FINAL

Compost and Low Impact Development Technical Memorandum
Contract 43A0172
Task Order 51

January 29, 2009

CTSW-TM-07-172.51.4

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1.0 Introduction

This draft Technical Memorandum (TM) has been prepared as part of Task Order 51 – Statewide Compost Reconnaissance Study. The primary objectives of the study are to: use available research to identify the risks and benefits of compost use as a standard Caltrans best management practice (BMP) for promoting the growth of vegetation, managing storm water runoff, and providing erosion control; address concerns on compost use stemming from Water Quality Objectives; identify the most appropriate and effective application methods and rates; and research the use of compost to achieve low impact development (LID) hydromodification goals outlined by the State Water Resources Control Board (SWRCB).

This TM addresses the third primary objective of the study, compost effects on LID. To provide context for the discussion of LID, this TM summarizes findings presented in two prior TMs, the Compost and Vegetation Establishment TM (Caltrans 2009a) and the Compost and Water Quality TM (Caltrans 2009b). This TM discusses both short-term (construction and vegetation establishment phases) and long-term (vegetation established) impacts of compost on runoff. The ultimate goal of this TM is to provide justification that the use of compost can help offset and reduce hydromodification through reduced peak flow rates and volume as well as reduce construction and maintenance costs by improving the overall effectiveness of BMPs.

The TM is organized as follows:

- Section 2 summarizes the findings of the Compost and Water Quality and Compost and Vegetation Establishment TMs, and presents a background summary of LID.
- Section 3 discusses how soil type, slope length and steepness, land use, soil compaction, and moisture content may affect the quantity of runoff. This section also summarizes existing research and literature pertaining to compost and runoff reduction potential.
- Section 4 discusses the differences in the short-term vs. long-term performance of compost.
- Section 5 discusses the potential to resize treatment BMPs (i.e., vegetated swales or strips) by incorporating compost into the design, taking into consideration infiltration and roughness factor effects for existing and proposed site conditions.
- Section 6 gives a summary of findings and outlines recommendations for future studies to quantify the effects of compost on BMP sizing.
- Section 7 provides references used in the TM.
- Appendix A provides an expanded research study, with the summary provided in Section 3.

2.0 Background

Prior to initiation of this TM, research was conducted to identify the risks and benefits of compost use as a standard Caltrans BMP on vegetation and water quality. The findings of the research were presented in the Compost and Vegetation Establishment (Caltrans 2009a) and Compost and Water Quality (Caltrans 2009b) TMs. Subsequent to research and evaluation of the benefits of compost for water quality and vegetation, additional evaluation was performed to assess the benefits for LID as presented in this TM (Caltrans 2008a). The intent of each of these evaluations, as summarized below, is to address potential roadblocks to the use of compost for storm water management. A Frequently Asked Questions (FAQ) brochure has also been prepared under this Task Order to summarize the key issues and present a concise summary of compost use.

2.1 Compost and Vegetation Establishment TM

The Compost and Vegetation Establishment TM reveals that compost is beneficial, at least in the short term, toward the establishment of vegetation for cut and fill slopes and difficult sites as tested. Case studies are limited in regard to the comparison of compost to traditional methods such as hydroseeding and container planting. In many circumstances, compost is used in conjunction with hydroseeding and container planting, not exclusive of these traditional methods. In addition, the case studies reveal that no one application type or method is appropriate in all situations. Site conditions vary greatly and there are many environmental factors to consider when establishing project goals. However, overall, the vegetation analysis concluded that most studies found composted plots to have exceptional vegetation establishment rates when compared to non-composted plots.

2.2 Compost and Water Quality TM

The Compost and Water Quality TM research indicates that the nutrient concentrations in compost of different feedstock materials vary and have the potential to leach into storm water runoff; however, concentrations in runoff from compost have been lower than in runoff from sites treated with fertilizer and, in some cases, in sites treated with other traditional erosion control methods. In addition, compost, when used as a BMP for filtering runoff such as in a filter sock, berm, or vegetated strip, can reduce nutrient, metal, hydrocarbon, and suspended solid total loads in construction and highway runoff. Compost-amended soils can also reduce the bioavailability of metals when compared to soils without compost. Metals and nutrient concentrations in compost materials can be higher when compared to topsoil initially (during first-flush of a storm) but the use of compost can produce significantly lower total masses in runoff of nutrients and all soluble and adsorbed forms of metals when compared to noncompost test plots, due to the significantly reduced volumes of runoff.

2.3 LID and Hydromodification

The objective of this TM is to research the use of compost to achieve LID goals outlined by the SWRCB. LID is a movement toward more sustainable storm water management.

LID is a newly defined, “comprehensive land planning and engineering design approach with a goal of maintaining and enhancing the pre-development hydrologic regime of urban and developing watersheds” (USCC 2008). The National Cooperative Highway Research Program (NCHRP) defines LID as a range of both natural and constructed treatments near the runoff sources to reduce water pollution and increase evapotranspiration and groundwater recharge (NCHRP 2006).

Caltrans defines hydromodification as a change to the pre-project hydrograph resulting in an increased quantity and rate of runoff. LID management practices seek to reduce both peak flow rates and runoff volume by slowing flows and increasing infiltration thereby decreasing pollutant loads entering water bodies (USCC 2008). In other words, the LID management practices seek to reverse or reduce hydromodification effects. Because compost has been proven to reduce runoff volume due to improved water-holding capacity and increased infiltration, it is a potential BMP to help mimic predevelopment hydrologic conditions.

Coupled with vegetation, compost forms part of a complete LID tool. Compost has been shown to support and encourage more rigorous vegetation establishment. Vegetated areas such as biostrips and bioswales are a critical part of the treatment BMP toolkit, and compost can be used to further these key elements of LID and return developed areas to a more natural, predeveloped hydrologic condition. Design criteria for compost-enhanced biostrips and bioswales are similar to those for non-compost implementations. Existing research shows the benefit of high water-holding capacity of compost, as described in further detail in Section 3.2. As compost-enhanced BMP designs (e.g. biostrips and bioswales) are developed by Caltrans and others, monitoring can help provide data to extend the quantitative analysis to a broader range of controlled conditions.

3.0 Runoff Reduction Associated with Compost Use

This section presents the key factors that can influence runoff quantities for both natural and constructed conditions: soil type, slope length and steepness, land use and soil compaction, and moisture content. In addition, this section focuses on a series of studies that quantify runoff effects of added compost and summarizes the findings of these studies.

3.1 Factors Affecting Runoff Rates

The quantity of runoff from a given area can be influenced by a number of factors as described below.

3.1.1 Soil Type

The movement of water through the soil depends on the characteristics of the underlying soil (USEPA 1999). Soil types are broken down into 4 Hydrologic Soil Groups (HSGs) as follows:

- HSG A soils typically consist of well-drained sand and/or gravel and generally have high infiltration rates, high rates of water transmission, and low runoff potential.
- HSG B soils typically consist of moderately coarse textured grains, have moderate infiltration rates, are moderately to well drained, and have a moderate rate of water transmission.
- HSG C soils typically consist of moderately fine to fine textured soils with slow infiltration rates and slow rates of water transmission.
- HSG D soils typically consist of clays or soils that have a high permanent water table, have very slow infiltration rates, and very slow rates of water transmission (USDA 1973).

The infiltration rate at the soil surface may be affected by the presence of a thin layer of silts and clay particles at the surface of the soil and vegetation. These particles may cause a surface seal that would decrease a normally high infiltration rate (Pitt, Chen, and Clark 2002). The water storage capacity of soils depends on the soil thickness, porosity, and moisture content (described in Section 3.1.4). Many factors, such as soil texture, root development, structure, and presence of organic matter, affect the effective porosity of the soil (Pitt, Chen, and Clark 2002).

It is important to note, however, that soil characteristics are important when considering a site during the pre-construction and construction phases of a project; however, these characteristics become less important when considering a site post-construction, when the soil is compacted at a uniform rate.

3.1.2 Slope Length and Steepness

Slope steepness can have a direct impact on runoff rates, with steeper slopes resulting in increased runoff velocities and increased erosion potential. The effects of slope length on soil erosion are dependent upon slope shape and slope-induced alterations in soil properties. With other factors remaining constant, soil erosion has been found to increase in proportion to slope length. Higher erosion on longer slopes may be due to increased runoff velocity on longer slope lengths and the potential resulting increase in rill erosion (IAHS 1988) or may be because longer slopes can collect larger volumes of water and provide opportunities for concentration of larger amounts of runoff. Because the effects of slope length on erosion are related to runoff velocity and volume, the significance of the length effect also depends on soil management such as the quantity of mulch, methods of seedbed preparation, canopy characteristics, and percent ground cover (IAHS 1988).

