January 2024

Developmental Investigation of Recycled Mixed Color Glass in Engineered Soils

EPA SBIR Phase II Contract # 68HERC22C0041

OLIN

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Project Team

OLIN

Richard Roark, RLA, ASLA - Partner
Rebecca Popowsky, RLA, ASLA - Research Associate
Pia von Barby, RLA - Landscape Architect
Joshua Leaskey, RLA, ASLA, CSI - Associate
Sarah Leaskey, RLA, ASLA - Associate
Melita Schmeckpeper - Landscape Designer
Adriana Hall - Landscape Designer

OLIN is a landscape architecture design, planning and research practice founded in 1976. Through our research arm OLIN Labs we develop novel materials, technologies and analysis that improve the function and lessen the environmental impact of development. Through our research we provide technical system plans, conduct analytical trials and pilot projects with the purpose of transferring this knowledge to public and private actors in the development of the built environment. OLIN research has been funded through the EPA, the nonprofit William Penn Foundation, supported by the McHarg Center at the University of Pennsylvania, Temple University Department of Landscape Architecture and Horticulture and the Maryland Department of Transportation.

OLIN acted as project lead and led the design and implementation of the pilot site, as well as monitoring and analysis of horticultural performance. OLIN also led the technical feasibility analysis of producing glass-based soil in Philadephia.

Engineering & Land Planning Associates

Edward Confair, PLA, PE, CPRP - Senior Program Manager
Megan Schmidt - Senior Project Engineer
Clare Moriarty - Senior Project Engineer
Jake McGillen - Engineer

Engineering & Land Planning Associates (E & LP) is a multidisciplinary engineering firm providing professional consulting services in civil/site, environmental, surveying, landscape architecture, natural resources, renewable energy, and project management fields. Their services are provided on projects throughout New Jersey and Pennsylvania by licensed Professional Engineers, Professional Planners, Licensed Site Remediation Professionals, Professional Land Surveyors, and Licensed Landscape Architects.

E & LP led the monitoring to determine how the glass-based media impacted the water quality and water quantity functions of a bioretention system.

Pennsylvania Recycling Markets Center

Robert J. Bylone, Jr. - President and Executive Director
Wayne Bowen - Senior Program Manager

The Pennsylvania Recycling Markets Center (RMC) is an independent, Pennsylvania nonprofit corporation with a mission to reduce or eliminate barriers that lead to new expanded end use of Pennsylvania's recycled items and materials. In operation since 2005 and with funding from the Pennsylvania Department of Environmental Protection, the RMC has an affiliation with Penn State and is headquartered at Penn State Harrisburg with an office in Pittsburgh. Core areas of RMC outreach include feedstock conversion pairing, applied research and commercialization assistance; technology acceleration; and service as a concierge to technical and business growth information. Building and supporting Pennsylvania's $22.6B recycling marketplace, the Pennsylvania Recycling Markets Center bridges relationships between economic development and recycled materials supply.

RMC provided commercialization planning and advisory support, focusing on state-wide markets outside of Philadelphia, including urban, suburban and rural contexts. RMC also facilitated the installation of a second field trial bioretention system in rural PA.

ReMark Glass and Bottle Underground

Rebecca Davies, Co-founder

ReMark Glass, founded in 2016, upcycles source separated waste glass (donated to them by residential and commercial sources), producing high-end glassware products. Bottle Underground (BU) is a recently established nonprofit sister company, focused on making the highest and best use of bottle glass through recirculation, recycling, down cycling, and up cycling with the goal of reducing glass waste on a local level.

BU piloted small-scale glass-sand manufacturing for this project. Additionally, BU provided expertise related to commercial and residential source-separated glass recycling systems.

Circular Philadelphia

Nic Esposito - Director of Policy & Engagement

Circular Philadelphia's mission is to drive growth of a thriving circular economy in the greater Philadelphia region through advocacy, education, infrastructure development, and collaboration. Circular Philadelphia is a membership organization that brings together individuals, businesses, manufacturers, institutions, local government, and policy makers to lead the shift to a circular economy in the region. Circular Philadelphia's core team consists of materials management and circular economy professionals including Nic Esposito who formerly served as the City of Philadelphia Zero Waste and Litter Cabinet Director.

In addition to commercialization assistance, Circular Philadelphia supported the logistical planning associated with the pilot manufacturing system, including coordination with city agencies.

Andela Products

Cynthia Andela, President and CEO

Cynthia Andela founded Glass Processing Solutions, (aka Sioneer) in 2004 in conjunction with Andela Products, the manufacturer of Andela Glass Pulverizer systems. In 2005 - 2007 Cynthia developed and built the initial demonstration plant to process mixed-color, dirty glass from Material Recovery Facilities into a clean material. The finished product is amorphous silica, an industrial mineral, with several commercial applications and consumer markets.

Andela provided advisory support and supplied the glass-pulverizing equipment for the pilot manufacturing operation.

Craul Land Scientists

Tim Craul, CPSSc - President

Tim Craul, President of Craul Land Scientists, Inc., is a Certified Professional Soil Scientist with extensive experience in soil design for urban planting and stormwater infrastructure. He is a guest lecturer at Penn State University, the University of Pennsylvania, and Harvard University School of Design. Tim's 2006 book Soil Design Protocols for Landscape Architects and Contractors is widely referenced by landscape practitioners. Tim has also been Ridge and Valley MLRA lead Soil Scientist for USDA-NRCS and has developed all the digital soil spatial data for Pennsylvania where both jobs required significant quality control, quality assurance and oversight to meet goals with quality data.

Tim contributed to material assessment and specification writing.

Bennett Compost

Jennifer Mastalerz, Co-owner

Bennett Compost is a local small business dedicated to making composting easy and accessible for households and businesses in the Philadelphia area. Bennett is engaged in a public-private partnership with the City of Philadelphia to collect food waste from city-owned recreation centers and provide food waste compost for public works. They have developed an extensive door-to-door waste and compost hauling operation, supported by private residential and commercial service subscriptions.

Bennett has provided expertise related to food waste compost, as well as technical details about their hauling and distribution network, partnership with the city, scalability and commercialization. Additionally, Bennett provided the food-waste compost for a second pilot site.

Advisors

Philadelphia Water Department

Staff consulted:

Jessica K. Brooks, PE - Assistant Deputy Commissioner
Stephanie Chiorean, AICP - Environmental Staff Scientist & Planner
Daniel Moran - Civil/Environmental Engineer
Liz Svekla, AICP -Strategic Planning Manager
Tim Linehan, ASLA - Site Design Specialist
Lindsay Reul - Landscape

The research team consulted the Philadelphia Water Department (PWD) to review specification and application standards for PWD's Green Stormwater Infrastructure implementation, standards, and specifications. PWD provided insights on considerations of feasibility for broader application as well as additional sites for implementation.

Philadelphia Department of Parks & Recreation

Staff consulted:

Sue Buck - Deputy Commissioner
Natalie Walker - Sustainability Director
Daniel Lawson - Sustainability & Quality Control Manager
Joshua Bell - Operations Manager
Max Blaustein - Environmental Scientist & Nursery Manager

Philadelphia Department of Parks & Recreation (PPR) provided access to the city-owned bioretention basin used as the pilot site for this study. The research team met with PPR throughout the Phase II project to discuss progress and findings related to soil performance and technical planning. PPR was instrumental in helping the team identify and communicate with key collaborators in the public and private spheres, particularly in the realm of sustainable waste management. Additionally, PPR reviewed planting trial progress and provided guidance that ensured the applicability of the research to municipal standards and operations.

We owe special thanks to Dr. Joshua Caplan of Temple University (Horticulture) and to Dr. Steven Goldsmith of Villanova University (Geography and the Environment) for offering invaluable technical support and expert advice over the length of the project.

Executive Summary

Introduction

OLIN, in partnership with Bottle Underground, Engineering & Land Planning Associates, Andela Products, the Pennsylvania Recycling Markets Center, Circular Philadelphia, Craul Land Scientists, and the City of Philadelphia, has developed an engineered glass-based soil (GBS) and engineered process that repurposes city-wide waste bottle glass into a soil blend suitable for horticultural and green infrastructure projects.

Recycling of solid waste materials, like glass, remains challenging in cities due to the costs of recycling in comparison to landfill disposal. Processing costs for post-consumer glass waste are high and products made from glass cullet have marginal commercial value. The combination of these factors result in glass recycling being economically non-viable for most cities, leading to high volumes of glass being sent to landfill. Food waste presents another similar challenge for cities: while it could be upcycled as compost, insufficient infrastructure prevents the use of this readily available resource at scale. Therefore, to reduce the environmental and financial impacts of landfilling these materials, a practical solution for redirecting these readily available waste products is critical.

Another challenge for cities is the difficulty of sustainably sourcing materials needed for green stormwater infrastructure (GSI) that is intended to increase municipalities' climate resilience and improve their environmental impacts. Large quantities of sand are typically a critical component of GSI soil blends. Along with gravel, sand is the most heavily-extracted material on the planet, ahead of even fossil fuels and biomass (Torres et al. 2017). The environmental, social,and human health impacts of this extraction typically occur far from cities themselves and are thus easily overlooked when considering urban environmental impacts, but are nevertheless significant. Moreover, some regions are already facing shortages of sand, especially of uncontaminated material with predictable physical properties.[1] Replacing mined sand with a locally-sourced recycled material would make GSI systems considerably more sustainable.

This project developed an engineered approach to converting glass waste and food compost into an engineered soil product that can serve the city's needs in the development of green spaces and grounds beautification. The technology consists of an engineered soil, and an engineered process plan, that cities can implement to utilize pulverized glass and food compost, to produce a viable soil product with demonstrated horticultural and hydraulic benefits. By partially or entirely replacing mined sand with glass-sand, GBS is a cost-competitive product that reduces the environmental footprint of GSI installations and increases the market value for mixed-color, small-particle glass cullet.

[1] Torres et al., "A Looming Tragedy of the Sand Commons."

Project Description

The team's Phase I and prior research into the horticultural performance and potential supply chain of recycled glass-based soil (GBS) support this product's viability as a substitute for mined sand; Phase II research addresses remaining technical questions and pilots a manufacturing and installation strategy. Specifically, the research builds on previous laboratory and greenhouse research by testing the prototype GBS product's performance in two Pilot Site Installations, improving understanding of its effect on water flow and quality, and its suitability as a planting medium. The primary tasks performed are:

- Task 1: Pilot Project Design & Planning: Work with Philadelphia Water Department (PWD) and Philadelphia Parks & Recreation (PPR) to identify and design a site for a pilot field experiment testing the performance of GBS in green stormwater infrastructure.
- Task 2: Pilot Project Materials Production: Implement a GBS manufacturing pilot locally. Facilitate collaboration between local material processing businesses and PPR to begin pilot production. Source and process prototypical glass-sand. Blend GBS prototype at PWD pre-approved soil blending facility.
- Task 3: Pilot Project Installation: Install a pilot field experiment testing the performance of GBS in green stormwater infrastructure, while providing a public amenity and supporting the City's hurricane recovery.
- Task 4: Pilot Project Monitoring & Analysis: Continuously monitor the pilot field site for 12 months to assess GBS performance in terms of water flow and quality, and plant health; perform statistical analysis of compiled data.
- Task 5: Phase II Technical Plan: Produce an expanded Technical Plan that builds upon Phase I analysis, extending the range of study to cover the state of Pennsylvania. Identify logistical opportunities and challenges related to glass-sand production in smaller municipalities and in peri-urban contexts. Analyze opportunities for public-private collaboration in GBS manufacturing.
- Task 6: Reporting and Communication: Make all study findings available to the public through OLIN's web-based platforms (website, social media and professional networks) and through industry publications and conferences. Search out additional opportunities for public dissemination through city partnerships.

The Pilot Project located at 2400 Kelly Drive in Philadelphia, PA retrofitted an existing stormwater bioretention basin damaged during Hurricane Ida. The final installation contains approx. 1,900 square feet of Green Stormwater Infrastructure soil at a depth of 24 inches. All glass used in the basin was collected by Bottle Underground from Philadelphia residents and businesses and pulverized by Andela Products. The basin is divided into two halves: one side matching typical Philadelphia Water Department specifications (control) and the other side using the glass-based soil (GBS) mix developed in Phase I. Five commonly specified herbaceous plant species were installed as plugs in random distribution throughout the basin. Water flow and water quality monitoring systems were installed in the existing basin outlet structure and soil moisture sensors were installed in the glass-based soil and in the control soil.

To measure bioretention function, the team divided the stormwater basin into four zones for their data collection. Monitoring was conducted to determine how GBS soil mix impacted the water quality and water quantity functions of the bioretention system. Data was collected over a 12-month period. Specific research questions included:

- Does the GBS soil mix impact water quality design targets for pH, temperature, total suspended solids, and dissolved oxygen?
- Does the GBS soil mix impact the runoff release rate from the outlet control system?
- Are there additional parameters of interest based on the pilot study's results?
- Are there design modifications necessary for bioretention systems using the GBS soil mix?

To measure plant performance and soil health, the team established a total of ten test plots for data collection (five on each side), specifically to measure vegetative cover and plant height. Specific research questions included:

- Does the GBS mix impact vegetative cover?
- Does the GBS mix impact plant growth or transpiration rates? If yes, is this impact the same across species?
- Does the GBS mix impact the presence of microorganisms and microarthropods?
- Does the GBS mix contain higher levels of metal concentrations when compared to the control?

Additionally, the Phase II Technical Planning Package, building upon the work completed in Phase I, analyzes the potential for a network of Philadelphia-based small businesses to partner with the City to manufacture GBS locally and proposes a waste diversion and manufacturing system that can be replicated by any municipality.

Finally, with the assistance of Andela Products, Circular Philadelphia, Bottle Underground, and the Pennsylvania Recycling Markets Center (RMC), the team developed a Commercialization Plan which provides critical information for prospective businesses that want to produce an environmentally, socially, and economically sustainable product used in the landscape architecture, grounds beautification, and green infrastructure sectors.

Summary of Research Findings

Monitoring and analysis indicate that the glass-based soil media did not adversely impact the water quality or water quantity performance of the bioretention system. This analysis was used to answer the research questions:

- Does the GBS mix impact water quality design targets for pH, temperature, total suspended solids, and dissolved oxygen? No, the GBS soil mix did not impact the ability of the system to meet water quality standards for effluent. Dissolved oxygen results were inconclusive.

- Does the GBS mix impact the runoff release rate from the outlet control structure? No, the GBS soil mix did not adversely impact runoff release rate. The system performed as well or better than a theoretical model counterpart in terms of flow rate leaving the system. Soil infiltration was higher and soil less compacted in the glass-based media. These results indicate that the change in media did not impact the hydrologic function of the bioretention system.

- Are there additional parameters of interest based on the pilot study's results? Monitoring of additional water quality constituents, such as metals, may be beneficial to better understand water quality function.

- Are there design modifications necessary for bioretention systems using the glass-based soil mix? No, the GBS mix appears to be a suitable substitution without additional design or installation requirements.

Monitoring and analysis indicate that the glass-based soil media had little to no adverse impact on the plant growth of plants in the bioretention system. This analysis was used to answer the research questions:

- Does the GBS soil mix impact vegetative cover? No, despite sample means being lower in most months in glass-based soil, there is no statistical evidence suggesting that glass-sand reduced vegetative cover. For the glass-based soil test plots, mean cover began slightly lower and ended slightly higher, suggesting that, if glass-sand did influence plant growth, it shifted the timing.

- Does the GBS soil mix impact plant growth? If yes, is this impact the same across species? When comparing mean plant height by species, some species demonstrated slightly lower mean height. For three species, height differences in mean growth were statistically significant.

- Does the GBS mix impact the presence of microorganisms and microarthropods? No, in fact samples of the GBS mix showed a higher fungal biomass.

- Does the GBS mix contain higher levels of metal concentrations when compared to the control? Yes, metal concentrations were elevated in the GBS mix. All recorded levels were well below the Pennsylvania Department of Environmental Protection standard limits for residential soils.

Commercialization

This Phase II Pilot Project provides proof of concept for glass-based soil (GBS) commercialization in Philadelphia. In so doing, it supports the growth, not only of the small business grantee (OLIN) but also, two other local small businesses: Bennett Compost and ReMark Glass/Bottle Underground (BU), a local specialized glass material recycler. The successful pilot installation demonstrates the efficacy of our engineering process, and encourages public and private entities to adopt the GBS specification, creating a demand for the new material and by extension, new demand for the glass-sand produced by BU and the food waste compost produced by Bennett. It will also decrease the (economic and environmental) costs of topsoil to the City of Philadelphia and improve the city's glass recycling rates. The proof of concept will make it possible to build new networks of public and private entities in other cities to implement similar plans.

Furthermore, the Commercialization Plan demonstrates that GBS will compete with conventional sand-based topsoil in medium and large-scale green stormwater infrastructure installations, such as rain gardens, detention ponds and low impact development tree planting trenches. Through extensive interviews with potential feedstock processors and suppliers, material specifiers, soil blending operations and potential end users located in the Philadelphia region, it has been determined a bona fide market exists for circular soils in the horticultural and green infrastructure industry sectors.

As a design and planning firm, OLIN sees planning and consulting services as an end product. OLIN will support public and private clients in implementing a glass diversion and soil processing system in their specific locations. To date, OLIN has installed GBS in a public park project and is additionally contracted to provide consulting services related to glass diversion and processing to a municipality. Competition, in this context, is other design and planning firms or public entities that can provide similar services. To our knowledge, there are no competing firms or institutions that offer the expertise network and end-use specifications that meet local application needs, as well as technical manufacturing and commercialization plans in this sector. Therefore, the service that we are developing through this research is unique in our field and gives our firm a competitive advantage in localities that desire improved glass waste and food waste management systems.

Conclusions

Phase II Pilot Project outcomes have demonstrated the long-term horticultural and hydraulic viability of GBS. Results of the study indicate that the GBS did not adversely impact the water quality or water quantity performance of the bioretention system. Minor decreases in plant height are noted, while vegetative cover is similar across soil treatments. Metal concentrations in GBS is higher than levels is the control soil, but all concentrations fall below drinking water limits. Commercialization analysis demonstrates that GBS can compete with conventional sand-based topsoil and that a bona fide market for GBS exists.

Site Design

The selected site was an existing bioretention basin on the north end of the East Park Canoe house, which had been originally designed by OLIN and E&LP for PPR (2018). The 2022 retrofit of this basin included removing all existing vegetation in the flat portion of the basin, along with two feet of existing soil, while protecting vegetation on the sloped perimeter of the basin (see Appendix A for Construction Documents).

Bioretention basin was divided into two zones: control and trial. The division of the site prioritized distributing water from the existing swale (southeast corner of site) as evenly as possible to both sides. Both control and trial zones include part-shade and full-shade conditions.

The control zone was installed using the standard PWD soil profile which includes mined sand and mushroom compost. The trial zone was installed using glass-based soil (GBS), replacing half of the mined sand with glass-sand (see Appendix C for the trial specification).[1]

For the plant selection, the team developed a plant mix consisting of plants typically specified by PWD for bioretention basins. The plant selection only included plants suited to part sun conditions. Additionally, the planting design considered the site's existing trees and shrubs. The final plant selection included:

- *Calamagrostis x acutiflora 'Karl Foerster'* / Karl Foerster Feather Reed Grass
- *Carex vulpinoidea* / Fox Sedge
- I*ris versicolor* / Blue Flag
- *Juncus effusus* / Common Rush
- *Penstemon digitalis* / Beardtongue
- *Vernonia noveboracensis* / Common Ironweed

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[1]A second pilot site replaced mushroom compost with food-waste comost. See Appendix F.

Aerial photograph of the pilot site. (Credit: Temple University)

View into the bioretention basin.

Sighting of bee on Beardtongue growing in GBS.

Pilot Site Monitoring & Analysis

Horticultural Performance

Plant and soil performance were identified as variables representative of horticultural performance to determine the long-term viability of GBS. For plant performance, vegetative cover and plant height were measured. For soil performance, the presence of microorgansisms and metals were measured. To measure vegetative cover and plant height, the team established a total of ten monitoring plots for data collection, five on the control side and five on the trial side (see Figure 1). To measure the presence of microorganisms and metals, samples were taken from both sides of the bioretention basin (control and trial).

Specific research questions included:

- Does the GBS soil mix impact plant growth as measured through vegetative cover and plant height?
- Does the GBS soil mix impact plant species differently?
- Does the GBS mix impact the presence of microorganisms?
- Does the GBS mix contain higher levels of metal concentrations when compared to the control?

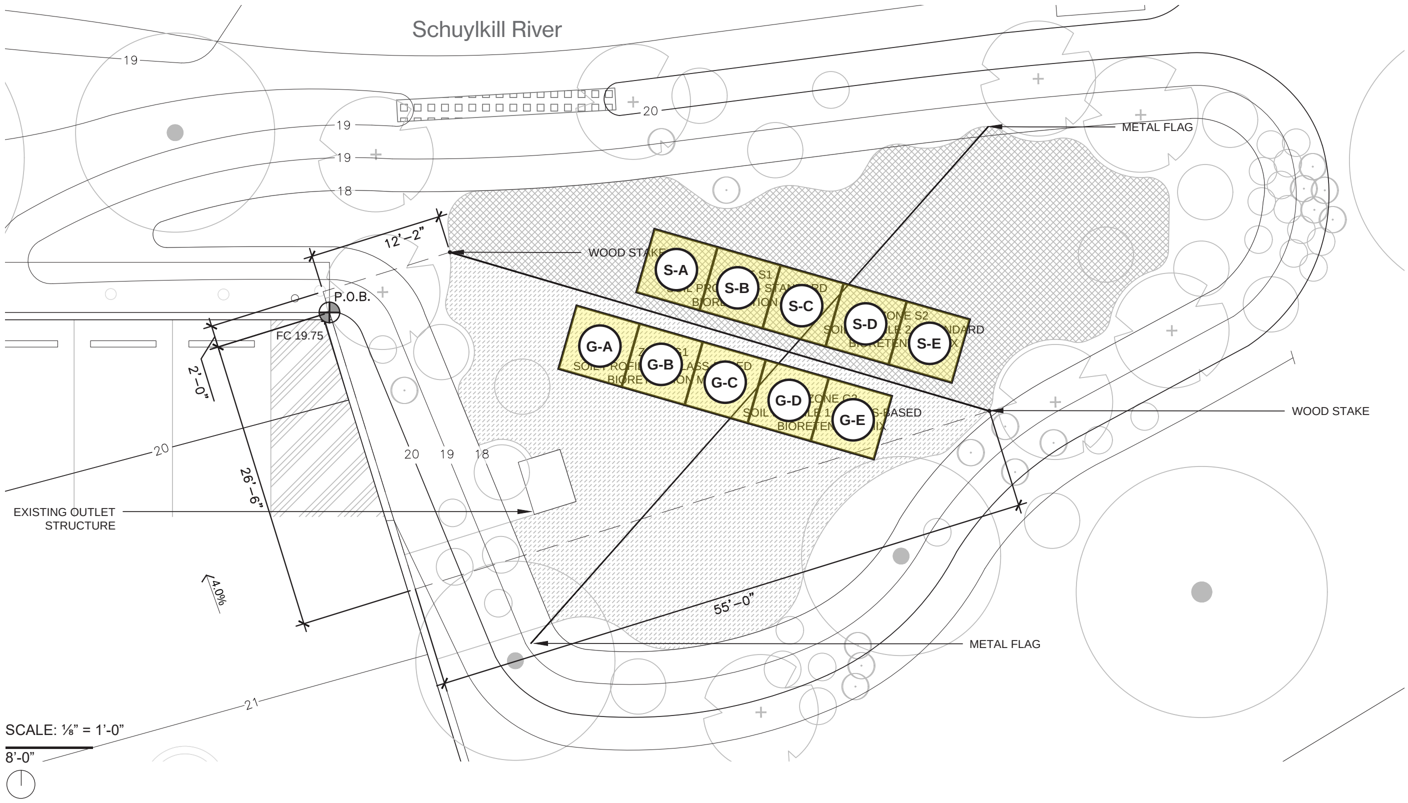


Figure 1: Plan indicating ten monitoring plots for vegetative cover and plant height. Plots indicated with 'G' are in the trial side. Plots indicated with 'S' are in the control side.

Table 1: Parameter Summary

Horticultural Viability	Parameter	Evaluation Approach	Data Collection Method
Plant Growth	Vegetative Cover	Direct Comparison	Overhead Photography, ImageJ Analysis
	Plant Height	Direct Comparison	Measuring Tape
Soil Performance	Presence of Microorganisms	Direct Comparison	Food Web Analysis of Soil Samples
	Metal Concentrations in Soil	Direct Comparison and Regulatory Limits	XRF, Acetic Acid Extraction + ICP-MS
	Metal Concentrations in Outflow	Regulatory Limits	ICP-MS

Pilot Site Monitoring & Analysis

Vegetative Cover

Methods

Vegetative cover was measured using a custom-built overhead photography rig that positioned a cellphone camera directly over each of the ten 5' x 5' observation plot at a height of approximately 10' (see Figure 2). Overhead photographs were taken monthly during the growing season, April-August 2023. Overhead photographs were processed using ImageJ software in accordance with procedures outlined by the University of Florida Institute of Food and Agricultural Sciences Extension. ImageJ converts photographs to binary black and white images. ImageJ then measures the number of black and white pixels which equates to percent coverage of each observation plot.

Figure 2: Overhead photograph being taken with photography rig.

Results

Despite sample means being lower in most months for plots in the trial side (GBS), there is no statistical evidence suggesting that glass-sand reduced vegetative cover (see Figure 28). For the GBS test plots, mean cover began slightly lower and ended slightly higher, suggesting that, if glass-sand did influence plant growth, it shifted the timing (see Figure 3).

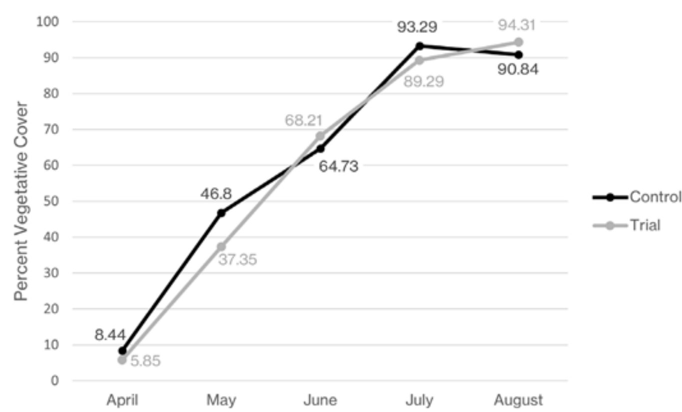


Figure 3: Vegetative cover over time for control (standard soil) vs. trial (GBS).

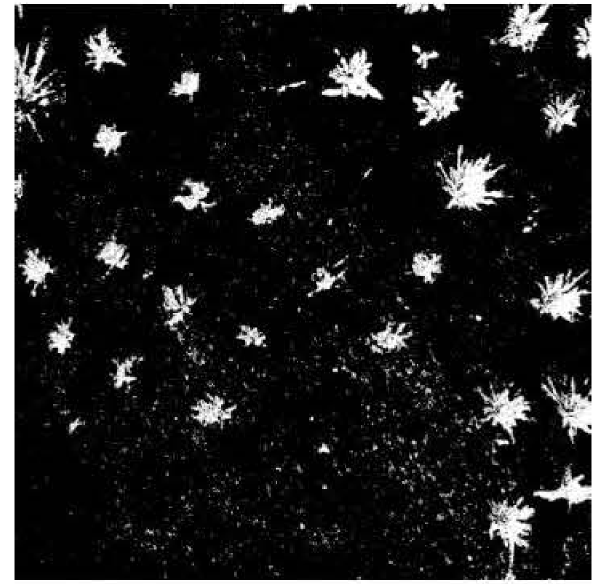
Vegetative Cover - ImageJ Analysis

4/4/2023

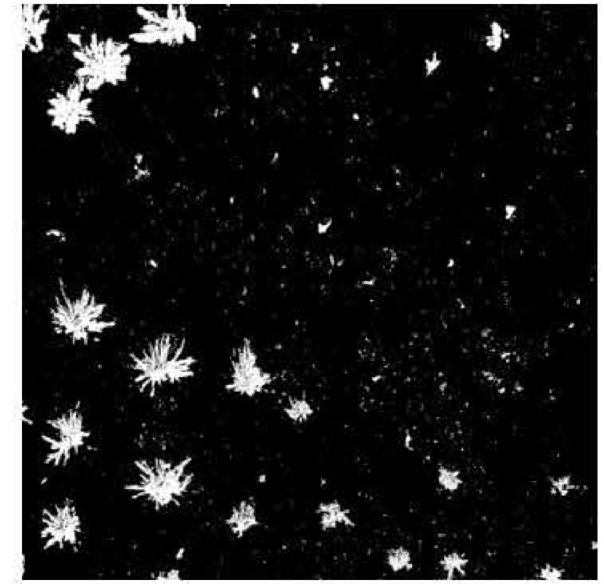
Control Zone - Standard Soil (vegetative cover shown in percent)

S-A: 7.11%

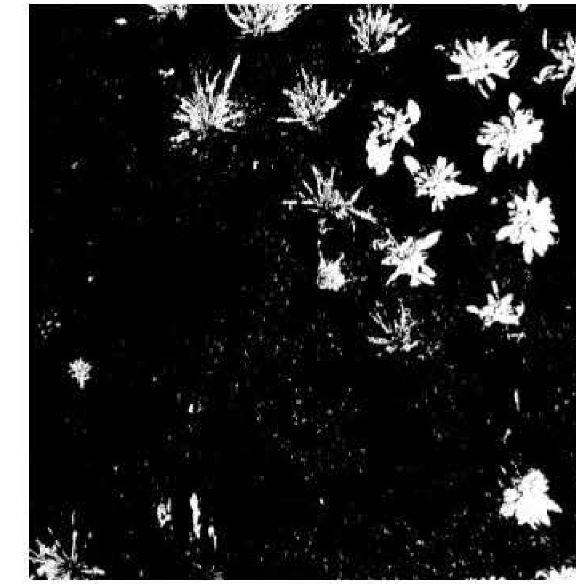
S-B: 12.45%



S-C: 7.87%



S-D: 5.77%

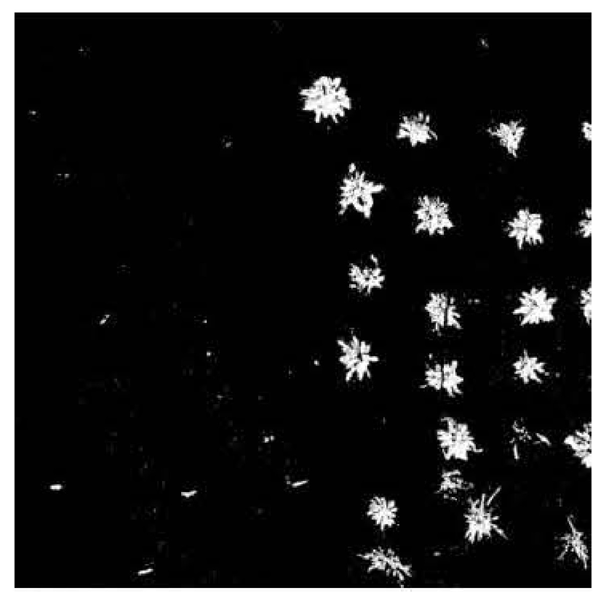


S-E: 9%

Experimental Zone - Glass-based Soil (vegetative cover shown in percent)

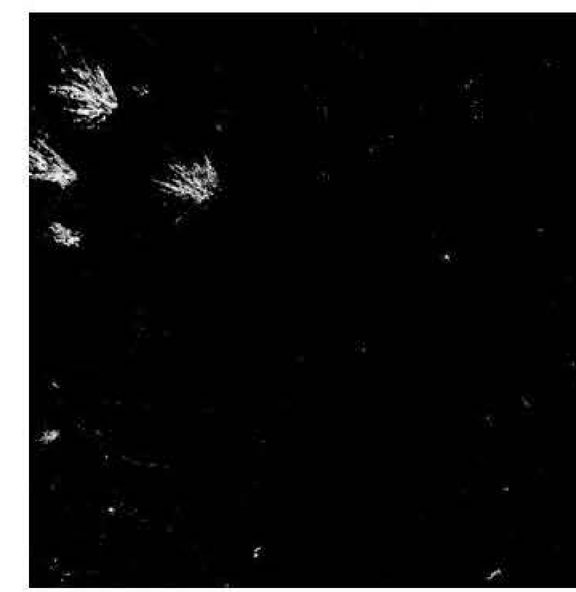
G-A: 9.98%

G-B: 7.40%



G-C: 4.08%

G-D: 6.83%



G-E: 0.95%

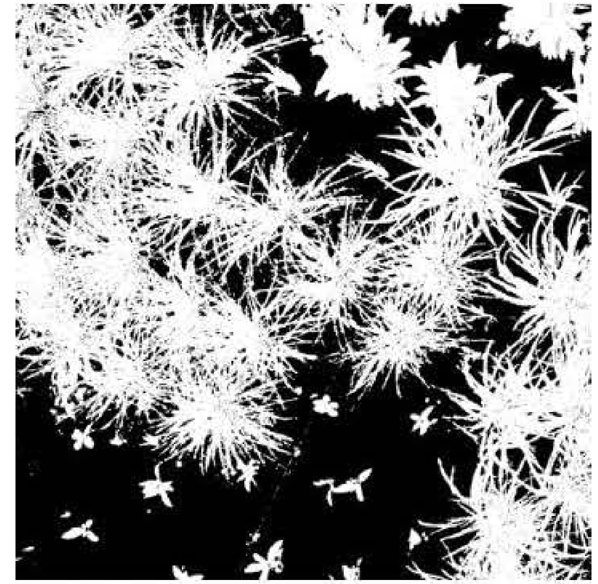
Vegetative Cover - ImageJ Analysis

5/3/2023

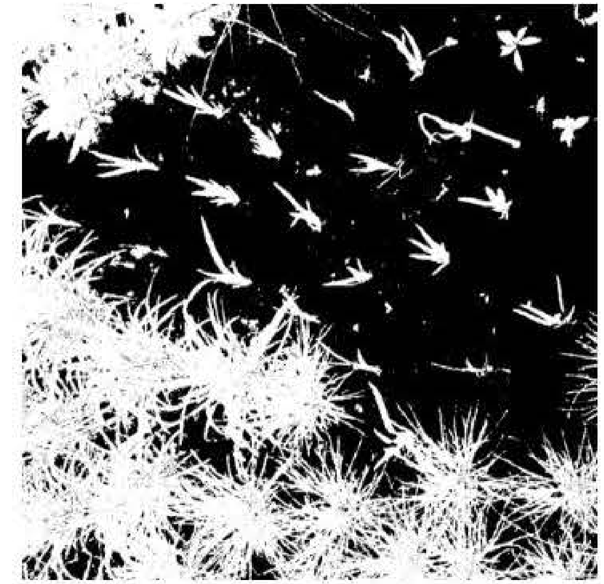
Control Zone - Standard Soil (vegetative cover shown in percent)

S-A: 33.05%

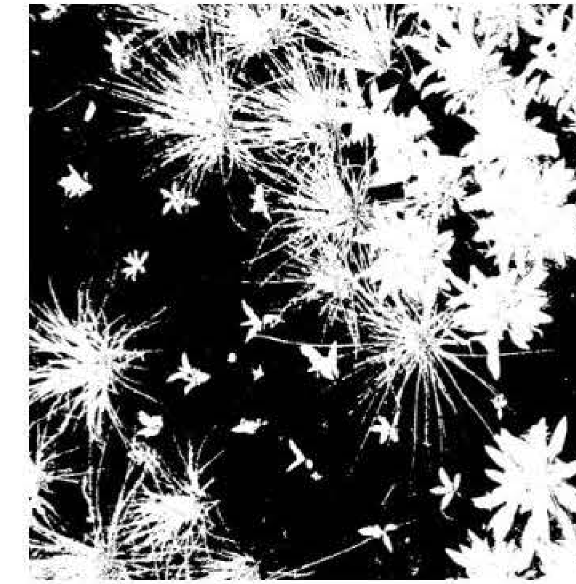
S-B: 67.86%



S-C: 52.58%

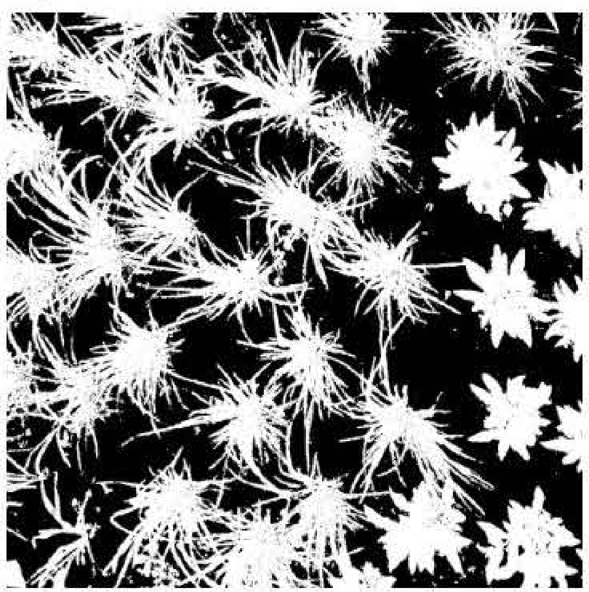


S-D: 38.44%



S-E: 42.07%

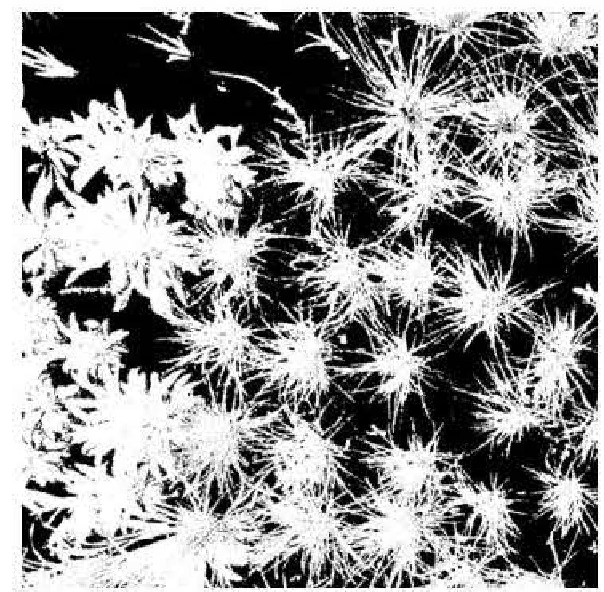
Experimental Zone - Glass-based Soil (vegetative cover shown in percent)



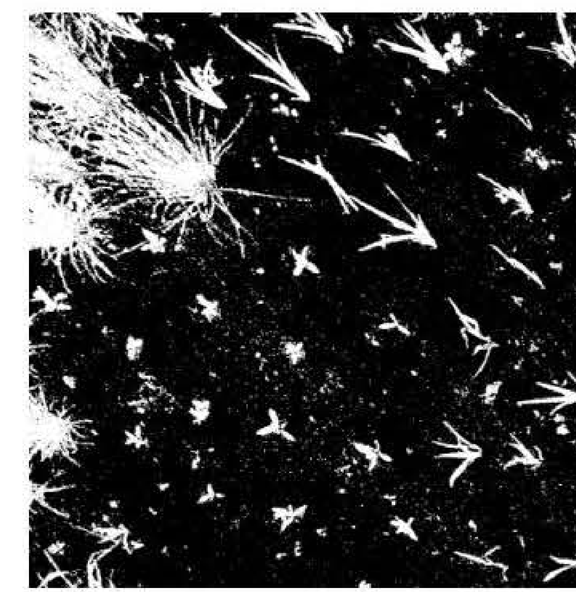
G-A: 46.10%

G-B: 37.82%

G-C: 33.92%



G-D: 52.36%



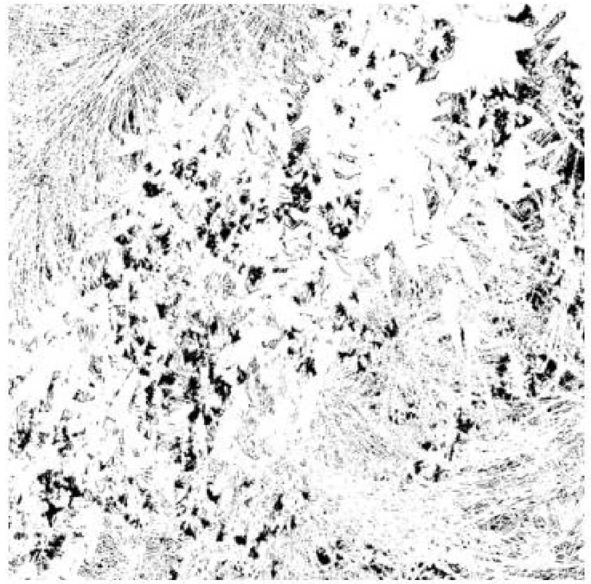
G-E: 16.55%

Vegetative Cover - ImageJ Analysis

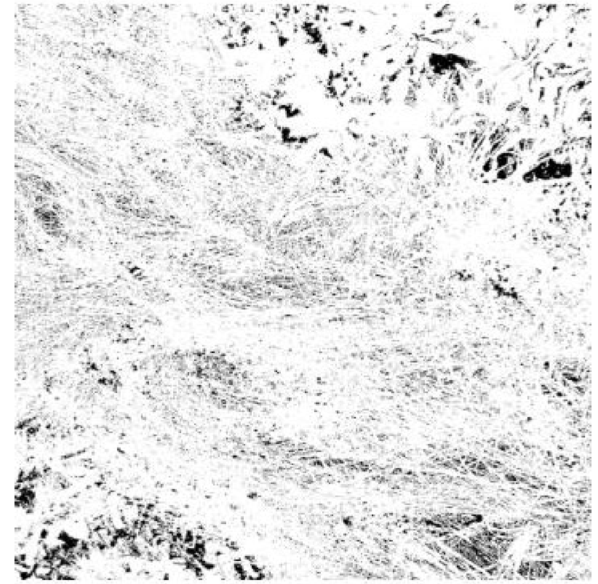
6/7/2023

Control Zone - Standard Soil (vegetative cover shown in percent)

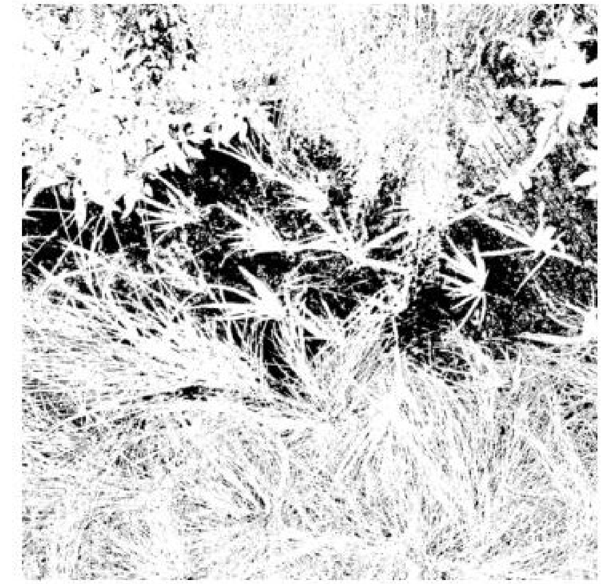
S-A: 67.87%



S-B: 87.59%

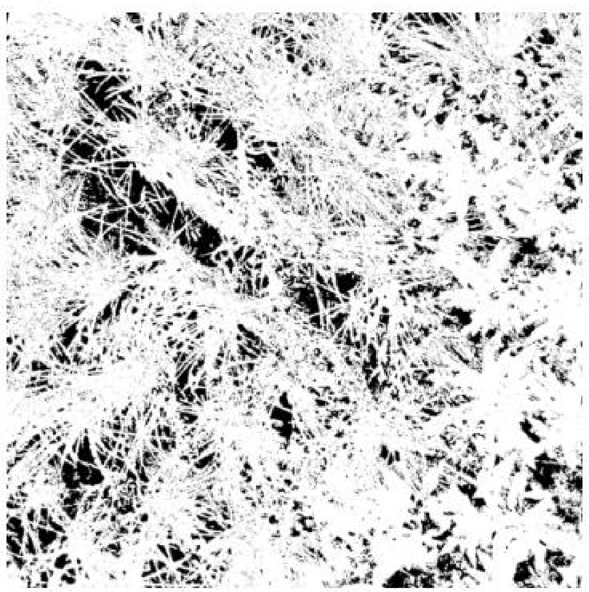


S-C: 90.30%

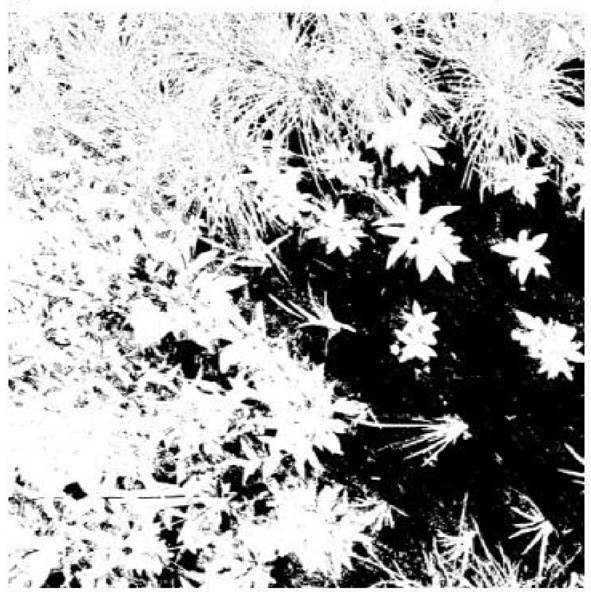


S-D: 77.91%

Experimental Zone - Glass-based Soil (vegetative cover shown in percent)

