Soil Amendment Guidance for Infiltration and Stormwater Treatment

Prepared by Office of Stormwater Program Development
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Executive Summary

Background

Caltrans Office of Stormwater Program Development is developing guidance to comply with new National Pollutant Discharge Elimination System (NPDES) permit requirements for post-construction stormwater treatment controls. The new permit requires Caltrans not only to prioritize soil-based BMPs but also to give first consideration to installing BMPs that are capable of infiltrating the amount of water from the 85th percentile 24-hour storm. This requirement must be implemented where feasible, based on other Caltrans safety and design requirements. Installing soil amendments adjacent to roadsides is a challenge because Caltrans Standard Specifications require 90% relative-compaction within the Clear Recovery Zone. For amended soils less than 90% compaction is preferred in order to enhance infiltration /retention of stormwater runoff. This project will develop the information needed for estimating stormwater runoff infiltration volumes and pollutant treatment provided by soil amendments for Caltrans practitioners to design, install and maintain soil amendments in the CRZ when viable, while addressing the NPDES permit requirements.

Currently there are gaps in information necessary to determine the infiltration rate or hydraulic conductivity, water holding capacity, bulk density and porosity of an amended and compacted soil, based on the properties of the soil, specifications of the amendment, and blending ratio. This information would be critical in helping to size a soil amendment BMP to capture, treat and infiltrate stormwater in order meet Caltrans annual stormwater treatment credit requirements mandated by the department's Clean Water Act NPDES Permit issued by the State Water Board

Specifically, Caltrans is interested in the following topics:

- Laboratory analysis of soils and their amendments for future use in identifying predictive relationships for determining the afore-mentioned parameters.
- Field testing of amended soils for the optimization of soil infiltration and performance of amended-soil based best management practices (BMPs)

To assist with this effort, Office of Stormwater Program Development conducted a review of literature and state and federal guidance, and interviewed staff at state DOTs with experience in this area.

Definitions

The following terms are used in this Preliminary Investigation.

Engineered Soil: An engineered soil is soil or growing media that has been formulated with specific components for specific purpose or application.

Soil Amendments: Soil amendments include any material added to soil to improve its physical, chemical, biological, or structural properties or to provide enhanced plant growth. Improved permeability, infiltration, drainage, structure, or nutrient availability may all be goals of using soil amendments.

Clear zone: The unobstructed, traversable area provided beyond the edge of the through traveled way for the recovery of errant vehicles. The clear zone includes shoulders, bike lanes, and auxiliary lanes, except those auxiliary lanes that function like through lanes. *(AASHTO Roadside Design Guide)*

Recovery area: Generally synonymous with clear zone. *(AASHTO Roadside Design Guide)*

Hydraulic Conductivity: Symbolically represented as K, is a property of vascular plants, soils and rocks, which describes the ease with which a fluid can move through pore spaces or fractures. It depends on the intrinsic permeability of the material, the degree of saturation, and on the density and viscosity of the fluid.

Infiltration: Infiltration of the process of water moving into the soil from the soil surface.

Summary of Findings

As part of the PI we conducted a preliminary literature review. Findings from the review are presented below.

"Building Healthy Soils with Compost to Protect Watersheds"

Bobby Bell and Brenda Platt. *Institute of Local Self Reliance,* June 2014,

www.ilsr.org

Healthy soils are vital for protecting watersheds. "Naturally occurring (undisturbed) soil and vegetation provide important stormwater runoff management functions: water infiltration; nutrient, sediment, and pollutant adsorption; sediment and pollutant bio-filtration; water interflow, storage and transmission; and pollutant decomposition." These functions are mostly lost when development replaces native soil and vegetation with minimal topsoil and sod.

From a stormwater management perspective, the goal is to "replace" these functions to a practicable extent, and literature review seems to indicate that this is possible by amending the soils.

