11711 East Market Place, Suite 200
Fulton, MD 20759
410.461.8323
www.cwp.org

Biochar as an Enhancement to Bioretention Practices in the Chesapeake Bay Watershed

Carol Wong[a], Alexandria Wilkins[a], Lisa Fraley-McNeal[a], Chuck Hegberg[b]
[a]Center for Watershed Protection
[b]Infinite Solutions

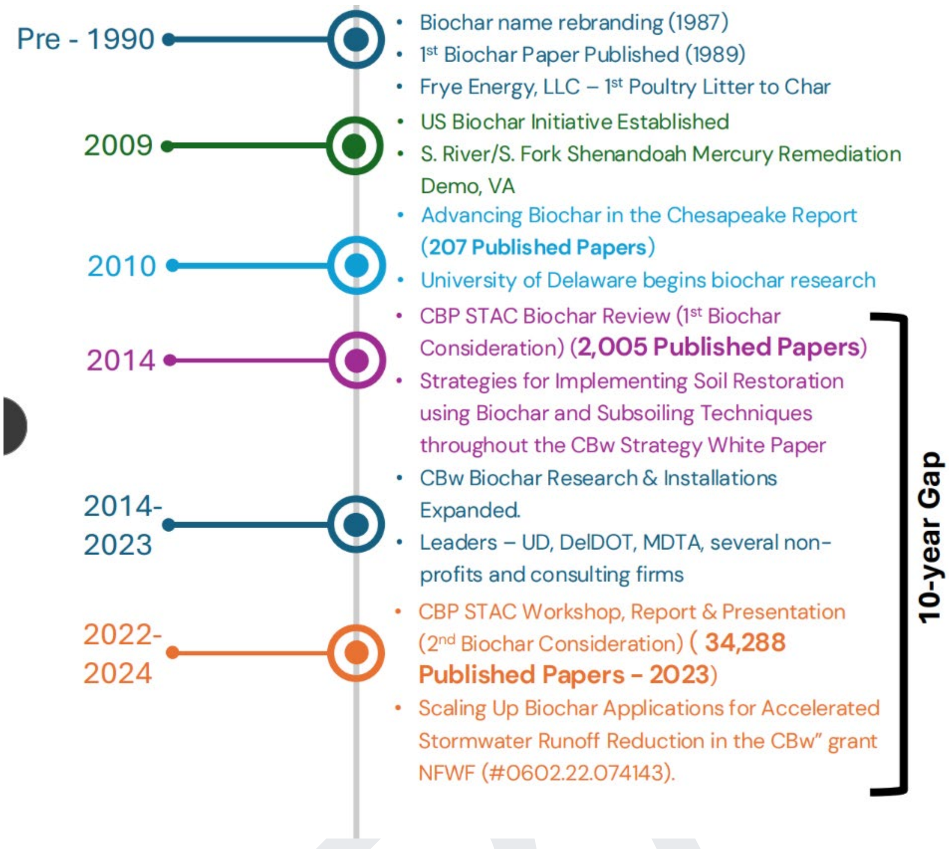
Submitted to the Urban Stormwater Workgroup on March 18, 2025.

Biochar is a solid, charcoal-like material created by burning biomass, or organic material in an oxygen-limited environment through the process of pyrolysis (Hegberg, 2024). The inclusion of biochar into existing approved bioretention best management practices (BMPs) has been shown to enhance runoff reduction through increases in soil porosity, water holding capacity, and infiltration rates (Hegberg, 2024; Wilkins, 2025). It also enhances pollutant removal through adsorption, desorption, and the exchange of anions and cations which support the capture and transformation of pollutants through processes such as denitrification and microbial conversion (Hegberg, 2024). While the incorporation of biochar in bioretention practices does not currently result in additional Chesapeake Bay Program credit for a bioretention BMP as credited by the Stormwater Retrofit Expert Panel (Schueler et al., 2012), the approach has been used throughout the Chesapeake Bay Watershed to improve environmental outcomes and has been verified by separate independent research efforts. Specifically, the use of biochar in bioretention practices has the following benefits:

- Reduction of stormwater runoff and flood mitigation
- Enhanced pollutant removal
- Promotion of plant growth
- Revival of compacted or degraded BMPs
- Carbon sequestration and storage
- Mitigation of emerging toxic contaminants
- Utilization of waste material
- Mitigation of road salt

State of the Practice and Technical Discussion

Biochar has been in use for millennia dating as far back as 7,000 to 8,000 years. After its discovery by Spanish explorers in the 16th century, a series of additional explorations were conducted over the following two centuries. These Initial studies and explorations were about the origins of what was then called *Terra Preta*. Then, in 1966, Wim Sombroek sparked research into biochar's agricultural properties and his work has led to continuous research on the use of biochar in ever-expanding applications to this day. Figure 1 presents a timeline of the history of biochar since the late 1980s highlighting events specific to the use of biochar in the Chesapeake Bay watershed. For more details on the history of biochar, see the Biochar STAC report in Appendix B.



The studies reviewed as a part of the "Biochar in Bioretention" literature review (see Appendix A for the full document), noted the need for more biochar-amended field-based experiments. Premarathna et al. (2023) states that "the limitations of lab-based studies and the inadequacy of field-scale investigations suggest that there is still a lack of comprehensive understanding regarding the effectiveness and long-term performance of biochar in real-world bioretention applications." Biswal et al. (2022) notes the need for additional research that considers "how plant growth and phytoremediation potential are influenced by the usage of biochar as filter media" in bioretention. To address some of these research gaps and facilitate more field-scale studies, Tirpak et al. (2021) recommends that regulatory agencies that wish to promote the use of bioretention amendments should develop specifications that allow for the flexibility to include approved amendments (i.e., biochar) based on their capacity to remove target pollutants. Therefore, these knowledge gaps are an opportunity to increase and support field-based experiments with biochar within the Chesapeake Bay watershed for increased sediment and nutrient reductions from urban stormwater runoff.

Research on the impact of biochar material amendments or enhancements have been conducted by the University of Delaware (UDel) and are discussed in detail in the "Biochar in and around the Chesapeake Bay Watershed" section of Appendix A. The studies conducted by Tian et al. (2019), Akpinar et al. (2023b,c), and Chowdhury et al. (2024) demonstrated positive results from the incorporation of wood-based biochar into stormwater practices for the reduction of stormwater runoff and pollutants.

- In Tian et al. (2019), biochar-enhanced bioretention showed greater water retention, longer residence time, and higher nitrate removal when compared to a control. The biochar increased

11711 East Market Place, Suite 200
Fulton, MD 20759
410.461.8323
www.cwp.org

the water retention by 11-27% in this study while preventing the clogging and the loss of infiltration capacity.

