Digging into the biogeochemistry of internal water storage: implications for greenhouse gas emissions and nitrogen treatment

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Highlights

- Internal water storage (IWS) is often of interest due to nitrogen reduction benefit and additional storage
- This study investigates the impact of IWS on emission of greenhouse gases from bioretention soils and water
- Our research indicates that IWS can provide the benefit of N reduction while also reducing greenhouse gas emissions compared to free draining or fully saturated stormwater basin conditions

Introduction

Internal water storage (IWS) has gained interest due to its potential to improve nitrogen removal in stormwater control measures and create additional storage. It is generally implemented via an upturned elbow or elevated underdrain, which serves to create a subsurface storage zone with saturated conditions conducive to nitrogen removal via denitrification. However, IWS also has the potential to alter emissions of microbially produced greenhouse gases due to changes in subsurface redox conditions. These greenhouse gases include carbon dioxide, methane, and nitrous oxide. This work was motivated by previous work by McPhillips and Walter (2015) where field measurements of well-draining and wet stormwater basins indicated that chronically saturated basins had strong nitrogen removal, but also generated high fluxes of methane. Here we hypothesize that IWS can still have strong nitrogen removal due to low oxygen conditions in a subsurface saturated zone, but that methane emissions from the surface would be much lower than a fully saturated basin, due to opportunity for the methane to oxidize.

Methodology

We have investigated these biogeochemical dynamics using mesocosms constructed to mimic free draining, IWS, and fully saturated stormwater treatment basins (4 replicates each). Mesocosms were constructed of six inch PVC with 12 inches of bioretention topsoil, 8 inches of sand with woodchips, and 2 inches of gravel. Partially or fully saturated conditions were created with the use of an upturned elbow. Columns were operated over 2.5 months in summer 2021 with weekly simulated storms. For four events, we quantified nitrogen removal from inflow, as well as dissolved gas concentrations in outflow, and surface soil emissions of greenhouse gases (Figure 1).

Figure 1. Soil column set-up during measurement of surface greenhouse gas emissions. PVC cap chambers on top of columns facilitate measurement of surface greenhouse gas fluxes over a 30 minute period.

Key Findings

IWS consistently had the best nitrate reduction compared to the other two treatments, ranging between 75 and 96% reduction. The fully saturated mesocosms also had very high nitrogen reduction, often indistinguishable from IWS outcomes. With respect to greenhouse gas emissions, the fully saturated mesocosms had highest methane concentrations in outflow water and highest fluxes from the soil surface, though there was a wide range of variability. The free draining mesocosms sometimes had higher nitrous oxide emissions, particularly after an induced drought period; this phenomenon has been documented in other settings where re-wetting of agricultural soils often induces a 'hot moment' of nitrous oxide emissions. Data analysis is ongoing to assess the total greenhouse gas flux from each treatment, including weighing relative fluxes of surface compared to dissolved emissions. However, these preliminary results of this laboratory experiment suggest that stormwater basins with IWS have the potential to enhance nitrogen removal relative to free-draining basins, and also to minimize biological greenhouse gas emissions, particularly due to their reduced methane emissions relative to fully saturated basins.

Recommendations

IWS is a promising technology that has potential to optimize biogeochemical benefits, as well as enhance hydrologic and other benefits. As Pennsylvania supports increased implementation of IWS as 'Managed Release Concept' design approaches, additional field monitoring should occur to further document the benefits of IWS and identify any further means of optimizing performance or improving design (i.e. particularly, if there are issues documented with anoxic conditions adversely affecting phosphorus or metals retention).

References

McPhillips, L.E and Walter, M.T. (2015). Hydrologic conditions drive denitrification and greenhouse gas emissions in stormwater detention basins, Ecological Engineering, 85: 67-75, doi:10.1016/j.ecoleng.2015.10.0

Tredyffrin Township Pollutant Reduction Plan (PRP) Strategy

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Highlights

- Tredyffrin Township developed a flexible strategic planning approach to meet PA DEP requirements.
- The approach includes eight (8) strategies to provide more than 209,000 lbs/year of sediment removal.
- The variety and flexibility of the strategies allow for adjustment during plan implementation.

