TECHNICAL BRIEF

Sustainable Technologies
EVALUATION PROGRAM

Low Impact Development

Improving nutrient retention in bioretention

> **Too much phosphorous and nitrogen contribute to nuisance aquatic plants and algae growth in lakes and rivers. Large increases in algae harms water quality, makes food harder for fish to find, and leads to a decline in the oxygen that fish and aquatic life need to survive.**

Several studies have shown that bioretention and other vegetated stormwater best management practices can act as a source of phosphorus and other nutrients. This study examined the effectiveness of reactive media amendments as a means of enhancing phosphorus retention in a bioretention cell draining a $1150 m^2$ parking lot in the City of Vaughan. For testing purposes, the bioretention was divided into three hydrologically distinct cells: one with a high sand, low phosphorus media mix (control); one with a proprietary reactive media (Sorbitve™) mixed into the sandy filter media, and one with a 170 cm layer of iron rich sand (aka red sand) below the sandy filter media. Outflow quantity and quality from each cell was measured directly, while inflows and runoff quality were estimated based on monitoring of an adjacent asphalt reference site over the same time period.

Water quality results from monitoring over the May to November period in 2016 showed that the cell amended with Sorbtive® media provided statistically better ($p<0.05$) overall total phosphorus retention than either the standard filter media or red sand amended media. In 2017, after stabilization of the media, the difference in phosphorus treatment performance between the Sorbtive® and red sand amended cells was no longer statistically significant ($p<0.05$). Relative to the control filter media, the Sorbtive® amended media had significantly lower effluent total phosphorus (TP) and ortho-phosphate (OP) concentrations in both years, while the red sand amended media exhibited significantly lower concentrations of these variables only in 2017. The reactive media were also shown to have some benefit in improving the removal of total nitrogen and some metals. Iron and aluminum were notable exceptions, with the red sand plot showing elevated iron concentrations in 2016, and both the red sand and control plots showing elevated aluminum concentrations in 2016 and 2017. Over the two year study, effluents from bioretention plots amended with the two reactive filter media types (Sorbtive® and red sand) had median concentrations of TP and OP that were at least 68% and 82% less than that of the control filter media, respectively.

INTRODUCTION

Bioretention is a low impact development (LID) practice that treats runoff from paved areas using the natural properties of soil and vegetation to remove nutrients. Overall the practice can provide substantial runoff retention, due to the presence of filter media and vegetation, which offer additional capacity to retain runoff and promote evapotranspiration. However field studies have shown that bioretention and other vegetated stormwater practices that use soil media to filter out pollutants can be a source of nutrients, resulting in elevated effluent concentrations of these constituents. The leaching of phosphorus and nitrogen can limit the adoption of these types of filtration LIDs, particularly on sites that discharge to receiving water systems that are sensitive to high nutrient levels.

Initiated in 2016, this two year study assesses potential solutions to the nutrient leaching problem through a side-by-side performance evaluation of three bioretention filter media types: the first with Imbrium Systems Sorbtive® Media, the second with a layer of iron-rich sand (also known as red sand), and the third with a standard low phosphorus, sandy filter media often used in bioretention systems in southern Ontario. The key objective of this study is to evaluate the effectiveness of engineered media in reducing phosphorous, nitrogen and metals in bioretention effluent. Other parameters examined include runoff volume reduction, surface ponding and infiltration, effluent quality and temperature, pollutant load reductions, and maintenance requirements.

STUDY SITE AND FACILITY DESIGN

The bioretention facility was constructed in the Fall of 2015 along the north edge of the Green Parking Lot Demonstration site at Kortright in Vaughan (Figure 1). It receives stormwater runoff from approximately 1150 m² of asphalt, as well as rain falling directly on the filter strip and bioretention area (approx.

Figure 1.Site location -Dark black lines represent asphalt speed bumps installed in 2017

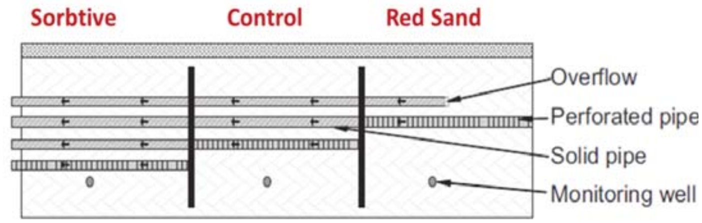

Figure 2. Plan view of the experimental set-up showing hydraulic barriers separating the plots (black lines).

