Date: December 7, 2018

Final Performance Report to N.C. Coastal Federation for:

Assessing Innovative Stormwater Management on Wrightsville Beach, N.C.

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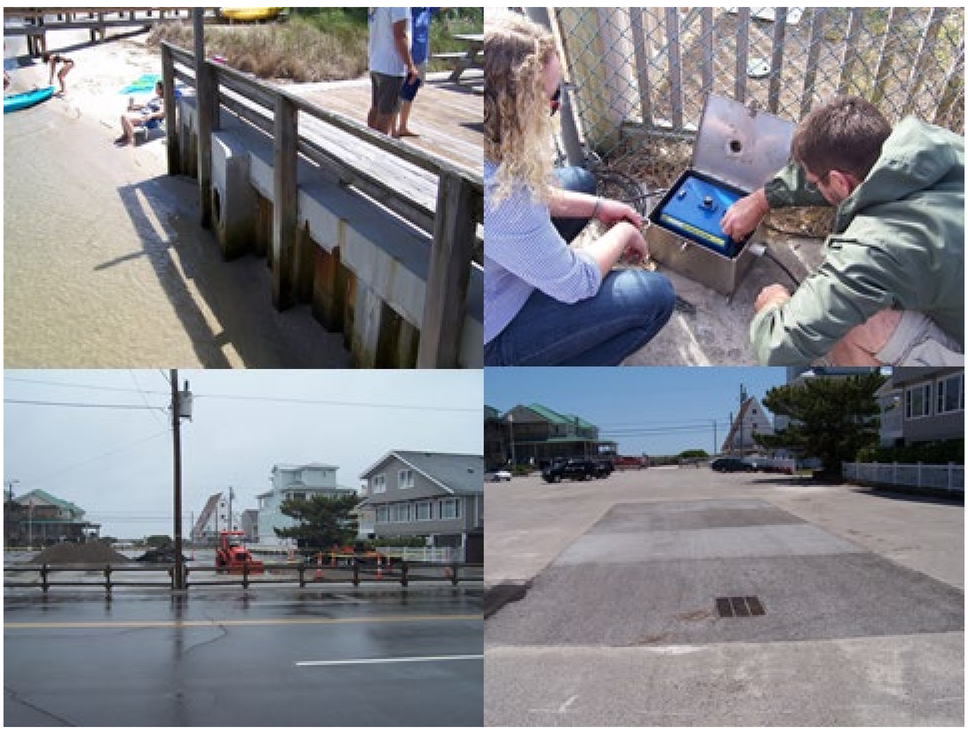


Cover photos: Top left; north stormwater outfall to Bank's Channel at low tide, showing heavy public usage. Top right; UNCW researchers setting up stormwater monitoring equipment prior to rain event. Bottom left; BMP construction in Hanover Seaside Club parking lot, early 2018. Bottom right; installed pervious pavement surrounding stormwater drain in the parking lot.

Executive Summary

The Hanover Seaside Club and the Town of Wrightsville Beach, southeastern North Carolina, partnered with the North Carolina Coastal Federation to convert portions of their existing stormwater collection systems into one that infiltrates polluted stormwater runoff through pervious pavement and an infiltration chamber system, with the goal of significantly reducing the runoff entering Bank's Channel. The performance of these installed BMPs, or best management practices was analyzed by researchers from the University of North Carolina Wilmington Center for Marine Sciences.

The design criterion for the BMP set was to be able to treat 1.5 inches of rain. The BMPs were successful in producing significant reductions of stormwater outflow to Banks Channel for rain events less than 1.5 inches, and overall reductions of 70-88% were achieved, as mean and median. There were also considerable reductions in the loadings of key estuarine pollutants. *Enterococcus* bacteria is a fecal bacterium that is used as a standard for human health contact in estuarine and marine waters. Loading of this pollutant decreased 43% and 83%, as mean and median, respectively. Total suspended solids (TSS) is a measure of land erosion, and such solids are common pipe pollutants in stormwater removal systems. TSS decreased 44% and 50% as mean and median, respectively. Total nitrogen (TN) represents the most important nutrient to control in order to limit algal bloom formation in coastal waters. TN discharge decreased by 72% and 86%, as mean and median, respectively. Total phosphorus (TP) is another nutrient that can stimulate algae growth as well as growth of bacteria, including fecal bacteria. The TP discharge decreased by 57% and 70%, as mean and median, respectively. Thus, these BMPs, which are designed to control stormwater runoff from parking lots and relatively small, but intensely used watersheds, provide efficient control of important estuarine and marine pollutants in coastal areas.