3.1.3 Land Use and Soil Compaction

Natural infiltration is significantly reduced in urban areas due to several factors: increased impervious (paved) surfaces, removal of surface soils and exposing subsurface soils, and compaction of the soils during grading operations. Increased impervious areas are associated with increased runoff volumes and peak flow rates (Pitt, Chen, and Clark 2002). Infiltration practices (i.e., providing areas of increased porosity) have long been applied in many areas to compensate for the decreased natural infiltration areas, often with limited success. Silting of the infiltration areas is often responsible for early failures of these devices, although compaction of underlying soil is also a recognized problem (Pitt, Chen, and Clark 2002). Compacted soil reduces the pore space available for water storage and movement, thus reducing infiltration rates and leading to increased runoff.

3.1.4 Moisture Content

The moisture content of the soil, whether it was initially dry or still wet from a recent storm (antecedent moisture), will have a great effect on the infiltration capacity of certain soils (Pitt, Chen, and Clark 2002). Moisture content in soil is defined as the volume fraction of water in a given volume of soil. The more saturated a soil column is, the less volume of void space available to store water. Saturated areas can act as impervious surfaces to runoff, leading to runoff values close or equal to rainfall values (USEPA 1999). The movement of water through the soil depends on the characteristics of the underlying soil. Once the surface soil layer is saturated, water cannot enter soil faster than it is being transmitted away, so this transmission rate affects the infiltration rate during longer storm events. The depletion of available storage capacity in the soil affects the transmission and drainage rates (Pitt, Chen, and Clark 2002).

The infiltration capacity of most soils allows low-intensity rainfall to completely infiltrate, unless the soil voids become saturated or the underlain soil is much more compact than the top layer. High-intensity rainfalls generate substantial runoff because the infiltration capacity at the upper soil surface is surpassed, although the underlain soil might still be very dry (Pitt, Chen, and Clark 2002).

3.2 Existing Studies on Compost and Runoff Reduction

Numerous studies have been conducted that demonstrate that under various conditions, compost increases infiltration and reduces runoff quantities due to its water-absorbing capacity and ability to increase soil hydraulic conductivity. Studies have also shown improvements in soil bulk density and reductions in post-construction compaction with compost incorporation. This section also summarizes findings of these studies, broken down by the various factors that influence runoff rates. Additional details associated with the studies presented below can be found in Appendix A.

3.2.1 Infiltration Rate and Water-Holding Capacity

Study 1: ISU 2008 – Using Compost for a Safer Environment

An Iowa State University study conducted from 2000-2002 sponsored by the Iowa Department of Natural Resources and the Iowa Department of Transportation examined runoff rates from sites treated with compost blankets in comparison with conventionally treated sites (i.e., sites treated with compacted subsoil and topsoil).

The study found that sites treated with compost significantly delayed runoff and resulted in reduced runoff volumes. The reductions in quantity and frequency of runoff provided by compost treatments were similar under both unvegetated and vegetated conditions and reflected a 99 percent reduction in runoff when compared to both topsoil and compacted topsoil. These results show that compost blankets can provide storm water runoff control (and erosion control) on construction sites in the short term before vegetative cover can be established. The significant benefit is risk reduction caused by rainfall events prior to establishment of vegetative cover.

Study 2: Harrison et al. 1997 – Field Test of Compost Amendment to Reduce Nutrient Runoff

A study conducted for the City of Redmond, Washington (Harrison et al. 1997) utilized the Iowa test beds (Study 1) and examined the use of compost as an amendment to increase water-holding capacity and reduce peak flow runoff. The study concluded that (1) water-holding capacity of the soil was about doubled with a 2:1 compost to soil amendment, and (2) water runoff rates were moderated with the compost amendment, with the compost-amended soil showing greater lag time to peak flow at the initiation of a rainfall event and greater base flow in the interval following a rainfall event (Harrison et al. 1997).

A study conducted by the University of Alabama for the U.S. Environmental Protection Agency (USEPA) concluded that the use of compost-amended soil resulted in significantly increased infiltration rates compared to soil alone (Harrison et al. 1997). In addition, the evapotranspiration rates increased with all compost-amended soils.

A Richmond, Washington, storm water management study performed in 1995 concluded that compost-amended soils could be used to reduce runoff quantity. It was also determined that soil amendments made on previously compacted urban soils significantly increased infiltration rates. In short, the results of the study exhibited that compost-amended soils consistently had longer lag times to response, longer times to peak flow, higher base flow, higher total storage, and smaller total runoff than unamended soils (Harrison et al. 1997).

Study 3: Kolsti et al. 1995 – Hydrologic Response of Lawns on Till with Compost Amendment

A 1995 University of Washington study evaluated the hydrologic response of tilled compost-amended residential lawns when compared with tilled non-amended lawns. The study analyzed various compost types, ages, and grain sizes (from fine to coarse) as well; wood mulch, yard waste, and sewage sludge-based composts of varying grain size (Kolsti et al. 1995).

The study concluded that application of high amounts of fine, aged compost resulted in significantly improved hydrologic behavior relative to unamended soil, with 25 to 88 percent runoff reduction over non compost-amended lawns. These compost-amended soils consistently resulted in reduced peak runoff flows, delayed peaks, and overall reductions in runoff volume. The resulting higher soil conductivity resulted in increased infiltration and baseflow (Kolsti et al. 1995).

3.2.2 Bulk Density and Soil Compaction

Study 4: Dane County 2003 – Quantifying Decreases in Stormwater Runoff from Compost-Amendment

A Dane County, Wisconsin, study analyzed and quantified the reductions in runoff for compost-amended soils when compared with non-amended tilled or plowed soils. The study found that when compost is incorporated into the soil, bulk density can be reduced by as much as 0.35 grams per cubic centimeter (g/cm^3), helping offset the effects of compaction. In addition to reducing bulk density, compost-amended soils reduced the volume of surface runoff by 29 to 50 percent. The study concluded that regardless of storm size, the compost-amended, chisel-plowed, and deep-tilled treatment resulted in the greatest reductions in total runoff volume and increased the water-holding capacity of the soil even when compared to plowed and tilled soils (Dane County 2003). This study supports the conclusion that compost can offset the negative effects of soil compaction on runoff.

3.2.3 Runoff Volume

Study 5: WSDOT 2007 – Compost-Amended Vegetated Filter Strips (CAVFS) Performance Monitoring Project

In 2003, the Washington State Department of Transportation (WSDOT) initiated a program to install and document the flow control effectiveness of one LID technique, CAVFS, with potential application as a BMP for storm water in shoulders/medians of highways. The primary goal of the study was to implement a monitoring program to document the performance of CAVFS with regard to reducing the peak discharge rates, flow volumes, and flow durations of highway runoff.

Three pilot vegetated filter strips were constructed along Interstate 5 in Snohomish County, Washington. Two of the strips were amended with tilled-in compost and a third received no compost. Untreated runoff from a curbed section of highway was routed to a single monitoring station to characterize influent runoff discharge rates. The test site was located on disturbed, compacted glacial till (freeway embankment soil) within urban areas of the Puget Sound region, representing a worst-case scenario for assessing the performance of CAVFS in western Washington.

The report concluded that compost amendment appears to improve filter strip performance for reducing runoff volumes. Runoff volumes in filter strips with compost amendment were between 45 and 50 percent lower than those in filter strips without compost. The study found that compost amendment in filter strips was most effective in reducing flow volumes for precipitation depths exceeding 0.2 inch. Additionally, the study found that compost amendment reduced peak discharge rates through the low end of the data range; however, other factors (such as slope) were likely influencing performance under saturated conditions at the high end of the range (WSDOT 2007).

3.3 Effects of Application Method on Runoff (Soil Incorporation vs. Surface Placement)

To enhance infiltration and eliminate stratification, many specifications call for the incorporation of compost into the underlying soil to a depth of at least 8 inches on flat or relatively flat sites. Incorporation through scarification/tilling breaks up the more impervious, dense underlying soil, which can become compacted during construction. This application not only improves water-holding and infiltration capacity but also provides for a deeper rooting zone for newly seeded vegetation, and helps to prevent a two-layer soil system that can lead to shallow rooting and poor growth. Many studies reviewed have identified the benefit of this type of compost application (Caltrans 2008a; 2009a and b).

On sloping construction sites, blanket compost applications (i.e., surface placement of compost) are recommended to provide immediate runoff and erosion control. Because composts are less dense and more porous than natural soils, they have an “open” structure that absorbs and holds water better than most natural soils. If the underlying soil is relatively fine textured, tilling or disking will mix fine particles into the compost matrix, reducing the compost’s water-storing capacity, increasing runoff and erosion, and exposing small highly erodible soil particles to the erosive force of direct rainfall impact (IDNR 2008). Although studies were found that identified the benefits of compost blankets for water quality (Caltrans 2009b), only one study was found that identified the benefit of different compost blankets on storm water runoff quantities. This Iowa State University Study (ISU 2008) looked at the various of different compost blanket depths and not at compost blankets compared to compost incorporation. The study found that 2-inch blanket applications of compost provided nearly the same performance as 4-inch applications in terms of runoff, erosion, and vegetation growth. Since the costs of acquiring, transporting, and applying compost will increase with the application depth, there appears to be little reason to apply more than 2 inches.