- Akpinar et al. (2023b,c) compared two (2) representative bioretention soil media (BSM) mixtures and the impacts from biochar amendment. One of the BSM mixes contained sand, fines, and sawdust (NC mix) and the other contained sand, mulch, and compost (DE mix). The paper discusses the impact of biochar, aggregation, and roots on water retention noting that the field capacity (FC) and plant available water (PAW) increased for both BSM mixes evaluated. However, it only increased FC significantly for the NC mix whereas PAW was significantly relevant for both BSM mixes when the biochar was applied at a rate of ~18% by volume (v/v).
- Chowdhury et al. (2024) evaluated the change in saturated hydraulic conductivity (Ksat) in biochar-enhanced soils between impervious pavement and pervious grassed slopes over a period of 5 months (two sites) to 15 months (two sites). Findings included the increase in Ksat by a factor of 7.1, drainable water storage capacity by a factor of 2, and available water content (AWC) by a factor of 2.1. Additionally, the study identified that the use of 18% biochar by volume (v/v) increased the soil's "organic matter content, aggregate mean weight diameter, organo-mineral content, and fungal hyphal length while decreasing bulk density."

While there are many different types of biochar as determined by the materials used for its production, biochar made from wood or forestry waste materials is primarily used for enhancing existing stormwater practices. The use of biochar feedstock from coarse-grained parent material such as woody biomass results in coarser particles that are harder to compact in bioretention systems minimizing the impacts on hydraulic conductivity from the addition of biochar. Additionally, wood-based biochars are more likely to have a higher surface area than other feedstocks, making it more effective at capturing nutrients and pollutants. Other studies have found wood-based biochar feedstock more favorable for the removal of hydrophobic organics. They are also more likely to have a lower pH, ash content, and nutrient and metal leaching potential than mineral-rich feedstock (i.e., manure) (Wilkins, 2025; Hegberg, 2024).

Typical Applications in the Chesapeake Bay Watershed

Bioretention is an existing approved Runoff Reduction (RR) practice that follows crediting protocols outlined in the Stormwater Retrofit Expert Panel (Schueler et al., 2012). The inclusion of Biochar-Enhanced Bioretention Media (BEBM) does not require significant design or construction changes to bioretention practices. Based on research conducted by UDel and corroborated through the literature review, our design recommendations for BEBM include the following:

Biochar Specification: Biochar must be wood-based and have a supplier proof of lab analysis that meets the former International Biochar Initiative (IBI) Standards[1] or the new "World Biochar Certificate (WBC)- Premium[2] and the following general specifications for biochar in stormwater applications.

[1] https://biochar-international.org/biochar-standards/
[2] https://www.carbon-standards.com/docs/transfer/4000036EN.pdf

Test/Method	Testing Responsibility	Criterion	Requirement
ASTM D7263-21	Manufacturer	Bulk density	6-12 lbs/cf (dry wt)
ASTM D2974-20 or ASTM D1762-84	Manufacturer	Total Ash	<10%
Total C and H analysis by dry combustion-elemental analyzer (EPA Method 440.0). Inorganic C analysis by determination of CO 2-C content with 1N HCl, as outlined in ASTM D4373 Standard Test Method for Rapid Determination of Carbonate Content of Soils. Organic C calculated as Total C – Inorganic C	Manufacturer	Fixed Carbon	≥ 80%
	Manufacturer	H:C ratio	<0.7
Butane Activity Surface Area Correlation Based on McLaughlin, Shields, Jagiello&Thiele's 2012 paper: Analytical Options for Biochar Absorption and Surface Area or ASTM D4404-10	Manufacturer	Surface area	≥ 325 m2/g dry
See IBI or WBC Guidance	Manufacturer	pH	<11
AOAC 955.01	Manufacturer	Liming Effect	<15%
ASTM D6913-04, ASTM D7928-17	Manufacturer	Particle size distribution	>6 mm: 0% 1-4 mm: 0-50% 2-4 mm: 20-50% <1mm: <15% <0.05 mm shall be minimized to the maximum extent possible

Biochar Amount: Biochar should constitute 14-18% of the bioretention media by volume and be incorporated up to a depth of 1-3 ft. These percentages of biochar generally result in increased nutrient sorption and decreased saturated conductivity in soil media. Since the research supporting biochar in bioretention only tested up to 18% of biochar, the percentage of biochar should not exceed 18% and percentages over 30% result in negative impacts on plant health (Brockhoff, 2010; Joseph et al., 2021). The existing amount of biochar included to enhance a practice should be based on the existing soil conditions and the inclusion of other types of organic matter (i.e., mulch, compost, etc.). The biochar range is to allow for flexibility when mixing the biochar.

11711 East Market Place, Suite 200
Fulton, MD 20759
410.461.8323
www.cwp.org

Method of Incorporation: There are two methods of incorporation, either at the soil vendor or on-site. To ensure performance as guided by the research, all of the bioretention media must have at least 60% sand by volume and less than 20% clay.

- Soil Vendor: See guidelines in Appendix D.1.
- On-Site:
    - Follow proper biochar storage and handling guidelines (Appendix D.2 and D.3)
    - Mix biochar into bioretention media stockpile: Incorporate the biochar into the media in the same manner as other soil amendments, such as compost. Refrain from crushing the biochar with heavy equipment.
    - Mix into already placed bioretention media or in-situ soils that meet bioretention specifications: Follow In-Situ Biochar Amendment guidelines (Appendix D.4)
- Implementation Type: The implementation method for bioretention enhancement with biochar will depend on whether a new practice is being constructed or if an existing practice is undergoing maintenance.
    - New Installation: The bioretention should be built per the appropriate state or local specifications, with the typical bioretention media replaced by BEBM.
    - Maintenance: Remove and replace at least the top foot of the existing material with BEBM is recommended, followed by replanting. The 1' depth is used for maintenance due to the potential impact to the underdrain if deeper. If there is no underdrain, the maintenance can be performed deeper.

The storage and handling guidelines apply to all projects (Appendix D.2 and D.3).

Life Cycle Costs:

The cost estimate is based on the Center for Watershed Protection's (CWP) experience adding biochar into bioretention systems. The cost estimate assumes that the biochar-enhanced bioretention media is imported from a soil vendor. For 100 cubic yards of bioretention media, there is a $5/CY increase for mixing the biochar into media, and a $23/CY increase for the biochar material, assuming 16% of biochar by volume is added. In total, it is a 37% increase in cost for the bioretention media. The cost of mixing is expected to decrease as the number of projects that use biochar increase, since these projects are currently mixed on a small scale, which increases the cost. The cost of biochar has also been steadily decreasing as supply goes up and material standards and market scale and pricing are established.

For the life cycle cost estimate, a bioretention was designed with the following parameters:

- 2,500 Square Feet
- 6" ponding
- 2' bioretention media
- 3" pea gravel
- 9" #57 stone
- 100', 4" underdrain

Based on CWP's previous experience, the bioretention media cost can range from 5%-15% of the entire construction cost. The variability is due to the range of soil media specifications for bioretention. In some jurisdictions, soil media must be imported through an approved soil vendor, which may be more expensive than mixing on site. Assuming the soil media is 5%-15% of the total cost, adding biochar to a bioretention increases the total cost of the bioretention by 2%-5.5%.

Potential Risks and Unintended Consequences:

The use of biochar in environmental management applications is not a new practice. However, the use of biochar in environmental management applications is expanding and is considered an emerging field of research and study. Many review papers in the last 5-10 years comment on the need for more practical field research to better understand the processes that create the useful impacts that make biochar such a helpful tool for multiple applications, such as pollutant adsorption. Additionally, as biochar material awareness and usage increases, there are concerns about the potential negative impacts related to contamination, negative impacts on soil properties and biota, adverse effects on greenhouse gas emissions, risks associated with biochar migration, and the need for standardization and further applicable field research.

