Biotreatment Soil Media and Specification:

Current Research on Trees and Water Quality Treatment

Literature Review
San Francisco Bay Area, California

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1.0 INTRODUCTION

Provision C.3 of the Municipal Regional Permit (MRP) requires that biotreatment (or bioretention) systems use biotreatment soil media (BSM) that meets the minimum specifications of the BASMAA BSM Specification. Like other municipalities around the country, the BASMAA Specification requires the BSM to be a mixture of sand and compost (Appendix A):

60% - 70% Sand
30% - 40% Compost

The Bay Area Stormwater Management Agencies Association (BASMAA) and its associated members have identified items of concern with the current specifications for BSM. In particular, trees have failed to thrive in bioretention systems. Trees have a number of potential benefits when included in bioretention: increased nutrient uptake, reduced stormwater runoff through rainfall interception and evapotranspiration, enhanced soil infiltration, soil stabilization, increased aesthetic appeal, wildlife habitat, and shading. Trees have been shown to capture stormwater, reducing the runoff volume directly and potentially reducing peak flows. Tree roots can also directly enhance infiltration rates. Studies in collaboration between Cornell, Virginia Tech, and University of California at Davis showed that black oak and red maple tree roots can penetrate compacted subsoils and increase infiltration rates by an average of 153% (Day and Dickinson 2008).

This report examines potential changes to the BSM and to the design of bioretention systems for the benefit of trees. A variety of potential additives to the BSM have been studies and have the potential to increase water holding capacity and/or compensate for minimal soil volume available in bioretention systems.

Additional concerns with the performance of the current BSM mix are also examined. In particular, nutrient and other pollutant leaching and flushing from bioretention has emerged as a concern in many municipalities. This report addresses changes to the mix and the design of bioretention that could reduce pollutant leaching and flushing.

Lastly, within the current specification, there are a number of improvements that can be made to correct identified problems. These items include:

- Sand Analysis: A need to qualify the sand source due to potential for toxicity, high pH, or other contaminants.
- Compost particle size gradation changes:
- Provide corrections to the infiltration test methods for meeting the alternative specification

This report provides a review of the available literature and municipal specifications for (BSM). In addition, numerous interviews of experts and stakeholders involved in BSM were conducted and incorporated into the report. Experts and stakeholders include: municipal representatives, soil and compost testing laboratories, soil suppliers, urban foresters, and stormwater soil researchers.

This report was presented at Roundtable hosted by BASMAA on June 30, 2016 which is summarized in a separate report dated July 27, 2016 (BASMAA 2016).

2.0 POTENTIAL ADDITIVES OR CHANGES TO BIOTREATMENT SOIL MIX TO BENEFIT TREES AND WATER QUALITY

Biotreatment Soil Mix (BSM) is designed to balance the needs to sustain healthy soil and plant growth, to optimize water quality treatment, and provide an infiltration rate of between 5 – 12 inches per hour. BSM in the Bay Area and in many other regions is a mix of 60% - 70% Sand and 30% - 40% Compost. Most municipalities and researchers (SFEI, San Diego, Seattle, Redmond, Washington State) expressed concern that high levels of nutrients and other pollutants are leaching from bioretention BMPs using the compost/sand BSM (Gilbreath, et al. 2015, BES City of Portland, 2010, RICK Engineering 2014, Herrera 2015, Hinman, personal communication 2016). San Diego, San Francisco, and Seattle have adopted specifications within the last 12 months that adjusted their mix to reduce the proportion of compost to a maximum of 30% by volume in response to this concern.

These concerns are backed by recent studies. Herrera Environmental Consultants, in a study for the City of Redmond, Washington, reports that of 19 different BSM mixes tested, the 60% sand and 40% compost mix was the worst performer in terms of pollutant flushing and pollutant reduction. Curtis Hinman confirmed that after testing numerous different potential BSM mixes, all mixes that contain compost and sand flushed pollutants initially and continued to leach over time (Hinman, personal communication 2016). Most notably, the 60/40 mixes leached nitrogen, phosphorous, and copper.

Others, including Caltrans, are concerned that bioretention BMPs may flush solids when first installed (Penders, personal communication, 2016). BASMAA has identified additional concerns with tree survival and the need for heavy irrigation in the drought limited Bay Area. This section reviews alternative mixes and additives to address tree health and water quality improvements.

Overall, much research has been done in recent years to identify BSMs that improve water quality performance of bioretention BMPs. Emerging trends in municipal specifications point toward providing for recommended alternative mixes to target different goals such as nutrient reduction, or metals reduction, or supporting trees. In general, the standard sand and compost mix is broadly available in our region and the cheapest. Most of the additives will add considerable cost and may need to be shipped from other parts of the country or world (Butch Voss, personal communication, 2016). However, the additional cost may be warranted to meet water quality goals or tree/plant performance goals in some locations.

At this time, research regarding plant growth in various BSMs is much more limited. Some studies of plant performance in alternative mixes are being launched in coming months. Nonetheless, this section summarizes the available research on both the water quality treatment potential and the potential to benefit trees and plants of each additive below.

2.1 Alternative Mixes in Specifications

In general, most municipalities allow for the use of alternative BSM mixes with additional performance testing to ensure they meet the performance criteria. Curtis Hinman feels that the standard 60/40 sand compost mix may be “just fine” for many locations, namely those that are not sensitive to nutrients or copper, and those without underdrains (Personal communication 2016). However, he sees municipalities moving towards a range of alternative mixes.

This is taking place in California as well. The City of San Francisco allows the replacement of up to 15% of the sand volume with other media or soil admixtures to enhance moisture retention capacity of the soil, provided admixtures are low in fines (less than 5% passing the 200 sieve) and do not break down under normal handling and use. However, San Francisco bars the use of topsoil, peat, silts, or clays as admixtures and any materials deleterious to plant growth. San Diego recently adopted recommended alternative BSM mixes including a mix with coconut coir for certain areas sensitive to phosphorous (see below for more detail).

2.2 Topsoil in Biotreatment Soil Mixes

In the San Diego Region, concern for the leaching of nutrients lead the County to evaluate and ultimately revise their BSM specification. Based on input from a task force that included engineers, soil agronomists, landscape architects, and geotechnical engineers, it was deemed important to introduce a sandy loam topsoil component that would still allow good plant growth but reduce the potential leaching of nutrients associated with high levels of organics in the compost. The collective agreement resulted in a mixture (by volume) of 65% sand, 20% Sandy Loam, and 15% Compost. This mix results in approximately 1.5% to 5% organic matter (by weight), once mixed (RICK Engineering, 2014). This mix was adopted and incorporated into the County of San Diego LID Handbook in 2014.

In contrast, the City of San Diego in its most recent *Stormwater Guidebook* (2016), the adopted a standard BSM of sand and compost only, but they encourage use of an alternative mixes for improving plant growth and performance in some areas. The standard mix is 70% to 85% by volume washed sand and 15% to 30% by volume compost 'or alternative organic amendment'. In order to reduce the potential for leaching of nutrients, the City requires that the proportion of compost or alternative organic amendment in the mix is "held to a minimum level that will support the proposed vegetation in the system" (City of San Diego 2016). San Diego allows for 'natural soils' subject to approval by the City Engineer.

In areas where phosphorous is associated with water quality impairment or a Total Maximum Daily Load (TMDL) and underdrains are required, the City recommends replacing the compost component with coco coir pith (see below) or adding an activated alumina polishing layer below the standard BSM to control phosphorous leaching. These recommended alternatives were added per the advice of Geosyntec consultants (Talamayan, personal communication, 2016). According to Jonard Talamayan at the City of San Diego, not many projects were installed while the topsoil BSM was in place. Of primary concern in their region has been the availability of the mix components rather than tree performance but few installations have taken place with trees to date.

CalTrans recently undertook testing of BSM that was a mix of 50% sand, 25% compost, and 25% topsoil (by weight). The mix was designed to have a higher fines content to retain moisture and support grasses and forbs. After 5 years, the overall long-term average infiltration rate was 15 in/hr despite the inclusion of added fines in the mix. In addition, vegetation (grasses) density was healthy and the sites showed improved water quality. Specific water quality data is not yet avialable (CalTrans 2016).

The City of Portland also allows for the inclusion of topsoil in their stormwater facility mix. Their specification calls for "any material that is a blend of loamy soil, sand, and compost that is 30-40% compost (by volume) and meets the other criteria" (City of Portland 2014). Other criteria include a particle size gradation limiting fines in the overall mix, however, hydraulic conductivity or infiltration testing is not required.

In Washington State, numerous studies are on-going to find superior alternatives to the standard sand and compost BSM and reduce pollutant flushing and leaching (Hinman, personal communication, 2016). One study for the City of Redmond Washington, evaluated a mix of 50% Sand and 50% Loamy Sand Topsoil. They tested two mixes to compare two separate sources of loamy sand topsoil. Overall, they found that compared to other BSM mixes, the loamy sand mix exported fewer nutrients but had the poorest infiltration rates at between 1.3 and 5.1 in/hour, based on lab permeability testing (Herrerra Engineering 2015). Herrera Environmental Consultants recommends against the use of the loamy sand mix because of the inconsistency of hydraulic performance. As a part of the Herrera Environmental Consultants study, the 'Loamy Sand Mix' was also tested for its ability to support plant growth (primarily grasses). In comparison to the 60/40 sand and compost mix, the loamy sand mix plant community was not as robust; however, the plant community was still healthy, indicating that growing conditions are at least favorable in the loamy sand mix.

2.3 Biochar in Biotreatment Soil Mixes

Biochar is made from biomass via pyrolysis, a thermochemical decomposition of organic material at elevated temperatures in the absence of oxygen. Raw biochar has no nutrients but it serves as a structure or lattice that can hold nutrients and water to improve soil structure (MacDonagh 2016). This internal carbon architecture is so stable that microorganisms can flourish there, and the long-term stable symbiotic root/microorganism relationships build more sustainable soil environments for tree function. The outcome of enhancing the nutrient- and water-holding capacity and biotic community, is that biochar strengthens soil structure and arrests soil leaching (Fite 2015). When added to soil along with compost, or otherwise activated with fertilizer, the response of trees is greater than with either raw biochar or compost alone (Fite and Macdonagh 2016).

Biochar also has the potential to improve water quality treatment of stormwater in bioretention applications. According to a study out of Oregon State University, researcher Myles Gray found that filtration with biochar alone removed copper and zinc from runoff at a boatyard in Washington State. This study used rinsed biochar, which had the fines removed from the raw biochar material (Gray 2015).

Other studies have examined biochar as an additive to typical sand-compost BSM. Herrera Environmental Consultants tested a mix containing 60% sand, 15% Compost, 15% Biochar, and 10% shredded bark (Herrera Environmental Consultants 2015). As compared to the Bay Area BSM, this mix has less compost but the same quantity of sand. The results showed that the biochar mix had a lower infiltration rate (6.0 in/hr) and seemed to be a source of nutrients. According to the study, the systems with the standard sand-compost mix exported the highest levels of copper, while the systems with biochar exported the highest levels of nutrients. The reduction in infiltration rate with the biochar additive is most likely because the biochar used in this study contained fines (Herrera Environmental Consultants 2015). According to Macdonagh and Fite (2016), washed biochar could be specified to avoid reduction in hydraulic performance. However, according to Curtis Hinman, washed biochar has also been shown to export nutrients and reduce the infiltration rate (personal communication, 2016).

Other studies show biochar has a significant benefit to plants when added under certain conditions. Cao et. al. (2015) studied a biochar mix for use in greenroof soil media and found that biochar significantly increased water retention in green roof substrates. Additional water was plant available and wilting was delayed by 2 days. Kelby Fite, Arboriculture Researcher with the Bartlett Tree Laboratory, conducted research on biochar amendments for street trees. Fite's research revealed that for trees, Biochar should be added to soil at a rate of no more than 5% by volume. When added at greater volumes, plant benefits level off or decline. He believes this may be because the biochar can hold too tightly to water and nutrients (Fite and MacDonagh 2016).

