Soil Media Designs for Bioretention of Nutrients and Plant Growth.
Or:
When is a spec not a spec?

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Objectives for Today

- Discuss current (and past) VA DCR specifications for bioretention media.
- Relate the current DCR specifications to our common soil science theory and knowledge base.
- Propose improvements in the specifications and how they are applied.

Important Disclaimer

I am <u>not</u> an expert in stormwater BMP designs, installations or treatment assumptions. However, I have worked extensively on the interactions of physical, biological, chemical and mineralogical soil properties on N and P leaching and runoff in a variety of settings.

Over the past year, however, I have spent untold hours of my (and my lab's) time trying to assist private sector contractors understand and meet the current DCR biofilter media specifications. All too often, my only response to these folks has been: "I have no idea why that spec is written that way and how you can possibly meet it".

Disclaimer #2

DCR-Richmond is clearly aware of our concerns with the current bioretention specification and has issued internal guidance to its field offices regarding the issues with mis-application of the P-index, etc.

The critique contained in this presentation is directed at the existing specification as it stands "on the books" and not at current DCR personnel who are trying to deal with it as best they can.

BIORETENTION

VERSION 1.9
March 1, 2011

SECTION 1: DESCRIPTION

Individual bioretention areas can serve highly impervious drainage areas less than two (2) acres in size. Surface runoff is directed into a shallow landscaped depression that incorporates many of the pollutant removal mechanisms that operate in forested ecosystems. The primary component of a bioretention practice is the filter bed, which has a mixture of sand, soil, and organic material as the filtering media with a surface mulch layer. During storms, runoff temporarily ponds 6 to 12 inches above the mulch layer and then rapidly filters through the bed. Normally, the filtered runoff is collected in an underdrain and returned to the storm drain system. The underdrain consists of a perforated pipe in a gravel layer installed along the bottom of the filter bed. A bioretention facility with an underdrain system is commonly referred to as a *Bioretention Filter*.

Bioretention can also be designed to infiltrate runoff into native soils. This can be done at sites with permeable soils, a low groundwater table, and a low risk of groundwater contamination. This design features the use of a "partial exfiltration" system that promotes greater groundwater recharge. Underdrains are only installed beneath a portion of the filter bed, above a stone "sump" layer, or eliminated altogether, thereby increasing stormwater infiltration. A bioretention facility without an underdrain system, or with a storage sump in the bottom is commonly referred to as a *Bioretention Basin*.

Table 9.1. Summary of Stormwater Functions Provided by Bioretention Basins

Stormwater Function	Level 1 Design	Level 2 Design
Annual Runoff Volume Reduction (RR)	40%	80%
Total Phosphorus (TP) EMC Reduction[1] by BMP Treatment Process	25%	50%
Total Phosphorus (TP) Mass Load Removal	55%	90%
Total Nitrogen (TN) EMC Reduction[1] by BMP Treatment Process	40%	60%
Total Nitrogen (TN) Mass Load Removal	64%	90%
Channel and Flood Protection	• Use the Runoff Reduction Method (RRM) Spreadsheet to calculate the Cover Number (CN) Adjustment ***OR*** • Design extra storage (optional; as needed) on the surface, in the engineered soil matrix, and in the stone/underdrain layer to accommodate a larger storm, and use NRCS TR-55 Runoff Equations[2] to compute the CN Adjustment.	

[1] Change in event mean concentration (EMC) through the practice. Actual nutrient mass load removed is the product of the removal rate and the runoff reduction rate(see Table 1 in the *Introduction to the New Virginia Stormwater Design Specifications*).

[2] NRCS TR-55 Runoff Equations 2-1 thru 2-5 and Figure 2-1 can be used to compute a curve number adjustment for larger storm events based on the retention storage provided by the practice(s).

Sources: CWP and CSN (2008) and CWP (2007)

How does the media remove N and P?

- P removal is presumably due to filtration/retention of sediment bound P plus adsorption/fixation of ortho-P onto Al, Fe, Ca compounds and clay edges.

- Considerable P is probably removed via uptake by the active microbial biomass. Limited P also goes to plant uptake and is cycled back to soil OM etc.

How does the media remove N and P?