When biochars are properly sourced and evaluated for the appropriate properties and tested for undesired pollutants (e.g., PAHs, Dioxins, VOCs, PFAS, POPs), risks and unintended consequences are minimized related to biochar's pollutant adsorption capabilities, and the potential transport of fine dust (<0.5 mm) biochar particles. While nutrients are absorbed and transformed, other pollutants (organic and inorganic contaminants) immobilized through the use of biochar are not destroyed. Therefore, there is potential for the sorbed pollutants to mobilize through environmental changes or biochar degradation. However, the contaminants bound in any mobilized biochar are sequestered from the environment and no longer biologically available. The following outlines considerations for risks and unintended consequences from the use of biochar in bioretention systems:

- Unbalanced Uptake of Plant Nutrients: Biochar's ability to immobilize chemicals and nutrients in soil may unbalance the uptake of nutrients by vegetation or may reduce nutrient availability in the soil with its high adsorption capacity *(Dong et al. 2025)*. This could impact plant growth in biochar enhanced soils or soil media. Since most Chesapeake Bay bioretention media standards are already low in nutrients, the plant palette selected for these systems are typically hardy and require minimal nutrients. The benefits of increased water available to the plants may outweigh the potential reduced nutrient availability (Akpinar et al., 2023).
- Pesticide Adsorption: Biochar may decrease the efficacy of soil-applied pesticides by adsorbing them, potentially leading to the need for higher application rates of certain herbicides. Biochar incorporation in soil can have opposing effects on pesticide leaching depending on the adsorption strength (Montanarella & Lugato, 2013; Qadeer et al., 2017). This is not a concern for bioretention, as pesticides should not be applied to them.
- Transport of Pollutants: The transport of biochar in the environment can increase its environmental risk, especially if it becomes polluted or immobilizes environmental pollutants. As biochar ages, it can degrade into nanoparticles, which can transport pollutants more quickly, increasing environmental risk. The accumulation of biochar nanoparticles in plant tissues can contribute to slow growth and oxidative stress *(Dong et al. 2025)*. The nanoparticle concern is important if the bioretention plants are harvested for food. University of Delaware research has not seen this as a concern.

- Dust Emissions: Biochar dust emissions during production or the grinding of biochar to increase its contact area can lead to the diffusion of biochar in the form of dust during application. This is a significant way biochar can impact human health and air quality *(Dong et al. 2025)*. The inhalation of fine biochar particles or toxic crystalline substances – like silica from rice hull biochar feedstock – may result in respiratory damage. Coarse biochars in sandy soils may contribute to higher rates of dust emissions due to the abrasive sand particles grinding the less stable biochar particles (Gerlardi et al.,2019). Proper storage and handling are noted to address the potential dust concerns of biochar. Proper PPE during handling and construction, as well as wetting the biochar during application are included in the guidelines to reduce the potential negative effects of dust.

The concerns and potential negative impacts associated with the use of biochar in bioretention can be minimized through the use of wood-based biochar and the design recommendations outlined above. While other types of biochar may have different benefits, the focus on runoff reduction and nutrient reduction in the Chesapeake Bay has led to using a wood-based biochar. The selection of clean, high quality wood feedstock provides for a consistent biochar product and has a lower pH, ash content, and nutrient and metal leaching potential. In addition, biochar that conforms to IBI or WBC standards provides for standardized product definitions and testing guidelines for the safe use of biochar in bioretention media. Regular bioretention maintenance and inspection along with removal and replacement of the BEBM media on the same recommended time frame as a regular bioretention will help to prevent pollutants adsorbed to biochar from remobilizing through environmental changes or biochar degradation.

Maintenance of a bioretention is vital to the performance. Due to the low nutrients and stressful conditions bioretention plants may experience, vegetation maintenance is important. The bioretention vegetation maintenance stays the same with biochar. Biochar is expected to provide more available water to the plants, decreasing stress on plants during drought conditions. Biochar has also been shown to decrease the rate of compaction in soils shown as a decrease in bulk density (Akpinar, 2023a; Chowdhury et al., 2024; Bowser, M.,2023) and helped prevent clogging and loss of infiltration capacity (Tian et al, 2019).

Crediting Considerations for Use of Biochar as an Enhancement to Bioretention in the Chesapeake Bay Watershed

The incorporation of biochar into bioretention practices is an enhancement to an existing already approved practice, therefore, no new BMP types are required to be approved through the CBP Expert Panel Process.

Proposed Crediting Methodology

A simple approach can be used to calculate the average annual pollutant removal percentages for the inclusion of biochar into bioretention practices using the retrofit removal adjustor curves from

11711 East Market Place, Suite 200
Fulton, MD 20759 | 410.461.8323
www.cwp.org

Schueler et al. (2012). While bioretention systems with biochar have shown to remove up to 95% of nitrate and 65% of total nitrogen, to align with how the retrofit curves were created, runoff reduction is proposed to calculate credit.

Based on the literature review, a SWMM model was created to determine the runoff reduction due to biochar addition to a bioretention. See Appendix C for details of the model. Based on the scenarios modeled in SWMM, biochar improved runoff reduction by 2%-89%. While this model has not been verified with field data, it provides some insight into the runoff reduction potential of biochar. The SWMM model has limitations, all of which cause the runoff reduction to be conservative. Some limitations include:

- Plant and plant-water interactions, including evapotranspiration, are not modeled. This may play a big role in biochar benefits, as biochar has shown to improve plant health and potentially plant survivability (Wilkins, 2025)
- Only a 1" storm was modeled. It is expected that for a continuous simulation, the bioretention with biochar would be able to reduce more runoff. Without the plant interaction in the model, the full runoff reduction potential of biochar will not be accounted for in SWMM
- Water does not exit the system laterally
- The model used is a 1D model, where once the water reaches the underdrain, it will immediately exit the system
- The underdrain is modeled as slots within a pipe, where once the water level reaches the invert of the underdrain, water leaves the system. In reality, water enters the underdrain at variable rates, depending on the water level at the underdrain. If the underdrain is large relative to the size of the bioretention, this error will decrease the runoff reduction significantly
  There were only 6 bioretention design scenarios modeled in SWMM. The underlying bioretention design can impact the overall performance. Since the retrofit curves "lumped" all bioretention designs into one curve, the biochar improvements were also "lumped" into one credit increase.

The average runoff reduction of the scenarios is 31%. To be conservative, the increased runoff reduction of 20% is proposed.

New Bioretention with BEBM

For new bioretentions with BEBM, the traditional method of calculating the runoff depth treated per impervious acre is multiplied by a factor of 1.2 (20% increase in credit). This value is then used in the retrofit curves to determine the pollutant load reduction percentage.

Adding BEBM into Existing Bioretention

The amount of credit received by adding BEBM into an existing bioretention depends on the percentage of bioretention media replaced. For example, in a 100 SF bioretention with 2' of media, if 1' of media is replaced with BEBM, then it would get 50% of the 20% increase in credit, which equates to 10% of credit. If the bioretention had 3' of media and 1' was replaced with BEBM, it would get 33% of the 20% increase in credit, which equates to 6.66% of credit.