Fite's research and experience revealed a number of additional recommendations for soil amendment with biochar which he described in a recent presentation (Fite and MacDonagh 2016):

- Characteristics of biochar vary based on the feed source and how it is made.
- There are no known open-source specifications for biochar, however, the International Biochar Initiative provides standards for selecting a biochar.
- Biochar for trees is best from a hardwood feed source.
- According to MacDonagh, for low flow bioretention applications, biochar does not cause clogging; however, washed biochar may reduce compromises to hydraulic capacity.

2.4 Coconut Coir Pith in Biotreatment Soil Mixes

Coco coir pith, or coconut coir, is a byproduct of the coconut industry and has previously been used as an alternative to peat moss in soil-less media. This product is not produced in the US and must be shipped from Asia.

In terms of BSM, coco coir pith is recommended in City of San Diego's most recent guidebook as an alternative to compost in areas where phosphorous is associated with water quality impairment or a Total Maximum Daily Load (TMDL) and underdrains are required. No specification for the type or quality of the coco coir is provided.

Curtis Hinman (pers. Communication 2016) and Herrerra Engineering (2015) also identify coconut coir (or coco coir pith) as an additive with potential as an alternative to compost. In their study, they tested a number of BSMs with coco coir replacing the compost component (Herrera Environmental Consultants 2015). The mixes tested included:

- 80% sand, 20% coconut coir
- 70% sand, 20% coconut coir, 10% diatomaceous earth
- 70% sand, 20% coconut coir, 10% granular activated carbon
- 70% sand, 20% coconut coir, 10% high carbon wood ash

The coconut coir mixes outperformed the 60% sand/40% compost mixes in terms of pollutant flushing and pollutant leaching. Basic tests of plant germination and growth were conducted on these mixes with cucumber, barley and clover. All mixes germinated plants. Mixes with compost were the best performers.

Plant growth studies in the context of bioretention systems, beyond the basic germination test, haven't been conducted but Washington State is about to begin some studies in 2016. In general, coconut coir has been shown to promote plant growth and it has been used as an alternative to peat in many hydroponic products. Some negative results have been reported when no other soil is present. Bugbee (2005) indicates that media with more than 50% coir may have reduced growth because of nitrogen immobilization and a high C:N ratio in the coir. Other studies find that coir has a high potassium and low calcium content, and potentially high sodium levels. Lastly, there are different types of coconut coir available on the market and one may be better than others in supporting plants.

2.5 Vermicompost in Biotreatment Soil Mixes

Vermicompost, also known as worm compost or worm castings, uses earthworms and microorganisms to turn organic wastes into high quality compost. The chemical secretions in the earthworm's digestive tract help break down soil and organic matter, so the castings contain more nutrients that are immediately available to plants. The level of nutrients in compost depends upon the source of the raw material and the species of earthworm; however, in general, vermicompost contains higher percentage of macro and micronutrients than traditional 'hot' compost (Nelson 2010). Vermicompost can also be produced at a faster rate than traditional compost. Vermicompost generally always has a high percentage of fines, whereas traditional compost can vary considerably depending on the feed source and processing. The "quality of the fines" is also an important consideration. Assaf Sadeh of Soil Control Lab, indicated that in his experience of testing BSM for permeability, worm castings are highly compressible such that if compacted, no water will infiltrate through a BSM containing a high proportion of vermicompost (Sadeh, personal communication, 2016).

Researchers at Cornell University Department of Plan Pathology and Plant Microbe Biology have shown that vermicompost has potential for plant nutrient management and suppression of plant disease especially for container plants without synthetic fertilizers (Nelson 2010). However, no other studies were identified to evaluate vermicompost over traditional compost for use in BSM. Anecdotally, in San Diego, prior the establishment of a BSM including topsoil, some soil suppliers were experimenting with alternative BSM mixes that included vermicompost (RICK Engineering 2014), but no data on its performance was available.

2.6 Perlite in Biotreatment Soil Mixes

Perlite is a mined material that is quickly heated to expand the mineral. Perlite has been utilized in stormwater treatment facilities and is comparable to sand. Perlite is also used in soil-less media in combination with peat or coco coir to grow plants. Perlite improves drainage and wicks water well much like sand but is more porous. It dries out quickly between rain events or watering. Perlite is not widely used in bioretention mixes although it is specified as part of the BSM in Montgomery County, Maryland. The planting media specified includes 1/3 perlite, 1/3 compost, and 1/3 topsoil (Montgomery County 2005). Studies of perlite for use in media filters have shown it to be superior in capturing fine particles and metals (Wigart 2011). Perlite could be considered as an alternative to the sand component but it appears to have minimal or no benefit for plants and is considerably costlier than sand meeting the current specification.

2.7 Volcanic Sands in Biotreatment Soil Mixes

Volcanic sand is an alternative to silica based sands such as those commonly used to meet the BASMAA Specification. Volcanic sands are more porous than sand specified in the current specification. Their pores can hold air and water and create favorable conditions for rich microbial life and strong root systems. Laboratory tests by researchers in Washington showed that volcanic sand and compost BSM reduce some pollutants in water more effectively that riverine sands mixed with compost (Gealogica 2015). Preliminary research by Gealogica has also shown volcanic sands surpass riverine sands in plant growth. As a pilot project in Washington, researchers installed identical planter boxes with either 60% volcanic sand and 40% compost or 60% riverine sand and 40% compost. After eight months, the planter boxes with the volcanic sands grew to a height that was 140-160% greater than the sedges in the silica sand mix with the same compost component. Tests also revealed that the volcanic sand mixes held water for longer periods of time (Amy Waterman, personal communication 2016). Fassman-Beck et al. (2015) also found that pumice sand had greater than 2.5 times the plant available water as compared to marine sands.

Herrera Environmental Consultants (2015) also tested a number of BSM mixes containing volcanic sand. In all cases, the compost component was either reduced to 10% or replaced with coco coir pith. As described above, the alternative volcanic sand was tested because previous studies had indicated that C-33 sand (the sand commonly used for BASMAA specified bioretention in Seattle and our region) tend to have a higher copper content than other sands. In contrast, the volcanic sand does have a lower copper content and did not leach copper. Volcanic sands could be considered as an alternative to the sand component to reduce copper leaching or possibly improve water holding capacity. Volcanic sands are also being studied for their potential use in polishing layers as described in Section 6 below.

2.8 Diatomaceous Earth in Biotreatment Soil Mixes

Diatomaceous earth or diatomite is the fossilized skeletal remains of single celled aquatic plants called diatoms. Diatomaceous earth is harvested from sedimentary rock and has been widely used as a material for water treatment for over 100 years in the chemical, beverage industries, and potable water production (Marsh 2004). Diatomaceous earth is naturally porous mineral and has the potential to increase drainage, oxygen access, and cation exchange capacity in soil. The pores trap bacteria, clay particles, and other suspended solids. It is also commonly used to repel insects without use of pesticides. Manufacturers recommend an amendment rate of between 5-10% to improve infiltration, reduce compaction, and to increase water availability in the soil. Researchers have confirmed that it can improve soil physical properties including soil moisture content under laboratory conditions when incorporated at a rate of 10% to 30% (Aksakal 2012).

Herrera Environmental Consultants (2015) tested a number of BSM mixes containing diatomaceous earth. Mixes tested contained 70% volcanic sand, 10% diatomaceous earth, and either 20% iron-coated wood chips or 20% coconut coir pith. These mixes out-performed the standard 60/40 sand and compost mix for nutrient and copper reduction. Herrera Environmental Consultants performed basic tests of plant germination and growth on the mixes with cucumber, barley and clover plants. All mixes germinated plants; however, mixes with compost were the best performers for plant coverage and biomass.

2.9 Fines in Biotreatment Soil Mixes

Fines are the clay and silt fraction of soil. Fines are beneficial for bioretention because they increase soil water and nutrient holding capacity, they improve pollutant removal, and they improve soil structure (Shanstrom 2016). Conversely, they have been associated with clogging and are more likely to flush out of a facility.

BSM specifications typically greatly limit fines content in order to protect from failure due to clogging. The current BASMAA specification limits fines (those passing the 200 sieve size) to a maximum of 5% for the sand component and up to 10% in the compost. The lower limit of fines in the compost was recently reduced from 2% to 1%. While this ensures that suppliers are meeting the required permeability, it also likely reduces the water holding capacity of the mix.

More “mature and stable” compost typically has more fines because the material has spent more time decomposing. More mature compost, is typically higher in nutrients – particularly nitrogen. Medium-coarse composts, produced from green waste material, typically more woody, less mature, together with a higher C:N ratio, seem to release less nitrogen than the finer, more mature products. (Greg Balzer, Caltrans, personal communication 2016)

Fines have been documented to contribute to clogging but other factors may mitigate their importance in hydraulic conductivity. Natural soils have better soil structure and therefore higher infiltration rates than an engineered soil with the same particle size profile. Some studies of infiltration rates in bioretention basins show that rather than decreasing over time due to clogging, many bioretention cells exhibit an increase in infiltration rates (Shanstrom 2016).. Lucas (2010) observed 21 bioretention systems in Australia. In systems with initial infiltration rates of over 7 in/hr, rates declined towards an average infiltration rate of 4 in/hr. In contrast, in systems with an initial rate of 0.4 in/hr, these systems increased over time to average nearly 0.8 in/hr, presumably due to the development of macropores (Le Coustumer et al. 2007). Other studies in the US also showed an increase in infiltration rates over time in rain gardens with sand and clay soils (Selbig and Baster 2010, Jenkins et al. 2010). Numerous basins have been documented to have infiltration rates above 1” per hour and up to 6” per hour with greater than 12% fines (Shanstrom 2016, Wardynski et al 2012). Possible explanations for this phenomenon are the presence and development of macropores in healthy soils. Growth and death of plants, earthworms, and other soil organisms can create soil structure than enhances permeability (Shanstrom 2016).

Besides clogging, variable compaction is another possible explanation for the variability seen in BSM that allow for natural soils and fines. Compaction has been shown to decrease infiltration by up to an order of magnitude (Pitt et al. 2008).

2.10 Granular Activated Carbon in Biotreatment Soil Mixes

Granular activated carbon (GAC), like biochar, is a form of stable carbon processed to have small pores that increase the surface area available for adsorption. It has been used for a number of years in water treatment and deodorizing systems. GAC can be specified at various sizes similar to sand. Infiltration rates are typically comparable or faster than sand depending on the specification of the granule size. GAC is one of the costliest additives available and is not made in California.

Pitt and Clarke (2010) in a comparison of filter media including local sand, rhyolite sand, peat moss, surface modified zeolite, and combinations of these materials, found that GAC provided the best reductions in pollutants including copper, lead, and dioxins. GAC was also shown to provide superior performance for removal of metals in the studies by Herrera Environmental Consultants (2015, 2016).

GAC alone does not provide any nutrients to plants. In water treatment studies, GAC was observed to provide sorption of dissolved organic nitrogen but was ineffective for phosphorous attenuation (Wendling 2013). GAC is not locally available and is the most expensive potential additive reviewed in this report.

2.11 High Carbon Wood Ash in Biotreatment Soil Mixes

High carbon wood ash is a waste product from electricity generation wood-fired boilers. Wood ash contains high concentrations of carbon and exhibits some of the properties of GAC and biochar, like high surface area and cation exchange capacity, but is generally cheaper.

Andrew Carpenter of Northern Tilth prepared a study of high carbon wood ash as a soil amendment. He found that the benefits of wood ash include: neutralization of soil acidity, reduction of aluminum toxicity, increased phosphorous availability, provides a source of some micronutrients but is not a source of nitrogen. In his study of germination and growth, wood ash amended soils showed increased cucumber and tomato plant growth after five weeks. When amended at 10% by volume with wood ash, the soil also had greater porosity and water holding capacity (Carpenter 2013). Another recent study in boreal peatland forests showed that amendment with granulated wood ash increased microbial activity and tree growth over two years (Maljanen et al. 2014).