- N removal presumably occurs via filtration of OM particulate N and denitrification of NO_3-N. NO_3-N is not attracted or sorbed by soil minerals or OM components like P is. NH_4-N is less common in urban runoff, but would be sorbed to CEC sites if it's not nitrified first to NO_3-N.
- Some N is probably removed via uptake by the active microbial biomass. Limited N also goes to plant uptake and is cycled back to soil OM etc.

Older (pre 2009) DCR Biofiltration Media Specifications based upon Prince George's County 1993 standards.

A desirable planting soil would 1) be permeable to allow infiltration of runoff and 2) provide adsorption of organic nitrogen and phosphorus.

1. Soil Texture and Structure

It is recommended that the planting soils for bioretention have a sandy loam, loamy sand, or loam texture. Experience in both Maryland and Virginia has indicated that the original soil specification contained in the Prince Georges County manual must be modified to decrease the clay content to no more than five percent to preclude premature failure of the basins due to clogging. Prince Georges County issued a design update in June 1998 in which the total depth of the facility is reduced to 2.5 feet by the elimination of the sand bed and the use of a soil media consisting of 50 percent sand, 20 percent leaf compost, and 30 percent topsoil. Virginia engineers with bioretention experience recommend using either the new Maryland media specification or a media of 50 percent sand and 50 percent hemic or fibric peat, using the Virginia topsoil thickness criteria in both cases, while retaining the sand bed. This could result in an overall thickness somewhat comparable to that specified in Maryland.

Note that this is clearly a "volume blend" that is relatively easy for a contractor to address and meet.

3. Soil Testing

The planting soil for bioretention areas must be tested prior to installation for pH, organic matter, and other chemical constituents. The soil should meet the following criteria (Landscape Contractors Association, 4th Addition, 1993):

pH range:	5.0 - 7.0
Organic matter:	Greater than 1.5
Magnesium (Mg):	100+ Units
Phosphorus (P_2O_5):	150+ Units
Potassium (K_2O):	120+ Units
Soluble salts:	not to exceed 900 ppm/.9 MMHOS/cm (soil) not to exceed 3,000 ppm/2.5 MMHOS/cm (organic mix)

<u>Water Quality Enhancement</u>

Bioretention basins enhance the quality of stormwater runoff through the processes of adsorption, filtration, volitization, ion exchange, microbial and decomposition prior to exfiltration into the surrounding soil mass. Microbial soil processes, evapotranspiration, and nutrient uptake in plants also come into play (Bitter and Bowers, 1995).

March 2011 DCR Bioretention Specifications – Part 1.9; Stormwater Specification 9

- ***General Filter Media Composition.*** The recommended bioretention soil mixture is generally classified as a loamy sand on the USDA Texture Triangle, with the following composition:
  - 85% to 88% sand;
  - 8% to 12% soil fines; and
  - 3% to 5% organic matter.

All sands are not created equal! VFS is very different from coarse sand! Is sand sized mica ok?

Soil fines here would be silt + clay; probably added along with sand as A+E materials. No pH or nutrient guidelines? No toxic exclusions?

Organic matter here is presumed to be by weight or volume? Quality of OM? Most high quality yardwaste compost is 50% ash/mineral. Do I add twice as much? Which technique should we analyze the OM by? Many more questions here!!

- ***P-Index.*** The P-Index provides a measure of soil phosphorus content and the risk of that phosphorus moving through the soil media. The risk of phosphorus movement through a soil is influenced by several soil physical properties: texture, structure, total pore space, pore-size, pore distribution, and organic matter. A soil with a lot of fines will hold phosphorus while also limiting the movement of water. A soil that is sandy will have a high permeability, and will therefore be less likely to hold phosphorus within the soil matrix.

  A primary factor in interpreting the desired P-Index of a soil is the bulk density. Saxton et. al. (1986) estimated generalized bulk densities and soil-water characteristics from soil texture. The expected bulk density of the loamy sand soil composition described above should be in the range of 1.6 to 1.7 g/cu. cm. Therefore, ***the recommended range for bioretention soil P-index of between 10 and 30*** corresponds to a ***phosphorus content range (mg of P to kg of soil) within the soil media of 7 mg/kg to 23 mg/kg***.