Background

The Hanover Seaside Club and the Town of Wrightsville Beach partnered with the NC Coastal Federation to convert portions of their existing stormwater collection systems into one that infiltrates polluted stormwater runoff through pervious pavement and an infiltration chamber system, with the goal of significantly reducing the runoff entering estuarine Bank's Channel. The site is the Hanover Seaside Club's parking lot and adjacent environs along Waynick Dr., bordering Bank's Channel. The lower area of the parking lot and adjacent areas have been treated by installation of Best Management Practices (BMPs), and several storm drains were impacted. The BMP design and installation was performed by Coastal Stormwater Services, Inc., of Wilmington, N.C.

There are two storm drains in the lower parking lot. The pavement immediately surrounding the drains has been replaced with pervious pavement, and the two drains have been connected by an infiltration system. Additionally, runoff from some street and limited greenspace surrounding the parking lot is treated by the pervious pavement and infiltration chamber as well. Construction was completed end of April 2018.

Water Quality Objectives

The water quality portion of the project was carried out by the Aquatic Ecology Laboratory of the UNC Wilmington's Center for Marine Science. The objective was to determine the effectiveness of the installed BMPs in reducing the quantity of runoff discharged to surface waters and for improving the quality of the discharge as measured by reduction of fecal bacteria, suspended solids, nitrogen and phosphorus loads. The main portion of the research was to sample and assess the stormwater loads entering Bank's Channel by comparing before-and-after impacts of the BMPs. The data within this report were collected up until November 28, 2018.

Methods

Sampling and analyses: Pre-BMP: Beginning October 9, 2017, water samples were collected at the discharge outfalls during rain events projected to be of at least 0.25 inches; 10 rain events were sampled through February 2018. Fecal bacteria samples were collected in pre-autoclaved 500 ml jars, immediately placed on ice, and processed within 12 hr of collection. The bacteria analysis used is Method 9230C for *Enterococcus* bacteria (APHA, 2005). Concentration data are reported as colony-forming units (CFU)/100 mL of water. Fecal bacteria are also often associated with suspended solids, and suspended sediments are a concern to stormwater managers and environmental engineers because they clog drainage systems, thus we analyzed total suspended solids (TSS) as well. TSS analysis was performed gravimetrically following Method SM 2540D. Total nitrogen (TN) and total phosphorus (TP) samples were collected and analyzed by AutoAnalyzer.

Post BMP: On May 24 and 28, 2018, rain events were sampled for stormwater flow only. Subsequently, rain events were sampled for all parameters June 9, June 26, July 12, July 24, July 30, October 26, November 15 and December 1 (the December sample for pollutant concentrations only.

To obtain discharge data the outfall pipes were fitted with ISCO 2150 Area Velocity Flow Modules to collect data before, during and after events. Stormwater discharge over the event was analyzed to produce an event-average basis (as L/hr) as well as total discharge per event. To estimate pollutant load to Banks Channel before and after BMP installation, bacterial, TSS and TN and TP concentrations were multiplied by average discharge to produce *Enterococcus* as CFU/hr, g TSS/hr, and mg N or P/hr, respectively. To check for statistical outliers the final data sets were submitted to Tukey's test. As such, an extremely high *Enterococcus* concentration from the south pipe on July 30 was deemed a statistical outlier and removed from the data set.

Statistical analyses: To assess the performance of the BMPs in reduction of stormwater to Banks Channel, outfall from both the north and south pipes were combined to get total flow per event. Local rainfall data was obtained from Wrightsville Beach Park station KNCWRIGH6, and regressed against total stormwater discharge (per event) from the pipes to determine if the BMPs significantly reduce stormwater discharge. This produced separate regression lines and equations for the before-and-after BMP periods. To compare the change in pollutant discharge between periods, the stormwater, *Enterococcus*, TSS, TN and TP average discharges were log-transformed and compared using t-tests. Differences were considered statistically significant for

Enterococcus data if $p < 0.10$ (due to the high variability in fecal bacterial count data), and for all other data if $p < 0.05$.

