Literature Review: Cost-Effectiveness of Nutrient Removal Practices

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Introduction

This literature review, from the Environmental Finance Center at the University of North Carolina at Chapel Hill (EFC), is part of a larger set of reports looking at ways for stakeholders to effectively manage nutrients in Jordan Lake. To learn more about this project, got to https://efc.sog.unc.edu/project/unc-nutrient-management-study.

This report examines the cost effectiveness of different nutrient removal practices and, stated simply, aims to answer this question: *If there is one more dollar available for nutrient removal in the Jordan Lake watershed, where should it be invested to remove the greatest amount of nutrients and have the greatest positive impact on water quality?*

Recommendations

The EFC found that the two most cost-effective strategies, illicit discharge control program and wastewater treatment plant (WWTP) upgrade, address point sources while the other strategies address non-point sources. It is highly unlikely that regulated Jordan Lake entities will be able to meet future rule requirements without investing in a portfolio of nutrient reduction strategies as there are insufficient opportunities for nutrient reduction with any one strategy.

The values in this literature review represent what one may typically expect a nutrient removal strategy to cost on a per-pound basis. As described in the methodology details below, however, calculating these values involves estimations and any comparisons must be made with caution. This analysis is a summary of the choices available for nutrient removal as well as a rough comparison of the costs of each of those choices; it should not be used to select or rule out a technology or measure based solely on cost. **The best nutrient reduction strategy will be highly specific to the entity implementing the strategy and the location in which the strategy is applied.**

Nutrient Removal Strategies

The EFC reviewed the available scientific and practitioner literature about the cost-effectiveness of nutrient removal strategies. Studies containing information from North Carolina and the Southeast were prioritized, but other relevant studies were also incorporated to obtain as complete a picture as possible. The strategies looked at fell into two categories: physical strategies and policy strategies. Table 1 summarizes findings. Strategies are listed in alphabetical order and by type:

Table 1: Costs per Pound and Reduction Efficiencies of Nutrient Removal Strategies

Strategy	Type	Avg. of TP Reduction [$/lb]	Avg. of TN Reduction [$/lb]	Avg. of TP Reduction [%]	Avg. of TN Reduction [%]	Count TP	Count TN
Bioretention	Physical	$ 10,637.79	$ 754.05	0.59	0.52	8	8
Dry Pond	Physical	$ 30,083.66	$ 659.10	0.16	0.08	10	16
Infiltration System	Physical	$ 10,183.49	$ 230.46	0.66	0.5	7	5
Land Conversion	Physical	$ 710.25	$ 226.13	0.56	0.64	4	4
Level Spreader-Filter Strip	Physical	$ 4,292.00	$ 199.44	0.38	0.35	2	3
Permeable Pavement	Physical	$ 34,956.95	$ 2,905.07	0.61	0.48	7	4
Proprietary Structure	Physical	$ 28,249.59	$ 7,146.10	0.46	0.08	10	1
Riparian Buffer	Physical	$ 164.50	$ 454.51	0.48	0.58	3	4
Sand filter	Physical	$ 16,195.37	$ 2,205.45	0.53	0.33	7	4
Stormwater Wetland	Physical	$ 4,348.10	$ 461.67	0.48	0.52	7	8
Stream Restoration	Physical	$ 9,095.00	$ 1,522.58	No Data	No Data	2	4
Treatment Swale	Physical	$ 3,134.12	$ 230.29	0.44	0.38	7	6
WWTP Upgrade	Physical	$ 50.84	$ 13.97	No Data	No Data	9	15
Wet Pond	Physical	$ 7,440.22	$ 438.67	0.44	0.28	6	15
Disconnected Impervious Surfaces	Policy	$ 7,354.09	$ 2,439.05	No Data	No Data	1	1
Illicit Discharge Control Program	Policy	$ 53.11	$ 13.28	1	1	2	2
Nutrient Management Programs	Policy	$ 626.60	$ 120.78	0.05	0.09	5	5
Street Sweeping	Policy	$ 9,595.35	$ 1,824.64	0.09	0.03	2	2
Urban Forestation	Policy	$ 5,736.24	$ 404.22	0.5	0.25	2	2
		$ 12,548.34	**$ 681.17**	**0.46**	**0.35**	**101**	**109**

As mentioned above, this report should not be used to select or rule out a technology or measure based solely on cost. The best nutrient reduction strategy will be highly specific to the entity implementing the strategy and the location in which the strategy is applied.

