Reducing N in the Watershed: An Analysis of Green Infrastructure and Low Impact Development Stormwater Solutions

New England Environmental Finance Center & Casco Bay Estuary Partnership
Matt Cannon, Martha Sheils, Curtis Bohlen
May 2019.

Background

Issue

The Casco Bay Nutrient Council has developed recommendations to "assess, understand, convey and reduce the negative impacts of nutrients on Casco Bay." The Council generated a list of 18 specific recommendations for followup. The focus of this report is to explore the Council's Recommendations #3 and #7, among others. Recommendation #3 calls for policymakers, regulators, and funders to:

> Revise state rules and guidance for stormwater and site design to highlight stormwater controls (e.g. green infrastructure, gravel wetlands) that meet existing rules and also remove nitrogen from stormwater.[1]

Recommendation #7 is to:

> …create stronger incentives for implementation of BMPs [Best Management Practices]; require BMPs on projects below state thresholds; protect forests and wetlands; develop ordinances that encourage green infrastructure in new development; increase density, redevelopment, and infill appropriate areas; manage and restrict fertilizer use.[2]

Implementing these recommendations will require understanding of the relative effectiveness of strategies for reducing nitrogen (N) in urban and suburban runoff. While a significant amount of literature has assessed effectiveness of many stormwater control devices and strategies, the information is voluminous and technical. The purpose of this report is to provide a synopsis of available information to facilitate discussion of alternatives to traditional stormwater management. To help inform decision-makers, this report highlights N removal efficiencies and cost effectiveness of potential solutions, especially "green infrastructure" and "low impact development."

These alternative approaches to stormwater management include a variety of practices that can reduce the flow of N to coastal waters, described by sometimes confusing terminology.

Structural v. non-structural

[1] (Bohlen, et al., 46)
[2] (Bohlen, et al., 47)

Structural approaches are those that involve constructing physical systems designed to remove pollutants from runoff (or sometimes reduce N loads) in developed landscapes. Non-structural approaches include nearly anything else. One academic review defines non-structural stormwater treatment strategies as practices that "rely on education and institutional behaviors to limit the transport of nutrients…"[3] Non-structural stormwater treatment includes maintenance and good housekeeping practices such as street sweeping, dumpster siting, catch-basin inspections, and site monitoring, as well as changes in municipal operations, public education, fertilizer restrictions or regulatory change.

Green Infrastructure and Low Impact Development definitions

"Low Impact Development" (LID) refers to practices that reduce water quality impact of urban and suburban development, principally via site design that minimizes runoff and reduces N loading. Additionally, LID includes landscape-scale planning and zoning tools, such as protection of wetlands, riparian zones, and steep slopes. "Green Infrastructure" (GI) refers to practices and technologies that incorporate natural processes and ecosystem services into site design or individual stormwater control features (usually structural), removing N from the system. As the term is now used, GI includes natural landscapes (e.g. wetlands and intact floodplains) that provide water quality benefits, but also built structures or devices that mimic natural systems. GI, in contrast to alternatives sometimes known as "gray infrastructure,"[4] often provides ecological or aesthetic co-benefits, such as recreational opportunities, wildlife habitat, greater biodiversity, or carbon sequestration. Most LID projects incorporate Green Infrastructure, so much so that the terms are sometimes used interchangeably. The state of Maine, in its site design rules for stormwater management, defines the terms together:

> "Low impact development" or "green infrastructure" means site planning and design strategies intended to replace or replicate predevelopment hydrology through the use of source control and relatively small-scale measures integrated throughout a site to disconnect impervious surfaces and enhance filtration, treatment, and management of stormwater runoff as close to its source as possible… Low impact development strategies include, but are not limited to: bioretention filters, grass swales and channels, vegetated filter strips, permeable pavements, rain gardens and vegetated rooftops.[5]

Incentives

Overall, incentives for developers, municipalities, or others to utilize GI or LID practices remain scarce. The primary regulatory tool in Maine that provides incentives is the state's "Chapter 500" stormwater regulations. Chapter 500 provides guidance for review of LID projects and offers modest reductions in area treatment requirements for projects incorporating LID, on a case-by-

[3] (Yang and Lusk 2018, 118)
[4] Gray infrastructure can be defined as structural technologies that do not consider the role of living plants. A detention basis is a good example.
[5] (Ch. 500, 3. 3(Q))

case basis, specifically through the use of low impact development credit.[6] In practice, it is unclear whether this system has incentivized either LID or GI.[7]

However, after reviewing the data on N removal efficiencies of various stormwater technologies, it is clear that Low Impact Development, which reduces N loads, and Green Infrastructure, which shows high N removal efficiencies, are likely to play an important role in reducing N loading in Casco Bay, and around Maine.

The best N reduction strategy would be to avoid nutrient loads in the first place, by employing low nutrient land uses. For example, focusing on compact development and protecting riparian areas can prevent the need for technological stormwater solutions.

Regulatory Chapter 500

A [land use] project "is required to meet appropriate standards to prevent and control the release of pollutants to waterbodies, wetlands, and groundwater, and reduce impacts associated with increases and changes in flow."[8] Chapter 500 generally applies to a project that "disturbs one acre or more of land area and requires a stormwater permit pursuant to the Stormwater Management Law 38 M.R.S. §420-D…, a site location of development (Site Law) permit pursuant to 38 M.R.S. §§ 481- 490" or certain other, less common circumstances.[9] The 'basic standards' apply to all of these projects.[10]

Certain projects must also meet the 'general standards' of Ch. 500, demonstrating that a stormwater management system "includes [ ] measures that will provide pollutant removal or treatment…"[11] A stormwater project must meet the 'general standards' if the project results in:

(a) 20,000 square feet or more of impervious area, or 5 acres or more of developed area, in the direct watershed of an urban impaired stream; or

(b) One acre or more of impervious area, or 5 acres or more of developed area anywhere else for a project that is not in the direct watershed of a lake.[12]

Stormwater management systems that meet the 'general standards' must provide treatment of 95% of impervious area (as low as 90% for some projects) and 80% of the developed area (75%

[6] (Ch. 500, 10. 4(C)(4))
[7] In a conversation with Aubrey Strause (ME DEP), she was not aware of any project that utilized the low impact development credit in Ch. 500.
[8] (Ch. 500, 1. 1)
[9] (Ch. 500, 1. 2)
[10] (Ch. 500, 6. 4(B))
[11] (Ch. 500, 6. 4(C)(2))
[12] (Ch. 500, 6. 4(C)(1))

for some projects).[13] Treatment here means that runoff from those areas flow to an appropriate system that provides water quality and quantity control.