Incorporating compost and compost-based products into the (concerned) area's soils is an important way to protect the watershed. Depending on the scale of application, it provides a number of additional benefits such as reducing greenhouse gases through carbon sequestration, diverting discarded biodegradable material from the waste stream, and creating "green" jobs. The benefits of compost-amended soils are:

(1) *Non-Point Source Pollution Prevention (Agricultural Runoff & Urban/Suburban Stormwater).* When used as biofiltration media, compost reduces contamination caused by urban pollutants by 60 to 95%;

(2) *Erosion & Sedimentation Control* - Mixing in the right amount of compost into native soils offers resistance to erosion and minimizes sediment-carrying runoff by as much as 50%. Besides the soil stabilization, the improved soil structure allows greater infiltration, capturing water runoff and sediment;

(3) *Improved Water Retention* - Compost can hold 3 to 5 times its weight in water. It can also "increase water storage by 16 thousand gallons per acre foot for each 1 percent of organic

matter.” This allows rainwater that would normally be lost through evaporation or runoff to remain in and replenish ecosystems. In contrast to other soil amendments, compost has a higher absorption and storage rate than raw manure, anhydrous ammonia, and commercial fertilizer.

(4) *Reduced Costs* – Amending soils with compost produces significant cost savings. A recent study indicated that under a 3---inch/24---hour period storm, a typical 10---acre development with a compost blanket (i.e. a layer of loosely applied compost) would reduce runoff volume as compared to an impervious site and avoid $181,428 per year in water treatment costs. If the runoff was treated on---site with a stormwater management pond, the compost blanket application equates to a cost reduction of $697,800, avoiding the need for a larger pond to accommodate an increased volume of water. Many other compost products can reduce the cost of erosion and overburdened stormwater management systems – a cost totaling $44 billion each year in America.

“Choosing a Soil Amendment”

J.G Davis and D. Whiting, *Colorado State University Fact Sheet No. 7.235,* February, 2013

“Soil amendments include inorganic materials and organic matter that helps restore the fertility and condition of the soil, supports infiltration and improves pollutant removal capabilities. Soil organic matter can be increased by adding materials such as compost, composted woody material, bio solids, and forest product residuals. Inorganic amendments include vermiculite, perlite, tire chunks, pea gravel and sand.

“ODOT – Hydraulics Manual”

Stormwater Treatment Facility Components, Appendix E, April 2014

Soil amendments are used to enhance the efficiency of filter strips (dispersion areas), biofiltration swales, bioretention facilities, and extended dry detention facilities. In those facilities, it assists in the retention of stormwater to allow for infiltration down into the underlying soil, as well as providing treatment before the stormwater “enters the groundwater or conveyance system.”

“Literature Review” *Soil Amendments to Enhance Infiltration,* Caltrans 2014

Soil amendment applications are intended to provide a sustainable, erosion resistant surface that minimizes runoff and therefore would satisfy certain Permit requirements. However, site specific factors can limit the selection and effectiveness of certain soil amendments, including harsh climates (e.g., deserts) and conditions not conducive to infiltration (e.g., steeply sloped areas compacted soils and roadsides with thin or no soil).

Soil amendments also have their limitations. Organic soil amendments eventually degrade. Steep slopes and compacted soil also present obstacles to infiltration that cannot be easily solved by soil amendments alone.

Inorganic or rock mulch is very useful for temporarily or permanently increasing infiltration in a variety of applications including arid areas and for steeply sloped (steeper than 4H: 1V) alpine areas above the tree line. In general, angular rock from ¾ to 3 inches in size enhances infiltration, and gravel and sand can improve infiltration in particular applications.

One of the primary benefits of rock mulches is that large rocks create larger pore spaces that allow rapid infiltration. Properly installed rock mulches are also essentially permanent with minimal maintenance required. However, the infiltration of rock mulch placed over compacted soils will likely be limited by the underlying soil infiltration. The Department specifications call for sterilizing soil within the excavation area with oxadiazon, then laying a geotextile fabric and finally backfilling and spreading the gravel as specified. While preventing weed growth the use of this herbicide may affect water quality; requiring Caltrans to develop a new specification for rock, gravel, sand and other inorganic mulches to enhance infiltration sans the use of herbicide.