Methodology

To obtain these values, the EFC conducted a literature review comparing 19 stormwater control measures, including best management practices (BMPs) and other construction projects, in addition to policies and programs cities and towns may enact. A total of 13 studies were evaluated (see list in references). If a study contained more than one value for a given measure, the research team averaged the values within that study under the assumption that all values within each study were derived using similar methodologies. (This helps reduce the effects of random errors.) Figure 1 and Figure 2 visualize findings for nitrogen and phosphorus, respectively, with each dot representing the average cost-effectiveness found by one study for one measure.

The research team then looked for concordance across studies for each measure. These consistencies, which highlight clustering of values across studies, are circled within Figure 1 and Figure 2, and the values in Table 1 are averages of those within these circles. (Where two circles are shown, we found that the values were in approximately two groups, and wherever there are ranges in Table 1 reflects this.) These values represent the most prevalent cost effectiveness estimates by excluding outliers. The higher costs of outliers may be attributed to study methodologies that included land acquisition, design, and/or operations and maintenance costs in addition to capital installation costs (see Table 2 in the Appendix). In an ideal world, all these costs would be incorporated into each measure's cost-effectiveness number, but not enough studies include all these costs.

In order to compare cost-effectiveness of strategies in this report, this report uses dollars/pound ($/lb.) figures wherever possible. The relative efficacy of physical stormwater control measures depends on the concentration of nutrients in the runoff entering the stormwater control measure (SCM). All else held constant, the SCM cost of nutrient removal ($/lb.) is lowest if the concentration of nutrients entering the SCM is highest. In short, the locations of SCMs matter. In studies that specified cost-effective estimates for A/B (soils with good drainage) and C/D soil types (soils with poor drainage), the research team used only the estimates for A/B soils, in order to be able to "compare apples to apples" as much as possible.

The values captured here are what is seen in the literature about cost effectiveness. Actual cost-effectiveness on the ground will be highly dependent on the siting of a measure—situated upstream or downstream, intercepting high concentrations or low concentrations of nutrients, placed on good soil or poor soil, etc.

Figure 1: Cost effectiveness of phosphorus removal, one value per study, with circles highlighting consistencies

