Soil Design for Stormwater

Soil Performance in Green Stormwater Infrastructure Systems Symposium

May 25, 2016

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President, Craul Land Scientists

Soil Properties

The stuff that makes a soil the
"Elixir of Life"

OR

"The cause of failure"

Soil Resource		Requirements	
		Min	Max
Oxygen in soil atmosphere (for root survival)		3%	21%
Air pore space (for root growth)		25%	60%
Soil bulk density of the surface 24”		-	93.6 lbs/ft^3 (clays) 109.3 lbs/ft^3 (sands)
Penetration resistance (moist)‡		50 lbs/in^2	275 lbs/in^2 (clays) 300 lbs/in^2 (sands)
Water content		12%	40%
Temperature limits for roots and soil biology		40°F/4°C	94°F/34°C
Soil pH		5.5	7.5
Soil Cation Exchange Capacity (CEC) of the surface 6”		8 meq/100g	>10 meq/100g
Soil organic matter content of surface 6” only		3%	10%
Soil organic matter content of subsoil		-	<1%
Soil coarse fragment content of the surface 6” (rocks etc. >75mm)		-	<20%

Source: developed from Coder, 2000 and Craul, 2006
‡ see Soil texture table from Urban Soil Quality, USDA-NRCS for greater detail

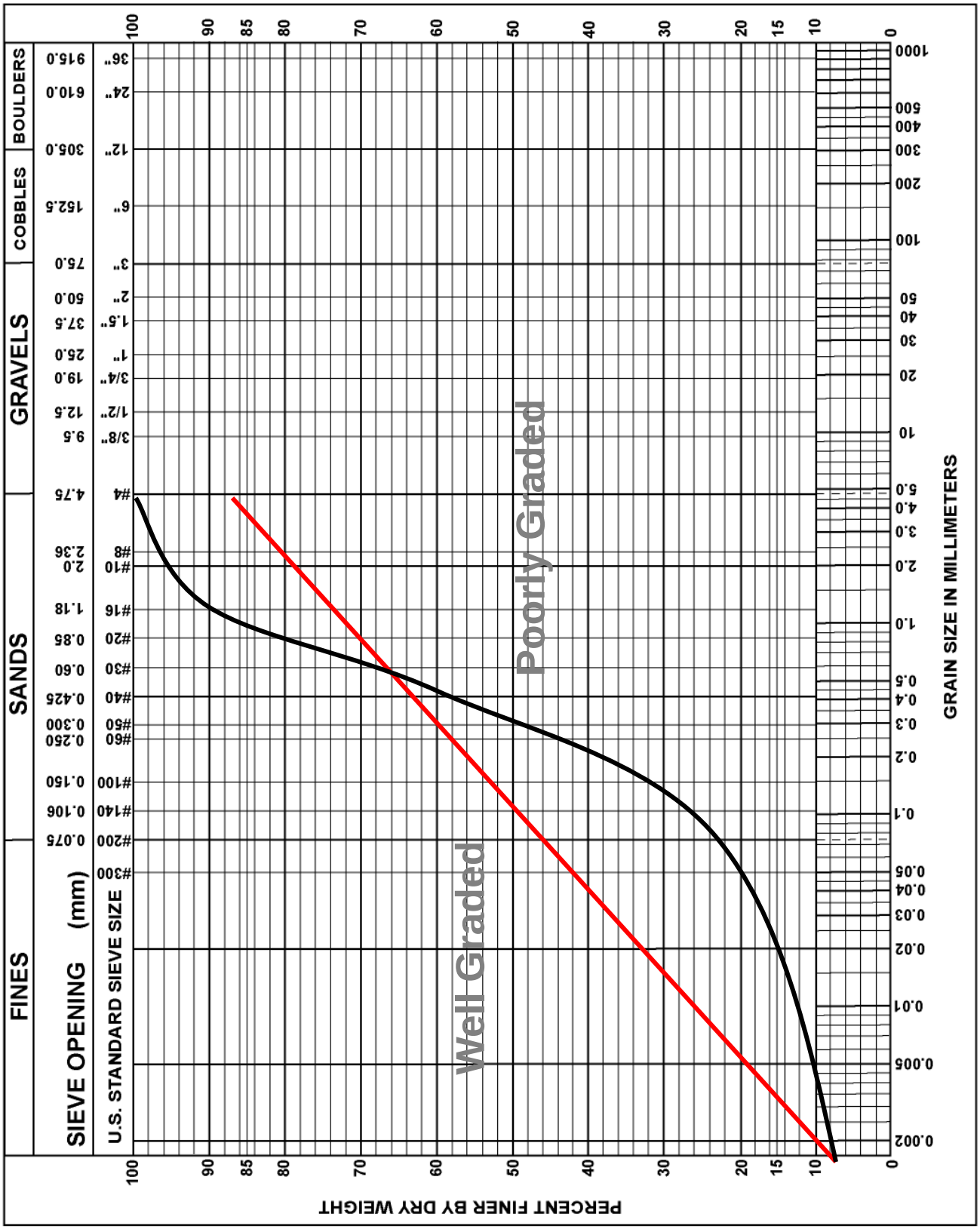
Particle Size Distribution

- Particle size distribution in urban soils is much more important than soil texture.
- There can be soils with the same soil textures, but extremely different reactions to outside forces usually induced by humans.
- Particle size distribution is a plot of the percent of various particle sizes.

PARTICAL SIZE DISTRIBUTION

Project Name: _____

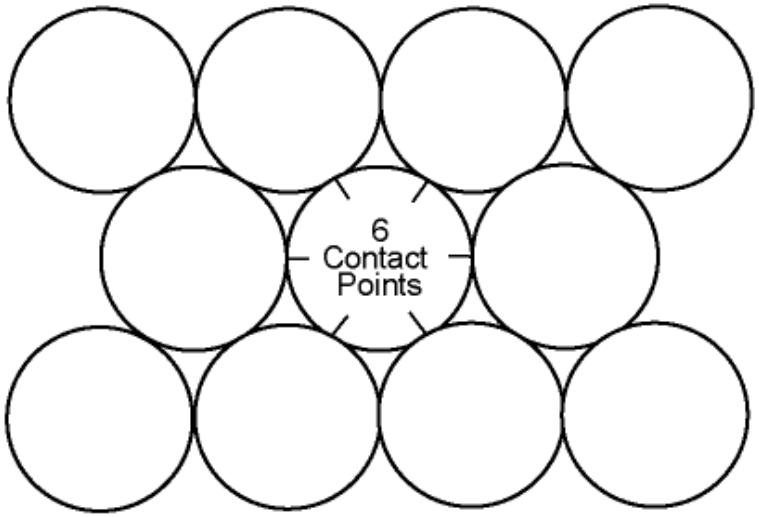
Calculated By: _____ **for:** _____ **Date:** _____



