumes and experiences regular flow bypass making it very difficult to conduct complete water balances. As the innovative feature at this facility was the red sand filter monitoring efforts were focused on evaluating this feature post-construction. Flow and concentrations into the pond were captured to give some context to incoming water quality to the pond.

Results

George Richardson Pond – Newmarket

The retrofit of the George Richardson Pond involved the clean out of the pond itself as well as the installation of a bottom draw to feed into the red sand filter. The red sand filter is a bed of iron rich sand through which the stormwater will slowly flow through. As iron has an affinity for dissolved phosphorus this will serve to bind and therefore remove a portion of the dissolved phosphorus from the stormwater. At the same time the sand, in combination with the oil grit separator installed at the inlet to the filter, will serve to filter the stormwater thereby removing a portion of the suspended solids and total phosphorus that may be attached to those particles. As this type of technology has seen minimal application in treating urban stormwater the key focus of the monitoring effort was to document the efficacy of the filter at removing phosphorus.

As the project was a retrofit there was a number of existing site constraints that had to be accommodated. This included a flow splitter to a permanently flowing by-pass channel to accommodate fish passage around the online facility, and minimal change to the grade of the facility as it lies in the flood plain.

The 155 ha upstream catchment is primarily residential and was seen to respond very quickly to rain events. Coupled with the design of the facility itself, this quick response caused the facility to often become overwhelmed by incoming flows with large volumes of water being routed through the by-pass or overtopping at the downstream end of the facility. As a result the portion of the storm event being routed through the red sand filter was, on average, 10% of the event volume. Therefore the red sand filter was not likely treating the volume of water it could have had there been fewer site constraints. In addition, monitoring of the various by-pass routes was not possible and could only be conducted at the inlet to the facility above the flow splitter, at the inlet to the red sand filter, and at the outlet of the red sand filter. These three monitoring locations, while not sufficient for a complete mass balance of the facility to be completed, did allow for the characterization of incoming pollutant loads and to determine the amount that is being treated by the red sand filter in addition to examining the efficacy of the red sand filter itself.

The retrofit of the facility and installation of the red sand filter was completed in 2012 prior to the funding used to support monitoring, therefor only post construction monitoring is presented here. While data were collected in 2012, equipment challenges surrounding outlet water clarity, discussed below, prevented representative sample collection, therefore only 2013 results were analysed and are presented below.

Figure 2 - Inlet Channel to George Richardson Pond showing stone flow splitter and By-pass Channel on right

Inlet Monitoring Results

Monitoring at the facility inlet occurred May 24 2013 until November 11 2013. Sampled water quality concentrations for this period are presented in Appendix A. In total, 15 precipitation events were captured sufficiently to allow for the pollutant loads to be calculated (Table 1). Interestingly ,the events captured on July 15th and October 10th were not due to rain events but rather a result of fire hydrant testing / pumping in the catchment. The majority of rain events captured were small events of less than 10 mm. The three largest events July 8th (17.8mm) August 1st (36mm) and August 26th (29.4mm) together generated more than 50% of the phosphorus, total suspended solids and water volume entering the facility and just less than 50% of the chloride.

Table 1 – George Richardson Inlet Monitoring Results

		Inlet (kg)				
Date	Rainfall (mm)	Total Phosphorus	Ortho phosphorus	Total Suspended Solids	Chloride	Volume (L)
June 17	6	0.7003	0.0578	611.67	744.52	5,724,900
June 25	5	0.6231	0.0188	387.50	524.32	4,096,800
July 4	9.2	0.5831	0.0392	224.76	279.81	2,253,600
July 5	9	1.8507	0.1064	1383.68	253.83	5,866,200
July 7	11	0.4966	0.0710	478.44	481.80	5,157,900
July 8	17.8	2.0733	0.1996	2133.56	1194.62	13,208,400
July 10	0.8	0.2731	0.0397	174.94	198.33	1,728,900
July 15	0	0.0505	0.0163	16.91	92.84	1,358,100
July 18	7.8	0.7922	0.0478	523.69	233.56	3,018,600
July 19	4.8	0.1765	0.0461	79.85	200.03	1,928,700
July 23	10	0.3731	0.0557	283.73	218.03	3,095,100
July 27	13.2	0.3464	0.0646	314.03	266.57	3,329,100
Aug 1	36	1.7482	0.2677	1581.98	320.93	13,183,200
Aug 26	29.4	3.1961	0.1531	4151.23	1726.31	17,527,500
Oct 10	0	0.0714	0.0201	7.33	219.78	1,831,500

Red Sand Filter Results

The typical monitoring setup used to capture urban stormwater in and out of ponds is an autosampler to collect water quality samples triggered off a flow logger that records flow volumes at 15 minute intervals. The flow logger captures water velocity by employing the Doppler effect on particles or air bubbles entrained in the flow where an emitted signal bounces a return off suspended particles to a receiver, which is typically not a problem in urban stormwater runoff. Interestingly, this was not the case at the outlet of the Red Sand Filter, which had a high filtration efficiency resulting in few suspended particles in the outlet flow. Combined with the relatively flat profile of the filter meant the outflowing water had low velocity with minimal air entrainment, resulting in very few logged velocities. To fill in missing velocities a stage / velocity relationship was developed for the red sand filter outlet and applied to the logged period of record. Due to the configuration of the inlet to the red sand filter, specifically a flow restrictor, the access point was prone to backwatering and turbulent flows that did not allow for accurate flow logging. As the filter is buried and lined there can be no loss of water from inlet to outlet. Therefore, volumes generated at the outlet were applied to the inlet and sampled inlet water concentrations were proportionally applied to generate pollutant loads into the red sand filter.