Pollutant Concentration Results

Pre-BMP pollutant concentrations:
The data indicates that the sub-watersheds draining into the two outfall pipes are highly polluted (Table 1). *Enterococcus* bacteria are used for ocean beach water safety; the single sample maximum is 104 CFU/100 mL; limit for 5 samples collected within 30 days is 35 CFU/100 mL. The stormwater coming off of the watershed's impervious surfaces is highly concentrated in fecal bacteria, in the multiple thousands (Table 1). As a comparison, in a previous study (Mallin et al. 2016) *Enterococcus* concentrations draining an outfall into Bank's Channel for the Iula St. watershed to the south of the present site were considerably lower (geometric mean 443 CFU/100 mL). Comparing between the two outfalls, arithmetic mean, median and geometric mean *Enterococcus* concentrations were all higher exiting the north pipe than the south pipe (Table 1).

Total suspended solid concentration has no ambient standard in North Carolina. Our experience in the coastal area is that TSS values exceeding 25 mg/L are generally rare. TSS concentrations in the stormwater samples were highly variable, ranging from low to high concentrations (Table 1). There was little overall difference between TSS concentrations exiting both pipes. TSS concentrations in the pre-BMP results were lower than those of the previous Iula St. study (mean = 52.5 mg/L; Mallin et al. 2016).

We performed an inspection of the area near the storm drains and accumulations of sand and other particulates were visible (Plate 1). Thus, depending upon rain event length and intensity there can be a substantial amount of suspended material coming off the watershed to pollute Bank's Channel.

Plate 1. Accumulations of dirt near stormwater outfalls draining into the south and north outfalls, i.e. sources of TSS.

Nutrient concentrations
TN and TP concentrations pre-BMP were somewhat greater exiting the north pipe than the south pipe (Table 3), and variability among dates was not great.

Post- BMP pollutant concentrations
Rainfall data collected in conjunction with pollutant parameter sampling showed no significant difference for rainfall pre-vs-post BMP installation (Tables 1 and 2). Pre-BMP average rain for 10 events was 23.4 + 17.9 mm (0.9-0.7 in), median 20.6 mm (0.8 in) with a maximum of 44.5 mm (1.8 in). The post BMP average for 8 events was 19.3 + 10.4 mm (0.8 + 0.4 in), median 20.1 mm (0.8 in) ranging up to 36.6 mm (1.4 in).

Concentrations of *Enterococcus* (from 8 post-BMP samples) show generally higher concentrations leaving the south pipe than the north pipe (Table 2). This may be due to a larger percent impervious surface area draining to the south outfall as opposed to the north outfall, as drainage to the south outfall is essentially 100% impervious surface.

TSS concentrations were highly variable (Table 2). Very high TSS concentrations were found in some of the first samples collected from the north pipe following installation of the BMPs. This was followed by a rapid decrease during the very rainy July period, wherein TSS concentrations decreased to zero by end of that month.

Post-BMP TN and TP concentrations revealed a pattern of greater concentrations in the north outflow, similar to the pre-BMP data (Table 3). Again, variability among dates was low except for one incident when north pipe effluent TN reached > 1.8 mg-N/L June 9. Notably, during July 2018 there was a continual dilution of TN and TP as time went on during this rainy month.

Stormwater Discharge Changes Following BMP Installation

Pre-BMP installation data were collected from 10 rain events, ranging from 4.4 mm (0.18 in) to 44.5 mm (1.75 in). Post-BMP data for stormwater alone were collected from 10 rain events ranging from 1.5 mm (0.06 in) to 74.9 mm (2.93 in on May 28, 2018, the project 24-hr maximum). Following the installation of the BMPs, average stormwater discharge to Banks Channel from both pipes combined decreased on average 88%, and showed a median decrease of 70% (Fig. 1). This decrease is statistically significant ($p = 0.026$). Reductions occurred at both the north and south outfalls (Tables 4 and 5).