The general standards define the minimum requirements for stormwater projects; cities and towns can impose stricter rules through local ordinances. For example, South Portland has applied Ch. 500 standards to smaller projects, thereby requiring stormwater management and oversight for more land use projects.[14]

Currently, allowable treatment measures under Ch. 500 include: wetpond, vegetated soil filter, infiltration, buffers and innovative treatment measures.[15] The technologies explicitly listed provide some N removal, but removal efficiencies are relatively low (under 40%, see 'Results' section below). Presumably most methods with high N removal efficiencies would be considered innovative, including many GI and LID practices, which may complicate design and permitting. In Ch. 500, use of any alternative not listed above "may be required to provide reports and studies… demonstrating the control efficiency of the measure."[16] In reference to this requirement, we have provided the N control efficiencies of GI and LID solutions in our Appendix, Table 1.

Chapter 500 regulates stormwater projects principally by the water volume treated. Volume treatment requirements may be reduced for projects incorporating LID methods through use of the LID credit.[17] In lake watersheds, Chapter 500 requires a phosphorous standard (for certain projects) that allows per acre phosphorus allocation based on lake characteristics.[18] Chapter 500 provides no N standard or similar option regarding N removal or allowable discharge to marine waters.

Methods

A principal goal of this project was to compile N reducing technologies into easy-to-read tables.

We gathered information on N removal efficiencies by reviewing available literature and talking with stormwater professionals and regulatory staff in Maine. We made no effort to do a comprehensive literature review, as our interest was principally in identifying the most promising technologies for ameliorating N pollution in runoff in Maine. However, we do present some resource information in the Appendix that would serve as a start to a comprehensive review. In addition to academic literature on pollutant removal efficiencies and cost effectiveness of stormwater technologies, several large synthesis projects have previously been carried out. We made extensive use of a few key sources.

[13] (Ch. 500, 6. 4(C)(2)(a))
[14] See South Portland Zoning Ordinance §27-1536.
[15] (Ch. 500, 9-10. 4(C)(3))
[16] (Ch. 500, 10. 4(C)(3)(e))
[17] (Ch. 500, 10. 4(C)(4))
[18] (Ch. 500, 12-13. 4(D)(2))

The UNH Stormwater Center has proven to be an invaluable resource. They have worked on stormwater management for many years, and they are an important research partner. We reviewed information from their website, interviewed staff, and reviewed related publications.

The Cape Cod Commission reviewed N management options as part of their ongoing efforts to control nutrient pollution entering adjacent waters. The results of their review are summarized in a "Technologies Matrix," which was the most comprehensive source of relevant information that we found. Our tables are based largely on information provided in the Technologies Matrix: the main product being Table 1 in the Appendix.

Similar information is available from other sources. For example, Opti-tool, developed by EPA Region 1, is intended to assist stormwater managers (SW) and consulting engineers in preparing technically sound and cost-effective watershed management plans at the sub-watershed scale. It incorporates estimates of pollutant removal efficiencies for many stormwater technologies. However, Opti-tool was created for engineers and designers, and it focuses on 'end of pipe' solutions, which is not useful as a summary for policy makers.

Analysis of Cape Cod Commission Technologies Matrix- See Table 1 in Appendix

The full Technologies Matrix provides an exhaustive list of N reducing technologies and strategies, attributed to one of three categories: source reduction, restoration, and groundwater remediation. It groups these technologies as: green infrastructure, innovative and resource-management technologies, waste reduction toilets, non-structural technologies, and system alterations. However, it was written for Cape Cod, which has different conditions, such as sandy soils, consistent groundwater flows, more seasonal population demographics, higher population densities, different development patterns, and extensive reliance on on-site wastewater disposal.

As a result, we removed technologies that were less likely to be implemented in the Casco Bay region. We did not include evaluation of on-site wastewater treatment systems (i.e. septic systems) or waste reduction toilets because our focus was on stormwater runoff. Moreover, areas relying on on-site wastewater treatment tend to have low population densities and thus minimal nutrient loading. Also, because Casco Bay watershed lacks the highly permeable sandy soils of Cape Cod, and groundwater dynamics are difficult to ascertain, we discounted some innovative methods to treat highly polluted groundwater, such as permeable reactive barriers. However, these are efficient and cost-effective technologies, and could be reevaluated in the future if land use patterns in Casco Bay change. Methods that the Cape Cod Commission considered principally groundwater remediation technologies (phytoremediation and "fertigation- turf") might be adapted to treating stormwater runoff as well, and so were included in our review. [19] We removed floating constructed wetlands due to their relatively low N reduction efficiency and our opinion that they seem unlikely to be utilized. Although coastal habitat restoration also has a low N reduction efficiency, we thought it useful to remain as habitat restoration projects are

[19] Fertigation is a term for applying fertilizer – nutrients – via an irrigation system. When the source of irrigation water is high-nutrient groundwater or surface water, the practice uses a potential pollutant to improve plant growth. (see Technologies Matrix for more details)

being implemented across the area already. Additionally, we did not include aquaculture solutions because they do not meet our N reduction efficiency threshold.[20]

After sorting based on local conditions, we retained only treatments with:

- life cycle cost, per unit N remediated below the mean of all methods reviewed by the Commission, and
- N reduction efficiency of at least 25%.

These cutoffs are arbitrary, but serve to highlight the most efficient and cost effective technologies identified by the Cape Cod Commission. We encourage interested readers to examine the full Technologies Matrix.