In 2013 preliminary monitoring results were presented to the Lake Simcoe Science Committee for the three stormwater retrofit projects. At the meeting questions were raised as to the potential for the red sand filter to become a source of dissolved iron to receiving watercourses. As such, a number of water quality samples were analyzed specifically for dissolved iron. The results (Table 2) show that for dissolved iron, all samples returned concentrations below the laboratory detection limits indicating that the filter is not currently acting as a source of dissolved iron. It may be worth collecting samples again after a few years of operation to see if this changes.

Figure 1 - *Leptothrix ochracea* bloom at red sand filter outlet in late July

Interestingly in late July, 2013 a rust coloured bloom was observed in the outflow water of the red sand filter. This was identified as *Leptothrix ochracea*, a species of iron-loving bacteria that also prefer low oxygen conditions. While water quality samples did not detect dissolved iron the presence of this bacteria would suggest that the bottom draw is introducing hypoxic waters into the filter from the pond. With the filter being iron rich this is also the likely source of the bloom. Continued blooms such as this one raise the question of the longevity of the filter. In addition the iron / orthophosphate bond that makes the filter effective at phosphorus removal is broken in low oxygen conditions. Indeed during the period the bloom was observed the efficacy of the filter was seen to fluctuate greatly including one instance with a negative removal on August 1st (Table 3).

Figure 4 - 400x magnification of *Leptothrix ochracea*

Table 2 – Dissolved and Total Iron Concentrations at Outlet of Red Sand Filter

	Outlet (µg/L)	
Date	Dissolved Iron	Total Iron
July 4	<100.00	
July 7	<100.00	
July 7	<100.00	
July 8	<100.00	
July 9	<100.00	
July 10	<100.00	
July 18	<100.00	
July 18	<100.00	
July 19	<100.00	
July 19	<100.00	
July 23	100.00	610.00
July 23	100.00	750.00
July 27	<100.00	200.00
July 27	<100.00	
Aug 1	<100.00	<100.00
Aug 1	<100.00	120.00

Total Suspended Solids, Total Phosphorus and Orthophosphate

Sample concentrations for stormwater inflow and outflow from the red sand filter are presented in Appendix A. In total, 77 samples were submitted for both inlet and outlet. Total suspended solids (TSS) concentrations at the inlet to the red sand filter are generally lower than those entering the pond highlighting the role of the pond in retaining pollutants. The same can be seen when comparing total phosphorus (TP) and orthophosphate (OP) concentrations in to the pond with those entering the red sand filter.

Average TSS concentrations into the filter were 61 mg/L with a maximum of 500 mg/L as compared to an outlet average of 10 mg/L and maximum of 67 mg/L highlighting the filtering capacity of the oil grit separator and red sand filter. Average TP concentrations into the filter were 0.12 mg/L with a maximum of 0.54 mg/L as compared to an average outlet concentration of 0.052 mg/L with a maximum of 0.13 mg/L. Average OP concentrations into the filter were 0.01mg/L with a maximum of 0.031 mg/L as compared with an average outlet concentration of 0.007 mg/L with a maximum of 0.044 mg/L.

In total, eight events were adequately captured through the red sand filter to produce a mass balance, (Table 3). From these results, it is clear that the combination of the oil grit separator and filtering capacity of the red sand filter were very effective at removing the particulate remaining after moving through the pond, with removal rates ranging from 66% to 93%. This efficiency at TSS removal was reflected in the total phosphorus reductions as a large portion of phosphorus can be transported by suspended particles. For most events higher or lower TSS removal is mirrored by TP removal rates, except for a few events where poor OP removal resulted in lower TP removal.

Poor OP removal is most obvious during a in a few events in mid-summer. The iron / phosphorus bond that facilitates the removal of OP in the red sand filter can be broken under hypoxic or anoxic conditions. With the water that is directed through the filter coming from a bottom draw in the pond it is very likely that the filter will periodically receive hypoxic / anoxic water. This is particularly likely during dry, hot spells in summer that would promote stratification in the pond (or from chemical stratification in the form of chloride as discussed below). As such it is suspected that the poor OP removal of the July 5th, July 23rd, and August 1st events are a result of hypoxic / anoxic water moving through the filter. That low oxygen conditions occurred at this time is further supported by bloom of *Leptothrix ochracea* observed in late July and August as these bacteria prefer low oxygen conditions.