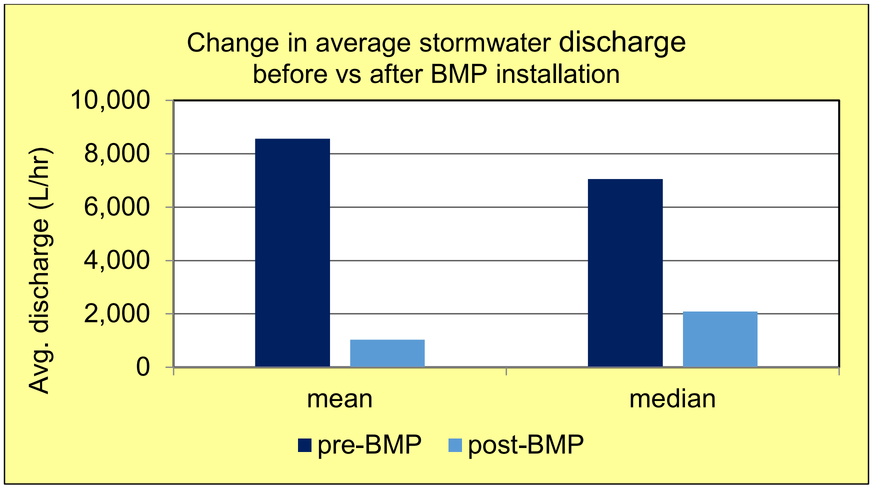


Figure 1. Change in average stormwater discharge (L/hr) to Banks Channel following BMP installation, north and south outfalls combined, comparison of 10 storms each.

There was a strong statistical relationship between the amount of precipitation observed at Wrightsville Beach Park and combined volume of flow from both pipes (Fig. 2). Prior to BMP installation, rain events greater than 12 mm (about a half-inch) were generating notable discharge into Banks Channel (Fig 2 black), greater than 75 m^3. However, following BMP installation that discharge level was not exceeded before rainfall amounts of 35 mm (1.4) in) were exceeded (Fig. 2 red). The regression lines on each panel predict (with good confidence) expected outflow relative to rainfall. Based on the regression equations, before BMP installation it required about 17.5 mm of rain (0.7 in) to generate 100 m^3 of outflow, whereas after BMP installation it requires about 34 mm (1.3 in) of rain to generate that same amount of outflow to Banks Channel. Thus, at low to moderate rain events outflow is well controlled. However, once roughly 35 mm (1.4 in) is surpassed, stormflow is not controlled nearly as well. We note that the project design is for the 1.5 in (38.1 mm) 24-hr storm, thus the collective BMP perform as designed.

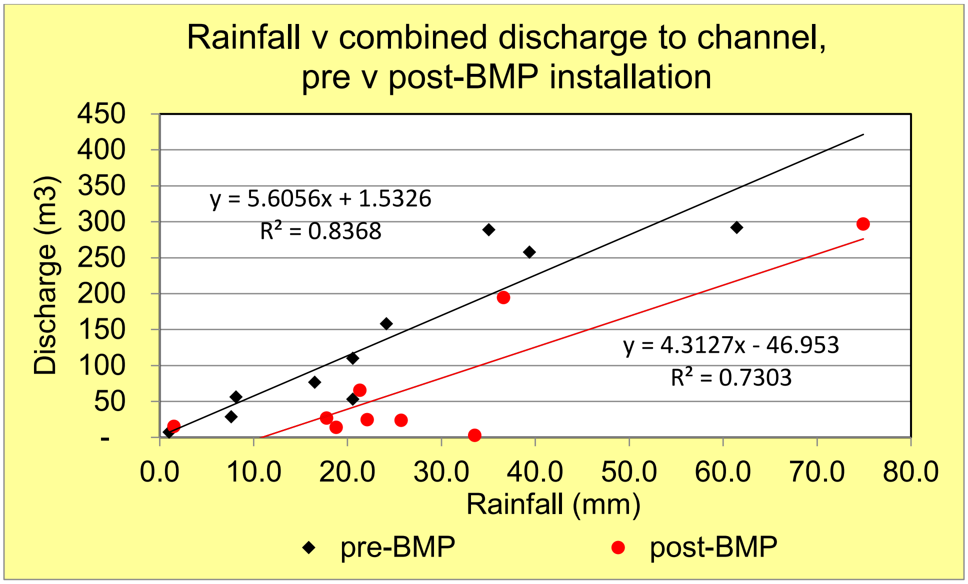
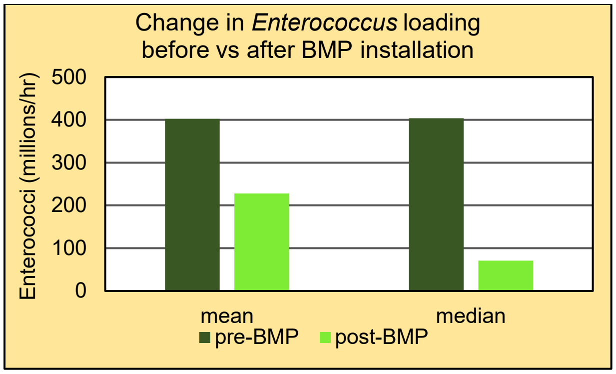