No citations or references are given for the P-index values or for how those values are somehow transformed into 7 to 23 (or 21?) mg/kg Mehlich 3 extractable P? <u>So, Why should I care?</u>

Virginia Phosphorus Index Version 1

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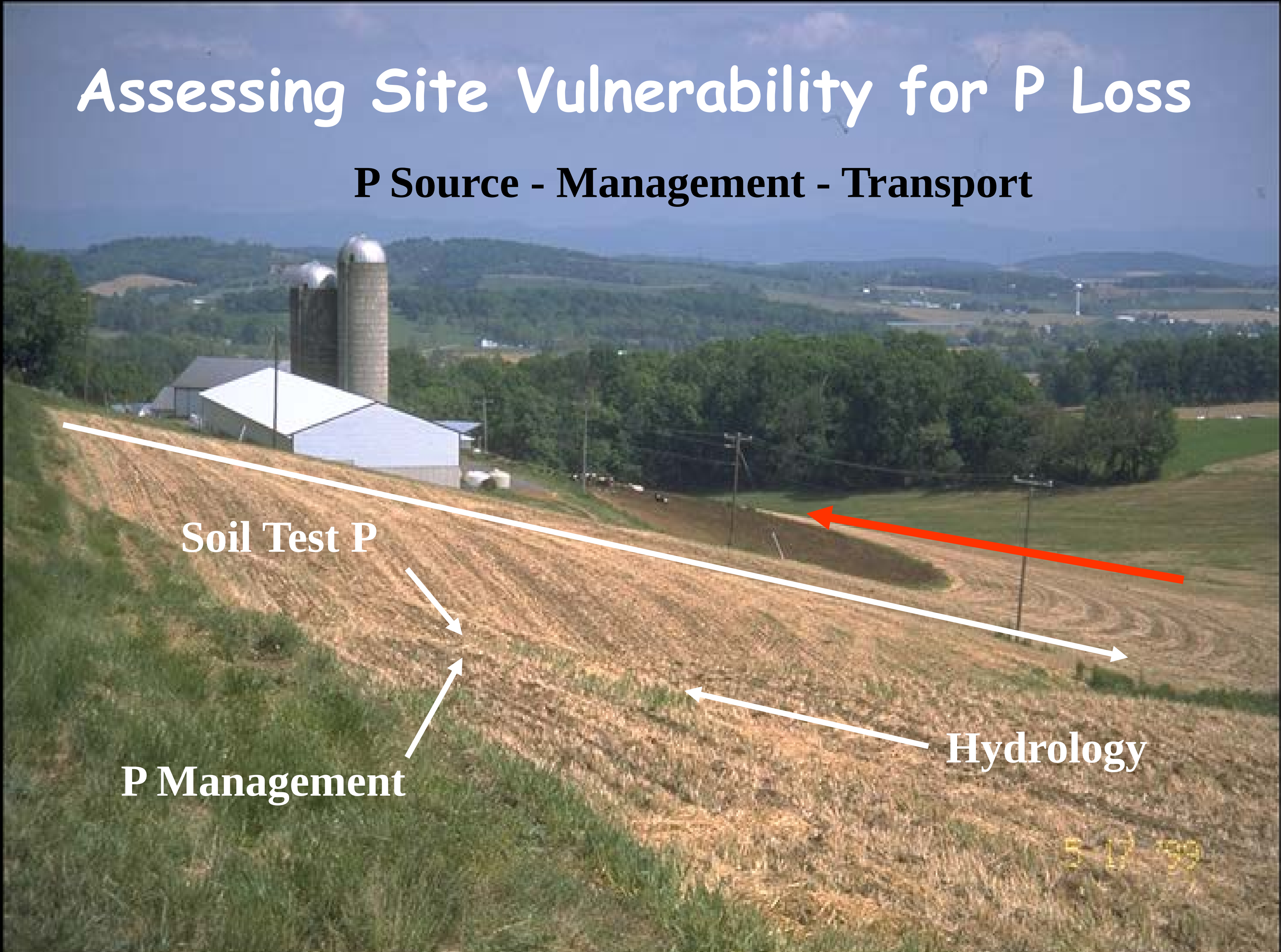
Virginia Tech

February 27, 2002

Assessing Site Vulnerability for P Loss

P Source - Management - Transport



Transport Factors

Erosion Risk Factor	=	Edge of field soil loss	X	Sediment P delivery factor	X	Sediment total P factor		
Runoff Risk Factor	=	Runoff from field	X	Runoff P delivery factor	X	Runoff DRP factor	+	Applied fertilizer DRP factor
Subsurface Risk Factor	=	Percolation	X	Soil texture/drainage factor	X	Subsurface DRP factor		