It is also worth noting that the August 1st event was the largest event captured in terms of both rainfall and volume moving through the filter. This was the only event to have more OP exiting the filter than entering which may be the result of anoxic waters moving through the filter and stripping phosphorus off the iron particles; flushing of the filter caused by the large volume of water moving through the filter; or possibly even contamination and backwatering of the pond overflow waters up into the filter. While a turbidity probe was deployed at the outlet sample point to detect potential backwater samples, a large volume into the filter with a slower release could potentially have skewed the samples.

Higher OP removal was also documented for a number of events with a high of 58% for the August 25th event. However, the high removal was not consistent and highlights the instability of the filter. Much of this instability is hypothesised to be due to hypoxic / anoxic water moving through the filter. With future applications of red sand this could be avoided by not directing pond bottom waters through the sand as well as not burying the filter which would allow the filter to dry between events and minimize the time standing water would interact with the sand.

Chloride

As chloride is soluble, a stormwater facility will do little to reduce concentrations, with inlet and outlet concentration remaining very similar. However, as water with higher concentrations of chloride will become denser it can promote stratification in ponds exacerbating problems of low oxygen in bottom waters. A comparison of the pond inlet chloride concentrations with those of the red sand filter inlet, which is fed by a bottom draw, shows the vast majority of red sand inlet samples to have higher and very stable chloride concentrations. This suggests the pond was stratified for much of the period of monitoring. Stratification would result in minimal mixing of top and bottom waters, reducing the efficiency of the pond, as well as promoting hypoxic / anoxic conditions in the bottom waters, the impact of which is discussed above. Thermal and chemical stratification of stormwater facilities is being recognized as a common occurrence in southern Ontario stormwater ponds along with the impact this could have on pond performance (McEnroe et al. 2012).

Chloride concentrations and loads were very similar from the inlet of the filter to the outlet with the majority balancing within 10%. There were however, two major exceptions, that being the August 1st and August 25th events. For both events considerably more chloride left the filter than entered. This is similar to what was seen at Colony Trail (below) however, the filter is a closed system with no other paths for chloride to enter the filter. As with the Sorbtive® media at Colony Trail, it has been suggested that the media, or in this case red sand, may slow or temporarily detain chloride between events and either large flushing flows or other physical properties of the water, for example lowered oxygen, could serve to mobilize the chloride again. With chloride increasingly becoming a parameter of concern further work on the impact of chloride on stormwater facilities and interaction with filter technologies such as the red sand would be warranted.

Table 3 – Red Sand Filter Performance

		Inlet (kg)				Outlet (kg)				Reduction (%)				% of event routed through Red Sand Filter
Date	Rainfall (mm)	Total Phosphorus	Ortho phosphorus	Total Suspended Solids	Chloride	Total Phosphorus	Ortho phosphorus	Total Suspended Solids	Chloride	Total Phosphorus	Ortho phosphorus	Total Suspended Solids	Chloride	
June 25	5	0.070	0.005	21.11	132.22	0.024	0.002	1.88	136.78	**65.02**	**52.27**	**91.08**	**-3.45**	11.13
July 5	9	0.020	0.002	4.31	55.68	0.012	0.001	1.16	57.11	**40.56**	**14.31**	**73.12**	**-2.58**	3.26
July 18/19		0.029	0.009	10.43	69.48	0.025	0.001	3.50	72.60	**14.39**	**91.08**	**66.46**	**-4.49**	8.26
July 23	10	0.119	0.004	44.83	87.43	0.042	0.004	4.48	111.41	**65.04**	**2.08**	**90.00**	**-27.43**	20.11
July 27	13.2	0.052	0.007	16.13	79.00	0.023	0.003	2.44	78.87	**55.52**	**54.47**	**84.86**	**0.17**	18.22
Aug 1	36	0.050	0.006	31.51	36.61	0.033	0.007	6.44	126.18	**34.05**	**-22.12**	**79.57**	**-244.68**	7.17
Aug 26	29.4	0.109	0.008	39.75	51.63	0.024	0.003	4.29	113.75	**77.62**	**58.02**	**89.20**	**-120.30**	3.64
Sept 2	7.2	0.016	0.001	16.60	10.32	0.005	0.001	1.08	11.18	**71.62**	**44.05**	**93.48**	**-8.39**	

Colony Trail – Holland Landing

Pre-Construction Monitoring

Figure 5 -Prior to the retrofit the facility consisted primarily of a grassed waterway

Monitoring was conducted on the Colony Trail facility from May through to mid-September of 2012 in order to capture pre-construction performance of the facility. The facility consisted primarily of a grassed channel between the outfall and receiving water course with minimal water retention occurring. It was decided that monitoring would be conducted only at one location (outlet) as there would be no discernable difference in water volume or quality between the storm sewer outfall and the facility outlet. Typically the facility was found to respond to storm events very quickly with the rise to peak on the event hydrograph occurring within 5 to 10 minutes.