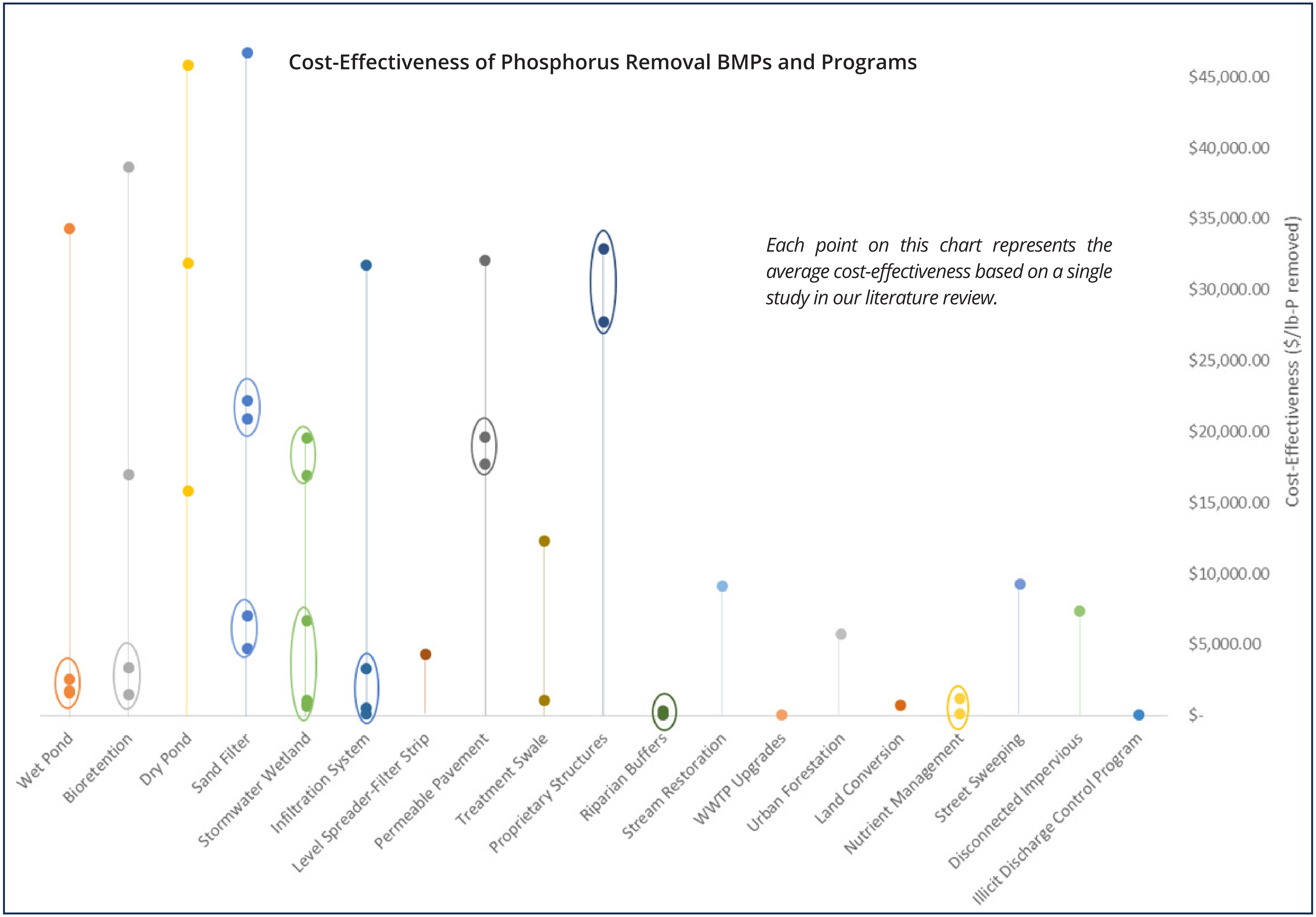
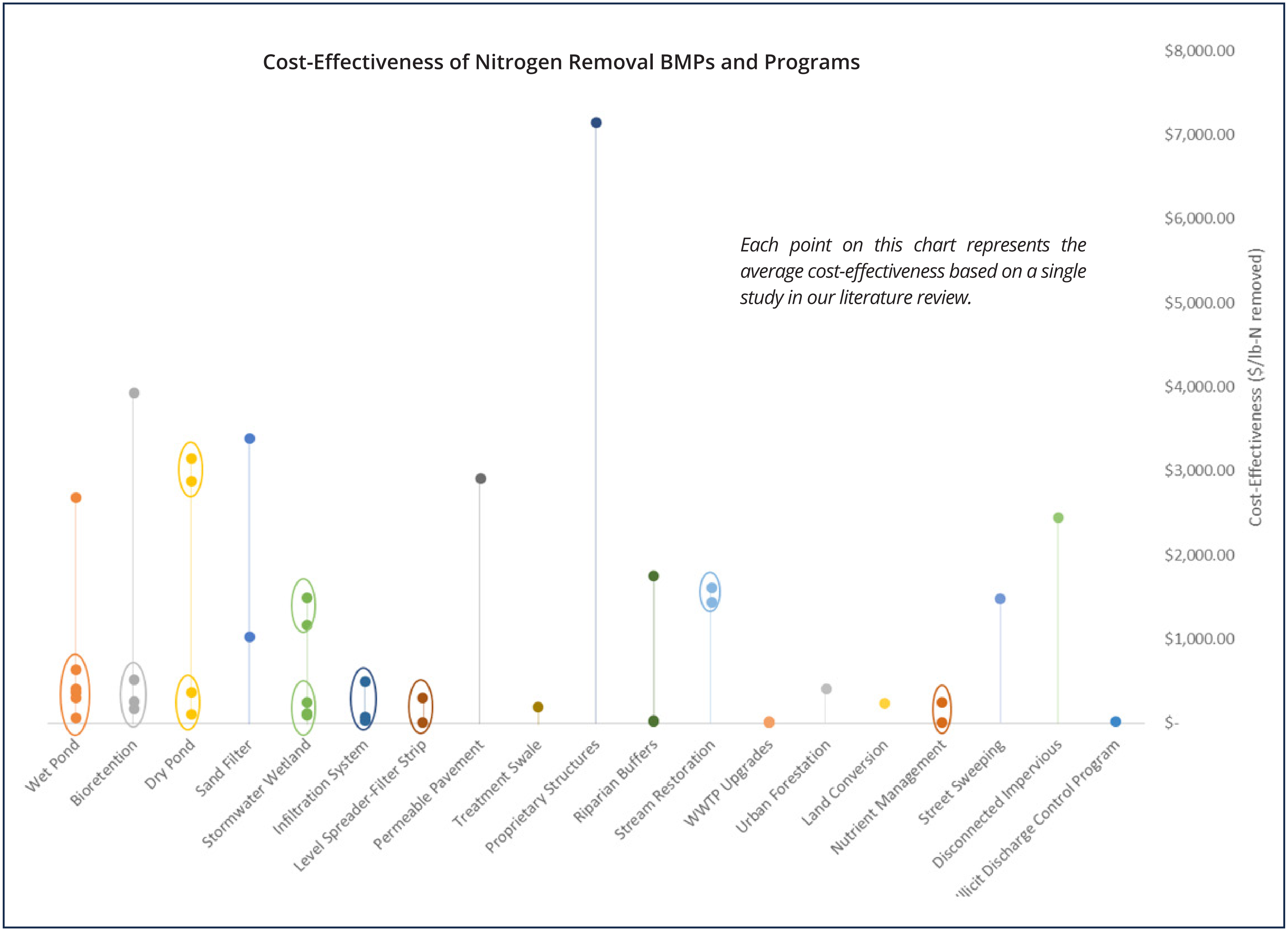


