Shifting sands: Evaluating crushed glass as a novel component of GSI soil media

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Highlights

- Replacing much of the sand used in green stormwater infrastructure with locally-sourced, crushed waste glass would make media more sustainable and is economically favorable.
- Glass-sand drains less quickly than mined sand, limiting the fraction that can be used but also providing more water to plants between storms.
- Municipally-sourced glass-sand contains some plastic debris and has a modestly-elevated chemical profile but the plastics are large enough to be sieved and chemicals are well-below regulatory limits.

Introduction

Sand is a primary component of the soil media in green stormwater infrastructure (GSI) but sand mining is an environmentally-damaging process (Torres et al. 2017). Simultaneously, most waste glass is currently landfilled, given low recycling demand (Jacoby 2019). If crushed glass fines (i.e., glass-sand) can be procured economically and is sufficiently similar to mined sand, glass could potentially be used as a more sustainable replacement for mined sand in GSI media. We carried out studies to evaluate (a) the viability of processing municipal waste glass so that it can be redirected for use in GSI, (b) how the physical and chemical properties of glass-sand compare to those of mined sand, and (c) how much plastic and paper residues municipal glass sources contain.

Methodology

Glass Procurement

We performed a survey of existing sources of glass fines near Philadelphia and analyzed key differences among available materials. We also compared, for the City of Philadelphia, the costs of mined sand with the hypothetical costs of locally-produced recycled glass-sand with respect to processing, transportation, and waste disposal.

Physical and Chemical Properties

We carried out a mesocosm experiment in which a 36” GSI soil profile was installed in each of four soil columns; the sand component of the media was 0, 33, 66, or 100% glass while the remainder was mined sand (Figure 1). Simulated storms were applied to each column every 2-4 weeks for four months. The chemical properties of leachate were measured after each storm. Simultaneously, soil moisture, tension, and outflow were monitored through time.

Figure 1. Setup of the mesocosm experiment. Columns vary only in the proportion of glass-sand vs. mined sand within the media.

Paper and Plastic Residues

Samples of clean glass and glass from three municipal sources were sieved into 8 diameter classes and subjected to near-infrared spectroscopy. The abundance of paper and several types of plastic were then quantified for each sample, yielding particle size distributions of plastic and paper residues in each glass source.

Key Findings

Glass Procurement

The cost of a glass-sand material that meets landscape requirements would be cost competitive with mined sand in the Philadelphia region, if produced locally. Given that the cost to cities to recycle or dispose of glass is very high, the opportunity to avoid this cost would make our proposed material use still more advantageous to cities and other waste generators. Ultimately, a hypothetical glass recycling model for use in soil blends would represent a cost savings once the material value, as well as processing, hauling, and disposal costs are considered.

Physical and Chemical Properties

Glass had strong effects on the hydraulic properties of soil mesocosms. Most notably, columns drained increasingly slowly as their ratios of glass to mined sand (G:S) increased. This is likely attributable to glass surfaces having hydrophobic or hydrophilic properties. Leachate from the columns contained more cations (notably sodium), organic carbon, and metals as G:S increased but concentrations were not unusually high for the intended urban context (e.g., roadsides) and decreased substantially after 2-3 water applications.

Paper and Plastic Residues

Both types of residues were present in glass from the municipal sources we evaluated, though microplastics were relatively large and most could potentially be removed by sieving to 1 or 2 mm. Paper residues were smaller but are likely to decompose without intervention.

Recommendations

Our results indicate that diverting waste glass to GSI would be economically favorable for Philadelphia, even when considering equipment, operational, and transport costs. Moreover, GSI media should contain a blend of crushed glass and mined sand to accommodate differences in hydraulic properties, in particular. We recommend that approximately 40% of media be comprised of glass-sand and have prepared a free soil specification for trial purposes.

References

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How to Improve Bioretention Success by Improving Soil Testing Knowledge

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Highlights

- Understanding soil testing related to bioretention soil media performance is important.
- Soil texture, organic matter, infiltration rate, pH, CEC and Nutrient concentrations will be reviewed.
- Engineers, architects, inspectors, and owners involved in bioretention will benefit from this knowledge.

Introduction

Bioretention Soil Media (BSM) is commonly specified utilizing local or state guidelines; however, much of the time the specifiers are unfamiliar with the details they are requiring of this important component of bioretention. Over the last 15 years, Luck Ecosystems has helped engineers, landscape architects, project inspectors and project owners to interpret bioretention soil specifications, properties, and testing procedures to facilitate clarity and project success.

Key Findings

The overall goal of BSM is to remove pollutants, which is accomplished by a variety of mechanisms that result in physical and chemical filtration, as well as infiltration and healthy plant growth. Supporting plant growth is a fundamental necessity of bioretention soil media and how this is accomplished tends to be less understood by engineers. The basics for healthy plant growth include availability of water, air, and nutrients, as well as microbial and fungal activity, which are supported by the soil's structure. Several laboratory analyses are commonly conducted on BSM to determine if properties are conducive to meeting the performance goals of BSM. However, there are limitations to these analyses and nuances with BSM that should be considered.