3.4 Comparison table

Table 3-1 summarizes the runoff reduction results and variables analyzed in the above studies.

Table 3-1. Summary of quantitative results reported in studies (ISU 2008; Harrison et al. 1997; Kolsti et al. 1995; Dane County 2003; WSDOT 2007)

	Study					
Variables	ISU 2008	Harrison et al. 1997	Kolsti et al. 1995, Natural Storms	Kolsti et al. 1995, Simulated Storms	Dane County 2003	WSDOT 2007
Soil Type/Group	native soil, Ames, Iowa	Alderwood Series, till	basal till, hard clay cap	basal till, hard clay cap	silty clay loam	Disturbed, compacted glacial till (freeway embankment soil, Interstate 5 near Lynnwood, WA): Alderwood-Urban Land complex
Infiltration Capacity/Range			hyd conductivity = 10^{-7} - 10^{-5} cm/sec	hyd conductivity = 10^{-7} - 10^{-5} cm/sec		
Plot Size	20 ft^2 and 78 ft^2	256 ft^2	256 ft^2	256 ft^2	96 ft^2	382.06 - 425.50 ft length
Slope	1 - 3%		5%	5%	10%	8 - 12%
Storm Event	30-minute high intensity storms (4 in/hr)	tipping bucket - soil test performed in lab	natural storms, 24-hour rain depths 0.65 to 1.38 inches (no greater than 6-month 24-hr storms)	Simulated storm: 100-yr 6-hr storm	1 - 2" over 30 minutes	mid to upper range of 35 - 50 inches annual rainfall - Puget Sound
Compost Type	biosolids, yard waste and bio-industrial		fine, aged	fine, aged	leaf and brush material	
Application Method	2- and 4-inch compost blankets	soil and compost plots with turfgrass mixture	roto-tilled to depth of 12"	roto-tilled to depth of 12"	chisel plowed, deep tilled, compost amended (to depth of 6")	amended vegetated filter strips with tilled-in compost
Application Rate (compost to soil ratio)		2:1	2:1	2:1	2:1	
Water-Holding Capacity without Compost			24%	24%		
Water-Holding Capacity with Compost			160 - 390%	160 - 390%		
Volumetric Field Capacity without Compost		33 - 53%				
Volumetric Field Capacity with Compost		36 - 50%				
Change in Field Capacity		2 - 10%				
Infiltration without Compost				0.010 - 0.016 in/hr		
Infiltration with Compost				0.004 - 0.018 in/hr		
Evapotranspiration without Compost			.0041 inches/hr			
Evapotranspiration with Compost			.0041 inches/hr			
Bulk Density without Compost		1.23 - 1.83 g/cm^3				
Bulk Density with Compost		0.84 - 1.20 g/cm^3				
Change in Bulk Density		- 0.39 - 0.63 g/cm^3			- 0.35 g/cm^3	
Porosity without Compost		30 - 48%				
Porosity with Compost		37 - 57%				
Change in Porosity		2 - 30%				
Runoff Volume reduction (1-total runoff/control)	99%		30-47%	26%	74-98%	45 - 50%

4.0 Short-Term vs. Long-Term Benefits of Compost

As evidenced by the study results outlined in Section 3.0, the use of compost and the resulting improvements to water-holding capacity (storage), infiltration, and reduced runoff would have substantial benefits, for both short- and long-term (resulting from enhanced vegetative growth) storm water management.

4.1 Short-term Benefits of Compost and LID

The short-term benefits for storm water management would reduce the risks associated with construction projects and potential impacts to downstream resources. The method of application and the construction phase BMPs selected would drive the extent of the benefits and the successful management of storm water runoff.

Construction phase BMPs can be used in the short-term to minimize runoff, erosion, and sedimentation onsite and reduce consequent water quality-related downstream impacts. As described in Section 3.2.1, compost blankets for erosion and runoff control were found to be effective in the Iowa study prior to vegetation establishment, reducing the time to initiate runoff and the quantity of runoff by 99 percent when compared to both topsoil and compacted topsoil.

Compost filter socks are a form of linear treatment device that can be used in the early phases of a project (during construction and early postconstruction) as an effective BMP. A compost filter sock is a type of contained compost filter berm. It is a mesh tube filled with composted material that is typically placed along the perimeter of a site, or at intervals along a slope, to capture and treat storm water that runs off as sheetflow. The compost filter sock, which is oval to round in cross section, provides a three-dimensional filter that, when installed perpendicular to storm water can reduce flow velocity and retain sediment and other pollutants (e.g., suspended solids, nutrients, and motor oil) while allowing the cleaned water to flow through (Tyler and Faucette 2005). They can also be used on pavement as inlet protection for storm drains and to slow water flow in small ditches (USCC 2008).

The use of compost socks in conjunction with compost-based vegetated strips or swales can act as a treatment train for filtering solids and other pollutants. Compost socks when installed at the toe of a strip or swale will act as the initial pollutant-reduction mechanism. In addition, compost filter socks can slow the velocity and quantity of runoff, thereby entering the strips or swales and improving infiltration.

4.2 Long-term Benefits of Compost and LID

Organic matter content in compost will decrease overtime. One study (Gupta et al. 1977) showed that, after 1 and 2 years, 58 percent and 50 percent (respectively) of the mass of the original sludge organic matter remained (Kolsti et al. 1995). Other studies concluded that microbial activity in compost is at its highest during the first few weeks after compost amendment (Kolsti et al. 1995). Gupta et al. recommended repeated amendment of soil (every 5 years in this particular study) to achieve optimal results in terms of increased soil water retention, infiltration, and particle surface area (Gupta et al. 1977). A USEPA study conducted in 1999 supported this conclusion, finding that the newer compost-amended test plots (1 year or less) outperformed the older compost-amended test plots (3 to 4 years) (USEPA 1999). Thus, the benefits of compost alone can be considered short-term. The use of compost as part of a system and LID tool, however, can lead to long-term beneficial impacts due to improved vegetation establishment and associated improvement in water quality.

The University of Alabama-USEPA study showed that sites with older compost displayed no reduction of runoff when compared to soil-only sites while the newer sites showed reduced runoff, suggesting potential limits associated with the effectiveness of compost at reducing runoff as a result of compost age or decay rate (Harrison et al. 1997).

The use of compost in the soil surface facilitates the development of improved soil structure. The heightened soil microbial activity that results from the presence of compost facilitates development and maintenance of an open soil structure, which promotes drainage and infiltration, even after the compost has degraded (Crohn 2008).

The use of compost to further vegetative establishment has a long-term benefit on the watershed and drainage areas flowing to and surrounding a project site as a whole. Vegetated areas lead to slower runoff velocities, enhanced water quality through biotic treatment mechanisms, and improved structural integrity of slopes. The benefits of enhanced vegetation, stronger slopes, improved soil structure, and improved infiltration and storage capacity work together as a system to enhance water quality downstream of the project site. The system provides these benefits long past the initial degradation phase of compost used for erosion control or enhanced vegetative growth.

5.0 BMP Sizing with Compost

As discussed in this TM, compost has been shown to increase infiltration and increase storage (water holding) in soil, which can reduce runoff volume. Compost can be used as an effective tool, in conjunction with other BMPs, to address hydrologic modification issues resulting from urbanization and development. Bioswales and biostrips are two common and effective LID BMPs that may be enhanced through the use of compost. Although it may not be practical to reduce bioswale size due to other device requirements such as flood flow conveyance, incorporation of compost to increase infiltration would provide treatment benefits, particularly for water quality treatment flow.

5.1 Bioswales

Bioswales are typically designed using general guidelines for storm water treatment vegetated swales. The design entails calculation of a water quality treatment flow using the Rational Method and intensity depending on local requirements and regional location (often based on the 85th percentile storm). The bioswale is then sized using Manning's equation and a number of guidelines. Specific engineering standards for bioswales are not typically available; however, Caltrans general guidelines are as follows (Caltrans 2008b):

- Evaluate the capacity of the swale using the 25-year design storm.
- Water quality flow velocity for sizing of bioswale/width should not exceed 1 foot/second.
- The width of the bioswale should be calculated for water quality flows assuming a Manning's coefficient of 0.20 for routinely mowed swales and 0.24 for infrequently-mowed swales.
- The width of the bioswale should also be calculated for 25-year storm flows using a Manning's coefficient of 0.04.
- Side slopes should not exceed 4:1 (Horizontal:Vertical).
- Width of the bioswale at the invert should be between 4 and 13 feet.
- The minimum hydraulic residence time in the swale is 5 minutes.
- The maximum depth of flow in the bioswale is 6 inches.