Table 1. Approximate layer depths in the bioretention

	Section 1: Filter and Sorbtive® media mix	Section 2: Filter media only	Section 3: Filter media and red sand
Ponding depth	200 mm	200 mm	200 mm
Filter media depth	570 mm, mixed with Sorbtive® media	570 mm	400 mm + 170 mm layer of red sand
Choking layer (HPB)	50 mm	50 mm	50 mm
19 mm clear stone depth	180 mm	180 mm	180 mm
Total depth	1000 mm	1000 mm	1000 mm

200 m²). The impervious to pervious ratio, not accounting for the filter strip and side slopes is roughly 15 to 1. This portion of the parking lot is a school bus drop off area, and also has parking for cars on the south edge.

The facility is divided into three equal sections, each 22 m in length and approximately 1.2 m wide (Figure 2). Each section receives sheet flow runoff from the drainage area, split evenly at approximately 450 m² each (including direct rainfall on the facility and filter strip). All sections are similar in design with mulch and 570 mm of filter media underlain with a 50 mm chocking layer of high performance bedding (HPB) and 180 mm of 19 mm clear stone (Figure 3 and Table 1). The section amended with Imbrium's Sorbtive media is mixed at a ratio of 1 part Sorbtive to 10 parts filter media. The second traditional bioretention media section (referred to as the control) is comprised of 85% sand and 15% silt and clay particles with 2 to 3% organic matter. The red sand section has a 170 mm layer of iron rich sand directly below the bioretention media (equivalent to roughly 30% of the total filter media depth). The third section contains a 170 mm layer of iron rich sand (or red sand) below the bioretention media (roughly 30% of the total filter media depth).

The Sorbtive®, Red Sand and Control media were tested for the primary phosphorus sorbing constitutents: calcium, iron, and aluminum. The results shown in Figure 4, indicate that the Sorbtive® includes considerably more aluminum than the other two media types. Sorbtive® also has more iron than the red sand product, but the red sand product is installed at a ratio of 1 to 3, versus 1 to 10 for the Sorbtive® product. Therefore the total

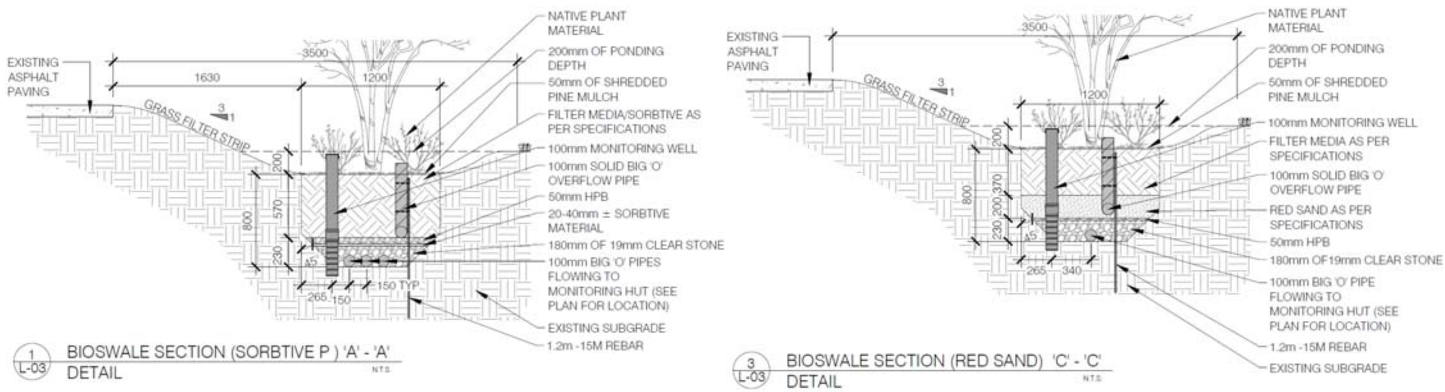

Figure 3.Bioretention cross-section for the sorbtive® and red sand plots. Note that the red sand layer was later modified to be only 170 mm, topped with 400 mm of filter media.

