Optimal Design of Stormwater Basins with Bio-Sorption Activated Media (BAM) in Karst Environments – Phase II: Field Testing of BMPs

BDV24-977-20

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March 2020

Final Report

DISCLAIMER

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
AREA				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
TEMPERATURE (exact degrees)				
ºF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	ºC

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
FORCE and PRESSURE or STRESS				
lbf	pounds force	4.45	Newtons	N
lbf/in^2	pounds force per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
AREA				
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds mass	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
TEMPERATURE (exact degrees)				
ºC	Celsius	1.8C+32	Fahrenheit	ºF

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
FORCE and PRESSURE or STRESS				
N	Newtons	0.225	pounds force	lbf
kPa	kilopascals	0.145	pounds force per square inch	lbf/in^2

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16. Abstract

Two new designs of stormwater Best Management Practices (BMPs) using Biosorption Activated Media (BAM) were developed, implemented, and tested: (1) blanket filters, located within a stormwater management facility, and (2) vertical infiltration reactors.

The blanket filter, comprised of a 1-ft top-soil layer and 3-ft BAM layer, removed 60%-66% of TN, NO_x, and NH_3 from roadway runoff. Mean removals of total nitrogen (TN), nitrate-nitrite (NO_x), and ammonia (NH_3) within a 3-ft top-soil layer (containing no BAM) range from 78%-92%, exceeding mean removals observed in the blanket filter.

Within a blanket filter, a 3-ft BAM layer removes considerably more nitrogen, and particularly NO_x, as compared to 1.5-ft layer of BAM. Similarly, a 3-ft soil layer above the BAM layer may remove considerably more nitrogen as compared to a 1-ft soil layer. It is estimated that through a 20- to 30-year design life, the cost of each pound of TN removed by blanket filters (a 3-ft layer of BAM placed in the vadose zone with 1-ft soil coverage) is $611-$715, while each pound of NO_x removed will cost $1,360-$1,590. Of six media configurations tested within vertical reactors, nitrogen removal was best achieved by a 4-ft layer of BAM; a mean 49% TN and over 53% NO_x was removed from incoming stormwater. It is estimated that through a 20- to 30-year design life, the cost of each pound of TN removed by vertical reactors placed in the vadose zone is $453-$498. It is estimated that each pound of NOx removed will cost $701-$732.

17. Key Word	18. Distribution Statement
Karst, stormwater BMPs, roadway runoff, blanket filter, Biosorption Activated Media, vertical reactor, nitrogen	No restrictions

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Unclassified	Unclassified	29	

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EXECUTIVE SUMMARY

Contamination of Florida's surface and groundwater resources by excess nutrient loadings degrades water quality and aquatic habitat. In this project, two new designs of stormwater Best Management Practices (BMPs) containing engineered media were developed, implemented, and tested in the field. Blanket filters and vertical reactors containing Biosorption Activated Media (BAM) were constructed in stormwater management basins and systematically tested for efficiency in capturing roadway runoff and removing nitrogen. Hydrologic data collected within BMPs were assessed over 101 storm events to characterize hydrologic fluxes. Roadway runoff and infiltrate from within the BMPs were sampled and evaluated for nutrient content over 11 discrete storm events. The goals of this research project were to (1) assess nitrogen removal potential of the BAM blanket filters and vertical reactors and (2) to understand relative costs and benefits of the BMPs over a 20- to 30-year BMP design life.

A blanket filter, consisting of a 1-ft top sandy soil layer and 3-ft BAM layer, placed in the vadose zone (unsaturated zone) of a stormwater management basin captured 100% of incoming roadway runoff during the monitoring period. The blanket filter reduced concentrations of total nitrogen (TN), nitrite-nitrate (NO_x), and ammonia (NH_3) in roadway runoff by a mean of 60%-66%. By comparison, mean removals of TN, NO_x, and NH_3 within a 3-ft soil layer (containing no BAM) in the same basin range from 78%-92%, exceeding mean removals observed in the blanket filter. Specific design parameters of the blanket filter were tested to understand how depth of the BAM and soil layers influence nitrogen remediation. Within a blanket filter, a 3-ft layer of BAM removes considerably more nitrogen, and particularly NO_x, as compared to 1.5-ft layer of BAM. Within a blanket filter, a 3-ft soil layer above the BAM layer may remove considerably more nitrogen as compared to a 1-ft soil layer.

Of six media configurations tested within vertical reactors, nitrogen removal was best achieved by a 4-ft layer of BAM. This configuration removed a mean 49% TN and over 53% NO_x from incoming stormwater. The vertical reactors captured only a small fraction (0.2%) of incoming stormwater. It is estimated that through a 20- to 30-year design life, the cost of each pound of TN removed by blanket filters (a 3-ft layer of BAM placed in the vadose zone with 1-ft soil coverage) is $611-$715. It is estimated that the cost of each pound of NO_x removed by blanket filters is $1,360-$1,590. It is estimated that through a 20- to 30-year design life, the cost of each pound of TN removed by vertical reactors placed in the vadose zone is $453-$498. It is estimated that each pound of NO_x removed will cost $701-$732.

This project is one of the first field-scale tests of BAM-based stormwater BMPs and the first testing of the blanket filter and vertical reactor designs. While testing indicates good performance of BAM blanket filters in removing nitrogen species from stormwater runoff, the nitrogen remediation benefits above that which may expected from the natural soil profile are unclear. Further controlled field-scale testing is recommended to better understand when and where BAM may be expected to deliver clear and measurable nitrogen removal benefits.