Results

As compared to conventional stormwater systems, LID systems, in general, "have lower marginal maintenance burdens (as measured by cost and personnel hours) and higher water quality treatment capabilities as a function of pollutant removal performance."[21]

Average Life Cycle Costs Ranking

After applying these criteria to the Cape Cod Commission's Matrix, the technologies ranked by average life cycle costs (in dollars per pound of N reduction) from lowest to highest are:

- pond and estuary dredging (.8 $/lb N),[22]
- fertilizer management (12.1 $/lb N),
- coastal habitat restoration (33.6$/lb N),
- constructed wetlands- subsurface flow (40.7 $/lb N),
- constructed wetlands- surface flow (41.9 $/lb N),
- vegetated swale (63.3 $/lb N),
- fertigation- turf (67.5 $/lb N),
- constructed wetlands- groundwater treatment (142.2 $/lb N),
- phytoremediation (160.7 $/lb N),
- stormwater BMPs- good housekeeping (284.3 $/lb N),
- stormwater BMP- gravel wetland (310.2 $/lb N), and
- stormwater- constructed wetlands (320.9 $/lb N).

With the exception of pond and estuary dredging (which physically removes nutrients from sediments in receiving waters) and fertilizer management (which reduces N loading), many of the most cost-effective solutions involve green infrastructure, especially natural, restored, artificial, or constructed wetland systems. This is because wetland systems often provide high

[20] Because aquaculture has a low N reduction efficiency, high aquaculture intensity is needed to achieve large N uptake.
[21] (Houle, et al. 2013, 937)
[22] Although we do not believe that polluted sediments are a major source of nutrients in Casco Bay, there is little data available at the moment, so we left pond and estuary dredging in our table.

rates of both nitrification and denitrification, converting dissolved N (a pollutant) to harmless N gas.

N Percent Reductions Ranking

The technologies from the Cape Cod Commission's Matrix ranked by percent reductions in N (with at least 25% efficiency) from highest to lowest were:

- transfer of development rights (TDRs; 100%).
- compact and open space development practices (100%),
- pond/estuary dredging (80-95%),
- constructed wetlands (including surface flow (70-92%), subsurface flow (70-92%), and groundwater treatment (85-95%) designs),
- phytoremediation (plants planted to uptake nutrients directly from groundwater, typically in riparian areas; 50-90%),
- stormwater- constructed wetland (50-90%),
- remediation of existing development, such as constructing stormwater retrofits (42-85%),
- fertigation- turf (60-80%),
- stormwater BMP- gravel wetland (50-75%),
- fertilizer management (25-75%),
- "good housekeeping" practices like street sweeping (25-75%),
- stormwater BMP- vegetated swale (25-40%), and
- coastal habitat restoration (10-25%).

The top performers are regulatory practices (TDRs) and site development practices that protect open space, thus preventing increases in N loading. Other high efficiency practices include GI practices that incorporate wetlands and plant uptake, and programs that remediate already developed landscapes or existing pollution sources.

According to the International Stormwater BMP Database 2016 Summary, conditions most 'conducive for significant denitrification or nitrogen uptake' include Best Management Practices (BMPs) with 'permanent pools (e.g. retention ponds and wetland basins)'.[23] They concluded that "a BMP designed for permanently reducing nitrogen may include a permanent wet pool followed by a vegetated swale or media filter."[24] Bioretention as an overall category "did not perform well for N removal."[25]

For GI, constructed wetlands and gravel wetlands are consistently reported as being among the most effective at reducing N, with many other structural BMPs providing significantly lower N

[23] (Clary, et al. 2017, 3-1)
[24] (Clary, et al. 2017, 3-1)
[25] (Clary, et al. 2017, 3-1). Note from the same page, "it may be worthwhile to evaluate bioretention designs with internal water storage zones as a separate category in the future."

removal efficiencies. According to a 2013 study, out of a sample of stormwater management solutions, gravel wetlands were the most efficient at removing total N (75%), followed by wet pond (33%), bioretention (29%), and dry pond (25%).[26] These results reflect the N reduction ranges in the Technologies Matrix.

N Reduction (% Removal) & Relative Cost: Edit from Cape Cod Commission Technologies Matrix. See more complete Table 1 in Appendix for details.

Technology / Strategy		Nitrogen Reduction (Percent Removal)									Relative Cost: Life Cycle		
		25	30	40	50	60	70	80	90	100	Low	Med	High
Green Infrastructure	Constructed Wetlands - Surface Flow						■	■	■		■		
	Constructed Wetlands - Subsurface Flow						■	■	■		■		
	Constructed Wetlands - Groundwater Treatment								■			■	
	Stormwater BMP - Vegetated Swale	■	■	■							■		
	Stormwater BMP - Gravel Wetland				■	■	■						■
	Stormwater: Constructed Wetlands				■	■	■	■	■				■
Innovative Technologies	Phytoremediation				■	■	■	■	■			■	
	Fertigation - Turf					■	■	■				■	
Non-Structural Technologies	Fertilizer Management	■	■	■	■	■	■				■		
	Stormwater BMPs	■	■	■	■	■	■						■
	Remediation of Existing Development				■	■	■	■			■		
	Compact and Open Space Development									■	■		
	Transfer of Development Rights									■	■		
System Alterations	Coastal Habitat Restoration	■									■		
	Pond and Estuary Dredging							■	■		■		

Ecosystem Services

There are ecological and social co-benefits that should be considered for all of these technologies. The Technologies Matrix utilized four categories of ecosystem services: habitat/ wildlife/ biodiversity benefit, green space/ conservation/ recreation benefit, energy savings/ nutrient recovery/ recycling benefit, and flooding/extreme event benefit. Although the Matrix highlights the ecological and social co-benefits of GI and LID, the results are too general. Only a 'yes' or 'no' is entered for the degree of benefit provided. For example, pond and estuary dredging and habitat restoration both indicate habitat benefit (the box is checked 'yes'), but clearly, varying degrees of habitat benefit exist between these technologies. Essentially, GI technologies that require significant management have only limited co-benefits.

Although the Matrix provides oversimplified categories that do not adequately capture all of the costs/ benefits of each technology on the environment, the overall conclusion is that these

[26] (Houle, et al. 2013, 937)

LID/GI technologies provide significant eco-system benefits. Whereas more traditional, structural 'gray infrastructure' does not.