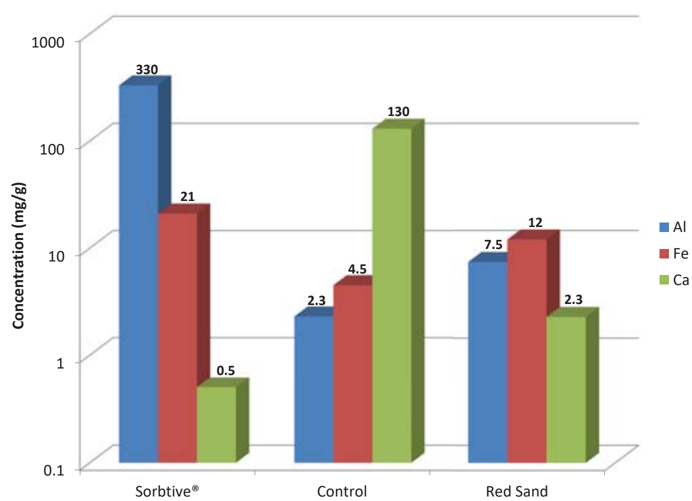

Figure 4. Media sorbing constituent concentrations.

iron mass in the red sand layer is approximately 40% greater than in the Sorbtive® plot. The control media is a richer source of calcium than the other media types.

The bioretention sections are hydraulically separated by impermeable barriers which extend down into the native soils. Each bioretention section is drained by a perforated pipe wrapped in filter fabric which is installed along the interface between the clear stone base and native soil (Figure 2). During large or intense rain events, excess ponded water drains to an overflow pipe in each section that drains to a wooded area downstream of the monitoring hut.

APPROACH

The two season monitoring program was undertaken from May to November in 2016 and 2017. Measurements included precipitation, flow rates and volumes, water level, water temperature and water quality. A tipping bucket rain gauge was installed within 500 m of the study site, logging at 5 minute intervals.

Flows entered the bioretention as sheetflow and could not be measured directly. Therefore, inflows and runoff water quality were estimated using unit area flow measurements and water quality sampling from an adjacent asphalt reference site (Figure 1). Surface ponding was measured inside a perforated well located at the centre of each bioretention cell. Outflow rates, volumes, water temperature and water quality were monitored in a surface sampling hut downstream of the site. Calibrated tipping bucket flow gauges were used to monitor flow. A flow restrictor was installed to ensure flow rates were below the maximum flow rate of 1 L/s for the measuring device.

Figure 5.Tipping bucket flow meters and water quality samplers inside the monitoring hut.

Samples from the asphalt surface and bioretention effluents were collected with automated samplers. Water quality samples were proportioned according to flow by measuring out a volume of water from each discrete sample bottle proportional to the volume of flow since the previous sample. The resulting flow volume proportioned composite samples for each event were subsequently prepared and delivered to the Ontario Ministry of the Environment Conservation and Parks (MECP) laboratory in Etobicoke for analysis following MECP lab preparation and submission protocols. Water quality variables analyzed included solids, general chemistry, nutrients and metals.

The capacity of each test section of the bioretention to improve water quality was assessed through:(i) analysis of the quality of runoff from the asphalt control and outflow quality from each section, and (ii) statistical comparisons of effluent quality from the three test sections. A Shapiro-Wilk normality test showed that the data were not normally distributed. Therefore a one-way Analysis of Variance (ANOVA) on ranks was conducted to determine statistically significant differences in water quality among treatments, followed by Dunn's method for pairwise multiple comparisons.

The first year was dry and flow volumes entering the red sand and Sorbtive® sections were lower than anticipated because of water draining laterally towards the drive lanes on either side of the drainage area. Asphalt speed bumps installed in the spring of 2017 directed more flows into these plots. Flow volumes were greatest in the red sand plot, followed by Sorbtive® and the control. Since effluent water quality concentrations were not correlated with flow volumes, the flow difference among plots was not expected to introduce significant bias.

STUDY FINDINGS

Both the Sorbtive® and red sand amended cells were shown to have lower effluent nutrient concentrations than the cell with standard filter media. The degree to which nutrients and metals were lower than the standard filter media (control) differed between plots and parameters, but a statistically significant ($p<0.05$) difference between the amended plots and the bioretention control was found for most parameters in at

Table 2. Median concentrations and percent differences from control for total phosphorus (TP), ortho-phosphate (OP4) and total nitrogen (TN) for the combined 2016 and 2017 monitoring seasons.

