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Deliverable 3.1 = Report on water retention curves of bioretention soil mix

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The Stormwater Management Manual for Western Washington (SWMMWW 2014) provides hydraulic conductivity specifications for both the custom and “default” (60% sand, 40% compost v/v) bioretention soil mixes (BSM). To understand the physical and hydraulic properties of the BSM prepared for this study, the soil was evaluated at the bench-scale to estimate the modified maximum dry density in order to determine appropriate target soil bulk density, the saturated hydraulic conductivity (K_{sat}) as a function of bulk density, and the moisture characteristic curve for several soil bulk densities.

According to the SWMMWW 2014, BSM should be installed such that it has a relative compaction of 85 percent of the modified maximum dry density according to ASTM 1557 Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort. The SWMMWW vis-à-vis the Western Washington Hydrology Model (WWHM) assumes that this value for the 60/40 mix corresponds to a K_{sat} of 30 cm/h. Despite these detailed guidelines, the SWMMWW does not provide an explicit target bulk density for the default 60/40 mix, so an effort to characterize the soil according to ASTM 1557 was undertaken to define this design parameter.

The premise of the ASTM 1557 method is that the same compressive force can compact soils to different densities depending on the moisture content of the soil. Soils that are very dry or very wet do not compact as much as soils with a moderate water content. The principle of the method is to subject a soil to standardized compaction conditions while varying the moisture content. The soil that is most compactable (yields the highest density) allows the calculation of the “maximum dry density.”

A metal cylinder (length=115 mm, diameter=102.5 mm) was filled with 60/40 BSM in five layers and was subjected to 78 blows per layer with a 2.7 kg slide hammer falling 0.25 m and striking the soil surface on a 2.5 cm diameter plate which was moved around the soil surface as described in the ASTM method. After compaction, the cylinder was weighed to the nearest gram and a moisture sample was collected. The wet density of the compacted BSM was calculated by dividing the wet mass of soil in the cylinder by the cylinder volume (949 cm^3). The gravimetric moisture content of the soil and the soil wet density were used to calculate the dry (bulk) BSM density. This procedure was repeated for BSM samples with varying

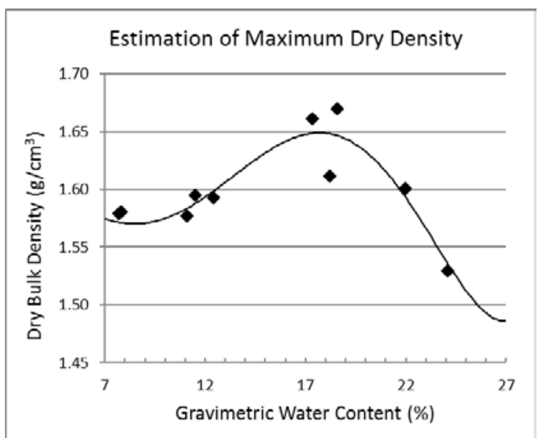

Figure 1: Estimation of maximum dry density of 60/40 BSM by ASTM 1557.

moisture contents. A plot of moisture content versus bulk density allows estimation of the maximum dry density as described in ASTM 1557 (Figure 1).

After estimating the appropriate bulk density for 60/40 BSM as described in the SWMMWW (85% of 1.65 g/cm^3= 1.40 g/cm^3), soil columns were prepared at various bulk densities bracketing this target value to determine if the SWMMWW compaction specification corresponded with the SWMMWW K_{sat} specification. Samples of BSM were placed in the metal cylinder previously described and were compacted with variable forces to produce columns with a range of soil bulk densities. Each soil column was placed on a 600 micron screen and saturated slowly from the bottom up to allow air to escape the BSM matrix. After saturation, the water level in the column was raised 10 cm above the soil surface and the falling head method was used to estimate the K_{sat} at three time points which were then averaged.

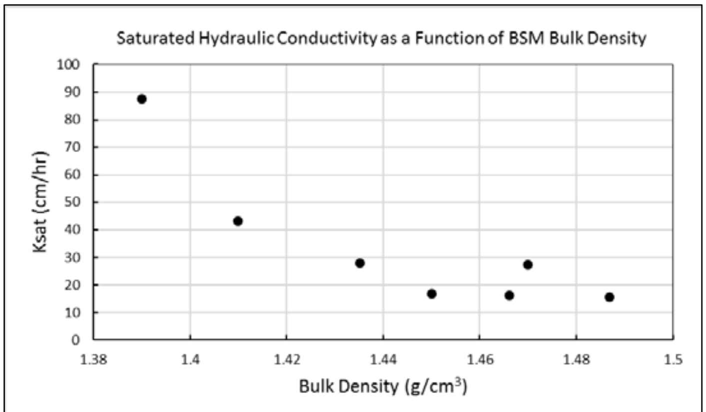

Figure 2: Estimation of falling head saturated hydraulic conductivity at various BSM bulk densities.