11711 East Market Place, Suite 200
Fulton, MD 20759
410.461.8323
www.cwp.org

The removal rate for adding BEBM into existing bioretention practices is defined as the difference between the enhanced rate and the existing rate. The removal rate for the existing bioretention should be determined from the retrofit removal adjustor curves. A higher removal for the biochar enhanced bioretention will reflect the higher degree of runoff treatment and/or runoff reduction associated with the use of BEBM, as determined from the adjustor curves. An example of how to apply this protocol for enhancing existing BMPs is provided in the next section.

Qualifying Conditions

If there are any regulated substances in soil, they must be reviewed to ensure the biochar meets the regulation. For example, Pennsylvania has 25 PA Code Chapter 250, Appendix A, Table 3 -" Medium-Specific Concentrations (MSCs) for Organic Regulated Substances in Soil" and Table 4-" Medium-Specific Concentrations for Inorganic Regulated Substances in Soil".

Reporting, Tracking, and Verification

The general accountability procedures for using biochar-enhanced bioretention media follow those defined in Section 6 of the Stormwater Retrofit Expert Panel Report (Schueler et al., 2012). These procedures include initial construction and performance verification, no double counting removal credits, reporting BMP data to the state stormwater agency, detailed recordkeeping, and ongoing field verification of BMP performance.

The typical duration for biochar enhanced bioretention removal credit will be 5 years. The removal credit can be extended if a field inspection verifies the BMP is still functioning as designed. Localities will need to verify that biochar-enhanced bioretention practices are installed properly, meet or exceed design standards, and are functioning as designed prior to submitting the BMP for load reduction credit. The verification will be the same as a bioretention without biochar.

When BEBM is incorporated into existing bioretention practices that have been previously reported, the higher pollutant load reduction achieved can be reported in subsequent years after the enhancement is completed. If the bioretention enhanced with BEBM was not previously reported to EPA, it is considered a new retrofit, and the RR curve is used to define the removal rate based on the total treatment volume provided and multiplied by a factor of 1.2 to account for the additional credit from the biochar.

Examples

The following examples demonstrate how the retrofit removal adjustor curves can be used to credit BEBM in accordance with the Stormwater Retrofit Expert Panel Report (Schueler et al., 2012).

Example 1:

A new, voluntary bioretention is planned in a local park. The drainage area is 3.21 acres with 32% imperviousness (1.03 impervious acres). The bioretention's storage volume is 3,028 cubic feet (0.07 acre-foot).

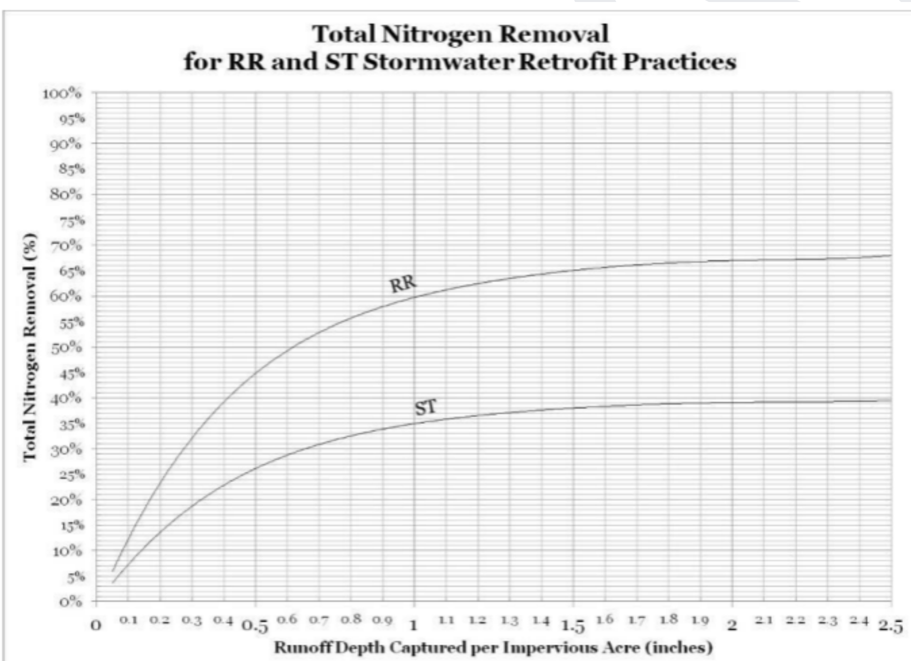
CENTER FOR WATERSHED PROTECTION
11711 East Market Place, Suite 200
Fulton, MD 20759
410.461.8323
www.cwp.org

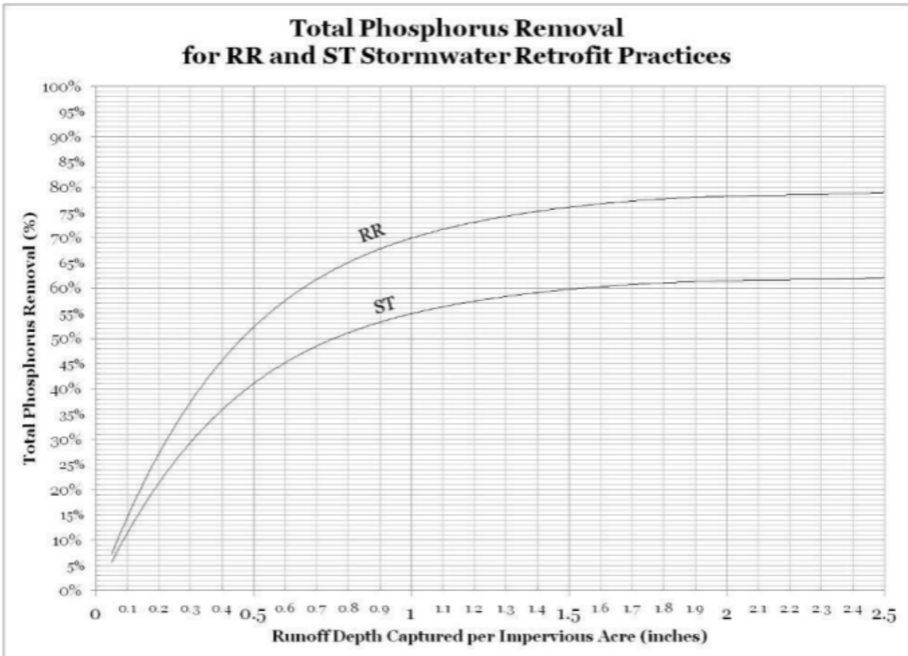
Scenario A: No biochar.
Runoff Storage Volume (acre-feet) * 12 / Impervious Area (acres) = Runoff volume in inches treated
0.07 acre-foot*12/1.03 acres = 0.81 inches