Site	Median Concentrations			Percent Difference from Control		
	TP	PO4	TN	TP	PO_4	TN
Asphalt	0.19	0.07	0.91	-16.9	56.1	-4.6
Control	0.17	0.15	0.87	--	--	--
Sorbtive®	0.04	0.02	0.39	78.3	85.8	55.2
Red Sand	0.05	0.03	0.71	68.7	82.4	18.4

least one of the two years (Table 3). For total phosphorus (TP) and ortho-phosphate (OP), Sorbtive® had significantly lower concentrations than the control in both 2016 and 2017, while red sand had significantly lower concentrations only in 2017. Sorbtive® also had significantly ($p<0.05$) lower total nitrogen concentrations in 2017, whereas the same was not true for red sand (Table 3). Both amended media cells had median

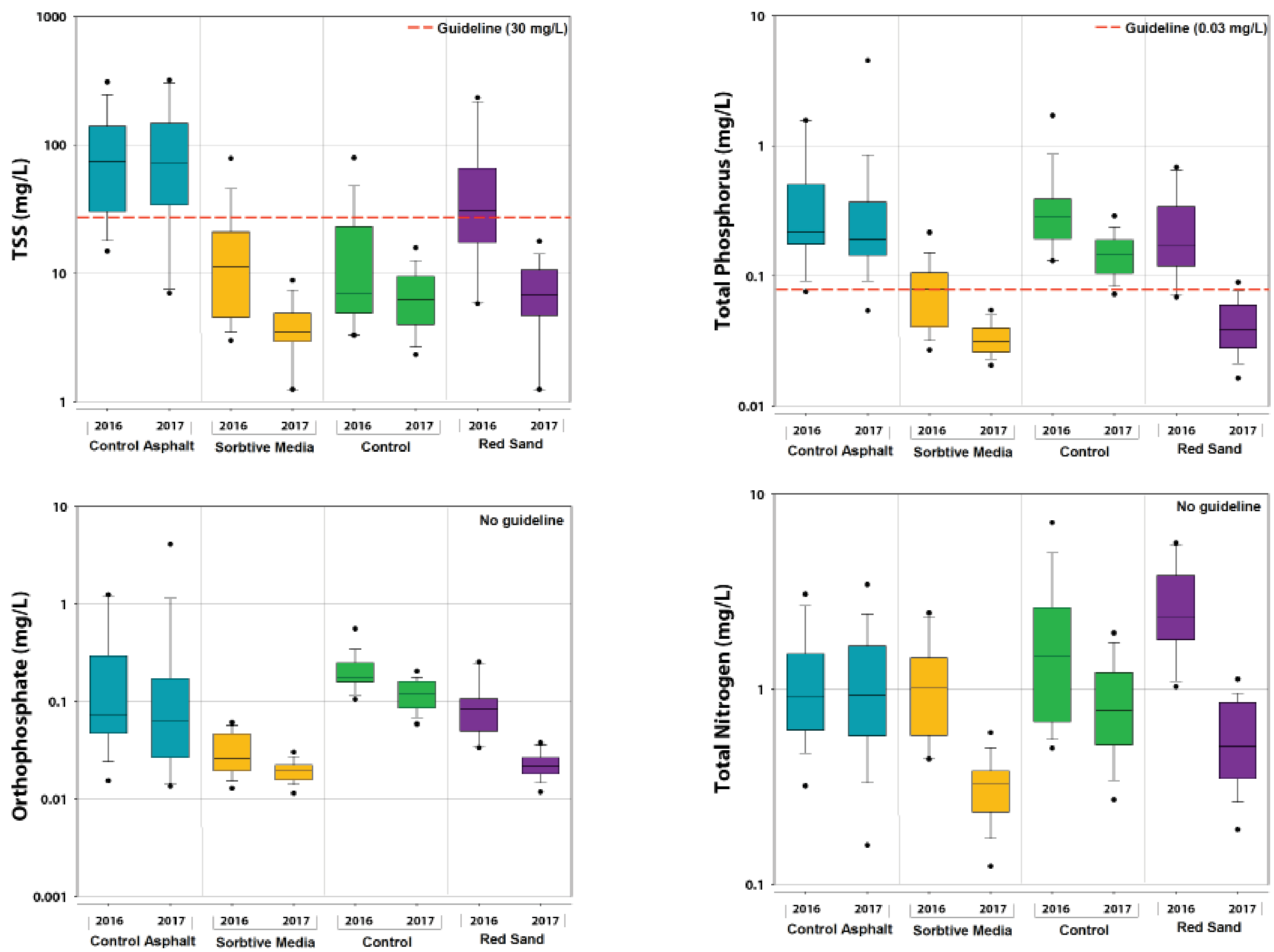

Figure 6. Box plots for TSS, total phosphorous, orthophosphate and total nitrogen

concentrations that were lower than the control media cell by at least 68% for TP and 82% for OP (Table 2).