"Minnesota Stormwater Manual" *Soil Amendments to Enhance Phosphorus Sorption,* January, 2017

"https://stormwater.pca.state.mn.us/index.php?title=Soil_amendments_to_enhance_phosphorus_sorption&oldid=30950 "

Minnesota DOT has soil amendments specifications to enhance phosphorus (P) sorption and for filtration of particulate-bound P.

"Journal of Soil and Water Conservation" *Effects of tillage and compost amendment on infiltration in compacted soils*, F Mohammad Shirazi, V.K. Brown, J.L. Heitman and R.A. McLaughlin, November, 2016

A study by North Carolina DOT on soil amendments/tillage shows that tillage to a depth of at least 6 inches can be "highly effective for improving soil conditions and decreasing runoff and erosion from soils compacted during construction activities. However, efficacy of pollutant treatment was not part of the study.

State Practices

Oregon's experience:

- A few years ago, Oregon DOT implemented amended soil outside of a freeway's gravel shoulder to infiltrate stormwater and prevent runoff from impacting fish species of concern in nearby rivers.
- Oregon typically uses amended soils only near the drainage line or bottom of a slope. When space limitations force amended soils to be used adjacent to driving lanes, ODOT uses geogrids to provide a relatively solid surface for vehicles that run off the road.
- Oregon's guidance prohibits installing stormwater infiltration BMPs where they could contribute to instability of the terrain. Engineers are directed to consult with geotechnical staff before implementing stormwater infiltration BMPs to ensure that slopes remain stable. (PI/DRISI – *Safety and Stability of Stormwater Infiltration BMPs Adjacent to Roadsides*)

Maryland's approach:

- In Maryland, stormwater infiltration BMPs are used to capture and treat a volume of stormwater runoff, and are "designed to infiltrate retained runoff with a 48-hour period. However, they are not constructed in locations where they might be driven over. (Maryland Stormwater Design Manual)

In addition, we contacted DOTs in Oregon, Maryland, and Washington.

Detailed Findings

Consultation with Experts

OSPD contacted staff at three state agencies—Oregon, Washington and Maryland—about Soil Amendment Guidance for Infiltration and Stormwater Treatment

. These interactions are summarized below.

Oregon DOT

Interviewee: William B. Fletcher, Water Resources Program Leader, 503-986-3509, William.B.Fletcher@odot.state.or.us.

Fletcher suggested seeking input from WSDOT, and referred briefly to the following:

The Oregon project involving amended soils adjacent to a highway shoulder. A few years ago, ODOT widened the shoulder on I-5 south of Portland. There were environmental concerns related to the impact of runoff from widened paved shoulders on fish species of concern in nearby rivers, so ODOT implemented amended soil outside of a gravel shoulder. Almost immediately, large numbers of ruts appeared on the amended soil.

In response, ODOT developed internal guidance. Under this guidance, amended soils should be used near the drainage line or the bottom of a slope, rather than adjacent to the driving lanes, if there is enough space to do so. When there isn't enough space, ODOT uses geogrids to provide a solid surface for vehicles that run off the road to drive on and limit the extent to which those vehicles will sink into the soil.

ODOT also utilizes geogrids with media filter drains (MFD)—a linear treatment also called a bioslope that runs parallel to the road. ODOT's media filter drain design consists of a narrow vegetated strip; drain rock and a mix of sand, pearlite and other materials to remove dissolved metals; and an underdrain to capture and discharge stormwater. (PI/DRISI – *Safety and Stability of Stormwater Infiltration BMPs Adjacent to Roadsides*)

Washington State DOT

Interviewee: Alex Nguyen, P.E., Hydraulics and Stormwater Office, 206-440-4537, Nguyeal@wsdot.wa.gov.