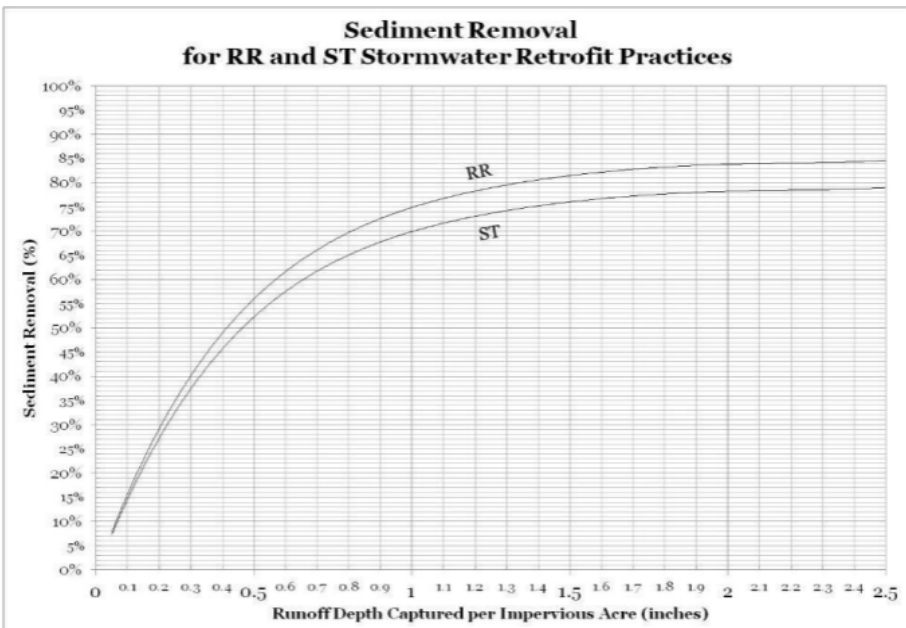
Scenario B: Biochar is used in the bioretention media, so the 0.81 inches is multiplied by 1.2 to account for the additional runoff reduction. The new runoff volume in inches treated is 1.2 x 0.81 inches = 0.97 inches.

Table A shows the associated pollutant load reduction for the two scenarios based on using the retrofit curves. Bioretention systems use the runoff reduction, "RR", curves.

Scenario	**Nitrogen Reduction Credit (%)**	**Phosphorus Reduction Credit(%)**	**Total Suspended Sediment Credit(%)**
Scenario A (No biochar)	55.9%	65.4%	70.1%
Scenario B (With Biochar)	59.3%	69.3%	74.3%
Increased Reduction with Biochar	3.4%	3.9%	4.2%







<u>Example 2:</u>

A 1,000 SF bioretention system installed in 2003 is inspected, there are no plants growing, and it is being retrofitted with biochar. It was designed with 2' of bioretention media and the runoff depth captured per impervious acre is 0.5". The contractor removes the top 1' of the bioretention media and replaces it with BEBM.

1' of BEBM / 2' of total bioretention media x 20% = 10% increase.

To use the retrofit curves:

11711 East Market Place, Suite 200
Fulton, MD 20759
410.461.8323
www.cwp.org

Runoff depth captured per Impervious Acre x (1+increased credit%) = 0.5 inches x (1+10%)= 0.55 inches

Scenario	Nitrogen Reduction Credit (%)	Phosphorus Reduction Credit(%)	Total Suspended Sediment Credit(%)
No biochar	44.8%	52.3%	56.0%
With Biochar	47.2%	55.1%	59.0%
Increased Reduction with Biochar	2.4%	2.8%	3.0%

Conclusions

The exponential increase in the number of scientific publications on biochar applications for stormwater management has documented the runoff reduction and pollutant removal capability. The addition of BEBM into new or existing bioretention practices represents a relatively small incremental cost and minimal design or construction changes to an already approved BMP that can significantly improve runoff reduction and enhance pollutant removal rates. However, local governments are reluctant to use BEBM due to the current lack of credit and accepted technical specifications. The crediting recommendations and specifications outlined in this document help address this gap and provide a pathway for use of BEBM that could help accelerate achieving the Chesapeake Bay and other MS4/TMDL goals, as well as provide additional environmental benefits beyond nutrient and sediment removal.

While this white paper focuses on runoff reduction, there are many other co-benefits of biochar, including (Hegberg, 2024):

- Other pollutant removal potential, such as organic/inorganic pollutant, PFAS, microplastics, E. coli, heavy metals
- Improvement of soil health benefits, including increase in soil carbon and increase soil aggregation
- Improvement of plant health and plant survivability
- Carbon sequestration
- Mitigation of heat island effect through soil temperature metering

CENTER FOR WATERSHED PROTECTION
11711 East Market Place, Suite 200
Fulton, MD 20759
410.461.8323
www.cwp.org

References

Akpinar, D., Tian, J., Shepherd, E. & Imhoff, P. T. Impact of wood-derived biochar on the hydrologic performance of bioretention media: Effects on aggregation, root growth, and water retention. Journal of Environmental Management 339, 117864 (2023b).

Akpinar, D., Chowdhury, S., Tian, J., Guo, M., Barton, S., & Imhoff, P. Understanding a wood-derived biochar's impact on stormwater quality, plant growth, and survivability in bioretention soil mixtures. Journal of Environmental Management, 348, 119359 (2023c).

Biswal, B. K., Vijayaraghavan, K., Tsen-Tieng, D. L. & Balasubramanian, R. Biochar-based bioretention systems for removal of chemical and microbial pollutants from stormwater: A critical review. Journal of Hazardous Materials 422, 126886 (2022).

Bowser, M. The impact of a wood biochar on stormwater retention and infiltration in roadside soils seeded with turfgrass. [Masters These, University of Delaware].(2023.

Brockhoff, S. Sand-based turfgrass root-zone modification with biochar. [Masters Thesis, Iowa State University] (2010).

Chowdhury, S., Akpinar, D., Nakhli, S.A.A., Bowser, M., Imhoff, E., Yi, S. C., Imhoff, P.T. Improving stormwater infiltration and retention in compacted urban soils at impervious/pervious surface disconnections with biochar. Journal of Environmental Management 360, 121032, ISSN 0301-4797 (2024).

Dong, M., Jiang, M., He, L. et al. Challenges in safe environmental applications of biochar: identifying risks and unintended consequence. Biochar 7 (12). (2025).https://doi.org/10.1007/s42773-024-00412-4.

Gelardi, D.L., Li, C., Parikh, S.J. An emerging environmental concern: Biochar-induced dust emissions and their potentially toxic properties. Science of The Total Environment, 678, 81320, ISSN 0048-9697 (2019).

Hegberg, C., J. Egan, C. Brosch, J. Hubbart, P. Imhoff, D. Lueckenhoff, T. Miles, W. Teel, and D. Wood. 2024. Using Carbon to Achieve Chesapeake Bay (and Watershed) Water Quality Goals and Climate Resiliency: The Science, Gaps, Implementation Activities and Opportunities. STAC Publication Number 24-005, Edgewater, MD. 110 pp.

https://www.chesapeake.org/stac/wp-content/uploads/2024/06/STAC-Report_Biochar_24-005.pdf

Joseph, S., Cowie, A.L., Van Zwieten, L., Bolan, N., Budai, A., Buss, W., Cayuela, M.L., Graber, E.R., Ippolito, J.A., Kuzyakov, Y., Luo, Y., Ok, Y.S., Palansooriya, K.N., Shepherd, J., Stephens, S., Weng, Z., & Lehmann, J. How biochar works, and when it doesn't: A review of mechanisms controlling soil and plant responses to biochar. Global Change Biology(GCB) Bioenergy,13(11), 1731-1764 (2021).