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CHAPTER 1. Introduction

Roadway runoff is a non-point source of pollution endangering surface and groundwater resources. Excess nutrient loads can lead to ecosystem degradation by causing eutrophication, algal blooms, and loss of biodiversity (Mallin et al. 2009; Suthar et al. 2009; Eller and Katz 2017). Although various sources of excess nitrogen loading are documented, such as septic tanks, chemical fertilizers, livestock wastes, and wastewater treatment sites (Eller and Katz 2017), roadway runoff has been ranked as a major source of non-point source nutrients in the U.S. and in Florida (Trenouth and Gharabaghi 2016). Engineered media, such as Biosorption Activated Media (BAM), may facilitate contaminant removal through physical, chemical, and biological interactions within the media (O'Reilly et al. 2012). The inclusion of engineered media within stormwater Best Management Practices (BMPs) may therefore enhance nutrient removal performance of the BMP. Overall performance of media-based stormwater BMPs will hinge upon the hydraulic design of the BMP to efficiently capture runoff, as well as the performance of the engineered media to effectively remove nutrients from infiltrated runoff.

In this project, two new designs of stormwater BMPs containing BAM engineered media were developed, implemented, and tested in the field. The goals of this research project were to (1) assess nitrogen removal potential of the BAM blanket filters and vertical reactors and (2) to understand relative costs and benefits over a 20- to 30-year BMP design life. To assess nitrogen removal potential of BAM blanket filters and vertical reactors, BMPs were instrumented with hydrologic monitoring equipment and subsurface sampling devices. Hydrologic data were collected within BMPs over 101 storm events to characterize hydrologic fluxes. Roadway runoff entering the BMPs and infiltrated stormwater from multiple locations within BMPs were sampled over 11 storm events and analyzed at a certified laboratory for total nitrogen (TN), nitrate-nitrite (NO_x), and ammonia (NH_3). To understand costs per pound of nitrogen removed over a 20- to 30-year project design life, modeling and field data were used to estimate TN and NO_x removal through BMP design life (through target years 2038 and 2048). Life cycle cost analysis was undertaken to compare BMP lifetime TN and NO_x removal benefits to construction/operational costs.

Projects goals were facilitated by the following research tasks:

Task 1: BMP Design

Task 2: BMP Construction and Instrumentation

Task 3: BMP Monitoring

Task 4: BMP Life-cycle Cost Assessment

Task 5: Project Draft Final Report

Task 6: Project Final Report

Interim reporting regarding each of these tasks (Kibler et al. 2017a; 2017b; 2017c; 2017d; Kibler et al. 2018; Kibler et al. 2019a; 2019b) are available on the UCF STARS data repository (https://stars.library.ucf.edu/fdot/).

CHAPTER 2. BMP Implementation and Monitoring

In this project, two new designs of stormwater Best Management Practices (BMPs) were developed, implemented and tested in stormwater management basins near Ocala in Marion County, FL (Figure 2.1). Basin 9b is located near Silver Springs State Park (29° 12' 56" N and 82° 03' 30" W) and collects runoff from State Road 40 and State Road 35. Basin 2 is located approximately 2 miles south of Basin 9b off SR 35 (29° 11' 16" N and 82° 03' 11" W) and collects runoff from State Road 35.

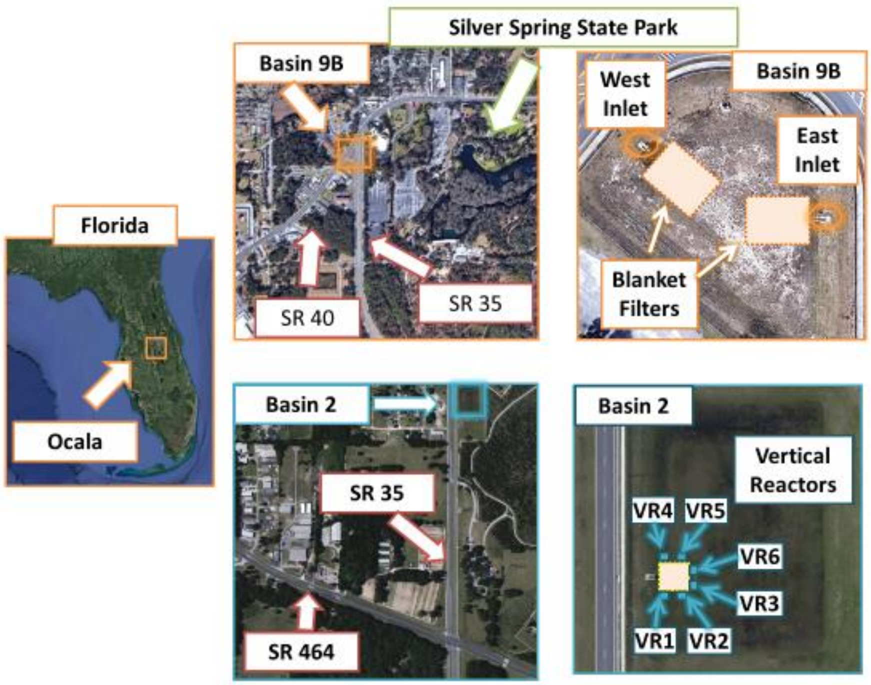

Figure 2.1. Location of Basin 9b and Basin 2 near Ocala, FL, and BMP schematics.

Two blanket filters containing biosorption activated media (BAM) were constructed in Basin 9b, one at a depth of 0-6 ft below ground surface (West Blanket Filter, WBF) and the other 0-4 ft below ground surface (East Blanket Filter, EBF) (Figure 2.2). A 3-ft layer of BAM in the WBF was overlain by a 3-ft layer of aerobic soil (topsoil from the site), while the EBF included a 3-ft layer of BAM and 1-ft soil layer. In Basin 2, six vertical reactors (VR1 to VR6) were constructed of concrete, containing different volumes of BAM or iron filings-based green environmental media (IFGEM-2) (Figure 2.3). All BMPs were instrumented with subsurface sampling devices and hydrologic monitoring equipment, including deep and shallow pressure transducers to characterize the depth to groundwater and transient fluxes within the vadose zone related to event runoff. Hydrologic data were collected within BMPs over 101 storm events to characterize hydrologic fluxes. Roadway runoff entering the BMPs and infiltrated stormwater from multiple locations within BMPs were sampled over 11 storm events and analyzed at a certified laboratory for total nitrogen (TN), nitrate-nitrite (NO_x), and ammonia (NH_3).