Figure 2: Cost effectiveness of Nitrogen removal, one value per study, with circles highlighting consistencies



Co-benefits

Many of these strategies have very important co-benefits, such as improving air quality, providing habitat for animals, and providing recreation space for residents. Co-benefits are also commonly referred to as ancillary benefits. However, co-benefits such as these can be difficult to quantify, particularly when one is not evaluating the siting of a specific SCM in a specific location. The Community-enabled Lifecycle Analysis of Stormwater Infrastructure Costs (CLASIC) tool is one way to quantify these co-benefits on a project and location-specific basis. If several potential SCMs are being considered for a specific site and nutrient removal levels and costs are approximately equal, this tool could help incorporate the value of co-benefits into the decision-making process. The CLASIC tool is currently in beta testing and is expected to be released in late 2019 by the Water Research Foundation.[1]

Strategy Costs and Efficiencies

The subsequent sections, Structures and Policies, include definitions of each of the stormwater control measures studied. Numbers for average reductions and expected reduction ranges are intended to find consistencies among studies included in this literature review. The EFC determined that outlier data points are not consistently due to components of cost included or not included such as design, capital/ installation, operations and management, and land.

Structures[2]

Bioretention

Bioretention basins are areas with designed soil filters and vegetation. Bioretention basins capture, store, treat, and infiltrate stormwater. They reduce the flow rate and volume of stormwater outflow.

	n	Average Reduction	Average reduction [$/lb]	Expected reduction range ($/lb)
Phosphorus	8	59%	$10,638	$1,300 - $3,400
Nitrogen	8	52%	$754	$100 - $600

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1. The Water Research Foundation. (2019). *Rolling Out "Community-enabled Lifecycle Analysis of Stormwater Infrastructure Costs"* (CLASIC) Tool. Webinar.

2. The main source for all structure descriptions is:
DEQ Stormwater Design Manual, https://deq.nc.gov/about/divisions/energy-mineral-land-resources/energy-mineral-land-permit-guidance/stormwater-bmp-manual

Dry Pond

Dry ponds are detention ponds designed to control stormwater flow rates and volumes using outlet controls. Stormwater treatment is achieved through sedimentation. Dry ponds only contain water following storm events.

	n	Average Reduction	Average reduction [$/lb]	Expected reduction range ($/lb)
Phosphorus	10	16%	$30,084	$10,600 - $40,000
Nitrogen	16	8%	$659	$100 - $3,200

Infiltration Systems

Infiltration systems are designed to capture, store, and infiltrate stormwater. These systems may be on-grade or subsurface.

	n	Average Reduction	Average Reduction [$/lb]	Expected reduction range ($/lb)
Phosphorus	7	66%	$10,183	$100 - $3,400
Nitrogen	5	50%	$230	$100 - $500

Level Spreader—Vegetative Filter Strip

A level spreader-filter strip is a concrete structure designed to disperse stormwater outflow over a grassed strip of land, designed to slow the velocity of, filter, and infiltrate the stormwater.

	n	Average Reduction	Average Reduction [$/lb]	Expected reduction range ($/lb)
Phosphorus	2	38%	$4,292	$3,700 - $4,800
Nitrogen	3	35%	$199	$100 - $400