USDA soil texture testing and classification, particle size analysis, organic matter vs. compost, laboratory infiltration testing methods, pH testing methods, buffering capacity of sandy soils, the role of CEC, and the leaching potential of nitrogen and phosphorous are all commonly misunderstood by engineers, architects, inspectors and owners involved in bioretention projects; however, understanding basic soil science related to these properties is important to properly specifying and sourcing BSM.

Recommendations

Engineers, architects, inspectors, and owners involved in bioretention projects should seek to better understand common bioretention soil media properties that are specified and used on their projects to ensure project success.

Hold the phone: Homing in on a more accurate ET estimate for vegetated GSI

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Highlights

- In comparing direct measurements of evapotranspiration (ET) to predictions from commonly-used models, the ASCE version of the Penman-Monteith was reasonably accurate at our site (vegetation <1 m), though it still over-predicted ET late in the growing season.
- The Hargreaves model over-predicted ET at our site but did so consistently; halving its values yielded reasonably estimates.
- Shade induces strong spatial variation in ET but can be accounted for with tools that are often readily-available.

Introduction

Evapotranspiration (ET) can be an important part of a GSI system's water budget but is challenging to measure directly (Ebrahimian et al., 2019). When quantifying ET, stormwater engineers therefore typically rely on one of the several models that estimate ET from meteorological data. However, these models were developed for settings very different from GSI (e.g., agricultural fields) so some of the assumptions inherent to the models may not be met (e.g., vegetation having uniform height). Moreover, even when the assumptions are met (e.g., negligible soil water limitation) they only reflect conditions where meteorological data were collected, ignoring spatial variability in factors like shade. We therefore sought to test and improve the accuracy of model-based ET estimates in the context of GSI, which we did by:

1. Determining how well common ET models match empirically-based estimates of ET,
2. Identifying simple means of adjusting modeled ET to improve prediction accuracy, and
3. Quantifying ET at the basin scale and determining how sensitive this quantification is to key spatial factors like plant size, spatial variation in shade, and topographic position.

Methodology

Field Data Collection

ET rates were measured empirically on 11 plots within a bioswale adjacent to I-95 in Philadelphia. Vegetation in plots was <1 m in height. Five measurements were typically made per plot per day, and this occurred on 7 dates from June through October 2019. ET was determined by measuring the accumulation rate of water vapor within closed, transparent chambers temporarily placed on the plots. ET rates were then interpolated to the daily timescale and, using a statistical model, calculated for all days through the growing season.

Comparison to Models

Meteorological data were used to compute ET according to 6 physical models (Guo et al. 2016). These included models describing potential ET (Priestly-Taylor and Matt-Shuttleworth), reference ET (Hargreaves and both FAO and ASCE variants of Penman-Monteith; PM), and actual ET (Granger-Gray). Model-based estimates had a daily timescale so they could be compared directly with field-based ET values. Coefficients for a subset of models were derived that could be used to improve the accuracy of estimates when applying them to stormwater basins similar to the study system.

Basin-Scale Estimate

Photogrammetric and LiDAR data were used to develop spatially-explicit descriptions of plant canopy height, shade conditions, and basin topography. These were used to quantify ET at the basin scale using our empirically-based statistical model. The importance of each variable to the basin-scale estimate was then determined via a sensitivity analysis.

Figure 1. Evapotranspiration measurements using closed chambers.

Key Findings

Empirically-Based ET

There was strong diurnal and seasonal variation in ET, with daily rates ranging from approximately 0.3 to 4.4 mm/d (mean = 1.9 mm/d). Rates were minimal during storms but often rose substantially afterwards. There was less variation due to vegetation height than expected, noting that all was <1 m in height. This was likely because evaporation is reduced as ground surfaces are increasingly covered by plants, offsetting increases in transpiration.

Comparison to Models

The ASCE-PM predicted empirically-based estimates of ET somewhat accurately, while the FAO-PM slightly under-estimated it. The Hargreaves model consistently over-predicted ET (by about 2×) while the remaining three models severely under-predicted ET (Priestly-Taylor, Matt-Shuttleworth, and Granger-Gray).

Basin-Scale Estimate

Quantifying ET at the basin-scale while accounting for variation in plant height, topographic position, and shade demonstrated that estimates were modestly, but not exceedingly, sensitive to these spatially-varying factors.

Recommendations

When estimating ET for GSI with short stature vegetation (and in temperate climates), the ASCE-PM should be used if the necessary meteorological data are available. While uncorrected estimates may be sufficiently accurate, increased accuracy can be achieved by accounting for the day of year. Otherwise, the Hargreaves model can be used to yield reasonable estimates, but it should be downscaled by about half. We further recommend accounting for spatial variation in shade when estimating ET for a GSI basin when feasible.

References

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