Herrera Environmental Consultants (2015, 2016) tested this product in combination with sand and coconut coir in a mix that contained 70% sand, 20% coconut coir and 10% high carbon wood ash. Hinman believes this mix has the most potential to avoid nutrient and metals flushing after installation and leaching over the long-term for bioretention basins (personal communication, 2016). Basic tests of plant germination and growth were conducted on this mix with cucumber, barley and clover. While this mix did germinate plants, the mixes containing compost outperformed this mix for plant germination and growth.

2.12 Availability and Cost of Additives

We reached out to local suppliers to provide some insight to the costs and feasibility of obtaining additives locally in the Bay Area. Some items were not readily available locally and would require further research to establish a supply chain. In their similar study of costs, Herrera Engineers concluded that the use of additives improves water quality but adds cost to the BSM.

Table 6. Relative Cost of Bioretention Soil Components

Additive	Potential % in mix by volume	Cost per yard (delivered to Bay Area)	Nearest Origin (bulk)
BASMAA Compost	10% - 40%	$15 - 25	Bay Area
BASMAA Sand	50% - 90%	$40 - 45	Bay Area
Biochar, washed	Up to 5%	$350.00[1]	unknown
Coconut Coir Pith	20%	$176.7[1]	India, SE Asia, South Pacific
Vermicompost	15% to 40%	Bulk source not identified	unknown
Perlite	Up to 5%	$50 - 75	Bay Area
Volcanic Sand (Scoria, Pumice)	50% - 70%	$55 - 60	Bay Area
Diatomaceous earth	10%	$300.00[1]	unknown
Clay (clean, non-dredge)	1% - 5%	$15 - 40	Bay Area
Granular Activated Carbon	10%	$718[1]	Nebraska
High Carbon Wood Ash	5-10%	$300[1]	unknown

[1]Local costing not available. Costs based on Seattle sources provided by Herrera Environmental Consultants (2016)

3.0 MODIFICATIONS TO THE CURRENT SPECIFICATION

This section reviews the potential changes to the current BSM Specification. Through working with the current specification BASMAA identified the following problems that warrant consideration:
These items include:

- Sand Analysis: A need to qualify the sand source due to potential for toxicity, high pH, copper, or other contaminants.
- Does the compost particle size gradation provide adequate balance between hydraulic conductivity and treatment?
- Provide corrections to the infiltration test methods for meeting the alternative specification

3.1 Sand Analysis and Qualification

BASMAA identified concerns that the sand component has the potential to contain toxins, high or low pH, or other contaminants. Anecdotally, at least one submitted BSM contained dredge sand material. Caltrans and Washington State also identified issues with potential contamination of the sand component.

Sean Penders, Senior Engineer at Caltrans, describes instances when the sand source was not uniform. Qualifying tests were conducted on the top of the sand pile, while the bottom of the sand pile contained significantly higher proportion of fines resulting in the export of solids from the built bioretention basin.

Herrera Consultants undertook synthetic precipitation leaching protocol (SPLP) testing of the sand component of the BSM mix for the City of Redmond, Washington. The Herrera results indicate that C-33 sands tend to have a higher copper content than other sands. They found that volcanic sands exhibit lower leachable copper levels (Herrera 2015). However, C-33 sand is inexpensive and locally available. Herrera recommends adding a requirement to test for copper in the C-33 sand for default and custom blends. The synthetic precipitation leaching protocol testing is relatively cheap whereas, requiring volcanic or other washed sand sources may add considerable cost to the BSM mix. Anecdotally, Curtis Hinman of Herrera Consultants tested several sands from the Puget Sound region and only found two sands that passed the synthetic precipitation leaching protocol testing (personal communication 2016).

The City of San Diego now specifies chemical suitability testing of the mixed BSM for systems with underdrains. Suitability criteria were established for Nitrate, Phosphorous, Zinc, Copper, Lead, Arsenic, Cadmium, Mercury and Selenium. San Diego requires either the Saturated Media Extract Method or the SPLP test to confirm BSM has limited potential to leach pollutants (Appendix D). It should be noted that Saturation Extract and SPLP tests are expected to result in somewhat more leaching than would be experienced with real storm water; therefore, a direct comparison to water quality standards or effluent limitations is not relevant (City of San Diego 2016).

Caltrans also has developed a sand specification to ensure the sand is clean and will not export solids (Appendix E).

3.2 Compost Particle Size Gradation

Fines, particles passing the 200 sieve, are the clay and silt fraction of soil. Fines are beneficial for bioretention because they increase soil water and nutrient holding capacity, they improve pollutant removal, and they improve soil structure (Shanstrom 2016). Conversely, they have been associated with clogging and are more likely to flush out of a facility. BSM specifications typically greatly limit fines content in order to protect from failure due to clogging.

Across municipalities, the sand gradation is relatively consistent and conforms to ASTM C33 sand. On the other hand, the compost gradation varies considerably more. In the Bay Area, the compost gradation was recently adjusted for the BASMAA specification as well as the City of San Francisco specification to allow a minimum of 1 percent passing the 200 sieve versus the previously required minimum of 2 percent passing. Reducing the allowable minimum fines component may allow soil suppliers to ensure they are meeting the hydraulic conductivity needed in the BSM but could reduce water holding capacity or result in permeability that far exceeds the upper target of 12" per hour.

Below Tables 1 through 4 provide a comparison of allowable compost gradation in bioretention soil mixes from different municipalities.

Table 1. Bay Area Compost Required Gradation (BASMAA, 2016 and San Francisco, 2016):

Sieve Size	Percent Passing (by weight)	
	Min	Max
1 inch	99	100
½ inch	90	100
¼ inch	40	90
No. 200 (0.0029")	1	10

Note: Sand gradation allows 0 – 5% passing 200 sieve.

Table 2. Los Angeles Compost Gradation (Los Angeles County, 2012):

Sieve Size	Percent Passing (by weight)	
	Min	Max
1 inch	99	100
½ inch	90	100
¼ inch	40	90
No. 200 (0.0029")	2	10

Note: This gradation is equivalent to the previously adopted BASMAA guidance. Sand gradation allows 0 – 5% passing 200 sieve.

Table 3. San Diego Compost Gradation (San Diego, 2016)

Sieve Size	Percent Passing (by weight)	
	Min	Max
5/8 inch	99	100
¼ inch	40	95
2 mm (0.079")	40	90
No. 200 (0.0029")	Not specified	

Note: Sand gradation allows 0 – 5% passing 200 sieve. Mixed BSM must have hydraulic conductivity of between 8 – 20 inches per hour.

Table 4. Seattle Compost Gradation (City of Seattle, 2016)

Sieve Size	Percent Passing (by weight)	
	Min	Max
2 inch	100	100
1 inch	99	100
5/8 inch	90	100
¼ inch	75	100

Note: Mixed BSM must have infiltration rate of at least 6”/hour

In addition to these examples, the City of Portland requires gradation of the blended soil to be tested. They allow for fines to be between 5 and 15% passing the 200 sieve size but do not require testing of the compost component and do not test the hydraulic conductivity. Los Angeles also has requirements for alternative BSM. They require the particles passing the 200 sieve size in alternative mixes to be between 2 and 5% by weight (Los Angeles, 2012). For municipalities that do not specify a gradation of fines in either the compost or the mixed BSM, they require hydraulic conductivity testing which may effectively limit the proportion of fines in the mix.

Fines have been documented to contribute to clogging but other factors may mitigate their importance in hydraulic conductivity. Natural soils have better soil structure and therefore higher infiltration rates than an engineered soil with the same particle size profile. Some studies of infiltration rates in bioretention basins show that rather than decreasing over time due to clogging, many bioretention cells exhibit an increase in infiltration rates (Shanstrom 2016). Lucas (2010) observed 21 bioretention systems in Australia. In systems with initial infiltration rates of over 7 in/hr, rates declined towards an average infiltration rate of 4 in/hr. In contrast, in systems with an initial rate of 0.4 in/hr, these systems increased over time to average nearly 0.8 in/hr, presumably due to the development of macropores (Le Coustumer et al. 2007). Other studies in the US also showed an increase in infiltration rates over time in rain gardens with sand and clay soils (Selbig and Baster 2010, Jenkins et al. 2010). Numerous basins have been documented to have infiltration rates above 1” per hour and up to 6” per hour with greater than 12% fines (Shanstrom 2016, Wardynski et al 2012). Possible explanations for this phenomenon are the presence and development of macropores in healthy soils. Growth and death of plants, earthworms, and other soil organisms can create soil structure than enhances permeability (Shanstrom 2016); however, in soils with a high sand content like the BASMAA BSM, soil structure is slow to develop, or may never develop.

Besides clogging, inconsistent compaction is another possible explanation for the variability seen in BSM that allow for natural soils and fines. Compaction has been shown to decrease infiltration by up to an order of magnitude (Pitt et al. 2008). Hinman (2009) showed that at constant relative compaction of 85 percent of maximum dry density), the percent fines is a strong controlling factor in the permeability test. However, variable compaction will result in variable infiltration across equivalent soils.

In contrast to the focus on fines, Assaf Sadeh, of Soil Control Lab, feels that the controlling particle size gradient does not always translate to passing the hydraulic conductivity performance criteria. Sadeh feels that the quality of the fine particles, i.e. are they angular, round, or humus-like, can play a major role in the hydraulic conductivity. In his experience, he has seen compost that meet the gradation but don’t pass the permeability testing (Personal communication 2016). He emphasized the need for hydraulic conductivity or permeability testing of all BSM. The allowable gradation may also be linked to the permeability testing methods described in the next section.

3.3 Permeability Test Methods

The BASMAA Specification requires permeability testing of the BSM standard mix every 120 days and on a project basis for large scale projects. Mixed BSM must have a permability of at least 5” per hour with no upper limit. However, a provision for meeting the performance standard of between 5 and 12 inches per hour for a custom BSM that deviates from the standard mix is provided. The current specification calls for compaction to 85 to 90% of the maximum dry density (ASTM D1557) and testing of hydraulic conductivity via the constant head permeability test ASTM D2434. According to Assaf Sadeh of Soil Control Laboratories, the specified testing method requires compaction to a degree that is above and beyond what is required in field installations. The method then produces a much reduced rate of permeability and is not representative of field conditions for alternative BSM mixes. Sadeh recommends using an alternative testing method that he believes to be more similar to actual installations of BSM: the Proctor Compaction Test or ASTM D698.

Other municipalities have modified the ASTM D2434 to make it more compatible with the goals of the BSM specification. The Cities of San Francisco and Seattle issued modifications to ASTM D2434 to make it more compatible with bioretention performance goals (SFPUC 2016 and Aspect Consulting, 2011).

In Washington State, the City of Redmond undertook a Bioretention Performance Study to evaluate alternatives to the standard sand and compost BSM (Herrera Environmental Consultants 2015). As a part of this study, eight types of different BSM mixes were tested including the Bay Area equivalent BSM mix of 60% sand and 40% compost. For this mix, researchers found that the permeability testing done with method ASTM D2434 at the lab resulted in a slightly higher but fairly comparable rate to field infiltration tests. The column falling head test, however, resulted in a much lower value than found in the field. The table below summarizes the results:

Table 5. Results from 60% Sand/40% Compost BSM Infiltration Rate Testing for Five Studies in Washington (Herrera Environmental Consultants 2015)

Infiltration Test	Rate (In/Hour)
Tacoma Field Test	20.9
Redmond Field Test Site 1	2.9
Redmond Field Test Site 2	11.8
Field Infiltration Average	**11.9**
WSU Column Falling Head Test	41.7
Redmond Column Falling Head Test	49.0
Kitsap Column Falling Head Test	84.0
Column Falling Head Average	**58.2**
Redmond Permeability ASTM 2434	11.9
Kitsap Permeability ASTM 2434	210
Permeability ASTM 2434 Average	**112.6**

4.0 EVALUATION OF MULCH OPTIONS

Many bioretention design guides specify placement of a mulch layer over the surface of bioretention devices. Mulch is specified to protect the medium from erosion, suppress weed growth, and increase water availability for plants during establishment. However, some organic mulches are prone to floating. Floating mulch can expose and erode the underlying growing medium, block overflows, and contaminate receiving waters.