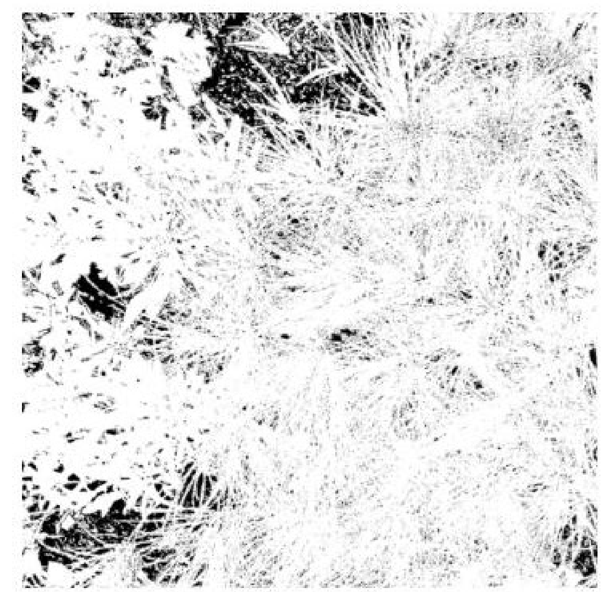


G-A: 80.89%

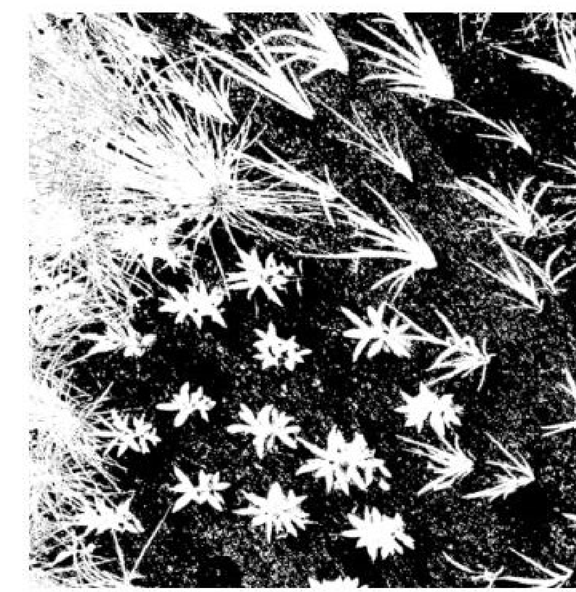


G-B: 64.04%

G-C: 66.14%



G-D: 88.29%

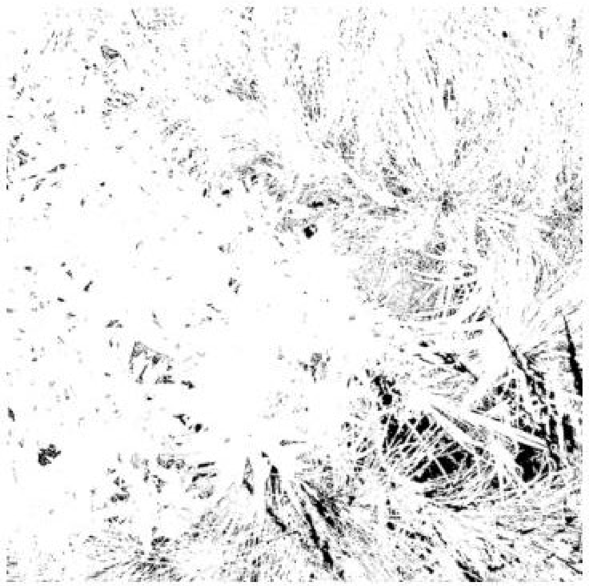


G-E: 41.69%

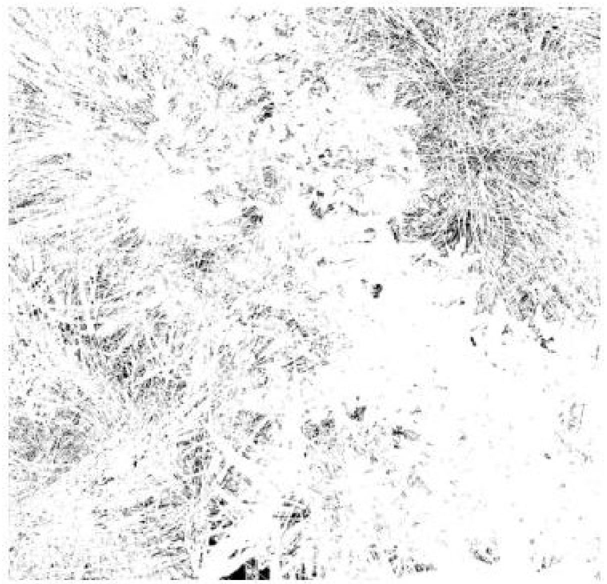
Vegetative Cover - ImageJ Analysis

7/2/2023

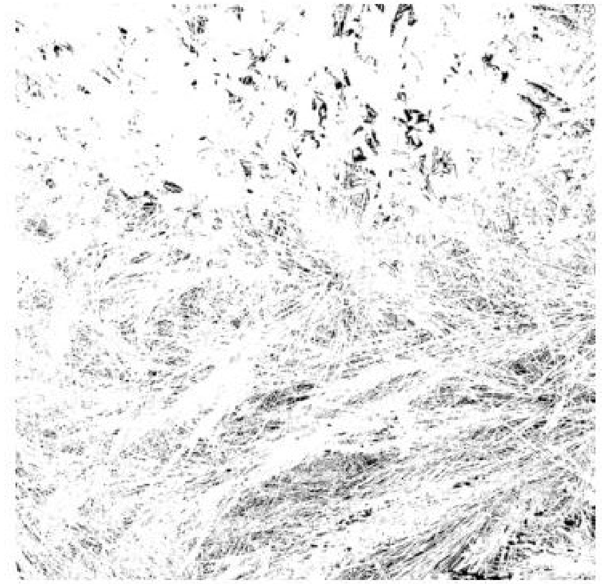
Control Zone - Standard Soil (vegetative cover shown in percent)



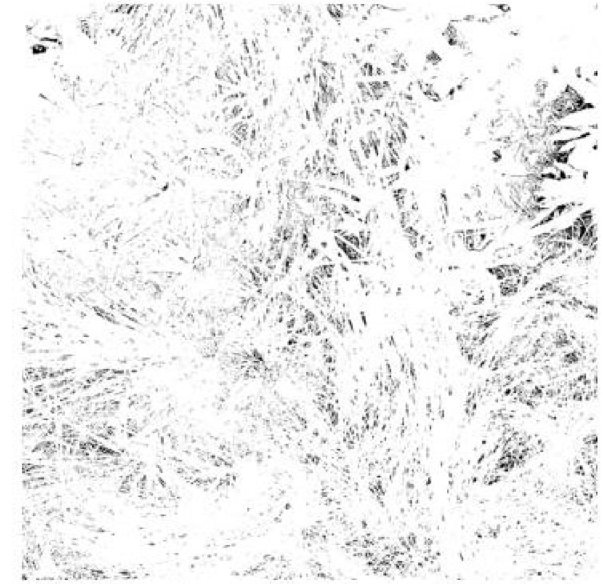
S-A: 92.46%



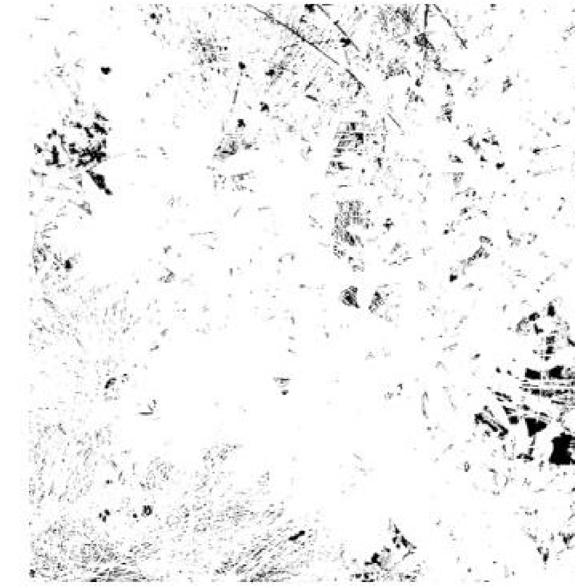
S-B: 92.82%



S-C: 91.77%



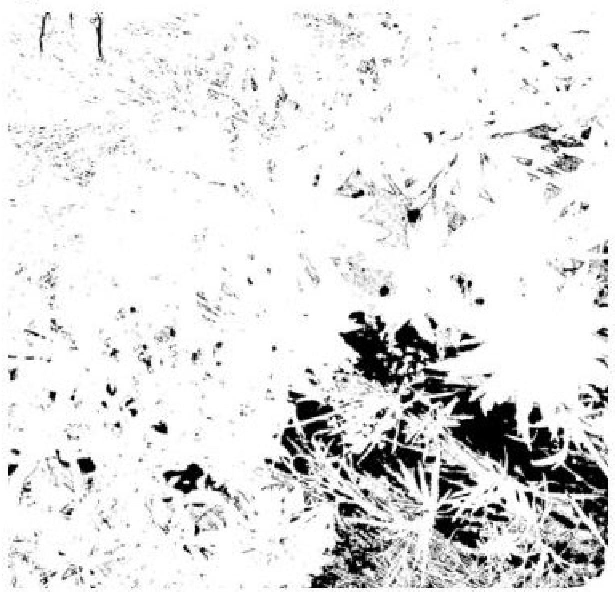
S-D: 94.12%



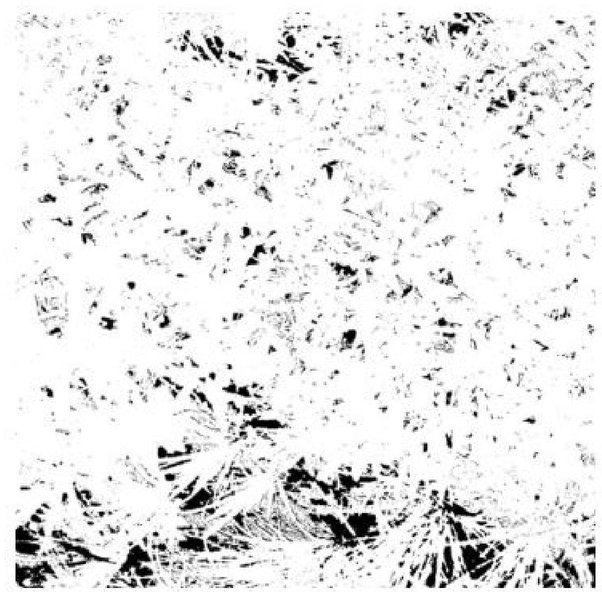
S-E: 95.30%

Experimental Zone - Glass-based Soil (vegetative cover shown in percent)

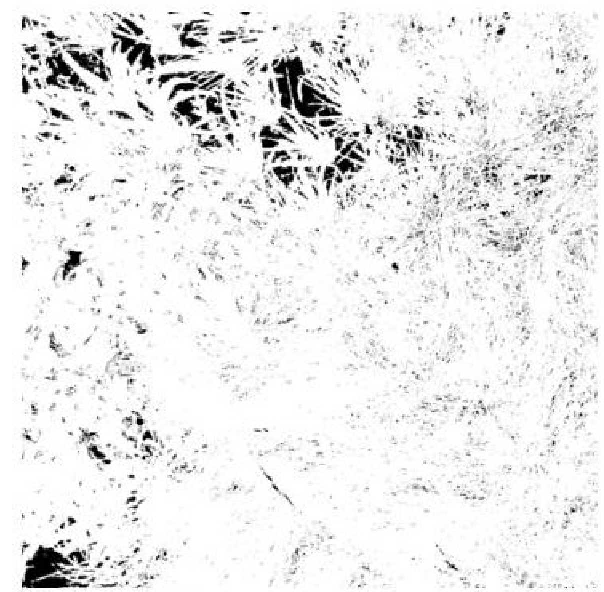
G-A: 91.74%



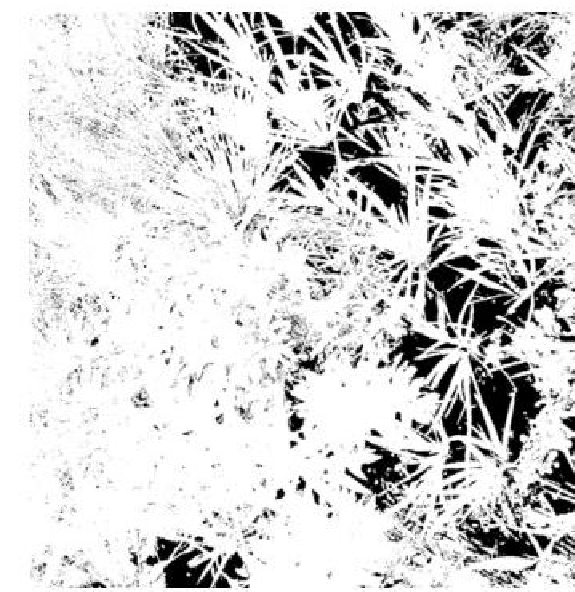
G-B: 89.05%



G-C: 91.42%



G-D: 92.69%

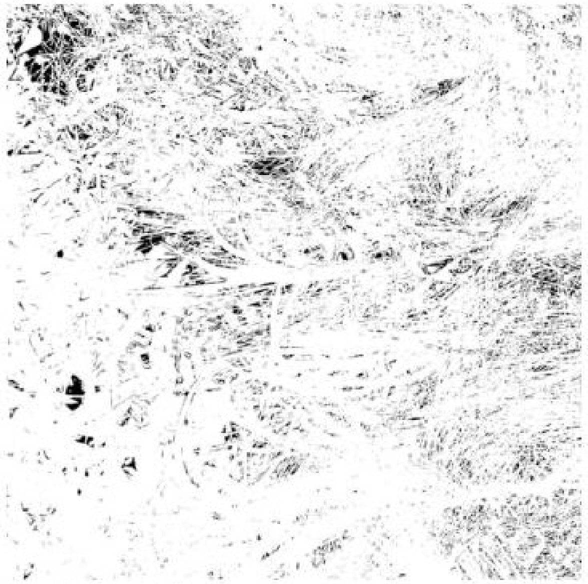


G-E: 81.56%

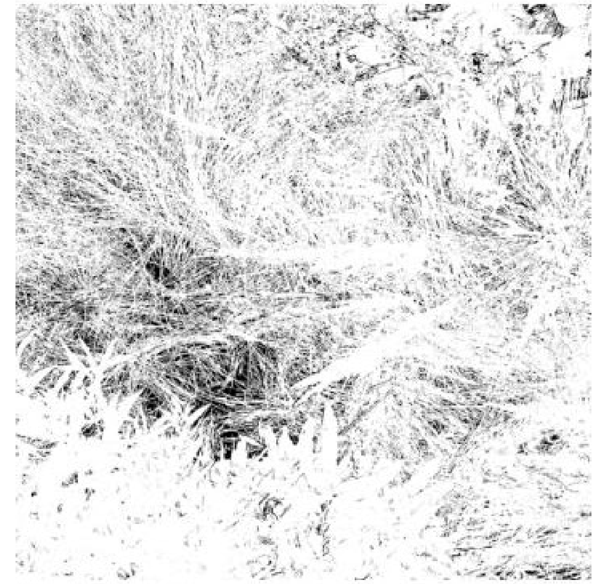
Vegetative Cover - ImageJ Analysis

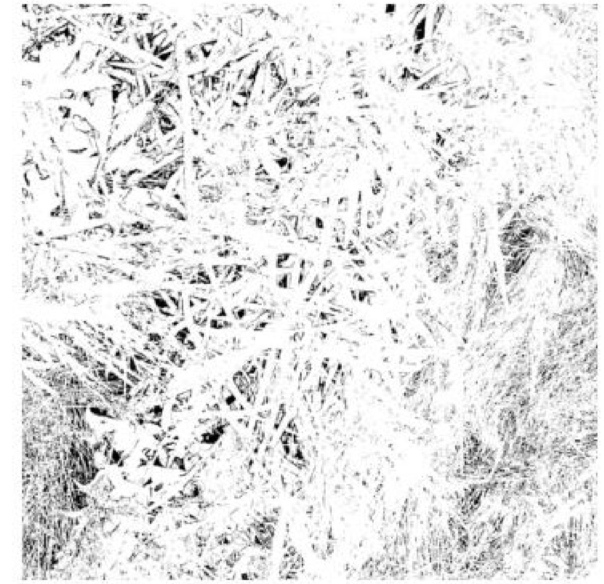
8/2/2023

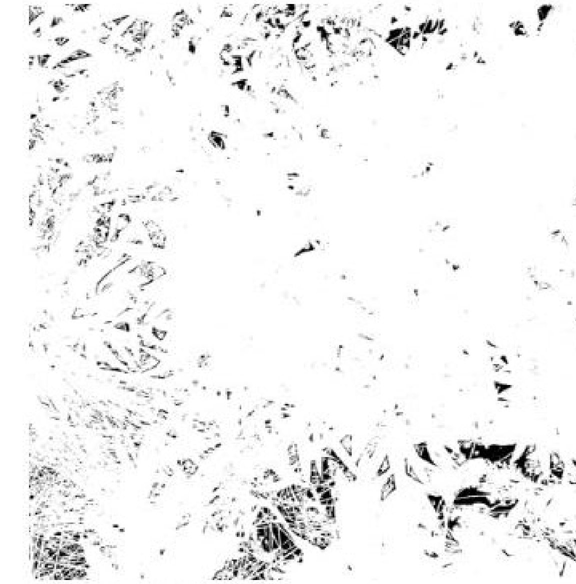
Control Zone - Standard Soil (vegetative cover shown in percent)


S-A: 92.77%

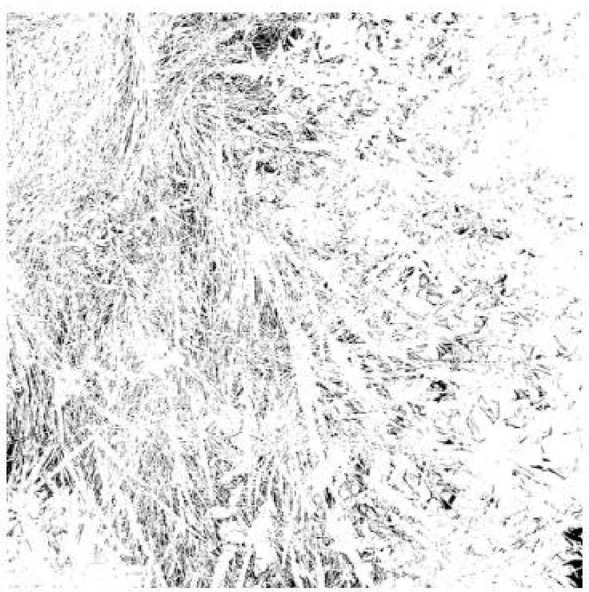

S-B: 88.21%

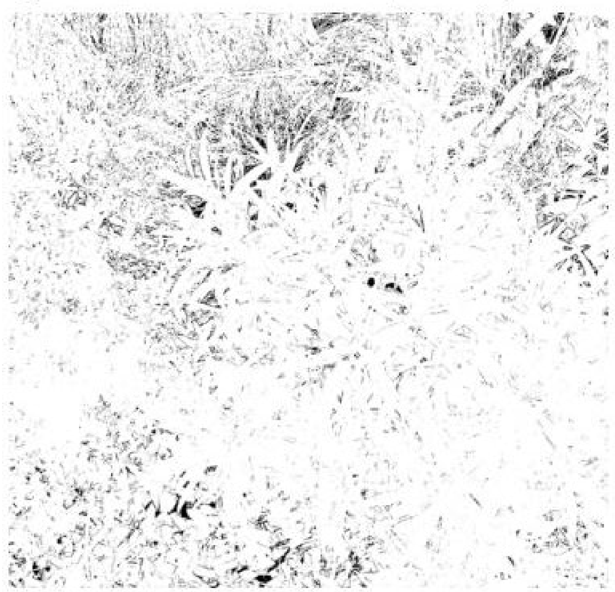

S-C: 88.56%

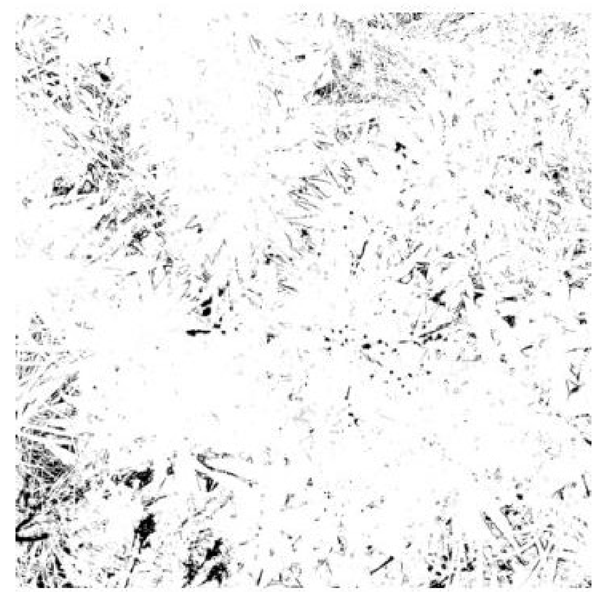

S-D: 89.29%

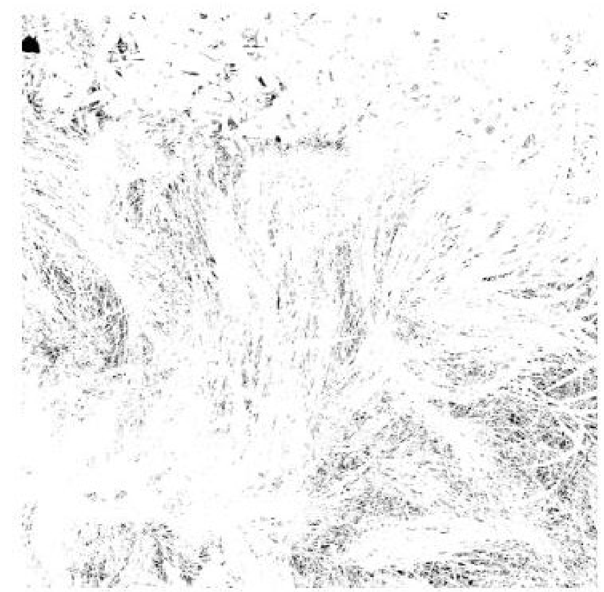

S-E: 95.38%

Experimental Zone - Glass-based Soil (vegetative cover shown in percent)


G-A: 89.34%


G-B: 94.00%


G-C: 94.53%


G-D: 95.40%


G-E: 98.29%

Pilot Site Monitoring & Analysis

Plant Height

Methods

To measure plant height, each plant within the ten 5’ x 5’ observation plots was identified with a unique ID (see Figure 4) and measured using a measuring tape. These measurements were taken in August 2023, the end of the growing season.

Figure 4: Observation Plots with Plant IDs.

Results

When comparing mean plant height by species, the height difference of three taxa were statistically significant when comparing to taxa growing in the standard soil vs GBS: Juncus effusus (19.7% lower), Iris versicolor (7.6% lower), and Penstemon digitalis (13.4% lower) (see Figure 5). These results may be due to several factors including the presence of glass-sand, site access, human occupation, surface runoff from the street and parking lot, and uneven sun exposure.

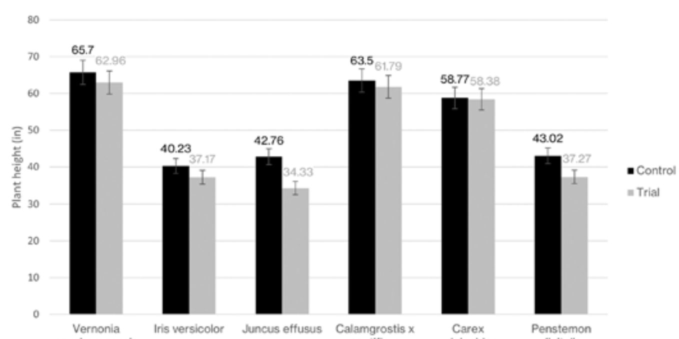


Figure 5: Plant height in control (standard soil) vs. trial (GBS)

Pilot Site Monitoring & Analysis

Presence of Microorganisms

Methods

For the Food Web Analysis, 1” diameter cores of the upper 3” of soil were collected using a 6” soil sample tool. Samples were taken at various locations on each side of the basin to get a representative sample. All microbes are expressed in numbers or biomass per gram of soil dry weight. The microbial testing included:

- Total bacterial and fungal biomass measured using direct count microscopy under differential interference contrast (DIC).

- Active bacterial and fungal biomass measured using direct count microscopy with a protein staining technique and counted under epi fluorescent lighting.

- Protozoan population is estimated based on a serial dilution and four replicates read at each dilution from 10-1 and 106 and again using DIC inspecting for the presence of flagellates, amoeba, and ciliates at each dilution and replicate.

- Nematodes are weighed and counted after being extracted from the soil sample using a funnel and filter.

- Mycorrhizal colonization is measured by staining roots and inspecting for mycorrhizal presence.

Results

The GBS mix sample exhibited high bacterial biomass and fungal biomass in range. The GBS mix showed higher fungal biomass than the control. The community of fungi present is very good. Predatory microbes are low in number.

Control (Standard Soil)

Soil Detail

Report prepared for:
The OLIN Studio
Pia von Barby
1617 JFK Blvd, Suite 1900
Philadelphia, PA 19104

For interpretation of this report, please contact your local Soil Steward or the lab.

Report Sent:	08/20/2023
Sample #	03-13578
Unique ID:	Control
Plant:	General Lanscape
Season:	summer
Invoice Number:	5205
Sample Received:	07/11/2023

SOIL FOODWEB NEW YORK
17 Clinton St.
Center Moriches, NY 11934
631-750-1553
soilfoodwebny@aol.com
http://soilfoodwebnewyork.com

Assay Name	Result	Units	Range	Commentary
		Organism Biomass Data		
Dry Weights	0.87	N/A	0.45 to 0.85	
Active Fungi	15.93	µg/g	> 30	
Total Fungi	253.79	µg/g	> 300	
Hyphal Diameter	3.25	µm	> 2.5	
Active Bacteria	36.88	µg/g	> 30	
Total Bacteria	1056.23	µg/g	> 300	
Actinobacteria	0.00	µg/g	< 20	
		Organism Biomass Ratios		
TF:TB	0.24		1 to 2	
AF:TF	0.06		> 0.1	
AB:TB	0.03		> 0.1	
AF:AB	0.43		1 to 2	
		Protozoa (Protists)		
Flagellates	3181.65	#/g	> 10000	
Amoebae	5284.78	#/g	> 10000	
Ciliates	0.00	#/g	< 85	
Nitrogen Cycling Potential	25-50	lbs/acre		Nitrogen levels dependent on plant needs. Estimated availability over a 3 month period.
		Nematodes		
Nematodes	0.36	#/g	> 10	Default Comment Override
Bacterial	0.33	#/g		
Fungal	0.00	#/g		
Fungal/Root	0.03	#/g		
Predatory	0.00	#/g		
Root	0.00	#/g		
		Mycorrhizal Fungi		
ENDO	8.00	%	> 10	
ECTO		%	> 10	
Ericoid		%	> 10	
		Miscellaneous Testing		
E.coli	Not Ordered	CFU/g	< 800	
pH	Not Ordered			
Electrical Conductivity	Not Ordered	µs/cm	< 1000	
Organic Matter	Not Ordered			
		Notes		

Manual watering; Field History: stormwater basin; Soil Type: green stormwater infrastructure soil mix

Control (Standard Soil)

Nematode Detail

Report prepared for:
The OLIN Studio
Pia von Barby
1617 JFK Blvd, Suite 1900
Philadelphia, PA 19104

For interpretation of this report, please contact your local Soil Steward or the lab.

Report Sent:	08/20/2023
Sample #	03-13578
Unique ID:	Control
Plant:	General Lanscape
Season:	summer
Invoice Number:	5205
Sample Received:	07/11/2023

SOIL FOODWEB NEW YORK
17 Clinton St.
Center Moriches, NY 11934
631-750-1553
soilfoodwebny@aol.com
http://soilfoodwebnewyork.com

Nematode Group and Genus	Result in #/g	Level	Notes
Total Nematodes	0.36	> 10	Default Comment Override
Bacterial Feeders	0.33	> 4	
Plectus	0.08		
Prismatolaimus	0.10		
Rhabditidae	0.15		
Fungal Feeders	0.00	> 4	
Fungal/Root Feeders	0.03	< 1	
Filenchus	0.03		
Predatory	0.00	> 2	
Root Feeders	0.00	< 1	

Trial (GBS)

Soil Detail

Report prepared for:
The OLIN Studio
Pia von Barby
1617 JFK Blvd, Suite 1900
Philadelphia, PA 19104

For interpretation of this report, please contact your local Soil Steward or the lab.

Report Sent:	08/20/2023
Sample #	03-13579
Unique ID:	Test
Plant:	General Lanscape
Season:	summer
Invoice Number:	5205
Sample Received:	07/11/2023

SOIL FOODWEB NEW YORK
17 Clinton St.
Center Moriches, NY 11934
631-750-1553
soilfoodwebny@aol.com
http://soilfoodwebnewyork.com

Assay Name	Result	Units	Range	Commentary
Organism Biomass Data				
Dry Weights	0.88	N/A	0.45 to 0.85	
Active Fungi	24.90	µg/g	> 30	
Total Fungi	449.26	µg/g	> 300	
Hyphal Diameter	3.50	µm	> 2.5	
Active Bacteria	39.56	µg/g	> 30	
Total Bacteria	1151.33	µg/g	> 300	
Actinobacteria	0.00	µg/g	< 20	
Organism Biomass Ratios				
TF:TB	0.39		1 to 2	
AF:TF	0.06		> 0.1	
AB:TB	0.03		> 0.1	
AF:AB	0.63		1 to 2	
Protozoa (Protists)				
Flagellates	5262.90	#/g	> 10000	Lacking species diversity.
Amoebae	6574.62	#/g	> 10000	
Ciliates	0.00	#/g	< 118	
Nitrogen Cycling Potential	50-75	lbs/acre		Nitrogen levels dependent on plant needs. Estimated availability over a 3 month period.
Nematodes				
Nematodes	0.50	#/g	> 10	Default Comment Override
Bacterial	0.50	#/g		
Fungal	0.00	#/g		
Fungal/Root	0.00	#/g		
Predatory	0.00	#/g		
Root	0.00	#/g		
Mycorrhizal Fungi				
ENDO	6.00	%	> 10	Low colonization, foods may be required.
ECTO		%	> 10	
Ericoid		%	> 10	
Miscellaneous Testing				
E.coli	Not Ordered	CFU/g	< 800	
pH	Not Ordered			
Electrical Conductivity	Not Ordered	µs/cm	< 1000	
Organic Matter	Not Ordered			
Notes				

Manual watering; Field History: stormwater basin; Soil Type: glass based green stormwater infrastructure soil mix

Nematode Detail

Report prepared for:
The OLIN Studio
Pia von Barby
1617 JFK Blvd, Suite 1900
Philadelphia, PA 19104

For interpretation of this report, please contact your local Soil Steward or the lab.

Report Sent: 08/20/2023
Sample # 03-13579
Unique ID: Test
Plant: General Lanscape
Season: summer
Invoice Number: 5205
Sample Received: 07/11/2023

SOIL FOODWEB NEW YORK
17 Clinton St.
Center Moriches, NY 11934
631-750-1553
soilfoodwebny@aol.com
http://soilfoodwebnewyork.com

Nematode Group and Genus	Result in #/g	Level	Notes
Total Nematodes	0.50	> 10	Default Comment Override
Bacterial Feeders	0.50	> 4	
Cephalobus	0.14		
Cuticularia	0.09		
Rhabditidae	0.27		
Fungal Feeders	0.00	> 4	
Fungal/Root Feeders	0.00	< 1	
Predatory	0.00	> 2	
Root Feeders	0.00	< 1	

Pilot Site Monitoring & Analysis

Concentration of Metals in Soil and Sediment

Methods

Metal concentration testing was completed by Dr. Steven Goldsmith of Villanova University. Samples were collected from the first few inches of the soil profile. Samples were collected from the control side (standard soil mix) and the trial side (GBS). Additionally, two sediment samples were collected from the adjacent parking lot.

The analysis included measuring total metal concentrations (in mg/kg or ppm) using a portable XRF which reflects the composition of the material but not trace metals. The analysis also included exchangeable metal concentrations (in mg/kg or ppm) using trace metal grade acetic acid extraction and inductively coupled plasma mass spectrometry (ICP-MS). The acetic acid extraction is a weaker acid than the method recommended in the project team's specification which uses a nitric/HCL mixture, therefore the levels of trace metals are lower. However, Dr. Goldsmith indicated that the results using acetic acid extraction are representative of trace elements that would readily leach off the glass-sand and be taken up by plants.

Results

While total metal concentrations for the trial sample were higher than the control sample, the trial sample did not exceed the Pennsylvania Department of Environmental Protection (PA DEP) standards for residential and non-residential soils (see Table 2).

While exchangeable metal concentrations for the trial sample were higher than the control sample in some cases, the trial sample did not exceed the PA DEP standards for residential and non-residential soils. Additionally, the sediment samples in the parking lot demonstrated higher concentrations of metals than the control and trial samples (see Table 2). Post-construction site observation indicated a higher amount of surface runoff from the adjacent street and parking lot entering the trial side of the site (see Figure 6 and 7).

Table 2: Metal concentrations in soil and sediment samples.

		As	Cd	Cr	Cu	Pb	Zn
Total Metal Concentrations (mg/kg or ppm)[1]	Control Sample (Standard Soil)	2	BDL	19	31	9	78
	Trial Sample (GBS)	13	BDL	100	15	162	75
Exchangeable Metal Concentrations (mg/kg or ppm)[2]	Control Sample (Standard Soil)	0.00315	BDL	0.0265	0.0168	0.00384	0.0265
	Trial Sample (GBS)	0.034	BDL	0.00885	0.034	0.00847	0.00885
	Parking Lot Sediment Sample 1	0.00264	0.37	0.0.0275	0.0454	0.0376	0.0275
	Parking Lot Sediment Sample 2	0.00181	BDL	0.0189	0.0352	0.0197	0.0189
PA DEP Medium Specific Concentrations in Non-Residential Surface Soils 0-2 feet (mg/kg or ppm)		61	1600	N/A	100,000	1000	180.000

BDL = Below Detectable Limit
[1]Determined using portable XRF.
[2]Determined using trace metal grade acetic acid and ICP-MS.

Pilot Site Monitoring & Analysis

Concentration of Metals in Outflow

Methods

Dr. Goldsmith also collected a water sample from the outflow structure and measured total metal concentrations (in ug/L or ppb) also using ICP-MS.

Since the outflow structure collected water from both the control and trial side, a comparative analysis was not possible.

Results

Metal concentrations were below US EPA Drinking Water Regulations for all metals (see Table 3). Additionally, concentrations of Cd, Cu, Pb and Zn in GSI output water were in-line with other field-based GSI studies.[1]

---

[1]Lefevre, G. H. et al. (2014, August 5). Review of Dissolved Pollutants in Urban Storm Water and Their Removal and Fate in Bioretenon Cells. Journal of Environmental Engineering. Note: data was compared to the C_{out} column in Table 2 of the paper.

Table 3: Metal concentrations in outflow water sample.

		As	Cd	Cr	Cu	Pb	Zn
Total Metal Concentrations (ug/L or ppb)[1]	Water Sample from Existing Outflow Structure	1.97	0.03	0.31	5.45	5.34	4.33
National Primary Drinking Water Regulations (in ug/L or ppB)		10	5	100	1300	15	5000

[1]Determined using trace metal grade acetic acid and ICP-MS.

Pilot Site Monitoring & Analysis

Confounding Variables

While every effort was made to ensure that both sides of the field plot experienced identical environmental inputs, the fact that the experiment took place in a publicly accessible retrofit of an existing landscape made complete control impossible. Variables that may have affected the outcomes of the experiment include:

- Site access: The interior of the bioretention basin was accessed regularly for data collection and regular maintenance. The access point was located on the southeast corner of the site, closest to the parking lot and the existing sidewalk. This resulted in more foot traffic on the trial side.

- Human occupation: During routine maintenance, the team noticed consistent human occupation in the basin (possibly for sleeping). A swath of grass had been pressed down, an area approximately 3 feet x 6 feet on the trial side, which overlapped with the plant height measurement zones.

- Runoff from street and parking lot: The design assumed that all water entering the basin would come from the southwest corner of the garden where there is a designed drainage swale. To ensure minimal runoff from other sides of the basin, installation included a coconut coir erosion control sock along the eastern side of the basin. This was meant to intercept surface runoff from the adjacent street, Kelly Drive (which does not have a curb). Early site observation indicated that the runoff prevention measure was not entirely effective, and so some volume of additional runoff entered the site from Kelly Drive during rain events (See Figure 6). Additionally, early site observation showed that water entering the site from the designed drainage swale seemed to be directed more toward the eastern side of the site, the trial side (See Figure 7).

- Sun exposure: While both sides had part-shade and full-shade conditions, existing trees on the site cast more shade on the trial side while the control side received more sun.

Figure 6: Access route and surface runoff from Kelly Drive entering the site.

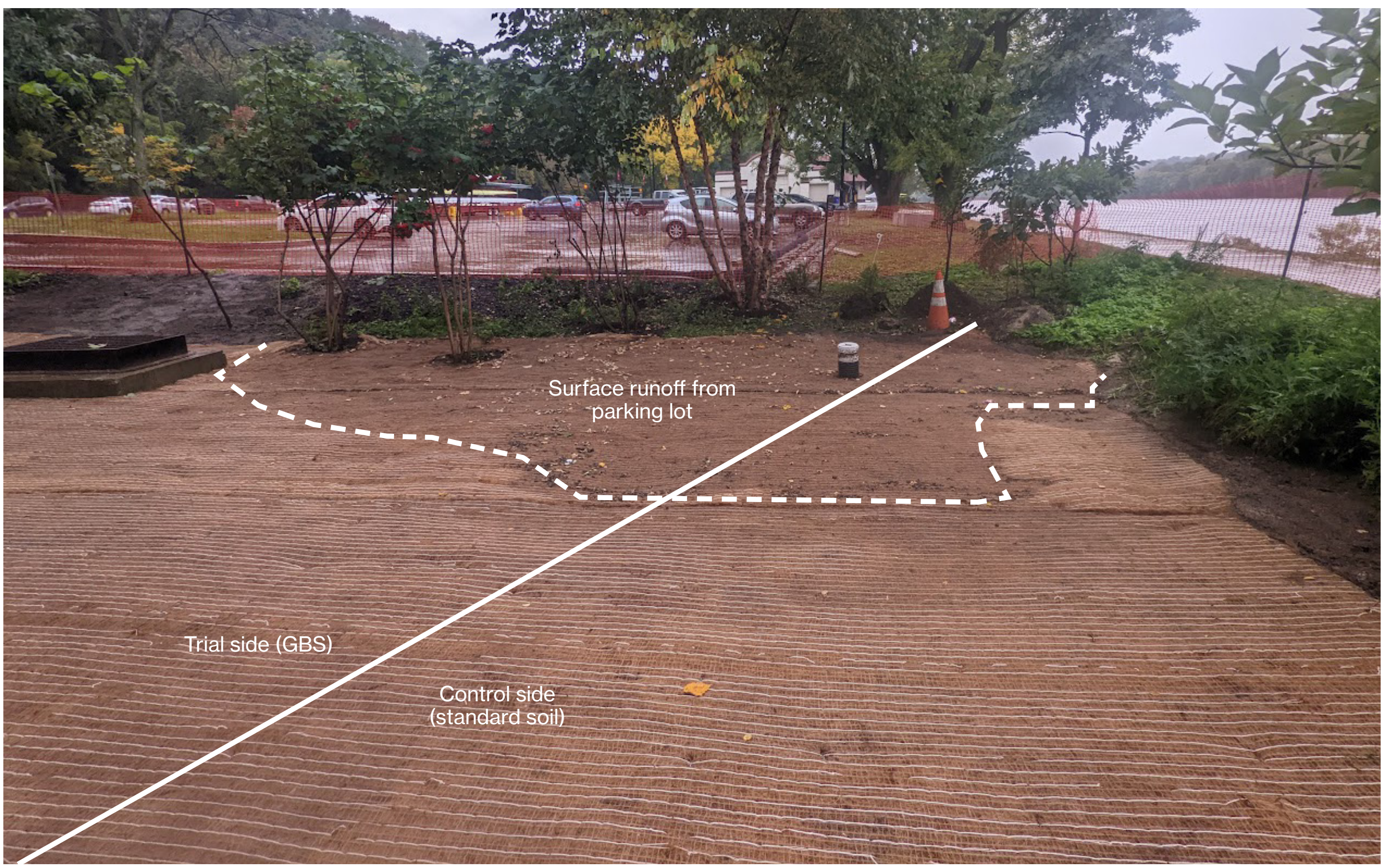


Figure 7: Surface runoff entering the site from the drainage swale being distrubted unevenly.

Pilot Site Monitoring & Analysis

Hydrological Performance

The following report was prepared by Engineering & Land Planning Associates as part of this project.

CIVIL ENGINEERING
WATER RESOURCES
ENVIRONMENTAL
SURVEYING
LANDSCAPE ARCHITECTURE

FINAL REPORT

Developmental Investigation of Recycled Color Mixed Glass in Engineered Soils
EPA CONTRACT #: 68HERC22C0041
Philadelphia, Pennsylvania

Preparer Information:
Engineering & Land Planning Associates
140 West Main Street
High Bridge, NJ 08829
Telephone: 215-330-4113

Report Period:
October 2022 to November 2023

November 17, 2023

E&LP

Headquarters
140 West Main Street | High Bridge, NJ 08829
T: 908.238.0544

Clinton | Asbury Park | Netcong | Philadelphia

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EXECUTIVE SUMMARY

This study was conducted in support of an Environmental Protection Agency Small Business Innovation Research (EPA SBIR) project (EPA Contract #: 68HERC22C0041) entitled "Developmental Investigation of Recycled Color Mixed Glass in Engineered Soils". The project was overseen by OLIN and was designed to study the use of glass-based soil media in green stormwater infrastructure. This report details methods and findings specific to a study site located at Temple University's East Park Canoe House at 2400 Kelly Drive in Philadelphia, Pennsylvania. The study site included a bioretention system retrofitted with 50% glass-based soil media and 50% standard bioretention soil media. Monitoring was conducted to determine how the glass-based media impacted the water quality and water quantity functions of a bioretention system. Specific research questions included:

- Does the glass-based soil media impact water quality design targets for pH, temperature, total suspended solids, and dissolved oxygen?
- Does the glass-based soil media impact the runoff release rate from the outlet control system?
- Are there additional parameters of interest based on the pilot study's results?
- Are there design modifications necessary for bioretention systems using the glass-based soil mix?