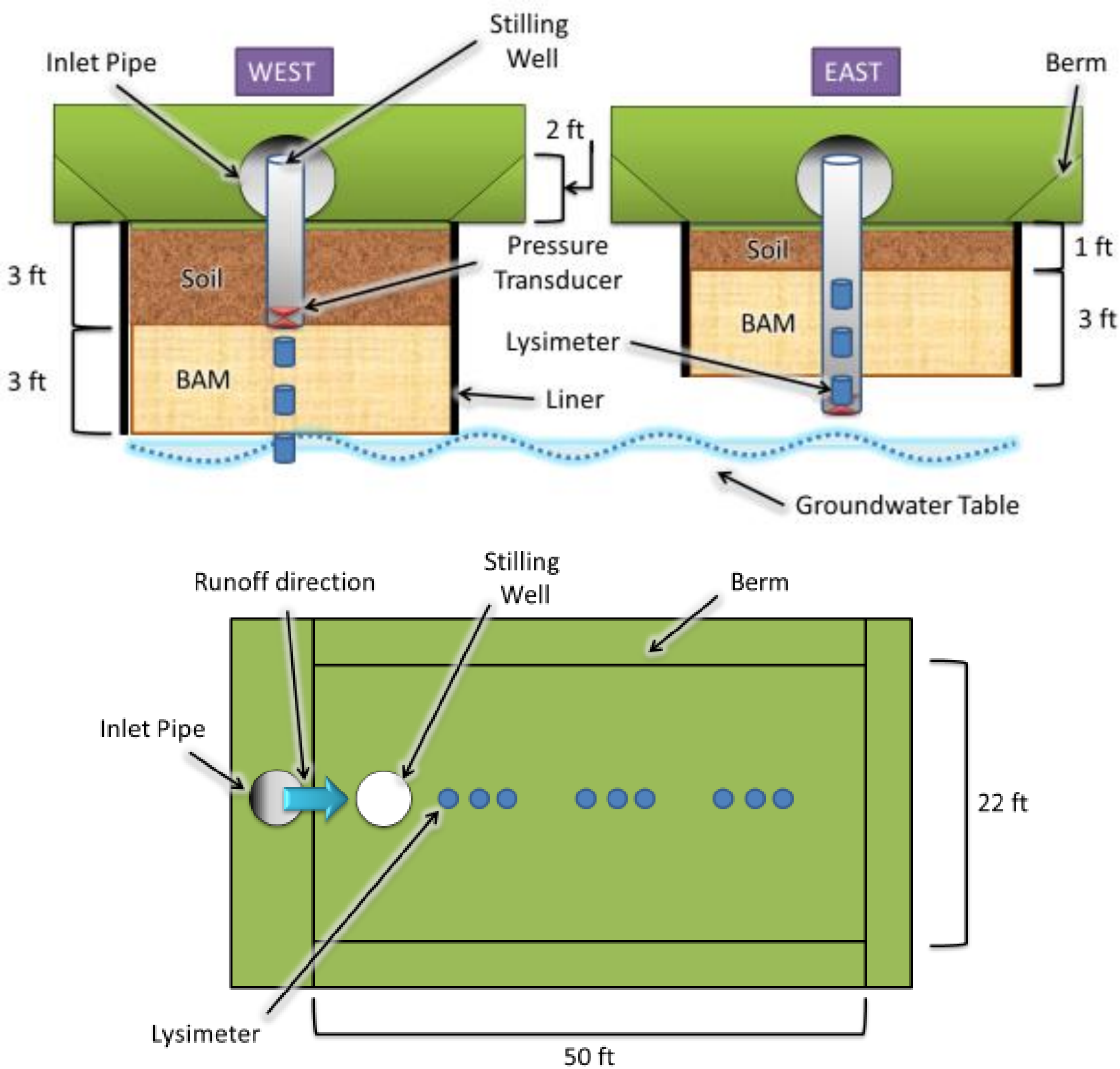

Figure 2.2. Basin 9b WBF and EBF in cross-section and plan view.

