Impact of Soil Compaction and Restrictive Layer Depth on Total Infiltration Volume and Flooding

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Highlights

- Depth to compaction layer where resistance >300 psi affects the volume and time of flooding.
- Antecedent moisture conditions affect the depth to the compaction layer.
- Urban soil recovery of infiltration rates may occur, but recovery of infiltration depth is not rapid.

Introduction

Urban development relies on soil compaction in order to provide structural stability for infrastructure (buildings, transportation, pipes, etc.). Research has shown that, without substantial intentional soil restoration, it may take up to 40 years to naturally recover reasonable soil infiltration rates in compacted soils (e.g., 1 -2 inches per hour). However, total infiltration volume in urban soils is controlled not just by the surface infiltration rate but also by the depth to a compaction layer where the resistance is greater than 300 psi. A compaction layer acts as a restrictive barrier, preventing infiltrating water from reaching the groundwater, and when the soil above the compaction layer is saturated, the remaining rainfall in a storm cannot infiltrate. This project is investigating 3 periods of development in Middletown, PA, to improve understanding of the impact of development age/type on infiltration rate and compaction depth. Current testing in the older areas of town where houses date to the late 1700s and early 1800s still have compaction depths ranging from 2 to 6 inches, whereas testing in a park developed during the 1950s has compaction depths of 1.25 to 3 inches. SWMM modeling in a nearby watershed highlighted the impact of shallow soil storage on flooding during high-intensity rains, with the flooding not seen when the same watershed is modeled using the SCS Type II design storm.

Methodology

During summer 2022, multiple locations in Middletown representing the three development periods were tested. Tests included soil moisture, soil electrical conductivity, double-ring infiltrometer testing, plus soil compaction at depth and at the soil surface. Tests were performed primarily in locations owned by the borough, including public parks, rights-of-way, and borough public works property. Some testing at houses has been performed, with the goal to expand yard testing in the fall of 2022.

Using the initial results on soil compaction, SWMM modeling was performed on a 20-ha watershed on Penn State Harrisburg's campus to demonstrate the impact of soil compaction on flooding. The 20-ha watershed represented the dormitory area. Slopes, etc., were measured in qGIS. Infiltration rates in these soils were measured in 2019 with the field data fitted to the Horton infiltration equation. Horton was selected for two reasons: values for parameters for compacted soils are not readily available for Green & Ampt and SWMM allowed for a maximum infiltration depth in Horton modeling, which was not available in Green & Ampt. The storm selected was the July 23, 2017 storm that resulted in flooding in the borough as well as on campus. One-minute rainfall data was obtained from the NOAA ASOS station across the street from the campus and adjacent to the borough.

Key Findings

As an example of the results obtained to date, Figure 1 shows the depth to the compaction layer in this urban park in Middletown. The houses surrounding the park were built between 1940 and 1960, approximately. Similar to other test locations in the borough, the depth to soil compaction was shallow, even in an open space, as defined by NRCS. It increased after a rain event, indicating the impact of antecedent soil moisture conditions on potential “bowl” storage and infiltration of stormwater.

Figure 1. Depth to 300 psi in Oak Hills Park.

Confirmation using SWMM modeling, using maximum Horton infiltration depths of 1.5 and 3 inches – all other parameters being the same, highlighted the challenge of reduced infiltration capacity in older urban areas. The modeling showed that, in a storm documented to flood in Middletown, a reduction of 50% in infiltration depth increased the number of nodes surcharged from 2 to 6, the number of nodes flooded from 1 to 2, and the flood time from 0.03 hr to 0.46 hr. While flood depth is not predicted from these results, substantial increased flooding time results in additional road closures.

Recommendations

Antecedent moisture conditions, as documented by the NRCS in creating curve numbers for antecedent moisture conditions, can affect the depth to the compaction layer. Substantial decreases in compaction depth resulting from dry weather, e.g., extended flash droughts, could result in increased flooding when rains recur. Relationships are needed to better understand the movement of the compaction layer in urban soils. Green & Ampt’s view of the wetting front could be useful if parameters are available to incorporate compaction into the selection of parameters.

This research also highlights the challenge of soils in urban areas and the need for soil rehabilitation in areas where the soils do not need to be structurally supportive.

Field installation of soil moisture equipment and flow meters will occur in late September 2022.

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Amending bioswale soil media with biochar mitigates the negative effects of compaction on hydraulic conductivity

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Highlights

- In compacted soil, biochar addition increased saturated hydraulic conductivity most strongly at 3% (w/w)
- Water retention increased in soils amended with biochar
- Soil hydraulic properties benefitted most from biochar that included coarse particles (>2mm)

Introduction

Compaction of urban soil has many deleterious effects, particularly in green stormwater infrastructure systems. For example, compaction reduces infiltration, vegetation growth, and stormwater treatment capacity (Ghavanloughajar et al., 2020). To counteract these effets, biochar may be useful as a soil amendment (Lehmann, 2007). However, the concentration and particle size of biochar that could provide the maximum benefit against soil compaction is unknown. We examined the effects of biochar concentrations and particle sizes on the water retention and hydraulic conductivity (saturated and unsaturated) of compacted stormwater media.