By comparing pre-construction storm events with post-construction events of a similar volume some evaluation of water quality improvements can be made. Pre-construction monitoring results are below (Table 4) and all water quality sample results are shown in Appendix A. A comparison with 2013 post-construction is detailed below.

Figure 6 - Overview of pre-construction facility

Table 4 – Colony Trail Facility Monitoring Results 2012

			Outlet (kg)			
Date	Rain (mm)	Total Phosphorus	Ortho phosphorus	Total Suspended Solids	Chloride	Volume (L)
May-03	18.4	0.1804	0.0198	101.39	19.07	952,200
May-08	7.4	0.0264	0.0070	6.29	11.43	279,900
May-09	2.6	0.0126	0.0031	3.10	5.37	113,400
May-28	1.6	0.0395	0.0066	18.58	2.94	73,500
May-29	trace	0.0016	0.0010	0.14	0.77	4,200
Jun-01	27.4	0.0979	0.0271	9.79	22.93	279,600
Jun-09	17.5	0.0551	0.0185	16.65	13.52	409,800
Jun-21	4.4	0.0106	0.0013	3.52	2.39	66,300
Jul-22	3.2	0.0060	0.0011	0.91	2.11	35,100
July 25/26	36.6	0.1104	0.0199	39.58	12.38	836,700
Aug-08	0.4	0.0993	0.0258	46.81	5.66	634,500
Aug-09	7.8	0.0124	0.0092	0.82	2.75	78,000
Sep-18	18.2	0.0633	0.0290	15.41	5.06	479,700

Post-Construction Monitoring

Construction on the facility was not complete until late September, 2013 leaving little time for adequate monitoring to be conducted before winter. As such, monitoring commenced mid-September and ran until mid-November capturing 6 events, 4 of which were of sufficient volume to be used for performance evaluation of the facility. Water quality and quantity were captured at the storm sewer outfall to the facility (inlet) as well as at the outlet. Monitoring at the outlet was set below the Sorbtive media chamber meaning water quality improvements would be a combination of water moving through the wetland and Sorbtive media chamber. Results are displayed below in Table 5.

Figure 7 - Overview of post-construction facility

Water Balance

For each event, a water balance was calculated. For small (> 3 mm) precipitation events, such as those on October 4 and November 9, the flow was at the lower limit of the flow logger range and a satisfactory water balance could not be achieved for their inclusion. For the remaining captured events, the water balance was within 10% and, with the exception of the September 21st event, were positive balances with more water exiting the facility than entering. This positive balance was likely the result of the outlet control structures as well as the Sorbtive media chamber that held water in the facility for a day or more, increasing losses to evaporation and infiltration. However, these losses are likely relatively small and the majority of the imbalance is due to the difficulty inherent in matching the very rapid and short duration inflows with the slower, longer outflows. The September 21st event was the largest event captured, as well as being the first event to move through the Sorbtive media chamber. These two factors likely contributed to the negative balance for this event.

Phosphorus – Total and Orthophosphate

Phosphorus inputs to the Colony Trail facility were relatively high for an 18 ha catchment as compared to other urban stormwater inputs measured by the LSRCA. Average input concentration of total phosphorus (TP) in 2013 was 0.262 mg/l (0.184 mg/l in 2012) and average orthophosphate (OP) concentration of 0.149 mg/l (0.046 mg/l in 2012). By comparison the George Richardson facility, with a 155 ha catchment, had an average TP concentration of 0.196 mg/l in 2013 and average OP concentration of 0.015 mg/L. The previously studied 71.5 ha Aurora Wetland catchment had an average TP concentration of 0.188 mg/l and an average OP concentration of 0.051 mg/l in 2012 (LSRCA 2012). The Lincoln Pond facility, with a more comparable catchment size of 18.5 ha, had an average input TP concentration of 0.05mg/l and average OP concentration of 0.007 mg/l in 2013. Through the use of bacterial sampling it would appear that the Aurora wetland is receiving sanitary sewer inputs, explaining the high OP inputs to the facility. While bacterial samples

Table 5 – Colony Trail Facility Monitored Performance 2013

		Inlet (kg)					Outlet (kg)					Reduction (%)				
Date	Rainfall (mm)	Total Phosphorus	Ortho phosphorus	Total Suspended Solids	Chloride	Volume (L)	Total Phosphorus	Ortho phosphorus	Total Suspended Solids	Chloride	Volume (L)	Total Phosphorus	Ortho phosphorus	Total Suspended Solids	Chloride	Water Balance (%)
Sept 21	40.6	0.1788	0.1295	15.77	78.86	1,816,200	0.1217	0.0633	18.22	58.33	1,643,400	31.9	51.1	-13.4	26.0	-9.5
Oct 16/17	19.6	0.1116	0.0611	4.11	15.64	506,700	0.0331	0.0142	4.13	60.97	556,200	70.3	76.8	-0.5	-74.4	8.9
Oct 26	8.5	0.0460	0.0335	0.87	8.32	124,200	0.0018	0.0017	0.53	17.08	131,400	96.0	94.9	39.5	-51.3	5.5
Oct 31 - Nov 2	19.6	0.1782	0.0955	10.57	78.72	860,400	0.0840	0.0391	3.52	100.45	915,300	52.9	59.0	66.7	-21.6	6.0

were not collected at the Colony Trail facility the phosphorus inputs, particularly the OP concentrations, are suggestive of sanitary sewer inputs or other atypical nutrient inputs.