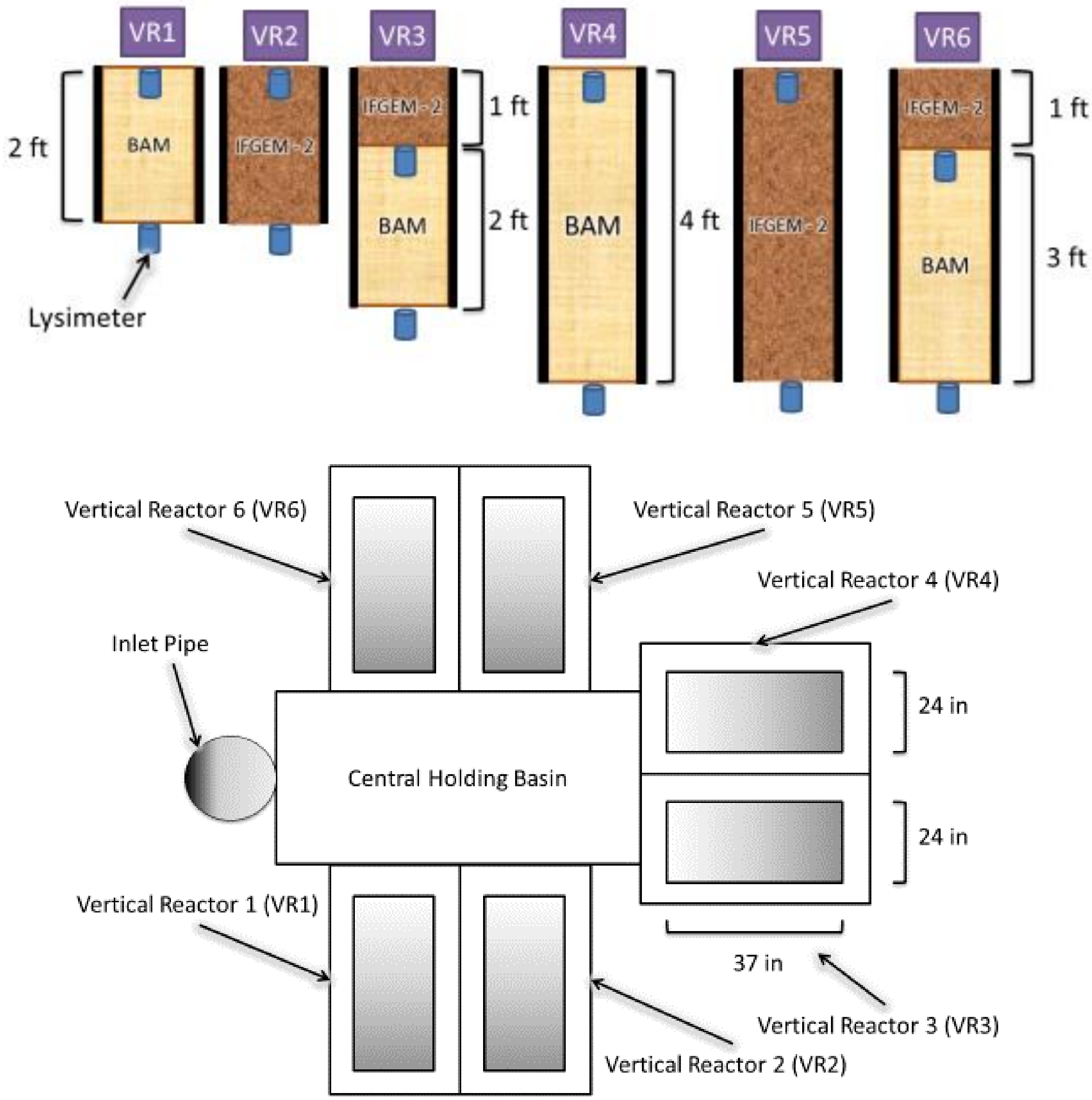

Figure 2.3. Basin 2 vertical reactors in cross-section and plan view.

CHAPTER 3. Study Results

3.1 Nitrogen removal performance of blanket filters in the vadose zone

What is the effectiveness of blanket filters to remove nitrogen from stormwater? This is the primary question managers may have following this study. By comparing the concentrations of different nitrogen species in stormwater before and after treatment in the blanket filter, this question can be assessed. Due to its close proximity to the groundwater table, the WBF in Basin 9b experienced salient groundwater intrusion impacts during the field-testing period of 2018, while groundwater intrusion in the EBF was minimal. Therefore, conclusions may be drawn regarding nitrogen removal efficiency of the EBF and top soil layer of the WBF only. Results will apply to blanket filters implemented within the vadose zone (unsaturated zone) that are not persistently saturated by groundwater. Mean removals of TN, NO_x and NH_3 within the EBF (including both the 1-ft top soil layer and 3-ft BAM layer) are 60%-66% (Figure 3.1).

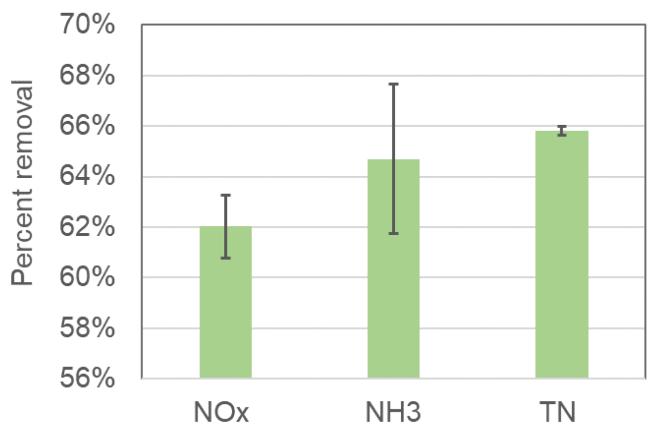

Figure 3.1 Mean nitrogen removal after blanket filter treatment in the EBF, relative to stormwater inlet concentrations.

The next question managers may have is whether nitrogen removal within a blanket filter compares favorably to nitrogen removal within an unaltered soil profile found in a stormwater retention basin. While this experiment contains no official control, data from the top 3-ft soil layer in the WBF can help managers assess performance of the blanket filter as compared to soil only (Figure 3.2). Mean removals of TN, NO_x, and NH_3 within the 3-ft soil layer range from 78%-92%, exceeding mean removal in the blanket filter by a wide margin. This result reflects the natural spatial heterogeneity of soil properties. Soil properties (e.g. texture, organic matter content) vary from place to place and influence the transformation of nitrogen through the soil profile. Therefore, nitrogen remediation that can be expected within unaltered soil profiles is also spatially variable. In some places, replacing the unaltered soil profile with a filtration media such as BAM will lead to greater transformation and removal of nitrogen; in other cases the natural remediation of the unaltered soil profile will exceed that of BAM. Better understanding of nutrient transformation within BAM relative to soils of variable properties will allow for better prediction of when replacing part of the soil profile with BAM blanket filters may lead to greater net removal of nutrients. Controlled, field-scale experimental applications of BAM BMPs are necessary to gain further knowledge.