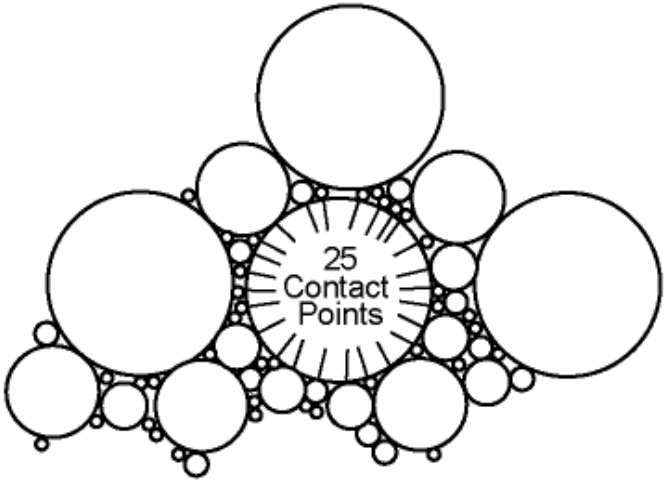
Revised by Timothy A. Craul, CPSSc

Revised from SCS-ENG-130

The Packing Model



Uniformly or Poorly Graded Soil

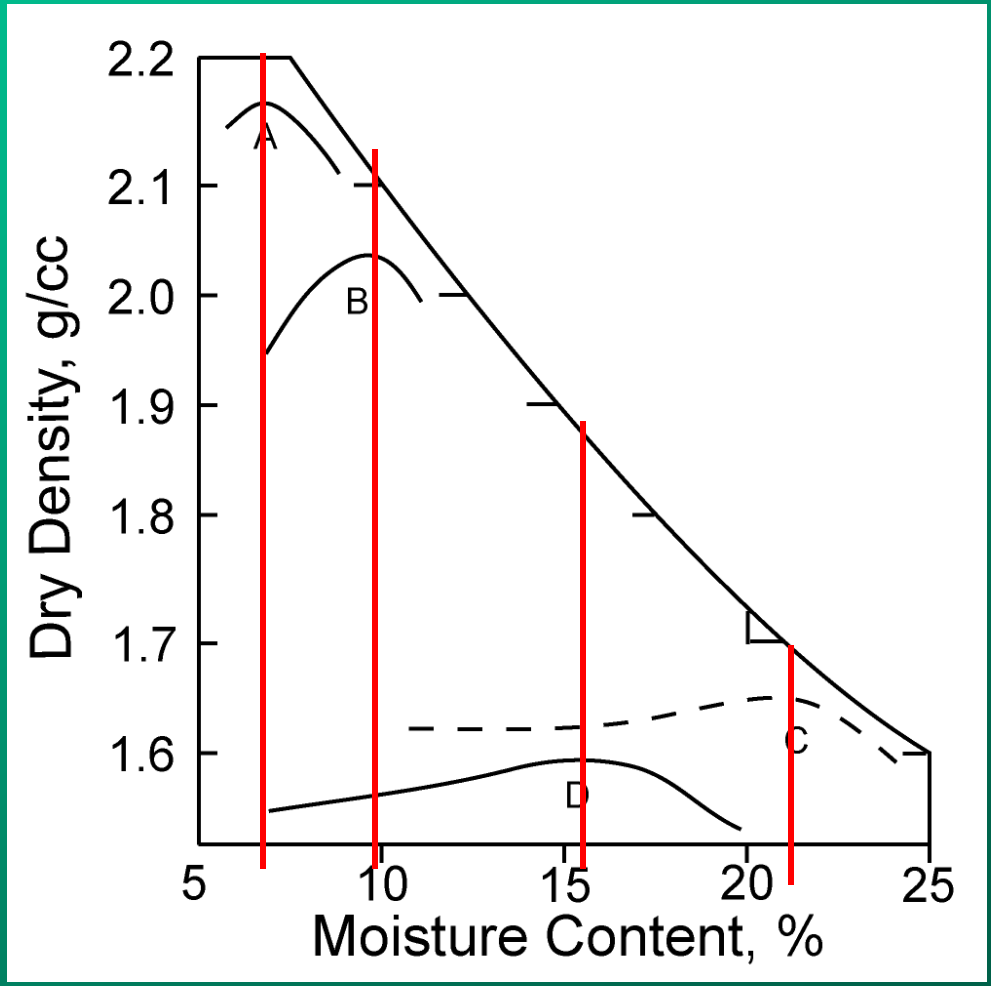


Well Graded Soil

- If you consider the number of contact points between the various distributions, the more contacts, the more dense the soil can become.
- Therefore, not all soil textures are created equally.

Proctor Compaction

- “A” and “B” are soils with well graded particle size distributions
- “C” and “D” are poorly graded particle sizes with significant amounts of sand sized particles.



Holtz and Kovacs, 1981

SOIL INFILTRATION PROPERTIES

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Soil Structure

Granular Structure typically found under grasses.

Subangular Blocky Structure typically found within ‘B’ horizons.

Landuse	Series	Horizon	Range In/hr	Percent decrease from Woodland Infiltration
Woodland	Glenelg	Topsoil	7.20 – 12.41	-
	Glenelg	Subsoil	2.30 – 9.23	-
Crops (rot)	Glenelg	Topsoil	2.20 – 3.81	69%
	Glenelg	Subsoil	0.20 – 2.47	91% - 73%
Hay (cont)	Glenelg	Topsoil	0.21 – 1.93	97% - 84%
	Glenelg	Subsoil	1.30 – 9.60	43% - (+4%†)
Urban (new)	Glenelg	Topsoil	0.32 – 0.52	96%
	Glenelg	Subsoil	0.04 – 0.49	98% - 94%
Urban (mid)	Glenelg	Topsoil	2.70 – 5.58	66% - 55%
	Glenelg	Subsoil	0.21 – 0.55	91% - 94%
Urban (old)	Glenelg	Topsoil	5.30 – 34.29	26% - (+3%†)
	Glenelg	Subsoil	0.22 – 16.00	90% - (+73†)

White and Chibirka, USDA-NRCS, 2006
†Soil structure, material and/or density variations

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Urban Soil Profiles at Princeton