The following parameters and equipment were chosen to monitor performance:

Table 1: Parameter Summary

Bioretention Function	Parameter	Evaluation Approach	Data Collection Method
Water Quality	pH	Performance Targets	Aqua Troll 500 Water Quality Sensor
	Temperature	Performance Targets	
	Dissolved Oxygen	Performance Targets	
	Turbidity	Performance Targets	
Water Quantity	Flow Rate	Performance Targets	FL16 Water Flow Logger by Xylem
	Plant Transpiration	Direct Comparison	SC-1 Leaf porometer by METER
	Soil Infiltration	Direct Comparison	Double Ring Infiltrometer

	Soil Compaction	Direct Comparison	Soil Compaction Tester by DICKEY-john
	Soil Moisture	Direct Comparison	Soil Moisture Sensor (S-SMC-M005 HOBO sensor)

Data was collected over a 12-month period. Due to economic constraints, the study was confined to a single bioretention system. This meant that all parameters related to basin effluent were monitored at a single outlet point. For water quality parameters monitored at the outlet, performance evaluation is based on established industry standards for water quality rather than a direct comparison between glass-based and standard soils. If the basin effluent met these standards, it was concluded that the glass-based media did not adversely impact performance. For flow rate, performance evaluation was based on a comparison to a theoretical model counterpart. If the observed flow rate met or was less than the model flow rate, the basin was considered to be successful in providing rate control. For parameters evaluated by direct comparison, data collected in the standard soil mixture was compared to the glass-based mixture. Results were evaluated to determine trends, correlations, similarities, and differences in performance characteristics. Summary findings for each parameter are below:

pH: The pH of the effluent was within the acceptable water quality standards range for the entire study period, with an average pH of 7.25. The pH trended slightly more basic over time and appeared more responsive to precipitation events towards the end of the study which may be due to loss of alkalinity.

Temperature: The temperature of effluent was below maximum acceptable ranges for the receiving water body for the majority of the study period. Slightly higher temperatures observed in January and February of the study period are likely due to the 21% higher air temperatures experienced in those months in 2023 compared to the average of the last 10 years.

Dissolved Oxygen: The dissolved oxygen results are inconclusive with readings throughout the study period dramatically lower compared to industry standard expected ranges. This could be due to the water quality sensor location in the outlet control structure sump where there was minimal light and stagnant water. Further study should be conducted with the sensor in an alternate location.

Turbidity: Turbidity readings demonstrated that the basin's effluent was slightly less than the 20 mg TSS/L maximum observed in 75% of bioretention systems (per the International BMP Database). The slightly elevated TSS readings may be due to a number of factors including drainage area characteristics, drain time, and the location of the water quality sensor.

Plant Transpiration: Stomatal conductance trends for both soil media were comparable, with the glass-based soil media having 4% higher stomatal conductance on average, across all plant species monitored. Stomatal conductance in the standard mixture had slightly higher correlation to temperature than the glass-based mix, suggesting that the standard soil mixture was more influenced by temperature.

Soil Infiltration: The infiltration rate of the glass-based mixture was higher than the standard soil mixture. Both media were within acceptable ranges of infiltration as defined by the Philadelphia Water Department.

Soil Compaction: Soil compaction was comparable for both soil media and was below maximum compaction suitable for woody plants at all measurements. The glass-based mixture was 7.6% less compacted on average.

Soil Moisture: On average, the soil moisture for both media was comparable, with the glass-based soil mix having 3.4% higher moisture overall. The standard soil mixture experienced greater variation and a steeper negative decline over time than the glass-based mixture. The standard soil mixture appeared more responsive to drought conditions and temperature than the glass-based mixture.

Flow Rate: The study site had 9% lower average flow rate leaving the system compared to the theoretical SWMM model of the basin. This result suggests that the glass-based media did not adversely impact the system's ability to provide flow rate reduction.

This analysis was used to answer the research questions:

- Does the glass-based soil media impact water quality design targets for pH, temperature, total suspended solids, and dissolved oxygen?
  No, the glass-based media did not impact the ability of the system to meet water quality standards for effluent. Dissolved oxygen results were inconclusive.
- Does the glass-based soil media impact the runoff release rate from the outlet control structure?
  No, the glass-based media did not adversely impact runoff release rate. The system performed as well or better than a theoretical model counterpart in terms of flow rate leaving the system. Soil infiltration was higher and soil less compacted in the glass-based media. These results indicate that the change in media did not impact the hydrologic function of the bioretention system.
- Are there additional parameters of interest based on the pilot study's results?
  Monitoring of additional water quality constituents, such as metals, may be beneficial to better understand water quality function.
- Are there design modifications necessary for bioretention systems using the glass-based soil mix?
  No, the glass-based media appears to be a suitable substitution without additional design or installation requirements.

In conclusion, the results of this study indicate that the glass-based soil media did not adversely impact the water quality or water quantity performance of the bioretention system. Areas for additional study and/or evaluation methodology improvements are noted in the conclusion section of this report.

1. INTRODUCTION

1.1 Study Overview

The data collection and analysis included in this report were conducted in support of an Environmental Protection Agency Small Business Innovation Research (EPA SBIR) project entitled "Developmental Investigation of Recycled Color Mixed Glass in Engineered Soils" and overseen by OLIN. The purpose of the research was to assess the suitability of using a recycled glass-based soil mixture in green stormwater infrastructure systems in lieu of traditional sand-based bioretention soil mixes. This report details findings related to the engineering functions of an existing bioretention system with 50% of the basin soils replaced with a glass-based mixture.

1.2 Description of Project Area

The study site is located at 2400 Kelly Drive in Philadelphia, Pennsylvania. The Schuylkill River directly abuts the western boundary of the property.

Figure 1: Aerial Location Map

In 2018, three bioretention basins were installed to manage runoff from the redevelopment of Temple University's East Park Canoe House. The basin of interest (SMP 1), collects 39,500 square feet of runoff from the adjacent parking lot and surrounding open space. The basin is lined with an impermeable geomembrane due to high groundwater on the site. Underdrains located below the soil layer direct runoff to a concrete outlet control structure. The outlet control structure has an overflow grate for larger storm events.

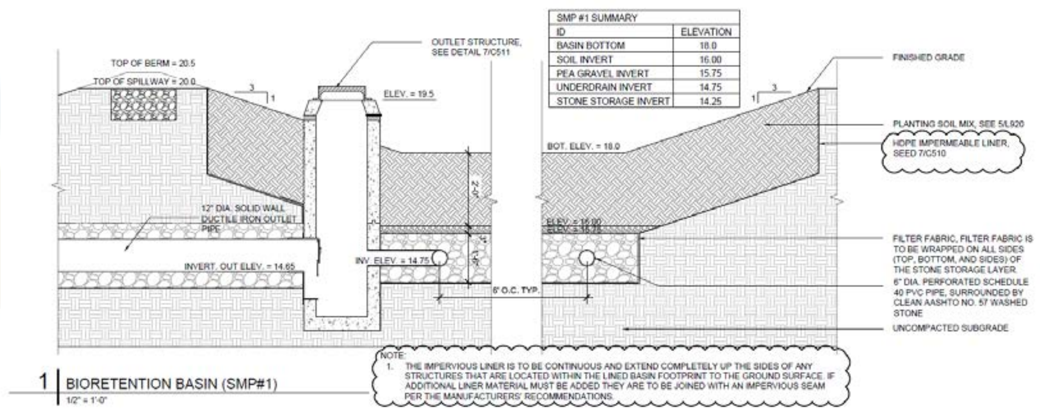

Figure 2: Construction detail for BMP 1, prior to retrofit.

In 2021, Hurricane Ida caused severe flooding along the Schuylkill River and inundated the site. The bioretention basins received significant sediment deposition and flood damage. In lieu of an in-kind retrofit, Philadelphia Parks and Recreation Department agreed to retrofit SMP 1 with a glass-based soil media for this experiment. The retrofit divided the basin into four zones: two with a standard bioretention soil mix (S1 and S2), and two with a glass-based mixture (G1 and G2). The purpose of dividing the basin into four zones was to differentiate two testing locations in each soil mix. Creating two testing locations per soil mix also accounted for variable shade conditions. The basin was replanted with six (6) herbaceous species. The planting design, plant schedule, and soil specifications can be found in a separate report prepared by OLIN.

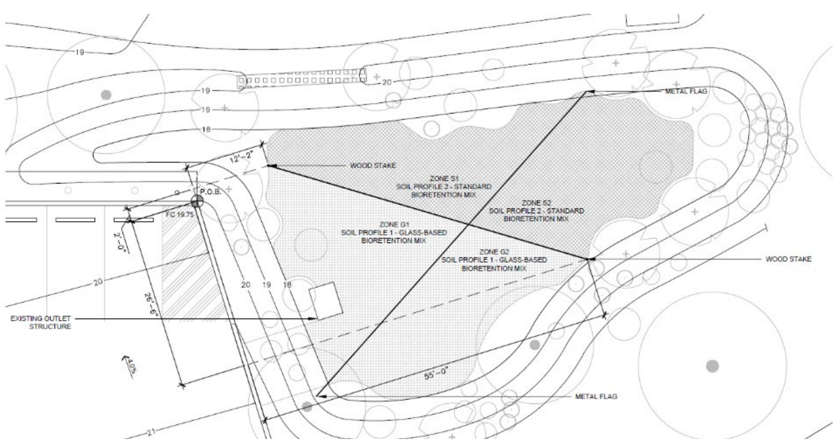

Figure 3: Plan view of soil zones within bioretention basin

2. EVALUATION APPROACH AND METHODOLOGY

2.1 Major Questions Answered

The goal of this pilot study was to assess the performance of the glass-based media under real-world conditions over a period of 12 months. The performance assessment was based on the dual stormwater management function of bioretention systems to reduce runoff peak rates during and after storm events and provide water quality treatment. Study parameters included pH, temperature, total suspended solids, dissolved oxygen, flow rate, soil moisture, soil compaction, soil infiltration, and plant transpiration. The study was designed to answer the following questions:

- Does the glass-based soil media impact water quality design targets for pH, temperature, total suspended solids, and dissolved oxygen?
- Does the glass-based soil media impact the runoff release rate from the outlet control system?
- Are there additional parameters of interest based on the pilot study's results?
- Are there design modifications necessary for bioretention systems using the glass-based soil mix?

Given the variability of real-world conditions and limitations in creating control conditions, interpretation of data collected is accompanied by potential sources for error and uncertainty.

2.2 Overall Evaluation Design and Schedule of Data Collection

The experiment was designed to collect approximately 1-year of data, post-basin retrofit. The first few months of study included procurement, testing, calibration, and installation of monitoring equipment. Testing and calibration continued throughout the experiment, as detailed in Section 2.5. Data collection began for the majority of parameters in November, 2022. Monthly data collection events were scheduled for the end of each month. Data was collected and evaluated for completeness, errors, and trendlines after each month.

Two methods were used to evaluate results: direct comparison and comparison to industry standards for bioretention systems. Direct comparisons involved collecting data from the standard mix and the glass-based mix. Direct comparison was utilized for plant transpiration, soil infiltration, soil compaction, and soil moisture.

Due to site and funding constraints, it was not feasible to directly compare effluent data from one basin with a glass-based mix to another basin with a standard soil mix. The study basin was retrofitted with 50% glass-based mix and 50% standard soil mix. The effluent data from the system outflow was compared to water quality standards and design flow targets in order to evaluate whether the glass-based mix influenced the system's performance. Parameters evaluated in this way included pH, temperature, dissolved oxygen, turbidity, and flow rate.

2.3 Water Quality Parameters of Interest and Targets

Water quality treatment is a key function of bioretention systems. These vegetative systems provide pollutant removal through a number of mechanisms including filtration, sedimentation, adsorption, and evapotranspiration. The experiment analyzed pH, temperature, dissolved oxygen, and turbidity to understand the impact of glass-based media on water quality treatment mechanisms.

pH

pH is used as a measure of acidity in the bioretention system's effluent. These values can indicate when chemical reactions from pollutants in the influent and/or basin media create unfavorable conditions for receiving water bodies and for in-basin plant growth. Per direction from the Pennsylvania Code Chapter 25, Section 93, pH should fall within 6.0 and 9.0 in effluent.

Temperature

Effluent temperature from stormwater management systems can have adverse impacts on receiving water bodies if outside acceptable ranges. This is particularly an issue for shallow ponding stormwater systems where receding surface water can be heated rapidly. Depending on the temperature of the receiving water body and types of aquatic life supported, effluent can contribute to unsuitable conditions for fish and other biota (Stajkowski, 2023).

Per the Pennsylvania Code Chapter 25, Section 93, the desired temperature range for receiving water bodies depends on the type of stream and time of year. The section of Schuylkill River abutting this project has a Warm Water Fishes (WWF) designation. Table 2 details the maximum acceptable temperatures in the receiving water body. Effluent temperatures appreciably higher than these values may raise temperatures at the outfall and adversely impact fish habitat. While a single basin releasing higher temperature effluent is unlikely to have significant impact, green infrastructure installments throughout the watershed with high temperature effluent is a concern.

Table 2: Maximum Acceptable Temperature of Receiving Water Body, per Pennsylvania Code	
Period	Temperature for Warm Water Fishes (F)
January 1-31	40
February 1-29	40
March 1-31	46
April 1-15	52
April 16-30	58
May 1-15	64
May 16-31	72
June 1-15	80
June 16-30	84
July 1-31	87
August 1-15	87
August 16-30	87

September 1-15	84
September 16-30	78
October 1-15	72
October 16-31	66
November 1-15	58
November 16-30	50
December 1-31	42

Dissolved Oxygen

Dissolved oxygen (DO) is a measure of oxygen content in aquatic systems. DO content has a strong correlation to the water quality index (Sanchez et al. 2006, Kannel et al. 2007) and is required to support aquatic life. While DO varies seasonally due to temperature, water bodies need to maintain sufficient concentrations year-round to avoid fish kills and other impacts to biota. A number of chemical and biological factors can reduce dissolved oxygen including presence of organic matter. While Pennsylvania State Code provides a minimum DO concentration of 5 mg/L for water bodies, no standard for urban stormwater runoff DO concentrations is provided. Several studies have analyzed DO in relation to stormwater management and have found low DO and high organic matter (McCabe et al. 2021, Kannel et al. 2007) which contribute to low DO in receiving water bodies. Dissolved oxygen is reviewed as a parameter of interest in this study against the 5 mg/L minimum for water bodies with the understanding that DO is expected to be lower in the stormwater effluent.

Turbidity

Turbidity refers to solids or organic matter that do not settle out of the water column. Turbidity can be used as a proxy for the measurement of total suspended solids (TSS) in stormwater runoff. According to Rugner et al., turbidity and TSS have a linear relationship with a typical relationship of 1 NTU = 1-2 mg/L (2013). TSS in stormwater runoff reduce water clarity and light entering aquatic systems. Solids may also transport adsorbed chemical pollutants such as nutrients and metals. (Minnesota Stormwater Manual).

When functioning properly, bioretention systems should reduce the concentration of TSS from runoff entering the system to effluent leaving the system through sedimentation and filtration processes (The Water Research Foundation, 2020). While standard percentage reductions are often selected to describe bioretention TSS removal (i.e. Bioretention systems reduce influent to effluent concentrations by X%) (Balascio and Lucas, 2007), the effluent concentrations are highly dependent upon loading conditions specific to the drainage area. Due to site constraints for this experiment, only effluent from the bioretention system was able to be analyzed as influent measurements were uncollectable. In lieu of direct comparison of influent versus effluent, data collected from installed bioretention systems was compared to data analyzed by the International BMP Database to understand how the study site performed in relation to other bioretention systems.

Per Table 2.2 from the International BMP Database 2020 Summary Statistics Report, the interquartile range of bioretention system TSS concentrations in effluent was 4.00-20.0 mg/L (i.e. 25% of stormwater basins had effluent of 4.00 mg/L or less and 75% of bioretention systems had effluent of 20.0 mg/L or less). The 75th percentile value of 20.0 mg/L was used as a standard for comparison in order to determine if the system was performing at least as well as 75% of bioretention systems. This value eliminated the influence of uppermost quartile outliers. (The Water Research Foundation, 2020).

2.4 Volume Reduction Parameters of Interest and Targets

In addition to water quality treatment, bioretention systems are designed to mitigate erosion and flooding conditions exacerbated by urbanization. Bioretention systems typically manage volume and rate control through infiltration, evapotranspiration, and controlled release. The study basin in this experiment had an impermeable liner and underdrain due to elevated groundwater at the project site. Therefore, infiltration into in-situ subsoils did not directly play a role in runoff volume removal. However, the infiltration rates of the glass-based and standard soil media were measured to understand how an infiltrating system may be impacted by a change in media.

Additionally, this experiment measures flow rate, plant transpiration, soil compaction, and soil moisture to understand how glass-based media may impact the water quantity functions of a bioretention system.

Flow Rate

One of the most common design targets for stormwater management features is rate control. A bioretention system's outlet control structure can delay the release of runoff entering storm sewers and reduce peak runoff rates during a storm event. While arguments over the effectiveness of rate control have been made (Emerson et al. 2005, Petrucci et al. 2018, Jefferson et al. 2017, Bledsoe 2002), meeting a reduced outflow target is used as a measure of successful design in Philadelphia and in the rest of Pennsylvania. When initially permitted and built, the underdrained system in this study used rate control as a measure of successful flood control and water quality treatment. The slow release rate target for the water quality storm was determined as a ratio of impervious surface in the drainage area to flow out from the system. This slow release target was set to encourage pollutant removal from effluent through sedimentation processes (PWD, 2023).

The goal of this study was to demonstrate that the use of glass-based soil media would not impact the system's ability to meet design flow rate targets.

Plant Transpiration

A major benefit of green infrastructure over traditional grey infrastructure systems is the introduction of evapotranspiration as a means of runoff volume reduction. Evapotranspiration accounts for both transpiration from plants and evaporation from soils and plant surfaces (Ebrahimian et al. 2019b). This process both eliminates runoff volume and restores storage space within soil media. While there is no quantified evapotranspiration target for green infrastructure in Philadelphia, it was a goal of the study to understand how the glass-based soil media mix would impact the system's ability to utilize this process.

Due to the difficulties in measuring evapotranspiration directly (Ebrahimian et al. 2019b), plant transpiration was indirectly assessed through stomatal conductance. Stomatal conductance, or the rate at which water vapor leaves a plant through stomata (Jeanguenin et al. 2017), has been used in other studies to assess plant transpiration's role in green stormwater infrastructure water budgets (Scharenbroch et al. 2016; Krasowski and Wadzuk, 2022). Krasowski and Wadzuk found a strong correlation between evapotranspiration rate and stomatal conductance for several plant species (2022).

Soil Infiltration

Infiltration rate is a key process for green stormwater infrastructure in volume removal, pollutant removal, and longterm function of the system. In the case of the lined system in this experiment, the infiltration of the glass-based soil mix and standard soil mix was measured without the influence of subsoil infiltration rates. Hydraulic conductivity can be influenced by a number of factors but is primarily a function of temperature, saturation, depth of media, and soil characteristics (Davis et al. 2022). Because infiltration testing for both media was performed on the same day when measured, it was assumed that temperature and saturation were control variables. Depth of media did not change throughout the experiment. Therefore, differences in hydraulic conductivity should indicate influence of the different soil characteristics for each mix.

The results of the study were compared to the acceptable infiltration range per local regulations (0.5-10in/hr).

Soil Compaction

Soil compaction was a parameter of interest due to its impacts on infiltration and plant health within green stormwater infrastructure systems. Soil compaction can inhibit vegetation establishment and has negative correlation with infiltration rate (Das et al. 2023). Soil compaction was analyzed in terms of penetrative resistance, one of the two common methods of determining soil compaction alongside bulk density measurements. While 2 MPa (290.1 psi) is typically used for a maximum acceptable resistance in row crops, Day and Bassuk speculated that 2.3 MPa (333.6 psi) is a more appropriate threshold for woody plants (1994).

This experiment measured compaction changes quarterly over the study period and compared results of compaction in the standard soil media to the glass-based mix. Direct comparison between results was used to assess whether the glass-based mix adversely impacted compaction within the system.

Soil Moisture

Soil moisture is an important indicator of green stormwater infrastructure behavior and is related to the dynamic processes of infiltration and evapotranspiration. Ideally, soil moisture will remain above the wilting point, or minimum amount necessary to sustain plant needs, at all times (Davis et al. 2022). However, high levels of soil moisture over prolonged periods of time after a precipitation event may indicate poor drainage of soils and may create unfavorable conditions for plant life. Plant growth and health observations are indicators that soil moisture falls within a desirable range for plants.

Soil moisture is also an important indicator of void space recovery in soil media for runoff storage (Shakya et al. 2023). Regaining storage capacity is a key function of dynamic green infrastructure systems. Direct comparisons between the standard soil mix and glass-based mix were used to evaluate the impacts of using glass-based media.

2.5 Data Collection Methodology

Data was collected using various monitoring equipment and collection methodologies. Equipment manuals can be found in Appendix A.

Flow Meter

A flow meter was installed to measure the flow rate in the outlet control structure. The flow meter was installed within a PVC sleeve case in the interior of the 12" discharge pipe from the outlet control structure. The PVC was secured within the pipe with a bolt. Another four bolts and 2 brackets were used to secure the sleeve case to the outlet control structure. The flow meter was connected to a data logger via USB which was used to calibrate and read flow readings. The logger directly measured flow depth and used Manning's equation to convert to flow via user specified pipe characteristics. Data was collected for every 5 minutes and interpreted as minimum, maximum, and average flow per day.

Data collection began on October 26th, 2022 after the meter had been installed. The logger was first read on November 10th, 2022 to ensure data collection was working. No issues were observed. The meter was checked again on December 1st, 2022 without issue. On December 30th, data collected indicated negative flow for several days towards the end of the month. When the issue persisted at the next monitoring event on February 1st, the manufacturer was contacted. The flow readings remained positive for flow events but were negative during dry conditions. The manufacturer recommended changing the batteries which did not rectify the issue, as shown in data collected on February 28th. At this point, the manufacturer recommended recalibrating and reinstalling the flow meter. On March 9th, the recalibrated meter data was reviewed and negative flows were still recorded for dry-weather. The flow meter was sent back to the manufacturer who tested and recalibrated the meter before sending it back on March 31st. On April 4th, data collected still showed negative values but these had been reduced to as low as -0.01, within the sensor's margin of error.

When negative values continued to grow in subsequent sampling events, the sensor was recalibrated on May 11th during dry weather on site. The manufacturer postulated that the differences in values were due to differing pressure conditions at their site in Texas during calibration compared to the project site in Philadelphia, PA. The manufacturer recommended frequent recalibration as the flow meter appeared to function better after calibration events. They also noted that the dry weather conditions were unlikely to cause issues with the flow readings after storm events. Data was also lost for the first half of September due to operator error. Gaps in data and negative values are excluded from the flow analysis for these reasons.

Water Quality Sensor

An AquaTroll 500 water quality sensor was installed on December 30, 2022. The sensor was installed within a perforated PVC pipe bolted to the interior of the outlet control structure. The sensor was connected to a Telemetry device which provided power and allowed for a Bluetooth connection via the VuSitu App.

Soil Moisture Sensors

A soil moisture sensor was initially only installed in the glass-based soil media on October 26, 2022. The S-SMC-M005 sensor, as manufactured by HOBO, was buried 6 inches below the soil surface. A cable connected the sensor to the data logger installed within the outlet control structure. The monitoring team decided that it would be beneficial to install an additional sensor in the standard soil mix for data comparison. This sensor was installed on March 29, 2023. No issues were observed in data collection from the soil moisture sensors throughout the study period.

Infiltration Testing

Infiltration information was collected via double ring infiltrometer tests, in accordance with Philadelphia Water Department (PWD) procedures. The tests were located in a glass zone (G2) and standard soil zone (S2).

The double ring was placed on a level surface within the basin. The outer ring was driven into the soil to a minimum depth of six inches. The inner ring was driven 2-4 inches into the soil. Both rings were filled with water as a presoak. If the water level dropped two inches or more in the 30-minute presoak, a 10-minute interval was used for the subsequent test. Otherwise, a 30-minute interval was used. A minimum of 8 readings were taken during the test unless the drop stabilized. Drop stabilization was defined as less than 0.25 inches of drop for four consecutive readings.

Infiltration testing is typically used to determine if the subsoils below a green infrastructure system can infiltrate collected runoff. Due to high groundwater at the study site, underdrains and an impermeable liner were installed in the basin. Infiltration testing was therefore only used to determine whether the bioretention media was adequately porous to allow runoff to reach the underdrains. Two double ring infiltrometer tests were performed at the end of the 12-month study to assess conditions after plant materials matured. Results of the tests were intended to demonstrate the hydrologic performance of the soils one year after installation.

Soil Compaction Testing

Soil compaction testing was performed using a penetrometer (Soil Compaction Tester manufactured by DICKEY-john). Penetrometers measure resistance within the soil column over a variety of depths. Quarterly compaction testing was conducted. The first compaction test was performed in December 2022. The manufacturer lock left on the product prevented data collection at this time. The second compaction test in December 2022 was inhibited by the frozen soils. Only one reading was obtained in zone G2. The remaining two compaction testing events produced readings in all four zones. Compaction test readings were obtained for 3-inch depth intervals to a maximum depth of 18 inches.

Stomatal Conductance

A leaf porometer (SC-1 Leaf manufactured by METER) was used to measure stomatal conductance. Measurements were taken by closing the sensor head on a leaf of the selected plant until the sensor completed reading. The sensor was shaken between each reading to dry the air in the desiccant chamber. Two readings per species in each of the four zones were collected at each monitoring event. Results for each species within each zone were averaged. Readings for the reed grass and fox sedge were difficult to collect during the winter when the thin leaves of these species were dry or absent. No readings were collected for the ironweed as this species did not sprout until May 2023.

High measurements collected in the January 2023 monitoring event were attributed to residual moisture on leaves from precipitation the night before data collection. Readings for the February 2023 monitoring event were also high and took longer to stabilize. These readings were attributed to high humidity and low temperatures. It should be noted that the leaf porometer is designed to operate between 41- and 104-degrees F and is therefore less reliable in extreme cold and heat. The temperatures at the time of measurement in January and February were in the low 30s.

3. RESULTS AND EVALUATION

3.1 Summary of Results

Overall, the results from this study indicate that the glass-based media did not adversely impact the water quality or water quantity performance of the bioretention system during the monitoring period. Tables 2 and 3 provide conclusions on the parameters of interest, which are discussed in more detail in Section 3.2.

Table 3: Direct Comparison Parameters

Parameter	Comparative Findings
Plant Transpiration	On average, plants in the glass-based media had 4% higher stomatal conductance than plants in the standard soil mix
Soil Infiltration	Glass-Based Media has higher infiltration rates than the Standard Soil Media
Soil Compaction	On average, glass-based media had 9.2 psi lower soil compaction
Soil Moisture	Glass-Based Media had less variation in soil moisture; Standard Mix shows steeper decline in soil moisture over time

Table 4: Parameters with Performance Targets

Parameter	Performance Target
pH	Effluent within acceptable range (6.50 – 8.50) Average observed pH = 7.25
Temperature	Effluent was below maximum seasonal limits for the receiving stream for the majority of the study period.
Dissolved Oxygen	Data inconclusive

Turbidity	Average TSS concentration during precipitation events was 19.24 mg/L, just below the maximum effluent of 20 mg/L observed in 75% of bioretention systems (International BMP Database)
Flow Rate	The system's ability to provide rate control is not adversely impacted by the glass-based mixture. On average, measured flow leaving the system is 91% of the flow for a model counterpart.

3.2 Evaluation of Findings

pH

The pH results indicate that the bioretention basin maintained acceptable ranges of pH in effluent at all points in the study. The acceptable upper and lower bounds are shown on Figure 3. The average pH throughout the study period was 7.25 with a standard deviation of 0.11. These results demonstrate that the glass-based mixture did not adversely impact pH of the effluent over time. It also likely indicates that the soil pH was relatively consistent and suitable for most common bioretention species (PWD, 2023). Future direct measurements of pH within the soil media are recommended to confirm.

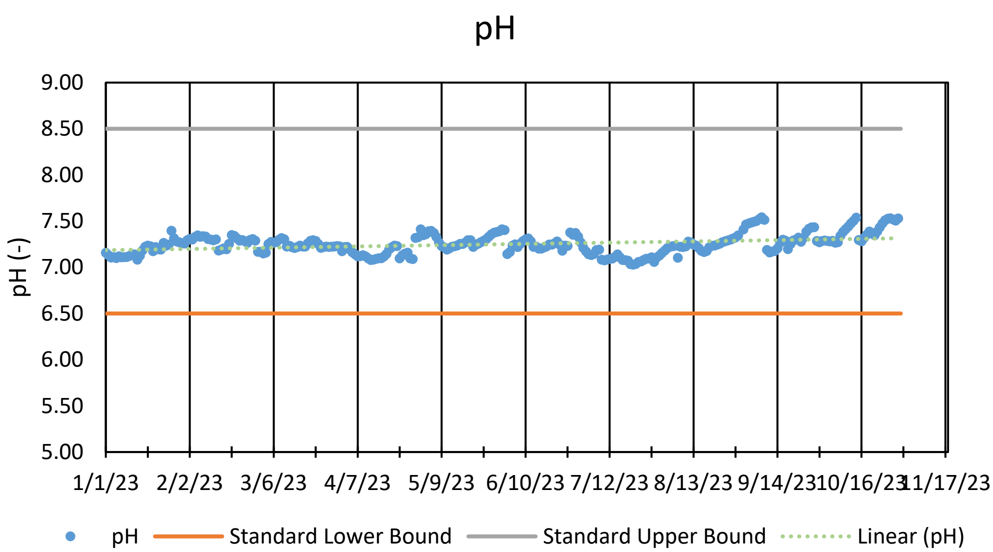

Figure 4: pH measurments

Applying a linear fit yielded a positive slope of 0.117. Extrapolating out from the linear trendline, the soil would not exceed the maximum effluent threshold of 8.50 for approximately 7.5 years. Based upon these results, the glass-based soil media would not need pH amendments for the first 7.5 years unless plant life requires otherwise. The basic pH trend agrees with the laboratory-based experiment performed by Temple University in 2021. In that study, pH trended upwards during a 13-week period.

The sudden drops in pH observed over the last several months of the study are important to note. The pH appears to steadily climb for short periods until abruptly dropping over a 24-hour period. The drops correspond to precipitation events. It is likely that precipitation entering the system, and therefore the runoff being measured, was slightly acidic. The less consistent pH over the September and October measurements may also indicate that the water in the outlet control structure sump was losing alkalinity, or the ability to resist changes in pH, over time.

Consideration should be given to the entire composition of soil media contributing to the water quality readings. The half of the basin containing a standard soil mixture may have buffered pH impacts from the glass-based mixture or vice versa. However, given the relatively stable pH condition well within acceptable range, a basin composed of entirely glass-based mixture is still likely to fall within an acceptable range. It is recommended that a future study compare pH and alkalinity within the effluent of an entirely glass-based mixture versus an entirely standard soil mixture in separate basins.

Temperature

The temperature data for effluent, as measured by the water quality sensor, is shown in Figure 4. The maximum allowable temperature for the warm water fish designation is shown in grey. Sensor readings indicate the basin did not discharge effluent with temperatures above the maximum desirable for warm water fish into the receiving water body, except in January and February.

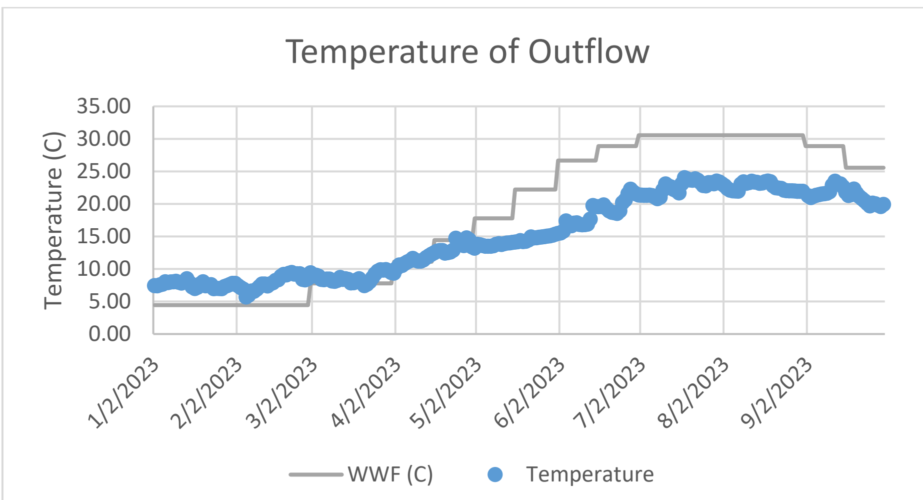

Figure 5: Temperature measurements

The lower temperatures for the majority of the study period are likely explained by the relatively quick infiltration and short drainage times observed in the basin. The longer it takes for the surface runoff to recede into the soil layer, the longer period of time the surface is exposed to sunlight. Longer ponding times can be a concern for this reason. It is unlikely that the runoff in this particular basin would be significantly impacted by thermal exposure because of the short ponding surface time.

The higher temperatures observed in the winter months may be attributed to the higher air temperatures experienced locally in the winter of 2023. Per temperature data measured at the Philadelphia International Airport, January and February 2023 had 21% higher maximum air temperatures than the average maximum air temperatures of the last 10 years.

One variable influencing the data could be the location of the water quality probe within the outlet control structure. The shaded sump area in which the sensor was submerged may have had cooled water temperatures. However, given the margin between maximum allowable temperature and measured temperature for the majority of the year, it is unlikely that this variable would account for an appreciable difference.

Dissolved Oxygen

The plot of dissolved oxygen over the study period is shown in Figure 5.

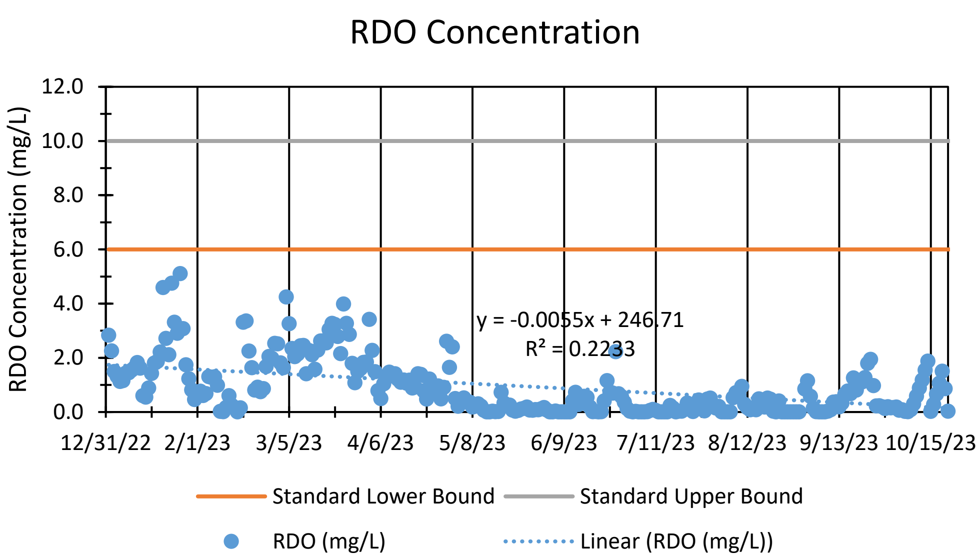

Figure 6: RDO Concentration Measurements

The plot indicates that the DO levels were below minimum acceptable water quality levels at all points during the study period. DO decreased to near 0 approximately 5 months into the study period. This trend was likely due to the location of the water quality sensor. As discussed in Section 2.5 of this report, the water quality sensor was positioned so that it was in constant contact with the outlet control's sump. The sump contained stagnant water and minimal light. These conditions can lead to low dissolved oxygen, particularly as effluents add nutrients to the stagnant water (Radwan et al. 2003). Given the low flow conditions and outlet control configurations, an alternative location for the water quality sensor was not feasible for this study. The slight increase in

DO towards the end of the study, as air temperatures cooled, suggests that the DO was behaving in accordance with seasonal trends.

The conditions of DO measurement do not yield useful results for analyzing the impacts of the glass-based soil mixture due to the sensor location. Should future study opportunities be available, it is recommended that alternate methods of measuring DO are employed. One option would be performing a laboratory analysis to analyze the relationship between dissolved oxygen and soil mixtures. A study conducted at a stormwater management practice with more suitable configuration for studying effluent DO concentration, and not effluent flow concentration mixed with stagnant runoff, would also be beneficial. Locating the water quality sensor in a monitoring well within the soils may also yield more accurate results.

Turbidity

TSS was analyzed through the turbidity measurements recorded by the water quality probe. A conversion factor of 1 NTU = 1.5 mg/L was used based upon a typical conversion range of 1 NTU = 1-2 mg/L (Rugner et al., 2013). Variation from this assumed conversion factor was considered in the uncertainty analysis. Results indicate that TSS increases generally correlated to storm events (Figure 7).

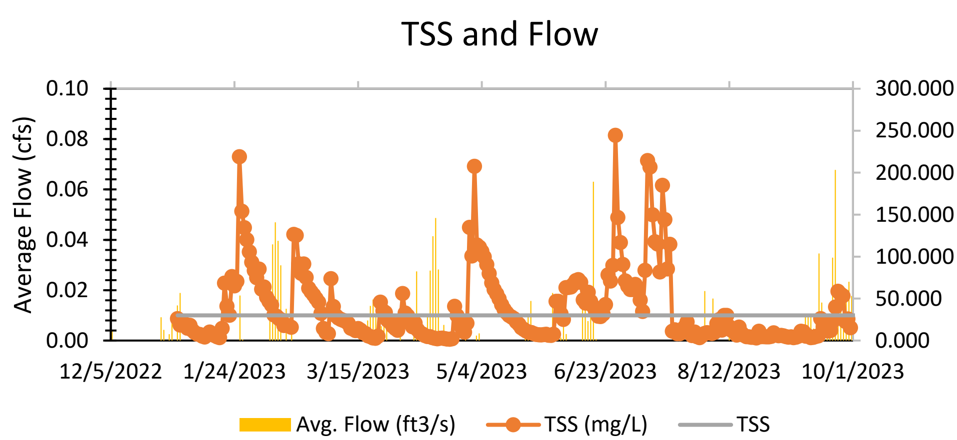

Figure 7: TSS Measurements Versus Peak Flow

The daily TSS measurements were averaged with a resultant concentration of 34.36 mg/L. This concentration is relatively high compared to observations collected in the International BMP Database. Therefore, the data was sorted to separate TSS measurements during precipitation events from TSS measurements during dry periods. During precipitation events, the average TSS concentration was 47.39 mg/L. The average TSS concentration during dry periods was 28.14 mg/L.

The 28.14 mg/L dry-period average is significant considering no new effluent was entering the outlet control structure. The sensor location within the outlet control structure sump likely inflated the TSS measurements of effluent during precipitation events. As effluent was added to the sump, settled particulates were resuspended. These particulates combined with effluent TSS loads may have exaggerated concentrations. Therefore, the 28.14 mg/L concentration during dry periods was considered a “baseline” unrelated to incoming effluent.

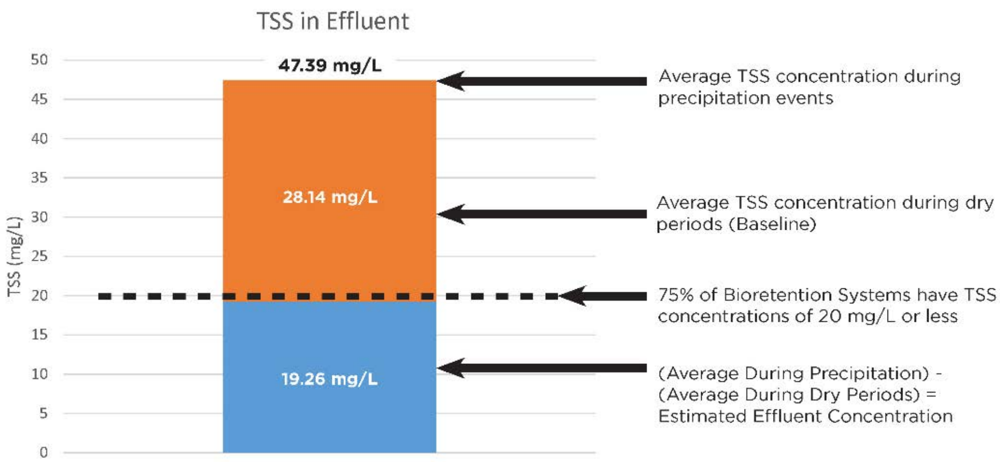

Figure 8: TSS effluent concentration determination

To understand the contributions of TSS from new effluent, the baseline TSS concentration was subtracted from the average TSS concentration during precipitation events. This resulted in an average effluent concentration of 19.26 mg/L. This concentration is below the 20 mg/L observed in 75% of bioretention systems (International BMP Database).

Uncertainty associated with the turbidity to TSS conversion factor should be considered in these results. It is likely that the measured effluent concentrations fell within a range of 12.84 to 25.67 mg/L when accounting for this conversion (See Table 5).

Table 5: Uncertainty Associated with Turbidity – TSS Conversion Factor

	1 NTU = 1 mg/L	1 NTU = 1.5 mg/L	1 NTU = 2 mg/L
Average TSS during Precipitation Events (mg/L)	31.60	47.39	63.19
Average TSS during dry periods (mg/L)	18.76	28.14	37.52
Estimated effluent concentration	12.84	12.84	25.67

The slightly higher TSS may also be attributed to a number of factors including the infiltration rate and contributory drainage area loading. As discussed in Section 2.3 of this report, TSS is removed from bioretention effluent through soil media sedimentation and filtration. The longer the recession rate, or rate at which ponded water enters the soil layer, the more opportunity for sediment to be removed from the effluent. The lining and underdrain in the study site's bioretention system reduced drain down times. It is recommended that further study on a site with infiltrating bioretention systems (no liner or underdrain) be conducted to further assess glass-based media infiltration impacts.

Higher TSS may also be attributed to contributory drainage area characteristics. Surrounding open space and highway use have associated median TSS concentrations of 77.9 and 58 mg/L, respectively (The Water Research Foundation, 2020). Erosion from open space in particular may lead to higher influent concentrations and corresponding higher effluent concentrations.

The total composition of soil media contributing to the TSS removal should also be considered when interpreting these results. The effluent concentrations are measured at the outlet control structure and are influenced by both the glass-based mixture and standard soil mixture. The results demonstrate that, even with the use of 50% non-standard soil mix, the system was providing comparable TSS removal to industry standards. However, it is unclear if the standard soil mixture or glass-based mixture had greater TSS removal capabilities. Future studies should include water quality monitoring in two separate bioretention systems, one with 100% glass-based mixture and one with 100% standard soil mixture for direct comparison.

Despite these factors, the system's TSS concentrations in effluent were within the 75^{th} percentile of expected bioretention basin effluent (The Water Research Foundation, 2020).

Flow Rate

Flow rate was analyzed through a comparison to an EPA SWMM model of the system. Design targets for the bioretention system were based on 24-hour design storm events. However, the flow meter for the study was measuring continuous flow of real-time precipitation. As design storm events are not representative of intensity or duration of real events, it was not possible to measure the success of the system through a direct comparison to 24-hour design storm targets. To understand how the glass-based soil media might impact the hydraulic/hydrologic behavior of the system, an EPA SWMM model was used with continuous simulation rainfall data for the duration of the study period rather than 24-hour design storms. The theoretical performance of the system, assuming ideal flow control and hydraulic behavior, provided a baseline to compare the observed outflow.

The EPA SWMM model simulated the system using a storage unit with the elevation, stage-storage, and outlet control information from the bioretention system's construction documents. Contributory drainage areas were simulated using the curve numbers and drainage areas for impervious and pervious area in these documents. The model used dynamic wave routing and Modified Green-Ampt infiltration methodology. Hourly precipitation data was obtained from ASOS for the Philadelphia International Airport Station (PHL).

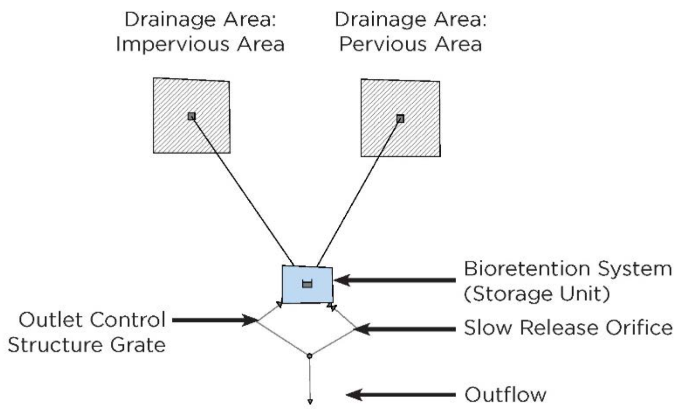

Figure 9: EPA SWMM Model Schematic

The model results were analyzed to assess flow rate reduction during a continuous simulation. Results indicate that the system provided rate control, reducing the peak rate of inflow. Figure 10 demonstrates the model system's performance during the largest storm event on August 9th, 2023. Therefore, if the observed system performance was similar or better than the model system performance, the observed system was also providing rate control.