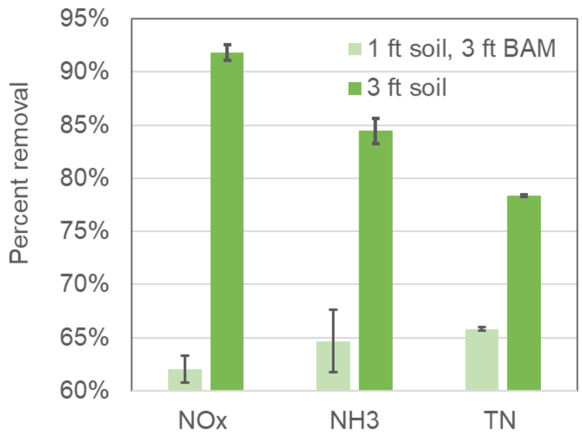

Figure 3.2. Mean nitrogen removal after treatment in blanket filter (1-ft top soil layer and 3-ft BAM layer) as compared to after treatment in 3-ft unaltered soil. Both are relative to incoming stormwater concentrations.

3.2 Blanket filter performance as a function of event size

Managers implementing blanket filters may wish to know about the variability of the blanket filter performance documented in this study and, in particular, if there is performance variation across small vs. moderate to large events. Blanket filter performance during larger events may be limited by system hydraulics. When event sizes are large, rates of incoming stormwater may surpass capacity of the blanket filters. Infiltration through blanket filters implemented in stormwater management areas, where runoff from larger catchment areas is concentrated, proceeds at a low rate compared to rates of incoming stormwater. Thus, stormwater will pond within the bermed blanket filter area and infiltrate slowly over time. If volumes of event runoff exceed the capacity of the BMP, stormwater flows over the berms and does not interact with the media. This overflow stormwater bypasses the blanket filter. The sizing of the blanket filter basin relative to the basin catchment area will determine the frequency of this occurrence and the cumulative hydraulic capture efficiency of the blanket filter (ratio of runoff that infiltrates into the blanket filter and is treated by the media to the total volume of the runoff entering the basin). For instance, during monitoring for this project, the capture efficiency of the EBF was 100%, and the capture efficiency of the WBF was 50%. The BMPs were sized similarly, but the catchment area draining to the WBF was larger, resulting in BMP exceedance during about 10% of the recorded events (10 of 101 recorded events). The exceedance events were larger events, thus on a cumulative volume basis the overall capture efficiency of the WBF is 50%. However, as this is a hydraulic capture efficiency, it may not reflect the proportion of pollutant mass that is captured. Even during larger events, blanket filters were able to capture the first part of runoff, which may contain the greatest pollutant loadings.

A difference in blanket filter performance may also be observed during small storms, where runoff volumes may be insufficient to promote uniform wetting of the filter media. To evaluate this question, we compared nitrogen removals through the entire blanket filter during small (cumulative precipitation depth < 0.1 in, cumulative runoff < 400 ft^3) versus larger (cumulative precipitation depth 0.2–1 in, cumulative runoff 910–2,870 ft^3) runoff events. Though sample sizes are low, there is detectable variation in blanket filter performance related to event size (Figure 3.3). Counterintuitively, removal rates of NO_x and TN are higher during small events.

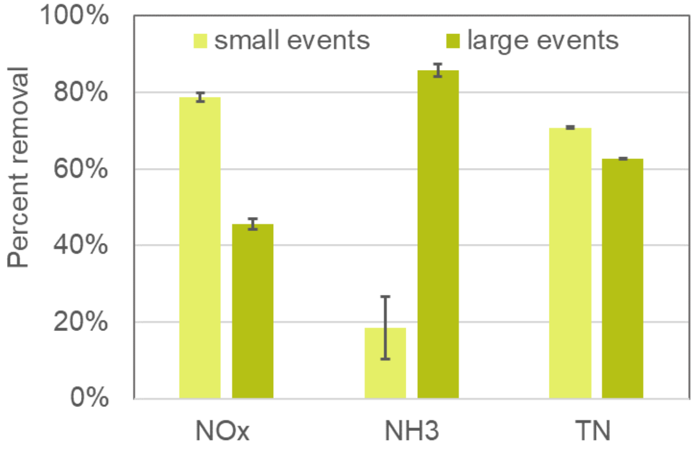

Figure 3.3. Mean nitrogen removal after blanket filter treatment in the EBF, relative to stormwater inlet concentrations, for small and large events.

3.3 Nitrogen removal through a 1.5-ft vs. 3.0-ft BAM layer

Managers wishing to implement BAM blanket filters may wish to know if there is a benefit in implementing a greater depth of BAM, given the extra cost. We therefore tested the difference in performance of a 1.5-ft vs. 3-ft BAM layer. A 3-ft BAM layer removes considerably more nitrogen, and particularly NO_x, as compared to 1.5-ft layer of BAM (Figure 3.4).

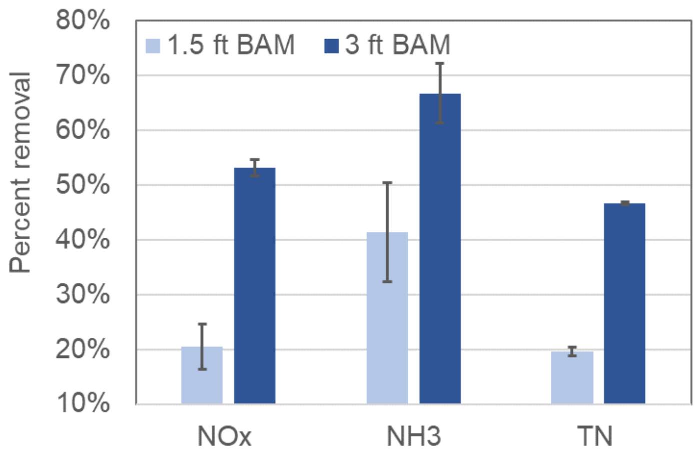

Figure 3.4. Nitrogen removal of stormwater after treatment through 1.5-ft and 3.0-ft layer of BAM, relative to infiltrated stormwater entering the BAM layer.