Montanarella, L., & Lugato, E. The Application of Biochar in the EU: Challenges and Opportunities. Agronomy, 3(2), 462-473 (2013). https://doi.org/10.3390/agronomy3020462.

Premarathna, K. S. D., Biswas, J. k., Kumar, M., Varjani, S., Mickan, B., Show, P. L., Lau, S. Y., Novo, L. A. B. & Vithanage, M. Biofilters and bioretention systems: the role of biochar in the blue-green city concept for stormwater management. Environ. Sci.: Water Res. Technol. 9, 3103–3119 (2023). https://doi.org/10.1111/gcbb.12885.

Qadeer, S., Anjum, M., Khalid, A. et al. A Dialogue on Perspectives of Biochar Applications and Its Environmental Risks. Water Air Soil Pollut 228(281).(2017).https://doi.org/10.1007/s11270-017-3428-z.

Schueler, T., Lane, C., Bahr, R., Brown, T., Hansen, J., Kelly, J., Papacosma, J., Snead, V., Stack, B., Stack, R., and S. Stewart. 2012. Recommendatiosn of the Expert Panel to Define Removal Rates for Urban Stormwater Retrofit Projects. Chesapeake Bay Program. https://www.chesapeakebay.net/what/publications/stormwater-retrofits-expert-panel-report-with-appendices

Tian, J., Jin, J., Chui, P. C., Cha, D. K., Guo, M. & Imhoff, P. T. A pilot-scale, bi-layer bioretention system with biochar and zero-valent iron for enhanced nitrate removal from stormwater. Water Research 148, 378–387 (2019).

Tirpak, R. A., Afrooz, A. N., Winston, R. J., Valenca, R., Schiff, K. & Mohanty, S. K. Conventional and amended bioretention soil media for targeted pollutant treatment: A critical review to guide the state of the practice. Water Research 189, 116648 (2021).

11711 East Market Place, Suite 200
Fulton, MD 20759
410.461.8323
www.cwp.org

Appendix A. Biochar in Bioretention Literature Review

Provided as a separate attachment.

Appendix B. STAC Report

https://www.chesapeake.org/stac/wp-content/uploads/2024/06/STAC-Report_Biochar_24-005.pdf

Appendix C. SWMM Model for Biochar

Provided as a separate attachment.

11711 East Market Place, Suite 200
Fulton, MD 20759
410.461.8323
www.cwp.org

Appendix D. Biochar Guidelines

The following guidelines were developed by the Biochar Partnership for the Chesapeake (BPC)'s Scaling Up Biochar project, led by the Center for Watershed Protection. The project was funded by the National Fish and Wildlife Foundation's Innovative Nutrient and Sediment Reduction Grant Program. The Core Team leading the BPC and are responsible for overall project administration and project tasks include the Center for Watershed Protection, Infinite Solutions, University of Delaware, and the United States Biochar Initiative (USBI).

The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the opinions or policies of the I.S. Government or the National Fish and Wildlife Foundation and its funding sources. Mention of trade names or commercial products does not constitute their endorsement by the U.S. Government, or the National Fish and Wildlife Foundations or its funding sources.

This material is based on work supported by the U.S. Environmental Protection Agency (Assistance Agreement No. CB96358201) and the National Fish and Wildlife Foundation's Chesapeake Bay Stewardship Fund, which promotes community-based efforts to develop conservation strategies to protect and restore the diverse natural resources of the Chesapeake Bay.

Find more information here: https://www.scalingupbiochar.com/

1. Biochar-Amended Bioretention Media (BEBM) Mixing Guide for Soil Vendors

Purpose

This document is intended to provide soil vendors with guidance in mixing bioretention media with biochar material for the Scaling Up Biochar project.

BEBM Composition and Materials

The BEBM shall contain, by volume:

- 82-86% bioretention media mix (per local design specifications)
- 14-18% Biochar as per material specification below

BEBM consists of a modified filter media using biochar. Biochar consists of a solid carbon-based material obtained from thermo-chemical conversion of biomass in an oxygen-limited environment. The biomass feedstocks should be limited to clean cellulosic material from:

1. woody by-products from forestry operations (including cut residues left after a timber harvest, cut trees that are not marketable as lumber),
2. chipped trees and brush from biomass reduction operations (i.e. commercial tree trimming),
3. clean Class A chipped wood from permitted C&D facilities and
4. agricultural residues such as nut shells, orchard pruning, seeds, hulls, and pits.

The biomass feedstocks should not include any post-consumer or post-industrial sourced woody biomass contaminated with paints or sealers, metal, plastic, or other deleterious materials).

The carbon and hydrogen analysis should be classified as a "Class 1" Biochar following the International Biochar Initiative (IBI) guidelines (IBI 2015) or Premium in the new WBC guidelines.

Process

The proposed "bubble-wrap" method below is suggested to avoid excessive handling of the biochar in an effort to prevent more fragmentation of biochar particles than necessary during the mixing process. Mixing should be performed on bare ground or an asphalt pad. Mixing should not be performed on grass. Use the bucket of the front-end loader to lift and mix the pile as each component material is added during the process outlined as follows:

1. Biochar will be delivered depending on the supplier in super sacks or in a covered dump or walking floor tractor trailer, a similar delivery method as compost and other materials.
2. Biochar should be covered when not in use.
3. Mixing should occur in dry weather and the material should not be fully saturated (such as after a rain event). The biochar can be mixed when dry, but the biochar having some moisture will reduce the dust.
4. Add the biochar to compost, as required by local bioretention design specifications. The ratio should be 14-18% biochar by volume or as determined otherwise by the Scaling Up Biochar team.
5. Mix the biochar and the compost using a front-end loader. Mix the biochar and compost until it is mostly turned or until the pile has been flipped at least 2-3 times.
6. Add sand and other components as required by local design specifications. Mix these components with the biochar/compost blend using a front-end loader. Mix until it is fully turned or until the pile has been flipped at least 2-3 times.
7. The completed BEBM mix should be stored in stockpiles uncovered.

2. Biochar Material Stockpile and Storage

Purpose

Proper management of biochar materials to prevent excess water on the material, reduce loss of material and sedimentation to waterways.

Design Criteria

1. Locate stockpile on impervious surface. If stockpile will be located on a pervious surface, an impervious liner is required.
2. Locate stockpiles away from drainage courses and storm drain inlets.
3. Locate stockpile out of concentrated flow areas. If infeasible, redirect concentrated flow around the stockpile.
4. Locate stockpiles away from sensitive areas including steep slopes.
5. The stockpile shall not be more than 20 feet high and slopes shall not be steeper than 2:1.

6. Moisture Content of biochar stockpile shall be between 30%-40% for the biochar material. Locating stockpile under cover such as roof, or impermeable tarp to prevent moisture loss and excesses precipitation collecting in the material .
7. For bagged biochar material (ie biochar in super sack), locate on a raised platform such as a wooden pallet. Locate pallets and super-sacks under cover such as a roof, or impermeable tarp.
8. Biochar shall not be stored in any air-tight containers or environments.