Permeable Pavement

Permeable (porous) pavement is pavement which has voids to allow stormwater infiltration. The pavement sits on a designed aggregate bed which filters the stormwater. Permeable pavement may be pavement with entrained voids or a paver system with unsealed connections between pavers.

	n	Average Reduction	Average Reduction [$/lb]	Expected reduction range ($/lb)
Phosphorus	7	61%	$34,957	$12,500 - $32,100
Nitrogen	4	48%	$2,905	$1,900 - $4,100

Proprietary Structures

Proprietary structures are water quality units which are installed as part of a stormwater management system and designed to remove suspended solids and nutrients from stormwater. Proprietary structures may be used in sites with limited space.

	n	Average Reduction	Average Reduction [$/lb]	Expected reduction range ($/lb)
Phosphorus	10	46%	$28,250	$7,600 - $43,800
Nitrogen	1	8%	$7,146	--

Sand Filters

Sand filters are designed to capture and filter stormwater through a sand bed. They may or may not infiltrate the stormwater and may be on-grade or subsurface.

	n	Average Reduction	Average Reduction [$/lb]	Expected reduction range ($/lb)
Phosphorus	7	53%	$16,195	$4,500 - $22,200
Nitrogen	4	33%	$2,205	$1,000 - $3,700

Stormwater Wetlands

Stormwater wetlands are constructed wetlands designed for stormwater treatment (in particular, flow rate and volume management). Vegetation is designed and installed to mimic natural vegetation in the area.

	n	Average Reduction	Average Reduction [$/lb]	Expected reduction range ($/lb)
Phosphorus	7	48%	$4,348	$300 - $6,700
Nitrogen	8	52%	$462	$100 - $1,500

Treatment Swales

Treatment swales are vegetated, open channels which filter and infiltrate stormwater in addition to slowing the flow rate. Check dams may be included to further slow stormwater and increase infiltration. Treatment swales have average removal efficiencies of 44% for phosphorous removal and 38% for nitrogen.

	n	Average Reduction	Average Reduction [$/lb]	Expected reduction range ($/lb)
Phosphorus	9	44%	$7,440	$1,600 - $2,900
Nitrogen	15	38%	$439	$100 - $700

Riparian Buffer

Riparian buffers are required, 50-foot vegetated buffers surrounding certain qualifying wetlands, including streams, lakes, reservoirs, and ponds. Riparian buffers slow the stormwater flow rate, as well as promote filtration and infiltration.

	n	Average Reduction	Average Reduction [$/lb]	Expected reduction range ($/lb)
Phosphorus	3	48%	$165	$100 - $400
Nitrogen	4	58%	$455	$100 - $1,800

Stream Restoration

Stream restoration is the process of improving the environmental health of a stream or river in order to increase its biodiversity and protect its ecosystem.

	n	Average Reduction	Average Reduction [$/lb]	Expected reduction range ($/lb)
Phosphorus	2	No Data	$9,095	--
Nitrogen	4	No Data	$1,523	$200 - $2,700

Wastewater Treatment Plant Upgrades

Wastewater treatment plants (WWTPs) may retrofit or add to their existing primary treatment systems to increase their nutrient removal efficacies. Secondary treatment may include biological nutrient removal systems including trickling filters and activate sludge.[3]

	n	Average Reduction	Average Reduction [$/lb]	Expected reduction range ($/lb)
Phosphorus	9	No Data	$51	$30 - $100
Nitrogen	15	No Data	$14	$8 - $20

Wet Pond

A wet pond reduces peak runoff flow by capturing runoff from a storm and then releasing it slowly over time. Wet ponds remove suspended solids by allowing them to settle while the runoff is held in the pond. Suspended solids are also diluted because wet ponds always have water in them.

	n	Average Reduction	Average Reduction [$/lb]	Expected reduction range ($/lb)
Phosphorus	6	44%	$7,440	$1,600 - $2,900
Nitrogen	15	28%	$439	$100 - $700

3. Summers, Robert. *Wastewater treatment, regulation and financing in Maryland*. Maryland Department of the Environment. Retrieved from: http://www.umces.edu/sites/default/files/Summers_MarylandDepartmentEnvironment_0.pdf

Policies/Programs

Pavement Removal/Disconnected Impervious Surfaces

Pavement removal reduces the area of impervious surfaces, decreasing the flow rate of stormwater and allowing for infiltration in the new pervious surfaces. Disconnected impervious surfaces are impervious surfaces whose runoff is directed to pervious surfaces to achieve flow rate attenuation and infiltration.