Introduction

The purpose of this presentation is to describe the strategic planning approach that was taken to provide Tredyffrin Township with a flexible Pollution Reduction Plan (PRP).

Tredyffrin Township developed a PRP which is a requirement and condition of the application for a National Pollution Discharge Elimination System (NPDES) municipal separate storm sewer system (MS4) permit from the Pennsylvania Department of Environmental Protection (PADEP). The majority of the surface waters in the township are classified as "impaired" according to PADEP's 2014 Integrated Water Quality Monitoring and Assessment Report. Under the PRP, the township must develop a plan to reduce its existing sediment (also referred to as total suspended solids, or TSS) load to surface waterways in the Urbanized Area by 10% (209,159 lbs./yr. of sediment removal) over the 5-year permit term (estimated June 1, 2021 to June 1, 2026). The strategies in the PRP were developed to meet the PADEP requirements, however these projects aid the Township in meeting other goals, including increasing resident quality of life, management of increased precipitation, and flooding issues.

Key Findings

To meet the requirement of reducing the sediment loading by 209,159 lbs./yr., the PRP presented eight (8) strategies (Figure 1), including both Capital and Operational projects.

Baseline Sediment Loading	2,091,591
Sediment Reduction GOAL	209,159

CELLS SHADED GREEN ARE USED TO ADJUST PROGRAM

Strategy	Strategy Type	Impervious Drainage Area	Pervious Drainage Area	Amount Treated	Description of Implementation Level		TSS **Loading to BMP**	TSS (Sediment) Reduction	Total Reduction by Strategy	Percent of Total Goal
		Acres	Acres	(%)	Quantity	Unit	(lbs./yr.)	(lbs./yr.)	(lbs./yr.)	
Tredyffrin Township Ordinance Enforcement (exceedance of PADEP requirements)	Capital	80.55	124.23	100%	52	projects	N/A	143,469	143,469	69%
Enhanced Street Sweeping (existing routes at DEP required frequency)	Operations	35	0	100%	35	lane miles swept	52,331	5,756	11,550	5.5%
Enhanced Street Sweeping with additional new routes	Operations	180	0	19%	35		52,667	5,793		
Inlet Cleaning - Solids Removal	Operations	1,067	N/A	22%	467	# of inlet cleanings/year (2,133 total inlets)	921,678	31,623	31,623	15%
Tree Planting	Operations	0	0	100%	800	new trees planted	1,481	296	296	0.1%
Green Streets on Township ROW	Capital	341	0	0.6%	2	1-acre projects	3,010	2,558	2,558	1.2%
Detention Basin retrofit, Township owned	Capital	10.9	36.1	10%	1	basin retrofits	3,979	2,895	2,895	1.4%
Detention Basin retrofit, Non-Township Owned	Capital	24.4	8.6	0%	0		0	0		
Stream Restoration on Township Property	Capital	N/A	N/A	3.0%	375	linear feet	N/A	16,830	16,830	8%
Projects on Township Properties (Parks and Facilities)	Capital	27	0	0%	0.0	2-acre projects	0	0	0	0.0%
								TOTAL	209,220	100.0%

Figure 1. A strategy matrix was developed to assess and present the costs and benefits associated with different PRP strategies.

Strategy 1: Future Private Redevelopment and Ordinance Requirements
Tredyffrin Township's stormwater ordinance is one of the most comprehensive stormwater ordinances in the region, requiring infiltration-based systems for any disturbance (new, additional or replacement impervious surfaces) over 500 square feet (SF). An analysis was performed to estimate the exceedance value of the Township's stormwater ordinance compared to PADEP's Chapter 102 requirements, and the additional pollutant removal from proposed projects was calculated.

Strategy 2: Street Sweeping
The current street sweeping program on existing routes will be enhanced and expanded to sweep additional township owned streets in the planning area (up to an additional 90 road miles).