Storage Specifications

1. Cover stockpile when not in use and contain within temporary perimeter sediment barriers such as berms, dikes, silt fences, or sandbag barriers.
2. The perimeter controls must be a minimum of 3 feet from the toe of the stockpile.
3. Access to the stockpile shall only be from the upslope side of the pile.
4. Avoid biochar heating over 300 degrees Fahrenheit.
5. Stockpile shall be located near a source of water or have water easily accessible to maintain the moisture content of stockpiled materials.
6. For bagged biochar material, the above construction specifications do not apply except for items 4 and 5.

Maintenance

During stockpiling, periodically maintain perimeter controls and covers to ensure proper functioning. Inspect stockpile areas after a rain event for scour or evidence that perimeter controls are being bypassed.

For super-sack or bagged biochar, inspect raised platforms. If damaged, replace the raised platform.

Routinely check the interior temperature of the stockpile, particularly in the summer months. Add water to stockpiled biochar to reduce pile temperature when needed.

3. Biochar Material Handling

Purpose

Proper handling of biochar materials to prevent harm to personal safety, reduce loss of material and minimize amount of biochar suspended in the air. As part personal safety and health, the supplier/producer are responsible to provide a Safety Data Sheet (SDS) that will outline critical safety, handling, storage, and emergency response information.

Hazards

1. Biochar can generate dust which may be harmful to airways if inhaled.
2. Eye exposure to biochar dust can lead to irritation and injury.
3. Skin exposure to biochar dust may cause irritation.
4. Workers with respiratory sensitivity should consider wearing proper personal protective equipment or avoid working with biochar as harmful biochar dust may occur.

Handling

Proper personal protective equipment to prevent inhalation, skin, and eye contact should be utilized when handling material in storage and during application.

Exposure Controls and Personal Protection

1. To minimize dust, dampen the biochar before handling or use wetting agents if necessary.
2. Use caution when transferring biochar from package to soil, or from package to applicator.
3. Avoid dumping biochar out of packages from a high height.
4. Apply biochar when winds are mild. Postpone applications when wind creates conditions that can easily suspend biochar.
5. If using an applicator, stay upwind during transfer of biochar to the applicator to reduce personal exposure.
6. Avoid breathing in biochar dust.
7. Avoid biochar dust contact with skin.
8. Personal protective equipment is recommended and required during windy conditions or when dust is present.
    1. Eye protection shall include non-vented safety goggles. In the case of eye exposure, treat biochar dust as a foreign object and flush with water for 15 minutes, including under the lids to remove any dust particles.
    2. Gloves are recommended. If biochar is wet, typical cloth, canvas, or leather gloves may not suffice. Consider latex or PVC gloves when working with biochar in wet conditions.
    3. Long sleeves and full-body clothing coverage is required. Consideration should be given to using disposable outer garments if the work environment is extremely dusty with biochar. Launder all clothing before reuse or discard disposable outer garments after use.
    4. If conditions are such that breathing in biochar dust cannot be avoided, if you have respiratory problems, or if you experience any discomfort with biochar dust, use an NIOSH-Approved N95 particulate filtering facepiece respirator.
9. Wash all exposed skin with soap and water.
10. If an allergy such as dermatitis, asthma, or bronchitis develops from exposure, it may be necessary to remove sensitive workers from further exposure to biochar dust. If persistent irritation, severe coughing, breathing difficulties or rash occur, get immediate medical advice before returning to work with biochar.

References

1. Master Gardener Safety Precautions for Handling, Applying, and Storing Biochar – cenusa bioenergy | Iowa State University Extension and Outreach (LINK)
2. How to Use Biochar: Where It Should and Should Not Be Placed | CharGrow (LINK)
3. Aries Green Biochar Safety Data Sheet (LINK)

4. In-situ Biochar Amendment for Bioretention

Description

This specification outlines the process for amending biochar and sand into existing soils, covering furnishing, soil preparation, and amendment applications. The process integrates biochar and sand to enhance stormwater infiltration, permeability, and bulk density while accounting for excess soil removal due to bulk density changes.

Purpose

Proper incorporation of biochar materials into existing (in-situ) soils can increase infiltration and water holding capacity and increase moisture and soil nutrient retention to improve urban plant growth and success. To ensure performance as guided by the research, all the bioretention media must have at least 60% sand by volume and less than 20% clay.

Characterizing Existing and Target Soil Properties

Characterization of existing soil conditions at the depth of proposed modification. Field testing is always preferable, but not always feasible. If field tests are not possible, technical sources such as the USDA Soil Survey and other references (Table 1) can be used or submit laboratory samples for accurate soil classification. In urban areas with highly disturbed soils, a quick soil sample sent to a laboratory that can provide accurate soil classification is advisable. If reference information is used in urbanized areas, compaction factors should be applied. Field soil tests to conducted include:

- Particle Size Distribution (PSD) – Sand, silt, and clay composition.
- Organic Matter Content (% SOM) – Affects soil structure and moisture retention.
- Bulk Density (g/cm³) – Indicates compaction and aeration.
- Saturated Hydraulic Conductivity (Ksat, in/hr) – Measures water movement through the soil.
- Infiltration Rate (in/hr) – Determines surface water absorption capacity.

ASTM testing standards have been provided for convenience in the Standards section below.

Soil Type	HSG	Water Holding Capacity (in/ft)	Infiltration Rate (in/hr)	Ksat (in/hr)	Bulk Density (g/cm^3)
Sand	A	0.5 - 1.0	> 8.27	4.0 - 15.0	1.50 - 1.70
Loamy Sand	A	1.0 - 1.5	2.41 - 8.27	1.0 - 4.0	1.40 - 1.60
Sandy Loam	A	1.3 - 1.8	1.02 - 2.41	0.5 - 1.0	1.35 - 1.55
Loam	B	1.8 - 2.5	0.52 - 1.02	0.2 - 0.5	1.20 - 1.50
Silt Loam	B	2.0 - 2.8	0.27 - 0.52	0.1 - 0.2	1.10 - 1.40
Sandy Clay Loam	C	1.5 - 2.0	0.13 - 0.27	0.05 - 0.1	1.35 - 1.55
Clay Loam	C	1.8 - 2.5	0.06 - 0.13	0.02 - 0.05	1.20 - 1.40
Silty Clay Loam	D	2.0 - 3.0	0.02 - 0.06	0.005 - 0.02	1.10 - 1.30
Sandy Clay	D	1.5 - 2.2	0.02 - 0.06	0.005 - 0.02	1.40 - 1.60
Silty Clay	D	2.0 - 3.0	0.00 - 0.02	< 0.005	1.10 - 1.30
Clay	D	2.0 - 3.0	< 0.02	< 0.005	1.10 - 1.30

Table 1- Soil Properties (averages)/Hydrologic Soil Groups (1

Biochar Characterization

1. Biochar must meet minimum IBI standards as well as the requirements as outlined in the "Biochar as an Enhancement to Bioretention Practices in the Chesapeake Bay Watershed" (CWP, 2025) white paper.