Maintenance Costs

According to a 2013 study by stormwater professionals and researchers, including James Houle, "if maintenance activities are simple, then periodic and routine maintenance costs are kept at a minimum."[27] In relation to life cycle costs, LID systems "had higher capital costs but lower annual maintenance costs compared to the conventional pond systems."[28] Also, LID systems involve maintenance practices that are more predicable than conventional pond systems.[29]

The 2013 study provides in-depth maintenance costs for some technologies, but they seem to contradict the comparable annual operations and maintenance findings in the Matrix. Specifically, the 2013 study found that annual operations & maintenance costs ($/year) were lower for vegetated filter systems (e.g. subsurface gravel wetland and bioretention) and higher for wet and dry ponds.[30] In the Matrix, both bioretention (which we omitted) and stormwater gravels wetlands (unclear if they are subsurface) show higher operations and maintenance costs ($/year) than vegetated swales. Nonetheless, the results of the 2013 study "should be considered as conservative in that they document the most expensive period of maintenance that might be anticipated (the start up years)."[31]

Conclusions/ Recommendations

The best N reduction strategy would be to avoid nutrient loads in the first place, by employing low nutrient land uses. For example, focusing on compact development and protecting riparian areas can prevent the need for technological stormwater solutions.

Discussion

Our review suggests that the most effective approaches to reducing N loading to coastal waters will be methods that avoid or minimize the initial water quality impacts of development, such as "low impact development", "conservation subdivisions", "land protection", or "compact development". Green infrastructure practices that incorporate plant uptake of nutrients, or the nitrification-denitrification cycles of wetland systems also perform well, and generally prove cost effective. Many standard stormwater technologies fare relatively poorly on both an efficiency and cost per pound of nitrogen removed basis.

---

[27] (Houle, et al. 2013, 934)
[28] (Houle, et al. 2013, 936). Note: with the exception of the sand filter.
[29] (Houle, et al. 2013, 934)
[30] (Houle, et al. 2013, 937). The Matrix uses 'vegetated swale' to define grassed channels, dry swales, wet swales, or biofilters.
[31] (Houle, et al. 2013, 934)

Conventional systems cost more than LID and GI solutions due to more materials, labor, and maintenance. Moreover, less maintenance results in higher ecological benefits for LID and GI.

In addition to cost and efficiency, developers evaluate potential stormwater treatment strategies in terms of their overall impact on project viability, including such considerations as market demand, aesthetics, and impact on site design or construction schedule. The top performing technologies for N removal at the site scale all involve water, living organisms, and land area, making them less attractive in highly urbanized sites where land costs are high.

In urbanized areas like the Portland peninsula, land constraints are severe, so complementary approaches are needed, like street sweeping, fertilizer management, and implementation of stormwater retrofits (i.e. through MS4), even if they are not required or encouraged through Chapter 500.[32]

In the rest of the Casco Bay watershed, more opportunity exists to implement innovative and larger-scale GI technologies. In large development projects, where land constraints may be less severe, gravel wetlands, stormwater constructed wetlands, and phytoremediation should be considered due to their high N efficiencies.

Almost all structural stormwater management efforts in Maine must meet Maine DEP Chapter 500 regulations, yet little in the rule favors technologies most likely to reduce N loading to coastal waters. Regulatory changes may be able to favor technologies that address N, the way a phosphorus limit helps protect water quality in vulnerable lakes. Alternatively, Ch. 500 could be modified to prioritize GI and LID site design principles. For example, the Sustainable Sites Initiative provides a framework that protects ecosystems and their services and allows flexibility for each site, providing performance measures rather than prescribing practices.[33] Distributed technologies might also be emphasized. In retrofit situations, Ch. 500 may lead to less cost-effective outcomes, as multiple small projects can be significantly less expensive than single large ones for N removal.

In addition to changing policy or as a requirement of new policy, there could be more financial incentives through the use of low interest loans for utilizing these technologies or starting businesses that focus on GI. Maine could also start a Clean Water State Revolving Fund to promote clean water projects; these funds have shown promise in other states.[34] Currently, there is one specific Maine nonpoint source water fund (319). There are other funding programs (both state and federal) for water-related projects, but they are not specific to GI or LID projects.

Fundamentally, non-structural and LID solutions should be considered first when initiating a stormwater project. We recommend that stormwater projects begin at the landscape-scale, move to reduction of impact, then to selection of site technologies, and finally to evaluation of the role of non-structural methods. Re-thinking site design will be a challenge for developers and policy-makers, but we think this institutional hurdle can be overcome.

[32] For more information on urban retrofit stormwater control measures, see: (Houle, et al. 2017)
[33] Sustainable Sites Initiative, SITES Rating System.
[34] See Iowa, Ohio, and Vermont State Revolving Funds.

Appendix: Table 1, Glossary, Literature Resources, Conversations, Legislation, & Bibliography

Table 1- Edited Cape Cod Commission Technologies Matrix

Source: 2017 Update at http://www.capecodcommission.org/index.php?id=656. 29 April 2019.

Glossary of Technologies

Green Infrastructure

Constructed Wetlands- Surface Flow

- After primary treatment in a septic tank or WWTF or secondary treatment at a WWTF, water is fed into a free water surface (FWS) constructed wetland. Free water constructed wetlands closely mimic the ecosystem of a natural wetland by utilizing water loving plants to filter wastewater through their root zone, a planted medium, and open water zones. FWS wetlands are systems where open water is exposed much like in a natural marsh.

- The reclaimed water is generally discharged into a leach field or similar system for discharge to the groundwater. The reclaimed water can also be discharged into a water body or used for open space irrigation after treatment. However, more strict permitting and water quality standards must be met if not discharging to groundwater.

- This technology can be used as an alternative to conventional polishing (i.e. mechanical and/or chemical) of secondary and advanced wastewater treatment.

- This is a source Reduction technology.

Constructed Wetlands- Subsurface Flow

- After primary treatment in a septic tank or WWTF or secondary treatment at a WWTF, wastewater is treated by pumping water slowly through subsurface gravel beds where it is filtered through plant root zones and soil media. Water flows 3-8" under the surface to prevent public exposure to wastewater and mosquito breeding. A combination of horizontal and vertical flow subsurface systems must be utilized to provide total nitrogen removal.