3.4 Nitrogen removal through 1-ft vs. 3-ft layer of aerobic media

Managers wishing to implement BAM blanket filters may wish to know if there is a benefit in implementing a greater depth of aerobic soil media above the BAM layer, given the extra cost. We therefore tested the difference in performance of a 1-ft vs. 3-ft aerobic soil layer. A 3-ft soil layer may remove considerably more nitrogen as compared to a 1-ft soil layer (Figure 3.5).

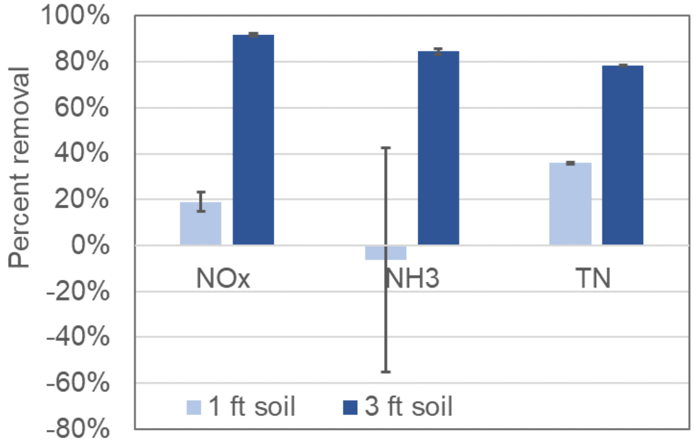

Figure 3.5. Nitrogen removal of stormwater after treatment through 1.0-ft and 3.0-ft layers of aerobic media (sandy soil), relative to stormwater entering the basin. Positive values indicate removal, negative values indicate generation.

3.5 Nitrogen removal through vertical reactors

In Basin 2, the primary research question was to determine which of the six tested media configurations (VR1 – VR6) performed optimally within vertical reactors. Based on highest and most consistent nitrogen removal performance (Table 3.1), VR4 was found to be the most promising reactor configuration. VR4 consisted of 4 ft of BAM (Figure 3), and removed a mean of 49% TN and over 53% of NO_x from incoming stormwater.

3.6 Lifetime cost analysis of BMPs

Through a 20- or 30-year design life, the cost of each pound of TN removed by blanket filters (a 3-ft layer of BAM placed in the vadose zone with 1-ft soil coverage) or vertical reactors (configured as VR4) ranges from $453-$715 and each pound of NO_x ranges from $701-$1590 (Table 3.2). Costs per pound of nitrogen removed are lower for vertical reactors as compared to blanket filters. However, it should be noted that the scale of vertical reactors tested herein was very small relative to basin catchment size (hydraulic capture efficiency of 0.2%). Nitrogen removal costs may scale with increasing size of BMPs. For vertical reactors built to treat small volumes of stormwater, these cost per pound estimates may be accurate. However, vertical reactors built to a larger scale (similar to scale of the blanket filters) may have a greater cost per pound of nitrogen removed.

Table 3.1. Mean nitrogen removal in vertical reactors of Basin 2.

	Removal compared to incoming stormwater		**Removal from Top to Bottom lysimeters**
	Top	**Bottom**	
	NO_x		
VR1	-56.2%	-171.2%	-73.7%
VR2	52.2%	47.0%	-11.0%
VR3	8.1%	71.8%	69.3%
VR4	-470.8%	53.6%	91.9%
VR5	-155.6%	94.6%	97.9%
VR6	-137.1%	-0.1%	57.8%
	NH_3		
VR1	-42.6%	37.6%	56.3%
VR2	31.7%	59.1%	40.2%
VR3	18.0%	81.2%	77.0%
VR4	74.7%	-19.49%	-371.9%
VR5	64.7%	-200.1%	-751.2%
VR6	60.1%	73.5%	33.4%
	TN		
VR1	-17.7%	-12.4%	4.5%
VR2	58.3%	57.2%	-2.5%
VR3	38.5%	78.5%	65.1%
VR4	-70.8%	48.7%	70.0%
VR5	5.4%	25.1%	20.9%
VR6	18.8%	59.6%	50.2%

Table 3.2. BMP cost per pound ($/lb) TN and NO_x removed after 20- and 30-year design life

		2038	**2048**
Blanket filter (based on EBF)	TN	$ 715 ± $27	$ 611 ± $ 23
	NO_x	$ 1,590 ± $ 61	$ 1,360 ± $ 52
Vertical reactor (based on VR4)	TN	$ 498 ± $ 25	$ 453 ± $ 23
	NO_x	$ 732 ± $ 37	$ 701 ± $ 35

CHAPTER 4. Design Guidance

4.1 Guidance on when to use different BAM recipes

Nitrogen removal performance documented herein is based on use of the Bold and Gold® Filtration Media, specifically the CTS mixture; hydraulic and nitrogen removal performance using other BAM mixtures may vary. Choice of BAM media to be used in a BMP typically depends on the incoming flow rate and desired remediation performance. The CTS mixture (Table 4.1) will typically infiltrate approximately 2-5 in/hr while other BAM mixtures are designed to infiltrate stormwater at greater rates. However, due to the hydraulics of blanket filter design, little benefit may be found from promoting greater flow rate through the engineered media layer. Faster infiltration in the filter will in theory allow for greater hydraulic capture efficiency of the BMP. However, since treated stormwater passing out of the BAM filter layer must infiltrate into the surrounding soil, permeability of the basin subsurface will ultimately control infiltration through the blanket filter. The sizing of the BMP relative to catchment size draining to the BMP is therefore the most influential design factor to determine hydraulic capture efficiency.

Depth of the BAM layer is a primary design consideration that influences nitrogen removal performance. This study clearly indicates that 3-ft of BAM removes more nitrogen than a 1.5-ft BAM layer.