Figure 2: Total stormwater outflow (discharge) to Banks Channel in cubic meters as a function of rainfall (mm) for all 10 pre-BMP installation sampling events (black diamonds) compared to 10 post-BMP installation sampling events (red circles); from the north and south pipe combined.

Pollutant Loads to Banks Channel

Enterococcus bacteria loads: Regarding *Enterococcus* loads to Banks Channel, the north pipe showed a major decrease following BMP installation (Tables 4 and 5), with the arithmetic mean decreasing by 80% and the median decreasing by 92%. In contrast, the south pipe showed virtually no difference in loads following BMP installation (Tables 4 and 5). When loads from both pipes were combined, there was an overall statistically significant decrease ($p = 0.07$ in *Enterococcus* loading post-BMP (Fig. 3).

Total suspended solids: The TSS loads exiting the two outfalls pre-vs-post BMP were highly variable (Tables 4 and 5); data from 10 pre-BMP and 7 post-BMP events are available. Median TSS post-BMP load was considerably lower than pre-BMP, as were arithmetic mean TSS loading for the south pipe (arithmetic means for the north pipe were similar (Tables 4 and 5). When the combined loads from both pipes were compared, there was a 44% decrease according to the arithmetic mean and an 50 % decrease considering the median (Fig. 3). The difference was not statistically significant ($p > 0.05$) however, due to the large variability. Overall, the TSS loads were considerably lower than the average TSS load exiting the Iula St. outfall (in a nearby drainage) in a previous study, which was 646 g/hr, pre-BMP (Mallin et al. 2016).



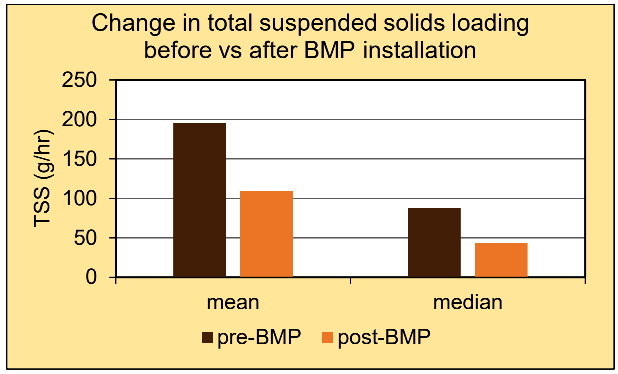
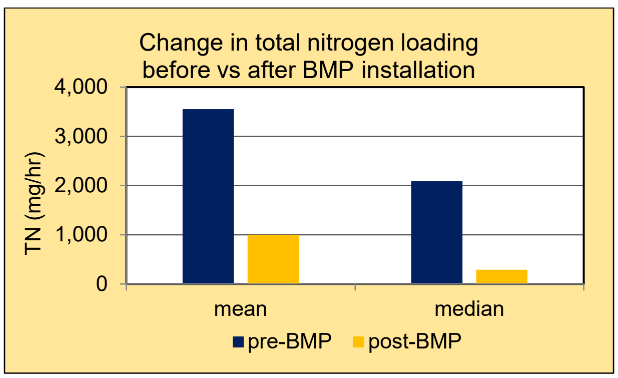


Figure 3 (left). Average *Enterococcus* discharge (millions of cell/hr) to Banks Channel before vs after BMP installation, north and south outfalls combined. Figure 4 (right). Average total suspended solids discharge (g/hr) to Bank's Channel before vs after BMP installation, north and south oufalls combined.

Nitrogen and Phosphorus load reduction: Nutrient loading data to Banks Channel appear much more clear-cut (Tables 6 and 7). As measured by mean and median, loading of both total nitrogen (TN) and total phosphorus (TP) were greatly reduced following BMP installation (Figs. 4 and 5). The TN decrease in particular was striking, 72% for the arithmetic mean and 86% for the median, and was statistically significant ($p = 0.008$). TP load decrease following BMP installation was 57 % for the mean and 70% for the median (non-significant).