- The reclaimed water is generally discharged into a leach field or similar system for discharge to the groundwater. The reclaimed water can also be discharged into a water body or used for open space irrigation after treatment. However, more strict permitting and water quality standards must be met if not discharging to groundwater.

- This technology can be used as an alternative to conventional polishing (i.e. mechanical and/or chemical) of secondary and advanced wastewater treatment.

- This is a source Reduction technology.

Constructed Wetlands- Groundwater Treatment

- After collecting groundwater with higher nitrogen concentrations, groundwater is treated by pumping water slowly through subsurface gravel beds where it is filtered through plant root zones and soil media. Water flows 3" to 8" under the surface to prevent public exposure to wastewater and mosquito breeding. A combination of horizontal and vertical flow subsurface systems must be utilized to provide total nitrogen removal. These systems occasionally use additional treatment steps to remove nutrients from wastewater. The preferred disposal method is an infiltrator chamber system similar to a leach field but larger in size and designed for overflows.

- The reclaimed water is generally discharged into a leach field or similar system for discharge to the groundwater. The reclaimed water can also be discharged into a water body or used for open space irrigation after treatment. However, more strict permitting and water quality standards must be met if not discharging to groundwater.

- This is a groundwater Remediation technology.

Stormwater BMP- Vegetated Swale

- Vegetated swales, such as a grassed channel, dry swale, wet swale or biofilter, are an open-channel used to convey stormwater runoff. Vegetated swales typically do not pond water for a long period of time and induce infiltration. Vegetated swales typically have a trapezoidal or parabolic shape with relatively flat side slopes. Individual vegetated swales generally treat small drainage areas (five acres or less).

- This is a groundwater Remediation technology.

Stormwater BMP- Gravel Wetland

- Subsurface gravel wetlands typically have a high pollutant removal efficiency. They filter stormwater as it flows horizontally through a sediment forebay and a series of gravel-bottomed wetland cells. The wetland cells consist of a thin layer of wetland soil which supports a thick vegetative cover; below which is a thick layer of gravel where algae and microbes grow in abundance. Treatment occurs through physical, biological and chemical reactions in the wetland soil and gravel layers. Water flows through the series of cells via subsurface pipes and is discharged to a receiving waterway or additional best management practice (BMP) through a submerged pipe in the final cell. These systems are designed to maintain constant saturation of the wetland soils. Existing dry ponds can be retrofitted into a gravel wetland to more effectively treat stormwater runoff and may require less excavation than new construction.

- This is a groundwater Remediation technology.

Stormwater- Constructed Wetlands

- Constructed wetlands provide aerobic chambers followed by subsurface anaerobic chambers that facilitate nitrification followed by denitrification, respectively. This process mimics that of natural systems coupled with engineering design guaranteeing residence time within a chamber containing anaerobic conditions. This partnership allows for year round removal efficiencies of nitrogen. The reclaimed water from the wetland can be discharged into a water body or used for open space irrigation after treatment. The reclaimed water can also be discharged into a leach field or similar system for discharge to the groundwater.

- This is a groundwater Remediation technology.

Innovative and Resource-Management Technologies

Phytoremediation

- Green plants with deep tap roots are planted as a buffer to intercept high nitrogen (nitrogen enriched) groundwater. The plants and microorganisms in their root zone reduce/use the nitrogen, removing it from the groundwater and watershed. Phytoremediation can be used to redirect a plume of nitrogen enriched groundwater or pull it up from deeper in the aquifer, allowing the plants to treat the plume. Ongoing, passive interception of the impacted ground water plume via shallow/deep interception of capillary fringe by roots occurs during the growing season and has seasonal limitations.

- This is a groundwater Remediation technology.

Fertigation-Turf

- Capturing nitrogen enriched groundwater using irrigation wells and using it to irrigate plants that use the nitrogen is called fertigation. Fertigation wells can capture nutrient enriched groundwater, typically from a concentrated source such as a WWTF discharge, and recycle it back to irrigated and fertilized turf grass areas. These irrigated areas include golf courses, athletic fields and lawns. Fertigation can significantly reduce nutrient loads to down gradient surface waters while reducing fertilizer costs to the irrigated areas.

- This is a groundwater Remediation technology.

Non-structural

Fertilizer Management

- Managing fertilizer application rates to lawns, golf courses, athletic facilities and cranberry bogs. Residential lawn loading rates could be reduced on existing developed parcels through an intensive public education/outreach program. This could include a “Cape Cod Lawn” branding program, replacing some turf areas with native vegetation, establishing naturally-vegetated buffer strips on waterfront lots, and reducing application rates. Fertilizer loading rates for new development could be accomplished by reducing lot sizes (cluster development), by restricting lawn sizes and/or by incorporating more naturally-vegetated open space areas. Municipalities could directly reduce fertilizer applications on athletic fields and other properties. Golf courses can significantly reduce nitrogen loading rates by using slow-release fertilizers and reducing application rates in rough areas.   Cranberry bog fertilizer exports from the bogs can be reduced using tail water recovery systems. Site-specific assessments are needed to estimate load reductions.

- This is a source Reduction technology.

Stormwater BMPs (Good Housekeeping)

- Non-Structural Stormwater strategies. These strategies include street sweeping, maintenance of stormwater utilities, education and public outreach programs, land use planning, and IC reduction and control.

- This is a groundwater Remediation technology.

Remediation of Existing Development

- Existing developments or schools with excess wastewater treatment capacity allow existing nearby developments to connect to their underutilized wastewater treatment infrastructure.

- This is a source Reduction technology.

Compact and Open Space Development

- Both Compact Development and Open Space Residential Development (OSRD) of subdivisions result in smaller lots and less maintained lawn acres. The higher density development reduces wastewater collection costs while providing a common disposal area.

- This is a source Reduction technology.

Transfer of Development Rights

- A regulatory strategy that transfers development and development rights from one property (sending area) to another (receiving area) to direct growth and associated nutrient loading away from sensitive receiving watersheds or water bodies. The protected parcels (sending areas) receive a deed restriction that limits the future level of development. The deed restriction can limit the number of homes or tie development to the availability to future WWTF infrastructure.

- This is a source Reduction technology.