USEPA and the California Storm Water Quality Association (CASQA) have also developed guidelines for the construction of bioswales to treat storm water runoff. Some of these guidelines are as follows:

- The swale should have a 2 to 4 percent slope. Less than 2 percent would require extra drains (i.e., an underdrain system).
- The swale should be a minimum of 100 feet long.
- The total surface area of the swale should be 1 percent of the treatment drainage area.
- Soil infiltration should be at least 0.5 inch per hour.
- A diverse selection of low-growing plants that thrive under the specific site, climatic, and watering conditions should be specified. Vegetation whose growing season corresponds to the wet season is preferred. Drought-tolerant vegetation should be considered, especially for swales that are not part of a regularly irrigated landscaped area.

Key factors that can influence bioswale size are the Manning's roughness coefficient, (n), the velocity of runoff flow (and resulting residence time), and the magnitude of water quality treatment flow. Bioswales are sized for water quality treatment flows, based on the Rational Equation:

$$Q \text{ (cfs)} = C*I*A$$

Where C = runoff coefficient, I = rainfall intensity, and A = tributary drainage area.

The rainfall intensity (I) is typically determined by local requirements and guidelines. The runoff coefficient (C) is dependent on land use and is equivalent to the ratio of runoff generated to rainfall, sometimes referred to as the volumetric runoff coefficient. This TM has demonstrated that compost-amended soil can result in increased infiltration and soil conductivity and reductions in runoff volume and flows (USEPA 1999). An increase in soil infiltration rate reduces the volumetric runoff coefficient, which in turn reduces the water quality treatment flow. The size of a storm water BMP is decreased by reducing the water quality treatment volume.

The University of Washington Study discussed in this TM quantified volumetric runoff coefficients at 0.54 and 0.75, respectively, for compost-amended soils compared with non-amended soils (Kolsti et al. 1995). A lower runoff coefficient results in greater infiltration, lower runoff generated, and lower resulting water quality treatment flows used for sizing of bioswales. Thus, a compost-amended soil has the potential to reduce the overall size of storm water BMPs. This result, however, is dependent upon a number of other factors as well, described below.

Once the water quality treatment volume is known, bioswale geometry can be computed using relations described in Manning's Equation:

$$Q\ (\text{cfs}) = \frac{1.49AR^{0.66}S^{0.5}}{n}$$

Where A = cross-sectional area of the bioswale, R = the wetted perimeter of the bioswale, S = the longitudinal slope of the bioswale, and n = Manning's roughness coefficient.

The resulting velocity (feet per second [ft/s]) will determine the residence time and thus drive the bioswale design. The velocity is calculated as flow divided by area or:

$$V\ (\text{ft/s}) = \frac{1.49R^{0.66}S^{0.5}}{n}$$

Manning's n, or the roughness coefficient, bioswale longitudinal slope, and cross-secitonal geometry are the factors driving the storm water velocity within the BMP. The roughness coefficient is a function of the extent and type of vegetation, grading, riprap size and placement, and other energy dissipation attributes. The roughness coefficient for a compost-amended soil or turf may be higher than for a non-amended soil or turf if the compost is applied on top of the turf and reapplied after initial decomposition (WSDOT 2008). However, a channel with larger plant material (i.e., willows) will have a higher roughness coefficient than a compost-amended soil or turf. Additionally, topical application of compost in a bioswale is not recommended, as the compost is likely to be mobilized during a larger storm event. Instead, a more effective method of runoff reduction in a bioswale in the long-term is compost incorporation to establish vegetation.

The sizing of the BMP will depend on the design approach and subsequent maintenance. A higher roughness coefficient will result in a lower velocity, as calculated above. The residence time is calculated by dividing the bioswale length by the velocity. Thus, the less length of bioswale required to achieve the optimal design residence time of 5 minutes is decreased with a decrease in bioswale runoff velocity. However, the final bioswale design is also contingent upon a number of other design constraints, such as depth of treatment flow, 50 to 100-year flood flows, and a minimum recommended bioswale length of 100 feet. Thus, the amount of bioswale size reduction that can be achieved through the use of compost-amended soil, if any, is dependent upon the site, bioswale design, and local requirements/constraints thus size reduction is most likely impractical. Additionally, for roadside bioswale sites where space limitations are driving design factors, tributary areas to bioswales may only consist of impervious, paved surfaces. The resulting change to the flows would be minimal-- diminishing the impact of a composted bioswale for size reduction.

5.2 Vegetated Filter Strips (Biostrips)

Vegetated filter strips are land areas of planted vegetation and amended soils situated between the pavement surface and, typically, a surface water collection system, such as a swale. Also called biostrips, vegetated filter strips are designed to accommodate overland sheet flow rather than concentrated or channelized flow, as with a swale. Vegetated filter strips are usually designed to accept overland sheet flow directly from adjacent impervious surfaces and are graded to have a flat cross-slope and dense vegetation to maintain sheet flows for proper operation. Vegetated filter strips function by reducing runoff velocities allowing them to trap sediment and other pollutants, and by providing some hydraulic infiltration and biologic uptake (WSDOT 2007). Frequently planted with grasses and forbs, the strips may also include ornamental native or nonnative shrubs that make the system more effective in treating runoff by providing infiltration-enhancing root penetration into the subsoils.

For purposes of sizing, the design guidelines for vegetated filter strips neglect the infiltration capacity of underlying soils and instead focus on the velocity-retarding effect of the surface roughness of the strip (Caltrans 2008c). Hydraulic conductivity of underlying soils is only considered for purposes of designing recovery structures such as underdrains, which must be added for compacted or poorly draining soils. However, when compost is incorporated into the soil of a biostrip, the resulting increased infiltration capacity is sufficient to affect the hydrograph by infiltrating and retaining a portion of the runoff volume. The increased infiltration affects pollutant removal rates by reducing velocities to allow suspended solids to settle and by providing increased filtration through the subsurface.

CAFVS have been tested by WSDOT (2007). The results from the WSDOT experiments showed that once permanent vegetation is established, the advantages of CAVFS over standard vegetated filter strips are a rougher surface, greater retention and infiltration capacity, improved removal of certain contaminants through sorption, improved overall vegetative health, and fewer invasive weeds (WSDOT 2007). The study also concluded that CAVFS have somewhat higher construction costs upfront due to more expensive materials but may require less land area for runoff treatment, which can reduce overall costs, particularly in the long-run.

5.2.1 Quantifying Infiltration Effects

Specifications and experiments with CAVFS have focused on improvements in vegetation achieved with compost incorporation. For instance, the WSDOT study did not sample runoff reduction prior to vegetation establishment. Also, the biostrips in the study were integrated with a collection drainage ditch at the toe of the slope; the runoff from the entire system is what is reported in the results not just the biostrips alone. The Caltrans guidelines for biostrips only mention compost addition in terms of its potential effect on Manning’s roughness coefficient and vegetation establishment and give the critical criteria as vegetative cover, which is enhanced by compost incorporation in the soil for most species of cover specified for biostrips (Caltrans 2008c). In the Caltrans guidelines, infiltration is acknowledged as important but is not considered in design.

To directly quantify the effect of compost incorporation on infiltration rate and water-holding capacity of biostrips, a conceptual model of the process must first be conceived. The simplest model is to assume that the compost-incorporated soil acts as a sponge, absorbing water up to a specified water-holding capacity with no significant drainage. Total runoff in such a scenario is computed as follows:

$$V_{eff} = V_t - V_{com}$$

> Where V_{eff} = actual new runoff, V_t = total inflowing volume, and V_{com} = compost-amended soil water-holding capacity.

This model is purely volumetric, which is overly simplistic. However, the advantage of this approach is that it requires determination of only one parameter, the effective volumetric water-holding capacity of the compost-amended soil. Design using this model is simply a matter of determining the volume of compost-amended soil necessary to contain the additional volume. Soil volume is the product of the length (parallel to slope), the width, and the depth of incorporation. This simplistic model does not provide an actual outflow hydrograph; it only assumes that as water flows over the strip, it infiltrates until the capacity is satisfied. At this time, there is no standard correlation to a field-measured parameter that gives a simple water-holding capacity for compost-amended soils. This is a critical area of future research. Water-holding capacity may be determined by simple soil box tests or by computing volume retained before runoff in a field test. Compaction at depth, slope of soil bed, application methods, prior saturation state, and hysteresis and time variance will all be important variables to consider. The WSDOT study also showed that underlying soil type is a critical factor for infiltration performance (WSDOT 2007).

5.2.2 Recommended Design Approach

A likely scenario for installation of a compost-enhanced biostrip is to offset increased runoff caused by roadway widening and facilitate compliance with hydromodification regulations. Current regulations require that a project maintain pre-project flows (defined in some regions as the 100-year storm event) in the post-project condition, and also treat the “first-flush” of a storm event (i.e., water quality flows) based on a regionally defined percentage of the 2-year, 24-hour or 85th percentile storm (RWQCB 2007).

Currently Caltrans is considering mitigating the impacts of hydromodification by maintaining the runoff volume up to and including the 2-year, 24-hour event (pre-project to post project) and maintaining post-project flows within 10 percent of the pre-project conditions for events up to the 10-year event.