Table 4.1. Composition (by volume) of Bold and Gold® CTS mixture.

	CTS
Sand	59%
Silt and Clay	27%
Tire Crumb	14%

(O'Reilly et al., 2012)

4.2 Guidance on aerobic media for top layer of blanket filters

The blanket filter design specifies that a layer of aerobic media should be placed over the BAM layer. The aerobic media serves the purpose of promoting nitrification and also allows establishment of vegetation, which prevents filter erosion. Depth of the aerobic media layer may vary; this study indicates that a greater depth of aerobic media promotes overall BMP nitrogen removal effectiveness. The aerobic media should be a sandy soil. Onsite materials may be used for this purpose, provided that basin soils will provide sufficiently high infiltration rates. Soils characterized by less than 1% of a sample (by mass) passing the No. 200 sieve are acceptable aerobic media for the top layer of blanket filters.

4.3 Guidance on blanket filter sizing

The sizing of the blanket filter relative to catchment size draining to the BMP is the most influential design factor that will determine BMP capture efficiency. Capture efficiency, the ratio of runoff that infiltrates into the blanket filter and is treated to the total volume of runoff entering the basin, is a hydraulic performance measure that relates directly to cumulative nutrient removal performance. When volumes of event runoff exceed capacity of the blanket filter, untreated stormwater flows over the berms. This overflow stormwater bypasses the blanket filter and is not treated. The sizing of the blanket filter basin relative to the basin catchment area will determine the frequency of overflow occurrence and the cumulative hydraulic capture efficiency of the blanket filter. Greater hydraulic capture efficiency will allow for greater capture and treatment of overall nutrient loadings, however, trade-offs with cost or logistical constraints may exist.

To size a blanket filter, the designer must choose a maximum event size that the BMP should fully contain. The filter should then be constructed such that the capacity is large enough to contain all runoff routed from the catchment area during this maximum design event. For example, if it is decided that the BMP should fully treat events up to 1.5 in depth, the BMP theoretical capture volume must be sized to contain all runoff routed from the catchment during a 1.5 in storm. A theoretical maximum capture volume can be calculated using the horizontal dimensions of the BMP, berm height, depth and porosity of the aerobic soil layer, and depth and porosity of the BAM layer. Assuming the BAM and soil are at field capacity at the start of runoff and neglecting infiltration out of the filter to deeper soil layers, the maximum capture volume will fill all available pore space in the subsurface filter and a free surface of water will rise to the height of the berms. Additional water entering the treatment area will pass over the berms and will not be treated by the filter. Actual maximum capture volume may be greater than theoretical, due to deep infiltration from the filter into surrounding soils. However, as blanket filters are implemented where runoff from larger catchment areas is concentrated, infiltration through the filter proceeds at a low rate compared to rates of incoming stormwater. At the event scale, neglecting deep infiltration will not significantly overestimate BMP sizing.

4.4 Costs for materials and installation

At the time of implementation (2017), costs of materials and installation associated with the blanket filters and vertical reactors tested herein respectively totaled approximately $46,690 and $16,150 (itemized in Tables 4.2 and 4.3). In addition to the approximately 8 person/days of labor represented by this estimate (encompassed in the contracting lines), UCF personnel provided an additional 8 person/days of direct labor to implementation of the two blanket filters and six vertical reactors. Use of onsite materials for berm construction and the top aerobic media layers of blanket filters reduced project implementation costs considerably. Additionally, since all BMPs were constructed at the same approximate time and place, contracting and equipment costs are likely lower.

Table 4.2. Costs of for materials and installation associated with the two blanket filters.

Item	Unit Cost ($)	Units (number)	Total Cost ($)
Contracting and equipment	$11,000	2 filters	$22,000
BAM media	$75	230 yd^3	$17,250
Freight to project site	$3,600	1	$3,600
Geotextile	$500	2 spools	$1,000
Wooden framing	$2.16	1,728 ft^2	$800
Berm fill	$0	245 yd^3	$0
Aerobic soil layer	$0	163 yd^3	$0
Gravel	$60	14 yd^3	$840
Erosion control blanket	$300	2 spools	$600
Seeding	$6	100 lb	$600
Total	$46,690		

Table 4.3. Costs of for materials and installation associated with the six vertical reactors.

Item	Unit Cost ($)	Units (number)	Total Cost ($)
Contracting and equipment	--	6 reactors	$7,000
BAM media	$75	20 yd^3	$1,500
Media freight to project site	$350	1	$350
Concrete boxes (order of varied sized boxes)	--	7 boxes	$5,500
Concrete freight to project site	$300	1	$300
Flow channels	$100	6	$600
Gravel	$60	15 yd^3	$900
Total	$16,150		

4.5 Residence time vs. removal curves for NO_x and TN

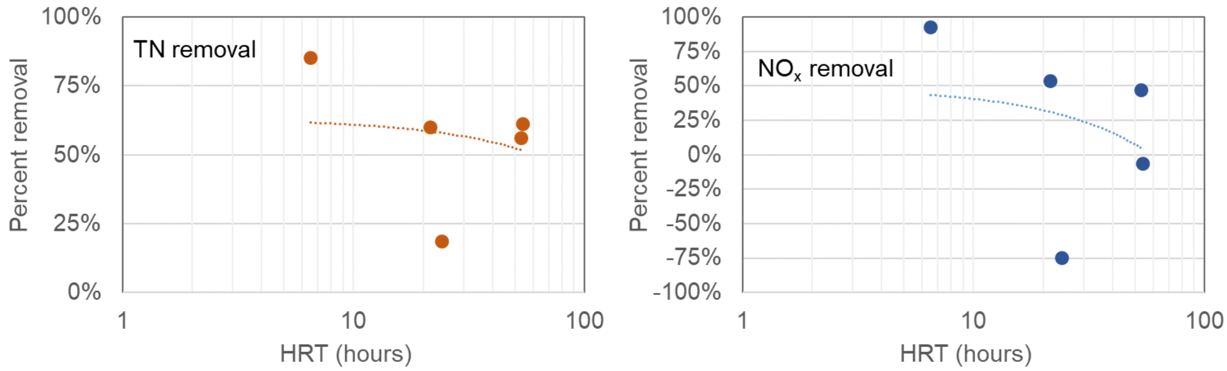

Figure 4.1. Hydraulic residence time vs. removal curves for NO_x and TN. Positive values indicate removal, negative values indicate generation.