System Alterations

Coastal Habitat Restoration

- Restoration of coastal habitats includes establishing and/or enhancing estuary salt marshes, eel grass beds, as well as shellfish and oyster beds together as an ecosystem. Habitat restoration should focus on creating or rehabilitating natural communities native to the area. The installation of riparian buffer zones and floating islands (next subheading) should be considered when restoring coastal habitats.

- This is a Restoration technology.

Pond and Estuary Dredging

- Lakes, ponds, streams and estuaries store nutrients within their sediments. These sediments tend to accumulate over time. Subsequently, these nutrients can be released into the overlying water column and can become a major source of nitrogen and phosphorus. Dredging and removing these sediments and accumulated nutrients removes the nutrients from the water body and potentially the watershed. TN>0.3 mg/L

- This is a water body Restoration technology.

Literature Resources

More supporting evidence of N reducing technologies:

NOTE: The academic literature reviewed support Cape Cod Commission's data range for N removal efficiency. The Matrix also has references, some of which is used in this report.

Constructed Wetlands

Based on an academic review on N in subsurface flow constructed wetlands, constructed wetlands which include a Free Water Surface (FWS) stage were the most effective at removing total N compared to other hybrid constructed wetlands.[35] Constructed wetlands with certain modifications can offer an even higher N removal performance. However, "the choice of such modification depends on the environmental effects, wetland arrangements, wastewater types, loading quantity, pollutant concentration and geographical locations."[36]

Gravel wetlands are a specific type of constructed wetland, in which gravel is used to provide a porous substrate, facilitating movement of runoff through the treatment structure below the surface. Gravel wetlands are typically planted with flooding-tolerant vegetation. The UNH Stormwater Center has studied performance of gravel wetlands in New Hampshire for many years, and they have proven very efficient at removing N.[37]

Phytoremediation

In one study, Water hyacinths removed 60% of N in one test plot and 85% of N in another.[38]

Fertilizer Management

According to Carrico, the top 20% of their sample applied 56% of the total share of N. 93% of all households "applied at or below levels recommended by landscaping professionals,

[35] (Vymazal 2013, 4795)
[36] (Saeed and Sun 2012, 444)
[37] (Houle, et al. 2013)
[38] (Phytoremediation 1 n.d.)

challenging the assumption that the over-application of fertilizer is widespread."[39] This finding suggests that fertilizer management can be targeted effectively to a small subset of the population. The study found that 'the desire for a green lawn is a significant predictor of fertilizer use."[40]

In one instance, there were fertilizer use reductions of approximately 30 to 70% over a period of 3 to 6 years following fertilizer education campaigns.[41]

Good Housekeeping- Street Sweeping

Source control, such as street sweeping, can be quite effective in reducing total N loading. In one case in Wisconsin, there was a 74% total N reduction after leaf-litter street cleanup.[42]

Wetland Restoration

In the Johnson study, they found "high denitrification rates in both flood plains and SCMs [stormwater control measures]" and that "surface area of hydrologically connected features plays a key role in controlling watershed N retention and removal."[43] Additionally, they reviewed other studies that "suggested that stream restoration projects that include floodplain reconnection may foster nitrogen retention."[44]

According to VanZomeren study, "thin layer sediment placement techniques may jump-start marsh recovery by maintain native vegetation seed sources, rhizomes, and microbes in near-surface soils compared to other restoration approaches."[45] VanZomeren states "past studies found lower soil organic matter and total nutrients in coastal wetland marshes constructed with dredged sediments compared to a natural marsh."[46] This suggests that the marsh will hold more total N, although it is unknown to what threshold amount. Another study found that aspects of restored marshes, like soil development and nutrient pools are "much less predictable."[47]

Precise Dredging

Precise dredging is a suitable management solution for N removal in rivers; it depends upon depth and amount of sediment removal.[48]

Eutrophication was still seen post dredging in a study of the Yangzhou River.[49]

---

[39] (Carrico, et al. 2018, 60)
[40] (Carrico, et al. 2018, 60)
[41] (Yang and Lusk 2018, 120)
[42] (Yang and Lusk 2018, 120)
[43] (Johnson, et al. 2014, 97)
[44] (Johnson, et al. 2014, 97)
[45] (VanZomeren, et al. 2018, 61)
[46] (VanZomeren, et al. 2018, 64)
[47] (Feher et al., 58)
[48] (Zhang, et al. 2014, 1129)
[49] (Weng 2017, 246)

Permeable Pavements

Permeable pavements have more benefits for other nutrients other than N. From studies, it appears most of the N removal occurs from denitrification. According to Borst 2019, Pervious Concrete (PC) or Permeable Interlocking Concrete Pavement (PICP) are the best types of pavements for N removal.[50] (More Background in Brown and Borst 2018)

Watershed Scale Review

Watersheds with more Stormwater Green Infrastructure (SGI) show 48% less total nitrogen exports compared to watersheds with minimal SGI.[51]

Constructed Wetlands

Overall, "removal efficiencies (means and standard deviation) of intensified CWs [with modifications] were estimated at... 63+-20% for TN."[52]

Most of the modifications are most relevant to high organic and nutrient loading, as might be expected in wastewater.

> The modification of operating conditions can substantially increase N and organics removal performances in wetland systems []. For example, controlled hydraulic and pollutant loading, feeding mode, forced aeration, and recirculation can provide optimal nitrogen and organics removal, particularly when wetlands are employed for treatment of strong wastewater.[53]

Conversations

Conversation with Aubrey Strausse at Maine DEP

Aubrey gave me the overview of Ch. 500 permitting process. She outlined the 'credit' system for GI projects, and said it is rarely used. She said managing stormwater nutrients is probably best achieved by managing water volume. Other regulatory efforts would require more funding, more monitoring, and might be challenging.

Conversation with Wendy Garland at Maine DEP

She reiterated that "it would be helpful to have a resource that shows N reduction practices and BMPs. Right now, their Stormwater BMP Manual only includes gravel wetlands; it does not highlight which BMPs are best at removing N." Wendy also confirmed that the State "has not yet established water quality criteria for either P or N."