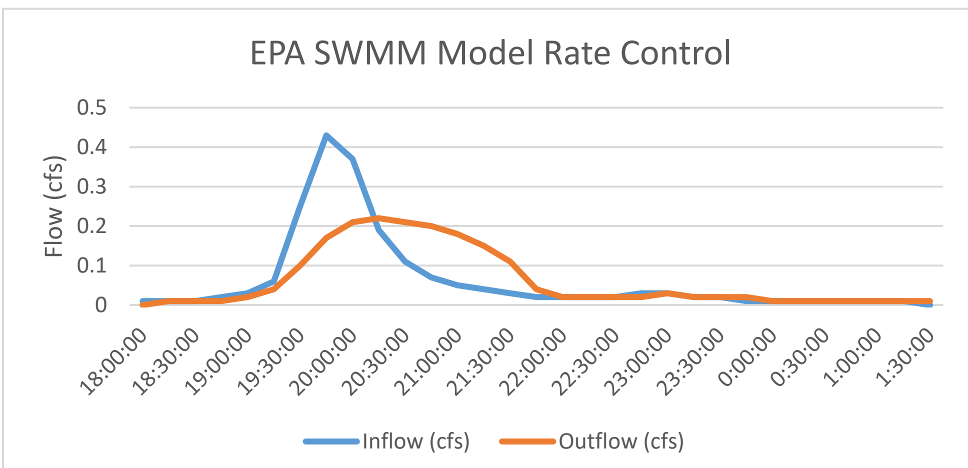

Figure 10: EPA SWMM Inflow and outflow results for the largest recorded precipitation event during the study period.

Periods where the model and/or flow meter observed zero outflow were removed from the analysis. Some variation between the model and observed system was expected due to variation in actual rainfall between the Philadelphia International Airport station used in the model and rainfall at the site. A comparative time series plot is shown in Figure 11. This plot illustrates a relatively strong correlation between modeled and observed behavior.

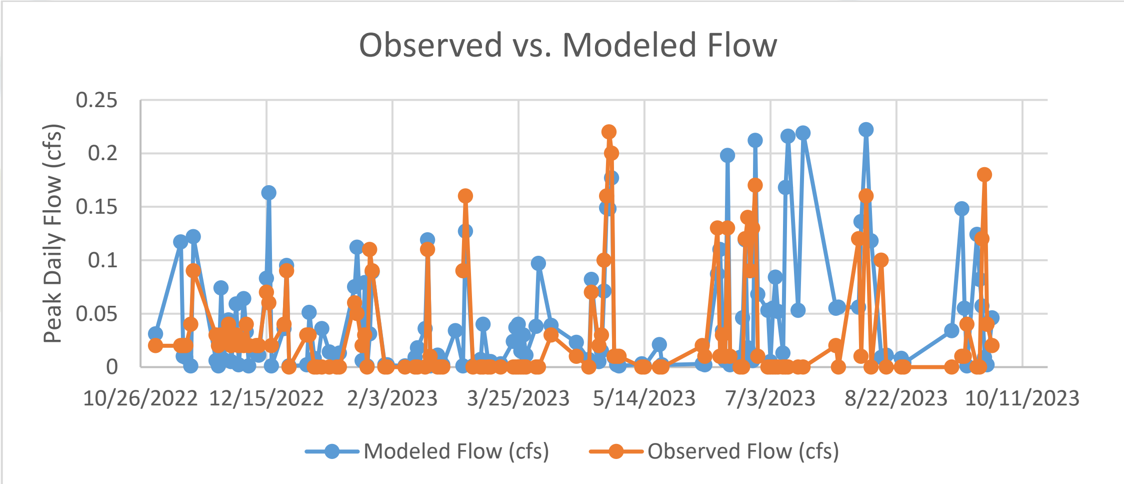

Figure 11: Measured peak flow rate versus the modeled peak flow rate.

To further understand how close observed flow is to modeled flow, the ratio of observed to modeled flow was plotted with respect to precipitation depth in Figure 12. Ratios of less than 100% indicate that the observed flow had less outflow than the modeled flow and overperformed against its theoretical counterpart. A ratio of over 100% indicates that the observed flow was greater than modeled flow and underperformed compared to the theoretical model.

Initial plots revealed several significant outliers, particularly at low flow rates. As the flow meter was not intended to measure low flow events, flows with associated precipitation events of less than 0.1 inches were removed. The resulting plot indicates that the system was overperforming for the majority of events. Approximately 64% of events have observed flow below modeled flow. The average ratio of observed to modeled flow is 91%.

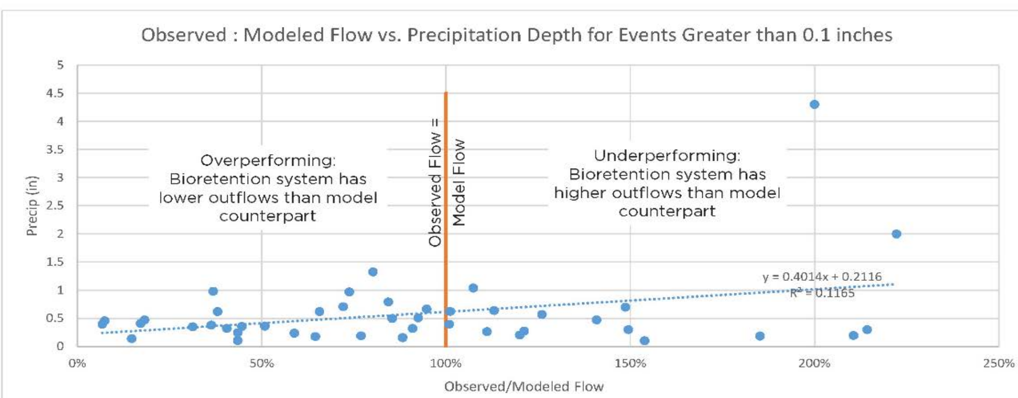

Figure 12: Precipitation depth versus observed to modeled flow ratio.

The analysis in this section serves as a proxy for a direct comparison between a basin with entirely glass-mix and a basin with entirely standard soil mix due to experiment constraints. Comparing the basin performance with 50% glass-mix to a theoretical model indicated that flow is behaved better than would be anticipated in an ideal scenario under similar precipitation conditions. Therefore, it is unlikely that the glass-based mix inhibited the rate control performance of the system.

Sources for error in the flow comparison include local differences in precipitation depth, flow meter sensitivity, differences in accounting for the vegetative components, and differences in drainage area behavior. The benefits of vegetation were unlikely to impact the outflow comparison in a meaningful way. While evapotranspiration was not accounted for in the EPA SWMM model, which would play a role in reducing outflow from the system, evapotranspiration would have little to no impact on the rainy days that were analyzed in the comparison. Infiltration was not a differentiating factor in this model as the system was lined and underdrained, which was simulated through zero seepage and a slow release orifice in the model counterpart. Drainage area differences may also have caused variations in basin outflow. The EPA SWMM model provides a typical slope, travel time, and runoff abstraction curve based on landcover (CN value). This representation of the drainage area does not fully account for localized variations in topography, benefits from trees, and other nuances of the actual drainage area. The simplification may have led to slight differences in the inflow between the model system and the actual bioretention system.

Plant Transpiration

Stomatal conductance was compared between the glass and standard mix amongst six plant species in order to understand evapotranspiration rate differences in the two types of media. Figures 13-18 show trends for both mixes for the duration of the study period. The two (2) locations in the glass mix and two (2) locations in the standard mix were averaged. Variation in stomatal conductance was observed but did not consistently indicate the standard or glass mix as having higher stomatal conductance.

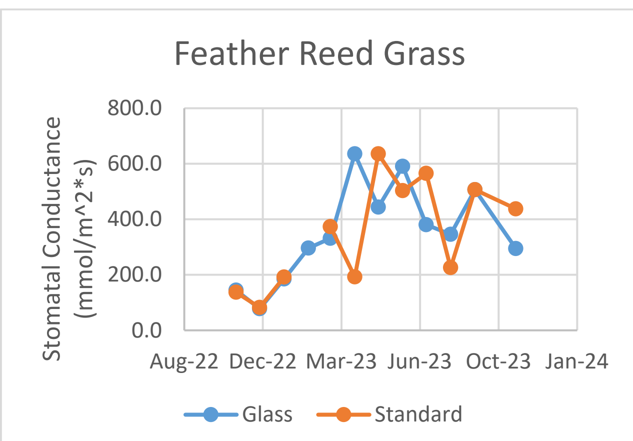

Figure 13: Stomatal conductance of Feather Reed Grass.

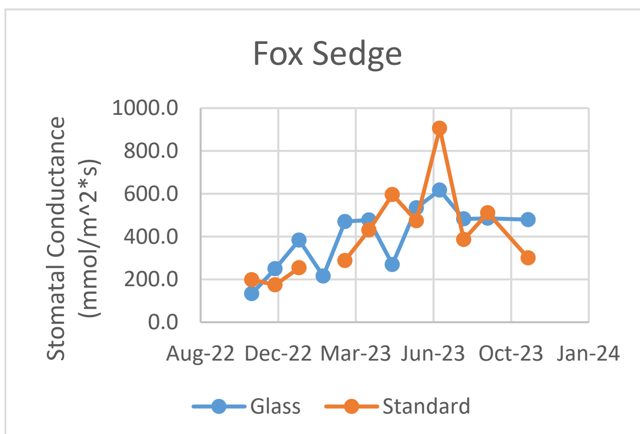

Figure 14: Stomatal conductance of Fox Sedge.

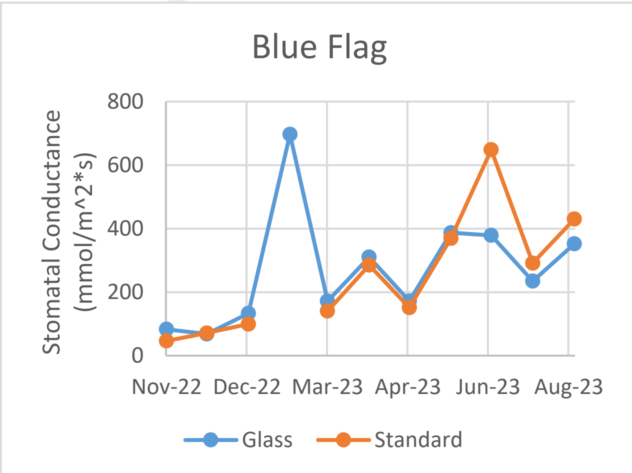

Figure 15: Stomatal conductance of Blue Flag.

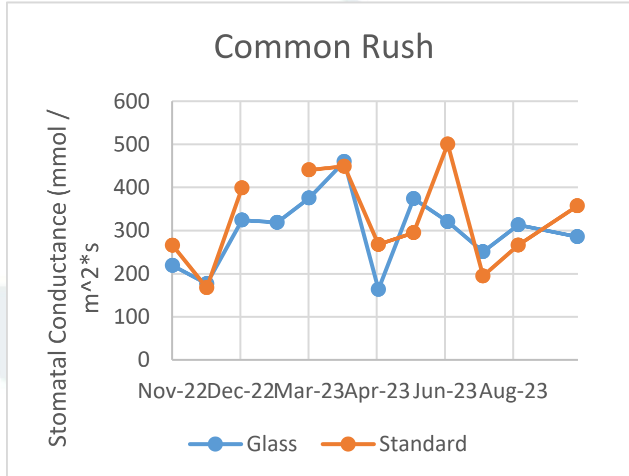

Figure 16: Stomatal conductance of Common Rush.

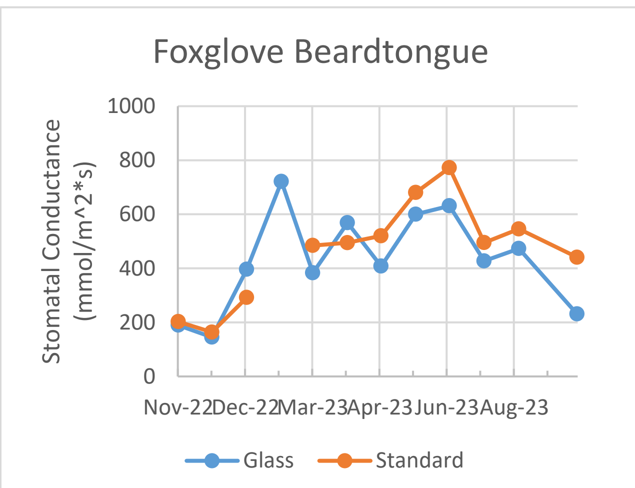

Figure 17: Stomatal conductance of Foxglove Beardtongue.

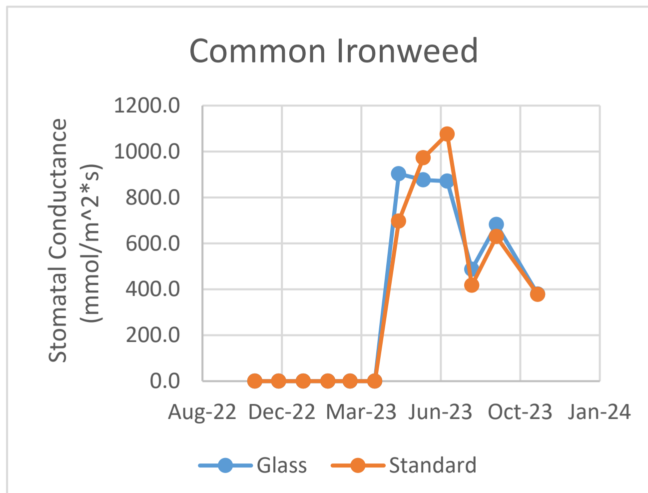

Figure 18: Stomatal conductance of Common Ironweed.

To further understand the difference between the two media, the ratio of glass-mix to standard mix stomatal conductance was calculated for each month. The monthly ratios were than averaged to understand overall variation throughout the study period. The study period ratios are shown in Table 6.

Table 6: Stomatal conductance comparison between standard soil mix and glass-based mix	
Species	Average Ratio of Glass / Standard Stomatal Conductance
Calamarostis x acutiflora "Karl Foerster"	117%
Carex vulpinoidea	113%
Iris versicolor	105%
Juncus effusus	94%
Penstemon digitalis	90%
Veronia noveboracensis	104%

All species are within 20% of one another, with four of the six species having higher stomatal conductance in the glass-based mix. The margin of difference between the readings confirms that the glass-based mix does not adversely impact the ability of bioretention vegetation to provide hydrologic function.

Sources of error in these readings can be attributed to a number of factors including wetness, sun conditions, and temperature. To understand impacts of the first two, a study of wetness and sun at measurement locations was recorded for the month of September 2023. Table 5 highlights impacts between measurements taken in sun and shade, and in wet and dry conditions. Measurements of the same species within the same soil media that were taken in the sun were consistently higher than those take in the shade.

Table 7: Variation in stomatal conductance based on variable conditions			
Species	Zone	Wet / Dry Stomatal Conductance Ratio	Shady/Sunny Stomatal Conductance Ratio
Calamarostis x acutiflora "Karl Foerster"	G1	69%	-
Iris Versicolor	G2	87%	-
Calamarostis x acutiflora "Karl Foerster"	S1	96%	-
Pensteman digitalis	G2	-	85%
Juncus effusus	S2	-	84%
Vernonia noveboracensis	S2	-	47%

Similarly, dryer conditions resulted in higher stomatal conductance than wet conditions. This variation is consistent with understanding of plant behavior. Waterlogged plants respond by closing stomata which decreases conductance (Huawei et al. 2022). Higher temperatures created by sunny conditions increase stomata opening (Urban et al. 2017). These variations throughout the study were not controlled. However, no trends were apparent based on measurement location (Figure 19). It is therefore unlikely that localized shady or wet conditions consistently skewed results.

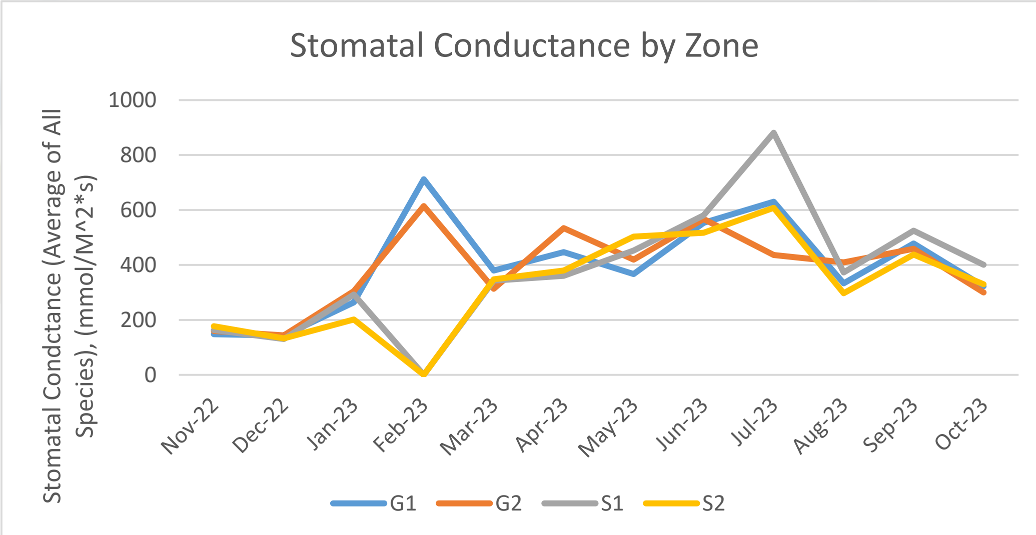

Figure 19: Average stomatal conductance for each soil zone

The relationship between temperature and stomatal conductance could also account for monthly variation. Both soil media showed slight positive correlation between stomatal conductance and temperature, as shown in Figure 20. The standard mix shows slightly higher correlation with an R^2 value of 0.58. The greater influence of temperature on the standard soil mix compared to the glass-based mix may be attributed to the poor heat conductance of glass. The glass media is less likely to transfer heat and influence temperature-based soil parameters such as stomatal conductance.

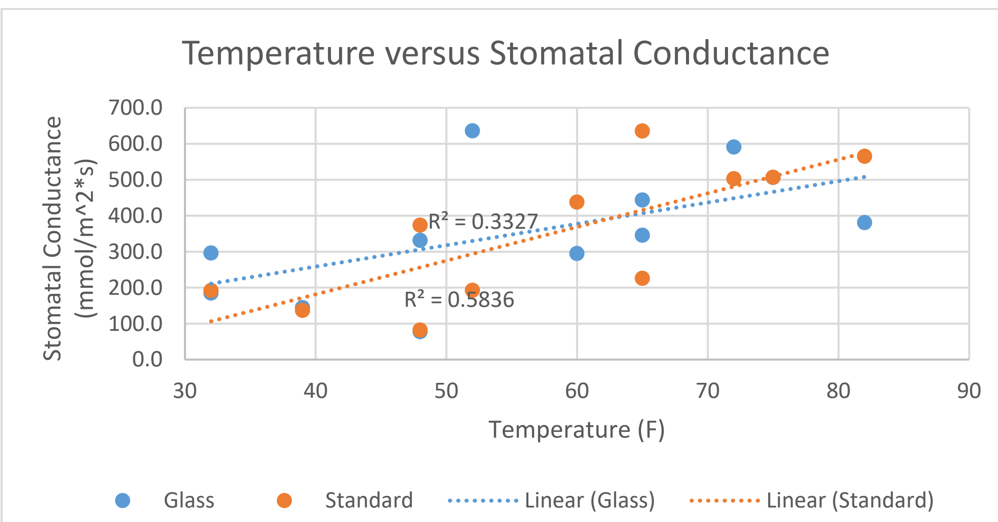

Figure 20: Correlation between temperature and stomatal conductance

Soil Infiltration

Soil infiltration rate for both media is shown in Figure 21.

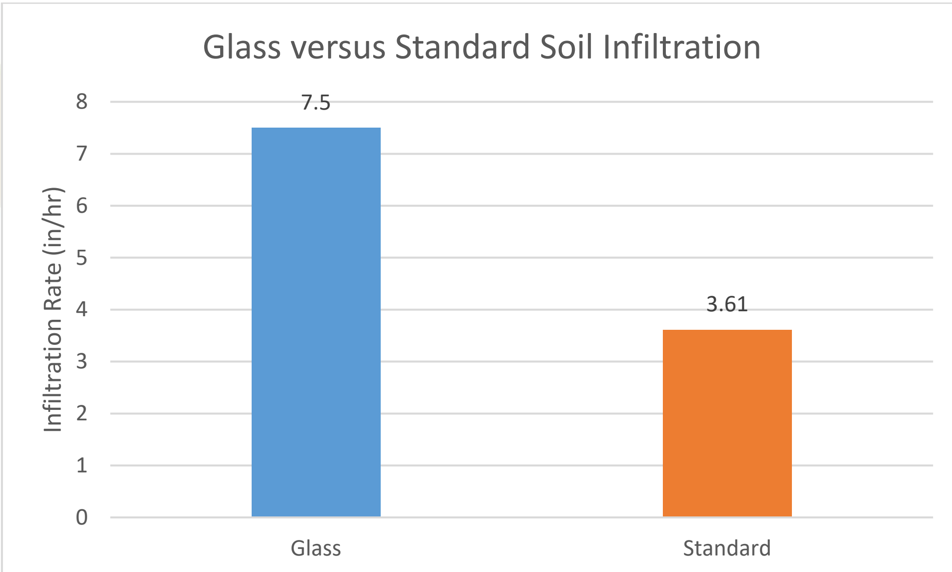

Figure 21: Infiltration rates in both soil media

For the glass-based media, the double ring infiltrometer test yielded an average infiltration rate of 7.5 in/hr. Applying the factor of safety of 2 required by Philadelphia Water Department, the design infiltration rate would be 3.75 in/hr, well within the 0.5 – 10 in/hr target range required. The standard soil media test yielded an average rate of 3.61 in/hr, less than half the rate of the glass-based mixture. With the factor of safety, the design infiltration rate was 1.81 in/hr, also within the standard range for bioretention infiltration.

It should be noted that the infiltration rate range of 0.5 – 10 in/hr specified by Philadelphia Water Department is intended to describe the subsoil infiltration. In order to adequately assess if a basin with glass-based media is meeting this standard, testing in an infiltrating system should be performed. However, results from this study indicate that the glass-based media exhibited higher infiltration rates and did not inhibit the hydrologic performance of the system.

Soil Compaction

Soil compaction testing results are shown in Figures 22 and 23 as a function of depth for the May and October 2023 testing events. As noted in Section 2.5, testing in December of 2022 could not be completed due to frozen ground conditions. In all tests, the readings were below the maximum resistance thresholds for woody plants identified in Section 2.4, indicating that neither soil media had compaction high enough to prevent vegetative growth.

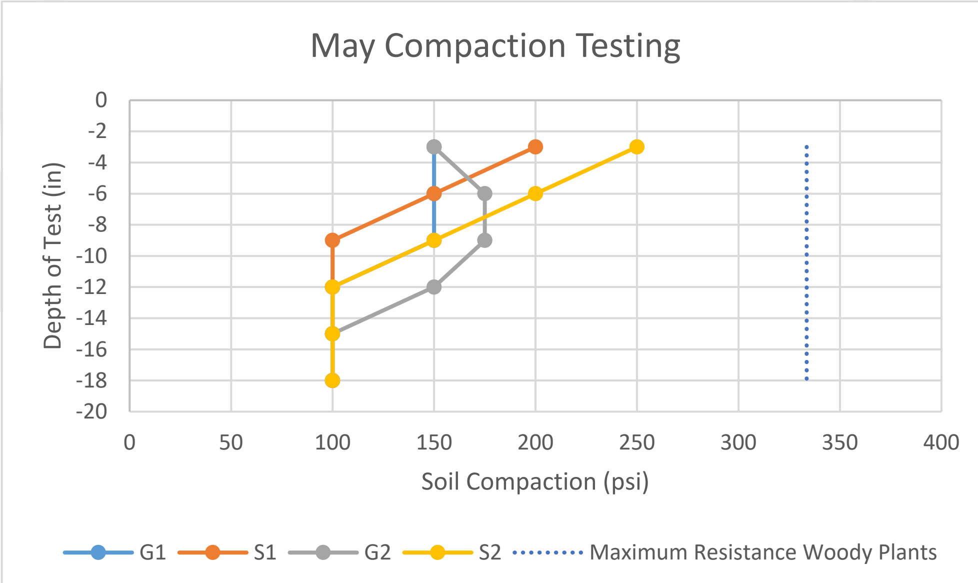

Figure 22: May 2023 soil compaction testing results as a function of depth.

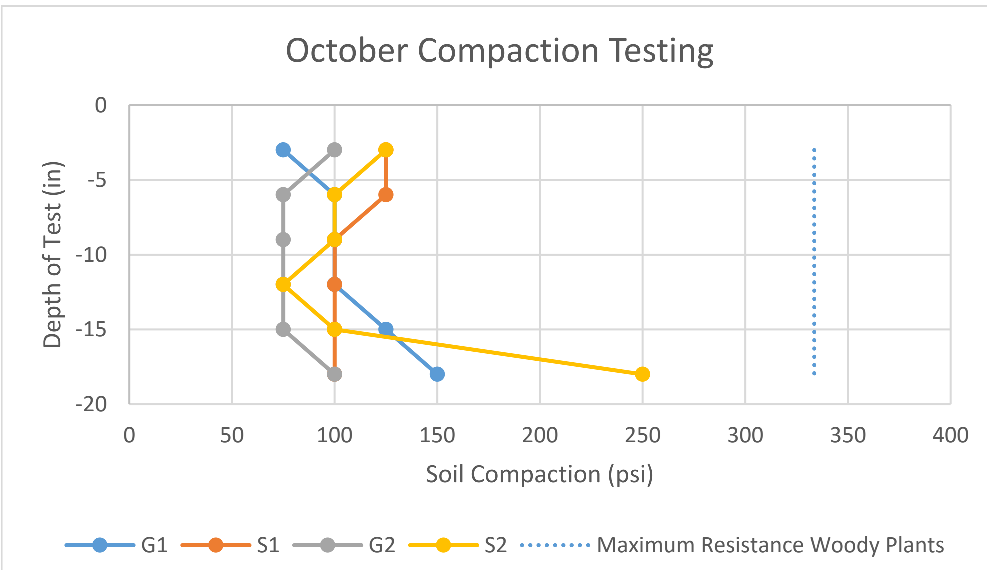

Figure 23: October 2023 soil compaction testing results as a function of depth.

Table 7 summarizes average compaction testing results between the media. The direct comparison indicates that the glass-based media has 8% lower compaction than the standard soil mix. As shown in Figures 22 and 23, the glass media was generally less compacted in the first 6 inches than the standard mix.

Table 8: Soil Compaction Testing Results					
Zone	Mix	Soil Compaction Test Results (psi)			
		December 2022	May 2023	October 2023	Average Compaction
G1	Glass-Based Mix	Frozen, no reading	125	108	111.6
G2	Glass-Based Mix	100	142	83	
S1	Standard Mix	Frozen, no reading	125	108	120.8
S2	Standard Mix	Frozen, no reading	150	100	

A possible source of error was variations in soil moisture. Soil moisture can create variable penetrometer reading conditions (Day and Bassuk, 1994). A future study might explore soil density through the other common technique of bulk density measurement to eliminate this variability.

Soil Moisture

The soil moisture of the glass-based mixture was compared to the standard soil mixture over the period in which soil sensors were installed in both media. Over the course of the entire study period, the average soil mixture of the glass-based media was 3.4% higher than the standard soil media.

Figure 24 indicates that both soil mixes are declining over time with negative trendlines observed for both mixes. While the initial soil moisture readings for the standard soil mix are an average of 0.04 higher than the glass mix, the standard mix moisture declined more rapidly over time, falling below the glass-based mix approximately 2 months after measurement began. After four (4) months, the glass-based mix had an average of 0.04 higher soil moisture than the standard mix. Had monitoring continued, the averages of the soil moistures would likely become further apart. The results indicate that the glass-based soil mix is better suited for retaining moisture over a longer period of time and would have more consistent hydrologic performance.

The magnitude of the dip in soil moisture in August to early September is notable. The standard soil mixture declined more rapidly and reached a local minimum 1 m^3/m^3 lower than the glass-based mix. The reduced soil moisture during this period corresponds to a dry period beginning in mid-August. The precipitation events in mid-September were followed by increases in soil moisture for both mixes. The response of each mixture to drought conditions is significant and indicates that the glass-based mixture may provide benefits to plant health during extended dry periods.

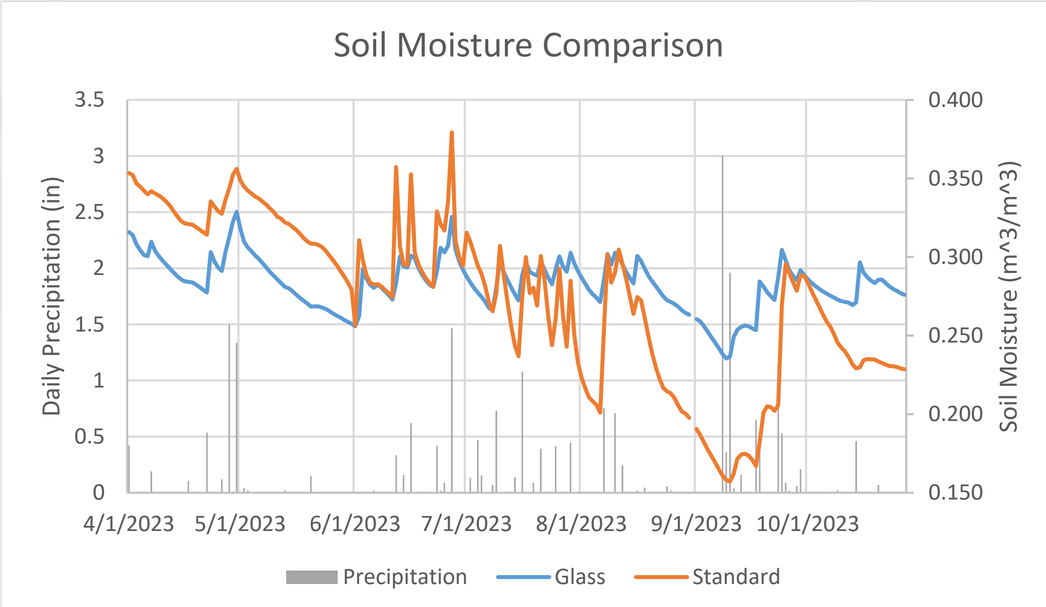

Figure 24: Moisture Content Measurements

In order to understand if negative trendlines were strictly a function of time or a function of climactic factors, soil moisture results were compared to temperature in Figure 25.

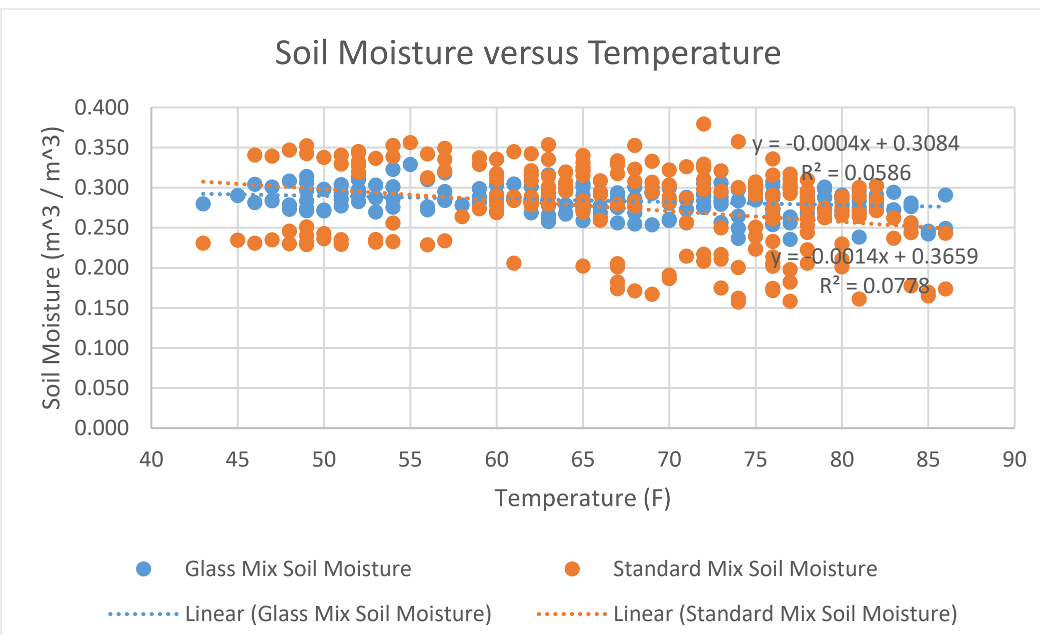

Figure 25: Soil moisture versus temperature

Temperature and soil moisture showed slight negative correlation. Increases in temperature increase evapotranspiration rates, thereby reducing moisture in the soil. While the linear fit was weak for both mixes, the standard mix has stronger negative correlation to increase in temperature with an R^2 value of 0.08. The glass-based mix has an R^2 value of 0.06, showing weak correlation. This may be explained by the poor heat conductivity of glass. As an insulator, glass has less reactivity to changes in temperature, and may therefore have less variation in evapotranspiration rates.

4. RECOMMENDATIONS FOR FUTURE STUDY

Due to available funding, the experiment was limited to a single basin retrofit. Therefore, no direct comparison between effluent from a basin with glass-based media and a basin with standard soil mix could be made. A direct comparison would be beneficial to ensure effluent concentrations and flow rates are comparable.

Additionally, measuring water quality parameters in the influent would be beneficial. Like many bioretention systems, this basin received surface runoff. A basin where a pipe discharges the majority of influent into the basin would allow for direct study of incoming pollutant concentrations and of basin flow rate. This measurement would provide a reduction rate of influent versus effluent, which can be used to more effectively assess the basin's water quality and quantity performance.

The measurement of pollutants in the effluent was complicated by the location of the water quality sensor in the outlet control structure sump. Relocating the sensor to either the basin underdrain or a monitoring well within the basin's soil profile could provide more clarity on contaminant concentrations.

It is also recommended that a similar study be performed on a basin that infiltrates directly into subsoils. This basin was lined and had underdrains due to high groundwater. Measuring infiltration rates in glass-based media installed within an infiltrating practice would give a more accurate understanding of basin drain time and hydrologic performance.

5. CONCLUSION

The results of this experiment indicate that the glass-based soil media is a comparable alternative to traditional bioretention soil. The following questions were answered through this process:

Question: Does the glass-based soil media impact water quality design targets for pH, temperature, total suspended solids, and dissolved oxygen?

Answer: The water quality parameters measured at the basin outflow indicate that the basin was functioning as designed. Both pH and temperature met the water quality standards for effluent set by Pennsylvania state code. TSS concentrations fell within the 75th percentile of bioretention systems analyzed in the International BMP Database. Dissolved oxygen measurements were inconclusive due to the water quality sensor location.

Question: Does the glass-based soil media impact the runoff release rate from the outlet control system?

Answer: The basin appeared to function as designed for rate control. While it was not possible to analyze the basin based on Philadelphia 24-hour design storm targets, an EPA SWMM model of the basin with continuous flow data was used to evaluate performance. The measured release flow rate was an average of 9% lower than the model flow rate over the course of the study period. The basin therefore overperformed by comparison. The infiltration testing for the glass-based soil mix was higher than the standard soil mix and therefore unlikely to adversely impact an infiltrating stormwater management practice. Soils were less compacted in the glass-based media and did not impede hydrologic performance.

Question: Are there additional parameters of interest based on the pilot study's results?

Answer: Additional water quality testing is recommended to understand dissolved oxygen, metals, and other contaminants of concern. It is recommended that these parameters be measured within the basin and at the outlet.

Question: Are there design modifications necessary for bioretention systems using the glass-based soil mix?

Answer: This study indicates that the glass-based mix is a comparable alternative and can serve as a substitute for the standard soil mix. The pH readings for the site indicate that the soils do not need amendments to buffer pH for a number of years after installation. The hydrologic function of plants, as measured through stomatal conductance, is not adversely affected by the substitution. Amendments to manage other constituents of concern may be necessary but are not within the scope of this experiment.

While additional studies are recommended to more fully understand the impacts of using glass-based media in bioretention systems, this experiment reveals no adverse impacts to stormwater function. The glass-based media performed as well or better than the stand soil mix based on the studied parameters.

REFERENCES

Alagoz, BI, Paltseva, A., Shaw, R. and Cheng, Z. (2021). "Variability of Infiltration Rates at Selected Green Infrastructure Sites in New York City". *Smart and Sustainable Cities Conference: Advanced Technologies for Sustainable Development of Urban Green Infrastructure, pages 88-99)*

Balascio, C. and Lucas, W. (2007). "A survey of storm-water management water quality regulations in four Mid-Atlantic States." *Journal of Environmental Management, Volume 90, 1-7.*

Bledsoe, B. P. 2002. "Stream Erosion Potential and Stormwater Management Strategies". *Journal of Water Resources Planning and Management. 128(6): 451-455.*

Davis, A., Hunt, W., and Traver R. (2022). Green Stormwater Infrastructure Fundamentals. Wiley

Day, S., and Bassuk, N. (1994). "A review of the effects of soil compaction and amelioration techniques on landscape trees". *Journal of Arboriculture, Volume 20(1).*

Ebrahimian, A., Sample-Lord, K., Wadzuk, B., and Traver R. (2019a). "Temporal and Spatial Variation of Infiltration in Urban Green Inrastructure." *Hydrological Processes, Volume 34(4), 1016-1034.*

Ebrahimian, A., Wadzuk B., and Traver, R. (2019b). "Evapotranspiration in green stormwater infrastructure systems". *Science of the Total Environment, Volume 688 (20), Pages 797-810.*

Emerson, C. H., C. Welty, and R. G. Traver. 2005. "Watershed-Scale Evaluation of a System of Storm Water Detention Basins." *Journal of Hydrologic Engineering. 10, 237-242.*

Huawei, L., Shouwei, H., Weibao, Y., Bin, Z., Lingan, K., Fahong, W. (2022). "Crop exposure to waterlogging stress: responses to physiological, biochemical, and molecular levels". *Sustainable Crop Productivity and Quality Under Climate Change, Pages 59-72.*

Jeanguenin, L., Mir, A.P., and Chaumont, F. (2017). "Uptake, Loss and Control". *Encyclopedia of Applied Plant Sciences (Second Edition), Volume 1, Pages 135-140.*

Jefferson, A. J., Bhaskar, A. S., Hopkins, K. G., Fanelli, R., Avellaneda, P. M., and McMillan, S. K. 2017. "Stormwater management network effectiveness and implications for urban watershed function: A critical review." *Hydrological Processes. 2017, 1-25.*

Kannel, P., Lee, S., Lee, Y., Kanel, S., and Khan, S. (2006). "Application of Water Quality Indices and Dissolved Oxygen as Indicators for River Water Classification and Urban Impact Assessment." *Environmental Monitoring Assessment, Volume 132, 93-110.*

Krasowski, D. and Wadzuk, B. (2022). "A Method to Assess Plant Behavior in Green Stormwater Infrastructure." *Journal of Sustainable Water in the Built Environment, Volume 8(3).*

McCabe, K., Smith, E., Lang, S., Osburn, C., and Benitez-Nelson, C. (2021). "Particulate and Dissovled Organic Matter in Stormwater Runoff Influences Oxygen Demand in Urbanized Headwater Catchments." *Environmental Science & Technology, Volume 55, 952-961.*

Petrucci, G., E. Rioust, J. Deroubaix, B. Tassin. 2018. “Do stormwater source control policies deliver the right hydrologic outcomes?” *Journal of Hydrology. 485, 188-200.*

(PWD) Philadelphia Water Department. (2023). “Stormwater Management Guidance Manual”. Retrieved from https://water.phila.gov/development/stormwater-plan-review/manual/

Radwan, M., Willems, P., El-Sadek, A., Berlamont, J. (2003). “Modelling of dissolved oxygen and biochemical oxygen demand in river water using a detailed and a simplified model.” *International J. River Basin Management, Volume 1(2), 97-103.*

Rugner, H., Schwientek, M., Beckinghma, B., Kuch, B., and Grathwohl, P. (2013). “Turbidity as a proxy for total suspended solids (TSS) and particle facilitated pollutant transport in catchments”. *Environmental Earth Science Volume 69: 373-380.*

Sanchez, E., Comenarejo, M., Vicente, J., Rubio, A., Garcia, M., Travieso, L., and Borja, R. (2006). “Use of the water quality index and dissolved oxygen deficit as simple indicators of watersheds pollution”. *Ecological Indicators, Volume 7, 315-328.*

Scharenbroch, B., Morgenroth, J., and Maule, B. (2016). “Tree Species Sutiability to Bioswales and Impact on Urban Water Budget”. *Journal of Environmental Quality, Volume 45(1), Pages 199-206.*

Shakya, M., Hess, A., Wadzuk, B., and Traver, R. (2023). “A Soil Moisture Profile Conceptual Framework to Idnetify Water Availability and Recovery in Green Stormwater Infrastructure.” *Hydrology, Volume 10(10), 197.*

Stajkowski, S., Hotson, E., Zorica, M., Farghaly, H., Bonakdari, H., McBean, E., and Gharabaghi, B. (2023). “Modeling stormwater management pond thermal impacts during storm events”. *Journal of Hydrology, Volume 620(A).*

The Water Research Foundation. (2020). “International Stormwater BMP Database 2020 Summary Statistics”.