Soil texture/drainage class factor (Table 13)

Soil drainage class	Soil texture to depth of 18”		
	Coarser than loamy fine sand	**Between loamy fine sand and sandy clay loam**	**Finer than sandy clay loam**
Very poorly and poorly drained	1.0	0.75	0.50
Somewhat poorly drained	0.25	0.25	0.0
Moderately-well and well-drained	0.0	0.0	0.0

- ***Cation Exchange Capacity (CEC).*** The CEC of a soil refers to the total amount of positively charged elements that a soil can hold; it is expressed in milliequivalents per 100 grams (meq/100g) of soil. For agricultural purposes, these elements are the basic cations of calcium (Ca^{+2}), magnesium (Mg^{+2}), potassium (K^{+1}) and sodium (Na^{+1}) and the acidic cations of hydrogen (H^{+1}) and aluminum (Al^{+3}). The CEC of the soil is determined in part by the amount of clay and/or humus or organic matter present. ***Soils with CECs exceeding 10 are preferred for pollutant removal.*** Increasing the organic matter content of any soil will help to increase the CEC, since it also holds cations like the clays.

The CEC of a soil mix is determined *entirely* by the clay suite present, the reactive OM content, and the pH of the bulk soil solution. *In part?*

No method is given for CEC determination which can vary by more than 100% by differing methods for the same soil (see following slides).

CEC per se has almost nothing to do with bulk media N removal and is only indirectly related to P removal in that higher clay soils would more than likely contain Al and Fe that might sorb P and OM can bind and retain P via ternary OM-Fe-P or OM-Al-P complexes.

Table 3. Cation exchange capacity (CEC) of weathered <2mm sandstone fragments amended with four different sizes of coal as determined by 3 different methods.

Method of CEC determination	Cation exchange capacity (meq/100g)			
	Coal particle size (mm)			
	(1-2)	(.25-.5)	(.05-1)	(<.05)
NH_4OAc bases + $BaCl_2$-TEA acidity	4.69	5.26	7.40	9.34
NH_4OAc bases + KCl exch. acidity	4.00	3.95	4.51	4.29
<u>N</u> $CaCl_2$-$MgCl_2$ Exchange	3.53	3.09	3.16	3.17

CEC for Sandy Soil Ap horizons
(Fiskell & Perkins, 1970)

Soil Series	CEC (NRCS)	CEC (Bases+Al)
	meq/100 g or $cmol_c$/ kg	
Low OM soils (< 1.5%)		
Norfolk Loamy Sand (NC)	3.2	1.0
Norfolk Loamy Sand (NC)	3.8	1.5
Portsmouth Loam (VA)	22.45	5.45
Dothan Loamy Sand (NC)	2.2	0.7
Moderate OM soils (3.5 to 5%)		
Pantego Sandy Loam (FL)	13.5	6.5
Portsmouth L. Sand (VA)	13.8	6.2

Man-made "Mine Soil" in Dinwiddie Co. made from 80% sand tailings and 20% slimes (VFS, silt + clay) and 5% by weight yardwaste compost.