	n	Average Reduction	Average Reduction [$/lb]	Expected reduction range ($/lb)
Phosphorus	1	No Data	$7,354	--
Nitrogen	1	No Data	$2,439	--

Illicit Discharge Control Programs

Illicit discharge control programs eliminate unpermitted discharges to watersheds.

	n	Average Reduction	Average Reduction [$/lb]	Expected reduction range ($/lb)
Phosphorus	2	100%	$53	$30 - $100
Nitrogen	2	100%	$13	$8 - $20

Land Conversion

Land conversion is the process by which the vegetative cover of land (including agricultural land) is changed to increase the nutrient retention.

	n	Average Reduction	Average reduction [$/lb]	Expected reduction range ($/lb)
Phosphorus	4	56%	$710	$100 - $1,800
Nitrogen	4	64%	$226	$100 - $400

New Development Stormwater Nutrient Management Requirements

Nutrient management programs are those which may limit the flow rate, volume, or nutrient concentration of stormwater runoff leaving a site.

	n	Average Reduction	Average Reduction [$/lb]	Expected reduction range ($/lb)
Phosphorus	5	5%	$778	$3 - $2,400
Nitrogen	5	9%	$146	$1 - $500

Street Sweeping

Street sweeping can remove leaves and other debris, both organic and inorganic, which can be conveyed to catch basins and contribute to nutrient concentrations.

	n	Average Reduction	Average Reduction [$/lb]	Expected reduction range ($/lb)
Phosphorus	2	9%	$9,595	--
Nitrogen	2	3%	$1,825	$1,300 - $2,300

Urban Forestation

Urban forestation is the creation of wooded areas within urban bounds. It captures stormwater, slows flow rates, and reduces outflow volumes. Treatment is achieved through filtration and infiltration.

	n	Average Reduction	Average Reduction [$/lb]	Expected reduction range ($/lb)
Phosphorus	2	50%	$5,736	$1,800 - $9,600
Nitrogen	2	25%	$404	$100 - $700

Land Conservation Note

Land conservation is different from many of the stormwater control measures discussed above. Where BMPs and nutrient management policies reduce the concentration of nutrients in stormwater, land conservation prevents the increase of nutrient concentrations in stormwater. It is therefore not included in graphical comparisons to other stormwater control measures.

However, Chapter 5 (Point and Nonpoint Source Reductions) of Minnesota's Nutrient Reduction Strategy estimates that conservation easements and land retirement have a nitrogen reduction efficiency of 83% and phosphorus reduction efficiency of 56%, and that such programs have a cost of $6-$110 per acre per year.[4]

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4. Minnesota Pollution Control Agency. *The Minnesota Nutrient Reduction Strategy*. Chapter 5: Point and Nonpoint Source Reductions. Retrieved from https://www.leg.state.mn.us/docs/2014/other/140284.pdf

References

Antoine, R., Bowen, M., & Howard, G. (2016). Worcester Polytechnic Institute *Reducing Phosphorus Contamination in Stormwater Runoff.*

Bashar, R., Gungor, K., Karthikeyan, K. G., & Barak, P. (2018). Cost effectiveness of phosphorus removal processes in municipal wastewater treatment. *Chemosphere*, 197, 280–290. https://doi.org/10.1016/j.chemosphere.2017.12.169

Center for Watershed Protection. (2013). *Cost-Effectiveness Study of Urban Stormwater BMPs in the James River Basin*. (March), 39. Retrieved from http://stat.chesapeakebay.net/?q=node/130&quicktabs_10=3.%0Ahttp://www.jswconline.org/content/65/6/413.short

Chesapeake Bay Commission. (2004). *Cost-effective Strategies for the Bay: Smart Investments for Nutrient and Sediment Reduction.*

CH2M Hill. (2008). *Jordan Lake Watershed Trading Project – BMP Cost Estimates and Cost-Effectiveness.* 1–44.