Pit #	Sample #	Core Sample Depth (in)	Ksat (in/hr)	Predicted Ksat (in/hr)	Dry Bulk Density (g/cc)	Bulk Density @ Field Capacity (g/cc)	Moisture Content @ Field Capacity (%)	Pore Space (%)
1	H-1	12	5.64	1.319	1.40	1.72	18.0	47.2
	H-2	22	0.05	0.470	1.60	1.88	9.3	39.6
	H-3	39	0.03†	0.097†	1.78	2.05	8.5	32.8
2	E-1	4	2.73	0.963	1.45	1.88	23.3	45.3
	E-2	20	0.03	0.059†	1.81	2.13	10.0	31.7
	E-3	37	0.02†	0.166	1.63	2.05	13.4	38.5
3	F-1	4	7.50	1.824	1.28	1.62	18.0	51.7
	F-2	23	0.02†	0.057†	1.79	2.10	9.7	32.5
5	G-1	4	0.17	0.759	1.52	1.80	15.6	42.6
	G-2	20	0.00†	0.038†	1.93	2.21	8.2	27.2
	G-3	32	0.40	0.481	1.56	1.94	12.6	41.1

† Most Restrictive Transmissive Layer for HSG

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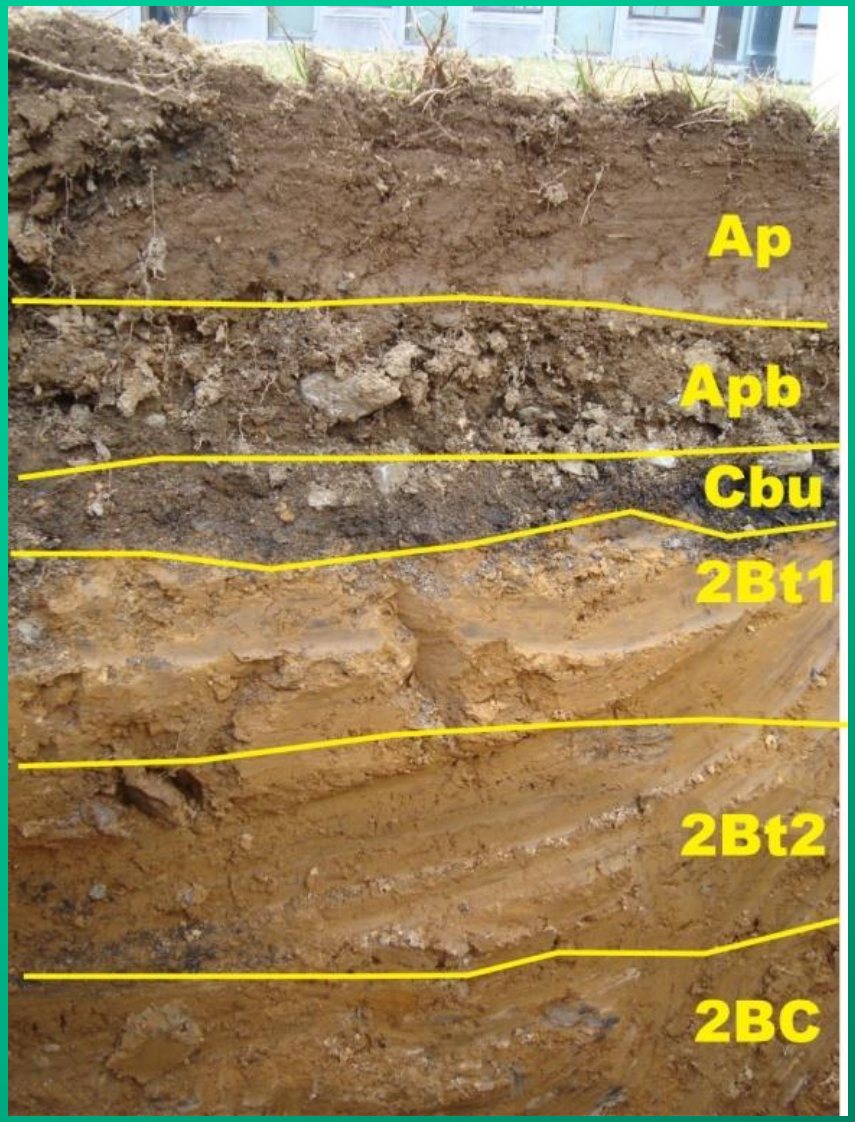
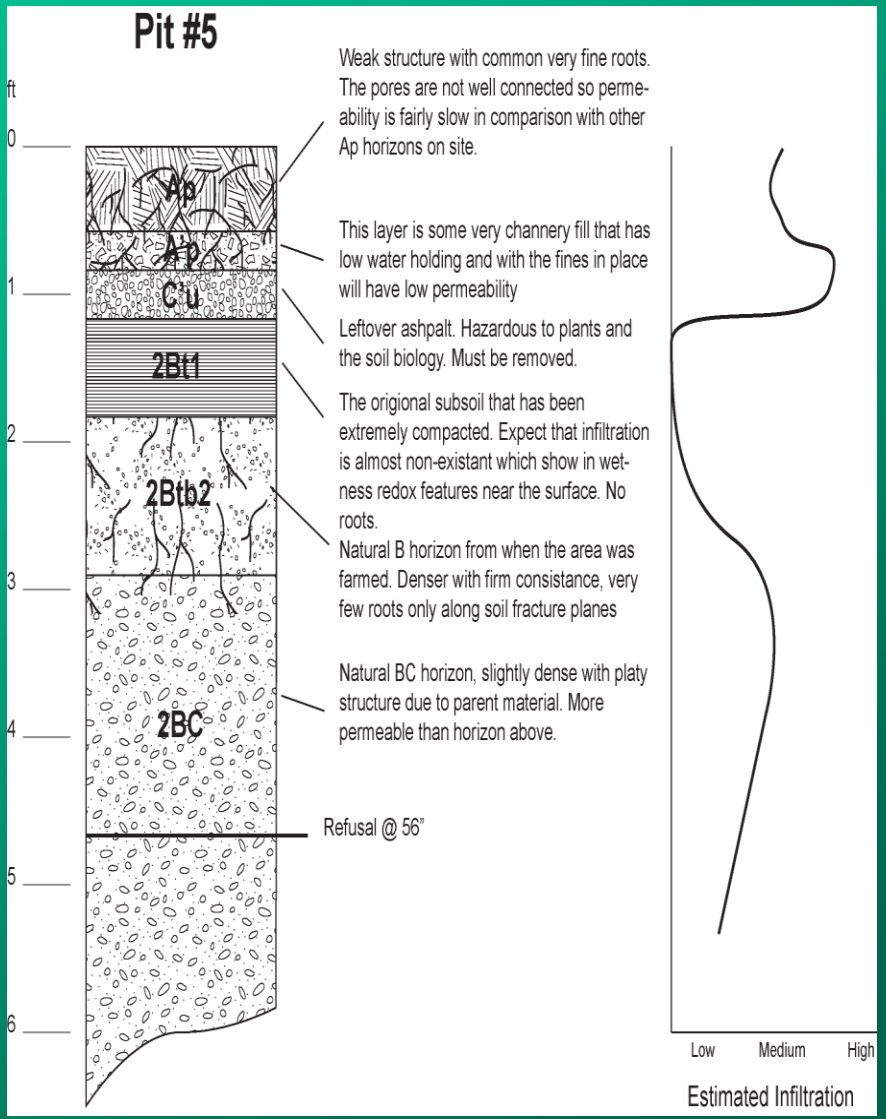
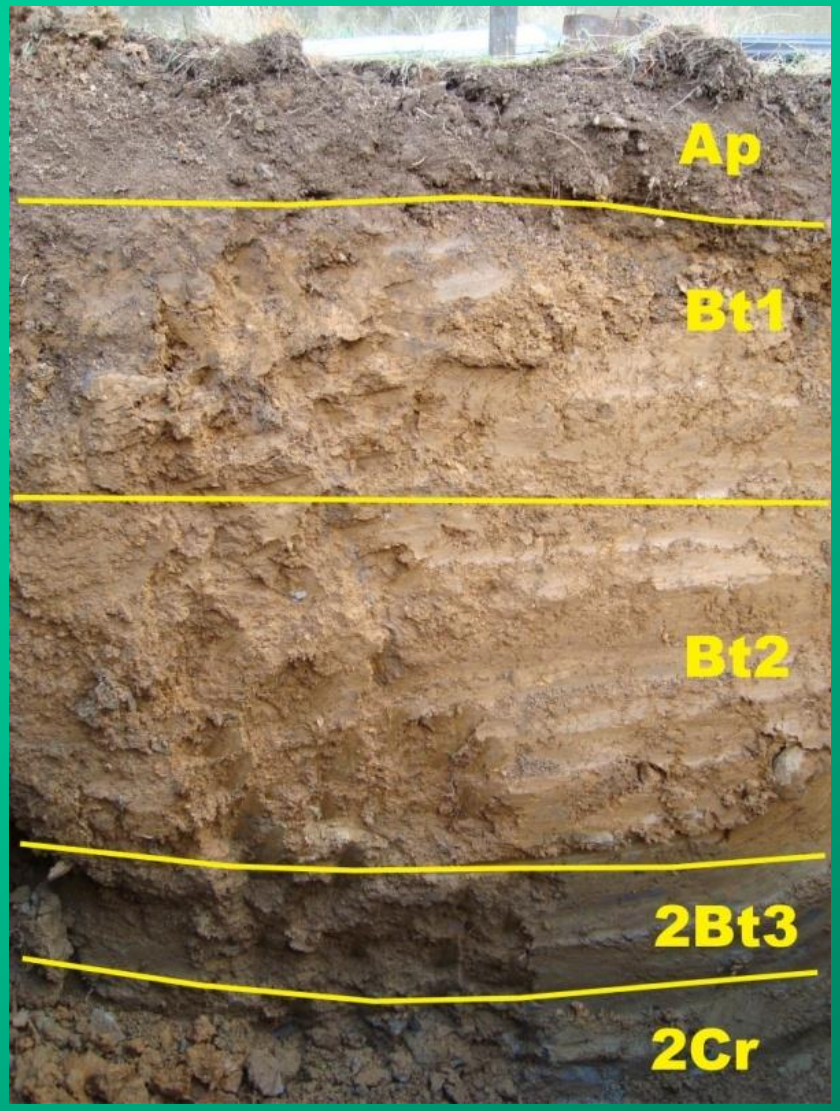
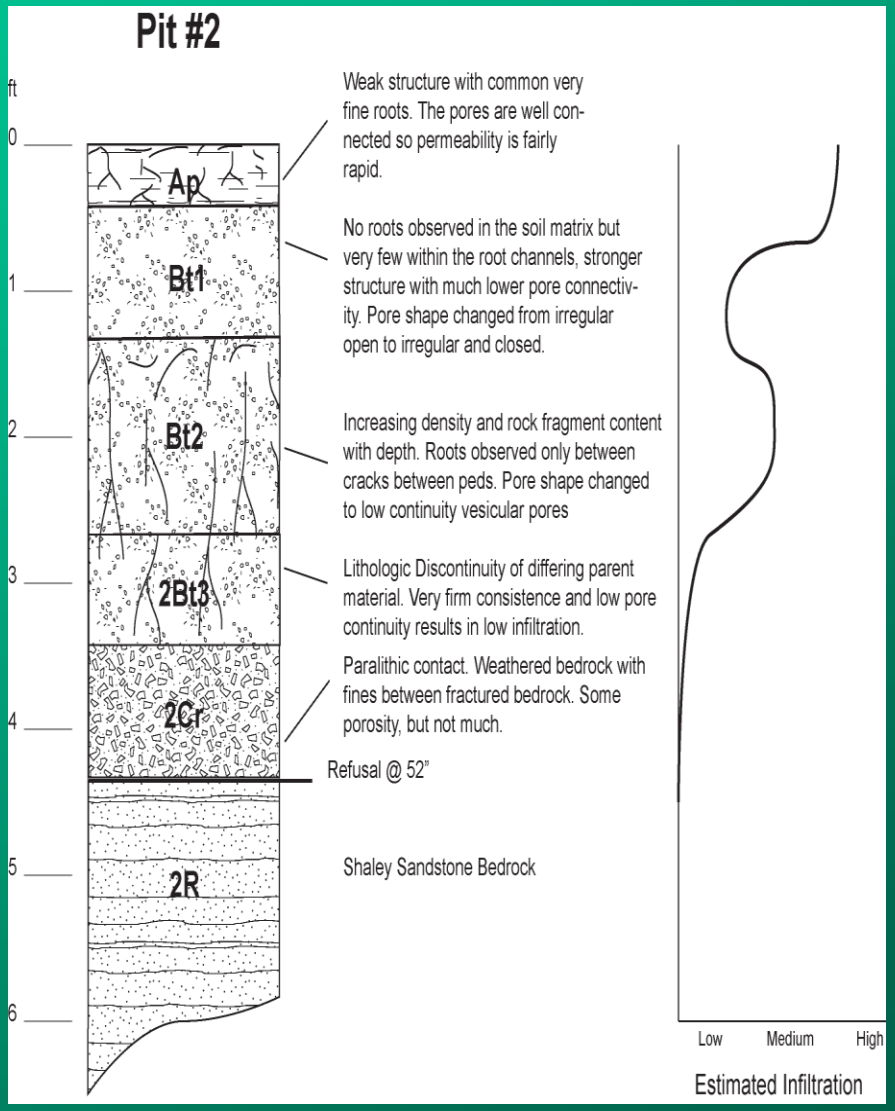
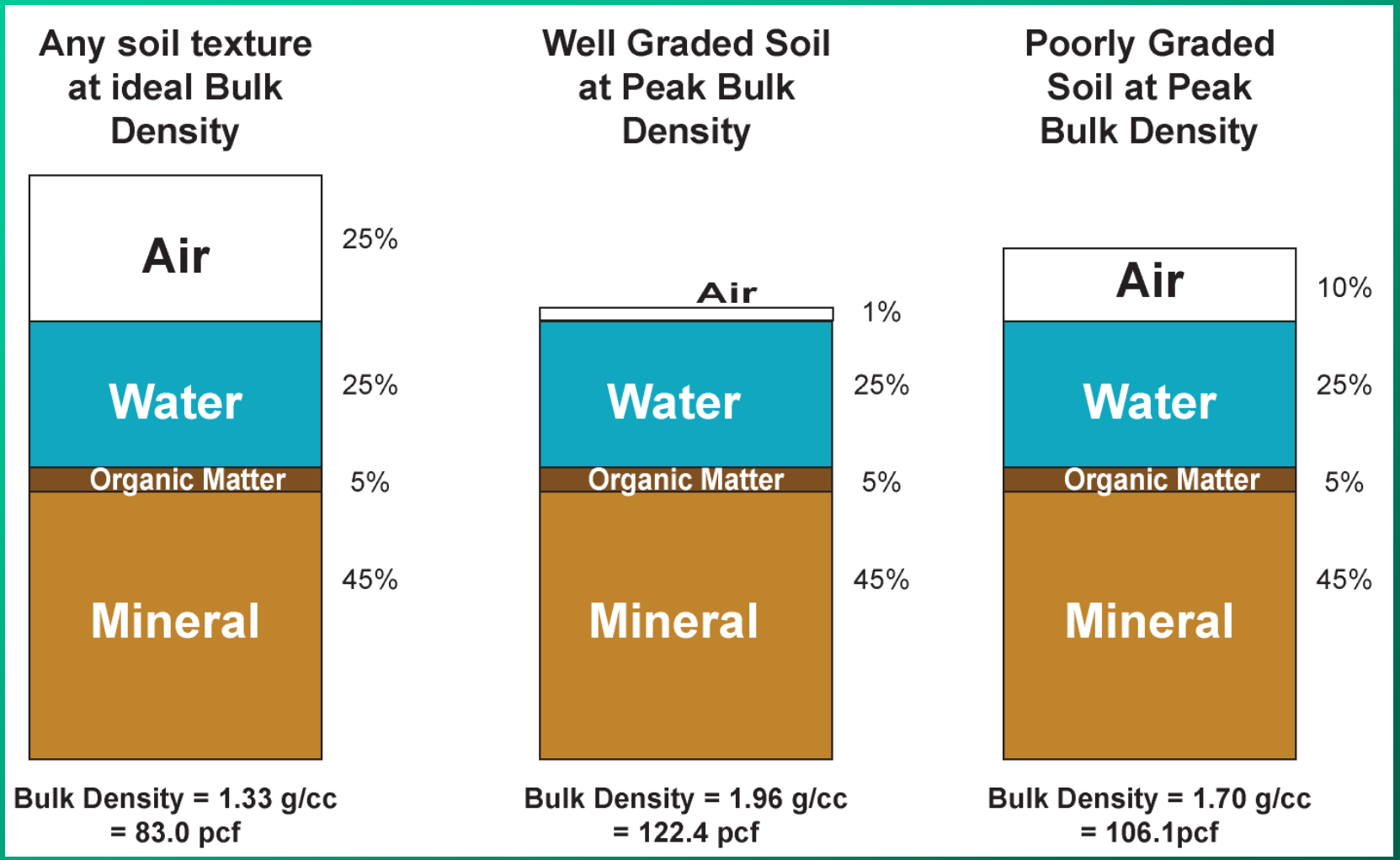