Figure 8 - View inside Sorbtive media chamber, media overlain with permeable layer to hold the Sorbtive media in place

With large and variable phosphorus inputs to a facility sized for an 18 ha catchment, achieving consistent and high phosphorus reductions will be a challenge for the facility. Indeed, from the four events captured, reductions range from 30% to 90% for TP and 50% to 90% for OP. Unsurprisingly, the efficiency of the facility appears to be strongly linked to the volume of runoff moving through the pond. The lowest phosphorus reductions achieved by the facility was with the large September 21st event and best reductions being achieved with the smallest event on October 26th (Table 5).

The Imbrium Sorbtive media chamber installed at this facility is designed to remove dissolved (ortho)phosphate. Ironically, with this facility receiving atypically high orthophosphate loads it turned out to be an ideal location to test the Sorbtive media. For the four events that were captured, OP made up approximately 50% to 75% of the TP load. It is somewhat atypical to have such a large proportion of the TP load comprised of OP as this is a very reactive and bioavailable form of phosphorus. For all inlet sample concentrations, the proportion of TP that was comprised of OP was on average 60%. Encouragingly, OP (and therefore TP) reductions were good (mean = 66%) considering the proportions entering the facility. Typically, high reductions in phosphorus will be a result of high total suspended solids (TSS) removal as these particles act as a transport mechanism for phosphorus. Given that TSS reductions were moderate to poor but good phosphorus reductions were still achieved suggests a high removal efficiency achieved by the Sorptive media. This is particularly evident in the September 21st event where no TSS reduction was achieved, poor TP reduction was achieved, but 50% of OP was still removed.

Total Suspended Solids

Total suspended solids (TSS) concentrations recorded in 2013 were generally low for stormwater runoff with an average inlet concentration of 13 mg/l. Reduction of TSS in the first two captured events was negative with a greater TSS load leaving the facility than entering. TSS reductions improve throughout the monitoring period. As construction and planting of the facility was only completed immediately prior to the commencement of our monitoring, it is possible that erosion from the banks of the facility itself contributed TSS directly to the facility. This was likely a large factor in the September 21st event where outlet concentrations show higher levels of TSS than inlet concentrations. As TSS concentrations were low these inputs could have been enough to skew the results. As the vegetation continued to establish itself the TSS reductions improve. However, with the relatively low TSS inputs captured reductions will be variable. Interestingly, the 2013 TSS concentrations were low even compared to 2012 where the average TSS concentration was 65 mg/l with a maximum value of 640 mg/l. As such, the

2013 monitoring likely does not fully reflect the performance of the facility with respect to TSS reduction.

Chloride

The primary source of chloride to surface waters is through the application of road salt as a de-icer in winter. Typically, chloride is monitored in urban stormwater for general information as this is the main source to the natural environment. As chloride is soluble, a stormwater facility will do little to treat or retain chloride and thus, what enters the facility should leave the facility. This can also make chloride a helpful parameter when calculating a water balance or identifying in-pond dynamics. In the case of the Colony Trail facility, chloride loads did not balance and for three of four precipitation events as more chloride was recorded leaving the facility than entering it. Sample concentration also primarily show greater chloride concentrations at the outlet as compared to inlet, with an average inlet concentration of 63 mg/l and maximum of 140 mg/l verses an average outlet concentration of 120 mg/l and maximum concentration of 190 mg/l. Therefore, even normalizing for the slight water volume imbalance for these events, more chloride is still leaving the facility. This suggests several things:

- there are additional inputs to the pond that were not identified such as groundwater, overland or piped flows,
- the depth of the pond promotes stratification and denser salt water may sit at the bottom until an event mixes and outlets a portion of the bottom waters,
- rock salt is being retained in the stormsewer system, or already in pond sediments, and is transported to the facility in particulate form where it dissolves into the water,
- the Sorbtive media retains some chloride between events and releases this stored chloride during subsequent precipitation events.

Increasing chloride concentrations are a growing concern the Lake Simcoe watershed (Winter et al. 2011) and therefore, continued research should be dedicated to understanding the transport and fate of chloride in stormwater facilities.

2012 vs 2013

A comparison of sample concentrations from 2012 with 2013 show some marked differences. As the configuration of the facility in 2012 was not deemed to be providing any significant water quality improvements the sampled concentrations should be comparable to 2013 inlet concentrations. Total phosphorus, orthophosphate and chloride concentrations are all generally higher in the 2013 data as compared to 2012 (Appendix A). Total suspended solids on the other hand show decreased concentrations in 2013.