Entry, J. A., & Gottlieb, A. (2014). The impact of stormwater treatment areas and agricultural best management practices on water quality in the Everglades Protection Area. *Environmental Monitoring and Assessment, 186*(2), 1023–1037. https://doi.org/10.1007/s10661-013-3436-4

Houle, J. J., Roseen, R. M., Ballestero, T. P., Puls, T. A., & Sherrard, J. (2013). Comparison of Maintenance Cost, Labor Demands, and System Performance for LID and Conventional Stormwater Management. *Journal of Environmental Engineering, 139*(7), 932–938. https://doi.org/10.1061/(ASCE)EE.1943-7870.0000698

JJ Environmental. (2015). *Final Report - Low Cost Retrofits for Nitrogen Removal at Wastewater Treatment Plants in the Upper Long Island Sound Watershed.* (March).

NC DEQ. (2018). *FINAL_New D Stormwater Calculations 12_5_2018*. Excel Spreadsheet.

Nobles, A. L., Goodall, J. L., & Fitch, G. M. (2017). Comparing Costs of Onsite Best Management Practices to Nutrient Credits for Stormwater Management: A Case Study in Virginia. *Journal of the American Water Resources Association, 53*(1), 131–143. https://doi.org/10.1111/1752-1688.12487

Riggs, Erin. Hughes, Jeff. Leopard, Kyle. Kirk, Evan. (2017). Environmental Finance Center. *Paying for Nutrient Reduction and Management in Jordan Lake: Summary of First Year of Research*.

RTI, & CWP. (2007). *A Study of the Costs Associated with Providing Nutrient Controls that are Adequate to Offset Point Source and Nonpoint Source Discharges of Nitrogen and Other Nutrients.* (0210565).

Wieland, R., Parker, D., Gans, W., & Martin, A. (2009). Costs and Cost Efficiencies for Some Nutrient Reduction Practices in Maryland. *Prepared for National Oceanic and Atmospheric Administration Chesapeake Bay Office and Maryland Department of Natural Resources.*

Appendix

Table 2: Data Points in This Literature Review with Components of Cost Estimates and Sources