Urban, J., Ingwers, M., McGuire, M.A. and Teskey, R. (2017). “Stomatal conductance increases with rising temperature.” *Plant Signaling & Behavior, Volume 12(8).*

APPENDIX A. EQUIPMENT LIST

SBIR EPA Grant
Stormwater Monitoring Equipment Plan

Monitoring Metric	Equipment	Installation	Monitoring Location	Data Collection	Frequency	Total Monitoring Events	Personnel
Water Quality	Aqua Troll 500 Multiparameter	Stationary	Outlet Control Structure	Based on set up, readings will occur once per hour and upload to VuLink once per day Retrieve instrument log, connect to VuLink with the VuSitu mobile app while on site Logs can be downloaded to your phone and shared via email	Collect data from Sonde once per Month	12	E&LP
Soil Moisture & Retention	10HS Soil Moisture Smart Sensor	Stationary	Basin Soil	10HS Soil Moisture Smart Sensor Cable is 16-ft long connecting into a H21 MicroStation H21 MicroStation attached to OCS grate (weatherproof but not waterproof) H21 MicroStation records data constantly and reports readings to HOBOware software (free download) within 100-ft range via bluetooth	Collect data from MicroStation once per Month	12	E&LP
Flow Rate	FL 16 Water Flow Loggers	Stationary	Outlet Pipe	Level sensor deployed in pipe and logger attached to a fixed secure point Provided USB cable used to connect logger to laptop with Global Logger Interface Software Download data as excel file from software	Collect data from Logger once per Month	12	E&LP
Soil Infiltration	Eijkelkamp Double Ring Infiltrometer	Mobile	Basin Soil	Insert rings two inches deep into soil and fill outer and inner rings with water Record drop during presoak and determine measurement interval Fill rings with water and begin test Record depths after required time lapses Perform calculations to determine soil infiltration	Manual Data Recordings at End of Study Period	2	E&LP
Compaction	Soil Compaction Tester	Mobile	Basin Soil	Insert probe evenly into the soil until approximate depth of soil Manually record data on compaction reader	Manual Data Recordings Every Three (3) Months	3	E&LP
Plant Transpiration	Leaf Porometer SC-1	Mobile	Basin Planting	Field measure leaf (approx. 30 sec. per reading) and save reading Use Leaf Porometer Utility to download data via USB connection	Manual Data Recordings once per Month	12	E&LP

APPENDIX B. INFILTRATION TESTING LOGS

PWD Stormwater Plan Review Infiltration Testing Log

Version 1 *7/1/2015*

Project Name: SBIR EPA Grant **Date:** 11/1/2023
Project Address: **Weather:** Sunny
Testing Company: ELP **Tester's Name:** **James M.**
Phone Number: 908 238 0544 **Email Address:** jmcgillen@elp-inc.com

Test Number: S-1 **Test Pit/Boring Hole Number:** **Test Method:** Double-ring infiltrometer
Test Depth (feet): **Surface Elevation (feet):** **Instrument Diameter (inches):** 11.0"/20.9"

Soil Characterization

Depth:	Soil Texture:	Limiting Layers Type and Depth (feet):

Presoak

Time:	Time Interval:	Measurement, (inches):	Drop in water level, (inches):
10:30	0	4	
11:00	30	0	4
11:30	30	1.9	2.1

Infiltration Testing

Time:	Time Interval (10 or 30 minutes):	Measurement, (inches):	Drop in water level, (inches):	Infiltration rate (inches per hour):	Remarks:
11:32	0	4			
11:42	10	3.5	0.5	3	
11:52	10	3.33	0.67	4.02	
12:02	10	3.5	0.5	3	
12:12	10	3.5	0.5	3	
12:22	10	3.53	0.47	2.82	

Stabilized Infiltration Testing Rate (inches per hour): 3.26

PWD Stormwater Plan Review Infiltration Testing Log

Version 1 *7/1/2015*

Project Name: SBIR EPA Grant **Date:** 11/1/2023
Project Address: **Weather:** Sunny
Testing Company: ELP **Tester's Name:** James M.
Phone Number: 908 238 0544 **Email Address:** jmcgillen@elp-inc.com

Test Number: G-1 **Test Pit/Boring Hole Number:** **Test Method:** Double-ring infiltrometer
Test Depth (feet): **Surface Elevation (feet):** **Instrument Diameter (inches):** 11.0"/20.9"

Soil Characterization

Depth:	Soil Texture:	Limiting Layers Type and Depth (feet):

Presoak

Time:	Time Interval:	Measurement, (inches):	Drop in water level, (inches):
10:45	0	4	
11:15	30	0	4
11:45	30	0	4

Infiltration Testing

Time:	Time Interval (10 or 30 minutes):	Measurement, (inches):	Drop in water level, (inches):	Infiltration rate (inches per hour):	Remarks:
11:47	0	4			
11:57	10	2.9	1.1	6.6	
12:07	10	2.62	1.38	8.28	
12:17	10	2.7	1.3	7.8	
12:27	10	2.58	1.42	8.52	
12:37	10	2.86	1.14	6.84	
12:47	10	2.58	1.42	8.52	
12:57	10	2.82	1.18	7.08	
1:07	10	2.74	1.26	7.56	
1:17	10	2.66	1.34	8.04	

Stabilized Infiltration Testing Rate (inches per hour): 7.80

PWD Stormwater Plan Review Infiltration Testing Log

Version 1 *7/1/2015*

Project Name: SBIR EPA Grant **Date:** 11/13/2023
Project Address: **Weather:** Sunny
Testing Company: ELP **Tester's Name:** **James M., Peter C.**
Phone Number: 908 238 0544 **Email Address:** jmcgillen@elp-inc.com

Test Number: S-1 **Test Pit/Boring Hole Number:** **Test Method:** Double-ring infiltrometer
Test Depth (feet): **Surface Elevation (feet):** **Instrument Diameter (inches):** 11.0"/20.9"

Soil Characterization

Depth:	Soil Texture:	Limiting Layers Type and Depth (feet):

Presoak

Time:	Time Interval:	Measurement, (inches):	Drop in water level, (inches):
10:00	0	4	
10:30	30	0	4
11:00	30	1.87	2.13

Infiltration Testing

Time:	Time Interval (10 or 30 minutes):	Measurement, (inches):	Drop in water level, (inches):	Infiltration rate (inches per hour):	Remarks:
11:03	0	4			
11:13	10	3.25	0.75	4.49	
11:23	10	3.33	0.67	4.02	
11:33	10	3.37	0.63	3.78	
11:43	10	3.41	0.59	3.54	

Stabilized Infiltration Testing Rate (inches per hour): 3.96

PWD Stormwater Plan Review Infiltration Testing Log

Version 1 *7/1/2015*

Project Name:	SBIR EPA Grant	**Date:**	11/13/2023
Project Address:		**Weather:**	Sunny
Testing Company:	ELP	**Tester's Name:**	**James M., Peter C.**
Phone Number:	908 238 0544	**Email Address:**	jmcgillen@elp-inc.com

Test Number:	G-1	**Test Pit/Boring Hole Number:**		**Test Method:**	Double-ring infiltrometer
Test Depth (feet):		**Surface Elevation (feet):**		**Instrument Diameter (inches):**	11.0"/20.9"

Soil Characterization

Depth:	Soil Texture:	Limiting Layers Type and Depth (feet):

Presoak

Time:	Time Interval:	Measurement, (inches):	Drop in water level, (inches):
11:38	0	4	
12:08	30	0	4
12:38	30	0	4

Infiltration Testing

Time:	Time Interval (10 or 30 minutes):	Measurement, (inches):	Drop in water level, (inches):	Infiltration rate (inches per hour):	Remarks:
12:42	0	4			
12:52	10	2.66	1.34	8.03	
1:02	10	2.86	1.14	6.85	
1:12	10	2.82	1.18	7.09	
1:22	10	2.86	1.14	6.85	

Stabilized Infiltration Testing Rate (inches per hour): 7.20

Technical Plan

Introduction

This Technical Plan presents research completed as part of Phases I and II of a US EPA SBIR project titled "Developmental Investigation of Recycled Color Mixed Glass in Engineered Soils." The purpose of this document is to provide scientific and technical information that can guide municipalities or other organizations that seek to improve glass waste diversion and reduce natural resource extraction, by producing glass-based soil (GBS) that includes glass-sand made from recycled bottle glass for inclusion in waste-based green infrastructure soil.

Project Team and Advisors

- Engineering & Land Planning Associates
- Pennsylvania Recycling Markets Center
- Andela Products
- Craul Land Scientist
- Circular Phildelphia
- ReMark Glass and Bottle Underground, Inc.
- Bennett Compost
- Laurel Valley Soils
- Waste Management, Inc.
- Philadelphia Department of Parks & Recreation (PPR)
- Philadelphia Water Department (PWD)

Problems with Using Mined Sand in GSI

Many U.S. cities and smaller municipalities are investing heavily in green stormwater infrastructure (GSI) to mitigate combined sewer overflows. This approach has been widely adopted due to its reputation for sustainably improving stormwater management and providing community benefits and ecosystem services like transpiration cooling, habitat, and resources for wildlife, and trapping airborne pollutants.[1] While GSI contributes immensely to the livability of cities, it also contributes to their ecological footprints. Modifying the soil mixes used in GSI to include a processed, recycled sharp-free glass rather than mined sand could simultaneously reduce the reliance on environmentally hazardous materials and provide a sustainable outlet for what is currently a major waste stream.

Though not widely discussed, sand and gravel mining negatively impact environmental and human health. These resources comprise the most heavily extracted material group on the planet, ahead of even fossil fuels and biomass, meaning their mining and transport have enormous effects.[2] As these impacts occur far from cities, they are easily overlooked when considering urban environmental impacts. Some regions are already facing shortages of sand or gravel, especially of uncontaminated material with predictable physical properties.[3] For these reasons, finding a sustainable alternative material is necessary and urgent.

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[1]Lovell, Sarah Taylor, and John R. Taylor. "Supplying Urban Ecosystem Services through Multifunctional Green Infrastructure in the United States." Landscape Ecology 28, no. 8 (October 2013): 1447–63. https://doi.org/10.1007/s10980-013-9912-y.

[2]Torres, Aurora, Jodi Brandt, Kristen Lear, and Jianguo Liu. "A Looming Tragedy of the Sand Commons." Science 357, no. 6355 (September 8, 2017): 970–71. https://doi.org/10.1126/science.aao0503.

[3]Torres et al.

Large quantities of sand are typically included in soil blends used for bioretention systems, as these blends facilitate infiltration and plant growth, resist compaction by foot traffic, and can also serve as water storage reservoirs. On June 1, 2011, Pennsylvania approved the City of Philadelphia's Combined Sewer Overflow Long Term Control Plan Update (LTCPU) and its supplements, also referred to as the *Green City, Clean Waters* program, and formalized its approval in a Consent Order & Agreement (COA).[4] The COA requires that the city construct and place into operation the controls necessary to achieve the elimination of the mass of pollutants that would otherwise be removed by the capture of 85% by volume of the combined sewage collected in the Combined Sewer System during precipitation events on a system-wide annual average basis. The *Green City, Clean Waters* initiative planned to spend $2.4b over 25 years to capture over one-third of the city's stormwater from impervious surfaces, of which $1.7b is for green stormwater management.[5] As of 2018, the Philadelphia Water Department (PWD) had built nearly 1,100 Greened Acres and planned to add another 1,300 by 2021.[6] Achieving the goals of the Green City, Clean Water initiative is necessary to allow the City to meet the COA made with the EPA.

Replacing Mined Sand with Glass-Sand

Green Stormwater Infrastructure

PWD uses GSI to reduce flooding and sewer overflows by decreasing the amount of runoff flowing into sewers.[7] PWD's primary GSI tools are bioinfiltration/bioretention basins, described as follows:

> "...often referred to as rain gardens, [bioinfiltration and bioretention Stormwater Management Practices (SMPs)] are vegetated depressions or basins that use surface storage, vegetation, planting soil, outlet controls, and other components to treat, detain, and retain stormwater runoff. Bioinfiltration and bioretention SMPs represent the highest level of preference in PWD's SMP Hierarchy by providing high-performance and cost-effective stormwater management, green space, and triple bottom line benefits."[8]

PWD provides standard details and specifications for their construction (see Figure 1). Mined sand could potentially be replaced with recycled, sharp-free, crushed glass in the soil layer (labeled 24" min. planting soil medium..."). This Technical Plan examines Philadelphia-area market conditions for recycling consumer waste glass into glass-sand for use in the soil layer.

Acceptable Coarse Sand for GSI Purposes

PWD's specification includes the particle size requirements for bioinfiltration/bioretention soil (see Table 1). This distribution describes a manufactured blended soil, typically produced by mixing sand, compost, and locally available topsoil. PWD's specifications are permissive in their established aggregate sieve ranges between fine gravel, coarse and medium sands. This range tolerance is suitable for mixed glass cullet which is typically found in grades specified as 3/8" minus and below. PWD's Stormwater Management Guidance Manual notes typical aggregate grades that satisfy the specification requirements: "sand, if proposed, is specified...to be AASHTO M-6 or ASTM C-33." ASTM C-33 is the standard specification for a commonly used industry sand, notably used in the manufacture of concrete (see Table 2 and Figure 2).

[4]Philadelphia Water Department. "Green City, Clean Waters Evaluation and Adaptation Plan: Report to the Pennsylvania Department of Environmental Protection." Philadelphia Water Department, 2016.

[5]Philadelphia Water Department.

[6]Yale E360. "With a Green Makeover, Philadelphia Is Tackling Its Stormwater Problem." Accessed October 1, 2020. https://e360.yale.edu/features/with-a-green-makeover-philadelphia-tackles-its-stormwater-problem.

[7]Green City, Clean Waters, https://water.phila.gov/green-city/, accessed June 28, 2021

[8]"Stormwater Management Guidance Manual Version 3.2." Philadelphia Water Department, October 2020. https://www.pwdplanreview.org/manual/introduction.

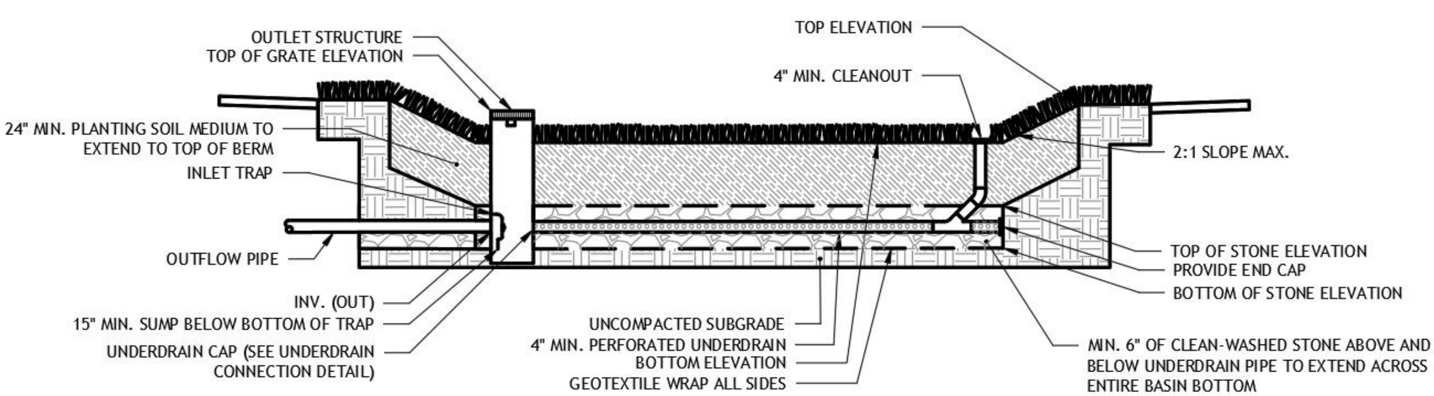

Figure 1: Standard Detail of Bioinfiltration and Bioretention Basins from the PWD Stormwater Management Guidance Manual.

Table 1: Bioinfiltration / Bioretention Soil Particle Size Distribution. Adapted from PWD Standard Specification 02830-Green Stormwater Infrastructure Soils.			
Particle Size Class	**Passing Sieve No.**	**mm Equivalent**	**Percent Volume (by ASTM D6913 and D7928 test methods)**
Coarse Fragments	#10	>2.000	≥65 (65 - 95)
Very Coarse Sand	#18	2.000 - 1.000	
Coarse Sand	#35	1.000 - 0.500	
Medium Sand	#60	0.500 - 0.250	
Fine Sand	#40	0.250 - 0.100	≤17 (3 - 17)
Very Fine Sand	#270	0.100 - 0.053	
Silt		0.050 - 0.002	≤20 (4 - 20)
Clay		<0.002	5 - 15

Table 2: ASTM C-33 Concrete Sand			
Particle Size Class	**Passing Sieve No.**	**mm Equivalent**	**Percent Passing (by ASTM E11 test method)**
Coarse	#4	4.750	95 - 100
	#8	2.360	80 - 100
	#16	1.180	50 - 85
	#30	0.600	25 - 60
	#50	0.300	5 - 30
	#100	0.150	0 - 10
Fine	#200	0.075	0 - 3

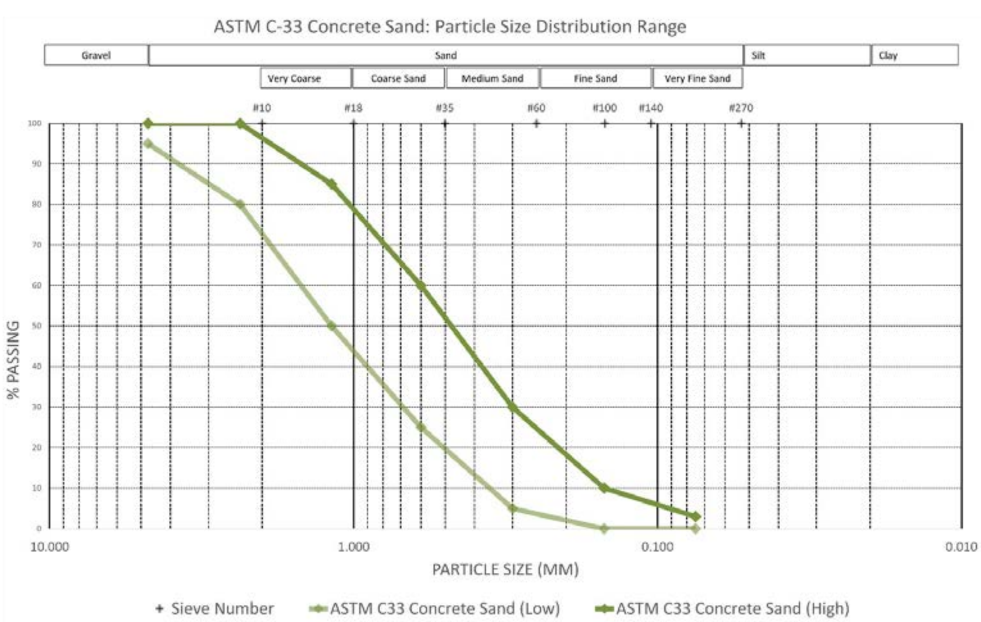

Figure 2: Acceptable particle size distribution range of ASTM C-33 concrete sand.

Background Research

Given the current negative commodity market for recycled glass, a few studies have evaluated manufactured glass-sand as a landscape construction material. One found that using recycled glass in sand drains improved permeability and drainage consolidation.[9] In a study that looked at golf course soils, recycled glass plus peat had greater porosity and hydraulic conductivity than a conventional mix.[10] Vegetation in an artificial dune had similar biomass in glass compared to beach sand.[11] Finally, in Hong Kong, glass-sand consumed less energy and therefore yielded fewer greenhouse gas emissions than mined sand.[12] From this positive data, and our own efforts at evaluating the commercial viability of glass-blended soils, we believe significant environmental and economic benefit can be achieved by demonstrating a process and product, based upon recycled glass cullet, that may even be cash positive for cities.

Prior to commencing the current EPA SBIR project, our research team performed a life-cycle assessment (LCA), lab-based chemical analyses, a greenhouse plant growth study, a mesocosm study and a glass-sand procurement analysis. Additionally, in Phase I of this SBIR project, the team performed a second greenhouse plant growth trial and a technical feasibility study. These studies have validated the potential environmental and economic impact of our proposed glass processing methods, and blended soil.

Life Cycle Assessment (2019): The LCA[13] compared the environmental impacts associated with the excavation, processing, and transport of one ton of natural sand to the collection, processing, and transport of one ton of manufactured glass-sand. The study (performed using Thinkstep Gabi LCA software) utilized Gabi LCA databases where relevant (US) data was available, along with primary-source data collected in Philadelphia. The LCA model was reviewed by a third-party LCA professional (Christoph Koffler, PhD, Thinkstep Technical Director Americas) for quality assurance. The study found a 67% reduction in greenhouse gas emissions, a 95% reduction in human toxicity, and a 70% reduction in oil-equivalent fossil depletion.

Pilot Growth Trial (2019): In 2019, we completed a greenhouse planting trial comparing plant growth in media containing amended glass vs. mined sand. The results of this pilot were presented by Dr. Sasha Eisenmann and Dr. Joshua Caplan (Temple University) at The Northeastern Plant, Pest, and Soils Conference (NEPPSC) in January 2020. A factorial experiment was run in a climate-controlled greenhouse in Philadelphia, Pennsylvania for 18 weeks. Eight individuals of three plant species were grown in six soil mixes (144 plants in total). An additional pair of unplanted pots were prepared containing each mix (12 in total). All mixes were composed of 60% sand (both mined and glass), 20% sandy loam, and 20% mushroom compost (by volume). The results of this pilot growth trial confirm that glass-based soil (GBS) mixes can support the growth of young plants. However, high pH may inhibit the growth of some taxa. None of the three taxa evaluated exhibited statistically significant reductions in above ground biomass in the GBS mix. The Phase I study built upon the findings of this pilot growth trial and tested three refined soil mixes that included locally-produced food waste compost.

Mesocosm Study (2020-21): The mesocosm study was performed by Dr. Sasha Eisenman and Dr. Joshua Caplan of Temple University and addressed two parameters:(1) hydraulic performance and (2) water quality.

Particle size data suggests that glass-based mixes should have appropriate hydraulic properties in GSI installations. These properties were examined in a 2020-21 mesocosm study, funded by the William Penn Foundation. The outcomes of that study showed that glass surfaces interact with water differently than sand (hydrophobic or hydrophilic), preventing it from draining. Based on this, we hypothesized that for green stormwater infrastructure (GSI) applications, glass-sand and mined sand should be combined to avoid exceeding the 72-hour regulation for standing water. On the other hand, glass would prevent water from draining too quickly which could support vegetation in drought-prone or low maintenance conditions. These results led us to test two different watering regimes (high-water and low-water) in the SBIR Phase I project.

In terms of water quality, early chemical analyses (performed prior to constructing mesocosm columns) indicated: (1) fine particles and some elevated levels of heavy metals were sufficiently high to warrant a detailed evaluation of leachate; and (2) the pH of manufactured glass-sand (9.8) is high for most plants. The leachate chemistry analysis of the mesocosm study indicated that the glass-sand released more inorganic and organic

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[9]Wang, F. C., X. N. Feng, H. Gong, and H. Y. Zhao. "Study of Permeability of Glass-Sand Soil." Archives of Civil Engineering 63, no. 3 (September 26, 2017): 175–90. https://doi.org/10.1515/ace-2017-0036.

[10]Owen, A.G., L.K.F. Hammond, and S.W. Baker. "Examination of the Physical Properties of Recycled Glass-Derived Sands for Use in Golf Green Rootzones." International Turfgrass Soc1i1e3ty1 Research Journal Volume 10 (2005): 1131–37.

[11]Makowski, Christopher, Finkl Charles W., and Kirt Rusenko. "Suitability of Recycled Glass Cullet as Artificial Dune Fill along Coastal Environments," June 1, 2018. http://proxy.library.upenn.edu:2084/apps/doc/A337070849/SCIC?sid=googlescholar.

[12]Hossain, Md. Uzzal, Chi Sun Poon, Irene M. C. Lo, and Jack C. P. Cheng. "Comparative Environmental Evaluation of Aggregate Production from Recycled Waste Materials and Virgin Sources by LCA." Resources, Conservation and Recycling 109 (May 1, 2016): 67–77. https://doi.org/10.1016/j.resconrec.2016.02.009.

[13]Zhang, Anqi. "Soil-Less Soil Study - A Sustainable Solution for Green Infrastructure Soil Media - Part 1, Life Cycle Assessment." University of Pennsylvania, May 2019. https://repository.upenn.edu/mes_capstones/78/.

carbon when compared to mined sand. In particular, bicarbonate was found which is added when producing glass. Additionally, glass-sand released more metals when compared to mined sand. While some metals (including lead and arsenic) exceeded EPA drinking water limits in the first flush rain event, researchers deemed that these levels would be safe in GSI applications and would not be toxic to plants or humans. The presence of contaminants, however, did warrant additional study in a pilot installation (see *Pilot Site Monitoring & Analysis*).

SBIR Phase I (2021): Phase I of this project was completed in 2021. This phase addressed the design of a GBS prototype material and a scalable manufacturing process to allow municipalities to divert waste glass into locally manufactured GBS. Through a greenhouse growth trial and development of an initial technical plan, the Phase I project demonstrated the potential for cities to repurpose waste glass and food waste into a commercially viable soil product.

The Phase I greenhouse growth trial indicated that there is no statistically significant difference between plant growth in a conventional sand-based soil blend and in GBS prototype mixes. Plant performance over the study period was measured through fresh and dry biomass in aboveground shoots and belowground roots. Three glass-based soil mixes were tested against a mined-sand control mix. The three GBS mixes tested different ratios of soil mix components: glass-sand, food waste compost and natural loam.

A cost analysis showed that manufacturing GBS in volumes sufficient to meet the needs of Philadelphia public works green infrastructure would potentially save money when compared to the status quo. Processing glass waste to meet product specifications can be accomplished by retrofitting local material recovery facilities (MRFs). Landfill diversion savings would more than cover the cost of these retrofits and long-term operations and maintenance.

Glass sources

For glass-sand to be a useful alternative in GSI applications, the material must match or closely approximate the ASTM C33 sand particle size distribution. Recycled glass aggregates are currently produced by several Material Recovery Facilities (MRF) in Pennsylvania. They produce a common glass cullet aggregate product. This glass cullet has variable particle size distributions with maximum sizes of 3/8" (often referred to as "3/8 minus" material). Table 3 lists currently operating MRFs in Pennsylvania that produce glass cullet. While this "3/8 minus" material has an extremely low market value and would therefore be a cost-competitive replacement for mined sand or gravel, it may require additional processing and screening for use in GSI soil blends due to the presence of large fragments and other residual materials.

Currently, in addition to its use as landfill cover, "3/8 minus" glass cullet can be purchased by manufacturers who clean, crush, and standardize particle sizes for other purposes. A commonly available refined glass product that could potentially replace ASTM C-33 sand is sandblasting aggregate. While this material's physical properties closely resemble washed and screened natural sand, its high price means it is not cost-competitive with mined sand. Table 4 compares a sampling of currently available glass aggregate products that are available to Pennsylvania purchasers. Price estimates were provided by each manufacturer's sales representative.

Table 3: PA Material Recovery Facilitie (MRFs) producing glass cullet. Courtesy of Pennsylvania Recycling Markets Center (RMC).

MRF Name	City	County
Dlubak Glass	Natrona Heights	Allegheny
C Bradish Glass, Inc.	Greensburg	Westmoreland
CAP Glass, Inc.	Mt. Pleasant	Fayette
CAP Glass Allentown, LLC	Northampton	Northampton
CAP-EWG Glass, LLC	Orwigsburg	Schuylkill
Municipal Recovery Inc.	Wilkes-Barre	Luzerne

Table 4: Examples of Glass Cullet Products Currently Available to PA Purchasers

Manufacturer and Product Type	Particle Size (by ASTM Sieve Number)	Approx. Price per Ton	Potential for GSI Soils
Typical MRF Glass Cullet	< 3/8"	Negligible	Additional screening required
Strategic Materials Sandblast Glass-Sand	#40 - #70	$320	Suitable size range
	#70 - #100	$320	
Precision Finishing Sand Blasting Glass	#10 - #40	$400*	Suitable size range
ECSA Sandblasting Glass	#10 - #20	$320	Suitable size range
	#20 - #30	$320	
	#40 - #70	$320	
AeroAggregates	#10 - #40	$200**	Suitable size range

*Assumes minimum purchase of 3 tons.
**Hypothetical product: AeroAggregates estimated cost to buyers for #10-#40 glass-sand according to current market conditions. Market price for the product they could produce competes against that for high end sandblasting applications.

Defining a Target Material

Table 5 below describes the particle size distribution of a glass-sand product produced by Andela Products for our use in this study. This glass-sand was used in the soil mixes tested in our Phase I greenhouse and laboratory studies and represents the target material for a cost-competitive alternative to mined ASTM C-33 concrete sand. Figure 3 compares this target material to ASTM C-33 sand.

Table 5: Particle Size Distribution of Target Glass-Sand Produced by Andela Products for this Study.			
Particle Size Class	**Passing Sieve No.**	**mm Equivalent**	**Percent Passing (by ASTM E11 test method)**
Coarse	#10	>2.000	87.5
	#18	2.000 - 1.000	66.8
	#35	1.000 - 0.500	43.1
	#60	0.500 - 0.250	20.2
	#140	0.250 - 0.100	8.3
Fine	#270	0.100 - 0.053	3.9

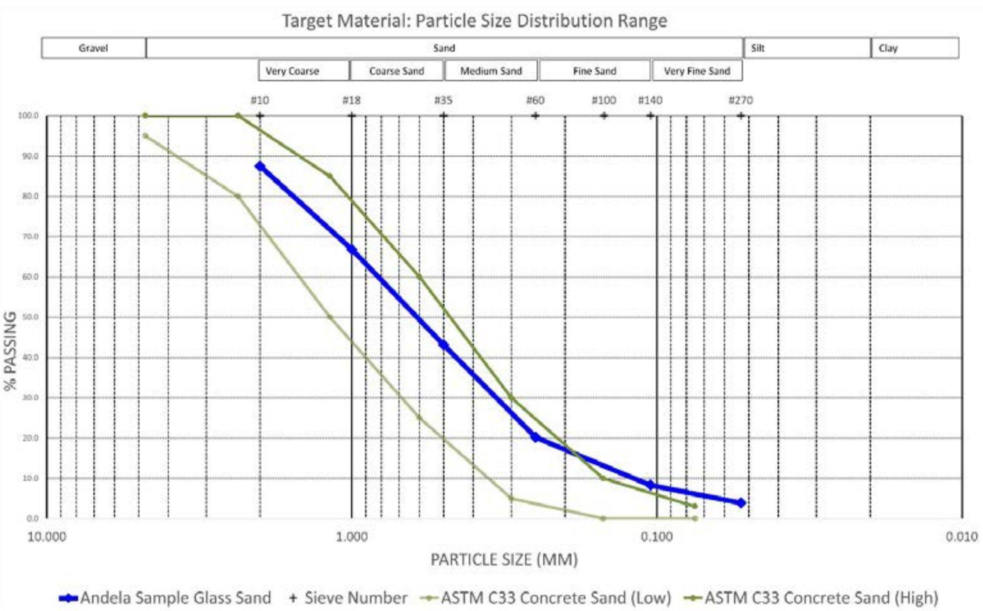

Figure 3: Particle size distribution of target glass-sand compared to ASTM C-33 concrete sand.

Safety and Quality Control

Previous studies have confirmed the safety of utilizing glass-sand and fine aggregates of sizes smaller than 5mm in landscape and civil engineering applications, in terms of sharpness and abrasiveness. A 2011 Occupational Health, Safety and Environment (OHSE) Risk Assessment for the Use of Recovered Crushed Glass in Civil Construction Applications, provides recommendations to ensure safety when working with crushed glass.[14] That report states that glass-sand of around 3mm or smaller carries risks that are comparable to mined quartz sand. Coarser glass particles, of greater than 5mm, can contain elongated, splintered or angular shapes which can cause skin abrasion, but smaller particles of around 3mm (#4 sieve size = 2.75mm) are more rounded and pose little risk for abrasion. Regarding long term health risks, glass-sand is considered safer than natural sand, because glass contains substantially less respirable crystalline silica, which causes silicosis (glass is composed primarily of amorphous silica). Glass-sand particles (2.2-2.5 g/cu cm) are also denser than sand (1.8 g/ cu cm) and therefore fall out of air more quickly, reducing the likelihood of inhalation. The OHSE report provides a Recovered Crushed Glass Materials Safety Data Sheet (MSDS) (see Appendix B). Material specifications and product data sheets should instruct users to wear personal protective equipment when handling glass-sand, as a precaution.

Glass-based soil (GBS) samples were analyzed as part of this SBIR project for metal concentrations. All samples showed levels of exchangeable trace metals below EPA drinking water standards (see *Pilot Site Monitoring & Analysis*). That said, using post-consumer waste materials in soils (such as compost and biosolids) can introduce risk of contamination. Analysis performed as part of this project has shown that levels of metals in source separated bottle glass produced as part of this SBIR Phase II project are very low, however a 2019 study indicates that some colored enamel used to decorate wine or liquor bottles may contain lead and cadmium.[15] For this reason, material specifications should require batch testing of glass-sand for lead, arsenic, cadmium, and chromium prior to installation in the landscape. Material testing for glass-sand can be similar to protocols typically used to test biosolids and compost (see Trial Soil Specification, Appendix C).

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[14] Winder, "Occupational Health, Safety and Environment (OHSE) Risk Assessment: Use of Recovered Crushed Glass in Civil Construction Applications."

[15] Turner, "Heavy Metals in the Glass and Enamels of Consumer Container Bottles."

Recycling and Waste Collection Costs

Waste collection and recycling costs were contracted through an agreement in 2019 between the City of Philadelphia and Waste Management Inc. Landfilling currently costs less than recycling for the following reasons: Philadelphia's single stream recycling requires labor and mechanical sorting activities and transactions with the secondary commodities market that landfilling activities do not require. Recycled materials that are sold to the commodities market avoid landfill tipping fees, defined as the cost to deposit waste in a landfill, however many recyclables are not actually being recycled; this is especially true of mixed glass.[16] According to our communication with Charles Raudenbush of Waste Management Public Sector Services, all glass that is part of Philadelphia's single stream recycling tonnage is being sorted and sent to landfills as residual waste.

The Waste Management Disposal Fee Contract states that hauling costs from the Philadelphia Waste Transfer Station to the Fairless Landfill was $65.25 per ton in 2019 with escalation rates of 3.5% per year. This fee is inclusive of a haul rate of $16.05 per ton paid to Waste Management's subcontractors (Table 6).

Market Barriers to Glass Recycling

Though glass is recyclable, it is often directed to landfills due to technological or market barriers. For one, glass particles smaller than ¼" are difficult to clean and color sort using current methods, making re-melting to form new glass labor intensive. Only a relatively small fraction of waste colored glass is recycled (26.6% nationally, according to the EPA), the majority being disposed into landfills. In 2015, approximately 7,000,000 tons of waste glass was disposed into landfill in the U.S.[17] Also, changes in China's recycling policies enacted in 2017 and 2018 have drastically reduced demand for recyclable materials,[18] dramatically raising the cost to municipalities. Because of this market shift, thousands of tons of recyclable material collected in dozens of American cities are now being redirected to landfills.[19] Vast amounts of colored glass, and most sand-sized glass particles (a.k.a. 'glass fines' or 'glass-sand'), are never recycled.

[16]City of Philadelphia, Municipal Waste Management Plan 2019 - 2028, 2019, 4-4

[17]EPA. "Advancing Sustainable Materials Management: 2017 Fact Sheet." EPA, November 2019. https://www.epa.gov/sites/production/files/2019-11/documents/2017_facts_and_figures_fact_sheet_final.pdf.

[18]Brooks et al, "The Chinese import ban and its impact on global plastic waste trade."

[19]Albeck-Ripka, "Your Recycling Gets Recycled, Right? Maybe, or Maybe Not."

Status Quo of Glass Recycling in Philadelphia

All single stream recycling in Philadelphia is currently handled by the private contractor Waste Management. Philadelphia holds a five-year contract with Waste Management that stipulates that the company will act as the recycling market outlet for the city's recyclable material, regardless of market fluctuations. It also states that, except for downgraded or rejected loads, "under no circumstances shall (Waste Management) landfill, burn, or convert for burning the Recyclable Materials provided." Despite this agreement, Waste Management is currently sending all of Philadelphia's single stream mixed glass to the landfill as a portion of their "residual waste" output.

The overall public cost of recycling is calculated as the processing fees charged by the recycling contractor (currently $115 per ton, charged by Waste Management), less a 70% share of the Recyclable Material Blended Value (established by industry-wide standards.) Recyclable materials such as aluminum cans and some plastics have relatively high market value (currently $1,570.00/ton and $300-$820/ton respectively). Glass, however, has a negative value,(-$35)/ton. Therefore, every ton of recyclable glass in Philadelphia's single stream recycling costs the city $24.50 ($35 x 70%) on top of the $115 processing fee. Since glass makes up about 25% of Philadelphia's recycling tonnage, the material decreases the value of every ton of mixed recyclables that enters the Waste Management MRF by $9.08. In 2018, 127,000 tons of single stream recyclables entered the MRF, which translates to a loss of about $1,150,000 for processing glass citywide (127,000 tons x $9.08/ton) on top of overall processing fees.

Table 6: 2021 Recycling and Hauling Fees for the City of Philadelphia (escalated from 2019 at 3.5%)*

Category	Landfill per ton	Recycling per ton
Hauling costs	$17.19	N/A
Landfill tipping fee	$52.70	N/A
Process and sort recycling	N/A	$115
Estimated value of glass at 70% value of commodity (note: mixed glass has a negative value)	N/A	$24.50
Total	**$69.89**	**$139.50**

*Adapted from City of Philadelphia, Municipal Waste Management Plan 2019 - 2028, 2019, Appendix A City Contract Documents

Meanwhile, public works GSI projects source manufactured soils from area soil blending companies, who use mined sand in their soil mixes (see Figure 4).

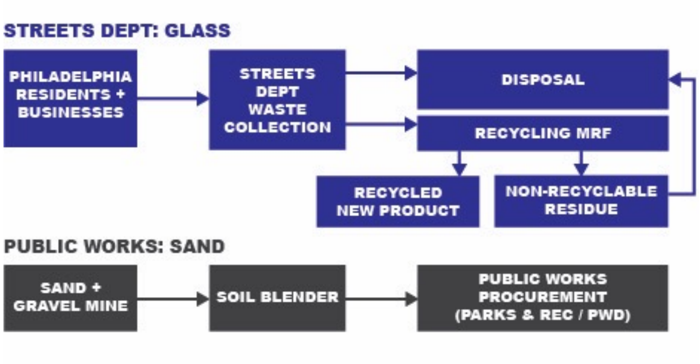

Figure 4: Philadelphia area glass waste and GSI soil procurement status quo.

New Market Opportunities for Recycled Glass Cullet

Some Pennsylvania Material Recovery Facilities (MRF) produce a common glass cullet aggregate product that is generally unwanted by the market. In conversations with industry experts at Aero Aggregates, we have learned that manufacturers downline of MRFs either receive this glass cullet for free or in some cases are paid by MRFs to take it. This condition has already created new businesses in the area, as evidenced in part by the success of Aero Aggregates. Along with new business opportunities, it also offers cost saving opportunities in many parts of the Philadelphia waste management and soil procurement system. Figure 5 describes a hypothetical case in which glass cullet is processed into glass-sand and is sold as a sand alternative to area soil blenders inclusion in GSI soil mixes.

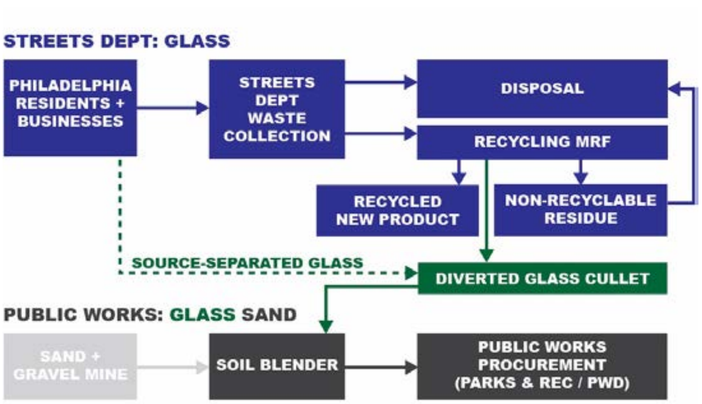

Figure 5: Linking Philadelphia area glass waste and GSI soil procurement streams.

In 2018, Philadelphia generated about 2,220,720 tons of Municipal Solid Waste (MSW), including 618,513 tons of residential waste and 1,602,208 tons of commercial waste (excluding construction and demolition waste).[20] Based on national averages, 4.2% of the overall MSW stream is made up of glass – or approximately 93,270 tons per year in Philadelphia.[21] Of this overall glass waste generated, approximately 32,844.51 tons of mixed broken glass is collected "curbside" by the City Streets Department and hauled to the Waste Management MRF. The rest is managed through private commercial waste hauling contracts. Since no portion of municipal solid waste (MSW) glass is currently being recycled, this suggests ample supply for the city if this glass were to be used for the *Green City, Clean Waters* program.[22]

[20]MSW Consultants and Philadelphia Street Department. "Municipal Waste Management Plan 2019-2028." Accessed July 9, 2021. https://www.philadelphiastreets.com/recycling/solid-waste-recycling-advisory-committee-swrac/documents/.

[21]EPA. "Advancing Sustainable Materials Management: 2017 Fact Sheet."

[22]Stormwater Management Guidance Manual Version 3.2.

Table 7: Residential glass as a percentage of recycled materials in Philadelphia (2018)*

Category	**Tons**	**% Glass**	**Net Glass (tons)**
Single stream (residential)	126,802	25.5	32,844.51
Commercial	798,075	unknown	unknown
Estimated tonnage of single stream glass collected for recycling in Philadelphia MRF (2018			32,844.51

*Adapted from City of Philadelphia, Municipal Waste Management Plan 2019 - 2028, 2019.

Table 8: Overall waste disposal combined residential and commercial in Philadelphia (2018)*

Category	**Residential**	**Commercial**	**Total (tons)**
Total all recycled materials	126,802	798,075	924,877
Total waste disposed	491,710	804,133	1,295,843
Total waste (recycled and disposed)			2,220,720
Estimated percentage of recyclable glass in waste stream (based on national average)			4.2%**
Estimated tonnage of recyclable glass in waste stream			93,720

*Adapted from City of Philadelphia, Municipal Waste Management Plan 2019 - 2028, 2019.
**EPA, "Advancing Sustainable Materials Management: 2017 Fact Sheet."

Cost Comparison Between Conventional Manufactured Soil and Glass-Based Soil

Laurel Valley Soils (a Pennsylvania supplier) regularly provides stormwater soil to the City of Philadelphia and shared typical material costs for comparison. The PWD specification for stormwater soils identifies Laurel Valley Soils as a known soil supplier that pre-submits soil test information and thus qualifies for reduced testing for each specific project approval. At the time of interview (2021), the cost to Laurel Valley of mined sand, delivered to their facility for further mixing, ranges between $19-$22 per ton. According to PWD, the approximate cost of GSI soil installed is $100 per cubic yard. One cubic yard of this soil weighs about one ton.

Over the course of our greenhouse and laboratory studies, Andela Products, our research partner and Northeast region manufacturer of glass crushing equipment and glass cullet processor, provided glass-sand samples to use in our soil mixes. This target material conforms closely to ASTM C33 sand and is a functional replacement for mined sand in green stormwater infrastructure soil mixes. Though this grade of glass cullet is not currently produced in Philadelphia, Andela Products does produce this material and has provided consultation to contractors and municipalities with guidance to produce this material locally.

The evolution of glass-sand production from pilot scale into something regularly available to the landscape construction industry takes different forms. The economic and operational adjustments to existing recyclers will differ depending on whether glass-sand is produced as a large-scale operation or a small-scale pilot project.

Cost Comparison for Large-Scale Facilities (up to 20 tons of glass per hour)

Andela Products estimates that the cost to process broken mixed-color glass into glass-sand that meets our target material specification is $30 per ton. This cost includes labor, equipment, maintenance, and other overhead costs.[23] These require at least one operator and one loader to operate. The expense per ton decreases as the number of tons per hour increases. The wear and maintenance costs are a fixed cost per hour, so higher operating rates decrease the cost per ton of glass-sand.

In Philadelphia, Waste Management landfills their recyclable glass and non-recyclable residue at a cost of $62.50 per ton.[24] This cost could be avoided by identifying a market for their broken mixed glass. Assuming a $30 per ton cost to process glass into a glass-sand product and a $16 cost per ton for hauling, Waste Management stands to save $16.50 in operational costs for each ton of glass they process if they find an outlet that will take the glass-sand for free. These savings could be passed on to municipalities through recycling contract negotiations.

Any positive market value for a glass-sand product could further compel Waste Management to adjust the way they manage waste glass. Furthermore, a glass-sand that costs less than mined sand would lower the cost of producing GSI soil blends to soil blenders like Laurel Valley. Should Laurel Valley agree, for example, to pay a minimal $5 per ton fee for glass-sand, they would save $14-$17 per ton compared to mined sand, and Waste Management would have justification to adjust their operations. Lower costs for soil blending could be passed on to buyers including PWD, lowering the cost of soil used in their GSI projects from $55 per ton to $38-$41 per ton (see Table 9).

Table 9: Philadelphia waste management cost savings (per ton) by producing recycled glass sand

Waste management tonnage costs	**Current**	**Proposed**	**Net savings**
Cost of waste disposal (including transport from MRF to landfill)	-$62.50		
Cost of glass-sand processing (including transport to soil blender)		-$46.00	unknown
Total	**-$62.50**	**-$46.00**	**$16.50 (operational)**
Possible purchase price of glass-sand		$5.00	
Total	**-$62.50**	**-$41.00**	**$21.50 (with purchaser)**

Operational Changes for Large-Scale Facilities (up to 20 tons of glass per hour)

The technology for glass-sand production already exists. Retrofitting existing large-scale MRF facilities to include a glass-sand production line is possible.

Andela Products provided a description of a typical process and set of equipment that would be required to retrofit a large-scale operation like that at Philadelphia's Waste Management MRF (see Appendix D). Typically, a set of individual pieces of equipment would be sold as a system. In Waste Management's case in Philadelphia, the Andela GP-2HD Glass Pulverizer System would be appropriate. Waste Management could put this system

[23]Andela products' equipment ranges in from $50,000 to $500,000 for complete turn-key systems, depending on the processing capacity required. Typical systems can process 10-15 tons of waste glass per hour into glass-sand.

[24]MSW Consultants and Philadelphia Street Department, "Municipal Waste Management Plan 2019-2028."

either next to or inside their facility to process the waste glass that they are now sending to the landfill as residue.

The MRF would collect the waste glass and have it left at the pulverizer site in a covered waste glass bunker. The waste glass can be mixed-broken MRF glass or collected at drop-off centers and brought by a waste and recycling hauler, typically in a roll-off container, but it can also be another type of container or truck. The incoming recyclable material can be mixed color bottle glass. Fluorescent or CRT tubes and plate glass are not permissible. The bunker is typically an enclosure with a concrete pad for tipping the waste glass. Bunker blocks or any steel or concrete enclosure will allow a skid steer to pick up the waste glass by acting as a backstop to push the glass against as it is picked up.

Waste glass would then be picked up by a skid steer or bucket loader and dumped into the top of a surge hopper.[25] A reciprocating plate feeder at the bottom of the surge hopper will meter, or shovel, the glass out of the bottom of the hopper at an even rate, and deposit it onto the pulverizer infeed conveyor. This metering surge hopper can control the rate of feed into the pulverizer by raising a door above the plate feeder and/or by regulating the speed of the feeder. The metering surge hopper allows for the bulk loading of glass without requiring personnel on the loader manually regulating the flow. It is best to keep the pulverizer system fed at an even rate.

The Andela Glass Pulverizer is integrated with the Andela Trommel rotating screen in the system. First, waste glass goes into the pulverizer barrel where it is selectively reduced into a sand/aggregate sized product. Any bottle caps, labels and other non-glass debris stay in their original larger size. Sharp edges of the glass particles are also tumbled off during this process. The pulverizer is lined with a very high abrasion resistant steel that will stand up glass abrasion over time. The pulverizing hammers are a consumable component, easily replaced with an impact wrench through maintenance access doors.