Comparing 2012 data to 2013 outlet concentrations (downstream of the Sorbtive media filter) shows both TP and TSS concentrations are generally lower in the 2013 data set with chloride concentrations remaining higher. Outlet OP concentrations are similar to 2012, although maximum values are lower (0.22 mg/L in 2012; 0.066 mg/L in 2013).

The difference between concentrations from 2012 to 2013 may be partly due to the different seasons in which the sampling occurred, or the result of alterations to the catchment. While there were no other construction projects or catchment alterations of which we were aware, the increase in incoming OP concentrations suggest a significant change occurred in the catchment. This change in incoming concentrations in 2013 as compared to 2012, particularly in increased OP and decreased TSS concentrations will influence the comparison of pollutant loads for 2012 verses 2013 events. To highlight this influence the 2012 loads were compared to both inlet and outlet loads for 2013 in table 6 and 7 below.

Figure 9 - Colony Trail wetland, outlet structured in foreground, inlet structure in background

Rainfall was not used to compare 2012 and 2013 events as the level of rainfall did not generate similar volumes into the facility, likely due to the differences in seasonal precipitation or the intensity / duration of the rainfall. Instead the incoming volume was used to select similar events for comparison. There was no event captured in 2012 generating a volume large enough to compare with the September 21 2013 event.

Comparing the selected 2012 loads to 2013 inlet loads (Table 6) highlights the greater amount of total phosphorus and chloride, and lower amounts of TSS entering the facility. The only exceptions being the May 3 2012 and October 31 2013 events which saw slightly less TP in the 2013 event but still significantly more OP. However, even with the increased nutrient inputs in 2013, nearly all outlet loads are lower than 2012 (Table 7), demonstrating that the new facility is improving water quality entering the receiving water course as compared to prior conditions. The exception to this was the larger of the captured events (October 31). As discussed above in the Post-Construction section, the effectiveness of the facility was seen to decline as the size of the event increased.

The improvement in TSS capture is largely a result of the lower concentrations in 2013 and, as discussed above, may not fully reflect the range of conditions the facility will experience and, therefore, the high 2013 reductions when compared to 2012 may be biased. Chloride loads, while not expected to be affected by the facility, show higher incoming loads in all events in 2013 as compared to 2012.

Table 6 – Selected 2012 Event Pollutant Load Compared with 2013 Inlet Pollutant Loads

	2012 Outlet (kg)						2013 Inlet (kg)					Reduction (%)			
Date (2012)	Total Phosphorus	Ortho phosphorus	Total Suspended Solids	Chloride	Volume (L)	Date (2013)	Total Phosphorus	Ortho phosphorus	Total Suspended Solids	Chloride	Volume (L)	Total Phosphorus	Ortho phosphorus	Total Suspended Solids	Chloride
May 9	0.0126	0.0031	3.1001	5.3735	113,400	Oct 26	0.0460	0.0335	0.8694	8.3214	124,200	-72.56	-90.84	71.96	-35.43
June 9	0.0551	0.0185	16.6548	13.5234	409,800	Oct 16/17	0.1116	0.0611	4.1076	15.6393	506,700	-50.66	-69.74	75.34	-13.53
Sept 18	0.0633	0.0290	15.4053	5.0634	479,700							-43.23	-52.58	73.34	-67.62
July 25/26	0.1104	0.0199	39.5754	12.3843	836,700	Oct 31-Nov 2	0.1782	0.0955	10.5705	78.7230	860,400	-38.04	-79.15	73.29	-84.27
May 3	0.1804	0.0198	101.3886	19.0701	952,200							1.19	-79.23	89.57	-75.78

Table 7 – Selected 2012 Event Pollutant Load Compared with 2013 Outlet Pollutant Loads

	2012 Outlet (kg)						2013 Outlet (kg)					Reduction (%)			
Date (2012)	Total Phosphorus	Ortho phosphorus	Total Suspended Solids	Chloride	Volume (L)	Date (2013)	Total Phosphorus	Ortho phosphorus	Total Suspended Solids	Chloride	Volume (L)	Total Phosphorus	Ortho phosphorus	Total Suspended Solids	Chloride
May 9	0.0126	0.0031	3.1001	5.3735	113,400	Oct 26	0.0018	0.0017	0.5256	17.0820	131,400	85.41	44.37	83.05	-68.54
June 9	0.0551	0.0185	16.6548	13.5234	409,800	Oct 16/17	0.03312	0.0141588	4.1292	60.9678	556,200	39.84	23.48	75.21	-77.82
Sept 18	0.0633	0.0290	15.4053	5.0634	479,700							47.71	51.16	73.20	-91.69
July 25/26	0.1104	0.0199	39.5754	12.3843	836,700	Oct 31-Nov 2	0.0840	0.0391	3.5183	100.4508	915,300	23.95	-49.10	91.11	-87.67
May 3	0.1804	0.0198	101.3886	19.0701	952,200							53.44	-49.29	96.53	-81.02

Lincoln Pond Engineered Wetland - Uxbridge

Pre-construction monitoring was conducted on Lincoln Pond from early May through to early August 2012. Post-construction monitoring was conducted from early May through to the end of October 2013. Sample results for both years can be seen in Appendix A.