Question: *Has WSDOT conducted studies on how to optimize infiltration rates of amended soils or their efficacy of stormwater pollutant treatment and/or life cycle cost analysis (LCCA) of soil amendments "designed" to accomplish both goals – optimized infiltration & pollutant treatment? If yes, can you please share the conclusions of such a study and associated reports; if not, can please you share your insight on this topic?*

Response: *To my knowledge, I don't think we have done any research that does specifically what you ask in your email. What I can give you is a list of the research reports that we have recently done that may help get to the answers that you are looking for.*

Below is the list of research topics that might help. Each page has a summary of the research that deals with compost in some way. The last link is a new report done by WSDOT that doesn't specifically deal with compost but is a revised method for estimating the saturated hydraulic conductivity for a highway embankment:

- *Chemical and Physical Characteristics of Compost Leachates - A Review https://www.wsdot.wa.gov/Research/Reports/800/819.1.htm*
- *Experimental Evaluation of Compost Leachate https://www.wsdot.wa.gov/Research/Reports/800/848.1.htm*
- *Design and Construction of a Field Test Site to Evaluate the Effectiveness of a Compost Amended Bioswale for Removing Metals from Highway Stormwater Runoff http://www.wsdot.wa.gov/Research/Reports/700/724.1.htm*
- *Compost-Amended Biofiltration Swale Evaluation http://www.wsdot.wa.gov/research/reports/700/compost-amended-biofiltration-swale-evaluation*
- *Assessment and Mitigation of Potential Environmental Impacts of Portland Cement Concrete Highway Grindings https://www.wsdot.wa.gov/Research/Reports/600/628.1.htm*
- *WSDOT BMP's for Stormwater Runoff in Confined Spaces https://www.wsdot.wa.gov/Research/Reports/400/451.1.htm*
- *Stormwater Infiltration in Highway Embankments -- Saturated Hydraulic Conductivity Estimation for Uncompacted and Compacted Soils https://www.wsdot.wa.gov/research/reports/800/stormwater-infiltration-highway-embankments-saturated-hydraulic-conductivity*

Maryland Department of the Environment

Interviewee: Amanda Malcolm, P.E., Acting Chief, Sediment and Stormwater Plan Review Division, 410-537-3551, amanda.malcolm@maryland.gov.

Amanda Malcolm did not respond to an email inquiry at the time of seeking input for this Preliminary Investigation.

State Guidance

Oregon DOT

Hydraulics Design Manual, Oregon DOT, 2014.
http://www.oregon.gov/ODOT/HWY/GEOENVIRONMENTAL/pages/hyd_manual_info.aspx
Chapter 14 of the manual provides general technical guidance for several stormwater control facilities, with further detail in appendices. Appendix C addresses media filtration facilities, including bioslopes and other BMPs "where stormwater flows through soil, amended soil, compost or a special mix of materials" to absorb dissolved pollutants. They consist of a vegetated filter strip upstream of the bioslope; a treatment zone that includes a mixture of aggregate, dolomite, gypsum and pearlite to remove pollutants; and a subsurface drain to allow runoff outflow.

According to Section 14.9.6.2, the soils on a site "determine whether infiltration-based BMPs are feasible or not." Hydrologic class A and B soils (with high or moderate infiltration rates when thoroughly wetted) support infiltration BMPs, class C soils permit a small amount of infiltration, and class D soils (primarily clay soils with high swelling potential or soils with a permanent high water table) are not suitable for infiltration. In addition, "Soil amendments can improve the pollutant removal characteristics of soils while maintaining acceptable permeability. They can also improve permeability in tight soils, but only in the layer with the amendment, so the amendment will support media filtration but not infiltration."

BMP siting criteria are described in Section 14.9.8. Geotechnical requirements include that embankments must be designed to safely impound stormwater runoff, long-term permeability of surrounding soil must be verified, and retaining walls must be designed according to the ODOT Geotechnical Design Manual.