The Sorbtive® amended cell had significantly($p<0.05$) lower effluent TP concentrations than the red sand amended cell in 2016, but in the wetter 2017 year, there was no statistically significant difference. This difference may be explained in part by the higher initial TSS concentrations from the red sand plot (Figure 6). The red sand amended cell had initially more wash out of fines than the control media cell, until the media stabilized in 2017. Higher TSS concentrations are correlated with TP because most of the phosphorus in underdrain flows is attached to sediment particles. The soluble ortho-phosphate fraction in the Sorbtive® media effluent was not significantly different than the red sand effluent in either year.

The reactive media cells showed mixed results for metals compared to the standard filter media cell. For iron, the red sand amended cell had significantly higher effluent concentrations than both other media mixes in 2016 (Figure 7). Median effluent concentrations of iron from this cell in 2016 were well above the provincial water quality guideline for the protection of aquatic life. Iron concentrations trended down over time as the fines available for mobilization were washed out of the red sand layer (Figure 7). Zinc showed no significant difference among the different media mixes in either year, and unlike asphalt, median concentrations in 2017 were below the provincial water quality guideline. Effluent concentrations of copper were above the guideline in drainage from all cells. In 2017, only the Sorbtive® media displayed significantly lower copper concentrations than both the control media and asphalt (Table 3). The Sorbtive® media also showed significantly lower concentrations than the control media and asphalt in 2016. Lead concentrations were below the provincial guideline (5 ug/L) in all cells. Although the Sorbtive product had higher aluminum content (Figure 4), effluent concentrations of aluminum were significantly lower than effluents from both the red sand and the control plots (Table 3). Aluminum concentrations from the red sand and control plots were well above the Provincial Water Quality Objective of 75 ug/L and the Canadian Water Quality Guideline of 100 ug/L for the protection of aquatic life (Figure 7).