Figure 10 - Overview of facility pre-construction

Figure 11 - Overview of facility post-construction

The outlet of the facility, which remained unchanged through the retrofit, shares a headwall structure with the uncontrolled King St catchment directly to the south. As part of the project a Wilkinson Box Oil-Grit Separator was installed to give some treatment to runoff from the King St catchment. On May 28 2013 the Wilkinson-Box became clogged leading to a surcharge flow eroding much of the bank around the shared outlet headwall. Remediation of the erosion required the placement of a silt fence downstream of the headwall in the outlet channel which remained in place until late July. The placement of the silt fence served to highlight the tendency of the faster responding, larger King St catchment to backwater into the Lincoln facility.

Figure 12 - Joint outlet of King St stormsewer and Lincoln facility under low flow conditions. Lincoln outlet is the small diameter pipe on right wing wall

Figure 13 - Lincoln and King St outlet under high flow conditions. Water depth exceeding 20 cm.

The outlet structure from the final wet cell of the facility, which was not altered during the retrofit, has two flow paths from the facility, a maintenance valve and a perforated riser. The perforated riser allows for a normal water level that is approximately 0.5 m higher than the maintenance valve when the valve is shut, and is the designed configuration.

When the valve is open there is a 20 cm fall to the headwall that is shared with the King St storm outlet (Figure 12). The smaller diameter Lincoln outlet is always partially full (at approximately 8 cm water depth) due to the toe configuration of the headwall structure. During storm events the larger, faster responding King St stormwater flows inundate the Lincoln outlet (Figure 13) and for the periods where the water depth exceeds 20 cm the King St stormwater can backwater into the final wet cell of the Lincoln Facility through the open maintenance valve.

Unfortunately, from the period between pond completion in the fall of 2012 and commencement of monitoring activities in the spring of 2013 the maintenance valve was opened and remained so throughout the period of monitoring. As a result, untreated stormwater was routinely routed into the final cell of the Lincoln facility contaminating the stormwater treated through the Lincoln facility and making performance monitoring results unusable.

The effect of this backwatering can be seen in the event captured on August 6 2013. The results (Figure 15) show a small but intense precipitation event at the Lincoln outlet. The velocity (in red) shows an initial backflow as the water levels in the uncontrolled King St catchment rise faster than stormwater flowing through the Lincoln facility. The water quality sample captured prior to backflow (A) (Table 8) shows the ambient water quality in the wet cell prior to a storm water input. Sample B highlights the poorer water quality associated with uncontrolled King St stormwater backwatering into the wet cell, particularly total suspended solids. The water quality captured by Sample C is a result of uncontrolled stormwater mixing in the final wet cell with stormwater that has moved through the engineered wetland. As a result, none of these samples would be considered representative of stormwater that has been treated