11711 East Market Place, Suite 200
Fulton, MD 20759
410.461.8323
www.cwp.org

2. Biochar supplier/producer are responsible for providing laboratory testing documentation for verification and quality control review prior to usage.
3. As the particle size distribution is a key aspect of enhancing in situ soils, a sample should be analyzed to ensure compliance.
4. Biochar supplier/producer are responsible in providing appropriate Safety Data Sheet (SDS) prior to usage.
5. Biochar provided by the Center for Watershed Protection's "Scaling Up Biochar in the Chesapeake Bay "project meets minimum IBI standards.

Application Methods

1. Application Rate of biochar for soil amendment shall be 10% to 18% by volume with remaining soil composition adjustments made with sand to align with HSG A. By adjusting the remaining soil composition with sand, the soil structure, hydraulic conductivity, and infiltration performance will align with the desired HSG classification.
2. Biochar must be coarse, with minimal fines, to enhance macroporosity and infiltration. Sand should be well-graded and free of excess silt and clay to prevent compaction.
3. Avoid over-mixing biochar to prevent increasing fines and breaking down the biochar particle size, which could negatively impact soil porosity and infiltration performance.
4. Depth of Integration shall be 6-24 inches. 6-12 inches of integration shall be suitable for turf cover applications while perennial and hardwood plantings require 6-24 inches minimum of biochar amendment integration to maximize soil and plant health benefits. (Sourced from CBP Expert Panel, VT SPR, Cornell Scoop and Dump, and Biohabitats).
5. The spreading and mixing of biochar and final stabilization shall be completed in a one-day operation or ≥5,000 sf with proper Erosion & Sediment Control (E&SC) permits and authorization to prevent the loss of biochar material from wind, rainfall, or runoff.
6. Complete the installation of each modified soil amendment area from top of slope to bottom and at no time shall more than one treatment area be open at the same time as another.

Sequence of Construction

1. Do not complete this work when soil moisture is greater than 40%.
2. Remove turf and overburden prior to beginning soil preparation work.
3. To avoid damaging in-situ soil structure by digging and turning unless being removed to blend in biochar and/or sand.
4. **Shallow Application (<12 inches)**
    a. Subsoil (yeoman or similar) the treatment area to a depth of 24 inches.
    b. Once subsoiling is completed, rotary power harrow (or other similar tool approved by Scaling Up Biochar project) shall be used to till the freshly subsoiled soil to a depth of 11 inches.
    c. Using the rotary harrow, till in the biochar at a speed to allow for a through mixing into the native soil.
    d. After the first pass of the rotary harrow, spread and rake out 1/3 of total project biochar uniformly. Use a drop spreader or similar to uniformly distribute biochar over project area.

e. Once all the required biochar has been thoroughly tilled into the in-situ soils, rake out any tracks and level out any high areas to minimize potential for concentrated runoff or ponding water.
f. Repeat this process (step 4d) twice before all project biochar is used.
g. Seed, straw, and tackify the disturbed area prior to disturbing any additional area. Coir peat matting can be used as an alternative. Seed variety to be determined by property owner or planting schedule.
h. In any area that could have concentrated water flow should use core logs to break up concentrated flows and velocities avoiding erosion issues.
i. Once modified soil amendment area has been stabilized and approved by the designated project consultant, the next soil amendment area can be started.

5. **Deep Application (>12 inches)**
    a. Remove soil to the desired depth based on modification requirements.
    b. Blend biochar into the soil mixture at 10%-18% by volume to improve infiltration and porosity.
    c. Mix sand at the required percentage by volume with the in-situ soil to adjust soil texture.
    d. Replace the amended soil in 12-inch lifts, ensuring even distribution throughout the soil profile.
    e. If feasible, subsoil using a single or double shank at the bottom elevation before replacing the mixed soil to improve natural infiltration and break up any restrictive layers.
    f. Do not compact the soil during mixing or replacement to maintain permeability.
    g. Once all the required biochar has been thoroughly tilled into the in-situ soils, rake out any tracks and level out any high areas to minimize potential for concentrated runoff or ponding water.
    h. Seed, straw, and tackify the disturbed area prior to disturbing any additional area. Coir peat matting can be used as an alternative. Seed variety to be determined by property owner or planting schedule.
    i. In any area that could have concentrated water flow should use core logs to break up concentrated flows and velocities avoiding erosion issues.
    j. Once modified soil amendment area has been stabilized and approved by the designated project consultant, the next soil amendment area can be started.
6. **Biochar Moisture Management**
    a. Biochar may need to be moistened to reduce dust and prevent biochar floating or surface accumulation during mixing. Do not saturate biochar or soils.
    b. Since biochar has a lower bulk density than native soils, the amendment process causes volume expansion, requiring excess soil removal. This ensures proper integration of amendments without increasing the final soil level.
    c. Ensure proper soil moisture levels before final grading to prevent uneven settling.

ASTM Testing Standards

- ASTM D6913-04 Standard Test Method for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis, % by mass (https://www.astm.org/d6913_d6913m-17.html)

- ASTM D7928-17 Standard Test Method for Particle-Size Distribution (Gradation) of Fine-Grained Soils Using the Sedimentation (Hydrometer) Analysis, % by mass (https://www.astm.org/d7928-21e01.html).
- ASTM D2974-20 Standard Test Methods for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils.
- ASTM D7263-21 Standard Test Methods for Laboratory Determination of Density (Unit Weight) of Soil Specimens (https://www.astm.org/d7263-21.html).
- ASTM D8152-18 Standard practice for measuring field infiltration rate and calculating field hydraulic conductivity using the modified Philip (https://www.astm.org/d8152-18.html

References

International Biochar Initiative. 2015. Standardized Product Definition and Product Testing Guidelines for Biochar That Is Used in Soil Version 2.1 [IBI-STD-2.1]. Retrieved from https://biochar-international.org/standard-certification-training/biochar-standards.

Table 1

- Brady, N. C., & Weil, R. R. (2008). The nature and properties of soils (14th ed.). Pearson Prentice Hall.
- U.S. Department of Agriculture (USDA) Soil Survey Staff. (2014). Keys to soil taxonomy (12th ed.). U.S. Government Printing Office.
- ASTM International. (2017). ASTM D2487-17: Standard practice for classification of soils for engineering purposes (Unified Soil Classification System). ASTM International. https://www.astm.org/d2487-17.html
- U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS). (2017). National Engineering Handbook Part 630: Hydrology (Chapter 7 – Hydrologic Soil Groups). U.S. Government Printing Office. Retrieved from https://www.nrcs.usda.gov/resources/data-and-reports/official-soil-series-descriptions
- Rawls, W. J., Brakensiek, D. L., & Saxton, K. E. (1982). Estimating soil water retention and hydraulic properties from soil texture. Soil Science Society of America Journal, 46(5), 1138-1144. https://doi.org/10.2136/sssaj1982.03615995004600050002x
- Rawls, W. J., Giménez, D., & Grossman, R. (1998). Use of soil texture, bulk density, and slope of the water retention curve to predict saturated hydraulic conductivity. Transactions of the ASAE, 41(4), 983-988. https://doi.org/10.13031/2013.17274