As expected, this bench scale trial illustrated that the BSM K_{sat} decreased as a predictable function of bulk density (Figure 2). The regression-estimated K_{sat} at the specified 85% of the maximum dry density (1.40 g/cm^3) was closer to 50 cm/h rather than 30 cm/h as stated in the SWMMWW. An alternative way to express the same relationship is that the 60/40 BSM soil demonstrated the target saturated hydraulic conductivity (30 cm/h) at approximately 1.44 g/cm^3 or 87% of the maximum dry density. These values are sufficiently close to the SWMMWW standards to confirm that the compaction and hydraulic conductivity guidelines given in the manual are congruent with the physical properties of the soil. The data also highlights how small differences in soil compaction (bulk density) can dramatically alter the hydraulic conductivity.

Once the appropriate degree of compaction (bulk density) was determined and the saturated hydraulic conductivity of the soil at that bulk density was confirmed, soil moisture characteristic curves were developed for BSM meeting the target bulk density as well as BSM at lower and higher densities. The soil moisture characteristic is a graphical representation of the relationship between the water content of the soil and the matric potential. While water content is a familiar concept, matric potential is less familiar. The matric potential represents how “tightly” the water is bound up in the soil. The conventional units of measurement are J/kg or kPa and essentially represent how much suction (as negative pressure or energy) is needed to get the water back out (1kPa ≈ -10 cm water column). For example, clay and sand at the same water content have very different matric potentials: sand has high potential (closer to zero) and clay has low water potential (large negative values).

The moisture characteristic was determined using the hanging water column method with supplementary higher suction data points collected using the pressure plate method at 0.3 and 1.0 bar of pressure. Briefly, BSM samples were collected in brass sampling rings, transferred into a sintered glass Büchner funnel and saturated. Incrementally increasing tension was applied to the BSM matrix by slowly lowering the outlet of a hanging water column. This method applies low levels of suction to the sample and allows measurement of the extracted water at various tensions (negative pressures). The extracted water is measured and the values are used to back-calculate the moisture content at each matric potential increment. Similarly, loss of mass before and after placing the soil sample in a pressure plate apparatus is used to determine the moisture loss at each pressure increment. As illustrated in Figure 3, the 60/40 BSM is best characterized as a high water potential medium, meaning that water is primarily held in the matrix in large diameter pores and is therefore only "loosely" bound in the BSM.

On a water retention curve, the saturation point of the soil is assumed to be equivalent to the porosity, while the volumetric water content at 330 cm tension (0.33 bar) is equal to the field capacity of the soil. Field capacity is the amount of water that a soil will hold "against gravity" assuming that evapotranspiration is ignored. At the target compaction leading to a bulk density of 1.40 g/cm^3, the saturated water content is 41% with a field capacity of about 18%. When the soil is over-compacted to 1.48 g/cm^3, the soil porosity drops to around 37%—but due to smaller pore volumes (stronger capillary forces) the energy required to remove the water increases. As a result, the field capacity of the over-compacted soil increases to around 30%. In under-compacted (essentially un-compacted) BSM, the increased pore volume allows for some additional porosity (43%) and the field capacity remains similar to the target BSM, but the BSM will drain down to this field capacity more quickly because the water is held more "loosely."

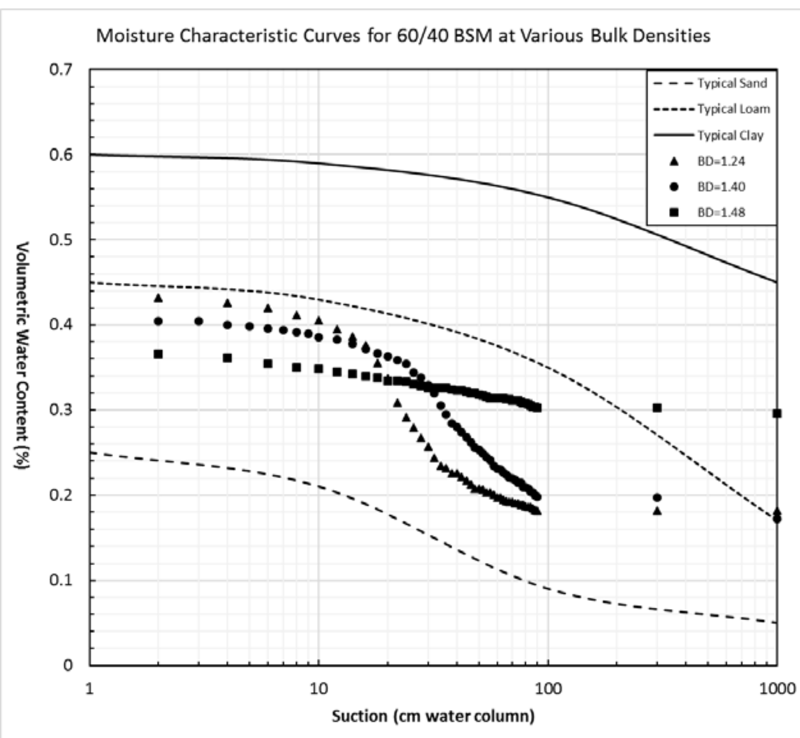

Figure 3: Low potential moisture characteristic for 60/40 BSM at a bulk density of 1.24, 1.40, and 1.48 g/cm^3 compared with generic field values for major soil types.