Methodology

Soil cores were created by mixing 0-5% unsieved biochar (by mass) with soil media from a bioswale along I-95 in Philadelphia. For a subset of cores, biochar was sieved to <2 mm. Finally, half of the cores were compacted using the standard Proctor method. Soil water retention curves were obtained using a combination of HYPROP (wet end) and WP4C (dry end) and fitted with the unimodal van Genuchten (1980) model. Saturated hydraulic conductivity was also measured, specifically with the falling head method.

Key Findings

The greatest increase in saturated hydraulic conductivity occurred at 3% unsieved biochar (Figure 1). The size of biochar also mitigated compaction effects; increasing the concentration of unsieved biochar (including particles >2 mm) increased hydraulic conductivity. This was likely because the larger biochar particles dissipated the energy imparted during compaction more effectively. Moreover, fine biochar reduced the hydraulic conductivity of compacted media, presumably by releasing fine particles that clogged pores. Water retention improved with biochar amendment regardless of its size distribution (Figure 2). The the addition of biochar may therefore reduce the irrigation requirement to maintain plant health during periods of drought or in dry climates. Overall, the results indicate that biochar additon can be effective in mitigating the negative impacts of compaction on green stormwater infrastructure media.

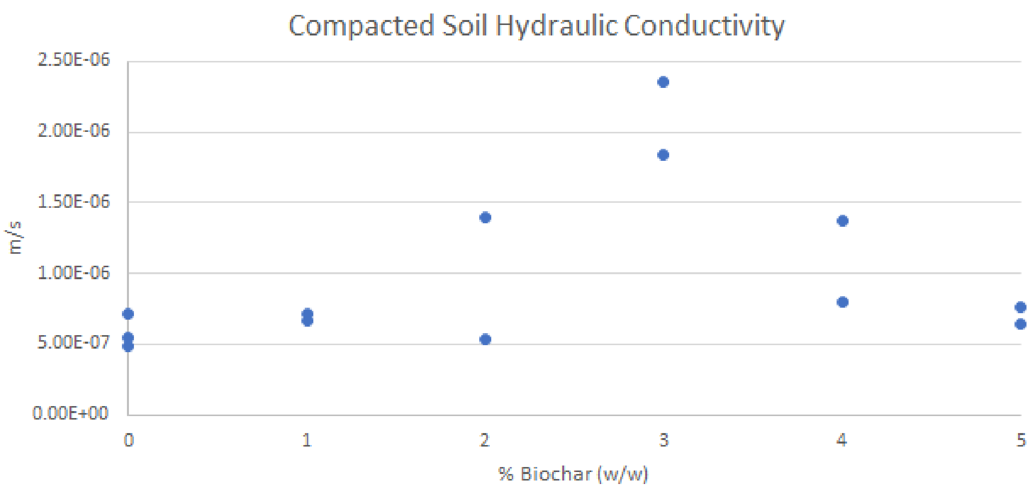

Figure 1. Hydraulic conductivity measurements for compacted amended soils. 3% biochar (by mass) shows the highest saturated hydraulic conductivity out of all treatments.

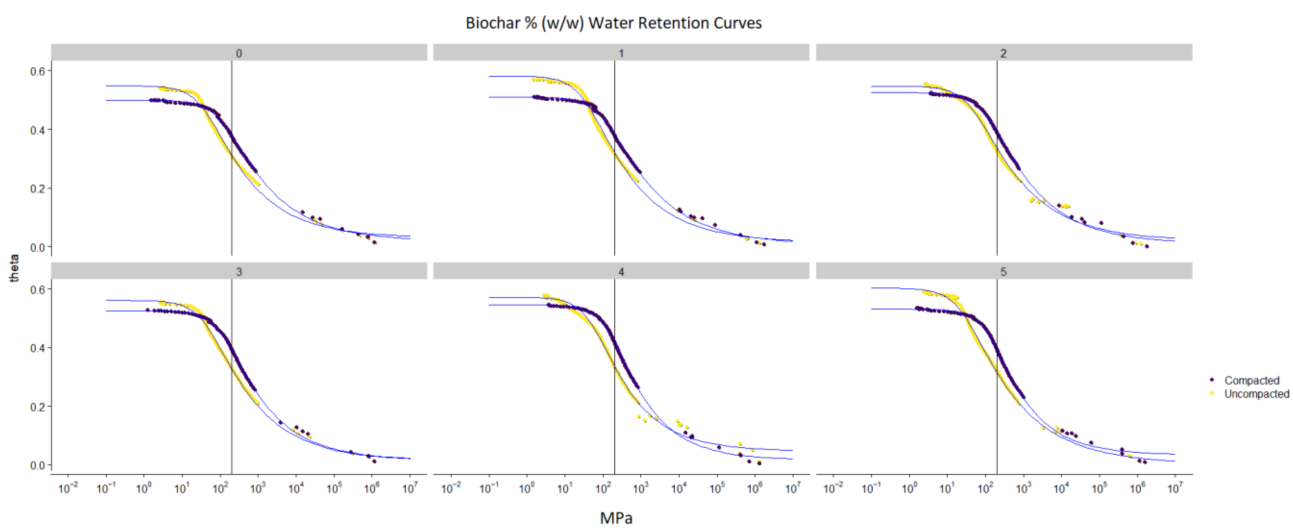

Figure 2. Soil water retention curves, comparing compacted versus uncompacted. Theta is % Moisture/100 and Megapascals are absolute values of suction (negative pressure).