Interviews with California municipal representatives revealed that few had tackled the issue of mulch. Most reported they leave the decision up to the designer and recommend inorganic mulches like stone mulches in areas of direct flow. The City of Seattle recommends 'coarse compost' for which they provide a specific gradation that contains larger particle sizes and limited fines.

A literature search revealed few resources; however, the City of Auckland, New Zealand did undertake a detailed study of mulch options for bioretention to minimize mulch movement into the storm system. Simcock and Dando (2013) evaluated several different mulch types in the field and through lab testing of floatability. The resulting recommendation is to use primarily inorganic mulch: stone and crushed shell mulches. This study also found that some organic mulches (shredded wood waste, shredded bark, arborist pruning and green waste) have reduced floatability when moisture contents and wet bulk density are higher. Here in California, shredded wood products are often barred from use by fire codes. Simcock and Dando found that the most floatable mulches were decorative bark or bark nuggets.

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Appendix A.
BASMAA Regional Biotreatment Soil Specification

Specification of Soils for Biotreatment or Bioretention Facilities

Soils for biotreatment or bioretention areas shall meet two objectives:

- Be sufficiently permeable to infiltrate runoff at a minimum rate of 5" per hour during the life of the facility, and
- Have sufficient moisture retention to support healthy vegetation.

Achieving both objectives with an engineered soil mix requires careful specification of soil gradations and a substantial component of organic material (typically compost).

Local soil products suppliers have expressed interest in developing 'brand-name' mixes that meet these specifications. At their sole discretion, municipal construction inspectors may choose to accept test results and certification for a 'brand-name' mix from a soil supplier.

Tests must be conducted within 120 days prior to the delivery date of the bioretention soil to the project site.

Batch-specific test results and certification shall be required for projects installing more than 100 cubic yards of bioretention soil.

SOIL SPECIFICATIONS

Bioretention soils shall meet the following criteria. "Applicant" refers to the entity proposing the soil mixture for approval by a Permittee.

1. General Requirements – Bioretention soil shall:
   a. Achieve a long-term, in-place infiltration rate of at least 5 inches per hour.
   b. Support vigorous plant growth.
   c. Consist of the following mixture of fine sand and compost, measured on a volume basis:
      60%-70% Sand
      30%-40% Compost
2. Submittal Requirements – The applicant shall submit to the Permittee for approval:
   a. A minimum one-gallon size sample of mixed bioretention soil.
   b. Certification from the soil supplier or an accredited laboratory that the Bioretention Soil meets the requirements of this guideline specification.
   c. Grain size analysis results of the fine sand component performed in accordance with ASTM D 422, Standard Test Method for Particle Size Analysis of Soils or Caltrans Test Method (CTM) C202.
   d. Quality analysis results for compost performed in accordance with Seal of Testing Assurance (STA) standards, as specified in 4.
   e. Organic content test results of mixed Bioretention Soil. Organic content test shall be performed in accordance with by Testing Methods for the Examination of Compost and Composting (TMECC) 05.07A, "Loss-On-Ignition Organic Matter Method".
   f. Grain size analysis results of compost component performed in accordance with ASTM D 422, Standard Test Method for Particle Size Analysis of Soils.
   g. A description of the equipment and methods used to mix the sand and compost to produce Bioretention Soil.

h. Provide the name of the testing laboratory(s) and the following information:

(1) Contact person(s)

(2) Address(s)

(3) Phone contact(s)

(4) E-mail address(s)

(5) Qualifications of laboratory(s), and personnel including date of current certification by USCC, ASTM, Caltrans, or approved equal

3. Sand for Bioretention Soil
   a. Sand shall be free of wood, waste, coating such as clay, stone dust, carbonate, etc., or any other deleterious material. All aggregate passing the No. 200 sieve size shall be nonplastic.
   b. Sand for Bioretention Soils shall be analyzed by an accredited lab using #200, #100, #40 or #50, #30, #16. #8, #4, and 3/8 inch sieves (ASTM D 422, CTM 202 or as approved by municipality), and meet the following gradation:

Sieve Size	**Percent Passing (by weight)**	
	Min	***Max***
3/8 inch	100	100
No. 4	90	100
No. 8	70	100
No. 16	40	95
No. 30	15	70
No. 40 or No.50	5	55
No. 100	0	15
No. 200	0	5

Note: all sands complying with ASTM C33 for fine aggregate comply with the above gradation requirements.

4. Composted Material

   Compost shall be a well decomposed, stable, weed free organic matter source derived from waste materials including yard debris, wood wastes or other organic materials not including manure or biosolids meeting the standards developed by the US Composting Council (USCC). The product shall be certified through the USCC Seal of Testing Assurance (STA) Program (a compost testing and information disclosure program).

a. Compost Quality Analysis by Laboratory – Before delivery of the soil, the supplier shall submit a copy of lab analysis performed by a laboratory that is enrolled in the US Composting Council's Compost Analysis Proficiency (CAP) program and using approved Test Methods for the Examination of Composting and Compost (TMECC). The lab report shall verify:
   (1) Organic Matter Content: 35% - 75% by dry wt.
   (2) Carbon and Nitrogen Ratio: C:N < 25:1 and C:N >15:1
   (3) Maturity/Stability: Any one of the following is required to indicate stability:
      (i) Oxygen Test < 1.3 O2 /unit TS /hr
      (ii) Specific oxy. Test < 1.5 O2 / unit BVS /hr
      (iii) Respiration test < 8 mg CO_2-C /g OM / day
      (iv) Dewar test < 20 Temp. rise (°C) e.
      (v) Solvita® > 5 Index value
   (4) Toxicity: Any one of the following measures is sufficient to indicate non-toxicity.
      (i) NH_4^+ : NO_3^--N < 3
      (ii) Ammonium < 500 ppm, dry basis
      (iii) Seed Germination > 80 % of control
      (iv) Plant Trials > 80% of control
      (v) Solvita® = 5 Index value
   (5) Nutrient Content: provide analysis detailing nutrient content including N-P-K, Ca, Na, Mg, S, and B.
      (i) Total Nitrogen content 0.9% or above preferred.
      (ii) Boron: Total shall be <80 ppm;
   (6) Salinity: Must be reported; < 6.0 mmhos/cm
   (7) pH shall be between 6.2 and 8.2 May vary with plant species.

b. Compost Quality Analysis by Compost Supplier – Before delivery of the compost to the soil supplier the Compost Supplier shall verify the following:
   (1) Feedstock materials shall be specified and include one or more of the following: landscaping/yard trimmings, grass clippings, food scraps, and agricultural crop residues.
   (2) Maturity/Stability: shall have a dark brown color and a soil-like odor. Compost exhibiting a sour or putrid smell or containing recognizable grass or leaves, or is hot (120F) upon delivery or rewetting is not acceptable.
   (3) Weed seed/pathogen destruction: provide proof of process to further reduce pathogens (PFRP). For example, turned windrows must reach min. 55C for 15 days with at least 5 turnings during that period.

c. Compost for Bioretention Soil Texture – Compost for bioretention soils shall be analyzed by an accredited lab using #200, 1/4 inch, 1/2 inch, and 1 inch sieves (ASTM D 422 or as approved by municipality), and meet the following gradation:

Sieve Size	**Percent Passing (by weight)**	
	Min	***Max***

1 inch	99	100
1/2 inch	90	100
1/4 inch	40	90
No. 200	1	10

d. Bulk density shall be between 500 and 1100 dry lbs/cubic yard
e. Moisture content shall be between 30% - 55% of dry solids.
f. Inerts – compost shall be relatively free of inert ingredients, including glass, plastic and paper, < 1 % by weight or volume.

g. Select Pathogens – Salmonella <3 MPN/4grams of TS, or Coliform Bacteria <10000 MPN/gram.
h. Trace Contaminants Metals (Lead, Mercury, Etc.) – Product must meet US EPA, 40 CFR 503 regulations.
i. Compost Testing – The compost supplier will test all compost products within 120 calendar days prior to application. Samples will be taken using the STA sample collection protocol. (The sample collection protocol can be obtained from the U.S. Composting Council, 4250 Veterans Memorial Highway, Suite 275, Holbrook, NY 11741 Phone: 631-737-4931, www.compostingcouncil.org). The sample shall be sent to an independent STA Program approved lab. The compost supplier will pay for the test.

VERIFICATION OF ALTERNATIVE BIORETENTION SOIL MIXES

Bioretention soils not meeting the above criteria shall be evaluated on a case by case basis. Alternative bioretention soil shall meet the following specification: "Soils for bioretention facilities shall be sufficiently permeable to infiltrate runoff at a minimum rate of 5 inches per hour during the life of the facility, and provide sufficient retention of moisture and nutrients to support healthy vegetation."

The following steps shall be followed by municipalities to verify that alternative soil mixes meet the specification:

1. General Requirements – Bioretention soil shall achieve a long-term, in-place infiltration rate of at least 5 inches per hour. Bioretention soil shall also support vigorous plant growth. The applicant refers to the entity proposing the soil mixture for approval.
   a. Submittals – The applicant must submit to the municipality for approval:
      (1) A minimum one-gallon size sample of mixed bioretention soil.
      (2) Certification from the soil supplier or an accredited laboratory that the Bioretention Soil meets the requirements of this guideline specification.

(3) Certification from an accredited geotechnical testing laboratory that the Bioretention Soil has an infiltration rate between 5 and 12 inches per hour as tested according to Section 1.b.(2)(ii).
(4) Organic content test results of mixed Bioretention Soil. Organic content test shall be performed in accordance with by Testing Methods for the Examination of Compost and Composting (TMECC) 05.07A, “Loss-On-Ignition Organic Matter Method”.
(5) Grain size analysis results of mixed bioretention soil performed in accordance with ASTM D 422, Standard Test Method for Particle Size Analysis of Soils.
(6) A description of the equipment and methods used to mix the sand and compost to produce Bioretention Soil.
(7) The name of the testing laboratory(s) and the following information:
    (i) Contact person(s)
    (ii) Address(s)
    (iii) Phone contact(s)
    (iv) E-mail address(s)
    (v) Qualifications of laboratory(s), and personnel including date of current certification by STA, ASTM, or approved equal.

b. Bioretention Soil
(1) Bioretention Soil Texture: Bioretention Soils shall be analyzed by an accredited lab using #200, and 1/2” inch sieves (ASTM D 422 or as approved by municipality), and meet the following gradation:

Sieve Size	**Percent Passing (by weight)**	
	Min	***Max***
1/2 inch	97	100
No. 200	2	5

(2) Bioretention Soil Permeability testing: Bioretention Soils shall be analyzed by an accredited geotechnical lab for the following tests:
    (i) Moisture – density relationships (compaction tests) shall be conducted on bioretention soil. Bioretention soil for the permeability test shall be compacted to 85 to 90 percent of the maximum dry density (ASTM D1557).
    (ii) Constant head permeability testing in accordance with ASTM D2434 shall be conducted on a minimum of two samples with a 6-inch mold and vacuum saturation.

MULCH FOR BIORETENTION FACILITIES

Three inches of mulch is recommended for the purpose of retaining moisture, preventing erosion and minimizing weed growth. Projects subject to the State’s Model Water Efficiency Landscaping Ordinance (or comparable local ordinance) will be required to provide at least three inches of mulch. Aged mulch, also called compost mulch, reduces the ability of weeds to establish, keeps soil moist, and replenishes soil nutrients. Aged mulch can be obtained through soil suppliers or directly from commercial recycling yards. It is recommended to apply 1" to 2" of composted mulch, once a year, preferably in June following weeding.

Appendix B.
Caltrans Sand Specificaiton

Add to section 68-2.02F:

68-2.02F(6) Class 5 Permeable Material

Class 5 permeable material for use in media filters must consist of hard, durable, clean sand, and must be free from organic material, clay balls, or other deleterious substances.