Ideally, a biostrip would be sized to capture the additional volume of sheet flow generated by additional impervious area from roadway widening to create a hydrograph that mimics the hydrograph prior to the roadway expansion as well as to treat the “first-flush” storm event, as described above. Figure 5-1 shows schematic hydrographs of the pre- and post-project runoff for such a scenario. The volume of additional flow (computed as the area between the red and blue curves) would equal the volume that can be absorbed and retained by the compost strip (area under the green infiltration hydrograph curve).

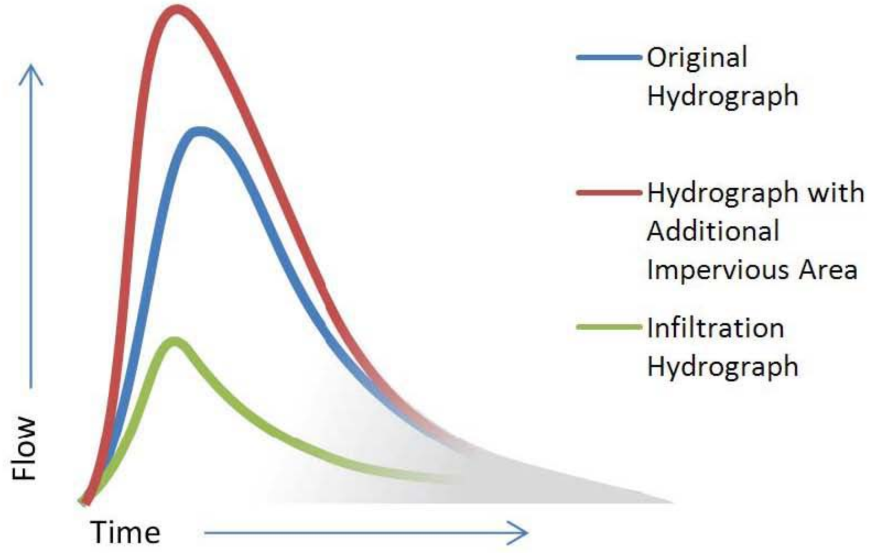


Figure 5-1. Conceptual hydrograph showing approximate increase in peak flow due to additional impervious area and infiltration hydrograph of hypothetical biostrip.

If the compost-amended biostrip cannot capture the increase (i.e., the area under the green curve is too small to limit total post-project runoff to a specified percentage increase of the pre-project runoff), additional BMPs may be necessary to meet the total runoff reduction requirements.

Since the objective of the biostrip design will be to capture the additional runoff volume generated by the new impervious area, computing this additional volume is the first step in design. Standard methods such as the rational method may be used to compute this volume. For the design scenario being considered, the additional volume of runoff will be approximately equal to the volume of additional precipitation since the lane surface is entirely impervious.

Because the strip is designed for sheet flow directly from an impervious area, sizing would only require length and depth for a unit width. First the unit width treatment volume is computed according to:

$$V_{unit} = \frac{V_t}{W}$$

Where V_{unit} = unit width volume, V_t = total inflowing volume, and W = width of biostrip.

Note that W (width of bisostrip) is the dimension perpendicular to the direction of flow. Determination of the compost depth would be calculated in two parts. Vegetation and roughness requirements (for flow velocity and pollutant removal) would govern the length of the slope and would be specified as currently set forth in existing standards (minimum length 15 feet and minimum vegetative cover, 70 percent). The compost incorporation depth would then be computed as:

$$D_{incorp} = \frac{V_{unit} \times H_{WHC}}{L}$$

Where H_{WHC} = volumetric water holding capacity and L = length of biostrip.

Volumetric water-holding capacity (H_{WHC}) is given as a volume of water per volume of soil and will depend on the experimentally determined capacity of the compost-soil mixture. The volumetric capacity chosen for design should consider the influence of the slope and the probable antecedent moisture condition.

Figure 5-2 shows a schematic for installation of a compost-enhanced biostrip to offset increased runoff caused by roadway widening. All dimension values in the figure are for example only but represent the values that would be computed for design of such an installation. Several considerations should be noted in the design as follows:

- The nature of the design storm and the width of additional impervious lane will affect the runoff volume.
- Slope of the installed biostrip will affect the effective water-holding capacity of the compost-amended soil.
- Length and depth of the compost-incorporated soil bed will ultimately determine the total infiltration capacity.
- Hydrologic characteristics of underlying soils such as compaction, amount of disturbance, and native permeability will influence performance but are not necessary to consider in design.

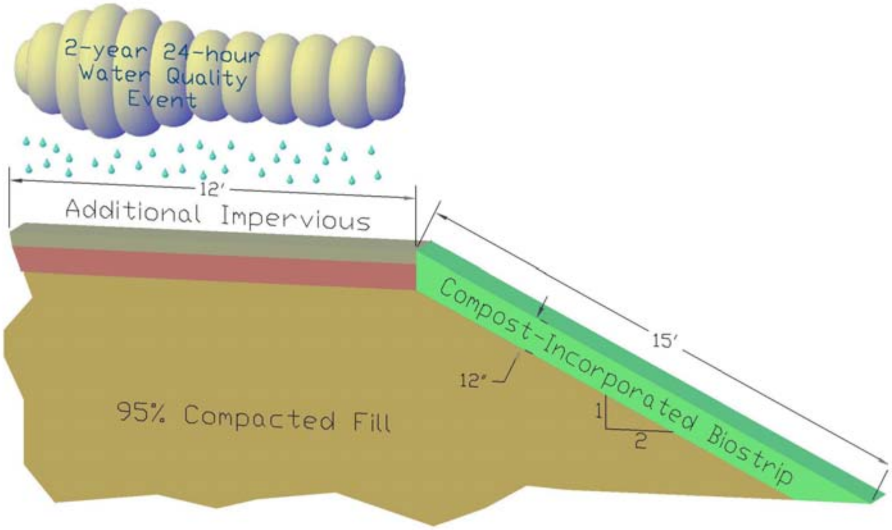


Figure 5-2. Installation scenario for a compost-enhanced vegetated filter strip (biostrip).

This design approach assumes that the design storm is of sufficiently low intensity and of great enough duration that the biostrip becomes saturated to capacity. Any volume above the capacity will either run off the surface or drain from the toe of the slope into other structures such as a bioswale or lined ditch. It is also assumed in this approach that no water is lost to evapotranspiration processes, which is conservative for a long storm event.

5.2.3 Other Conceptual Design Approaches

To account for more complex effects such as hortonian runoff (from high-intensity storms), drainage, deep percolation, or evapotranspiration, a more complex conceptual model must be considered. The advantage of a more complex model is the potential improvement in the quantification of compost effects. With a more complex model, the peak timing and size of the outflow hydrograph may be estimated from the design. The disadvantage of more complex conceptual models is the increased need for experimental data collection to supply parameter values.

The conceptual model may be expanded to include infiltration rate. In this case, the compost-amended soil is considered as a sponge but the rate at which it can absorb water is limited by a maximum infiltration rate. It is known that infiltration rate is affected by the initial moisture condition, and depth and velocity of surface flow, as well as the effective vertical hydraulic conductivity of the compost amended soil. During intense runoff events, the compost will not capture all of the water that passes over. In this model, it is assumed that infiltration is constant over the area of the strip and that the compost-amended soil retains all of the water it receives during an event. An infiltration ring test on the soil can provide an estimate of this parameter. Infiltration rates may also be inferred from a time-to-runoff study (such as the ISU study), but this only provides an “at-least” rate (i.e., the test rainfall intensity for the Iowa study was 4 inches per hour and no runoff was produced for 30 minutes so the maximum infiltration rate is at least 4 inches per hour under the given initial conditions). Further research is needed to extend the numerical analysis of rates. Slope of the composted soil (affecting the velocity of surface flow), depth of amended soils, depth of surface flow, and presence of vegetative cover will all affect the infiltration rate.

Further complexity may be added by considering the contribution of drainage at the toe of the biostrip to the total runoff volume. Drainage will occur according to the hydraulic conductivity of the compost-amended soil, the slope of the section, and the degree of saturation. Research is needed to determine when it is necessary to consider drainage. Mesopores and other preferential pathways will significantly affect subsurface drainage.

Coupling a drainage model with variable infiltration rate would provide the most complex model short of full numerical simulation with variably saturated flow equations. The runoff hydrograph with such a model would be computed the same as with a constant infiltration model (runoff at the top minus the rate into the biostrip equals outflow at the bottom) but the infiltration rate would vary in time with the saturation conditions of the soil. The effect of incoming peak flow timing on total peak attenuation could be computed using this approach.

6.0 Conclusions

Based on available information, compost has the potential to significantly benefit short-term storm water management BMPs. Compost alone provides significant benefits for stormwater management. Coupled with vegetation, compost use can help offset hydromodification and reduce peak flow rates. Risks associated with compost (as identified in prior Technical Memos) exist in certain conditions; however, they appear to be limited. In general, compost provides a significant net benefit. Due to the significant benefits, in the appropriate conditions and applications, compost should be systematically considered as part of Caltrans BMP design.