Recommendations

Amending GSI soil media with any practical amount of biochar (1-5% by mass) that includes coarse particles is likely to increase total soil moisture content and water retention. However, we recommend using 3% to maximally alleviate the negative effects of compaction on hydraulic conductivity in stormwater retention basins.

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Stormwater Drainage Wells as a Post-Construction Stormwater Management Best Management Practice in Pennsylvania

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Highlights

- Stormwater Drainage Wells are an approvable alternative PCSM BMP when guidelines are followed.
- Stormwater Drainage Wells may be a costly and complex alternative when compared to stormwater volume management.
- Adherence to PADEP draft Stormwater Drainage Wells recommendations will greatly serve applicants.

Introduction

Stormwater Drainage Wells (SDWs) are a relatively new Post-Construction Stormwater Management (PCSM) Best Management Practice (BMP) in Pennsylvania. Stormwater Drainage Wells are systems involving discharge of effectively treated stormwater to a receiving bedrock aquifer that addresses stormwater volume management. SDWs may be utilized when no lower maintenance-intensive solution is practical. Recommendations for the use of SDWs have been developed by Pennsylvania Department of Environmental Protection (PADEP) independently from the Pennsylvania Stormwater BMP Manual to assist prospective applicants. This presentation will provide an overview of these recommendations and provide insight for when SDWs may, or may not, be an appropriate PCSM BMP.

Background

SDW projects in Pennsylvania are currently handled by the PADEP Regional Permit Coordination Office (RPCO). The first documented use of this BMP was in 2008. As these systems have steadily gained in popularity, DEP staff noticed that many project proposals were lacking details required to review and approve use of SDWs for stormwater volume management. No formal guidance existed therefore as DEP was undergoing an update to its stormwater manual, a parallel effort was underway to develop recommendations to: (1) define SDWs when utilized as a PCSM in Pennsylvania, (2) discuss the applicability and suitability for using SDWs as a PCSM, (3) provide an overview of federal and state regulatory considerations, (4) propose stormwater management criteria, (5) provide recommendations for site investigation and evaluation (6) establish general design guidelines and recommendations, and (7) provide a list of state permits/authorizations that may be required.

The document is separate and supplementary to existing DEP guidance, including but not limited to the Pennsylvania Stormwater Best Management Practices Manual (as updated), and has been prepared to assist in the planning, design, permitting, and operation/maintenance for these systems.

Key Findings

SDWs are inherently different than other stormwater BMPs and are suited for land development and redevelopment being proposed on parcels with carbonate geology/ karstic aquifers due to their unique hydrology.

Discharging to a SDW, when designed and built responsibly, in accordance with applicable regulations and guidance, can offer significant post construction volume management, maintain aquifer recharge, reduce the risk of sinkhole formation in karst areas, and have the added benefit of functioning year-round unlike other BMPs affected by freezing or other weather variation. However, SDWs require a more extensive process than other BMPs including:

(1) Upfront investment in hydrogeologic investigations to determine feasibility.

(2) A source control treatment assessment prior to final site design to discern the most appropriate treatment method to achieve the cleanest runoff to be controlled using underground disposal.

(3) A heightened level of water quality treatment to protect groundwater resources.
(4) A robust monitoring and operation/maintenance program of SDWs, and other appurtenant or supporting BMPs, after construction is completed.
(5) Due to the public health and safety considerations, the design professional(s) involved with SDWs should be Pennsylvania licensed professional(s) experienced in local geologic and hydrogeologic conditions, trained in geology and hydrogeology, with demonstrated training and experience in siting and operating wells. This may require the services of both a P.E. and a P.G.
(6) Use of SDWs as a stormwater management BMP will require early design coordination.

Recommendations

SDW are an approvable alternative PCSM BMP however they are a costly and complex alternative to be utilized only under a narrow set of circumstances. These recommendations for SDWs should be carefully reviewed by prospective applicants and their design team along with other available options. Early coordination with DEP's Regional Permit Coordination Office is also highly recommended whenever SDW(s) are being considered to manage stormwater volume. Due to the required rigor of geologic investigations, engineering design, regulatory review, and necessary monitoring, these practices may necessitate the close involvement of a Pennsylvania licensed P.G. and P.E. during planning, design, permitting, construction, and post-construction. A pre-application conference with DEP is necessary prior to submitting a NPDES application.