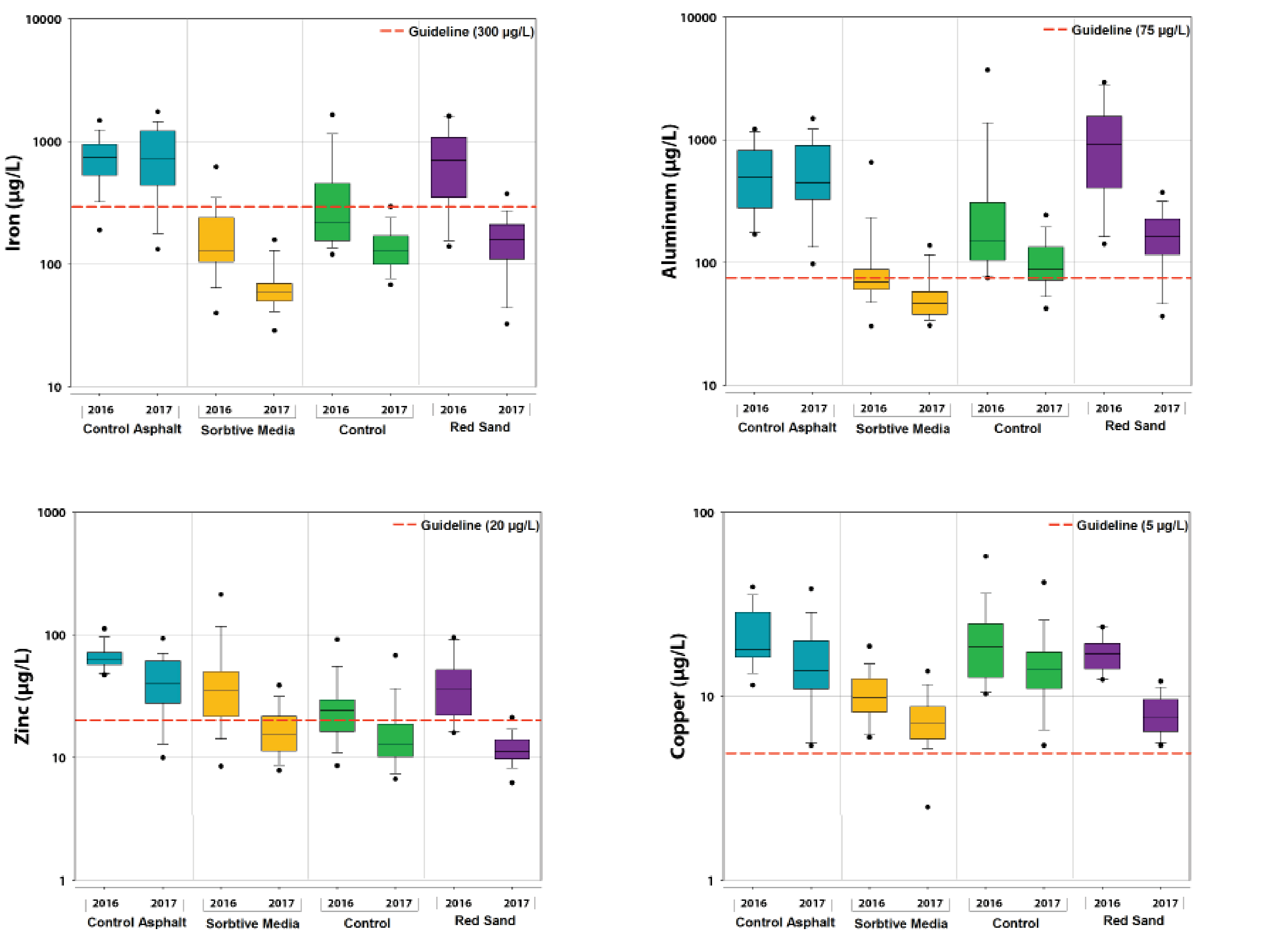

Figure 7. Box Plots for iron, aluminum, zinc and copper

Mixing the reactive media with the bioretention filter media or installing it as a layer below the media were both regarded as reasonable approaches to achieving treatment objectives. While it is impossible to determine whether the observed differences in reactive media performance were explained to some degree by the method of application, the results suggest that both methods had merit. Fully mixing the Sorbtive® and bioretention filter media has the following advantages: (i) rodents or large roots do not have the opportunity to create holes or cracks that would facilitate short circuiting of flows through the reactive media; (ii) treatment is provided over a longer flow path, which may increase contact time; (iii) nutrients retained by the reactive media are more available to plants, which can increase longevity, and (iv) anoxic conditions produced by periodic inundation of the bottom layers would be less likely to mobilize previously retained nutrients. The argument for the layer is that all the nutrients from the surface and mobilized within the media would be forced to move through a large and concentrated quantity of reactive media as the water passes through to the underdrain. While the Sorbtive® media would likely function very well as a layer, as it is sometimes installed in vaults as a standalone filter, it is unclear whether the red sand would function as well if mixed into the bioretention media. This study suggests this method of application warrants further attention.

The bioretention facility reduced runoff volumes from the asphalt by 66% through infiltration and evapotranspiration over the two year study period. Runoff volume reductions before and after the speed bumps were installed were 70%

Table 3. All plots and relevant effluent concentrations compared using Dunn's method for pairwise multiple comparisons.to determine significant statistical differences .