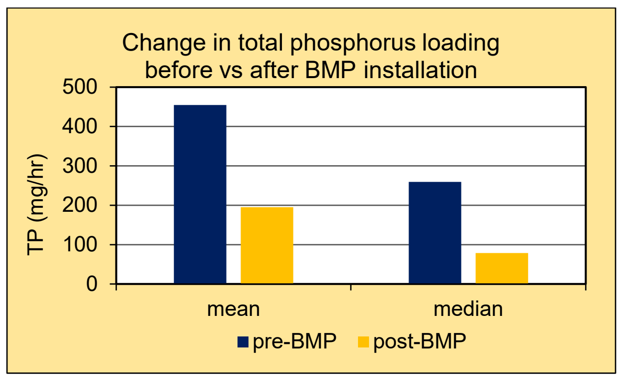


Figure 5 (left). Average total nitrogen discharge (mg/hr) to Banks Channel before vs after BMP installation, north and south outfalls combined. Figure 6 (right). Average total phosphorus discharge (mg/hr) to Bank's Channel before vs after BMP installation, north and south oufalls combined.

Summary

Hydrological data available from 10 pre-BMP and 10 post-BMP rain events show that following BMP installation, considerable reductions in stormwater outflow to Banks Channel were achieved for local rainfall events < 1.5 inches (about 37 mm). However, once this level was exceeded, the stormwater retention benefit was lost. As the design criterion was for the 1.5 inch storm, the BMP functions as designed. Overall, the BMP installation led to average (L/hr) rain-event specific stormwater mean and median reductions of 70% and 88%.

Clear-cut reductions in concentrations in *Enterococcus*, TSS and TP were not evident. However, some reductions in TN concentrations were achieved.

There were definite reductions in discharge of pollutants (pollutant load) to Banks Channel, based on 7 post-BMP sampling events compared to 10 pre-BMP sampling events. Average *Enterococcus* discharge from both pipes combined decreased from 403 million/hr down to 228 million/hr as mean, and from 404 million/hr to 71 million/hr, as median. Post-BMP, mean TSS discharge was reduced 44% and median TSS discharge was reduced 50%.

There were clear-cut decreases in both TN and TP load to Banks Channel following BMP installation, especially so for TN. For the combined load entering the estuary from the outfalls, there was an average 72% TN reduction, post-BMP, and an 86% reduction considering the median. Based on several fall samples, the TN/TP ratio for Banks Channel water is 6.4, indicating that the local phytoplankton are nitrogen limited. Thus, the strong TN reductions are especially useful considering estuarine BMP placement if algal bloom formation is an issue. Regarding TP load reduction, there was a 57% mean load reduction and a 70% median load reduction post-BMP installation.

Acknowledgements

Funding was provided by the State of North Carolina Clean Water Management Trust Fund CWMTF Project Number**:** 2016-1002, to the North Carolina Coastal Federation. For project facilitation we thank Tracy Skrabal of the North Carolina Coastal Federation. The BMP system was designed by Larry Sneeden of Coastal Stormwater Services, Inc., Wilmington, NC, who installed the BMPs. We thank Nick Iraola of UNCW for nutrient analysis.

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Table 1. Pre-BMP installation rainfall and pollutant concentration data for the two pipes draining into Bank's Channel from Hanover Seaside Club's parking lot and adjacent street area (NA = no data available).

	Rainfall (mm)	*Enterococcus* (CFU/100 mL)		TSS (mg/L)	
Date		north	south	north	south
Oct 9 2017	1.0	12,475	1,082	12.5	11.1
Oct 10 2017	20.6	3,000	3,000	12.5	57.1
Oct 29 2017	39.4	3,380	8,125	12.9	28.6
Nov 9 2017	16.5	5,135	1,660	10.0	4.3
Dec 6, 2017	7.6	14,375	5,330	62.4	33.3
Dec. 8, 2017	24.1	5,293	1,087	2.9	5.7
Dec. 20, 2018	20.6	NA	NA	24.3	7.1
Jan. 12, 2018	61.5	4,486	2,953	20.0	20.0
Jan. 28. 2018	35.1	9,267	7,133	18.6	32.9
Feb. 4, 2018	8.1	60	3,507	24.3	21.4
Mean	23.4	6,386	3,764	20.0	22.2
Sd. Dev.	17.9	4,692	2,572	16.3	16.5
Median	20.6	5,135	3,000	15.8	20.7
Geometric mean		3,678	2,984		
Range	1.0-61.5	60-14,375	1,082-8,125	2.9-62.4	4.3-57.1

Table 2. Post-BMP installation rainfall and pollutant concentration data for the two pipes draining into Bank's Channel from Hanover Seaside Club's parking lot and adjacent street area.