Washington State DOT

Highway Runoff Manual, April 2014.
http://www.wsdot.wa.gov/Publications/Manuals/M31-16.htm
Chapter 4 (page 4-29) advises that infiltration facilities should be located 20 feet downslope and 100 feet upslope from building foundations, and 50 feet or more behind the top of slopes that are steeper than 15 percent. It also advises that designers should "Request a geotechnical report for the project that would evaluate structural site stability impacts due to extended subgrade saturation and/or head loading of the permeable layer, including the potential impacts to downgradient properties (especially on hills with known side-hill seeps.)"

Design Manual, July 2014.
http://www.wsdot.wa.gov/Publications/Manuals/M22-01.htm
Chapter 610 provides guidance on conducting a soil investigation. Geotechnical investigation is conducted by the WSDOT Geotechnical Office, and requires data such as soil borings, testing and geometric data. Known unstable slopes adjacent to the transportation network may be stabilized to prevent landslides or rockfall.

Geosynthetics—including geotextiles, geogrids, geonets, geomembranes, or geocomposites—can be used to stabilize soils and are described in Chapter 630. Before implementation, designers should ask whether the geosynthetic is truly needed, identify the properties that will ensure that it functions as intended, determine where it should be located, and determine maintenance needs.

Regarding soft soils, the guide states that “Soil stabilization geotextile is used in roadway applications if the subgrade is too soft and wet to be prepared and compacted as required in the [WSDOT] Standard Specifications [for Road, Bridge, and Municipal Construction].”

Related Research and Resources

This section summarizes published research and guidance related to the vehicle safety impacts of roadside soil amendments. These resources mainly address -among others - stormwater infiltration.

Stormwater Infiltration BMPs

This section summarizes published research and guidance that addresses stormwater infiltration BMPs. In general, state and federal guidelines related to soil hydraulics focus on a soil’s ability to infiltrate stormwater rather than its ability to remove and control pollutants.

National Research and Guidance

“Limitations of the Infiltration Approach to Stormwater Management in the Highway Environment,” NCHRP Project 25-51, in progress.
This project is intended to provide guidance to DOTs at sites where infiltration techniques are the best option (or where they are required) but where there are site concerns such as a high water table that could lead to groundwater contamination. The project is funded and is anticipated completion date is 02/09/18.

http://www.trb.org/NotesDocs/25-25(51)_FR.pdf
The objective of this research is to develop guidance for state DOTs to determine appropriate siting of stormwater infiltration BMPs based on the limitations, risks, and benefits in the context of the built and natural environments (e.g., surface water and groundwater, soils, existing infrastructure). The guidance should address a broad range of issues and needs associated with choosing and siting infiltration BMPs for mitigating roadway stormwater that may include but not be limited to the following:

- Limitations (e.g., cost, maintenance, regulatory, receiving waters, geotechnical)
- Effects of climate, soils, topography, geology, vegetation, and land use
- Effects of pollutants of concern on surface water and groundwater quality
- Effects on surface water and groundwater quantity (e.g., recharge, baseflow augmentation, groundwater mounding)
- Identification of gaps in the body of knowledge

Volume Reduction of Highway Runoff in Urban Areas: Guidance Manual, NCHRP Report 802, 2015. http://www.trb.org/main/blurbs/172415.aspx
This manual provides guidance for reducing the volume of stormwater runoff in a wide range of urban highway environments. It provides recommendations for specific project types, site conditions and climate zones. Relevant sections of the report include:

- Chapter 4 (1) Prioritization of volume reduction and pollutant removal goals. (2) Reliability of infiltration measurement techniques Table 14 (see page 74) summarizes geotechnical impacts related to various classifications of stormwater VRAs. According to this table, vegetated conveyances are typically located at least 10 feet from travel lanes.
- Chapter 2 describes a step-by-step approach for incorporating stormwater infiltration into project development for an urban highway project. This chapter provides an example process that covers project planning, site investigation and project design.
- Appendix D Potential Impacts of Highway Stormwater Infiltration on Water Balance and Groundwater Quality in Roadway environments (White Paper #2) Chapter 3 characterizes the urban highway environment as it relates to stormwater volume reduction approaches (VRAs). Included in this chapter is a section related to how highway safety standards—including geometric design standards, vegetation and landscaping standards, and drainage standards—affect stormwater infiltration.
- Table 2 (see page 25) addresses the role of several aspects of the physical setting on VRAs. In particular, it states that "Compaction of fine-grained soils may be necessary for structural stability but may greatly reduce the infiltrating capacity of soils."

Guidelines for Evaluating and Selecting Modifications to Existing Roadway Drainage Infrastructure to Improve Water Quality in Ultra-Urban Areas, NCHRP Report 728, 2012.
http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_728.pdf
This report provides guidance for retrofitting stormwater management BMPs at existing highway facilities in dense urban areas. Chapter 3 describes general drivers and practices for BMP retrofits.

Urban Stormwater Management in the United States, National Research Council, 2008.
http://www.epa.gov/npdes/pubs/nrc_stormwaterreport.pdf
This report reviews the Environmental Protection Agency's permitting program for stormwater discharge under the Clean Water Act and recommends improvements. It focuses on stormwater BMPs' impacts on water quality.

Chapter 6 references soil amendments as one innovative stormwater management technique. Page 409 describes common reasons for opposition to infiltration techniques, including soil amendments. The objections described are typically related to insufficient effectiveness in clay soils, impact on groundwater quality, the effect of overirrigation of lawns and municipal wastewater treatment system capacity.

Gaps in Findings

- There seems to be no studies on how to optimize infiltration rates of amended soils or their efficacy of stormwater pollutant treatment or life cycle cost analysis (LCCA) of soil amendments "designed" to accomplish both goals – optimized infiltration & pollutant treatment.
- What is the relationship between compaction and hydraulic conductivity? This could be addressed by additional testing, although this may be a significant effort given the wide variety of soil types.
- No investigational data for the following:

  (a) effectiveness of various organic/inorganic soil amendments to enhance infiltration

(b) effectiveness of scarifying or tilling the surface, approximately 0 to 12 inches,
(c) Research incorporation of soil amendments into the embankment.
(d) Compatibility of current specifications for amendments incorporation.
(e) Construction methods and specifications for amending slopes.
(f) Construction materials and specifications for increased infiltration.
(g) Compaction of soil amendments and appropriate relative compaction for Clear Recovery Zone and traversable slopes
(h) Can organic and inorganic soil amendments be used in combination?

Next Steps

Based on the findings of the preliminary investigation Caltrans may wish to consider a phased project described in the section below. Funding is being requested for all 3 Phases of the project.

Phase 1:

- Conduct a literature survey of soil amendment practices used by DOTs to enhance infiltration, design methods and soil properties used
- Identify highway sites for soil sample collection and field testing

Phase 2:

- Conduct laboratory testing to determine the infiltration rate or hydraulic conductivity, water holding capacity, bulk density and porosity of an amended and compacted soil based on: (a) properties of the soil, (b) specifications of the amendment, and (3) blending ratio.
- Analyze the test data to develop statistically based predictive relationships for optimizing amended soil infiltration and BMPs.

Phase 3:

- Select field test sites
- Conduct field testing on amended soils
- Develop design guidance and specifications

Specific Objectives of the Project

- Develop variation of soil amendment infiltration and treatment capacity for different compaction levels.
- Define optimum depth of incorporation, compaction and ratio of soil to amendment for select soil hydrologic groups for enhancing infiltration/treatment.
- Develop design criteria for earthen stormwater infiltration BMPs for roadside applications.
- Develop specifications and construction guidance to build BMPs that maximize infiltration, enhance stormwater quality by reducing pollutants

Contacts

OSPD contacted the individuals below to gather information for this investigation.

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