Figure 14 - Plant and Algae growth in final wet cell, September 2013

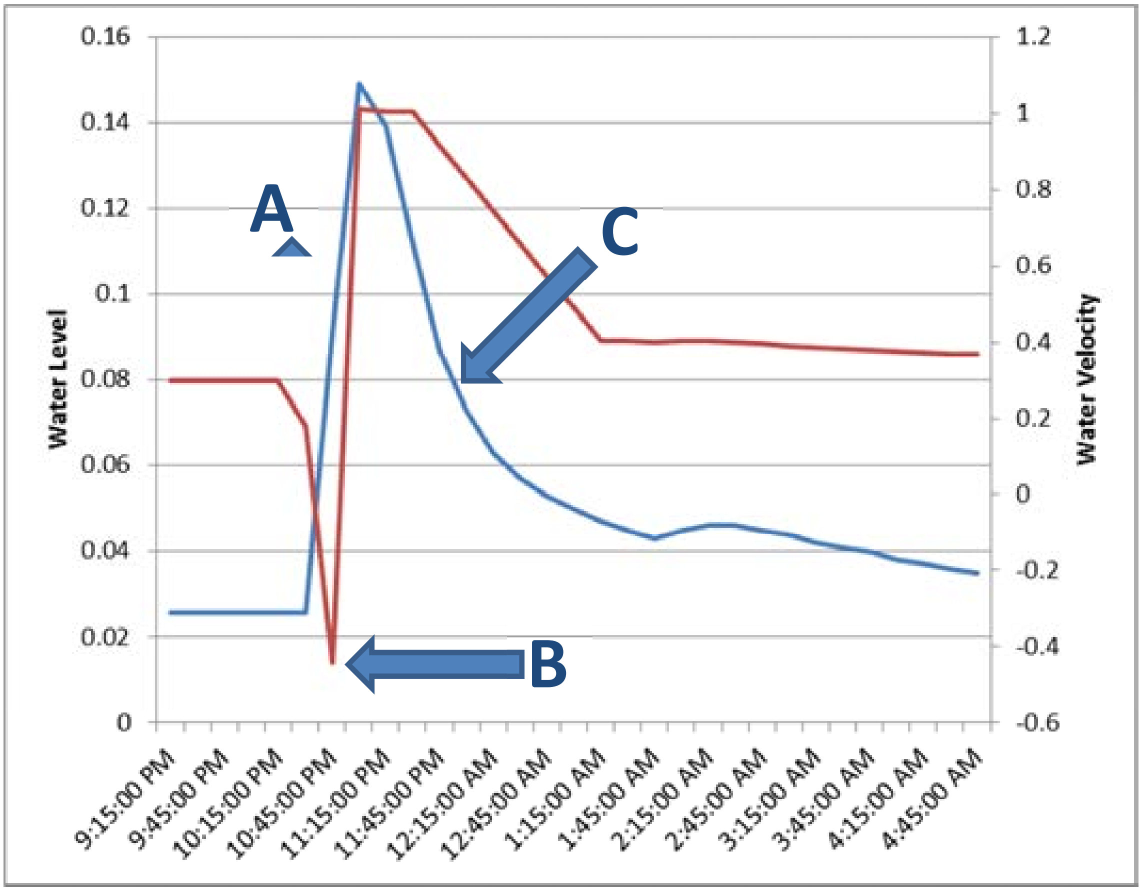

Figure 15 – Hydrograph of backflow event in final wet cell at Lincoln Facility

through the wetland facility. Indeed, due to repeated backwatering and mixing of stormwater into the final cell of the Lincoln facility, it was not possible to capture any samples that were considered to be uninfluenced by uncontrolled King St stormwater. Therefore, evaluation of the effectiveness of the facility could not be conducted as the facility itself was not functioning as designed.

The effect of the backwatering was also evidenced by the increasing proliferation of plants and algae observed in the final wet cell as the summer and fall progressed (Figure 14)Based on visual inspections, the growth in the final wet cell was seen to equal, if not exceed, that of the preliminary wet cell.

Following the analysis of the 2013 monitoring results and identification of the backwatering effect, discussions with the design consultant revealed the cause of the backwatering to be the open maintenance valve. As a result the valve was closed in spring of 2014 and the facility should now be performing as designed. The valve will also be secured to avoid accidental opening in the future. Therefore while monitoring did not yield the anticipated result, namely an evaluation of the performance of an engineered wetland, the identification and rectification of an operational issue in a relatively timely fashion will mean improved performance of the facility moving forward. This incident also highlights that as stormwater management facilities evolve and incorporate more innovative and non-conventional approaches, the operational and maintenance requirements of the facility must be clearly outlined and communicated to the facility managers to insure it will continue to function at the intended design efficiency.

Table 8 – Backflow event sample results

	Orthophosphorus (mg/l)	Total Phosphorus (mg/l)	Total Suspended Solids (mg/l)
Sample A	0.003	0.005	1
Sample B	0.005	0.04	29
Sample C	0.005	0.007	2

Summary

From the monitoring of the three innovative stormwater treatment technologies there are a few general conclusions that can be derived. First would be the challenges associated with retrofitting existing stormwater facilities such as working within the existing footprint, and using existing, and likely aged, infrastructure. This can be addressed through the design phase but may require more attention to existing conditions in order to mitigate changes from the original design. This was highlighted with the George Richardson facility where design / site constraints impacted the ability to route more storm flows through the red sand filter.

A second conclusion is that as increasingly complex / non-conventional technologies are employed in stormwater management facilities, there is a need to communicate the operational specifics or maintenance requirements to the agency responsible for the operation of the facility to ensure proper performance. This type of communication would have easily rectified the open maintenance valve at the Lincoln Pond facility that led to the improper operation of the facility for its first year of operation.

Monitoring of these ponds also served to highlight the variation in urban stormwater both between seemingly similar catchments but also over relatively short time spans. In addition the impact of road salt, low oxygen conditions, and sewer cross connections further highlight the need for continued monitoring and research into the lifecycle performance of stormwater management facilities as well as characterizing a variety of contributing catchments.

Of the three ponds, the Colony Trail facility utilizing Sorbtive media had the best performance for improving water quality, especially considering the high levels of orthophosphate entering the facility during the period of study. The red sand filter at George Richardson Pond also demonstrated water quality improvements, which would likely be improved with a different pond configuration; namely not using bottom waters with potential low oxygen levels as the feed water to the iron-based filter and a site with greater elevation would allow a greater volume of water to move through the red sand. Configuring the filter to allow periodic drying and faster draining post event would likely also improve the performance of the filter.

While the Lincoln Engineered Wetland facility could not be properly evaluated through this study, the LSRCA evaluated a similar facility in Aurora in 2012. The results of this study can be found on the LSRCA webpage (http://www.lsrca.on.ca/).

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