The glass drops into the rotating trommel screen which consists of a barrel with interchangeable screens of various sizes wrapped around it. Rotating brushes keep the screen open when processing glass that is wet or has a high organic content. As the material lifts and falls inside of the trommel screen, the sand sized glass (3/16" or No. 4 mesh) falls through the screen section and collects in a large tip bin that is removed when full and tipped onto a glass-sand stockpile located in the same general vicinity.

An optional component is a recirculation conveyor which allows the facility to eliminate waste and convert all glass into glass-sand. As pulverized glass moves through the trommel screen, larger sized pieces (3/16" - 7/16" or No 4 mesh - No. 2 mesh) are allowed to fall onto a recirculation conveyor. Pieces larger than 7/16" are separated out along with bottle caps, paper, plastics, and other non-glass residue. If desired, this remaining material can be fed back into the surge hopper to pulverize the remaining glass. Non-glass residue stays in its original size and falls out the end of the trommel screen for disposal.

In Waste Management's case, their waste glass feedstock includes large volumes of paper. The Andela Glass Clean-Up Unit can be installed before the glass processing line as an additional component to blow out some or most of the shredded paper prior to pulverization.

Cost and Operation for Small-Scale Facility (1,000-1,500 lbs of glass per hour)

Establishing a small-scale operation or retrofitting a small-scale recycling facility to include a glass-sand production line involves a similar process as with large-scale facilities, but with smaller equipment.[26] In communities or municipalities where glass recycling is not already part of waste management, there are a variety of glass collection strategies that can be considered, including voluntary, no cost drop-offs of bottles only from residents and businesses at collection point(s). Drop-offs do not include industrial glass or lightbulbs. Alternative strategies could include subscription pick-ups.

The Traveling Glass Bin Program run by the Pennsylvania Resources Council (PRC) offers a model for glass collection for communities and municipalities that do not offer glass recycling as part of waste management. The program establishes glass recycling drop-off sites in strategic primarily residential locations in partnership with southwestern PA municipalities, councils of government, and county partners. Grant funding supports the purchase of recycling containers. Containers can be permanent or temporary ("traveling"). Costs associated with hauling the material are covered by the municipalities as a service to residents. This cost is approximately $400 per pick up. Containers hold approximately 5-6 tons of material and are only picked up when full. In the case of the PRC model, a nearby hauler, Michael Brothers haul and store the recycled glass. The cost of hauling is minimized because pick up locations fall along Michael Brothers' pre-existing route. The glass is then shipped in bulk to CAP Glass (Mt Pleasant, PA), the regional glass recycler. The recycled glass is of value to CAP as it provides a consistent, clean feedstock source. The same system could be applied to the model outlined in this report, with the substitution of a soil blender (such as Laurel Valley Soils) in place of a glass recycler (such as CAP Glass).

[25] The Andela Metering Surge Hopper will hold about 4 tons of waste glass.

[26] The Andela Glass Pulverizer System contains the same components for the smallest system (GP-05L, 1-2 tons per hour) to the largest system (GP-2HD, 20 tons per hour). See Appendix D for pricing of the GP-05L system.

Once waste glass has been collected, the pulverization process is mostly similar to that described for a large-scale facility. To set up a small-scale operation, the following costs should be considered. Assuming an Andela GP Mega Mini Glass Pulverizer System which produces 1,500 tons of glass-sand per year, equipment costs are estimated at $85,500 (including installation on a concrete pad). Assuming the market value of glass-sand is $20-$40, the cost of equipment could be recouped in the first two years of operation. The cost per ton of glass-sand produced by a small-scale facility will be greater than a large-scale facility because the labor rate is higher per ton of glass-sand produced. For example, the Andela GP-Mini can operate with one operator but the manual feeding and metering of the glass into the system, and more frequent handling of the glass-sand produced decreases the rate of production. The cost per ton varies depending on local labor rates and the shared resources of loaders and facilities. For example, systems located near a recycling facility or municipal facilities (such as Streets Departments) can benefit from shared use of loaders and labor to pulverize glass as needed. In addition to labor and equipment costs, the cost per ton also includes wear and tear and maintenance costs.

In the case of a small-scale operation, buckets of waste glass are manually fed into an infeed conveyer to be pulverized. The operator can also use tip bins or a Gaylord tipper to feed the pulverizer system which could reduce labor costs. Pulverized glass-sand is dispensed into super sacks or bins and can be stored on pallets or in a bunker. The pulverized glass-sand can be collected in a covered bunker until it is picked up or it can be conveyed directly into a truck on-demand. This depends on the size and regularity of demand for glass-sand. To prepare the material for delivery to the soil blender, a skid steer is required to transfer the glass-sand from the stockpile. Alternatively, a forklift could transfer pallets of 50 lbs bags or super sacks into a tri-axle truck for hauling.

Efficiency can be optimized by locating the site close to the source of the feedstock or end use (in this case, a soil blender) or by capitalizing on existing hauling routes, as illustrated in the Traveling Glass Bin Program outlined above. Co-location of glass-processing and glass storage would maximize efficiency and lower operating costs for a small-scale facility. Depending on whether the facility is in an urban or peri-urban/rural context, costs associated with site preparation will vary. In addition to the pulverizing system, costs may include securing the property, site demolition and clearing, construction of a waste glass and glass-sand bunker, material handling equipment such as a skid steer and/or forklift, fencing, drainage infrastructure, a storage container or canopy to keep glass-sand dry, and utilities (electrical, plumbing, etc) as needed. Local permitting and regulatory requirements associated with non-hazardous waste storage and material processing need to be considered when setting up a processing and storage site.

The scale of storage space for pre-crushed and post-processed glass-sand is an important variable in high volume markets like engineered soils. Large-scale soil blenders require a stockpile of materials to be available to source glass-sand for projects. For example, Laurel Valley Soils would require 300-3,000 tons of glass-sand to be consistently available at an off-site storage location. Therefore, in order to enter this market, sufficient storage for pre- and post-processed waste glass is essential for a small-scale facility.

Case Study: Small-Scale Urban Glass-Sand Producer, Bottle Underground (Philadelphia, PA)

<u>ReMark Glass / Bottle Underground</u>

Phase II of this project included expanding an existing local glass recycling nonprofit to include glass-sand production. ReMark Glass was founded in 2016 and focuses on innovative and creative reuses of recycled glass. Bottle Underground (BU) is ReMark's recently established nonprofit sister company focused on making the highest and best use of bottle glass through recirculation, recycling, downcycling, and upcycling with the goal of reducing glass waste in Philadelphia.

This project supported the expansion of BU's business to include the small-scale production of commercializable glass-sand through the purchase and installation of an Andela GP Mini glass-pulverizing system and associated facility upgrades.

ReMark/BU sources glass from voluntary drop-offs of mixed color bottles and jars from residents and businesses. ReMark separates and cleans desirable glass to be upcycled and made into glassware products. As an alternative to hauling excess glass cullet outside of Philadelphia, this project aims to create an outlet for negative-value glass overage and support BU's ability to increase glass waste intake and processing volumes.

In July 2023, BU received and installed the Andela GP Mini pulverizing equipment and commenced glass-sand production (see Figure 9 and 10). As part of this Phase II project, BU provided glass-sand at a cost of $150/ton. However, the actual cost to produce the glass-sand was higher given facility limitations and retrofit costs. In 2023, BU processed 65 tons of glass-sand and expects to process 100-150 tons in 2024 depending on demand. Glass-sand pricing ranges depending on the order size and color.

<u>Laurel Valley Soils</u>

The project team worked closely with Jacob Chalfin of Laurel Valley Soils (LVS), a primary supplier of engineered soils to PWD. For the pilot bioretention basin, LVS blended both the control (standard GSI soil) and trial (GBS soil) mixes. LVS replaced a portion of typical mined sand with the glass-sand processed by Andela Products in order to meet the trial GBS soil specification. LVS noted that the glass-sand seemed abrasive but otherwise behaved comparably to mined sand during the blending process. LVS did not need to alter their blending process or require additional equipment. LVS did not foresee any issues with incorporating glass-sand into their soil blending process, other than material availability. The team recommends requiring the use of work gloves to minimize any risk of abrasion when handling glass-sand.

LVS depends on high volumes of mined sand being readily available at a low cost. To meet demand, LVS estimates a glass-sand producer should stockpile five times the average order request, approximately 300-3,000 tons[27] of glass-sand. A consistent and predictable demand would diminish stockpiling needs. Since LVS supplies PWD with soil for public works projects, existing hauling routes could be used to transport glass-sand produced by BU to LVS' soil blending facility. After delivering soil to a project site within the city, LVS could haul the glass-sand from BU's facility. LVS' existing hauling routes pass by South Philadelphia since their soil blending facility is located southwest of the city.

[27]Laurel Valley Soils' minimum production run is 20 cubic yards of blended soil, but their average order size range is 200-2,000 cubic yards. Assuming the glass-sand component of these soils is 30%, the minimum sand requirement is 6 cubic yards, but the average range is between 60-600 cubic yards.

Figure 6: ASTM C-33 concrete sand (left) and glass-sand (right).

Figure 7: GBS blending at Laurel Valley Soils.

Figure 8: GBS blended at Laurel Valley Soils.

Figure 9: Andela GP Mini glass pulverizer installed at BU's facility.

Figure 10: Glass-sand stockpiled in sacks at BU's facility.

Figure 11: Excavated site with new soils for installation (credit: ThinkGreen).

Figure 12: Laying out plugs prior to installation.

Figure 13: Installation of plant plugs.

Figure 14: Monitoring equipment installed in outflow structure on site.

Figure 15: Leaf porometer readings.

Commercialization Plan

The following report was prepared by Pennsylvania Recycling Markets Center as part of this project.

Executive Summary/ Background

Through SBIR Phase 1 research and Phase 2 pilot and commercialization studies, and with the assistance of Andela Products, Circular Philadelphia, Bottle Underground, and the Pennsylvania Recycling Markets Center; OLIN, a Philadelphia-based landscape architecture firm, has developed a prototype glass-based soil mix design specification (herein termed "circular soils") and a manufacturing process that repurposes recycled container glass and compost into an engineered soil product suitable for horticultural and green infrastructure projects. Circular soils will compete with conventional sand-based topsoil in medium and large-scale green stormwater infrastructure installations, such as rain gardens, detention ponds and low impact development (LID) tree planting trenches.

This project supports the EPA's goal to improve sustainable materials management to reduce landfill burdens and conserve materials and resources. Use of circular soils provides both economic and environmental benefits through realization of avoided disposal costs by diverting recyclable glass and organic materials from landfills and incinerators. Shortages of construction-grade sand and increased costs of sand use in soil preparations are addressed by using circular soils as a viable substitute. Climate change issues are addressed through greenhouse gas (GHG) emission reductions achieved by an increase of sustainable material recycling/ reuse versus disposal and a decrease of virgin material extraction (i.e. natural, stone, sand and peat mining). Also, construction projects that utilize circular soils may qualify for certification credits under the LEED (Leadership in Energy and Environmental Design) used green building rating system.

Recycled glass comprised mainly of glass food and beverage containers will be sourced from single-stream, dual stream (aka comingled) and source-separated collection programs. Municipal material recovery facilities (MRF's) and recycled glass beneficators in turn convert glass-laden processing residue and/or separated glass containers into a marketable feedstock. Compost (including compost that uses food scrap feedstocks) will be sourced from authorized composting operations. Blending of the crushed glass, compost and natural soils occurs at typical commercial/ industrial soil blending operations, however this manufacturing step could occur at MRF's, glass processing facilities or composting operations.

Through extensive interviews with potential feedstock processors and suppliers, material specifiers, soil blending operations and potential end users located in the Philadelphia region, it has been determined a bona fide market exists for circular soils in the horticultural and green infrastructure industry sectors.

Several examples of a Circular Soils Business Models are provided in this document, which can include many combinations of processing soil, compost, and glass feedstocks operations and/ or operations that blend and prepare for market and shipping specified Circular Soil products. This commercialization plan provides critical information for prospective businesses that want to produce an environmentally, socially, and economically sustainable product used in the landscaping and green infrastructure sectors.

I. Business Process Flow Diagram

Figure 1 below graphically describes the flow of materials and processes involved with the manufacturing of circular soils.

II. Market Identification and Marketing Customer Base

The market for Circular Soils lies within the horticultural and landscaping industry, green infrastructure, and projects that are seeking LEED accreditation. Circular soils will compete with conventional sand-based topsoil in medium and large-scale green stormwater infrastructure installations, such as rain gardens, detention ponds and low impact development (LID) tree planting trenches. The customer base for Circular Soils includes but is not limited to landscaping firms, construction contractors, home and garden centers, greenhouses, and municipalities. Landscape design architects and civil engineers will play a critical role as they specify material that are to be utilized in projects. Bulk sales and delivery in truck load or super-sac quantities appear to be the preferred marketing method. However, there are opportunities to break into the retail markets with a bagged product.

As part of the commercialization planning process, Circular Philadelphia conducted interviews with nine different companies/organizations that have the potential to either supply feedstock(s) and/or produce Circular Soils, or be an end user of the product. Of those nine companies, six companies/organizations (plus one who was not interviewed) signed a letter of intent (LOI) to enter into a non-binding agreement to support the Circular Soils project.

Three organizations signed LOI's to buy (or verbally agreed to buy) Circular Soils: Philadelphia Parks and Recreation (for small amounts), Philadelphia Water Department (for larger projects) and OLIN Architects (for client work to specification). Two companies signed LOI's to provide steady streams of glass derived sand: Bottle Underground and Andela Products. Two companies signed LOI's to provide compost to mix with the glass: Laurel Valley and Bennett Compost (see Appendix E).

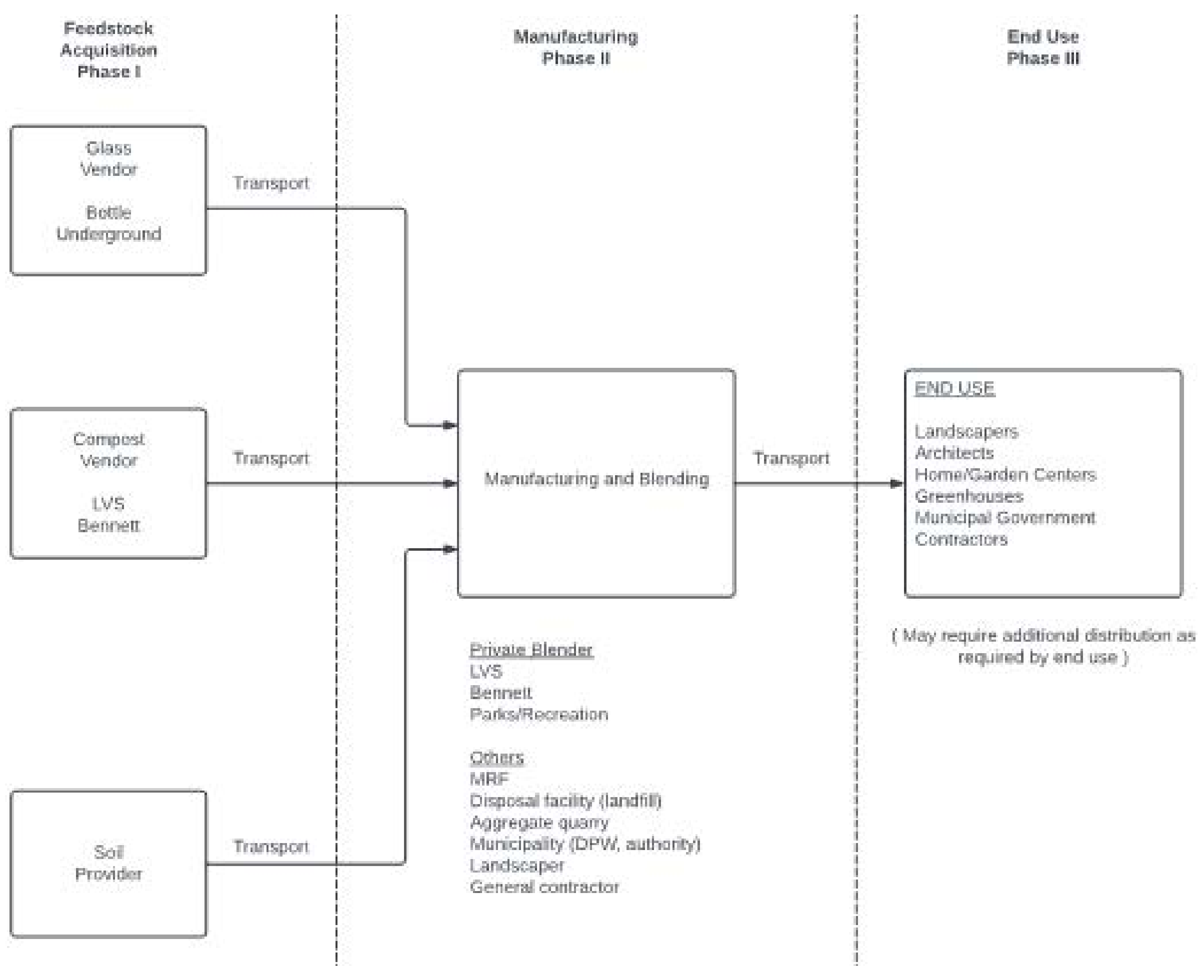

Figure 1: Flow of materials and processes involved with manufacturing of circular soils.

III. Product Feedstock Identification

Circular Soils consist of three feedstocks - natural or manufactured soils, compost, and crushed recycled glass, which are further described below. OLIN has developed a Trial Soil Specification (Appendix C).

Natural or Manufactured Soils

Natural soils obtained for commercial purposes are typically obtained from mine site overburden, construction sites that require excess soils to be removed to accommodate structures and site infrastructure, and farms. Desired soil structure types are loams, silt loams, and sandy loams and are free of excess clay and coarse fragments. Although not as prevalent as natural soils, manufactured soils can be made from soil-like residues from mining and industrial processes such mineral and ore dusts, spent foundry sand, slags and dust collected air handling systems. Often these materials are blended with natural soils.

Depending on the region, pricing for clean, screened natural or manufactured soils that meet the Circular Soils specification can range from $20 to $50 per cubic yard (FOB Origin)

Compost

The Association of American Plant Food Control Officials (AAPFCO) defines compost as product manufactured through the controlled aerobic, biological decomposition of biodegradable materials. The product has undergone mesophilic and thermophilic temperatures, which significantly reduces the viability of pathogens and weed seeds (in accordance with EPA 40 CFR 503 standards) and stabilizes the carbon such that it is beneficial to plant growth. Compost is typically used as a soil amendment but may also contribute plant nutrients. Finished compost is typically screened to reduce its particle size, to improve soil incorporation.

The U.S. EPA states that composting, or controlled decomposition, requires a proper balance of "green" organic materials and "brown" organic materials. "Green" organic material includes grass clippings, food scraps, and manure, which contain substantial amounts of nitrogen. "Brown" organic materials include dry leaves, wood chips, and branches, which contain substantial amounts of carbon but little nitrogen. Obtaining the right nutrient mix requires experimentation and patience and is part of the art and science of composting.

With over 400 municipal and private compost operations, Pennsylvania has a robust compost industry and market. This is due in part to Act 101 of 1988, Pennsylvania's recycling law, which requires municipalities with a population of greater than 5,000 to recycle certain items and collect leaves for composting. In addition to leaves, municipalities collect or accept at drop-off sites, grass clippings and woody yard waste. Private operations such as land clearing, tree trimming and landscaping companies accumulate large quantities of these materials which are then delivered compost and mulch operations. Major quantities of food scraps are also being collected and composted, from grocery stores, produce companies, large office and institutional campuses and restaurants. Residential food scrap collection activity in Pennsylvania is limited to its two largest cities, Pittsburgh and Philadelphia, and their suburbs. However, there are several municipal and commercial food scrap collection services offered in the rural areas. Currently, there are 29 commercial non-captive compost facilities in Pennsylvania that are authorized by PADEP to accept food scrap feedstocks.

Depending on the region, pricing for clean, mature, and screened compost that meets the Circular Soils specification can range from $15 to $35 per cubic yard (FOB Origin)

Crushed Recycled Glass

Feedstocks of crushed recycled glass originate from food and glass food and beverage containers recovered from single-stream, dual-stream and source-separated collection programs. Municipal material recovery facilities (MRF's) and recycled glass beneficators will in turn convert glass-laden processing residue and/or separated glass containers into a marketable feedstock. Manufacturing uses of crushed recycled glass other than circular soils include new bottles, lightweight foamed glass used for structural fill, fiberglass insulation, water and wastewater filtration media, and decorative countertops and landscaping.

Based on the 2021 Pennsylvania ReTrac Report, 1,242 municipalities included glass bottles and containers in their recycling collection programs. Currently in Pennsylvania, there are 11 single-stream and 40 dual stream or source-separated MRF's that accept glass containers at their facility. Collectively, the single stream MRF's handle the majority of the recycled materials in the Commonwealth and generate the most processing residue, which is comprised mostly of broken glass. There are 14 manufacturing plants in the Commonwealth that utilize glass feed stocks.

Depending on the region, pricing for crushed recycled glass aggregate made from single stream, dual stream, or source separated MRF's that meet the Circular Soils specification can range from $12 to $150 per ton. (FOB Origin)

V. Estimated Climate Impacts

By utilizing waste materials as feedstocks in the manufacturing of Circular Soils, there is significant potential to reduce GHG emissions. EPA's Waste

Table 1: Estimated PA Annual Recycled Organics Processing Facility Feedstock Component Availability (in tons)								
		PA DEP Region						
Data Source	**Type**	**NE**	**NC**	**NW**	**SW**	**SC**	**SE**	**Statewide**
Annual PA DEP ReTrac Report (organics recycled)	Food Waste	20,358	18.426	3,865	3,330	91,463	57,144	194,586
	Yard Waste	172,388	96,958	58,919	86,606	239,061	191,072	845,004
PA DEP Waste Characterization Study (organics landfilled or incinerated)	Food Waste	242,429	85,944	116,367	264,777	285,061	598,506	1,593,109
	Yard Waste	26,388	12,204	26,966	56,555	57,775	152,174	332,062
Total Organics Generation		**461,564**	**213,532**	**206,116**	**411,268**	**673,385**	**998,897**	**2,964,760**

Table 2: Estimated PA Annual Recycled Glass Processing Facility Feedstock Component Availability (in tons)								
		PA DEP Region						
Data Source	**Type**	**NE**	**NC**	**NW**	**SW**	**SC**	**SE**	**Statewide**
Annual PA DEP ReTrac Report (glass recycled)	Glass Waste	46,689	12,058	8,610	22,838	30,329	92,997	216,521
PA DEP Waste Characterization Study (glass landfilled or incinerated)		33,897	11,821	21,846	52,112	46,080	69,369	235,125
Total Glass Generation		**83,586**	**23,879**	**30,456**	**74,950**	**76,409**	**162,366**	**451,646**

Table 3: Climate Impact of Diverting Disposal Waste Glass, Food Waste, and Yard Trimmings to Produce Circular Soils						
Circular Soil Mix Components Evaluated	**Component Weight (tons) per 50,000 Cubic Yards**	**Addition / (Reduction)of MTECO$_2$E**	**Component Weight (tons) per 100,000 Cubic Yards**	**Addition / (Reduction) of MTECO$_2$E**	**Component Weight (tons) per 150,000 Cubic Yards**	**Addition / (Reduction) of MTECO$_2$E**
Food Scraps for Compost	10,625	(3,788)	42,500	(15,114)	63,750	(22,671)
Yard Trimmings for Compost	2,125	394	8,500	1,577	12,750	2,366
Waste Glass for Glass-Sand	15,593	(4,647)	31,185	(4,647)	46,778	(13,939)
Total	**29,343**	**(8,041)**	**82,185**	**(18,184)**	**123,278**	**(34,244)**

Reduction Model (WARM) is an appropriate tool to provide high-level estimates of (GHG) emissions reductions, as well as energy savings and economic impacts from several different waste management practices.

WARM calculates GHG emissions, energy, and economic impacts for baseline and alternative waste management practices, including source reduction, recycling, combustion, composting, and landfilling.

Using WARM, Table 3 provides an example of estimating of the positive climate impact from utilizing recycled glass, yard trimmings and food scrap feedstocks for the manufacturing of aggregate and compost components of Circular Soils. Climate impact is typically measured in the net reduction of metric tons carbon dioxide gas emissions ($MTECO_2E$). In this example, the climate impact is based on the manufacturing of 50,000, 100,000 and 150,000 cubic yards of Circular Soils respectively. It should be noted that based on WARM, the yard trimmings feedstock component compost results in an addition of GHG emissions. However, when combined with the food scraps and recycled glass aggregate feedstock components, there is a net reduction in GHG emissions.

WARM also calculates GHG reduction equivalents to show how reductions of GHG impact our economy and energy usage. Table 4 shows three examples of GHG reduction equivalents attributed to the production of Circular Soils.

VI. Compliance and Permitting Requirements.

Local/ County – In Pennsylvania, the level of local regulation and permitting depends on the type and size of municipality in which the proposed Circular Soils manufacturing operation or component operation is located. Zoning, land use and land development is typically regulated by ordinance by a municipality, which is the lowest level of government. However, individual and joint municipal planning commissions, as well as county and regional planning commissions, can assume these functions on behalf of one or more municipalities. On-site sewage disposal, potable water supplies, and stormwater management are also typically regulated/ operated at the local level but can be operated by a multi-municipal agency, authority, county health department, or in some cases a private entity through municipal contract or state utility commission authority.

Table 4: Green House Gas Reduction Equivalents

	Circular Soils		
	50,000 Cubic Yards	100,000 Cubic Yards	150,000 Cubic Yards
Metric Tons of CO2 Added / (Reduced)	(8,041)	(18,184)	(34,244)
Number of Passenger Vehicles Taken Out of Use	1,705	3,861	7,271
Gallons of Gasoline Conservted	90,652	2,046,055	3,853,326
Cylinders of Propane Conserved	334,615	757,637	1,426,854

County conservation districts regulate earth disturbance activity and review and enforce erosion, sedimentation, pollution control plans and post-construction stormwater management plans. Some counties administer the Commonwealth's National Pollutant Discharge Elimination System (NPDES) stormwater permitting program for sites that disturb greater than 1-acre of earth during construction activities.

From a local zoning use perspective, Circular Soils manufacturing would typically be classified as an industrial operation and would be a use permitted by right only in an industrial zoning district. A soil harvesting or manufacturing operation could typically be classified as mining or industrial and would be allowed as use permitted by right only in industrial and/ or mining zoning districts. Composting and soil blending operations could typically be classified as agricultural or industrial and would be allowed as use permitted by right only in agricultural and/ or industrial zoning districts.

Commonwealth – The level of permitting and compliance monitoring involvement from Pennsylvania agencies depends on the size and scope of the Circular Soils operation or component feedstock operation. The Pennsylvania Department of Environmental Protection (PA DEP) will likely have the most involvement with a Circular Soils operation. Typically, an operation that mechanically processes source-separated recycled materials (i.e. glass bottles and jars), is exempt from permitting by the Waste Management Bureau. Depending on size of operation and type of feedstocks, a permit-by-rule, general permit or individual permit is required by the Waste Management Bureau. The Air Quality and Water Quality bureaus may have jurisdiction if potential air and water pollutant discharges warrant permits. For a soil harvesting operation, a non-coal mining permit may be required from the Mining Bureau.

PA Department of Agriculture – Compost or product that contain compost operations that sell their products require registration the Bureau of Plant Industry, Division of Agronomic Services.

In summary, permitting or some type of approval will be required from all levels of government in Pennsylvania. It is recommended that proposed Circular Soils manufacturing operations seek assistance from a professional consultant and/ or an attorney to assist in navigating through the permitting process.

VII. Description/ Identification of Real or Perceived Competition

Existing soil blending operations located within close proximity will be the main competition of a proposed Circular Soils operation. They will most certainly compete for customers of the product(s) that they produce, therefore pricing will be a critical factor to consider. If premium pricing is considered, marketing is critical as the customer should be well informed of the potential social, environmental, and economic benefits of using Circular Soils vs. traditional blended soil. It is also possible they may compete for the common feedstocks utilized by each operation (i.e. compost and soil) which may drive up their cost if supplies are limited in the region in which they are located. These same issues may hold true even if a Circular Soils operation manufactures its own feedstocks by also operating a compost and/or a crushed recycled sand site.

VIII. Best Available Technology

The technology of Circular consists of an engineered soil, and an engineered process plan to utilize soil, pulverized glass and to produce a clean, functional, soil product with demonstrated plant growth, and water draining potential similar to sand-based blended soils. The production of Circular Soils requires equipment containing typical levels of modern technology, including but not limited to:

- For soil feedstocks: excavators, conveyors, loaders, trommels, screeners hauling trucks
- For compost feedstocks: loaders, grinders, windrow turners, trommels, conveyors and hauling trucks. For aerated compost systems, blowers with electrical controls and piping.
- For crushed recycled glass feedstocks: crushing and screening plant, loaders and trucks. Literature on a typical recycled glass processing plant is provided as Appendix D and further discussed in Section XII.

IX. Launch Schedule

The estimated time from project greenlight to commencement of operations for a new Circular Soils operation that includes compost and crushed recycled glass production is 18 – 24 months.

X. Management of Intellectual Property

There are no intellectual property issues related to this project.

XI. Marketing Strategy

The recycling industry has seen immense growth over the past fifty years. That's in part because, according to the EPA, the U.S. recycles over 35% of its total municipal solid waste annually. That figure has increased from under 10% before 1990. This increase in recycling activity led to a significant rise in the number of smaller recycling companies and the competition that ensued. This competition means recycling-based businesses need to have innovative marketing plans to stand out from the crowd. Below are some marketing strategies that may help a new recycling business become successful:

Engage and inform customers on social media and utilize internet-based tools.

- The use of social media such as Twitter, Facebook, Instagram, and Linkedin is an effective way to help build trust with customers and inform customers of new product offerings and promotions.
- Hashtags have made their way onto every major platform, from Instagram to Pinterest, which presents an opportunity for businesses and are a great way to connect with potential customers and find topics that are trending.
- Blogging about the benefits of Circular Soils and customer's projects can inform current clients and attract new ones.
- Improving a website's visibility and use of industry directories to enhance local SEO (Search Engine Optimization) can improve search engine visibility for local businesses and can improve traffic from searches performed by customers in nearby areas.
- Digital marketing services can reduce paid advertising costs.
- Creating and maintaining internet business profiles such as Google My Business can help customers find local businesses easier.
- Get published in local newspapers, industry publications, and more.
- Local newspapers, chambers of commerce and industry associations, both online and offline, are often looking for quality content from industry experts to feature in their publications. Reaching out to these businesses to see if they will publish an informative piece about your company, the

industry, or any other topics. The goal is to share valuable information with the readers of their publications, while also establishing yourself as an industry authority.

- Industry organizations such as the U.S. Green building Council and the U.S. Composting Council and their state and local affiliates focus on advocacy, research & development, and education & outreach. In person or remote opportunities exist to present, exhibit, or attend numerous conferences, seminars, meetings, and webinars. The networking alone at these events provides valuable marketing opportunities.

XII. Example Business Models

Below are several examples of Circular Soils business models, which can include combinations of operations that process soil, compost, and glass feedstocks as well as operations that blend, prepare for market, and ship specified Circular Soil products.

Example Business Model 1 – No brick-and-mortar facility/ business operated through supply and service contracting.

- No investment of capital is required for setting up and operating Circular Soils feedstock or blending facilities.

- Through contracting with feedstock suppliers, one or more soil blending operations, hauling companies, business can market its own Circular Soils brand.

- Minimum quantity, delivery timing and non-compete contract provisions are critical.

Advantages – No capital investment required. Business can commence as soon as supply contracts are in place and orders are obtained.

Disadvantages – Business depends solely on performance supply agreements and service contracts. Feedstock supply pricing may lean towards retail markets vs. wholesale. Non-performance of even one contract can result in delays in production and order fulfillment.

Example Business Model 2 – Addition of Circular Soils to the product line of an existing compost or soil blending operation.

- If sufficient compost and blending production capacity exists, investment of capital may not be required to add a Circular Soils product.

- A supply agreement with one or more recycled glass sand producers would be required. Minimum quantity, delivery timing and non-compete contract provisions are critical.

Advantages – Little to no capital investment required. Business can commence as soon as recycled glass sand supply contract(s) is in place and orders are obtained.

Disadvantages – May need to consider the possibility of additional labor requirements and other operational costs. Business depends on the performance of recycled glass supply agreement(s). Feedstock supply pricing may lean towards retail markets vs. wholesale. Non-performance of a recycled glass supply contract can result in delays in production and order fulfillment.

Example Business Model 3 – Establishment of a new Circular Soils feedstock production and/ or blending operation at an existing MRF (Material Recovery Facility) or/ and undeveloped site.

- Significant investment of capital will be required to add one of more Circular Soils feedstock production and blending operations.

- Local, county state approvals and permitting come into play with new land development proposals and additions to existing operations (see Section VI.).

Advantages – The operation controls all or most of the Circular Soil feedstocks. The need for supply contracts has been eliminated or reduced.

Disadvantages – Larger capital investment, additional labor requirements and operational costs may be required. Local and state approvals will delay the commencement of operations.

Example of a Recycled Glass Pulverizing System

Andela Products, a woman-owned business enterprise headquartered in Richfield Springs, NY, is one of several U.S.-based companies that manufactures and delivers ready-to-operate individual units or turnkey systems designed specifically to turn waste glass back into user-friendly sand. Production capacities of Andela pulverizers range from ½ ton per hour to 20 tons per hour.

Not including pre-installation site work such 3-phase 240/460 power, concrete pads, and bunkers pricing ranges from $60K to 350K. Installation using a crew of mechanics and electricians takes up to one week at an additional cost of up to $10K. Additional accessory equipment such as surge hoopers, conveyors trommels and clean-up equipment can be acquired.

One person can operate the smaller units and up to two people can operate the larger units. For a typical 8-hour shift, one hour is reserved for cleanup and equipment maintenance. Operational costs range from $15 to $20 per ton of pulverized recycled glass produced.

Appendix A

Construction Documents

EPA SBIR PHASE II PILOT

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ONE PENN CENTER
1617 JOHN F. KENNEDY BOULEVARD, SUITE 1900
PHILADELPHIA, PA 19103
TEL 215.440.0030 / FAX 215.440.0041
WWW.THEOLINSTUDIO.COM
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The Creative Arts Building
219 Cuthbert Street, 5th Floor
Philadelphia, PA 19106
215-330-4113

LEGEND

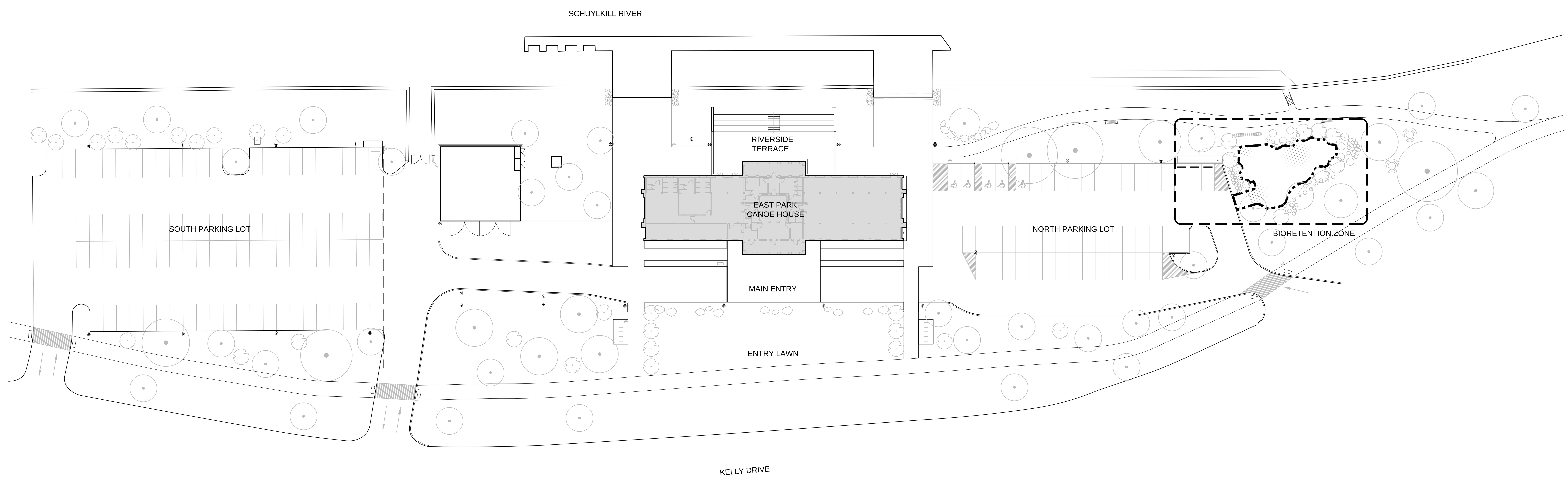
- LIMIT OF WORK
- EXISTING TREE
- EXISTING UNDERSTORY TREE
- EXISTING SHRUBS
- PROPOSED BIORETENTION PLANTING - SEE L900

GENERAL NOTES:

1. CONTRACTOR SHALL COMPLY WITH ALL APPLICABLE CODES AND REGULATIONS GOVERNING THE WORK.
2. DO NOT SCALE OFF DRAWINGS, USE DRAWING DIMENSIONS ONLY. VERIFY ALL DIMENSIONS AND EXISTING CONDITIONS IN THE FIELD PRIOR TO COMMENCEMENT OF WORK. BRING TO THE ATTENTION OF LANDSCAPE ARCHITECT ANY DISCREPANCIES BETWEEN FIELD CONDITIONS AND DRAWINGS PRIOR TO THE BEGINNING OF WORK. FIELD CONDITION DISCREPANCIES SHALL NOT BE USED AS THE BASIS FOR CHANGE ORDER CLAIMS ONCE WORK HAS BEGUN.
3. PRESERVE AND PROTECT ALL EXISTING STRUCTURES, FURNISHINGS, SURFACE MATERIALS, ABOVE AND BELOW - GRADE UTILITIES, FOOTINGS AND VEGETATION INDICATED TO REMAIN WITHIN AND ADJACENT TO LIMIT OF WORK DURING ALL PHASES OF DEMOLITION AND CONSTRUCTION.
4. THE EXISTENCE AND LOCATION OF EACH AND EVERY UNDERGROUND UTILITY IS NOT GUARANTEED AND UNDOCUMENTED CONDITIONS MAY EXIST. COORDINATE WITH LANDSCAPE ARCHITECT FOR LOCATIONS OF UTILITIES NOT SHOWN ON THE BASE DRAWING INCLUDING, BUT NOT LIMITED TO, HIGH VOLTAGE ELECTRIC, ABANDONED STEAM LINES, ABANDONED WATER LINES, TELEPHONE, CABLES, ETC. STAKE OUT LOCATION OF ALL UTILITIES PRIOR TO COMMENCEMENT OF WORK. ANY UTILITY THAT IS DAMAGED DURING SITE WORK OPERATIONS SHALL BE REPAIRED AT THE CONTRACTOR'S EXPENSE.
5. MAINTAIN VEHICULAR TRAFFIC FLOW TO AND AROUND THE SITE. MAINTAIN CLEARLY MARKED PEDESTRIAN ACCESS TO AREAS ON-SITE NOT AFFECTED BY CONSTRUCTION ACTIVITIES.
6. CONTRACTOR SHALL MEET EXISTING GRADES AT ALL EDGES OF LIMIT OF WORK.
7. CONTRACTOR IS RESPONSIBLE FOR ALL NECESSARY MEASURES TO PREVENT SOIL EROSION. APPROVED SOIL EROSION AND SEDIMENTATION CONTROL MEASURES MUST BE INSTALLED BEFORE SITE CLEANING AND SITE GRADING OPERATIONS BEGIN.
8. SOIL DISTURBANCE WITHIN TREE PROTECTION ZONES SHALL BE KEPT TO A MINIMUM. HEAVY MACHINERY, MECHANICAL TRENCHING OR MATERIAL STORAGE IS NOT PERMITTED WITHIN THE TREE PROTECTION ZONE. ALL DIGGING WITHIN TREE PROTECTION ZONE SHALL BE BY HAND.
9. CORE AERATOR, TOP DRESSING MACHINE, AIR SPADING, HAND DIGGING OR OTHER APPROVED METHOD OF DIGGING AND TRENCHING SHALL BE USED IN PLACE OF ROTOTILLER TO COMPLETE ALL WORK IN TREE PROTECTION ZONES. CARE MUST BE TAKEN TO AVOID DISTURBANCE TO ROOTS OF ALL EXISTING TREES, INCLUDING ROOTS EXTENDING OUTSIDE THE TREES PROTECTION ZONES. EXCAVATION WITHIN PROTECTED ZONES SHALL BE BY MEANS OF AIR SPADING, OPERATED BY A TRAINED AND CERTIFIED OPERATOR.

SURVEY NOTES:

1. EXISTING BOUNDARY LINE, TOPOGRAPHIC AND SITE UTILITY INFORMATION IS BASED UPON SURVEY PLANS BY E&LP DATED SEPTEMBER 14TH, 2015 AND JANUARY 6TH, 2017. ACTUAL CONDITIONS MAY HAVE CHANGED SINCE SURVEY WAS PERFORMED. CONTRACTOR SHALL VERIFY EXISTING CONDITIONS IN THE FIELD AND REPORT ANY DISCREPANCIES TO LANDSCAPE ARCHITECT.