	Rainfall (mm)	*Enterococcus* (CFU/100 mL)		TSS (mg/L)	
Date		north	south	north	south
Jun 9, 2018	1.5	775	712	195.1	93.3
Jun 26, 2018	17.8	1,340	4,650	72.8	30.5
Jul 12, 2018	22.1	2,290	22,220	315.0	83.3
Jul 24, 2018	21.3	2,975	18,840	6.7	3.3
Jul 30, 2018	36.6	4,145	NA	0.0	0.0
Oct 26, 2018	25.7	9,090	6,638	11.7	43.3
Nov 15	18.8	935	12,830	15.0	2.5
Dec 1, 2018	10.4	1,428	1,920	65.0	10.0
Mean	19.3	3,079	9,687	85.2	33.3
Sd. Dev.	10.4	2,911	8,429	112.9	37.2
Median	20.1	2,290	6,638	40.0	20.3
Geometric mean		2,200	5,822		
Range	1.5-36.6	775-9,090	712-22,220	0-315.0	0-93.3

Table 3. Summary nutrient concentration data for the north and south pipes, pre-and-post BMP installation; in g N or P/L.

Pre-BMP	TN		TP	
N = 10	north	south	north	south
Mean	619.2	363.1	48.6	37.8
St. Deviation	451.0	232.9	31.3	25.1
Median	496.6	304.1	38.1	29.2
Range	109-1.428	121-780	15-109	5-85
Post-BMP N = 7	north	south	north	south
Mean	571.5	266.5	101.7	60.1
St. Deviation	748.8	300.8	107.8	48.3
Median	151.6	140.0	34.8	43.3
Range	55-1,854	44-883	10-285	21-156

Table 4. Pre-BMP construction stormwater and pollutant loading data for the north and south outfalls to Bank's Channel opposite the Hanover Seaside Club, October 2017-February 2018.

Parameter	north outfall	south outfall
Stormwater discharge (L/hr)		
Arithmetic mean	3,341	5,230
Median	2,672	4,630
N = 10		
Enterococcus load (million/hr)		
Arithmetic mean	178.6	223.9
Median	191.6	73.6
N = 10		
TSS load (g/hr)		
Arithmetic mean	51.7	143.9
Median	48.1	42.9
N = 10		

Table 5. Post-BMP construction stormwater and pollutant loading data for the north and south outfalls to Bank's Channel opposite the Hanover Seaside Club, May-July 30, 2018.

Parameter	north outfall	south outfall
Stormwater discharge (L/hr)		
Arithmetic mean	1,604	2,646
Median	1,031	906
N = 7		
Enterococcus load (million/hr)		
Arithmetic mean	35.9	224.4
Median	15.6	70.6
N = 7 (N), 6 (S)		
TSS load (g/hr)		
Arithmetic mean	55.3	53.8
Median	15.8	27.6
N = 7		

Table 6. Pre-BMP construction stormwater and nutrient loading data for the north and south outfalls to Bank's Channel opposite the Hanover Seaside Club, October 2017-February 2018.

Parameter	north outfall	south outfall
Total nitrogen load (mg/hr)		
Arithmetic mean	1,780	1,770
Median	1,082	1,131
N = 10		
Total phosphorus load (mg/hr)		
Arithmetic mean	202	252
Median	90	140
N = 10		

Table 7. Post-BMP installation nutrient loading data for the north and south outfalls to Bank's Channel opposite the Hanover Seaside Club, June 9-November 15, 2018.

Parameter	north outfall	south outfall
Total nitrogen load (mg/hr)		
Arithmetic mean	375.3	627.5
Median	72.9	228.8
N = 7		
Total phosphorus load (mg/hr)		
Arithmetic mean	62.7	132.4
Median	31.4	61.1
N = 7		