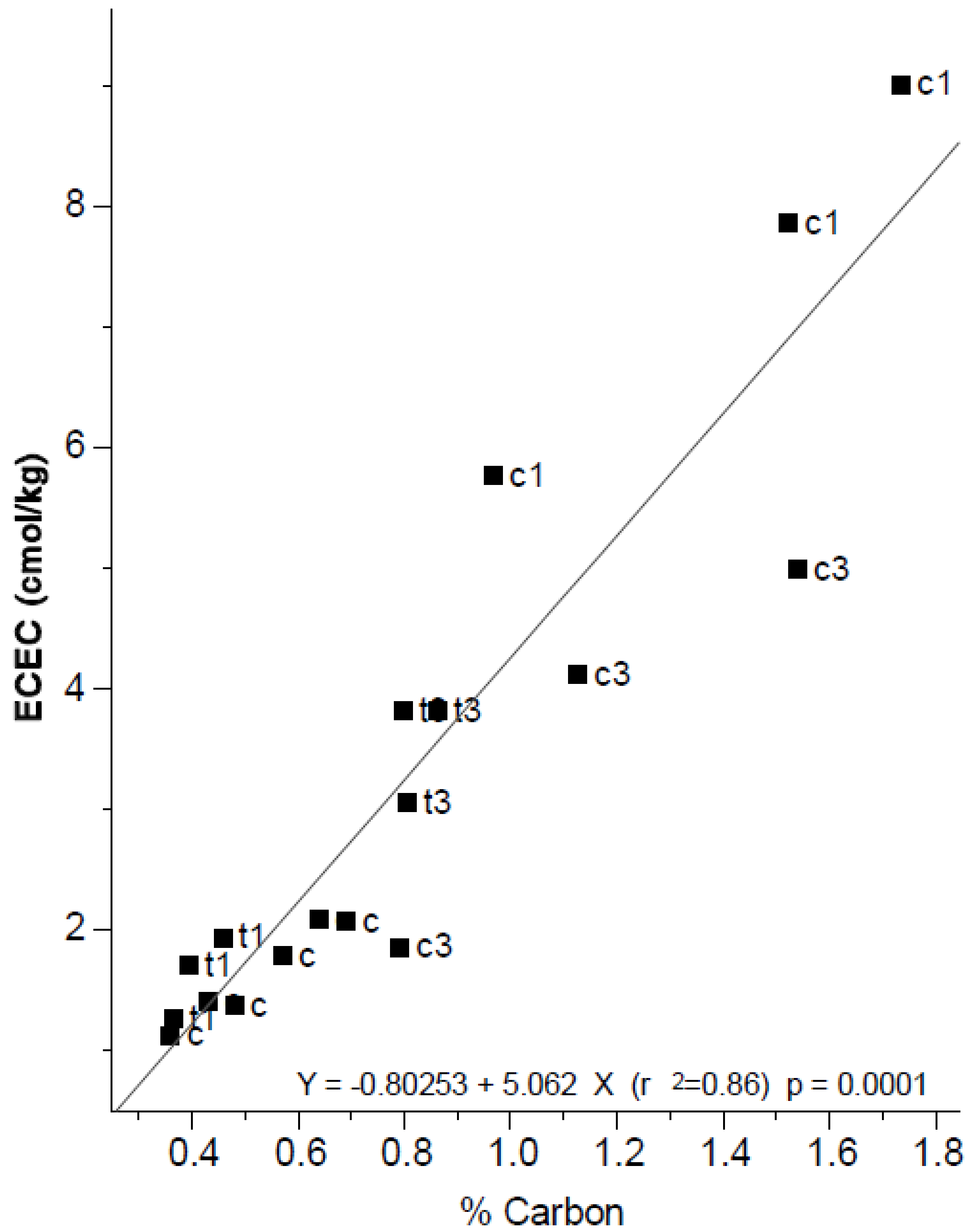
Effective CEC of sandy loam quartz mine tailings (~15 % silt + clay) amended with two treatments receiving 5% yard waste compost by weight in 1994 (Schroeder M.S., 1997).

Table 7. Effective cation exchange capacity data for samples taken from pits dug after soybean harvest(November 24, 1996). Surface indicates A horizons. Subsurface samples were not differentiated by treatment but by whether they were from undisturbed or mined areas.

Treatment	Surface ECEC (cmol kg^{-1})	Subsoil ECEC (cmol kg^{-1})
Control	1.65 b†	3.99 a‡
Pit 1 Topsoil	1.64 b	1.96 b
Pit 1 Compost	7.55 a	
Pit 3 Topsoil	3.72 a	1.89 b
Pit 3 compost	3.66 ab	

† Means followed by the same letter are not different. (P = 0.01)

‡ Means followed by the same letter are not different. (P = 0.0002)



ECEC (cmol/kg)
% Carbon
Y = -0.80253 + 5.062 X (r 2=0.86) p = 0.0001
c1
c1
c1
c3
c3
t1
t3
t3
t1
t1
t1
c
c
c
c
c3
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2
4
6
8

- *Infiltration Rate.* The bioretention soil media should have a minimum infiltration rate of 1 to 2 inches per hour (a proper soil mix will have an initial infiltration rate that is significantly higher).