The percentage composition by weight of Class 5 permeable material in place must comply with the grading requirements shown in the following table:

Class 5 Permeable Material Grading Requirements

Sieve sizes	Percentage passing
3/8"	100
No. 4	95–100
No. 8	80–100
No. 16	45–85
No. 30	15–60
No. 50	3–15
No. 100	0–4
No. 200	0

Standard ASTM 6913	Range
Effective Particle size (ES)=(D_{10})	0.0098”-0.0197”
Uniformity Coefficient Uc = (D_{60}/D_{10})	< 4

Class 5 permeable material must have a durability index of not less than 40.

At least 5 days before placing Class 5 permeable material, submit a certificate of compliance for gradation of the material.

No more than 5 days after placing Class 5 permeable material, submit:

1. At least one ASTM D 6913 test on the permeable material at an authorized location.
2. Verification that the placed permeable material complies with the grading requirements

Prior to placement, wash Class 5 permeable material:

1. To remove silt and clay particles.
2. With potable water equal to at least four times the volume of the material to be placed.

After placement, wash Class 5 permeable material:

1. With potable water.
2. Until the discharged water has a turbidity reading of:
   a. 30 NTU or less for jobs within the Tahoe Hydrologic Unit
   b. 200 NTU or less for jobs outside of the Tahoe Hydrologic Unit

You must capture and dispose of the wash water, and

1. Dispose of outside the state right of way.
2. Use as dust control.
3. Disperse onsite in an authorized location other than the BMP.

Place Class 5 permeable material:

1. In a manner that will not damage or cause permanent displacement of the filter fabric.
2. Using methods that will produce a finished surface as shown.

Appendix C.
City of San Diego Bioretention Soil Media (BSM) Specificaiton

F.4. Bioretention Soil Media (BSM)

F.4.1 General

Bioretention Soil Media (BSM) is a formulated soil mixture that is intended to filter storm water and support plant growth while minimizing the leaching of chemicals found in the BSM itself. BSM consists of 70% to 85% by volume washed sand and 15% to 30% by volume compost or alternative organic amendment. Alternative proportions may be justified under certain conditions. BSM shall be mixed thoroughly using a mechanical mixing system at the plant site prior to delivery. In order to reduce the potential for leaching of nutrients, the proportion of compost or alternative organic amendment shall be held to a minimum level that will support the proposed vegetation in the system.

F.4.1.1 Sand for Bioretention Soil Media.

The sand shall conform to ASTM C33 "fine aggregate concrete sand" requirements. A sieve analysis shall be performed in accordance with ASTM C 136, ASTM D 422, or approved equivalent method to demonstrate compliance with the gradation limits shown in Table F.4-1. The sand shall be thoroughly washed to remove fines, dust, and deleterious materials prior to delivery. Fines passing the No. 200 sieve shall be non-plastic.

Table F.4-1 Sand Gradation Limits

Sieve Size (ASTM D422)	Percent Passing (by weight)	
	Minimum	Maximum
3/8 inch	100	100
#4	95	100
#8	80	100
#16	50	85
#30	25	60
#50	5	30
#100	0	10
#200	0	5

Note: Coefficient of Uniformity (Cu = D60/D10) equal to or greater than 4.

F.4.1.2 Compost.

Compost shall be certified by the U.S. Composting Council's Seal of Testing Assurance Program or an approved equivalent program. Compost shall comply with the following requirements:

1. Organic Material Content shall be 35% to 75% by dry weight.

2. Carbon to nitrogen (C:N) ratio shall be between 15:1 and 40:1, preferably above 20:1 to reduce the potential for nitrogen leaching/washout.
3. Physical contaminants (manmade inert materials) shall not exceed 1% by dry weight.
4. pH shall be between 6.0 and 7.5.
5. Soluble Salt Concentration shall be less than 10 dS/m (Method TMECC 4.10-A, USDA and U.S. Composting Council).
6. Maturity (seed emergence and seedling vigor) shall be greater than 80% relative to positive control (Method TMECC 5.05-A, USDA and U.S. Composting Council)
7. Stability (Carbon Dioxide evolution rate) shall be less than 2.5 mg CO_2-C per g compost organic matter (OM) per day or less than 5 mg CO_2-C per g compost carbon per day, whichever unit is reported. (Method TMECC 5.08-B, USDA and U.S. Composting Council). Alternatively a Solvita rating of 6 or higher is acceptable.
8. Moisture shall be 25%-55% wet weight basis.
9. Select Pathogens shall pass US EPA Class A standard, 40 CFR Section 503.32(a).
10. Trace Metals shall pass US EPA Class A standard, 40 CFR Section 503.13, Tables 1 and 3.
11. Shall be within gradation limits in Table F.4-2 (ASTM D 422 sieve analysis or approved equivalent).

Table F.4-2 Compost Gradation Limits

Sieve Size	**Percent Passing (by weight)**
16 mm (5/8")	99 to 100
6.3 mm (1/4")	40 to 95
2 mm	40 to 90

F.4.1.3 Alternative Mix Components and Proportions.

Alternative mix components and proportions may be utilized, provided that the whole blended mix (F.4.2) conforms to agricultural, chemical, and hydraulic suitability criteria, as applicable. Alternative mix designs may include alternative proportions, alternative organic amendments and/or the use of natural soils. Alternative mixes are subject to approval by the City Engineer.

Alternative mixtures may be particularly applicable for systems with underdrains in areas where phosphorus is associated with a water quality impairment or a Total Maximum Daily Load (TMDL) in a downstream receiving water. BSM with 15% to 30% compost by volume (as specified in F.4.1.3) will likely contribute to increased phosphorus in effluent. Alternative organic amendments, such as coco coir pith, in place of compost should be considered in these areas. A sand or soil substrate with low plant available phosphorus (< 5 mg/kg) should also be considered. The use of compost in these mixes should be limited to the top three to six inches of soil and limited to the minimum level needed to augment fertility. Additionally, an activated alumina polishing layer can be considered to control phosphorus leaching.

Additional mix components, such as granular activated carbon, zeolite, and biochar may be considered to improve performance for other parameters.

F.4.2 Whole BSM Testing Requirements and Criteria.

The Contractor shall submit the following information to the City Engineer at least 30 days prior to ordering materials:

- Source/supplier of BSM,
- Location of source/supplier,
- A physical sample,
- Available supplier testing information,
- Whole BSM test results from a third party independent laboratory,
- Description of proposed methods and schedule for mixing, delivery, and placement of BSM.

Test results shall be no older than 120 days and shall accurately represent the materials and feed stocks that are currently available from the supplier.

Test results shall demonstrate conformance to agricultural suitability criteria (F.4.2.1), chemical suitability criteria (F.4.2.2), and hydraulic suitability criteria (F.4.2.3). No delivery, placement, or planting of BSM shall begin until test results confirm the suitability of the BSM. The Contractor shall submit a written request for approval which shall be accompanied by written analysis results from a written report of a testing agency. The testing agency must be registered by the State for agricultural soil evaluation which indicates compliance stating that the tested material proposed source complies with these specifications. Third party independent laboratory tests shall be paid for by the Contractor.

F.4.2.1 BSM Agricultural Suitability

The BSM shall be suitable to sustain the growth of the plants specified and shall conform to the following requirements:

a) pH range shall be between 6.0-7.5
b) Salinity shall be less than 3.0 millimho/cm (as measured by electrical conductivity)
c) Sodium adsorption ration (SAR) shall be less than 3.0
d) Chloride shall be less than 150 ppm

The test results shall show the following information:

a) Date of Testing
b) Project Name

c) The Contractor's Name

d) Source of Materials and Supplier's Name

e) pH

f) E_C

g) Total and plant available elements (mg/kg particle concentration): phosphorus, potassium, iron, manganese, zinc, copper, boron, calcium, magnesium, sodium, sulfur, molybdenum, nickel, aluminum, arsenic, barium, cadmium, chromium, cobalt, lead, lithium, mercury, selenium, silver, strontium, tin, and vanadium. Plant available concentration shall be assessed based on weak acid extraction(ammonium Bicarbonate/DTPA soil analysis or similar)

h) Soil adsorption ratio

i) Carbon/nitrogen ratio

j) Cation exchange capacity

k) Moisture content

l) Organic content

m) An assessment of agricultural suitability based on test results

n) Recommendations for adding amendments, chemical corrections, or both.

BSM which requires amending to comply with these specifications shall be uniformly blended and tested in its blended state prior to testing and delivery.

F.4.2.2 BSM Chemical Suitability

For systems with underdrains, the BSM shall exhibit limited potential for leaching of pollutants that are at levels of concern. Potential for pollutant leaching shall be assessed using either the Saturated Media Extract Method (aka, Saturation Extract) that is commonly performed by agricultural laboratories or the Synthetic Precipitation Leaching Procedure (SPLP) (EPA SW-846, Method 1312). The referenced tests express the criteria in terms of the pollutant concentration in water that is in contact with the media. In areas in which a pollutant or pollutants are associated with a water quality impairment or a TMDL, BSM in systems with underdrains shall conform to the following Saturation Extract or SPLP criteria for applicable pollutant(s):

a) Nitrate < 3 mg/L

b) Phosphorus < 1 mg/L[10]

c) Zinc < 0.1 mg/L

d) Copper < 0.025 mg/L

---

10 Alternative mixtures should be considered for systems with underdrains in areas where phosphorus is associated with a water quality impairment or a TMDL or where the BSM does not achieve the Saturation Extract or SPLP criteria of < 1 mg/L total phosphorus as specified in 800-4.2.2. Details regarding alternative mixtures requirements and potential components are included in F.4.1.3.

e) Lead < 0.025 mg/L

f) Arsenic < 0.02 mg/L

g) Cadmium < 0.01 mg/L

h) Mercury < 0.01 mg/L

i) Selenium < 0.01 mg/L

Criteria shall be met as stated where a pollutant is associated with a water quality impairment or Total Maximum Daily Load (TMDL) in any downstream receiving water. Criteria may be waived or modified, at the discretion of the City Engineer, where a pollutant does not have a nexus to a water quality impairment or TMDL of downstream receiving water(s). Criteria may also be modified at the discretion of the City Engineer if the Contractor demonstrates that suitable BSM materials cannot be feasibly sourced within a 50-mile radius of the project site and a good faith effort has been undertaken to investigate available materials.

Note that Saturation Extract and SPLP tests are expected to result in somewhat more leaching than would be experienced with real storm water; therefore, a direct comparison to water quality standards or effluent limitations is not relevant.

The chemical suitability criteria listed in this section do not apply to systems without underdrains, unless groundwater is impaired or susceptible to nutrients contamination.

F.4.2.3 BSM Hydraulic Suitability

The saturated hydraulic conductivity or infiltration rate of the whole BSM shall be measured by one of the following methods:

a. Measurement of hydraulic conductivity (USDA Handbook 60, method 34b) (commonly available as part of standard agronomic soil evaluation), or

b. ASTM D2434 Permeability of Granular Soils (at approximately 85% relative compaction Standard Proctor, ASTM D698)

BSM shall conform to hydraulic criteria associated with the BMP design configuration that best applies to the facility where the BSM will be installed (options describe below).

Systems with unrestricted underdrain system (i.e., media control). For systems with underdrains that are not restricted, the BSM shall have a minimum measured hydraulic conductivity of 8 inches per hour to ensure adequate flow rate through the BMP and longevity of the system. The BSM should have a maximum measured hydraulic conductivity of no more than 20 inches per hour. BSM with higher measured hydraulic conductivity may be accepted at the discretion of the City Engineer. In all cases, an upturned elbow system on the underdrain, measuring 9 to 12 inches above the invert of the underdrain, should be used to control velocities in the underdrain pipe and reduce potential for solid migration through the system.

Systems with restricted underdrain system (i.e., outlet control). For systems in which the flowrate of water through the media is controlled via an outlet control device (e.g., orifice or valve) affixed to the outlet of the underdrain system, the hydraulic conductivity of the media should be at least 15 inches per hour and not more than 40 inches per hour. The outlet control device should control the flowrate to between 5 and 12 inches per hour. This configuration reduces the sensitivity of system performance to the hydraulic conductivity of the material, reduces the likelihood of preferential flow through media, and allows more precise design and control of system flow rates. For these reasons, outlet control should be considered the preferred design option.