Conversation with Jamie Houle at UNH Stormwater Center

[50] (Razzaghmanesh and Borst 2019, 20)
[51] (Pennino, McDonald and Jaffe 2016, 1044)
[52] (Ilyas and Masih 2017, 381)
[53] (Saeed and Sun 2012, 444)

Jamie said the most effective stormwater solution for N reduction is gravel wetlands. He suggests that modifying gravel wetlands with saturated zones creates a higher N removal efficiency. He mentioned that the New Hampshire MS4 permit Appendix F has performance curves and modeled removal efficiencies, which are helpful for developers and policymakers. Regional curves serve as accounting methods.
* Emailed Jamie on April 30 to verify.

Conversation with Don Witherall

He reiterated what Wendy said. He said DEP "expects to re-engage in a rule-making process for P by the end of this year." Don followed by saying "we do not yet have a schedule for N as we are still in the mode of collecting and assessing data."

Conversation with Nancy Gallinaro at City of Portland Water Resources

They should have some preliminary data about the efficiency of nutrient reduction in their CSOs, however it probably will not be published for another year. She said there is little to no post construction water quality monitoring, mainly due to costs.

Legislation

Current Related Bills in Legislature as of April 18, 2019

LD 199- An Act to Create the Water Resources Planning Committee
LD 347- An Act to Provide Sustainable Funding for Drinking Water and Wastewater Infrastructure
LD 543- An Act to Protect Public Health Through Subsurface Wastewater Disposal System Inspections in Shoreland zone
LD 563- An Act to Help Municipalities Prepare for Sea Level Rise
Better planning for sea level rise especially with wastewater. More non-structural solutions, especially out of floodplains and storm-surge areas.
LD 565- An Act to Establish the Maine Coastal Risks and Hazards Commission
LD 1336- Penobscot Bay into National Estuary Program

Bibliography

Asseng, Senthold, Peter C. McIntosh, Guomin Wang, and Nirav Khimashia. 2012. "Optimal N fertiliser management based on a seasonal forecast." *European Journal of Agronomy* 38 (1): 66-73.

Białowiec, Andrzej, Wojciech Janczukowicz, and Peter F. Randerson. 2011. "Nitrogen removal from wastewater in vertical flow constructed wetlands containing LWA/gravel layers and reed vegetation." *Ecological Engineering* 37: 897-902.

Bohlen, Curtis, Marti Blair, and Victoria Boundy. 2019. "Nutrient Pollution in Casco Bay, Maine, State of the Science and Recommendations for Action: A Report of the Casco Bay Nutrient Council." Draft of January 11, 2019.

Carrico, Amanda R., Urooj S. Raja, Jim Fraser, and Michael P. Vandenbergh. 2018. "Household and block level influences on residential fertilizer use." *Landscape and Urban Planning* (Elsevier B.V.) 178: 60-68.

Clary, Jane, Jonathan Jones, Marc Leisenring, Paul Hobson, and Eric Strecker. 2017. "Final Report: International Stormwater BMP Database, 2016 Summary Statistics." Water Environment & Reuse Foundation. http://www.bmpdatabase.org/ (29 April 2019)

Maine Department of Environmental Protection (DEP). Chapter 500. 06-96. 1-73. https://www.maine.gov/dep/land/stormwater/storm.html. (29 April 2019)

Deletic, Ana, Michael R. Grace, Douglas G. Russell, Perran L. M. Cook, Tim D. Fletcher, Belinda E. Hatt, Victor Evrard, Timothy R. Cavagnaro, and Emily G. I. Payne. 2014. "Temporary Storage or Permanent Removal? The Division of Nitrogen between Biotic Assimilation and Denitrification in Stormwater Biofiltration Systems." *PLOS ONE* March 2014 Volume 9 Issue 3.

UNH Stormwater Center. 2015. "Design and Maintenance of Subsurface Gravel Wetlands." https://www.unh.edu/unhsc/design-and-maintenance-subsurface-gravel-wetlands. (29 April 2019)

Faucette, Britt, Fatima Cardoso, Walter Mulbry, and Pat Millner. 2013. "Performance of Compost Filtration Practice for Green Infrastructure Stormwater Applications." *Water Environment Research* (Wiley) 85 (9): 806-814.

Feher, Laura C., Jonathan M. Willis, and Mark W. Hester. 2018. "Importance of Site History and Environmental Setting on Soil Properties in Restored Louisiana Back-Barrier Island Salt Marshes." *Journal of Coastal Research* 34 (1): 58-66.

Houle, James J., Thomas P. Ballestero, James Sherrard, Timothy A. Puls, and Robert M. Roseen. 2013. "Comparison of Maintenance Cost, Labor Demands, and System Performance for LID and Conventional Stormwater Management." *Journal of Environmental Engineering* 139: 932-938.

Houle, James J., Thomas P. Ballestero and Timothy A. Puls. 2017. "The Performance Analysis of Two Relatively Small Capacity Urban Retrofit Stormwater Controls." *Journal of Water Management Modeling* 25: C417. https://www.unh.edu/unhsc/sites/default/files/media/undersized_systems.pdf. (29 April 2019)

Hsieh, Chi-hsu, Allen P. Davis, and Brian A. Needelman. 2007. "Nitrogen Removal from Urban Stormwater Runoff Through Layered Bioretention Columns." *Water Environment Research* 79:12.

Ilyas, Huma, and Ilyas Masih. 2017. "The performance of the intensified constructed wetlands for organic matter and nitrogen removal: A review." *Journal of Environmental Management* 198: 372-383.

Iowa State Revoling Fund. http://www.iowasrf.com/ (30 May 2019)

Jing, Lian Dong, Chen Xi Wu, Jian Tong Liu, Hua Guang Wang, and Hong Yi Ao. 2013. "The effects of dredging on nitrogen balance in sediment-water microcosms and implications to dredging projects." *Ecological Engineering* 52: 167-174.

Johnson, Tamara A Newcomer, Sujay S Kaushal, Paul M Mayer, and Melissa M Grese. 2014. "Effects of stormwater management and stream restoration on watershed nitrogen." *Biogeochemistry* 121: 81-106.

Koch, Benjamin J., Catherine M. Febria, Muriel Gevrey, Lisa A. Wainger, and Margaret A. Palmer. 2014. "Nitrogen Removal by Stormwater Management Structures: A Data Synthesis." *Journal of the American Water Resources Association* 50(6): 1594- 1607.