SCM Category	Source	$/lb P (avg.)	$/lb N (avg.)	Design	Capital/ Installation	O&M	Land
Wet Pond	Wieland, R., Parker, D., Gans, W., & Martin, A. (2009).		$ 63.43		X	X	X
	Riggs, Erin. Hughes, Jeff. Leopard, Kyle. Kirk, Evan. (2017).		$ 411.07		X	X	
	Houle, J. J., Roseen, R. M., Ballestero, T. P., Puls, T. A., & Sherrard, J. (2013).		$ 2,677.27		X	X	
	Center for Watershed Protection. (2013).	$ 2,579.92	$ 631.08	X	X	X	
	RTI, & CWP. (2007).	$ 1,642.50	$ 294.85	X	X	X	X
	NC DEQ. (2018).	$ 1,769.50	$ 366.00	?	X	X	?
	Antoine, R., Bowen, M., & Howard, G. (2016).	$ 34,300.00			X	X	
Bioretention	Riggs, Erin. Hughes, Jeff. Leopard, Kyle. Kirk, Evan. (2017).		$ 260.25		X	X	
	NC DEQ. (2018).	$ 1,454.00	$ 172.00	?	X	X	?
	RTI, & CWP. (2007).	$ 3,392.00	$ 514.20	X	X	X	X
	Houle, J. J., Roseen, R. M., Ballestero, T. P., Puls, T. A., & Sherrard, J. (2013).	$ 38,636.36	$ 3,927.27		X	X	
	Antoine, R., Bowen, M., & Howard, G. (2016).	$ 16,952.50			X	X	
Dry Pond	Wieland, R., Parker, D., Gans, W., & Martin, A. (2009).		$ 106.92		X	X	X
	Riggs, Erin. Hughes, Jeff. Leopard, Kyle. Kirk, Evan. (2017).		$ 366.00		X	X	
	Houle, J. J., Roseen, R. M., Ballestero, T. P., Puls, T. A., & Sherrard, J. (2013).		$ 3,150.00		X	X	
	Center for Watershed Protection. (2013).	$ 15,857.37	$ 2,873.25	X	X	X	
	Nobles, A. L., Goodall, J. L., & Fitch, G. M. (2017).	$ 31,895.97		X	X	X	
	Antoine, R., Bowen, M., & Howard, G. (2016).	$ 45,850.00			X	X	
Sand Filter	Nobles, A. L., Goodall, J. L., & Fitch, G. M. (2017).	$ 46,735.00		X	X	X	
	Houle, J. J., Roseen, R. M., Ballestero, T. P., Puls, T. A., & Sherrard, J. (2013).	$ 20,909.09			X	X	
	Center for Watershed Protection. (2013).	$ 4,741.27	$ 1,022.41	X	X	X	
	NC DEQ. (2018).	$ 7,038.00	$ 3,388.50	?	X	X	?
	Antoine, R., Bowen, M., & Howard, G. (2016).	$ 22,165.00			X	X	
Stormwater Wetland	Riggs, Erin. Hughes, Jeff. Leopard, Kyle. Kirk, Evan. (2017).		$ 241.10		X	X	
	Entry, J. A., & Gottlieb, A. (2014).	$ 645.68		X	X	X	X
	Center for Watershed Protection. (2013).	$ 6,670.36	$ 1,160.28	X	X	X	
	Houle, J. J., Roseen, R. M., Ballestero, T. P., Puls, T. A., & Sherrard, J. (2013).	$ 19,545.45	$ 1,490.91		X	X	
	Jordan Lake RTI Study	$ 778.50	$ 89.85	X	X	X	X
	NC DEQ. (2018).	$ 1,075.50	$ 114.50	?	X	X	?
	Antoine, R., Bowen, M., & Howard, G. (2016).	$ 16,895.00			X	X	
Infiltration System	James River Basin Paper	$ 3,325.23	$ 492.65	X	X	X	
	CH2M Hill. (2008).	$ 103.00	$ 30.00	X	X	X	X
	NC DEQ. (2018).	$ 528.00	$ 68.50	?	X	X	?
	Antoine, R., Bowen, M., & Howard, G. (2016).	$ 31,737.50			X	X	
Level Spreader-Filter Strip	Riggs, Erin. Hughes, Jeff. Leopard, Kyle. Kirk, Evan. (2017).		$ 5.33		X	X	
	NC DEQ. (2018).	$ 4,292.00	$ 296.50	?	X	X	?
Permeable Pavement	Center for Watershed Protection. (2013).	$ 19,596.60	$ 2,905.07	X	X	X	
	Houle, J. J., Roseen, R. M., Ballestero, T. P., Puls, T. A., & Sherrard, J. (2013).	$ 17,727.27			X	X	
	Antoine, R., Bowen, M., & Howard, G. (2016).	$ 32,082.50			X	X	
Treatment Swale	NC DEQ. (2018).	$ 1,072.75	$ 195.75	?	X	X	?
	Antoine, R., Bowen, M., & Howard, G. (2016).	$ 12,330.00			X	X	
Proprietary Structures	Center for Watershed Protection. (2013).	$ 32,865.88	$ 7,146.10	X	X	X	
	Antoine, R., Bowen, M., & Howard, G. (2016).	$ 27,736.67			X	X	
Riparian Buffer	Riggs, Erin. Hughes, Jeff. Leopard, Kyle. Kirk, Evan. (2017).		$ 1,750.00		X	X	
	CH2M Hill. (2008).	$ 79.25	$ 23.25	X	X	X	X

	RTI, & CWP. (2007).	$ 335.00	$ 21.55	X	X	X	X
Stream Restoration	Riggs, Erin. Hughes, Jeff. Leopard, Kyle. Kirk, Evan. (2017).		$ 1,607.90		X	X	
	Center for Watershed Protection. (2013).	$ 9,095.00	$ 1,437.27	X	X	X	
WWTP Upgrades	Riggs, Erin. Hughes, Jeff. Leopard, Kyle. Kirk, Evan. (2017).		$ 4.03		X	X	
	Chesapeake Bay Commission. (2004).		$ 8.50				
	Bashar, R., Gungor, K., Karthikeyan, K. G., & Barak, P. (2018).	$ 47.94			X	X	
	New England WWTP Study		$ 15.15	X	X	X	
Urban Forestation	Center for Watershed Protection. (2013).	$ 5,736.24	$ 404.22	X	X	X	
Land Conversion	CH2M Hill. (2008).	$ 710.25	$ 226.13	X	X	X	X
Nutrient Management	Chesapeake Bay Commission. (2004).	$ 62.03	$ 3.04				
	Center for Watershed Protection. (2013).	$ 1,191.17	$ 238.51	X	X	X	
Street Sweeping	Center for Watershed Protection. (2013).	$ 9,595.35	$ 1,824.64	X	X	X	
Disconnected Impervious	Center for Watershed Protection. (2013).	$ 7,354.09	$ 2,439.05	X	X	X	
Illicit Discharge Control Program	Center for Watershed Protection. (2013).	$ 53.11	$ 13.28	X	X	X	

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