Systems without underdrains. For systems without underdrains, the BSM shall have a hydraulic conductivity at least 4 times higher than the underlying soil infiltration rate, but shall not exceed 12 inches per hour.

F.4.3 Delivery, Storage and Handling

The Contractor shall not deliver or place soils in frozen, wet, or muddy conditions. The Contractor shall protect soils and mixes from absorbing excess water and from erosion at all times. The Contractor shall not store materials unprotected during large rainfall events (>0.25 inches). If water is introduced into the material while it is stockpiled, the Contractor shall allow the material to drain to the acceptance of the City Engineer before placement.

BSM shall be thoroughly mixed prior to delivery using mechanical mixing methods such as a drum mixer. BSM shall be lightly compacted and placed in loose lifts approximately 12 inches (300 mm) to ensure reasonable settlement without excessive compaction. Compaction within the BSM area should not exceed 75 to 85% standard proctor within the designed depth of the BSM. Machinery shall not be used in the bioretention facility to place the BSM. A conveyor or spray system shall be used for media placement in large facilities. Low ground pressure equipment may be authorized for large facilities at the discretion of the City Engineer.

Placement methods and BSM quantities shall account for approximately 10% loss of volume due to settling. Planting methods and timing shall account for settling of media without exposing plant root systems.

The Engineer may request up to three double ring infiltrometer tests (ASTM D3385) or approved alternative tests to confirm that the placed material meets applicable hydraulic suitability criteria (800-4.2.3). In the event that the infiltration rate of placed material does not meet applicable criteria, the City Engineer may require replacement and/or decompaction of materials.

F.4.4 Quality Control and Acceptance

Close adherence to the material quality controls herein are necessary in order to support healthy vegetation, minimize pollutant leaching, and assure sufficient permeability to infiltrate/filter runoff during the life of the facility. Amendments may be included to adjust agronomic properties. Acceptance of the material will be based on test results certified to be representative. Test results shall be conducted no more than 120 days prior to delivery of the blended BSM to the project site. For projects installing more than 100 cubic yards of BSM, batch-specific tests of the blended mix shall be provided to the City Engineer for every 100 cubic yards of BSM along with a site plan showing the placement locations of each BSM batch within the facility.

F.4.5 Integration with Other Specifications

This specification includes is related to, and may depend or have dependency on other specifications, including but not limited to:

- Plantings and Hydroseed
- Mulch
- Aggregate (choking stone, drainage stone, energy dissipation)
- Geotextiles
- Underdrains
- Outlet control structures
- Excavation

Execution of this specification requires review and understanding of related specifications. Where conflicts with other specifications exist or appear to exist, the Contractor shall consult with the City Engineer to determine which specifications prevail.

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F.5. Aggregate Materials for BSM Drainage Layers

Drainage of BSM requires the use of specific aggregate materials for filter course (aka choking layer) materials and for an underlying drainage and storage layer.

F.5.1 Rock and Sand Products for Use in BSM Drainage

Size classifications detailed in Tables F.5-1 and F.5-2 shall apply with respect to BSM drainage materials. All sand and stone products used in BSM drainage layers shall be clean and thoroughly washed.

Table F.5-1 Crushed Rock and Stone Gradation Limits

Sieve Size	Percent Passing Sieves	
	AASHTO No. 57	ASTM No. 8
3 in	-	-
2.5 in	-	-
2 in	-	-
1.5 in	100	-
1 in	95 – 100	-
0.75 in	-	-
0.5 in	25 – 60	100
0.375 in	-	85 – 100
No. 4	10 max.	10 – 30
No. 8	5 max.	0 – 10
No. 16		0 – 5
No. 50		-

Table F.5-2 Sand Gradation Limits

Sieve Size	Percent Passing Sieves
	Choker Sand - ASTM C33
0.375 in	100
No. 4	95 – 100
No. 8	80 – 100
No. 16	50 – 85
No. 30	25 – 60
No. 50	5 – 30
No. 100	0 – 10
No. 200	0 – 3

F.5.2 Graded Aggregate Choker Stone

Graded aggregate choker material is installed as a filter course to separate BSM from the drainage rock reservoir layer. This ensures that no migration of sand or other fines occurs. The filter course consists of two layers of choking material increasing in particle size. The top layer of the filter course shall be constructed of thoroughly washed ASTM C33 fine aggregate sand material conforming to gradation limits contained in Table F.5-2. The bottom layer of the filter course shall be constructed of thoroughly washed ASTM No. 8 aggregate material conforming to gradation limits contained in Table F.5-1.

F.5.3 Open-Graded Aggregate Stone

Open-graded aggregate material is installed to provide drainage for overlying BSM and filter course layers, provide additional storm water storage capacity, and contain the underdrain pipe(s). This layer shall be constructed of thoroughly washed AASHTO No. 57 open graded aggregate material conforming to gradation limits contained in Table F.5-1.

F.5.4 Spreading

Imported BSM drainage material shall be delivered to the BMP system installation site as uniform mixtures and each layer shall be spread in one operation. Segregation within each aggregate layer shall be avoided and the layers shall be free from pockets of coarse or fine material.

Aggregate shall be deposited on underlying layers at a uniform quantity per linear foot (meter), which quantity will provide the required compacted thickness within the tolerances specified herein without resorting to spotting, picking up, or otherwise shifting the aggregate material.

The thickness of the aggregate storage layer (AASHTO No. 57) will depend on site specific design and shall be detailed in contract documents.

The bottom layer of the filter course (ASTM No.8) shall be installed to a thickness of 3 inches (75 mm). The layer shall be spread in one layer. The top layer of the filter course (ASTM C33) shall be installed to a thickness of 3 inches (75 mm). The layer shall be spread in one layer. Marker stakes should be used to ensure uniform lift thickness.

F.5.5 Compacting

Filter course material and aggregate storage material shall be lightly compacted to approximately 80% standard proctor without the use of vibratory compaction.

F.5.6 Measurement and Payment

Quantities of graded aggregate choker material and open-graded aggregate storage material will be measured as shown in the Bid. The volumetric quantities of graded aggregate choker stone material and open-graded storage material shall be those placed within the limits of the dimensions shown on the Plans.

The weight of material to be paid for will be determined by deducting (from the weight of material delivered to the Work) the weight of water in the material (at the time of weighing) in excess of 1% more than the optimum moisture content. No payment will be made for the weight of water deducted as provided in this subsection.

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Appendix D.
San Francisco Bioretention Specification 33 47 27

DESIGNER NOTE: Green text corresponds to notes to the designer. Remove prior to use.

DESIGNER NOTE: Replace "Engineer/Landscape Architect" with person in responsible charge for the project (e.g., Owner, Engineer, Landscape Architect).

PART 1 GENERAL

1.01 SUMMARY

A. This section includes:

1. Bioretention Soil Mix
2. Aggregate Storage
3. Mulch [To be completed by designer.]
4. Streambed Gravel [To be completed by designer.]

B. Related Sections:

1. Section 01 57 29 – Temporary Protection of Green Infrastructure Facilities

DESIGNER NOTE: The designer should list any additional specification sections which relate to the bioretention work (i.e., clean outs and underdrains, overflow structures, planting, temporary erosion control, utilities, irrigation, earthwork, other appurtenances, etc.).

1.02 STANDARDS AND CODES

A. Reference Standards: This section incorporates by reference the latest versions of the following documents. These references are a part of this section as specified and modified.

Reference	Title
Caltrans	Standard Specifications
San Francisco DPW	Engineering Standard Specifications
ASTM	Annual Book of ASTM Standards, American Society for Testing and Materials, Philadelphia, PA, 1997 or latest edition.

1.03 DEFINITIONS

A. Bioretention Soil Mix (BSM): A soil mix that has been specially blended and tested for use in bioretention facilities with the intent to meet the following objectives:

1. Infiltrate runoff at a minimum rate of 5 inches per hour throughout the life of the facility, and
2. By nature of its components be capable of the removal of certain suspended and dissolved stormwater pollutants, and
3. Have sufficient moisture retention and other agronomic properties to support healthy vegetation.

1.04 REFERENCES

DESIGNER NOTE: Designer to provide references to all project specific documents (e.g., geotechnical report).

1.05 SUBMITTALS

A. Pre-Installation Submittals: The Contractor shall submit to the Engineer/Landscape Architect the following a minimum of 20 calendar days (or as directed by the Engineer/Landscape Architect) prior to the construction of bioretention facilities:

1. BSM Submittals

a. Two one (1) gallon samples of the BSM.

b. Source certificates for all BSM materials.

c. Sieve analysis of BSM per ASTM D422 performed within two (2) months of product delivery to site

d. Certification from the soil supplier or an accredited testing agency that the BSM, including sand and compost components, conforms to all industry or technical society reference standards specified in Sections 2.01.A, 2.01.B, and 2.01C.

e. A description of the equipment and methods used to mix the sand and compost to produce BSM.

f. Organic content test results of the BSM, performed in accordance with Testing Methods for the Examination of Compost and Composting (TMECC) 05.07A, "Loss-On-Ignition Organic Matter Method."

g. Permeability test results for BSM per ASTM D2434 (Modified). See SFPUC Modified ASTM D2434 Procedures for required modifications to test.

DESIGNER NOTE: On larger projects, it may be appropriate to require that the above testing be performed on samples taken at the supplier's yard from the stockpile to be used for the project; see designer note in Section 1.06.C.2.

2. Sand Submittals

a. Sieve analysis of sand per ASTM D422 performed within two (2) months of product delivery to site.

DESIGNER NOTE: Consider revising acceptable age of sieve tests depending on scale of project. On a larger project it may be appropriate to require testing on samples taken at the supplier's yard from the stockpile to be used for the project.

3. Compost Submittals

a. Quality analysis results for compost performed in accordance with Seal of Testing Assurance (STA) standards, as specified in Section 2.01.C, and performed within two (2) months of product delivery to site.

b. Sieve analysis of compost per TMECC 02.02-B performed within two (2) months of product delivery to site.

4. Other Submittals

a. Cut sheets of any media or soil admixes to enhance moisture retention properties, if used.

b. Testing agency qualifications as specified in Section 1.06.B.

DESIGNER NOTE: Designer should include relevant submittal requirements for mulch and streambed gravel (e.g., sieve analysis), to ensure quality of delivered products.

1.06 QUALITY CONTROL AND QUALITY ASSURANCE

A. General: Test and inspect bioretention materials and operations as Work progresses as described in this section. Failure to detect defective Work or materials at any time will not prevent rejection if a defect is discovered after installation, nor shall it constitute final acceptance.

B. Testing Agency Qualification:

1. General: Agencies that perform testing on bioretention materials, including permeability testing, shall be accredited by STA, ASTM, AASHTO, or other designated recognized standards organization. All certifications shall be current. Testing agency shall be capable of performing all tests to the designated and recognized standards specified and shall provide test results with an accompanying Manufacturer's Certificate of Compliance. The following information shall be provided for all testing laboratories used:

a. Name of lab(s) and contact person(s)

b. Address(es) and phone number(s)

c. Email address(es)

d. Qualifications of laboratory and personnel including the date of current certification by STA, ASTM, AASHTO, or approved equal.

2. Compost: Laboratory that performs testing shall be independent, enrolled in the US Composting Council's (USCC) Compost Analysis Proficiency (CAP) program, and perform testing in accordance with USCC Test Method for The Examination of Composting and Compost (TMECC). The sample collection protocol can be obtained from the U.S. Composting Council, 4250 Veterans Memorial Highway, Suite 275, Holbrook, NY 11741, 631-737-4931, www.compostingcouncil.org.

C. Responsibilities of Contractor

1. Submittals: Some of the tests required for this specification are unique, and BSM shall be considered a long-lead-time item. Under no circumstance shall failure to comply with all specification requirements be an excuse for a delay or for expedient substitution of unacceptable material(s). The requirements of Division 0 apply in their entirety.

Pre-Placement Conference: A mandatory pre-placement conference will take place, including at a minimum the Engineer/Landscape Architect, the Resident Engineer, the Owner/Client Representative, Installer, and general Contractor, to review schedule, products, soil testing, permeability testing, and installation. The Contractor shall notify the Engineer/Landscape Architect a minimum of 2 working days prior to conference.