Variable	Asphalt vs Sorb	Asphalt vs Ctl	Asphalt vs RS	Ctl vs Sorb	Ctl vs RS	Sorb vs RS
2016 site comparison						
TSS	Asphalt>Sorb	Asphalt>Ctl	Not sig	Not sig	Not sig	Not sig
Hardness	Asphalt<Sorb	Asphal<Ctl	Not sig	Ctl<Sorb	Not sig	Sorb>RS
Oil & Grease	Asphalt>Sorb	Asphalt>Ctl	Asphalt>RS	Not sig	Not sig	Not sig
Total Phosphorous	Asphalt>Sorb	Not sig	Not sig	Ctl>Sorb	Not sig	Sorb<RS
Ortho-phosphate	Asphalt>Sorb	Not sig	Not sig	Ctl>Sorb	Not sig	Not sig
Total Nitrogen	Not sig	Not sig	Asphalt<RS	Not sig	Not sig	Sorb<RS
Nitrates + Nitrites	Not sig	Not sig	Not sig	Not sig	Not sig	Not sig
Lead	Asphalt>Sorb	Asphalt>Ctl	Not sig	Not sig	Not sig	Not sig
Iron	Asphalt>Sorb	Asphalt>Ctl	Not sig	Not sig	Not sig	Sorb<RS
Copper	Asphalt>Sorb	Not sig	Not sig	Ctl>Sorb	Not sig	Sorb<RS
Zinc	Asphalt>Sorb	Asphalt>Ctl	Not sig	Not sig	Not sig	Not sig
Aluminum	Asphalt>Sorb	Asphalt>Ctl	Not sig	Ctl>Sorb	Ctl<RS	Sorb<RS
2017 site comparison						
TSS	Asphalt>Sorb	Asphalt>Sorb	Asphalt>RS	Ctl>Sorb	Not sig	Sorb<RS
Hardness	Asphalt<Sorb	Asphalt<Ctl	Asphalt<RS	Not sig	Not sig	Sorb>RS
Oil & Grease	Asphalt>Sorb	Asphalt>Ctl	Asphalt>RS	Not sig	Not sig	Not sig
Total Phosphorous	Asphalt>Sorb	Not sig	Asphalt>RS	Ctl>Sorb	Ctl>RS	**Not sig***
Ortho-phosphate	Asphalt>Sorb	Not sig	Asphalt>RS	Ctl>Sorb	Ctl>RS	**Not sig***
Total Nitrogen	Asphalt>Sorb	Not sig	Asphalt>RS	Ctl>Sorb	Not sig	Sorb<RS
Nitrates + Nitrites	Asphalt>Sorb	Not sig	Asphalt>RS	Ctl>Sorb	Ctl>RS	Not sig
Lead	Asphalt>Sorb	Asphalt>Ctl	Asphalt>RS	Not sig	Not sig	Not sig
Iron	Asphalt>Sorb	Asphalt>Ctl	Asphalt>RS	Ctl>Sorb	Not sig	Sorb<RS
Copper	Asphalt>Sorb	Not sig	Asphalt>RS	Ctl>Sorb	Ctl>RS	Not sig
Zinc	Asphalt>Sorb	Asphalt>Ctl	Asphalt>RS	Not sig	Not sig	Not sig
Aluminum	Asphalt>Sorb	Asphalt>Ctl	Asphalt>RS	Ctl>Sorb	Not sig	Sorb<RS
						***has a statistical diference at 90% confidence**

and 57% respectively. The difference can be explained in part by the larger volumes of runoff directed into the facility after installation of the speed bumps, but also by the larger and more frequent rain events in 2017. The native soils below the facility are comprised of silty clay, that do not drain rapidly. When these volume losses are accounted for, the load reductions for phosphorus exceeded 80%.

CONCLUSIONS

This study evaluated the capacity of reactive media to improve retention of nutrients and metals in a bioretention system. Results showed that the Sorbtive® product, mixed into standard filter media at a ratio of 1:10, provided better overall retention of phosphorus than both red sand and the control media during the drier 2016 year. However, during the wetter 2017 year, after the media had stabilized, the red sand and Sorbtive® media cell effluent concentrations of phosphorous were not statistically different, and both cells amended with reactive media had significantly lower effluent concentrations than those from the control filter media cell.

The reactive medias also performed better than the control media for some metals, with varying results by metal type. The red sand media, for instance, was found to have high initial iron concentrations, but these declined over time with stabilization of the media. The red sand and control media both displayed median effluent concentrations of aluminum above receiving water quality guidelines. The Sorbtive® media showed significantly low iron and aluminum levels than red sand. Metal concentrations from all bioretention effluents were significantly lower than asphalt concentrations in most cases.

Reactive medias are particularly useful for lined or low infiltrating bioretention systems that do not benefit from enhanced water quality load reductions through infiltration. Previous studies have shown that these systems can export phosphorus due to nutrient leaching from growing medias, and release from vegetation during the fall when plants senesce (STEP, 2008; STEP 2019). Leaching can be significant if the filter media contains high organic matter content (STEP 2019).

REFERENCES

STEP (2008) Performance Evaluation of Permeable Pavement and a Bioretention Swale Seneca College, King City, Ontario, Toronto.

STEP (2019). Comparative Performance Assessment of Bioretention in Ontario , Toronto.

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About STEP

The water component of the Sustainable Technologies Evaluation Program (STEP) is a partnership between Toronto and Region Conservation Authority (TRCA), Credit Valley Conservation (CVC), and Lake Simcoe Region Conservation Authority (LSRCA).

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