Law, Neely L., Lawrence E. Band, and J. Morgan Grove. 2004. "Nitrogen input from residential lawn care practices in suburban watersheds in Baltimore County, MD." *Journal of Environmental Planning and Management* 47 (5): 737-755.

Leisenring, Marc., et al. 2012. "International Stormwater Best Management Practices (BMP) Database, BMP Performance Summary: Chesapeake Bay and Related Areas." http://www.bmpdatabase.org/ (29 April 2019)

Lin, J. L., Y. T. Tu, P. C. Chiang, S. H. Chen, and C. M. Kao. 2015. "Using aerated gravel-packed contact bed and constructed wetland system for polluted river water purification: A case study in Taiwan." *Journal of Hydrology* 525: 400-408.

Liu, Cheng, Jicheng Zhong, Jianjun Wang, Lu Zhang, and Chengxin Fan. 2016. "Fifteen-year study of environmental dredging effect on variation of nitrogen and phosphorus exchange across the sediment-water interface of an urban lake." *Environmental Pollution* (Elsevier Ltd) 219: 639-648.

Lucke, Terry, Mohamed Ansaf Kachchu Mohamed, and Neil Tindale. 2014. "Pollutant removal and Hydraulic reduction performance of field grassed swales during runoff simulation experiments." *Water (Switzerland)* 6: 1887-1904.

Macmullan, Ed, and Sarah Reich. 2007. "The Economics of Low-Impact Development: A Literature Review." ECONorthwest. Center for Watershed Protection. https://owl.cwp.org/mdocs-posts/macmullen-2007-econorthwest-economics-literature-review1/ (29 April 2019)

Ohio Water Resource Restoration Sponsor Program. November 2017. https://www.epa.ohio.gov/Portals/29/documents/ofa/WRRSPfactsheetNov2017.pdf (30 May 2019)

Pennino, Michael J., Rob I. McDonald, and Peter R. Jaffe. 2016. "Watershed-scale impacts of stormwater green infrastructure on hydrology, nutrient fluxes, and combined sewer overflows in the mid-Atlantic region." *Science of the Total Environment* 565: 1044-1053.

Razzaghmanesh, Mostafa, and Michael Borst. 2019. "Long-term effects of three types of permeable pavements on nutrient infiltrate concentrations." *Science of The Total Environment.* https://www.sciencedirect.com/science/article/pii/S0048969719312719?via%3Dihub (29 April 2019)

Reddy, Krishna R., Tao Xie, and Sara Dastgheibi. 2014. "Nutrients removal from urban stormwater by different filter materials." *Water Air Soil Pollut.* 225:1778.

Rodriguez, Fabrice, Abdelkader Lakel, Alexandre Fardel, Béatrice Béchet, and Pierre-Emmanuel Peyneau. 2018. "Analysis of swale factors implicated in pollutant removal efficiency using a swale database." *Environmental Science and Pollution Research* 26: 1287-1302.

Ruan, Tian-shun, Wen Dong, Bin-hong Zhang, Jia-ke Li, Chun-bo Jiang, and Huai-en Li. 2018. "Design parameters and treatment efficiency of a retrofit bioretention system on runoff nitrogen removal." *Environmental Science and Pollution Research* 25: 33298-33308.

Saeed, Tanveer, and Guangzhi Sun. 2012. "A review on nitrogen and organics removal mechanisms in subsurface flow constructed wetlands: Dependency on environmental parameters, operating conditions and supporting media." *Journal of Environmental Management* 112: 429-448.

Salk, Kateri R., Alan D. Steinman, and Nathaniel E. Ostrom. 2018. "Wetland restoration and hydrologic reconnection result in enhanced watershed nitrogen retention and removal." *Wetlands* (Springer Netherlands) 38 (2): 349-359.

South Portland Code, §27-1536. https://www.southportland.org/files/2114/6825/0142/CH_27__Zoning_with_New_TOC_format.pdf (31 May 2019)

Sustainable Sites Initiative. "SITES Rating System." http://www.sustainablesites.org/certification-guide (30 May 2019)

UNH Stormwater Center. November 2018. "BMP Performance Fact Sheets." https://www.unh.edu/unhsc/ms4-resources. (29 April 2019)

Taylor, Geoff D., Tim D. Fletcher, Tony H.F. Wong, Peter F. Breen, and Hugh P. Duncan. 2005. "Nitrogen composition in urban runoff - Implications for stormwater management." *Water Research* 39: 1982-1989.

Toor, Gurpal S., Marti L. Occhipinti, Yun Ya Yang, Tammy Majcherek, Darren Haver, and Lorence Oki. 2017. "Managing urban runoff in residential neighborhoods: Nitrogen and phosphorus in lawn irrigation driven runoff." *PLOS ONE* (Public Library of Science) 12 (6). https://doi.org/10.1371/journal.pone.0179151 (29 April 2019)

Vermont's Water Infrastructure Sponsorship Program. https://dec.vermont.gov/facilities-engineering/water-financing/cwsrf (30 May 2019)

Vymazal, Jan. 2013. "The use of hybrid constructed wetlands for wastewater treatment with special attention to nitrogen removal: A review of a recent development." *Water Research* 47: 4795-4811.

Wu, Shubiao, Peter Kuschk, Hans Brix, Jan Vymazal, and Renjie Dong. 2014. "Development of constructed wetlands inperformance intensifications for wastewater treatment: A nitrogen and organic matter targeted review." *Water Research* 57: 40-55.

Xu, Bing, Xue Wang, Jia Liu, Jiaqiang Wu, Yongjun Zhao, and Weixing Cao. 2017. "Improving Urban Stormwater Runoff Quality by Nutrient Removal through Floating Treatment Wetlands and Vegetation Harvest." *Scientific Reports* 7:7000.

Yang, Yun Ya, and Mary G. Lusk. 2018. "Nutrients in Urban Stormwater Runoff: Current State of the Science and Potential Mitigation Options." *Current Pollution Reports* 4:112-127.

Yue, Chaoyang, Loretta Y. Li, and Chris Johnston. 2018. "Exploratory study on modification of sludge-based activated carbon for nutrient removal from stormwater runoff." *Journal of Environmental Management* 226: 37-45.