6.1 Study Conclusions

One way to mitigate the hydrologic changes caused by increased development and urbanization is to maximize the storage and natural infiltration capacity of post-development soils. LID management practice goals are to minimize, detain, and retain post-development stormwater runoff; replication of the site's predevelopment hydrologic functions is considered ideal. Compost, with its proven ability to increase infiltration in soil and thereby reduce runoff volume, can be used effectively as an LID tool to help mimic pre-development hydrologic conditions (LID 2008).

Soil amendments increase the spacing between soil particles so that the soil can absorb and hold more moisture. This in turn reduces runoff and the damaging effects of excessive runoff on local streams. The amendment of soils changes various other physical, chemical, and biological characteristics so that the soils become more effective in maintaining water quality. The humus contained in compost acts as glue that holds soil particles together, making the soil more resistant to erosion and improving the retention of moisture.

As many of the studies analyzed in this TM concluded, compost amendment can delay the initiation of runoff due to increased infiltration and water-holding capacity. Compared to compacted, unamended soils, compost-amended soils provide greater infiltration and subsurface storage, and thereby help reduce a site's overall runoff volume and maintain the predevelopment peak discharge rate and timing.

Additionally, healthy soils rich in organic matter help promote faster and more sustainable vegetation establishment. The results of the vegetation analysis presented in the Compost and Vegetation Establishment TM supported this conclusion for cut and fill slopes and difficult sites that were tested in case studies (Caltrans 2009a). A vegetated site can provide treatment of runoff, added storage capacity, decreased runoff velocities, and can further restore a site to predevelopment hydrologic conditions.

<u>Summary of Hydrologic Effects of Compost-amended Soils:</u>

- Increased infiltration rates
- Increased conductivity

- Increased water-holding capacity
- Increased vegetation densities (affecting roughness, evapotranspiration rates)
- Potential changes to variables (e.g. Manning's "n"; runoff coefficient "C") that influence storm water BMP sizing criteria (WSDOT 2008)
- Long-term systematic (enhanced vegetation, soil structure, reduced erosion, reduced runoff, and restored predevelopment hydrologic conditions) benefits to watershed as a whole
- Reduced and delayed peak flow rates

6.2 Future Studies

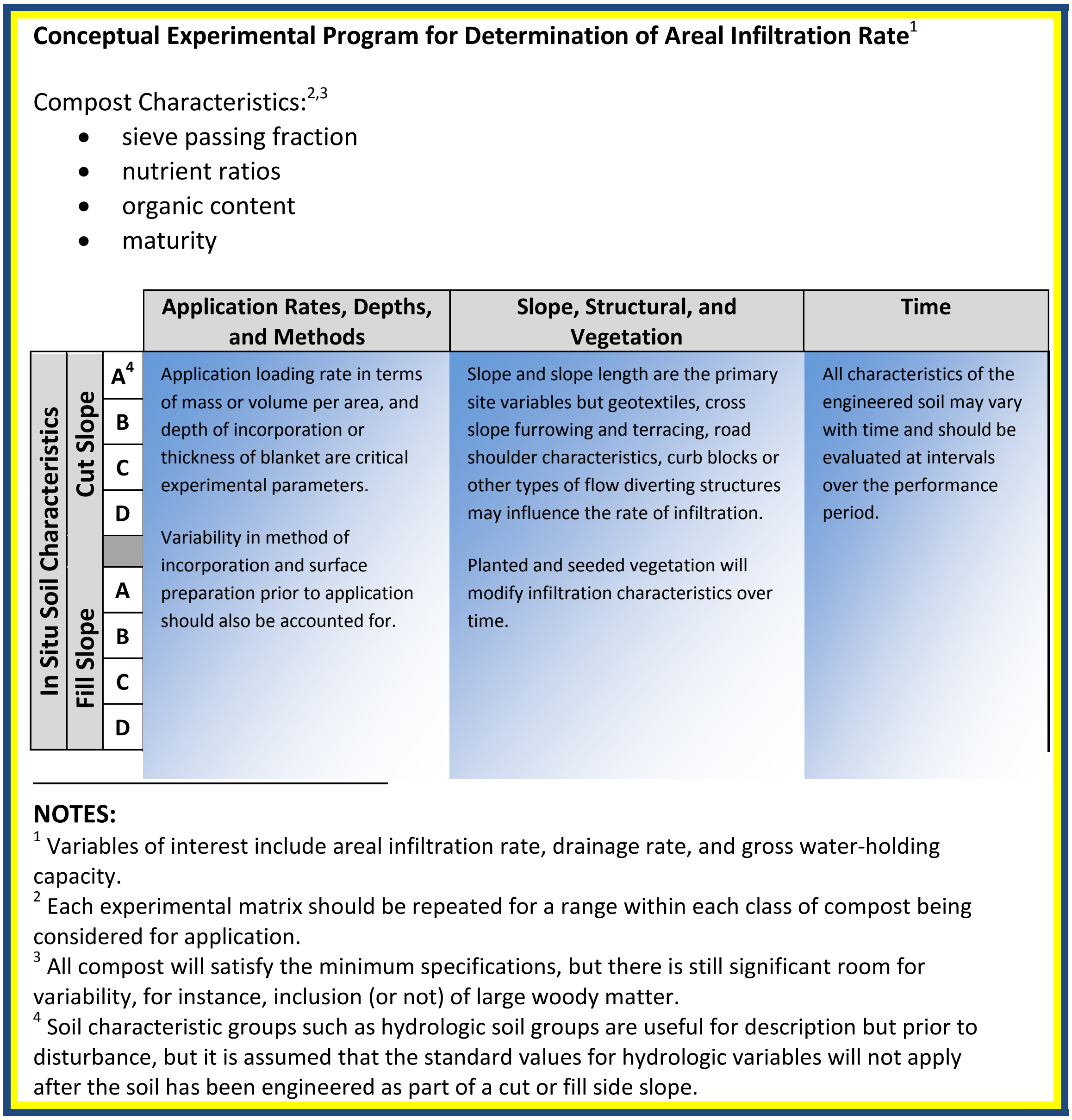
Current research has highlighted a number of individual hydrologic consequences of compost amendment in soils using case studies. These studies, however, were not targeting quantification of infiltration. Rather, the studies focused on the ultimate affect of compost use on runoff reduction. The studies analyzed in this TM limit their analysis to confined cases and use varying methods of testing and analysis. These factors make it difficult to draw direct comparisons and quantitative conclusions on compost's effects on storm water quantity, particularly in terms of infiltration. It is recommended that the approaches and situations presented in the case studies be utilized to develop a comprehensive and controlled study that analyzes compost's effect on infiltration at a broader scale and develop a quantitative method of assessing the effects of compost as part of the storm water treatment BMP toolkit to reduce runoff.

This comprehensive study must consider all variables that affect the performance of the system and currently make it difficult to use existing information to universally quantify the beneficial impact of compost use on infiltration. The primary variables to be considered in this study include:

- Compost management type/application method (compost blanket, compost incorporation, etc.) and rate
- Hydrology and runoff regime for small storm events (water quality volume, 2-yr, 24-hr, etc.)
- Slope
- Soils
- Vegetation

One potential study could be set up similar to the WSDOT CAVFS study summarized in Section 3.2.3 and Appendix A. Several changes to the methodology would be recommended, particularly sampling during the first year prior to vegetation establishment to analyze effects of compost alone; and incorporation of soil moisture probes to examine antecedent moisture effects on runoff generation.
However, more information could be obtained from a bench-scale rainfall simulation study on boxes filled with a broad range of soil types and compost mix rates. Time to saturation, quantity of flow through the soil media, surface runoff, and the effects of slope and surface application could all be tested in a bench-scale study.

To produce a comprehensive specification, direct experiments (rather than case studies) must be performed that systematically isolate and analyze the hydrologic performance of compost-amended soil. A conceptual experimental design for determination of areal infiltration rate is presented in Figure 6-1.



Conceptual Experimental Program for Determination of Areal Infiltration Rate[1]

Compost Characteristics:[2,3]

- sieve passing fraction
- nutrient ratios
- organic content
- maturity

			Application Rates, Depths, and Methods	**Slope, Structural, and Vegetation**	**Time**
In Situ Soil Characteristics	**Cut Slope**	**A**[4]	Application loading rate in terms of mass or volume per area, and depth of incorporation or thickness of blanket are critical experimental parameters. Variability in method of incorporation and surface preparation prior to application should also be accounted for.	Slope and slope length are the primary site variables but geotextiles, cross slope furrowing and terracing, road shoulder characteristics, curb blocks or other types of flow diverting structures may influence the rate of infiltration. Planted and seeded vegetation will modify infiltration characteristics over time.	All characteristics of the engineered soil may vary with time and should be evaluated at intervals over the performance period.
		B			
		C			
		D			
	Fill Slope	**A**			
		B			
		C			
		D			

NOTES:

[1] Variables of interest include areal infiltration rate, drainage rate, and gross water-holding capacity.