Residence time/removal curves suggest that nitrogen removal rates are greater when the residence time of stormwater in BAM is shorter. This is similar to the results of the small/large storm analysis (Figure 3.3), which indicated that rates of TN and NO_x removal were greater during the very small storm events. This behavior differs from findings of laboratory studies, which generally suggest that longer contact times promote greater nitrogen transformations. Such differences in performance between lab and field studies emphasize the need for further field-scale testing of BAM BMPs.

CHAPTER 5. Construction Specifications

As an additional reference, practitioners are referred to the as-built construction drawings for specifications relevant to blanket filter and vertical reactor construction (Kibler et al. 2017c).

5.1 Blanket filter construction

Footprints of blanket filters are measured and staked, aligned along the centerline of stormwater inlets. Fill is excavated within the footprint to the design depth. Careful observation and sorting of excavated materials at this stage can save the project time and money, as heterogeneous subsurface materials may be used for different project components. Pockets of soils containing greater clay content, for instance, may be suitable for building berms, while pockets of sandy soils may be used as the top aerobic blanket filter layer. Use of onsite materials will reduce materials costs and costs of spoil disposal. It is recommended that excavated materials be sorted into pre-designated storage areas according to quality.

Framing of the excavated area using wooden boards or plywood may be necessary to prevent wall slumping and collapse. However, this is only necessary for construction purposes and may be omitted is the soil structure can be maintained without framing. An impermeable liner (30 mil) is to be installed along all sides of the excavation before filling with media, to prevent horizontal infiltration. This promotes vertical infiltration through the filter, ensuring the greatest possible contact time of stormwater within the treatment media. Care must be taken to prevent the impermeable liner from covering the bottom of the filter, as this would impede drainage.

Media should be delivered and staged near the excavation. It is recommended that the media be covered at all times until loading begins. Media is to be placed in the excavated area in 1 ft layers using a front-end loader. Use of smaller machinery (e.g. a Bobcat) within the excavation is recommended for even application. There is not a compaction standard for this design, but the final layer depth will be achieved after natural settling. Some compaction of media will occur during installation. This is desirable, as light compaction at the time of installation will ensure that true depth of design is achieved. The aerobic media layer is placed directly on top of the BAM layer, and leveled to the ground surface. The berms are then shaped around the filter, using compacted excavated materials with greatest clay content. Berm specifications may vary according to site constraints. Berms may be steep on the interior, (test implementations were 4:1 slope), but should have a gentler slope on the berm exterior to prevent erosion. It is important that the top of the berms are horizontally level. Dips and peaks in the berm tops will concentrate flows, potentially leading to berm scouring and eventual failure. Ideally, water will overtop the berms uniformly during overflow events. The berms must be revegetated as soon as possible following construction, as a primary erosion control. Erosion-control blanket or matting should be staked over the berms after construction and the berms should be seeded regularly until vegetation is established. A 3 in layer of gravel should be placed within the filter, in the vicinity of the stormwater inlets to stabilize the filter media against high flows.

Vegetation should be encouraged to establish on the berms and within the bermed area, as this will enhance infiltration, assist with nutrient transformation, and prevent erosion. However, grasses should be seeded and sod should not be used. No fertilizers should be applied. Once established, vegetation must be maintained regularly. Overgrowth of vegetation within the bermed area will reduce the volume of stormwater the BMP can hold and therefore reduce the capture efficiency of the BMP. As it may be difficult to bring mowers into the bermed areas, grasses should be mowed with hand-held devices to maintain a short, uniform ground cover. Vegetation established on the berms should be similarly short and uniform. Nonuniform distribution of vegetation on the berms will concentrate flows, potentially leading to berm scouring and eventual failure.

5.2 Vertical reactor construction

The vertical reactor design implemented in this project (a central holding box splitting flow to six vertical reactors) was designed specifically for the research experiment of determining the optimal reactor configuration. Construction of a vertical reactor in the field is therefore likely to deviate considerably from the implementation in this project. For instance, the central holding box will not be necessary in the field. Rather, the optimal design selected through testing (a 4-ft BAM reactor, capped with gravel), will be implemented within a single reactor box. The reactor will be sized according to the catchment area and positioned to collect stormwater from an inlet. As noted in previous reports (Kibler et al., 2018; Kibler et al., 2019a), the maximum capture volume of a vertical reactor is small relative to the volume of stormwater delivered to a stormwater retention basin. In this experiment, the six vertical reactors collectively captured 0.2% of the stormwater delivered to Basin 2. Vertical reactors may therefore be poorly suited to stormwater retention basins. A design suited to treat larger volumes, such as the blanket filter, should be used as an alternative. Vertical reactors may be better suited to filter stormwater runoff from smaller impervious areas such as roofs and parking lots.

Soils should be excavated from the site and a gravel footing placed. A pre-constructed, 4-walled concrete box is placed in the excavation and filled with media and gravels. Media and gravels should be delivered and staged near the excavation. It is recommended that the media be covered at all times until loading begins. There is not a compaction standard for this design, but the final reactor depth will be achieved after natural settling. Media should thus be compacted during installation to ensure that true depth of design is achieved. A layer of gravel should be placed within the reactor to stabilize the BAM against high flows. The top layer of gravel should be approximately at the ground level. The space around the reactor is then backfilled using excavated materials.

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