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KEY PLAN

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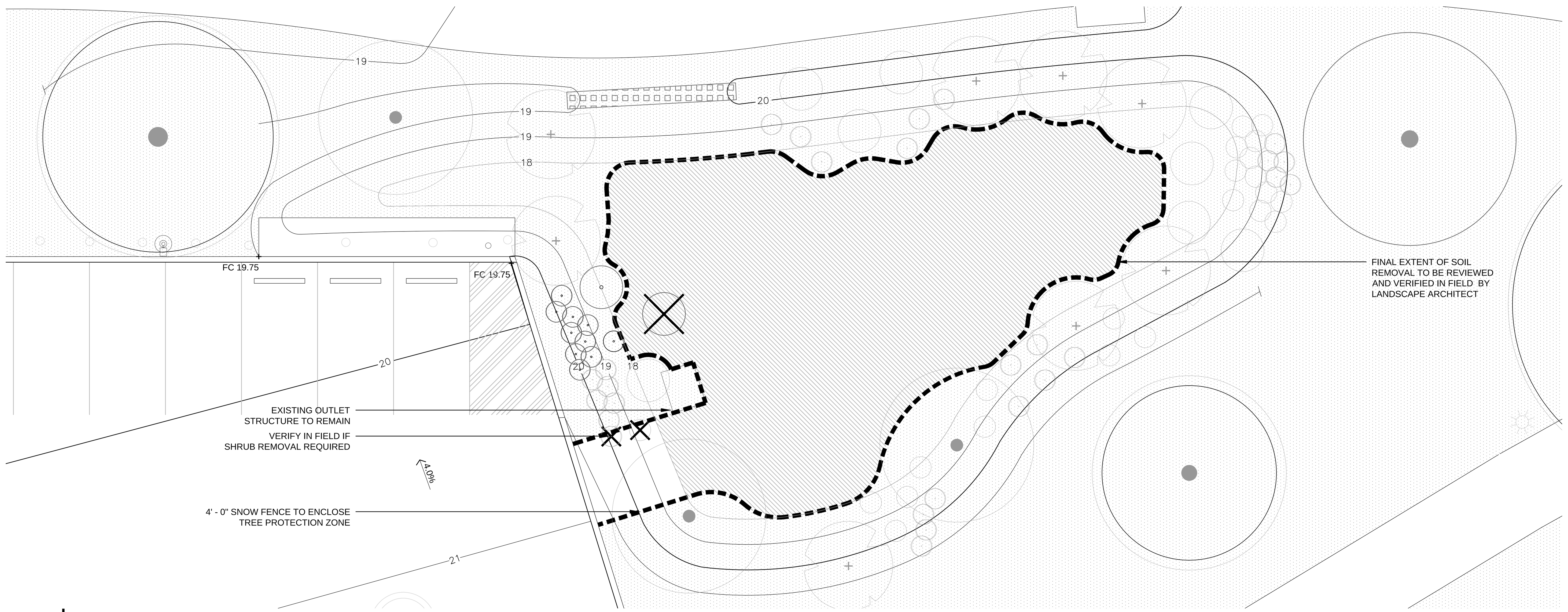


1 | BIORETENTION ZONE PLAN
1/8" = 1'-0"

TREE PROTECTION PLAN LEGEND

EXISTING SHRUB TO BE REMOVED

EXISTING TREE OR SHRUB TO BE PROTECTED

EXTENT OF SOIL REMOVAL

EXTENT OF TREE PROTECTION

TREE PROTECTION AND DEMOLITION PLAN NOTES:

1. ALL TREES AND SHRUBS WITHIN TREE PROTECTION ZONE BOUNDARIES SHALL REMAIN AND BE PROTECTED DURING CONSTRUCTION, UNLESS SPECIFICALLY DESIGNATED TO BE REMOVED. PRIOR TO REMOVAL, THE CONTRACTOR SHALL ARRANGE AN ON-SITE MEETING WITH THE LANDSCAPE ARCHITECT TO REVIEW THE CLEARING LIMIT LINES AND DATES OF REMOVAL.
2. TREE PROTECTION ZONE FENCING SHALL BE ERECTED AT THE EDGE OF THE CRITICAL ROOT ZONE OR BEYOND PRIOR TO THE START OF ANY CONSTRUCTION ACTIVITY. LOCATION OF TREE PROTECTION FENCING CORRESPONDS TO THE DRIPLINE RADIUS OF EXISTING TREES OR CONSTRUCTION LIMITS. DRIPLINE TO BE VERIFIED IN THE FIELD AS EXISTING CONDITIONS MAY VARY.
3. TREE PROTECTION ZONE FENCING SHALL BE MINIMUM 4' HIGH ON ALL SIDES AND SHALL BE SUPPORTED BY VERTICAL POSTS ANCHORED INTO THE GROUND. MULTIPLE TREE FENCE LAYOUT PREFERRED OVER FENCING EACH TREE OR SHRUB INDIVIDUALLY.
4. SOIL DISTURBANCE WITHIN TREE PROTECTION ZONES SHALL BE KEPT TO A MINIMUM. HEAVY MACHINERY, MECHANICAL TRENCHING OR MATERIAL STORAGE IS NOT PERMITTED WITHIN THE TREE PROTECTION ZONE. ALL DIGGING WITHIN TREE PROTECTION ZONE SHALL BE BY HAND.
5. CORE AERATOR, TOP DRESSING MACHINE, AIR SPADING, HAND DIGGING OR OTHER APPROVED METHOD OF DIGGING AND TRENCHING SHALL BE USED IN PLACE OF ROTOTILLER TO COMPLETE ALL WORK IN TREE PROTECTION ZONES. CARE MUST BE TAKEN TO AVOID DISTURBANCE TO ROOTS OF ALL EXISTING TREES, INCLUDING ROOTS EXTENDING OUTSIDE THE TREES PROTECTION ZONES. EXCAVATION WITHIN PROTECTED ZONES SHALL BE BY MEANS OF AIR SPADING, OPERATED BY A TRAINED AND CERTIFIED OPERATOR.
6. PROHIBITED ACTIVITIES: THE FOLLOWING ACTIVITIES ARE PROHIBITED DURING DEMOLITION AND CONSTRUCTION WITHIN TREE PRESERVATION AREAS:

7.1 PLACING BACKFILL; EXCEPT AS AUTHORIZED FOR REGRADING AND UNDER OBSERVATION BY LANDSCAPE ARCHITECT.

7.2 SWINGING BACKHOES INTO TREE CANOPIES.

7.3 STORING OR DUMPING SUPPLIES AND MATERIALS INCLUDING STOCKPILING EXCAVATION AND FILL MATERIALS.

7.4 RAISING OR LOWERING GRADES; EXCEPT AS AUTHORIZED FOR REGRADING BY LANDSCAPE ARCHITECT.

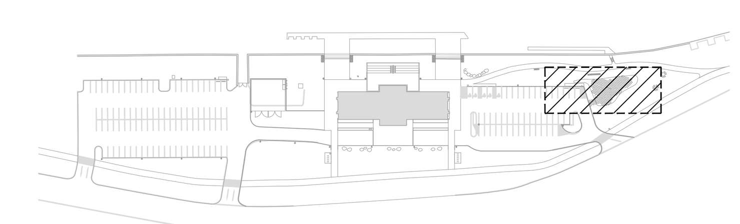
7.5 DRIVING OR PARKING EQUIPMENT, MACHINERY, OR VEHICLES.

7.6 DUMPING OF WASH-OUT FROM CLEANING EQUIPMENT, TRASH, OR DEBRIS.

7. DO NOT DIRECT VEHICLE OR EQUIPMENT EXHAUST TOWARD TREE PRESERVATION AREAS.
8. PROHIBIT HEAT SOURCES, FLAMES, IGNITION SOURCES, AND SMOKING WITHIN OR NEAR TREE PRESERVATION AREAS AND ORGANIC MULCH.
9. LOCATION OF TREE PROTECTION FENCING MAY BE TEMPORARILY ADJUSTED TO FACILITATE CONSTRUCTION. ADJUSTMENTS TO BE MADE IN CONSULTATION WITH LANDSCAPE ARCHITECT ON SITE.
10. ALL TREES DESIGNATED TO BE PROTECTED THAT ARE DAMAGED OR KILLED DURING CONSTRUCTION ARE TO BE REPLACED WITH A TREE OF OF THE SAME SPECIES AND CALIPER (OR LARGEST COMMERCIALLY AVAILABLE CALIPER) OR ALTERNATIVE SPECIES RECOMMENDED AND APPROVED BY THE LANDSCAPE ARCHITECT.
11. CONTRACTOR WILL BE RESPONSIBLE FOR ALL TREE PROTECTION OUTSIDE THE LIMIT OF WORK.

SURVEY NOTES:

1. EXISTING BOUNDARY LINE, TOPOGRAPHIC AND SITE UTILITY INFORMATION IS BASED UPON SURVEY PLANS BY E&LP DATED SEPTEMBER 14TH, 2015 AND JANUARY 6TH, 2017. ACTUAL CONDITIONS MAY HAVE CHANGED SINCE SURVEY WAS PERFORMED. CONTRACTOR SHALL VERIFY EXISTING CONDITIONS IN THE FIELD AND REPORT ANY DISCREPANCIES TO LANDSCAPE ARCHITECT.



KEY PLAN

EPA SBIR PHASE II PILOT

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LANDSCAPE ARCHITECTURE / URBAN DESIGN / PLANNING
ONE PENN CENTER
1617 JOHN F. KENNEDY BOULEVARD, SUITE 1900
PHILADELPHIA, PA 19103
TEL 215.440.0030 / FAX 215.440.0041
WWW.THEOLINSTUDIO.COM
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219 Cuthbert Street, 5th Floor
Philadelphia, PA 19106
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No.	Date	Description

TREE PROTECTION AND DEMOLITION PLAN

Scale:	VARIES
Date:	6/16/2022
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SOILS PLAN LEGEND

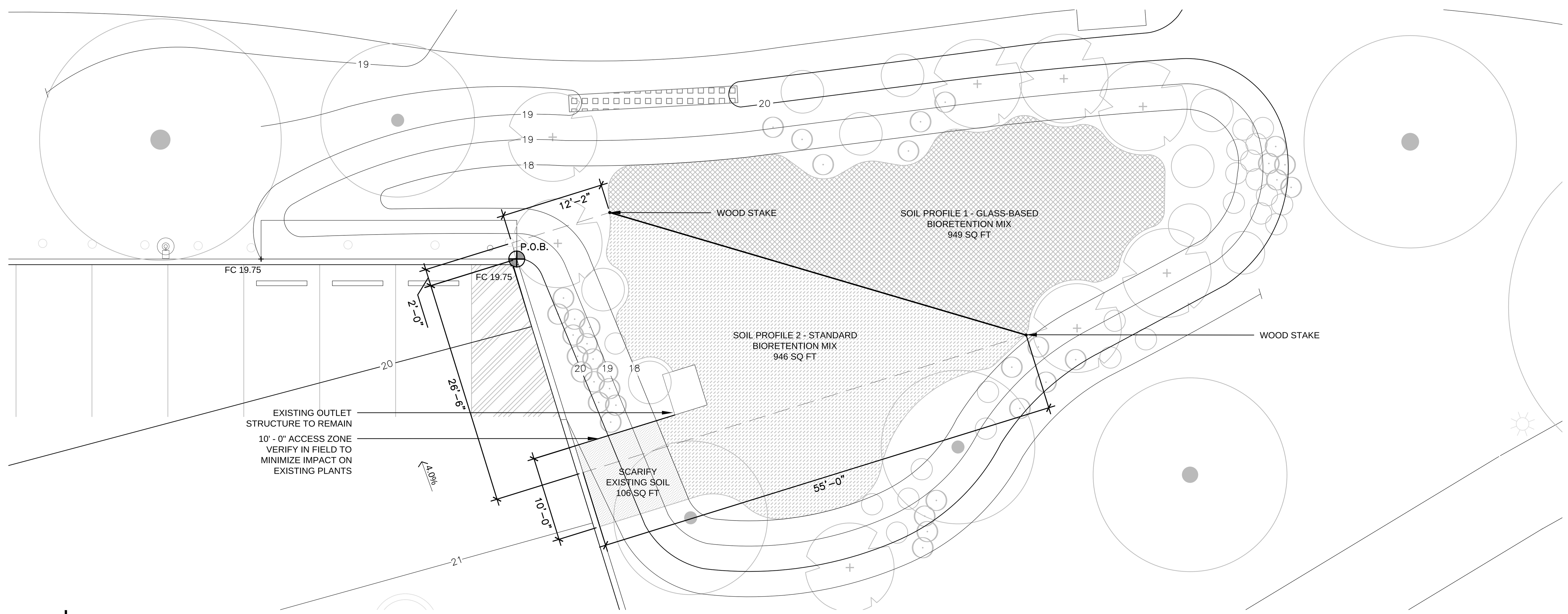
- ZONE DIVISION FENCING
- SOIL PROFILE 1 - GLASS-BASED BIORETENTION MIX - SEE 2/L400
- SOIL PROFILE 2 - STANDARD BIORETENTION MIX - SEE 3/L400
- SCARIFY EXISTING SOIL

SURVEY NOTES:

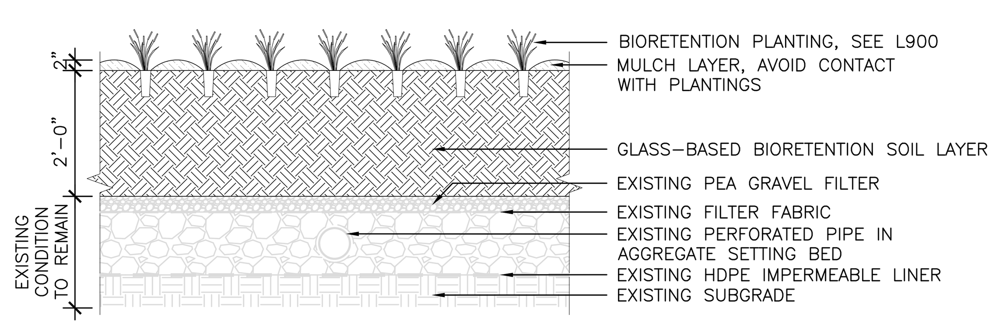
1. EXISTING BOUNDARY LINE, TOPOGRAPHIC AND SITE UTILITY INFORMATION IS BASED UPON SURVEY PLANS BY E&LP DATED SEPTEMBER 14TH, 2015 AND JANUARY 6TH, 2017. ACTUAL CONDITIONS MAY HAVE CHANGED SINCE SURVEY WAS PERFORMED. CONTRACTOR SHALL VERIFY EXISTING CONDITIONS IN THE FIELD AND REPORT ANY DISCREPANCIES TO LANDSCAPE ARCHITECT.

SOILS NOTES:

1. ALL AMENDED SOIL MATERIAL SHOULD BE THOROUGHLY BLENDED AND BE CONSISTENT THROUGHOUT.
2. SOIL SHALL BE INSTALLED IN 12 INCH LIFTS AT 85% COMPACTION
3. SCARIFY EXISTING SUBGRADE WHEN DRY AND PRIOR TO ADDING FILL
4. REFER TO SOIL SPECIFICATION.



1 BIORETENTION ZONE PLAN
1/8" = 1'-0"



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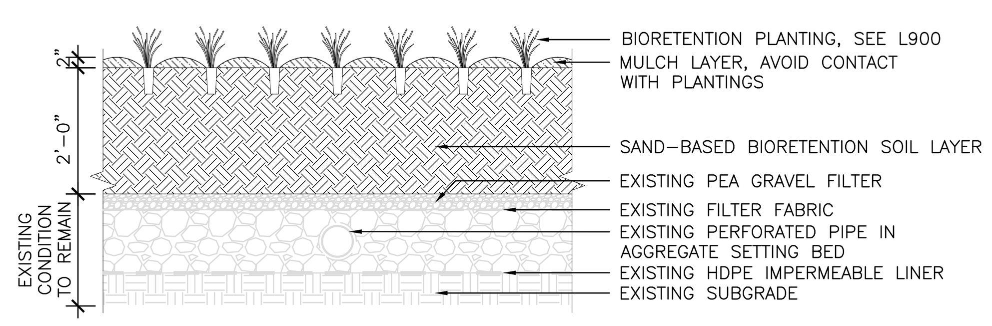
SCALE: 1/2" = 1'-0"



3 SOIL PROFILE 2 - STANDARD BIORETENTION MIX
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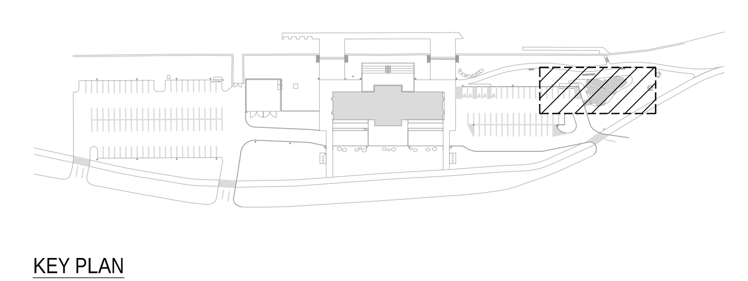

KEY PLAN

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GRADING AND SOILS PLAN

Scale: VARIES
Date: 6/16/2022
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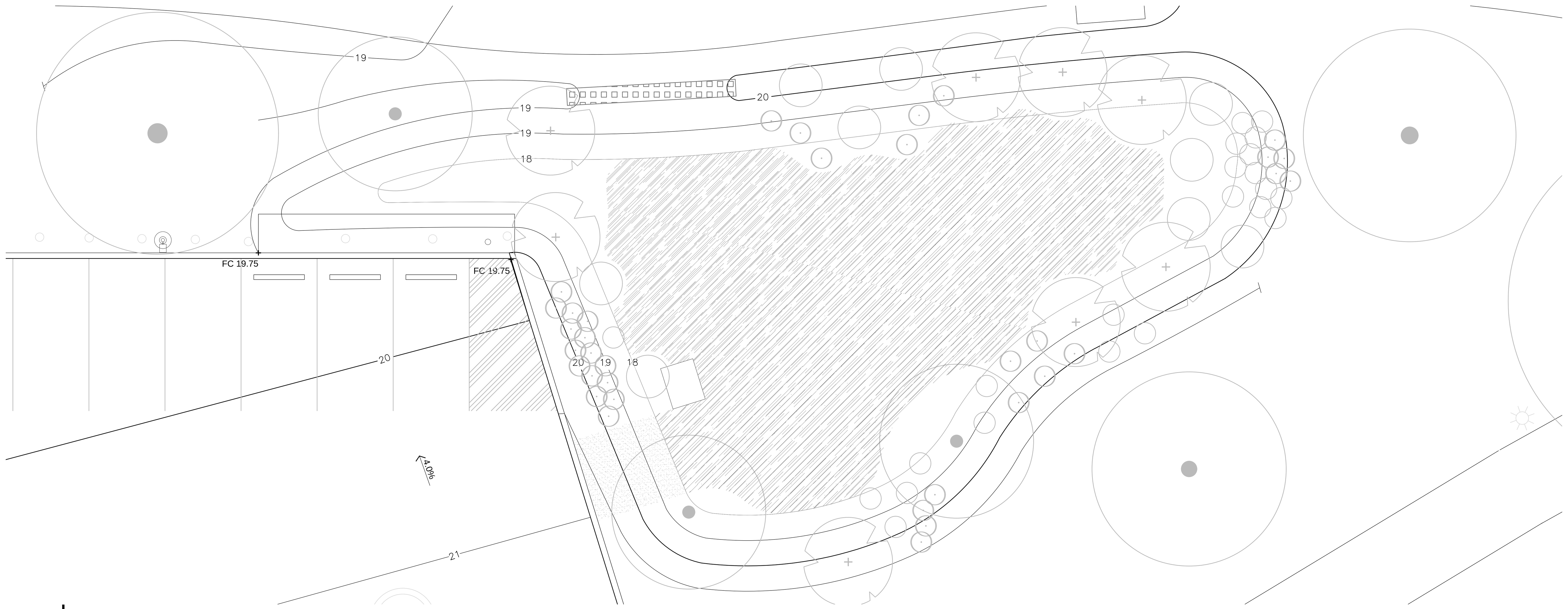


1 | BIORETENTION ZONE PLAN
1/8" = 1'-0"

PLANTING PLAN LEGEND

EXISTING TREE

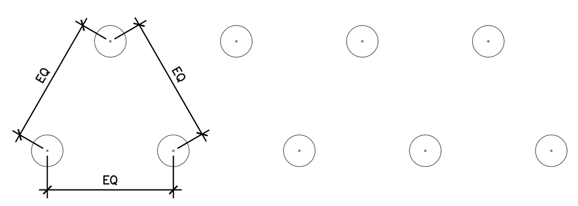
EXISTING SHRUBS

PLANTING NOTES:

1. ALL TREES SHALL REMAIN AND BE PROTECTED DURING CONSTRUCTION, UNLESS SPECIFICALLY DESIGNATED TO BE REMOVED. PRIOR TO REMOVAL, THE CONTRACTOR SHALL ARRANGE AN ON-SITE MEETING WITH THE LANDSCAPE ARCHITECT TO REVIEW THE CLEARING LIMIT LINES. VERIFY LOCATIONS OF ALL UTILITIES PRIOR TO EXCAVATION OR PLANT PITS.
2. P.B. = PLANT BED. MULCH ALL PLANT BEDS TO A DEPTH OF 2". BEDS SHALL BE KEPT 1" MIN AWAY FROM TRUNK OF ALL TREES, SHRUBS, AND FOLIAGE OF ALL PERENNIALS.
3. THE CONTRACTOR SHALL SUPPLY ALL PLANT MATERIAL IN QUANTITIES SUFFICIENT TO COMPLETE THE PLANTING SHOWN IN THE DRAWINGS.
4. CONTRACTOR SHALL REMOVE ALL HARD LUMPS OF CLAY, STONES OVER 1" IN DIAMETER, AND ALL CONSTRUCTION DEBRIS INCLUDING GRAVEL, ROOTS, LIMBS AND OTHER DELETERIOUS MATTER WHICH WOULD BE HARMFUL, OR PREVENT PROPER ESTABLISHMENT AND/OR MAINTENANCE OF PLANTING AREAS.
5. ALL PLANTS SHALL BE CONTAINER GROWN UNLESS OTHERWISE NOTED IN THE PLANTING SCHEDULE.
6. ALL PLANTS SHALL BE APPROVED BY THE LANDSCAPE ARCHITECT PRIOR TO THEIR ARRIVAL ON THE SITE
7. THE CONTRACTOR SHALL LOCATE AND VERIFY UTILITY LINE LOCATIONS PRIOR TO PLANTING AND REPORT ANY CONFLICTS TO THE LANDSCAPE ARCHITECT.
8. THE LAYOUT OF PLANTS IN THE FIELD IS TO BE APPROVED BY THE LANDSCAPE ARCHITECT PRIOR TO PLANTING.

SURVEY NOTES:

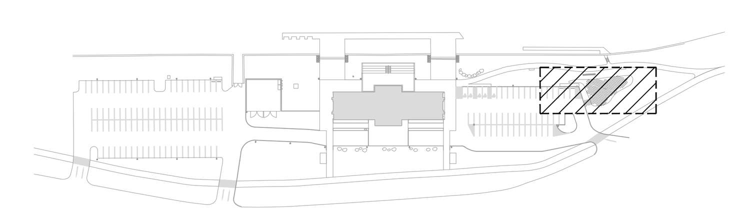
1. EXISTING BOUNDARY LINE, TOPOGRAPHIC AND SITE UTILITY INFORMATION IS BASED UPON SURVEY PLANS BY E&LP DATED SEPTEMBER 14TH, 2015 AND JANUARY 6TH, 2017. ACTUAL CONDITIONS MAY HAVE CHANGED SINCE SURVEY WAS PERFORMED. CONTRACTOR SHALL VERIFY EXISTING CONDITIONS IN THE FIELD AND REPORT ANY DISCREPANCIES TO LANDSCAPE ARCHITECT.



2 | PLANT SPACING
SCALE: 1" = 1'-0"

PLANT SCHEDULE

PART SUN EXPERIMENTAL MIX		
CALAMAGROSTIS X ACUTIFLORA 'KARL FOERSTER' / KARL FOERSTER FEATHER REED GRASS	LP50 PLUG	16.7% @ 12" oc
CAREX VULPINOIDEA / FOX SEDGE	LP50 PLUG	16.6% @ 12" oc
IRIS VERSICOLOR / BLUE FLAG	LP50 PLUG	16.6% @ 12" oc
JUNCUS EFFUSUS / COMMON RUSH	LP50 PLUG	16.7% @ 12" oc
PENSTEMON DIGITALIS / BEARDTONGUE	LP50 PLUG	16.7% @ 12" oc
VERNONIA NOVEBORACENSIS / COMON IRONWEED	LP50 PLUG	16.7% @ 12" oc
PART SUN SLOPE MIX		
ANDROPOGON VIRGINICUS / BROOMSEDGE BLUESTEM	LP50 PLUG	66.6% @ 12" oc
JUNCUS EFFUSUS / COMMON RUSH	LP50 PLUG	33.4% @ 12" oc



KEY PLAN

No.	Date	Description

PLANTING PLAN

Scale:	VARIES
Date:	6/16/2022
Drawn:	MS
Checked:	SL
Project No.:	2109

L900

Y:\Projects 2021\2109-Soil-less EPA Small Business Grant\04_Working\PHASE II\CAD\3CD_OLIN\Plotsheets\L_901-Planting Plan-Ground.dwg; Schmeckpeper, Mello 8/22/2022 4:53:12 PM

Appendix B

Recovered Crushed Glass

Materials Safety Data Sheet

Appendix 2: Material Safety Data Sheet

This Material Safety Data Sheet (MSDS) for RCG has been created for this project. It is based the requirements outlined in the latest edition of the Safe Work Australia *National Code of Practice for Preparation of a Safety Data Sheet.*

Any organisation supplying, using or handling RCG may add their name, contact details and other information to this SDS where "?" appears, for use by their customers or employees.

Materials Safety Data Sheet

SDS No:		Issued	?
Product Name:	**Recovered Crushed Glass (RCG)**		
Other names:	Glass Fines, Crushed glass, Glass Granulates, Glass Aggregate		

Hazard Classification: Not classified as being a Hazardous Substance according to the classification criteria of Safe Work Australia.

Section 1: Company and Product Details

Company Details:

Company Name:
Address:
Telephone: Fax:
Emergency contact: Mobile:

Product Details:

Product Name: RCG

Product Use: Crushed recycled glass for use in construction of road base or trench backfill.

Section 2: Identification of Hazards

Hazard Classification:

Hazardous Substance: No classification
Dangerous Goods: No classification
Poisons Schedule: No schedule

Health Effects:

Precautionary Note: While this material does not meet hazard classification criteria, It is still considered that exposure to this dust may be irritating and it is recommended that wherever possible, exposure be avoided, or where this is not possible, recommended respiratory eye and skin protection be used, as indicated in Section 8.

Inhaled: Inhalation of dusts may cause irritation of the airways of the nose, throat and respiratory system
Repeated inhalation may add to the serious health effects caused by smoking tobacco.

Appendix C

Trial Soil Specification

GREEN INFRASTRUCTURE SYSTEMS DESIGNED FOR INFILTRATION

PART 1 – GENERAL

1.1 SUMMARY

A. SCOPE:

This specification is to use recycled glass cullet as a sand replacement at a mix ratio needed for infiltration for GSI systems. Excess use of glass cullet within the soil mix reduces infiltration rates.

1. Evaluation of rough subgrade water infiltration.
2. Design for infiltration for sizing and infiltration rates.
3. Final Mix.

B. LEEDs and SITES Documentation:

1. This material will qualify for recycled content components for LEEDS and SITES:
    a. Declare Label.
    b. Cradle to Cradle product certification.
    c. Environmental Product Declaration (EPD).

2. Specific project goals that may impact this area of work include: use of recycled-content materials, and use of locally-manufactured materials. The Contractor shall ensure that the requirements related to these goals, as defined in the Articles below, are implemented to the fullest extent. Substitutions, or other changes to the work proposed by the Contractor or their Subcontractors, shall not be allowed if such changes compromise the aforementioned environmental and LEED goals.

3. Sustainable Design Documentation: Provide documentation per - Sustainable Design Requirements to demonstrate compliance with LEED requirements for this material.
    a. Credit MRc3 - Building product disclosure and optimization - Sourcing of Raw Materials:
        1) Recycled Content.
        2) Regional Materials.

    b. Credit MRc4 - Building product disclosure and optimization - Material Ingredients.

4. SITES Credits: Provide documentation per - Sustainable Design Requirements to demonstrate compliance with SITES requirements for this material.
    a. Credit 5.4 - Reuse salvaged materials and plants
    b. Credit 5.5 – Use Recycled Content Materials

C. Qualifications:

1. *Analysis and Testing of Materials Qualifications*: For each type of packaged material required for the work of this Section, provide manufacturer's certified analysis. For all other materials, provide complete analysis by a recognized laboratory made in strict compliance with the standards and procedures of the following:

    American Society of Testing Materials (ASTM)
    American Society of Agronomy
    Soil Science Society of America (SSSA)

Association of Official Agricultural Chemists (AOAC)
U.S Composting Council

2. Quality Assurance Qualifications: Work and materials shall meet the standards of the following references:

International Society of Arboriculture (ISA)
American Society for Testing Materials (ASTM)
Environmental Protection Agency (EPA)

3. *Soil Mixing Contractor Qualifications*:

   a. Shall be able to provide soil mixes that meet the specifications within tolerances assigned.
   b. Shall be able to produce enough consistently uniform soil material for the project to meet the scheduled demands.

4. *Testing Laboratory Qualifications*: An independent laboratory, recognized by the State Department of Agriculture, with experience and capability to conduct the testing indicated and that specializes in types of tests to be performed.

   a. A laboratory that follows ASTM, AOAC and SSSA standards for sampling, testing, and reporting soil data.
   b. The approved laboratory shall be able to report data as per ASTM standards for whole soil testing.

1.2 TESTING FOR CONFORMANCE

A. *Certificates:* Provide certificates required by authorities having jurisdiction, including any composted materials containing sewage sludge and material sources as defined by the Sites documentation. Approval as EPA Type 1 "exceptional quality" is required as well standards for application of composted organic material by the Commonwealth of Pennsylvania.

B. *Test Procedures and Reporting:* Submit certified report for each test required. Each test report shall have its associated soil layer clearly marked along with the name of the soil supplier. Only complete submittals with all corresponding test results and samples as list within Part 1 will be reviewed.

1. *Compost:* Analyses of composted organic materials, including composted biosolids, are required prior to initial soil mix acceptance. Analyses shall include all tests specified below and meet the criteria listed in Part 2 of this section.

   a. Maturity index either by Solvita, Dewar Self Heating or CO2 evolution sometimes called respirometry.
   b. Reaction in 1:1 water
   c. Carbon/Nitrogen ratio
   d. Foreign Material on a dry weight basis
   e. Organic Matter percent on a dry weight basis
   f. Ammonium-N using an extract method
   g. Salinity using a 1:2 water paste method
   h. Basic Nutrient content of macro nutrients (P, K, Ca, Mg)
   i. Additional tests are needed to calculate SAR and ESP: Ca, Mg, Na concentrations in milliequivalents/L and Cation Exchange Capacity if manure-based compost is to be used.

j. If the compost material contains any biosolids, heavy metals must be tested to meet EPA Chapter 503 and/or Pennsylvania Department of Environmental Protection levels for human use.

2. *Soil Mixes:* Testing shall be performed and reported for particle size requiring percent of gravel (>2.0 mm, #10 sieve), very coarse sand (2.0 – 1.0 mm, #18 sieve), coarse sand (1.0 – 0.5 mm, #35 sieve), medium sand (0.5 – 0.25 mm, #60 sieve), fine sand (0.25 – 0.10 mm, #140 sieve), very fine sand (0.10 – 0.05 mm, #270 sieve), silt (0.05 – 0.002 mm, hydrometer) and clay (< 0.002 mm, hydrometer). Soil Reaction (pH), total porosity, salt content (EC), and organic matter percentage for the whole soil on a dry weight basis shall also be tested. For the topsoil material additional CEC, Phosphorus, Potassium, Calcium, and Magnesium shall be tested.

   a. Particle size distribution by ASTM F1632-03 for all soil layers. Fines passing the #270 sieve are to be measured using the hydrometer method as outlined in ASTM F1632. If any alternate method is used such as ASTM D422, the results still must be reported at the specified particle size breaks listed above.
   b. Organic matter and Foreign Material (plastics and paper) content by ASTM F 1647-02a, commonly known as loss on ignition.
   c. Salts test using Woods End Research Laboratory # 104 Soluble Ion Test <u>or</u> 1:2 soil/water extract test as specified in *Methods of Soil Analysis, Part 3* and must be tested and made available to the Landscape Architect or Soil Scientist within two weeks of planned soil installation.
   d. Soil moisture testing by gravimetric oven dry method as described in Soil Science Society of America, *Methods of Soil Analysis*, Part 1, 1986.

3. *In-place Rain Garden Soil Testing*:

   a. General Rain Garden soil installation shall be tested using a cone penetrometer with ¾ inch cone or equivalent for approximately one point every 100 ft^2 at an interval after S3 layer installation and again after complete soil profile installation. The Rain Garden soil penetration resistance shall be uniformly increasing in density with depth, not exceeding 250 lbs/in^2. There shall not be any compacted dense layers within the soil profile. Specific penetration resistance rates are given in Part 2 of this section for each soil layer.
   b. Additional testing shall follow local guidance.

PART 2 – PRODUCTS

2.1 MIX COMPONENTS:

A. General
   1. All plant mix material shall fulfill the requirements as specified and be tested to confirm the specified characteristics.
   2. The Landscape Architect and Soil Scientist may request additional testing by the Contractor for confirmation of mix quality and/or plant soil mix amendments at any time until completion if quality control samples deviate from the specifications and initially approved submittals.

B. *Glass Cullet Supply:*

   1. In the event that any of the soil materials are not available from the supplier or are not in compliance with specifications herein, the Contractor shall obtain material from other suppliers and conduct tests specified herein to provide materials in compliance with these specifications.
   2. The client shall be notified of all soil mix substitutions or problems with the Rain Garden soil supply in order to assist with a smooth delivery and installation.

C. *Rain Garden Soil Sources:* Submit information identifying sources for all soil components and the contractor responsible for mixing of Rain Garden soil mixes.

D. *Mixing Components:*

1. *Glass Cullet:* This material should follow the following criteria with its particle size following below and is equivalent to ASTM C33 – Fine Aggregate if a bit on the fine side of the range.

    a. The Glass Cullet is:

Glass Cullet Physical and Chemical Criteria

Particle Size Class	Passing Sieve No.	Range in Percent Passing ASTM F 1632-03
gravel	4	100
fine gravel	10	85 – 100
medium sand	60	<40
very fine sand	270	<10
Chemical		
pH	1:1 Water	<10.0
EC	1:2 Water	<2.0 dS/m
Physical		
Foreign Organics %	ASTM F 1647-02a	<0.5 by weight

    b. Test for Metals using EPA Method 3050B + 6010 to confirm glass cullet meets US Composting Council levels for compost.

2. *Coarse Sand:* This mix component follows the following criteria.

    a. The Coarse Sand can be equivalent to ASTM C33 – Fine Aggregate if it also follows the particle size below. Masonry Sand, or Concrete Sand if it is not Limestone washings can also be used.

Coarse Sand Physical and Chemical Criteria

Particle Size Class	Passing Sieve No.	Range in Percent Passing ASTM F 1632-03
gravel	4	95 – 100
fine gravel	10	80 – 100
medium sand	60	10 – 40
very fine sand	270	<10
Chemical		
Organic Matter %	ASTM F 1647-02a	<0.25
pH	1:1 Water	5.5 – 6.8 ± 0.5
EC	1:2 Water	<2.0 dS/m

3. Fine Earth mix component: The material needed to mix with the Glass/Sand mix for deriving the topsoil horizon for the Rain Garden Basin.

    a. The Fine Earth can be silt loam, loam or sandy loam if it also follows the particle size below.

Fine Earth Physical and Chemical Criteria

Particle Size Class	Passing Sieve No.	Range in Percent Passing

		ASTM F 1632-03
gravel	4	98 – 100
fine gravel	10	85 – 100
medium sand	60	<60
very fine sand	270	<35
Chemical		
Organic Matter %	ASTM F 1647-02a	<0.25
pH	1:1 Water	5.5 – 7.0 ± 0.5
EC	1:2 Water	<2.0 dS/m

4. *Organic Amendment:* The compost added to the topsoil mix .

   a. The compost shall be tested using US Composting Council criteria.
   b. Compost can be from brewer's waste, food waste, leaf mulches, municipal yard waste, biosolids, or mushroom substrate.
   c. If manure derived compost (biosolids or used mushroom substrate) is to be used, the Sodium Absorption Ratio (SAR) and Exchangeable Sodium Percentage (ESP) will need to be calculated to determine if the EC values are Sodium or Potassium salts derived.
   d. **† <u>FOR Animal Derived Compost</u>**. Additional tests are needed to calculate SAR and ESP: Ca, Mg, Na concentrations in milliequivalents/L and Cation Exchange Capacity if manure-based compost is to be used.
   e. **‡ <u>Electroconductivity</u>.** If SAR and ESP meet criteria, the EC can be as high as 7 dS/m. if SAR and ESP is not met, Sodium salts are deriving the EC and the limit should be <2.0 dS/m.

Criteria	Test Method	Acceptable Range
Type		brewer's waste, food waste, biosolids. Mushroom compost or leaf mulches are acceptable. If meeting all of the criteria noted below
Carbon/Nitrogen Ratio		11:1 – 22:1
Degree of Maturity	Dewer Self Heating <u>or</u>	VI – V
	Solvita Maturity Index <u>or</u>	6 – 8
	CO_2 Evolution	1.2 % C/day
Foreign Material	Dry wt.	< 1" dia. And < 2% (of total)
Organic Matter %	Dry wt.	25 – 75%
Reaction	1:1 water	5.5 – 8.0
EC	1:2 water	2 dS/m or < 7 dS/m‡
Ammonium	extract	< 200 ppm
Sodium Adsorption Ratio (SAR)†	calculated	< 12 †
Exchangeable Sodium Percentage (ESP)†	calculated	< 10 †
Nutrient Content	extract	Contains some nitrogen, phosphorus, potassium, calcium, magnesium, and micronutrients including iron, copper, boron, and manganese. Nutrients shall

		be present in appropriate agricultural and horticultural proportions to prevent ion antagonism.
Heavy Metals	extract	Concentrations of zinc, mercury, cadmium, lead, nickel, chromium, and copper must be below EPA's Part 503 standards.

2.2 FINAL SOIL MIX:

A. Expected Saturated Hydraulic Conductivity for these planting soil mixes within a standard two horizon Rain Garden soil profile is between 5 to 7 inches per hour after one growing season. Complete drainage of ponded stormwater shall be within 36 hours from initial storm event.

B. Soil Layers:

1. *Filter Soil layer:* Rain Garden Filtration Layer consisting of a minimum 18-inch layer of material with a USDA Texture of coarse sand.

    a. The filter layer within the bio-retention swale shall have a, uniformly increasing with depth, penetration resistance of < 250 lbs/in^2 after installation. No dense layers (+ 50 lbs/in^2 from background rate) are allowed.
    b. There shall be no visible organic material present in this layer.
    c. Material can be a natural sand or finely ground recycled glass meeting the following particle size distribution

Drainage and Filtration Layer Physical and Chemical Criteria

Particle Size Class	Passing Sieve No.	Range in Percent Passing ASTM F 1632-03
gravel	4	98 – 100
fine gravel	10	85 – 100
medium sand	60	10 – 40
very fine sand	270	1 – 10
Chemical		
Organic Matter %	ASTM F 1647-02a	<0.25
pH	1:1 Water	5.5 – 8.0 ± 0.5
EC	1:2 Water	<2.0 dS/m

3. *TopSoil layer:* Bio-retention Topsoil. A 6 – 8 inch layer consisting of material with a USDA Texture of sand to loamy sand. (must be tested to meet specs after compost is approved and added)

    a. The S1 layer shall have a uniformly increasing with depth, penetration resistance of < 120 lbs/in^2 after installation. No dense layers (+ 25 lbs/in^2 from background rate) are allowed.
    b. The particle size distribution shall be:

Topsoil Layer Physical and Chemical Criteria

Particle Size Class	Passing Sieve No	Range in Percent Passing ASTM F 1632-03
gravel	4	100
fine gravel	10	90 – 100

medium sand	60	30 – 40
very fine sand	270	9 – 18
Chemical		
Organic Matter %	ASTM F 1647-02a	4 – 6% (weight)
pH	1:1 water	6.5 – 7.0 ± 0.5
EC	1:2 Water	<2.0 dS/m
Phosphorous (P)	extract	20 – 100 ppm
Potassium (K)	extract	200 – 600 ppm
Cation Exchange (CEC)	Extract	>10 Meq/100g

2.3 ESTIMATED MIXING RATIOS

The mix ratios are rough estimates based on usual components found in the area and their physical properties. Slight adjustments to the mix may be needed to achieve the required Rain Garden soil properties. Mix ratios are based on volume of moist soil, not wet or powdery dry.

Layer Designation	**Base Material or Equivalent**	**Second Soil Mix Component**	**Third Soil Mix Component**	**Mix Ratio % (Volume)**
Filter Layer	USGA straight sand or non-calcareous Masonry Sand	Approved Glass Cullet	None	65:35
Topsoil Layer	Approved Filter material	sandy loam‡	Approved Compost	60:20:20
		loam‡	Approved Compost	65:15:20

‡USDA Soil Textures

PART 3 – MIXING PROCEDURES

3.1 COORDINATION

A. *Acquiring Materials*: The materials that constitute this mix should have these minimum requirements for meeting acceptable material for LEED, SITEs and basic clean standards. The following parameters are guidance for obtaining these materials

1. Glass Cullet: Component should have documented chain of custody for recycled material.
2. Coarse Sand: Material should not be from areas designated as Prime Farmland by USDA. The material shall be sourced within 50 miles.
3. Sandy Loam, Loam: Material should not come from areas designated as Prime Farmland by USDA. The material shall be sourced within 50 miles.
4. Compost: Document the chain of custody to prove use of recycled materials.

3.2 MATERIAL MIXING

A. Preparation:

1. *Cullet Preparation:*
   a. Ensure that material does not have excessive plastics, paper or other foreign material that would reduce the functionality of the material.

2. Coarse Sand Preparation:

   a. Ensure that material does not have excessive organics or free calcium carbonate or other foreign material that would reduce the functionality of the material.

3. Fine Earth Preparation:
   a. Ensure that material does not have excessive organics or rock fragments larger than ½ inch or other foreign material that would reduce the functionality of the material.

4. Compost Amendment Preparation:
   a. Ensure that material does not have excessive foreign material that would reduce the functionality of the material.

B. MIXING PROCEDURES:

1. The materials shall be slightly moist during mixing. Components that are too wet will ball and clump together not providing a homogenous mixture. Components that are too dry will separate based on their specific gravity also not accomplishing a homogenous mixture.
2. The soil components shall be mixed in a ball mill, trommel, or tub mill fitted with proper screening and paddles. Windrowing the materials is not acceptable, as it does not produce uniform mixing of the components.

Appendix D

Andela Products Equipment Specifications

Andela **GP Mini**

Glass Pulverizer/Screener

Accepts all types of glass

Separates glass sand from larger debris

Hand Feed Conveyor

5-1/2 HP
3 phase, 230-460V

Environmentally friendly
Reduces waste
Provides cost effective remedy for environmentally conscious communities

ANDELA PRODUCTS

493 State Route 28
Richfield Springs, NY 13439

(315) 858 0055
www.andelaproducts.com
info@andelaproducts.com

- Process 1000 1500 pounds of glass per/hour.
- All types of glass infeed. No pre cleaning required.
- Produce a glass sand/aggregate mix without sharp edges.
- Integrated trommel screen separates out the residue (caps, labels, and corks).
- Compact and integrated unit with Pulverizer, Trommel Screen, and Elec Controls

- Quiet Operation
- Simple to operate and maintain
- Shipped complete and ready for operation
- Reasonably priced
- Industrial duty design
- Big machine features with a small machine footprint
- Single frame construction

Mid-size Unit – Model GPT1 – HD

Andela GPT-1HD

Glass Pulverizer/Screener

3-5 TPH Capacity

Accepts Bulk Quantities of Waste Glass Material

Generates Glass Sand and Gravel with Non-Glass Removed

Large Scale Features on a Small Scale Footprint

Environmentally friendly
Reduces waste
Provides cost effective remedy for environmentally conscious communities

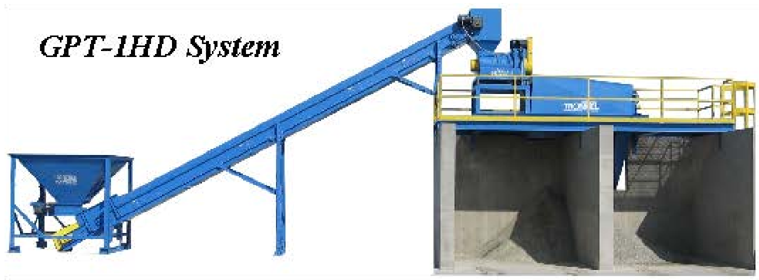
ANDELA PRODUCTS

493 State Route 28
Richfield Springs, NY 13439

Phone: (315) 858-0055
Fax: (315) 858-2669

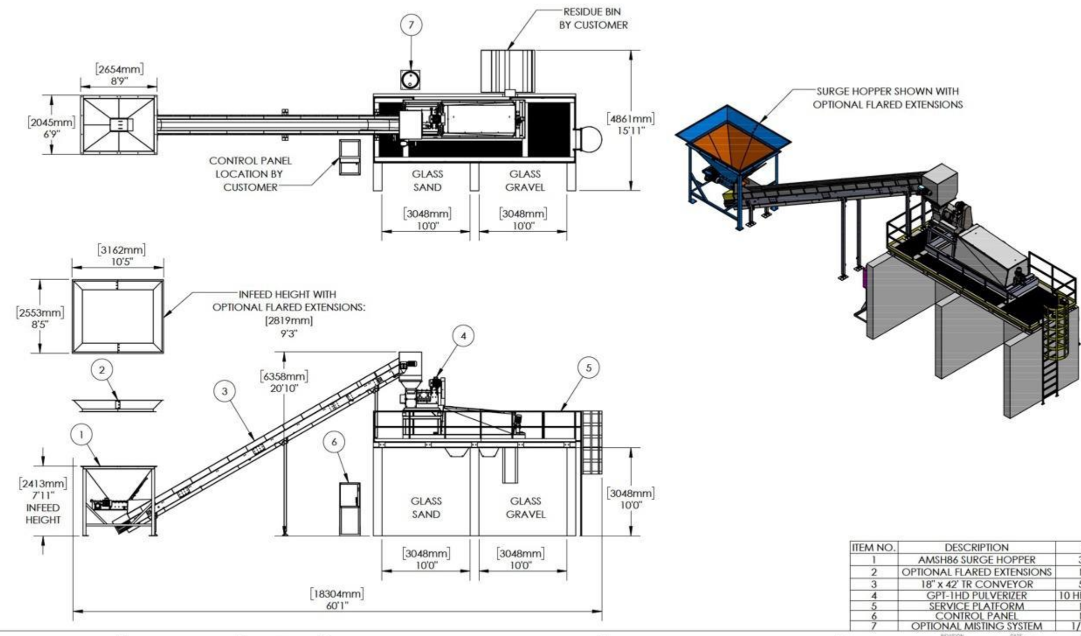
www.andelaproducts.com
info@andelaproducts.com

GPT-1HD System



- Pulverizer/trommel combination unit provides a condensed lay-out ideal for those looking to optimize recycling capacity within a limited space
- Machine design features access doors with bolt in replacement liners and hammers for hassle free maintenance and service
- Dual screening trommel size separates glass sand and gravel product for potential resale
- Material uses include: backfill, drainage, filtration media, glass-phalt, decorative landscape mulch and so much more!