[2] Each experimental matrix should be repeated for a range within each class of compost being considered for application.

[3] All compost will satisfy the minimum specifications, but there is still significant room for variability, for instance, inclusion (or not) of large woody matter.

[4] Soil characteristic groups such as hydrologic soil groups are useful for description but prior to disturbance, but it is assumed that the standard values for hydrologic variables will not apply after the soil has been engineered as part of a cut or fill side slope.

Figure 6-1. Conceptual experimental program for Defining LID BMP design specifications for compost amended soils.

This experimental design could be used to determine other important variables that influence design parameters such as soil-water holding capacity, infiltration rate, and saturated hydraulic conductivities. Such an experimental setup could be performed in a laboratory under simulated rainfall conditions or as a pilot program of actual installations with monitoring incorporated into the contracts for installation. Necessarily, the initial installations would have to rely on existing design equations for sizing. As data are collected, further implementations could use the accumulating results to modify sizing requirements. It is important to note that the experimental process (whether implemented as a series of pilot studies or in a laboratory) would need to be repeated a substantial number of times to cover the range of experimental variables and produce a complete design specification.

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Appendix A Supporting Studies

Study 1: ISU 2008 – Using Compost for a Safer Environment

An Iowa State University study conducted from 2000–2002 sponsored by the Iowa Department of Natural Resources and the Iowa Department of Transportation examined runoff rates from sites treated with compost blankets in comparison with conventionally treated sites.

Compost, in 2- to 4-inch-thick blankets, was applied to the surface of 3:1 Horizontal to Vertical (H:V) construction site slopes and exposed to high intensity rainfall (4 inches/hour) for a duration 30 minutes or more. The study found that sites treated with compost significantly delayed runoff and resulted in reduced runoff volumes. The following table presents the mean runoff volume and mean time to runoff from the test sites.

Mean Runoff Quantity and Mean Time to Initiate Runoff from Test Plots

	Treatment				
	Biosolids Compost	Yard Waste Compost	Bio-industrial Compost	Compacted Subsoil	Topsoil
Geometric mean runoff (mm) during 30-minute rainfall	0.13[a]	<0.01[a]	0.08[a]	26.22[b]	15.54[b]
Mean time (min)	31.08[c]	56.92[d]	32.17[c,d]	4.67[a]	7.83[b]

Means within the same row with different letter designations are significantly different ($p<0.05$).
Source: ISU 2008.

The following findings were determined (ISU 2008):

- Runoff from compost-treated areas during a 30-minute high intensity rain storm was less than 0.8 percent of the runoff from areas treated with topsoil, and 0.5 percent or less of that from compacted subsoil.

- Although the amount of runoff from the yard waste compost appears to be less than from the other two composts, these differences are not statistically significant.

- Due to the water-absorbing capacity of the compost, initiation of runoff from compost-treated areas was significantly delayed. While compacted subsoil and topsoil typically began producing runoff within 5 to 8 minutes after rainfall began, areas treated with any of the three types of compost took, on average, 30 to 60 minutes to begin producing runoff.

- The reductions in quantity and frequency of runoff provided by compost treatments were similar under both unvegetated and vegetated conditions. These results show that compost blankets can provide storm water runoff control (and erosion control) on construction sites in the short term before vegetative cover can be established. The significant benefit is risk reduction caused by rainfall events prior to establishment of vegetative cover.

Study 2: Harrison et al. 1997 – Field Test of Compost Amendment to Reduce Nutrient Runoff

A study conducted for the City of Redmond, Washington (Harrison et al. 1997) examined the use of compost as an amendment to Alderwood series soil to increase water-holding capacity and reduce peak flow runoff. The soil at the project site is disturbed and characterized by a compacted subsurface layer that restricts vertical water flow. Seven test plots were constructed and filled with Alderwood subsoil or mixtures of soil and compost. Surface and subsurface flow samples were obtained from a series of seven simulated rainfall events. Analysis of varying antecedent soil moisture conditions was conducted. Simulated rainfall was applied at total amounts ranging from 19 to 62.4 millimeters (mm) (0.76 to 2.46 inches) per storm, with rainfall intensities ranging from 7.4 to 16 mm/hr (0.29 to 0.63 inches per hour [in/hr]). The study concluded the following (USEPA 1999):

- Water-holding capacity of the soil was about doubled with a 2:1 compost to soil amendment.
- Water runoff rates were moderated with the compost amendment, with the compost-amended soil showing greater lag time to peak flow at the initiation of a rainfall event and greater base flow in the interval following a rainfall event.

The study found that the compost-amended plots continued to store higher rates and total amounts of water for a longer period of time. Total storage increased by about 65 percent, and the field capacity increased by about 60 percent, with compost amendment. During one test with a rainfall intensity of 8mm/hr (0.3 in/hr), the control (unamended) plot required about 30 minutes to respond with total surface runoff and subsurface flow greater than 0.25 mm/hr (0.01 in/hr). The compost-amended site, however, required nearly twice as long to respond with a similar flow. It required 0.75 hour from the start of the rainfall simulation for the total flow to become greater than 2.5mm/hr (0.1 in/hr) in the unamended soil, while it required 1.75 hours for the compost-amended soil to increase to that rate. For the total runoff (surface plus subsurface flows) to reach 90 percent of the input rainfall intensity, it required nearly 2.0 hours for the unamended site, compared to 5.25 hours for the compost-amended site. Following the cessation of rainfall, it required 0.75 hour for total runoff in the unamended site to drop to less than 10 percent of the rainfall intensity, where it required 1.5 hours for the compost-amended site. Similar results occurred during the other tests using smaller rainfall intensities and total amounts, including one series of natural rainfall events. Compost-amended soils consistently had longer lag times to response, longer times to peak flows, higher base flows, higher total storage, and smaller total runoff than unamended soils. This indicated that compost-amended soils have better water-holding and runoff characteristics than the unamended Alderwood soils (USEPA 1999).

A study conducted by the University of Alabama for the U.S. Environmental Protection Agency examined the effectiveness of using compost as a soil amendment to increase rainwater infiltration, and to reduce the quantity and/or intensity of surface and subsurface runoff from land development.

The study utilized the test plots previously used for the City of Redmond, Washington Study (Harrison et al. 1997) summarized above, as well as field sites at two other locations.

The test beds were constructed and filled with Alderwood series soil, which is characterized by a compacted subsurface layer that restricts vertical water flow and soil-compost mixes. Glacial till soil (Alderwood series) was added to the bays and compacted before adding compost to represent natural field conditions. Compost was added at a 2:1 soil to compost rate and rototilled into the soil surface. Two types of compost were used in the study; the GroCo compost-amended soil is a sawdust/municipal waste mixture (3:1 ratio, by volume) that is composted in large windrows for at least 1 year and the Cedar Grove compost is a yard waste compost that is also composted in large windrows. Once installed, all bays were cropped with perennial ryegrass. Separate surface runoff and subsurface flow collectors were installed within each bay. Infiltration rates were measured during a series of natural rainfall events, as presented in the following table.

Infiltration Rate Measurements at Field Test Plots

Location	Test Plot Treatment	Ave Infiltration Rate (cm/hr) (in/hr)	Improvement with Compost (cm/hr)	Percentage Improvement
CUH plot 1	Alderwood soil A	1.2 (0.5)	6.3	525
CUH plot 2	Alderwood soil A w/ Cedar Grove compost	7.5 (3.0)		
CUH plot 5	Alderwood soil B	0.8 (0.3)	7.6	950
CUH plot 6	Alderwood soil B w/ GroCo compost	8.4 (3.3)		
Timbercrest	Alderwood soil C	0.7 (0.3)	1.6	228
Timbercrest	Alderwood soil C w/ Cedar Grove compost	2.3 (0.9)		
Woodmoor	Alderwood soil D	2.1 (0.8)	1.3	62
Woodmoor	Alderwood soil D w/ Cedar Grove compost	3.4 (1.3)		

Source: USEPA 1999

The data illustrate that the use of compost-amended soil resulted in significantly increased infiltration rates compared to soil alone. The infiltration rate increased from 1.5 to 10 times the untreated rates and was expected to substantially decrease the runoff volumes and flow rates from turf areas during rain storms.

The study found that the soil-only and compost-amended-soil test plots at the Center for Urban Horticulture (CUH) were quite similar, with both test plots in each pair having very similar Rv values (even though the infiltration measurements reported previously indicated large differences). In contrast, the newer test plots at Timbercrest and

Woodmoor showed significant decreases in surface runoff for the compost-amended test plots, compared to the soil-only test plots. Very little surface runoff was observed at the Timbercrest compost-amended test plot while the soil-only plot at Timbercrest had an average Rv of only about 0.04. Therefore, the improved infiltration improvement at Timbercrest is not very important from a flow perspective but could be from a mass pollutant runoff perspective. However, the Woodmoor site showed large and important improvements in infiltration conditions, with the Rv being reduced from about 0.25, to a much smaller Rv of about 0.05. In addition, the evapotranspiration rates increased with all compost-amended soils, although by only a very small amount at one of the CUH test plot pairs. The increase in evapotranspiration ranged from about 33 to 100 percent at the newer sites at Timbercrest and Woodmoor (USEPA 1999).