DESIGNER NOTE: Pre-placement conference is mandatory for all projects within the public right-of-way, or on other public property, and is strongly recommended for privately-owned parcel projects.

2. Testing: All testing specified herein is the responsibility of the Contractor and shall be conducted by an independent testing agency, retained by the Contractor. The Owner reserves the right to conduct additional testing on all materials submitted, delivered, or in-place to ensure compliance with Specifications.

DESIGNER NOTE: Batch-specific test results and certifications shall be required for projects installing more than 500 cubic yards of BSM.

1.07 DELIVERY, STORAGE, AND HANDLING

A. Protect the BSM and mulch from contamination and all sources of additional moisture at supplier site, during transport, and at the project site, until incorporated into the Work.

B. The Contractor is required to coordinate delivery of BSM and aggregates with bioretention facility excavation and soil installation. A written schedule shall be submitted for review as part of the submittal package. BSM should not be stockpiled onsite for any length of time. In no case shall BSM be stockpiled onsite for more than 24 hours without prior written approval by the Engineer/Landscape Architect. If stockpiling onsite for any length of time, BSM stockpiles shall meet the following requirements:

1. Locate stockpiles away from drainage courses, inlets, sewer cleanout vents, and concentrated stormwater flows

2. Place stockpiles on geotextile fabric

3. Cover stockpiles with plastic or comparable material

4. Contain stockpiles (and prevent contamination from adjacent stockpiles) with temporary perimeter barrier (e.g., sand bags, wattles, silt fence)

PART 2 PRODUCTS

2.01 BIORETENTION SOIL MIX (BSM)

A. General: BSM shall be a well-blended mixture of sand and compost, shall have sufficient moisture retention to support healthy plant growth, and shall meet the following criteria:

1. Mixture proportions: 30 to 40 percent Compost by volume and 60 to 70 percent Sand by volume

   DESIGNER NOTE: Up to 15 percent of the sand fraction may be replaced with other media or soil admixtures (e.g., scoria, coconut coir, perlite, expanded shale, gypsum, vermiculite, pumice, biochar, etc.) to enhance moisture retention capacity of soil, provided admixtures are low in fines (less than 5 percent passing the 200 sieve) and do not break down under normal handling and use. No topsoil, peat, silts, or clays are permitted to be used as admixtures. Admixtures shall be free of sediments and other materials deleterious to plant growth.

2. Organic matter content: 4 to 8 percent as determined by TMECC 05.07-A, Loss on Ignition Method.

3. Extraneous materials: BSM shall be free of all roots, plants, weeds, sod, stones, clods, pockets of coarse sand, construction debris, or other extraneous materials harmful to plant growth.

4. Permeability/Saturated Hydraulic Conductivity: 10 inches per hour (minimum) tested in accordance with ASTM D2434 (Modified). See SFPUC Modified ASTM D2434 Procedures for required modifications to test.

   DESIGNER NOTE: 10-inch-per-hour minimum rate assumes a design rate of 5 inches per hour and a correction factor of 2 to account for reduction in performance from initially measured rates.

5. Acceptance of BSM quality and performance may be based on samples taken from stockpiles at supplier's yard, submitted test results, and/or onsite and laboratory testing of installed material at the discretion of the Engineer/Landscape Architect. The point of acceptance will be determined in the field by the Engineer/Landscape Architect.

DESIGNER NOTE: Designer to consider non-compost based BSM specification if facility is serviced by an underdrain and if it is draining to phosphorus sensitive water body.

B. Sand: Sand in the BSM shall conform to the requirements for Sand, Type [specify type from table below] specified herein, unless otherwise approved by the Engineer/Landscape Architect.

DESIGNER NOTE: Designer to specify sand type based on project specific requirements. If bioretention facilities will be subjected to heavy sediment loads (e.g., arterial runoff), consider specifying Sand, Type B (low fines sand) in an effort to reduce clogging risk (pending local availability). Additionally, projects anticipating heavy sediment loads should incorporate pre-settling measures at the upstream end of the facility to allow for more efficient maintenance of facilities.

1. Sand shall be free of wood, waste, coating, or any other deleterious material.

2. Sand material shall meet the following specifications for gradation.

Sieve Size[1]	Percent Passing by Weight	
	Type A[2]	Type B (low fines)[3]
3/8 inch	100	100
No. 4	90 to 100	90 to 100
No. 8	70 to 100	70 to 100
No. 16	40 to 95	40 to 85
No. 30	15 to 70	15 to 60
No. 50	5 to 55	8 to 15
No. 100	0 to 15	0 to 4
No. 200	0 to 5	0 to 2

[1] Sieve provided in nominal size square openings or United States Standard Sieve Series sizes.

[2] Sand conforming to ASTM C33 for Fine Aggregate satisfies the requirements of this specification for Sand, Type A.

[3] Type B (low fines) sand gradation pending local availability.

3. Coefficient of Uniformity: $C_u = \frac{D_{60}}{D_{10}}$: 4 or less for Sand, Type B.

4. Effective Particle Size (D_{10}): 0.3 to 0.5 mm for Sand, Type B.

5. All aggregate passing the No. 200 sieve shall be non-plastic.

6. Acceptance of grading and quality of the sand may be based on samples taken from stockpiles at supplier's yard or a submitted gradation report at the discretion of the Engineer/Landscape Architect. The point of acceptance will be determined in the field by the Engineer/Landscape Architect.

C. Compost: Compost in the BSM shall be well decomposed, stable, weed free organic matter sourced from waste materials including yard debris, wood wastes or other organic materials, not including biosolids or manure feedstock. Compost shall conform to California Code of Regulations

Title 14, Division 7, Chapter 3.1 requirements, be certified through the USCC Seal of Testing Assurance (STA) Program, and meeting the criteria specified herein.

1. Feedstock: Feedstock materials shall be specified and include one or more of the following: landscape/yard trimmings, grass clippings, food scraps, and agricultural crop residues. Feedstock shall not include biosolids or manure.

2. Organic Matter Content: 35 to 75 percent by dry weight tested in accordance with TMECC 05.07-A (Loss on Ignition Organic Matter Method).

3. Carbon to Nitrogen Ratio: C:N between 15:1 and 25:1 when tested in accordance with TMECC 05.02-A.

4. Maturity/Stability: shall have a dark brown color and a soil-like odor. Compost exhibiting a sour or putrid smell, containing recognizable grass or leaves, or is hot (120°F) upon delivery or rewetting is not acceptable. In addition any one of the following is required to indicate stability:

a. Specific Oxygen Uptake Rate (SOUR): 1.5 milligrams O_2 per gram biodegradable volatile solids per hour (maximum) per TMECC 05.08-A.

b. Carbon Dioxide Evolution Rate: 8 milligrams CO_2 per gram volatile solids per day per TMECC 05.08-B.

c. Dewar Self Heating Test: 20°C temperature rise (maximum) per TMECC 05.08-D (Class IV or V).

d. Solvita®: Index value greater than 6 per TMECC 05.08-E.

5. Toxicity: Seed Germination: greater than 80 percent of control AND Vigor: greater than 80 percent of control per TMECC 05.05-A.

6. Nutrient Content: provide analysis detailing nutrient content including N-P-K, Ca, Na, Mg, S, and B.

a. Total Nitrogen: 0.9 percent (minimum).

b. Boron: Total shall be < 80 ppm

7. Salinity/Electrical Conductivity: less than 6.0 deciSiemen per meter (dS/m or mmhos/cm) per TMECC 04.10-A (1:5 Slurry Method, Mass Basis).

8. pH: 6.5 to 8 per TMECC 04.11-A (1:5 Slurry pH).

9. Gradation: Compost for BSM shall meet the following size gradation per TMECC 02.02-B (test shall be run on dry compost sample):

Sieve Size	Percent Passing by Weight

	Min	*Max*
1 inch	99	100
1/2 inch	90	100
1/4 inch	40	90
No. 200	1	10

10. Bulk density: 500 to 1,100 dry pounds per cubic yard.

11. Moisture content: 30 to 55 percent of dry solids.

12. Inerts: compost shall be relatively free of inert ingredients, including glass, plastic and paper, less than 1 percent by weight or volume per TMECC 03.08A.

13. Weed seed/pathogen destruction: provide proof of process to further reduce pathogens (PFRP). For example, turned windrows must reach minimum 55°C for 15 days with at least 5 turnings during that period.

14. Select Pathogens

a. Salmonella: less than 3 Most Probable Number per 4 grams of total solids, dry weight per TMECC 07.02.

b. Coliform Bacteria: fecal coliform less than 1,000 Most Probable Number per gram of total solids, dry weight per TMECC 07.01.

15. Trace Contaminants Metals (lead, mercury, etc.): Product must meet US EPA, 40 CFR 503 regulations.

D. Soil Admixtures: [Specify admixtures, if used]

2.02 AGGREGATE STORAGE

DESIGNER NOTE: Aggregate storage layer requirements are dependent on location of project (i.e., MS4 areas vs. combined sewer areas), site specific conditions (e.g., native soil infiltration rates, storage volume needs of project). The designer should update this specification based on the aggregate storage materials required for the project.

DESIGNER NOTE: Aggregate storage is optional in combined sewer areas for facilities without underdrains. BSM depth may also be increased for additional storage capacity (in lieu of an aggregate storage layer), provided the facility is within a combined sewer area and not serviced by an underdrain.

A. Aggregate Storage shall consist of hard, durable, and clean, sand, gravel, or mechanically crushed stone, substantially free from adherent coatings. Materials shall be washed thoroughly to remove fines, organic matter, extraneous debris, or objectionable materials. Recycled materials are not permitted. The material shall be obtained only from a source(s) approved by the Engineer/Landscape Architect. Written requests for source approval shall be submitted to the Engineer/Landscape Architect not less than ten (10) working days prior to the intended use of the Material. Should the proposed source be one that the Engineer/Landscape Architect has no history of Material performance with, the Engineer/Landscape Architect reserves the right to take preliminary samples at the proposed source, and make preliminary tests, to first determine acceptability of the new source and then perform the applicable Material approval testing. Continued approval of a source is contingent upon the Materials from that source continuing to meet Contract requirements. Materials shall meet the Standard Specifications for grading and quality for use in the Work; however, allowable exceptions may be specified in the Contract.

B. Aggregate storage shall meet the following specifications for grading and quality.

1. Aggregate gradation testing in accordance with ASTM C136 at least once per 500 cubic yards.

Sieve[1]	Percent Passing by Weight		
	Choking Course ASTM No. 9 (Modified)[3]	**Reservoir Course ASTM No. 7 (Modified)[4]**	**Caltrans Class 2 Permeable Aggregate (MS4 Areas Only)**
1 inch	–	–	100
3/4 inch	–	100	90 to 100
1/2 inch	100	90 to 100	–
3/8 inch	100	40 to 70	40 to 100
No. 4	85 to 100	0 to 15	25 to 40
No. 8	10 to 40	0 to 5	18 to 33
No. 16	0 to 10	–	–
No. 30	–	–	5 to 15
No. 50	–	–	0 to 7
No. 200[2]	0 to 2	0 to 2	0 to 3

[1] Sieve provided in nominal size square openings or United States Standard Sieve Series sizes.

[2] Gradation modified from ASTM for portion passing the No. 200 sieve.

[3] Materials likely to meet this specification are available locally as Graniterock 1/4” premium screenings (Wilson 1/4" x #10 Premium Screenings).

[4] Materials likely to meet this specification are available locally as Graniterock 1/2” premium screenings (Wilson 1/2" x #4 Roofing Aggregate).

2. <u>Crushed Particles</u>: 90 percent (minimum) fractured faces tested in accordance with California Test 205. Do not use rounded river gravel.

3. <u>L.A. Abrasion</u>: 40 percent (maximum) tested in accordance with ASTM C 131.