- **Simple Operation & Maintenance**
- **Easy Installation**
- **Reasonably Priced**
- **Lined Wear Surfaces for Added Durability**
- **Single Frame Construction**
- **Generates Glass Product with No Sharp Edges**



ITEM NO.	DESCRIPTION	HP
1	AMSH86 SURGE HOPPER	3 HP
2	OPTIONAL FLARED EXTENSIONS	N/A
3	18" x 42' TR CONVEYOR	5 HP
4	GPT-1HD PULVERIZER	10 HP/1.5 HP
5	SERVICE PLATFORM	N/A
6	CONTROL PANEL	N/A
7	OPTIONAL MISTING SYSTEM	1/12 HP

Andela

493 State Route 28
Richfield Springs, NY 13439
Tel: 315-858-0055
andelaproducts.com

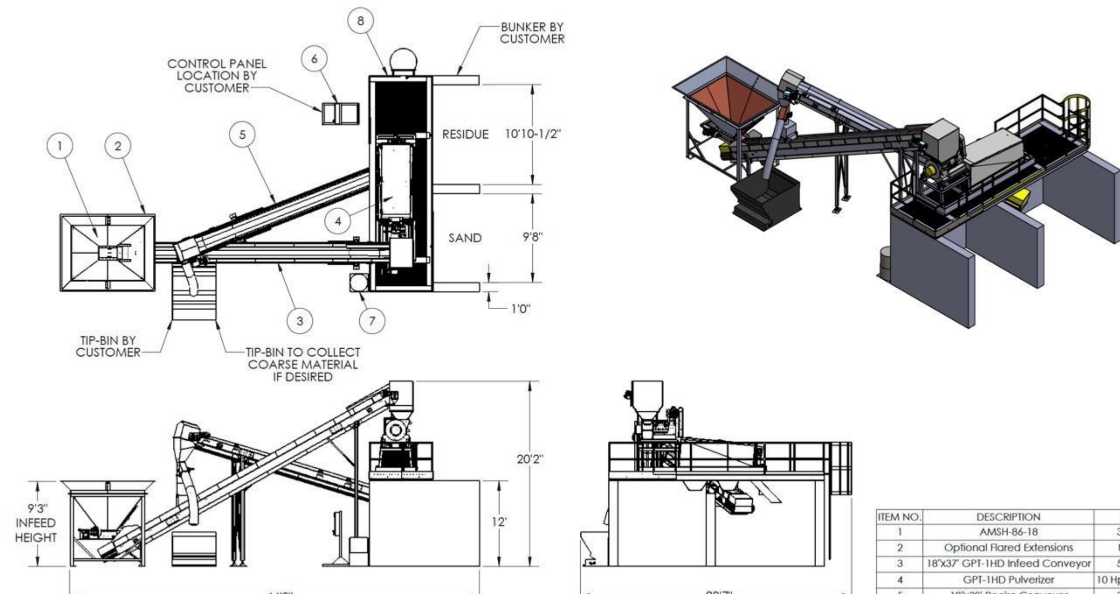
DRAWN BMT
DATE 4/21/2021
CHECKED
DATE
SCALE 1 : 100

GPT-1HD SYSTEM ON BUNKER

REVISION DATE

FILE NO GPT-1HD

SHEET 1 OF 1



ITEM NO.	DESCRIPTION	HP
1	AMSH-86-18	3 Hp
2	Optional Flared Extensions	N/A
3	18"x37' GPT-1HD Infeed Conveyor	5 Hp
4	GPT-1HD Pulverizer	10 Hp/1.5 Hp
5	18"x30' Recirc Conveyor	3 Hp
6	Control Panel	N/A
7	Optional Misting System	1/12 Hp
8	Service Platform	N/A

Andela

493 State Route 28
Richfield Springs, NY 13439
Tel: 315-858-0055
andelaproducts.com

DRAWN JEA
DATE 5/24/2021
CHECKED
DATE
SCALE 1:96

GPT-1HD-BR
GPT1-HD SYSTEM ON BUNKERS W/ RECIRC

ANDELA PRODUCTS

REVISION DATE

FILE NO GPT-1HD-BR

SHEET 1 OF 1

Andela Hoppers

Surge Hopper

Evenly Distributes Material

Essential for Bulk Loading

Models:
AMSH86-12
AMSH86-18
AMSH86-24

Environmentally friendly
Reduces waste
Provides cost effective remedy for environmentally conscious communities

ANDELA PRODUCTS

493 State Route 28
Richfield Springs, NY 13439

Phone: (315) 858-0055
Fax: (315) 858-2669

www.andelaproducts.com
info@andelaproducts.com

- The Andela Metering Surge Hopper is designed to accept bulk loading of glass or other materials
- Holds 4 cubic yards, or up to 6 cubic yards with optional flared extensions (shown in picture)
- Reciprocating plate feeder meters the flow rate of material into the system
- Adjustable slide gate regulates whole, or mixed broken glass to desired throughput

- **Simple to Operate & Maintain**
- **Easy Installation**
- **Reasonably Priced**
- **Heavy Duty Construction**
- **12", 18" or 24" wide Discharge**
- **Abrasion Resistant Materials on All Wear Surfaces**

ANDELA METERING SURGE HOPPER
MODEL AMSH86-18FS
with flared sides

MACHINE SPECIFICATIONS

Dimensions

Capacity.. 6 to 7 cubic yrds.
Overall Length ....125"
Overall Width ....101"
Overall Height ....111"
Discharge Opening ....18" wide x Adjustable Height
Discharge Height ....40"

Drive Componentry

Motor Size ....(1) 3 hp
Direct Drive System .... Totally Enclosed Gear Reducer
....Reciprocating Plate with Eccentric Drive

Electrical

Motor Voltage.. 230/460 VAC, 60 HZ, 3 Phase
(VAC and HZ provided to customer specifications)

Selected surfaces hardened for long wear and durability.

The manufacturer reserves the right to change designs
and specifications without notice.

493 State Route 28, Richfield Springs, NY 13439 315-858-0055

Andela Conveyors

Belt Width Options:
18”, 24”, 30” & 36”

Variable Lengths, Bed Types, & Pans Available.

Stainless Steel Sections for Crossbelt Magnets

Conveyor Types:
Slider Bed
Troughing Roll

Belt Tread Type:
Cleated belt
Smooth belt
Chevron belt

- Andela Conveyors are available in various sizes and configurations to fit any application
-
- Remote grease fittings and lines extend to base of conveyor for ease of maintenance

- **Increases Production**
- **Less Handling of Material**
- **Heavy Duty Construction**

ANDELA PRODUCTS

493 State Route 28
Richfield Springs, NY 13439

Phone: (315) 858-0055
Fax: (315) 858-2669

www.andelaproducts.com
info@andelaproducts.com

ANDELA SYSTEM CONVEYORS
MACHINE SPECIFICATIONS

Heavy Duty – Troughing

Overall Length/Width	According to Quotation
Drive System	3-phase motor and gear reducer, direct drive
Conveyor Body	10" x 3/16" formed steel channels
Carry Surface:	Troughing Roller
Belt	Smooth, chevron or cleared rubber belt
Head Pulley	10" head pulley
Tail Pulley	10" self cleaning tail pulley
Take Up	Adjustable Side Mounted bearings with 1 15/16" bore.
Returns	Return rolls with smooth and chevron belts Belly pans with wear resistant glides for cleated belt
Hopper/Sides/	Formed 10 gauge painted steel

The manufacturer reserves the right to change designs
and specifications without notice.

Electrical Control Panel

Enclosures - Enclosures are rated per the environment and are NEMA 4 or better. All enclosures are supplied with an emergency stop.

Main Disconnect - The main disconnect is provided with fuses or a circuit breaker and has a "Lockout/Tagout" feature.

Motor Starters - The motor starters are IEC rated.

Branch Circuit Protectors - The Branch circuit protectors are provided with a circuit breaker and a motor overload as an integral part of the unit.

Push Buttons - All push buttons are Heavy Duty dust tight/water tight design.

Standards - Built to UL-508 Industrial Standards. Electrical schematics and parts lists are supplied with the unit when the whole system is shipped. Can be CE certified upon request.

Andela

TWIN BARREL

Andela GP-2HD
Glass Pulverizer

Model:
GP-2HD: 20 TPH

Designed for High Capacity Applications

Flexible Impact Hammers

Reduces waste

Provides a cost effective remedy for environmentally conscious communities

ANDELA PRODUCTS

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∀ Selective size reduction produces a glass sand, and glass aggregate, while leaving non glass residue in-tact for ease of separation

∀ Machine design features access doors with bolt in replacement liners and hammers for hassle free maintenance and service

∀ Generates safe handling glass product with no sharp edges suitable for a variety of applications

∀ **Quiet Operation**

∀ **Simple to Operate and Maintain**

∀ **Low Horsepower**

∀ **Reasonably Priced**

∀ **Durable**

∀ **Bolt in Liners and Hammers for Easy Maintenance.**

∀ **Processes whole glass bottles and/or MRF glass**

ANDELA GLASS PULVERIZER
MODEL GP-2HD
20 tons/hr. capacity

MACHINE SPECIFICATIONS

Dimensions

Overall Length ....Approx. 88”
Overall Width ....Approx. 79”
Infeed Hopper Opening ....36” x 36”
Machine Input Opening ....20” x 20”
Input Chamber Diameter and Length ....30” x 44”
Output Chamber Diameter and Length ....30” x 58”
Chamber Type....................Steel Frame & Heavy Duty Support Stand
Liners ....Bolt-in Heavy Duty Abrasion Resistant Steel
Heavy Duty Frame with Vibration Isolation ....(5) Mechanical Spring Isolators

Drive Componentry

Motor Size ....Two (2) 20 HP TEFC
Solid Steel Shaft Diameter ....3” Dia.
Number of Hammers 56
Hammer Type ....Flexible Impactor/Hardened Steel
Bearing Size....................3” Heavy Duty
Seal Protection....................Two (2) Seals At Each Shaft Bearing

Safety Features

Protective Guards ....Cover Input Hopper, Drive Unit and Bearings
Access Doors....................Hammer and Liner Maintenance

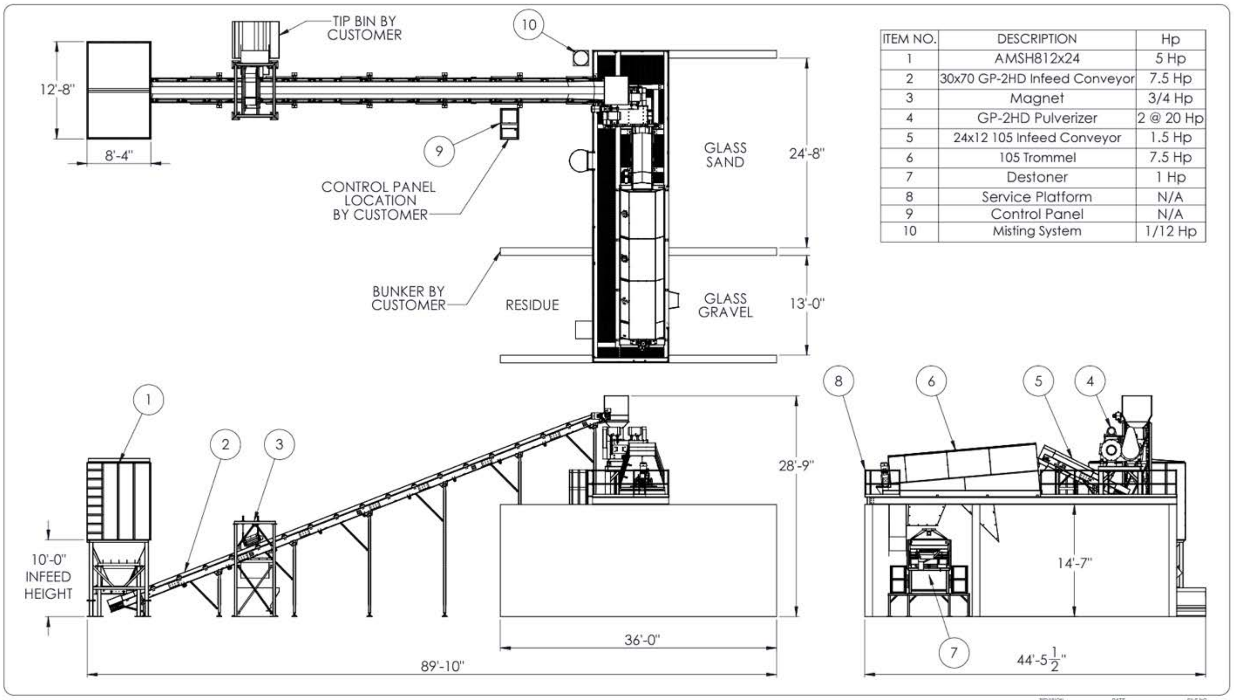
Electrical

Motor Voltage ....230/460 VAC, 60 HZ, 3 phase

Weight

Static Weight ....7,500 lbs.

The manufacturer reserves the right to change designs
and specifications without notice.

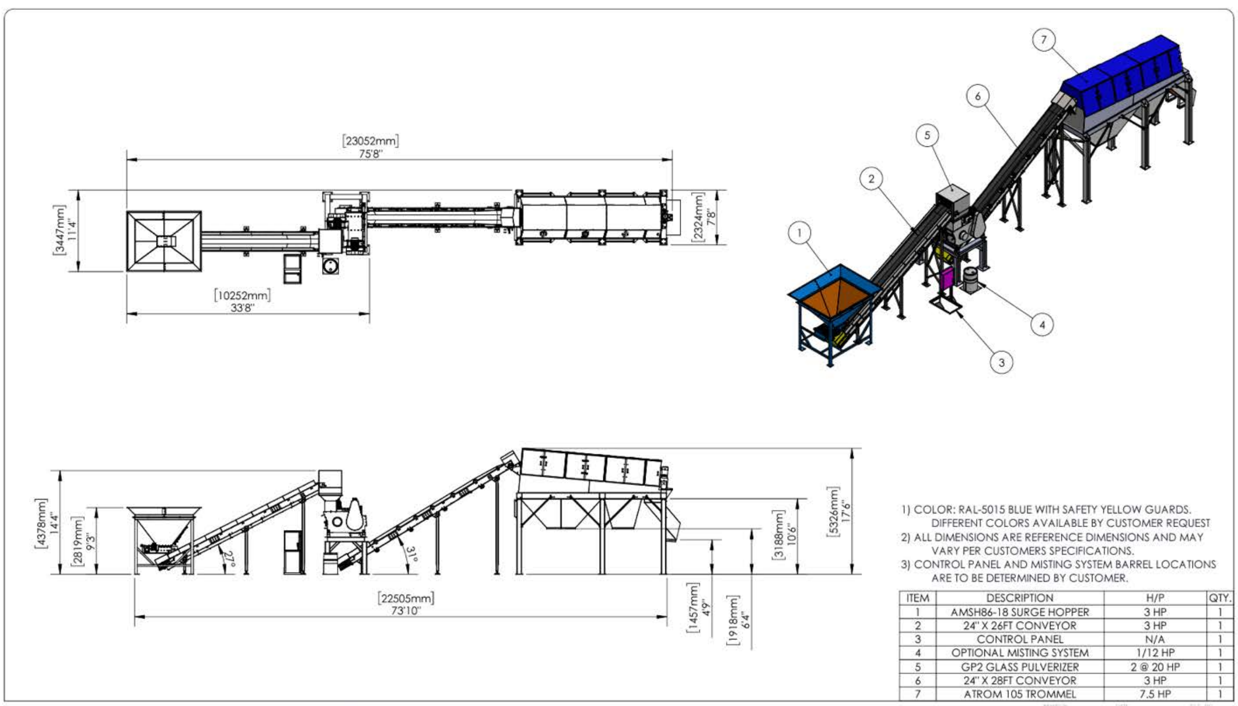


ITEM NO.	DESCRIPTION	Hp
1	AMSH812x24	5 Hp
2	30x70 GP-2HD Infeed Conveyor	7.5 Hp
3	Magnet	3/4 Hp
4	GP-2HD Pulverizer	2 @ 20 Hp
5	24x12 105 Infeed Conveyor	1.5 Hp
6	105 Trommel	7.5 Hp
7	Destoner	1 Hp
8	Service Platform	N/A
9	Control Panel	N/A
10	Misting System	1/12 Hp

ANDELA Products, Ltd.
493 State Route 28
Richfield Springs, NY 13439
tel: 315-858-0055
fax: 315-858-2669

GP-2HD SYSTEM
WITH DESTONER

OC-000



1) COLOR: RAL-5015 BLUE WITH SAFETY YELLOW GUARDS. DIFFERENT COLORS AVAILABLE BY CUSTOMER REQUEST
2) ALL DIMENSIONS ARE REFERENCE DIMENSIONS AND MAY VARY PER CUSTOMERS SPECIFICATIONS.
3) CONTROL PANEL AND MISTING SYSTEM BARREL LOCATIONS ARE TO BE DETERMINED BY CUSTOMER.

ITEM	DESCRIPTION	H/P	QTY.
1	AMSH86-18 SURGE HOPPER	3 HP	1
2	24" X 26FT CONVEYOR	3 HP	1
3	CONTROL PANEL	N/A	1
4	OPTIONAL MISTING SYSTEM	1/12 HP	1
5	GP2 GLASS PULVERIZER	2 @ 20 HP	1
6	24" X 28FT CONVEYOR	3 HP	1
7	ATROM 105 TROMMEL	7.5 HP	1

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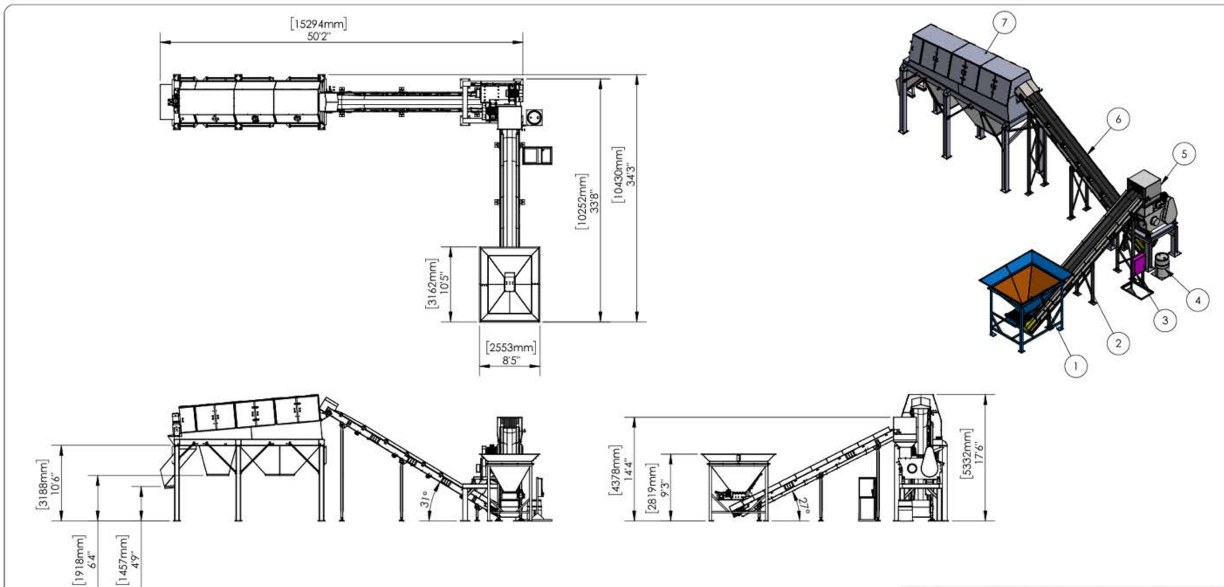
DRAWN JEA
DATE 5/11/2021

GP2-105 SYSTEM
GP2 GLASS PULVERIZER AND 105 TROMMEL SYSTEM

ANDELA PRODUCTS

GP2-105
SHEET 1 OF 1



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4	OPTIONAL MISTING SYSTEM	1/12 HP	1
5	GP2 GLASS PULVERIZER	2 @ 20 HP	1
6	24" X 28FT CONVEYOR	3 HP	1
7	ATROM 105 TROMMEL	7.5 HP	1

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DRAWN JEA
DATE 5/17/2021
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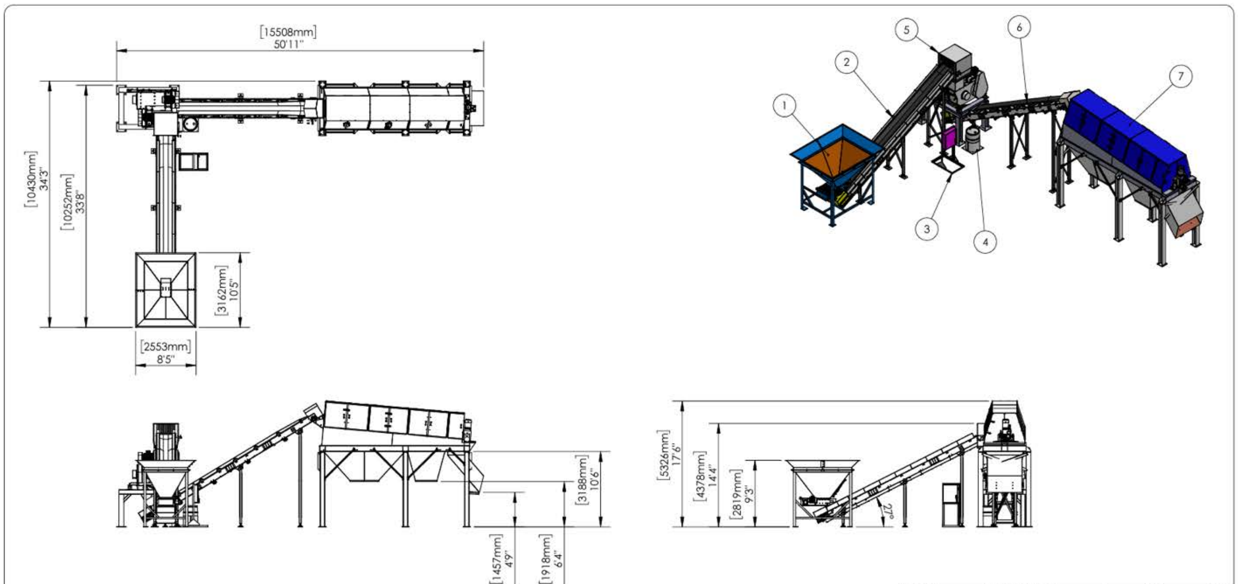
DATE
SCALE 1:128

GP2-105 SYSTEM
GP2 GLASS PULVERIZER AND 105
TROMMEL SYSTEM

ANDELA PRODUCTS

GP2-105
SHEET 1 OF 1



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4	OPTIONAL MISTING SYSTEM	1/12 HP	1
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6	24" X 28FT CONVEYOR	3 HP	1
7	ATROM 105 TROMMEL	7.5 HP	1

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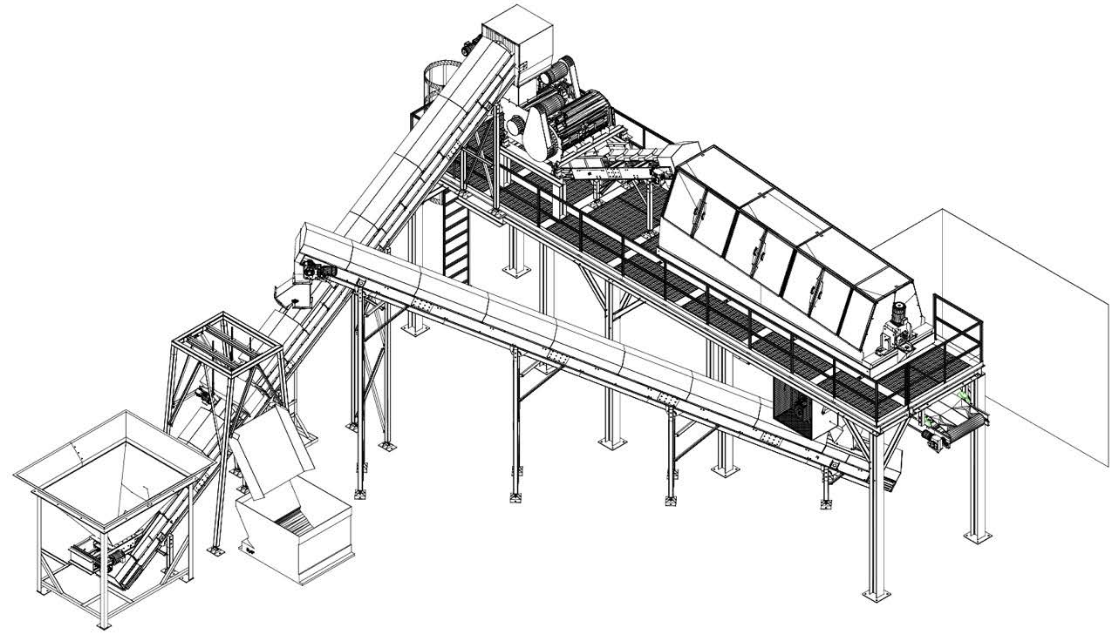
DATE
SCALE 1:128

GP2-105 SYSTEM
GP2 GLASS PULVERIZER AND 105
TROMMEL SYSTEM

ANDELA PRODUCTS

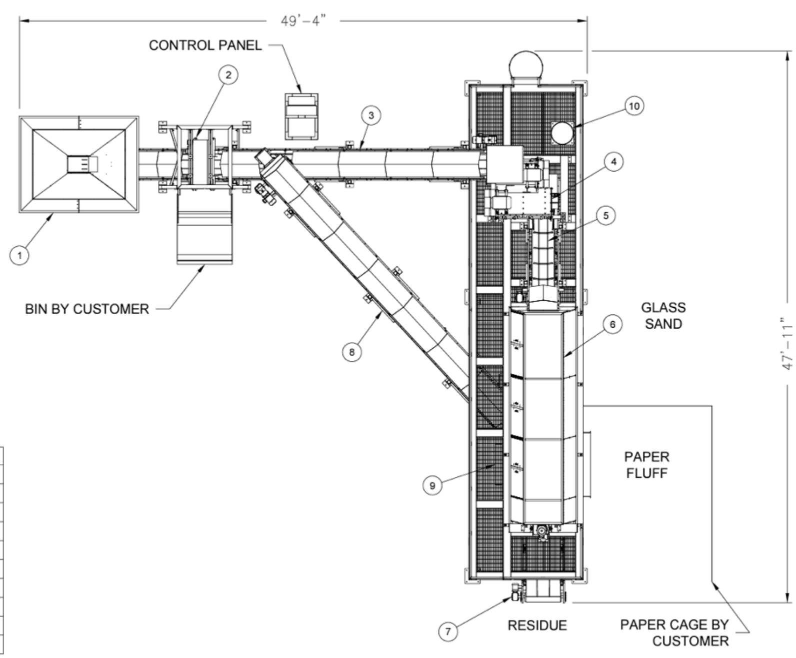
GP2-105
SHEET 1 OF 1



ANDELA Products	493 State Route 28 Richfield Springs, NY 13439 tel: 315-858-0055 fax: 315-858-2669	DRAWN VTB DATE 2/24/16 CHECKED DATE SCALE 1:60	GP2-HD/105 SYSTEM LAYOUT	REVISION / DATE	FILE NO SWC-00 SHEET 4 OF 5

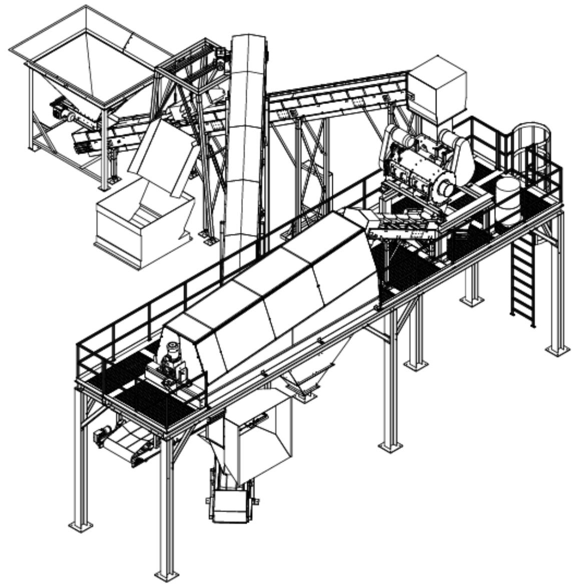
NOTE
DETAILING, PRODUCTION, AND COMPONENT PURCHASING WILL NOT BEGIN UNTIL ONE (1) SET OF DRAWINGS HAS BEEN APPROVED, SIGNED, AND RETURNED TO ANDELA PRODUCTS

NOTES:
1) MISTING PUMP IS SINGLE PHASE, 120V, 60 Hz.
2) SPECIFY ELECTRICAL REQUIREMENTS FOR SYSTEM:
   PHASE : 3__________ INITIALS:__________
   VOLTAGE :__________ INITIALS:__________
   FREQUENCY :________Hz INITIALS:__________
3) ALL DIMENSIONS ARE REFERENCE DIMENSIONS AND MAY VARY PER CUSTOMERS SPECIFICATIONS
4) MISTING BARREL & CONTROL PANEL LOCATIONS TO BE DETERMINED BY CUSTOMER.
5) PAPER CAGE BY CUSTOMER.



ITEM	DESCRIPTION	QTY.	HORSE POWER
1	AMSH86-18" SURGE HOPPER	1	3 HP
2	CROSS BELT MAGNET	1	3/4 HP
3	INFEED CONVEYOR (24"x44')	1	5 HP
4	GP2 PULVERIZER	2	20 HP EACH
5	TRANSFER CONVEYOR (24"x14')	1	1 HP
6	105 TROMMEL	1	7.5 HP
7	RESIDUE CONVEYOR (36"x10')	1	1.5 HP
8	RECIRC CONVEYOR (24"x44')	1	5 HP
9	BLOWER	1	1 HP
10	MISTING PUMP	1	1/12 HP

ANDELA Products	493 State Route 28 Richfield Springs, NY 13439 tel: 315-858-0055 fax: 315-858-2669	DRAWN VTB DATE 2/24/16 CHECKED DATE SCALE 1:60	GP2-HD/105 SYSTEM LAYOUT	REVISION / DATE C Added diverter on #8 VTB 4/10/16 D Added Covers to conveyors #3 & 8 VTB 6/30/16	FILE NO SWC-00 SHEET 1 OF 5



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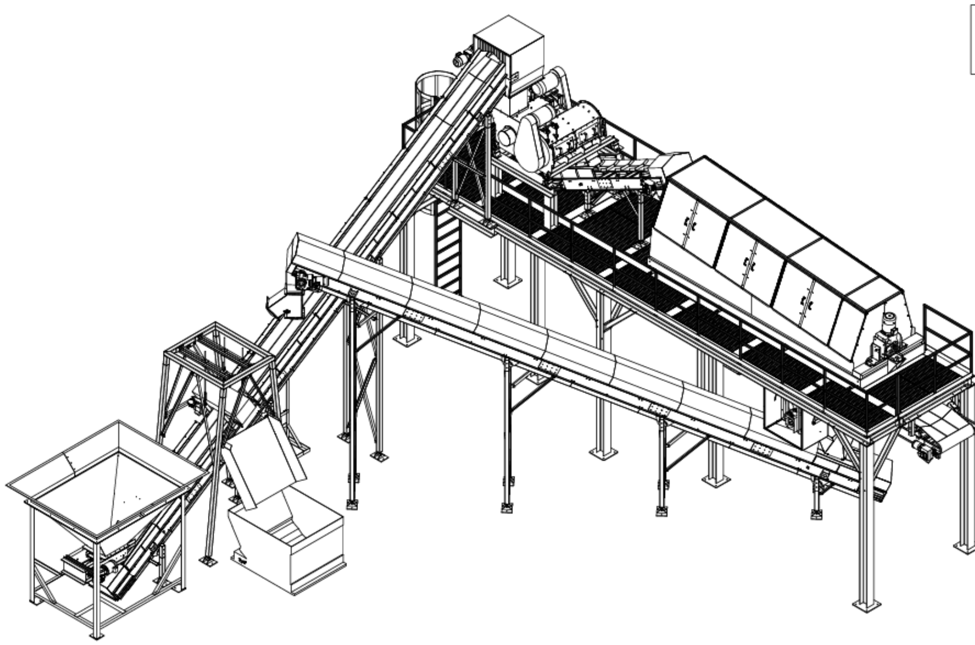
DRAWN VTB | DATE 2/24/16 | CHECKED | DATE | SCALE 1:70

GP2-HD/105
SYSTEM LAYOUT

	REVISION		DATE
C	Added diverter on #8	VTB	4/10/16
D	Added Covers to conveyors #3 & 8	VTB	6/30/16

FILE NO
SWC-00
SHEET 5 OF 5



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DRAWN VTB | DATE 2/24/16 | CHECKED | DATE | SCALE 1:60

GP2-HD/105
SYSTEM LAYOUT

	REVISION		DATE
C	Added diverter on #8	VTB	4/10/16
D	Added Covers to conveyors #3 & 8	VTB	6/30/16

FILE NO
SWC-00
SHEET 4 OF 5

ITEM	DESCRIPTION	QTY.	HORSE POWER
1	AMSH86-18" SURGE HOPPER	1	3 HP
2	CROSS BELT MAGNET	1	3/4 HP
3	INFEED CONVEYOR (24"x44')	1	5 HP
4	GP2 PULVERIZER	2	20 HP EACH
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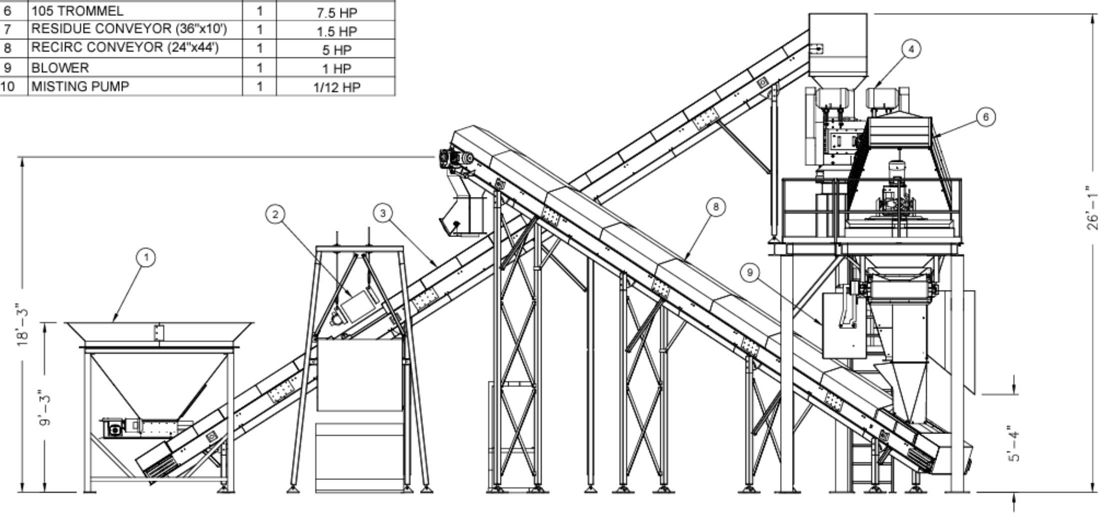

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DRAWN VTB
DATE 2/24/16
CHECKED
DATE
SCALE 1:50

GP2-HD/105
SYSTEM LAYOUT

	REVISION		DATE
C	Added diverter on #8	VTB	4/10/16
D	Added Covers to conveyors #3 & 8	VTB	6/30/16

FILE NO
SWC-00
SHEET 3 OF 5

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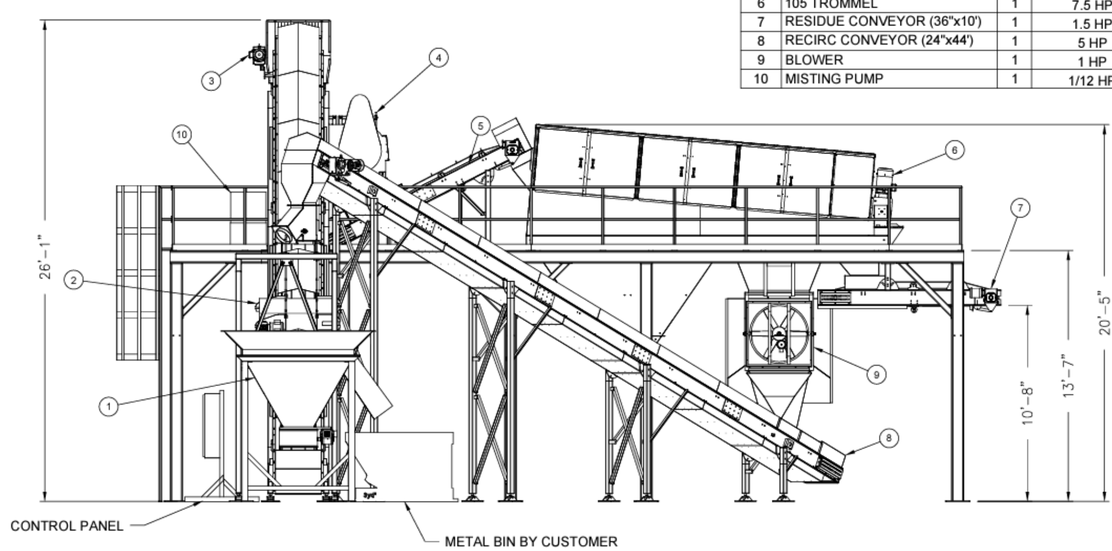

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DRAWN VTB
DATE 2/24/16
CHECKED
DATE
SCALE 1:50

GP2-HD/105
SYSTEM LAYOUT

	REVISION		DATE
C	Added diverter on #8	VTB	4/10/16
D	Added Covers to conveyors #3 & 8	VTB	6/30/16

FILE NO
SWC-00
SHEET 2 OF 5

ANDELA Products
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website: www.andelaproducts.com email: info@andelaproducts.com

Andela Glass Pulverizer

Budgetary Turnkey System Pricing 2021

GP-MINI	1,500 LBS/HR	$31,400	
GP-MEGAMINI	1 TPH	$57,500	
GP-05L	1-2 TPH	$118,000	
GPT-1HD	3-5 TPH	$180,000	
		$210,800	WITH SERVICE PLATFORM

(ADD $49,000 FOR ADDITIONAL GLASS CLEAN-UP SYSTEM)

*GP-1HD	10 TPH	$270,000	
		$310,100	WITH SERVICE PLATFORM

(ADD $75,000 FOR ADDITIONAL GLASS CLEAN-UP SYSTEM)
(ADD $89,000 FOR WINDSHIELD STRIPPER + CONVEYOR)

*GP-2HD	20 TPH	$350,000	
		$420,000	WITH SERVICE PLATFORM

(ADD $75,000 FOR ADDITIONAL GLASS CLEAN-UP SYSTEM)
(ADD $89,,000 FOR WINDSHIELD STRIPPER + CONVEYOR)

Andela Laminated Glass Processing System

AWS-2/ATROM-104	3-5 TPH	$185,000	
		$220,000	WITH SERVICE PLATFORM

Appendix F

Second Pilot Site

Secondary Pilot Site

The project team had an opportunity to expand into a secondary pilot site in a more rural location: North Manheim Township, Schuylkill County, PA. The second pilot site was incorporated into a design and construction project that was already underway in North Manheim Township. Wayne Bowen of RMC, a partner on this Phase II project, was instrumental in facilitating the incorporation of the research plot into a planned trail park project. The park was projected to include three rain gardens along a loop trail, adjacent to an existing parking lot (see Figure 1). One of the three rain gardens, adjacent to the parking lot, was designed to serve as the secondary pilot site for GBS. The GBS mix for the secondary pilot site included glass-sand produced by Bottle Underground and post-consumer food waste compost provided by Bennett Compost.

The Recycling Markets Center, the Department of Conservation and Natural resources, and the local township contributed funds to complete this comparative analysis pilot. The second pilot site will allow the project team to directly compare the performance of mushroom compost and post-consumer food waste compost.

OLIN and E & LP provided design details and specifications for the secondary pilot site, and the North Manheim implementation team incorporated them into the larger project. The secondary pilot site was designed to be about the same size as the original Kelly Drive pilot site. Like the primary pilot site, the secondary pilot site was divided into two zones: a control zone using a standard soil mix and a trial GBS zone.

Construction also included two observation wells (one on each side) to allow for direct comparison of water samples for water quality.

Construction was completed in October 2023 (see Figure 2 and 3). The final plant selection included:

- *Calamagrostis x acutiflora 'Karl Foerster'* / Karl Foerster Feather Reed Grass
- *Carex vulpinoidea* / Fox Sedge
- I*ris versicolor* / Blue Flag
- *Juncus effusus* / Common Rush
- *Penstemon digitalis* / Beardtongue
- *Vernonia noveboracensis* / Common Ironweed

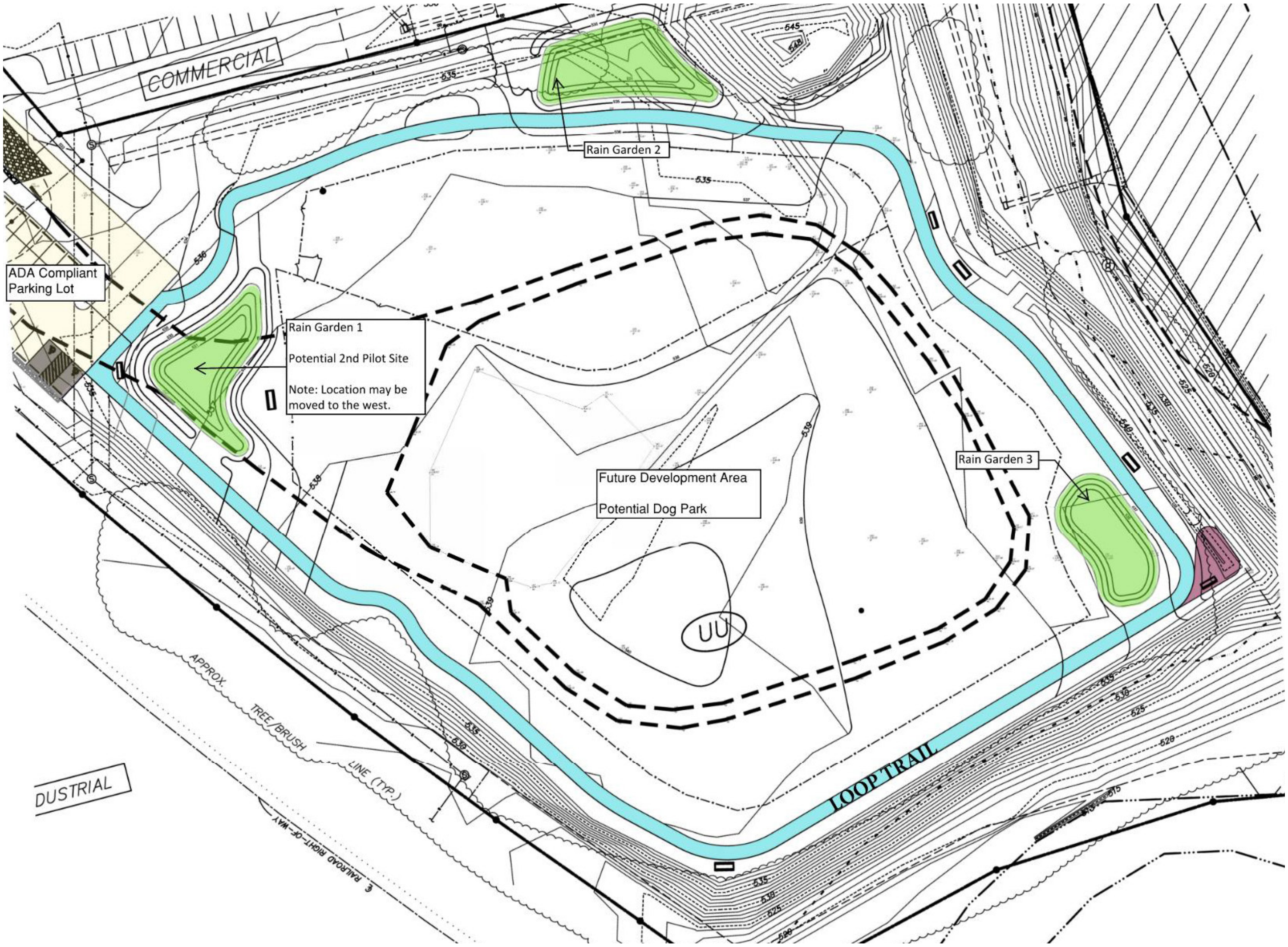

Figure 1: Site plan with secondary pilot site labeled as "Rain Garden 1."


Figure 2: Rain garden under construction.


Figure 3: Rain garden with plugs and observation wells installed.

OLIN