This study found that the infiltration rate increased by 1.5 to 10.5 times after amending the soil with compost, compared to unamended sites. There were mixed results with surface runoff of the compost-amended plots. The two older CUH test plots appeared to have no effect, the Woodmoor site had a ratio of 5.6 reduced runoff, and the Timbercrest site had no reported runoff. Because the older CUH sites did not show any runoff improvements in these tests while the new Timbercrest and Woodmoor sites did, further study should determine, if possible, the limits of effectiveness of compost amendment (i.e., age or decay rate) and a maintenance/reapplication schedule (USEPA 1999).

The study also noted the differences in the findings of the earlier Redmond-sponsored tests (Harrison et al. 1997) and the current study and suggested that some of these differences were likely associated with the age of the test plots, different rainfall conditions, and other site characteristics (USEPA 1999).

A Richmond, Washington, stormwater management study performed in 1995 concluded that compost-amended soils could be used to reduce runoff quantity. It was also determined that soil amendments made on previously compacted urban soils significantly increased infiltration rates. Within the plots tested, the water-holding capacity of the soil was doubled (when compared with a non-amended soil) with a 2:1 compost to soil amendment. Total storage for compost-amended soils increased by about 65 percent from that of non-amended soil. Rainfall runoff rates were restrained with the compost-amended soils. The amended soils showed a greater lag time to peak flow at the initiation of a rainfall event and attributed to an overall greater baseflow. In short, the results of the study exhibited that compost-amended soils consistently had longer lag times to response, longer times to peak flow, higher base flow, higher total storage, and smaller total runoff than non-amended soils (Harrison et al. 1997).

Study 3: Kolsti et al. 1995 – Hydrologic Response of Lawns on Till with Compost Amendment

A 1995 University of Washington study looked at the hydrologic response of tilled compost-amended residential lawns when compared with tilled non-amended lawns. The study analyzed various compost types as well; wood mulch, yard waste, and sewage sludge-based composts of varying grain size (Kolsti et al. 1995).

The study compared hydrographs for a series of storms in varying size and intensity over a 5-month period for each test plot. One of the compost-amended test plots (yard waste) reduced the first storm peak runoff of one of the storms studied by 25 percent and delayed the peak by approximately 1 hour relative to the non-amended test plot. A control plot generated 88 percent more runoff than another compost-amended test plot (sewage-sludge compost), producing 85 percent of its runoff during the storms (compared with only 63 percent released during storms for the amended plot) (Kolsti et al. 1995).

The study concluded that application of high amounts of fine, aged compost resulted in significantly improved hydrologic behavior relative to unamended soil. These compost-amended soils consistently resulted in reduced peak runoff flows, delayed peaks, and overall reductions in runoff volume. The resulting higher soil conductivity resulted in increased infiltration and baseflow (Kolsti et. al 1995).

The study found that the greatest beneficial effects in terms of runoff reductions were observed for the fine-grained, well-aged compost. The coarser-grained (containing visible wood fragments) compost produced little beneficial hydrologic effects. The results of the study demonstrate that compost-amended lawns in conjunction with till can significantly enhance the ability of the lawn to infiltrate, store, and release water as baseflow (Kolsti et al. 1995).

Study 4: Dane County 2003 – Quantifying Decreases in Stormwater Runoff From Compost-Amendment

A Dane County, Wisconsin, study analyzed and quantified the reductions in runoff for compost-amended soils when compared with non-amended tilled or plowed soils. This study involved four differing test plots: a control plot; deep-till plot; chisel-plow, deep-till plot; and a chisel-plow, deep-till, compost-amended plot. The study also pulled conclusions from previous studies in its analyses. The study found that when compost is incorporated into the soil, bulk density can be reduced by as much as 0.35 grams per cubic centimeter (g/cm^3), helping offset the effects of compaction. In addition to reducing bulk density, compost-amended soils reduced the volume of surface runoff by 29 to 50 percent.

For 30 minutes of rainfall (totaling 5 to 6 cm) the study found that drastic reductions in runoff volume occurred for all treatments compared to the control. The treatment utilizing compost, however, had the greatest reduction in runoff at 98 percent compared to the chisel-plowed, deep-tilled treatment which reduced runoff by 71 percent, and the deep-tilled treatment which reduced runoff by 54 precent. . As the study progressed, the amount of vegetative cover on each plot increased. A drastic and rapid increase in the amount of cover on the compost-amended plots was observed. The compost-amended plot remained green, continued to grow, and remained healthy and vigorous throughout the study, regardless of temperature and precipitation.

The study also analyzed smaller storms (totaling less than 2.5 cm). Again, the compost-amended treatment had the greatest reduction in runoff compared to the control, at 74 percent. The deep-till plot actually produced greater runoff compared with the control plot and the chisel-plow, deep-till plot and reduced runoff by 54 percent compared with the control plot.

For larger storms (totaling greater than 2.5 cm) the compost-amended treatment again produced the greatest reduction in runoff compared to the control, at 74 to 91 percent. The deep-till plot again resulted in greater runoff compared to the control plot and the chisel-plow, deep-till plot reduced runoff by 36 to 53 percent. The study concluded that regardless of storm size, the compost-amended, chisel-plowed, and deep-tilled treatment resulted in the greatest reductions in total runoff volume and increased the water-holding capacity of the soil (Dane County 2003).

Study 5: WSDOT 2007 – Compost-Amended Vegetated Filter Strips (CAVFS) Performance Monitoring Project

In 2003, WSDOT initiated a program to install and document the flow control effectiveness of one LID technique, CAVFS, with potential application as a BMP for stormwater in shoulders/medians of highways. The primary goal of the study was to implement a monitoring program to document the performance of CAVFS with regard to reducing the peak discharge rates, flow volumes, and flow durations of highway runoff. Monitoring for the project occurred over 3 years. Annual monitoring reports were prepared at the end of each water year within the study period. The Water Year 2006 Data Report outlined below is the most recent monitoring report available. This monitoring report evaluates and compares the hydrologic and water quality treatment performance of filter strips with and without compost amendment (WSDOT 2007).

Three pilot vegetated filter strips were constructed along Interstate 5 in Snohomish County, Washington. Two of the strips were amended with tilled-in compost and a third received no compost. Untreated runoff from a curbed section of highway was routed to a single monitoring station to characterize influent runoff discharge rates. Automated water quality and quantity sampling equipment was used at each of the pilot strips. The test site was located on disturbed, compacted glacial till (freeway embankment soil) within urban areas of the Puget Sound region, representing a worst-case scenario for assessing the performance of CAVFS in western Washington. The soils in the test site area were mapped as Urban Land within the Alderwood-Urban Land complex, 2 to 8 percent slopes (WSDOT 2007). The permeability of undisturbed Alderwood soil is moderately rapid above the hardpan and very slow through it. In constructed, compacted sites infiltration rates are lower, however. The monitoring project evaluated data from the approximate mid to upper range of the 35 to 50 inches of annual rainfall characteristic of Puget Sound region urban areas.

Statistical analyses were performed on the normalized data from runoff-producing storms to compare hydrologic characteristics for the Curb and Gutter station to those for the three filter strips, as well as the characteristics of the vegetated filter strips (VFS) to the CAVFS. Storms that occurred during the testing period ranged from 0.01 to 2.30 inches in precipitation depth and 0.25 to 59.8 hours in duration, with average intensities up to 0.21 inches/hour and peak intensities up to 0.17 inch/15 minutes. The monitoring project found that one of the CAVFS stations (CAVFS1) outperformed the other CAVFS station (CAVFS2) significantly in all hydrologic characteristics. This was attributed to the CAVFS1 site containing a surface depression consisting of permeable advance outwash with an organic silt layer. This depression occupies approximately 40 percent of the CAVFS1 filter strip’s total length and likely explains its superior performance relative to the VFS and CAVFS2 filter strips. Thus, the CAVFS2 station was used to determine the conclusions outlined in the monitoring project report (WSDOT 2007).

The report concluded that compost amendment appears to improve filter strip performance for reducing runoff volumes. Runoff volumes in filter strips with compost amendment were between 45 and 50 percent lower than those in filter strips without compost. The study found that compost amendment in filter strips was most effective in reducing flow volumes for precipitation depths exceeding 0.2 inch. Additionally, the study found that compost amendment reduces peak discharge rates through the low end of the data range; however, other factors (such as slope) were likely influencing performance under saturated conditions at the high end of the range (WSDOT 2007).