- *Depth.* The standard minimum filter bed depth ranges from 24 and 36 inches for Level 1 and Level 2 designs, respectively, (18 to 24 inches for rain gardens or micro-bioretention). If trees are included in the bioretention planting plan, tree planting holes in the filter bed must be at least 4 feet deep to provide enough soil volume for the root structure of mature trees. Use turf, perennials or shrubs instead of trees to landscape shallower filter beds.

The infiltration rate is probably the most critical component of this specification and is the most loosely defined?

What happens over time as the media mix, settles, sorts, the compost decomposes, etc.?

- ***Mulch.*** A 2 to 3 inch layer of mulch on the surface of the filter bed enhances plant survival, suppresses weed growth, and pre-treats runoff before it reaches the filter media. Shredded, aged hardwood bark mulch makes a very good surface cover, as it retains a significant amount of nitrogen and typically will not float away.

- ***Alternative to Mulch Cover.*** In some situations, designers may consider alternative surface covers such as turf, native groundcover, erosion control matting (coir or jute matting), river stone, or pea gravel. The decision regarding the type of surface cover to use should be based on function, cost and maintenance. Stone or gravel are not recommended in parking lot applications, since they increase soil temperature and have low water holding capacity.

- ***Media for Turf Cover.*** One adaptation is to design the filter media primarily as a sand filter with organic content only at the top. Leaf compost tilled into the top layers will provide organic content for the vegetative cover. If grass is the only vegetation, the ratio of compost may be reduced.

Conclusions and Recommendations

For the base mix, DCR should make it very clear that all these ratios are on a weight basis. Certain vendors are adding in the OM on a volume basis. Also, the range here is very tight. If the critical issue is permeability, then I think we need some leeway in this part of the spec and more emphasis on the permeability testing instead.

Conclusions and Recommendations

DCR needs to specify the sand size to some extent. There's a huge difference between a coarse sand and very fine sand in the USDA system, but they are all "sand".

DCR needs to consider whether or not sand sized mica flakes above some level (5 to 10%?) pose a concern or not. They will report in a PSA as sand, but they will not hold open the macropores or resist compaction and settling like angular quartz sand does.

Conclusions and Recommendations

For the OM component, DCR needs to specify whether they mean 3 to 5 % soil organic matter (humus) and which analytical technique (LOI, C-furnace, Walkely-Black etc.) should be used to estimate it. For example, if you add 5% compost by weight, that would probably only bump up the actual % OM content of the soil by 1 to 2% due to a number of factors. Compost is typically up to 50% mineral by weight and much of the OM in it is not humified.

There's nothing in the specification to preclude the use of biosolids etc. as long as you can keep the bulk P under 23? Why not papermill sludge?

Conclusions and Recommendations

DCR has recognized that the P-index is not applicable here, but local county level inspectors and private sector providers may not have received that guidance?

It's also good that DCR has specified the P extractant to use (Mehlich 3 is fine), but they still need to tie down where that range of 7 to 23 mg/kg comes from? I agree it's reasonable, although 7 may be a little low for long term plant growth if the system is not receiving influent P in stormwater.

FYI: the older guidance had some *really strange* language about "150 units of P". The unit was totally unspecified. So, even "wart and all", this is much, much better.

Conclusions and Recommendations

The CEC specification here of 10 has more problems than I could begin to discuss in this 30 minute talk. First of all, it's just about impossible to get a CEC of 10 in loamy sand soil, even with 3 to 5% OM. Secondly, you have got to specify which CEC technique you are going to use. For a given soil, the measured CEC can easily vary by 100% or more, all depending on which method you use.

As an aside, the values for CEC you get from VT and A&L are not an actual CEC method at all, but are simply multiplied out of the Mehlich 1 or 3 extracts plus the buffer acidity values.

Conclusions and Recommendations

Overall, for better or <u>worse</u>, what is happening on the local level is that the county level regulatory folks enforcing the specs are treating the current values for texture, CEC etc. as if they are *<u>set in stone</u>* rather than guidance. I think that issue needs to be dealt with as well?

Conclusions and Recommendations

What is very clear here is that the soil specifications here were not reviewed by anyone with adequate professional training in basic soil science?

How did that happen? What happened in the regulatory review process? Maybe we (soil scientists) are to blame?

Disclaimer #2 Again!

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