DESIGNER NOTE: If the designer chooses to specify materials that differ from those provided herein, the designer should check their filter criteria to evaluate the likelihood of finer-graded material migration into underlying coarser graded materials or reduction in permeability relative to the underlying material. Refer to the SFPUC Aggregate Filter Criteria Guidance document for information on selecting appropriate alternate materials.

DESIGNER NOTE: Designer should verify that underdrain slot dimensions for project are compatible with aggregate gradation specified. Refer to the SFPUC Aggregate Filter Criteria Guidance document for information on selecting appropriate underdrain materials.

2.03 MULCH

DESIGNER NOTE: This section intentionally left blank. Designer to specify mulch requirements for bioretention facilities. Mulch may be wood, compost, or rock mulch. Mulch shall be free of dyes, recycled dimensional lumber, and bark. Materials selected shall be sufficiently permeable to allow water to pass through at a rate equal to or greater than the underlying BSM. Typical mulch recommended for this application includes tree trimming mulch per Caltrans Standard Specification Section 20-7.02D(6)(a) and (e), or other comparable material (e.g., arbor mulch).

2.04 STREAMBED GRAVEL

DESIGNER NOTE: This section intentionally left blank. Designer to specify gravel requirements, including gradation, for bioretention facilities. Streambed Gravel shall be sized to provide energy dissipation and to minimize erosion at facility inlets and outlets. The following text is a sample/template specification for cobbles within a bioretention facility:

Streambed Cobbles shall be clean, naturally occurring water rounded gravel material. Streambed Cobbles shall have a well-graded distribution of cobble sizes and conform to the following gradation [Designer to specify]:

Streambed Cobbles	
Approximate Size[1]	**Percent Passing by Weight**

[1] Approximate size can be determined by taking the average dimension of the three axes of the rock, Length, Width, and Thickness, by use of the following calculation: (Length + Width + Thickness)/3 = Approximate Size Length is the longest axis, width is the second longest axis, and thickness is the shortest axis.

The grading of the cobbles shall be determined by the Engineer/Landscape Architect by visual inspection of the load before it is dumped into place, or, if so ordered by the Engineer/Landscape Architect, by dumping individual loads on a flat surface and sorting and measuring the individual rocks contained in the load. Cobbles must be washed before placement.

PART 3 EXECUTION

3.01 GENERAL

A. Prevent runoff from adjacent pervious and impervious surfaces from entering the bioretention facility (e.g., sand bag inlet curb cuts, stabilize adjacent areas, flow diversion) until authorization is given by the

Engineer/Landscape Architect. Refer to SFPUC Specification Section 01 57 29 Temporary Protection of Green Infrastructure Facilities.

B. Exclude equipment from bioretention facilities. No equipment shall operate within the facility once bioretention facility excavation has begun, including during and after excavation, backfilling, mulching, or planting.

C. Prevent foreign materials and substances, such as silt laden run-off, construction debris, paint, paint washout, concrete slurry, concrete layers or chunks, cement, plaster, oils, gasoline, diesel fuel, paint thinner, turpentine, tar, roofing compound, or acid from entering or being stored in the facility at any point during construction.

3.02 GRADING

A. The Contractor shall not start bioretention facility grading until all areas draining to the facility are stabilized and authorization has been given by the Engineer/Landscape Architect.

B. Construct bioretention facility subgrade to +/- 3/4 inch of the grades and slopes specified on the Plans.

C. Excavation within 6 inches of final native soil grade shall not be permitted if facility soils have standing water, or have been subjected to more than 1/2 inch of precipitation within the previous 48 hours.

3.03 SUBGRADE PREPARATION AND PROTECTION

A. Protect the bioretention excavation from over compaction and/or contamination.

1. Areas which have been over compacted by equipment or vehicle traffic or by other means and which need to be ripped, over excavated, receive additional scarification, or other restorative means shall be done at the Contractor’s expense and at the direction of the Engineer/Landscape Architect.

2. Excavated areas contaminated by sediment laden runoff prior to placement of BSM or Aggregate Storage material shall be remediated at the Contractor’s expense by removing the contaminated soil (top 3 inches minimum) and replacing with a suitable material, as determined by the Engineer/Landscape Architect.

B. Remove all trash, debris, construction waste, cement dust and/or slurry, or any other materials that may impede infiltration into prepared subgrade.

C. The subgrade shall be inspected and accepted by the Engineer/Landscape Architect prior to placement of any materials or final subgrade scarification.

D. Scarify the surface of the subgrade to a minimum depth of 3 inches immediately prior to placement of BSM or aggregate storage material. Acceptable methods of scarification include use of excavator bucket teeth or a rototiller to loosen the surface of the subgrade.

E. Place aggregate storage material, where shown on drawings with conveyor belt or with an excavator or loader from a height no higher than 6 feet unless otherwise approved by the Engineer/Landscape Architect (i.e., do not dump material directly from truck into cell).

F. Aggregate Storage areas contaminated by sediment-laden runoff prior to placement of BSM shall be remediated at the Contractor's expense by removing the contaminated aggregate storage material (top 3 inches minimum or as directed by the Engineer/Landscape Architect) and replacing with clean aggregate storage material per Section 2.03, to the lines and grades on the Plans.

G. Aggregate Storage material shall be inspected and accepted for placement and finish grade by the Engineer/Landscape Architect prior to the installation of BSM. Any material that does not conform to this Specification shall be removed and replaced with acceptable material or remediated to the satisfaction of the Engineer/Landscape Architect, at the Contractor's expense.

3.04 BIORETENTION SOIL MIX PLACEMENT

A. The Contractor shall not place BSM until the Engineer/Landscape Architect has reviewed and confirmed the following:

1. <u>BSM delivery ticket(s)</u>: Delivery tickets shall show that the full delivered amount of BSM matches the product type, volume and manufacturer named in the submittals. Each delivered batch of BSM shall be accompanied by a certification letter from the supplier verifying that the material meets specifications and is supplied from the approved BSM stockpile.

2. <u>Visual match with submitted samples</u>: Delivered product will be compared to the submitted 1-gallon sample, to verify that it matches the submitted sample. The Engineer/Landscape Architect may inspect any loads of BSM on delivery and stop placement if the soil does not appear to match the submittals; and require sampling and testing of the delivered soil to determine if the soil meets the requirements of Section 2.01 before authorizing soil placement.

3. Inspection of the aggregate storage layer, underdrain, cleanout, and overflow structure installation, where included on the plans.

DESIGNER NOTE: On larger projects, it may be appropriate to require that the testing specified in Section 2.01 be performed on samples taken at the supplier's yard from the stockpile to be used for the project; see designer note in Section 1.06.C.2.

B. BSM placement, grading and consolidation shall not occur when the BSM is excessively wet, or has been subjected to more than 1/2 inch of precipitation within 48 hours prior to placement. Excessively wet is defined as being at or above 22 percent soil moisture by a General Tools &

Instruments DSMM500 Precision Digital Soil Moisture Meter with Probe (or equivalent). A minimum of three readings with the soil moisture probe will be used to determine the average percent soil moisture reading per each truck load. There should be no visible free water in the material.

C. The Contractor shall place BSM loosely with a conveyor belt or with an excavator or loader from a height no higher than 6 feet, unless otherwise approved by the Engineer/Landscape Architect (i.e., do not dump material directly from truck into cell). Soil shall be placed upon a prepared subgrade in accordance with these Specifications and in conformity with the lines, grades, depth, and typical cross-section shown in the Drawings or as established by the Engineer/Landscape Architect.

D. Excessively dry BSM may be lightly and uniformly moistened, as necessary, to facilitate placement and workability.

E. Compact BSM using non-mechanical compaction methods (e.g., boot packing, hand tamping, or water consolidation) to 83 percent (+/- 2 percent) of the maximum dry density per modified Proctor test (ASTM D1557), or as directed by the Geotechnical Engineer. Determination of in-place density shall be made using a nuclear gauge per ASTM D6938. Moisture content determination shall be conducted on a soil sample taken at the location of the nuclear gage reading per ASTM D2216.

DESIGNER NOTE: BSM compaction target density will be updated as more data from installed projects becomes available on the optimal compaction to minimize settlement while maintaining the infiltration capacity of the media. Designers are encouraged to report field density measurements, observed infiltration rates (if available), and anecdotal field observations (e.g., soil appears well draining, settlement observed minimal).

F. Grade BSM to a smooth, uniform surface plane with loose, uniformly fine texture. Rake, remove ridges, and fill depressions to meet finish grades.

G. Final soil depth shall be measured and verified only after the soil has been compacted. If after consolidation, the soil is not within +/- 3/4 inch of the grades and slopes specified on the Plans, add material to bring it up to final grade and raked.

H. The BSM shall be inspected and accepted for placement and finish grade by the Engineer/Landscape Architect prior to the installation of planting and mulch. Any BSM that does not conform to this Specification shall be remediated to the satisfaction of the Engineer/Landscape Architect, or removed and replaced with acceptable BSM, at the Contractor’s expense.

3.05 PLANTING AND MULCHING

A. Bioretention facilities shall be planted and mulched as shown on the Plans.

B. Bioretention facilities shall not be planted or mulched when soils are excessively wet as defined in Section 3.04.

C. Bioretention facility areas contaminated by sediment laden runoff prior to planting or placement of mulch shall be remediated at the Contractor's expense by removing the contaminated BSM (top 3 inches minimum) and replacing with BSM per Section 2.01, to the lines and grades on the Plans.

D. All mulch shall be inspected and accepted by the Engineer/Landscape Architect to ensure appropriate depth and material prior to facility commissioning (e.g., unblocking of inlets).

DESIGNER NOTE: Planting and mulching requirements shall be determined by the designer and included or referenced herein.

3.06 FLOOD TESTING

A. Inlets shall be constructed per the Plans and free from all obstructions prior to commencing flow testing.

B. Testing shall be conducted at the conclusion of the 90-day plant grow-in period. Protection and flow diversion measures installed to comply with Section 01 57 29 Temp Protection of GI Facilities shall be removed in their entirety prior to commencing flow testing.

C. Underdrains shall be plugged at the outlet structure to minimize water consumption during testing.

D. Prior to testing, broom sweep gutter and other impervious surfaces within the test area to remove sediments and other objectionable materials.

E. The Engineer/Landscape Architect shall be present during the demonstration. The Contractor shall notify the Engineer/Landscape Architect a minimum of 2 working days prior to testing.

F. The Contractor shall water test each facility to demonstrate that all inlet curb openings are capturing and diverting all water in the gutter to the facility, outlet structures are engaging at the elevation specified, and the designed ponding depth is achieved. Testing shall include application of water from a hydrant or water truck per Section 00 73 73, Article 3.04 (Requirements for Using Water For Construction), at a minimum rate of 10 gallons per minute, into the gutter a minimum of 15 feet upstream of the inlet curb opening being tested. Each inlet shall be tested individually. If erosion occurs during testing, restore soils, plants, and other affected materials.

DESIGNER NOTE: Designer should update test flow rate for inlets to reflect project-specific design, as needed.

G. Engineer/Landscape Architect will identify deficiencies and required corrections, including but not limited to relocating misplaced plants, adjusting streambed gravel, adjusting mulch, adjusting inlets, splash aprons, and forebays, removing and replacing inlets, and removing debris.

H. Once adjustments are made, the Contractor shall re-test to confirm all test water flows into the facility from the gutter and correct any remaining deficiencies identified by Engineer/Landscape Architect.

I. Inlets, outlets, and other bioretention facility appurtenances shall not be accepted until testing and any required correction and retesting is complete and accepted by the Engineer/Landscape Architect.

DESIGNER NOTE: The Owner may, at any time, conduct additional testing on all materials submitted, delivered, or in-place, to ensure compliance with the Specifications. Testing may include permeability testing per ASTM D2434 (Modified), density testing per ASTM D6938, etc., if the Engineer/Landscape Architect suspects the facility does not conform to these specifications (e.g., as evidenced by lower than anticipated infiltration capacity).

DESIGNER NOTE: Designer should consider adding a similar requirement to the Concrete Paving and Sanitary Sewerage Utilities sections of the Specifications, as needed.

END OF SECTION