Strategy 3: Inlet Cleaning and Solids Removal
The current inlet cleaning practice will be enhanced to align with PADEP guidelines for greater sediment reduction. This includes the development and implementation of a standard operating procedure (SOP) for tracking the material removed from the sewer system.

Strategy 4: Tree Planting
The township has a regular tree planting program based on volunteer labor and donated materials and services. A total of 800 trees are planned to be planted in the planning area at no direct cost to the township.

Strategy 5: Green Streets on Township Right-of-Way
Township owned roads and right-of-way (ROW) are a significant contributing land area and component of the stormwater system and offer a unique opportunity to manage stormwater through green street projects. BMPs that could be employed for this strategy include bioretention, infiltration trenches, permeable pavement, tree trenches, vegetated curb bumpouts, rain gardens, swales and more.

Strategy 6: Detention Basin Retrofits
Existing dry detention basins are proposed to be converted to extended detention basins and paired with hydrodynamic structures and other BMPs to increase their sediment removal capacity.

Strategy 7: Stream Restoration
The stream restoration strategy involves restoring, protecting, and/or enhancing banks of streams against scour and erosion by using vegetative plantings, soil bioengineering, and/or structural systems.

Strategy 8: Projects on Township Owned Properties
This strategy involves projects at key township properties, including retrofits and construction of new BMPs to manage stormwater runoff.

Funding
The design and construction of capital projects, as well as the investment needed to meet operational enhancements, will be funded through a variety of sources including capital reserves, bonds, general fund revenue, stormwater fee (if approved by Township Board of Supervisors), and/or grants (if available). The Township secured funds through the American Rescue Plan Act of 2021 (ARPA).

Recommendations

Unit cost analysis (looking at dollar per pound of sediment removed) identifies the most cost-effective strategies.
Flexibility is necessary for townships to implement PRPs, to allow for adjustments throughout PRP implementation.
Utilize existing partnerships and community programs.
Future work to be performed includes adjustment of the PRP implementation after the pilot programs commence.

Hydrologic Evaluation of a Vegetated Compost Blanket (VCB) Amending a Vegetated Filter Strip (VFS) on a Highway Median

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Highlights

- Highway medians have limited volume storage capacity due to highly compacted soils.
- VCB/VFS storage capacity can be accurately predicted using time-step simulation.
- VCBs significantly improve hydrologic performance but have serious water quality implications.

Introduction

An effort is being made to improve the performance of existing highway stormwater systems which have limited performance in terms of volume reduction and pollutant removal. Amendment of highway Vegetated Filter Strips (VFS) with a Vegetated Compost Blanket (VCB), a layer of seeded compost placed on an established slope, has been proposed. Compost has high water holding capacity and organic matter content which can immobilize contaminants of concern. Compost blankets have been used effectively as an erosion prevention method in steep areas prone to stormwater erosion, however the effectiveness of VCBs as a stormwater control measure has not been fully assessed. The goal of this study is to evaluate the effectiveness a VCB as an amendment to a highway VFS for improved stormwater runoff removal and treatment.

Methodology

Complimentary greenhouse and field experiments were conducted to determine VCB effectiveness for runoff volume reduction and water quality improvement. Experimental design parameters include variable slopes, drainage areas (runoff flow rates), underlying soil types, compost depths, blanket lengths, and pollutant concentrations. A focus on stormwater volume removal focuses on the connected VCB-VFS system since infiltration below these layers is limited by highly compacted clayey soils. Storage volume is evaluated using the curve number method as well as a time-step simulation of volume storage using evapotranspiration estimates and antecedent dry time. Performance variation based on the tested parameters was statistically evaluated through analysis of the residuals, multivariate analysis, and regression analysis.

Key Findings

The VCB greatly increases the storage capacity of the VFS, however, greater volumes of compost have tradeoffs with water quality performance. Field and laboratory experimental volume storage data will be presented and compared to simulated volume storage performance values. Recommendations on stormwater volume reduction design will be made. Summary water quality performance for Total Suspended Solids (TSS), nutrients (N and P), and heavy metals will also be presented.

Recommendations

Compost greatly improves stormwater retention on highway slopes, but compost composition should be seriously considered before widespread implementation.