Ap
Apb
Cbu
2Bt1
2Bt2
2BC

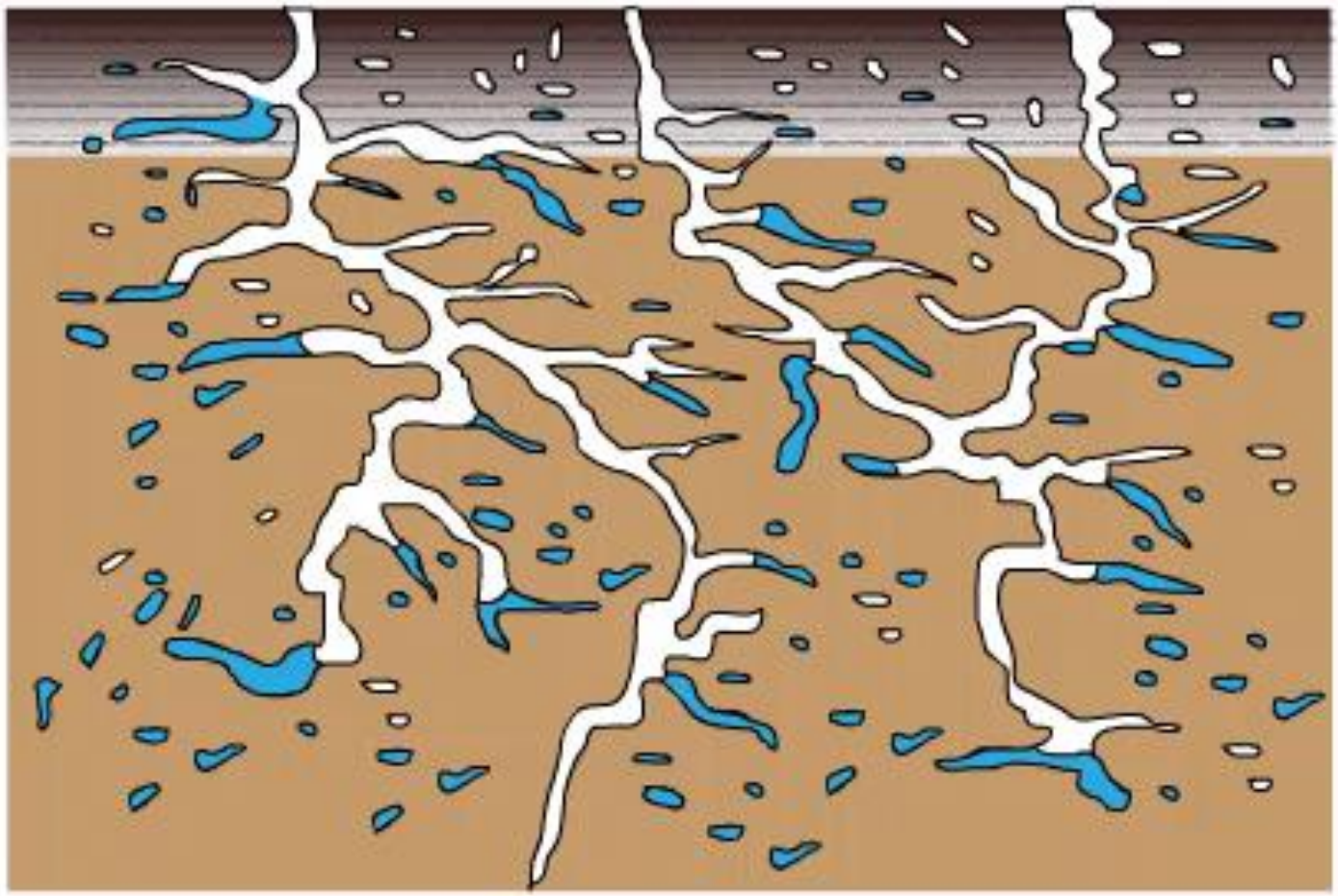

Pit #5
ft
0
1
2
3
4
5
6
Ap
Apb
Cbu
2Bt1
2Btb2
2BC
Weak structure with common very fine roots. The pores are not well connected so permeability is fairly slow in comparison with other Ap horizons on site.
This layer is some very channery fill that has low water holding and with the fines in place will have low permeability
Leftover ashpalt. Hazardous to plants and the soil biology. Must be removed.
The origional subsoil that has been extremely compacted. Expect that infiltration is almost non-existant which show in wetness redox features near the surface. No roots.
Natural B horizon from when the area was farmed. Denser with firm consistance, very few roots only along soil fracture planes
Natural BC horizon, slightly dense with platy structure due to parent material. More permeable than horizon above.
Refusal @ 56"
Low
Medium
High
Estimated Infiltration

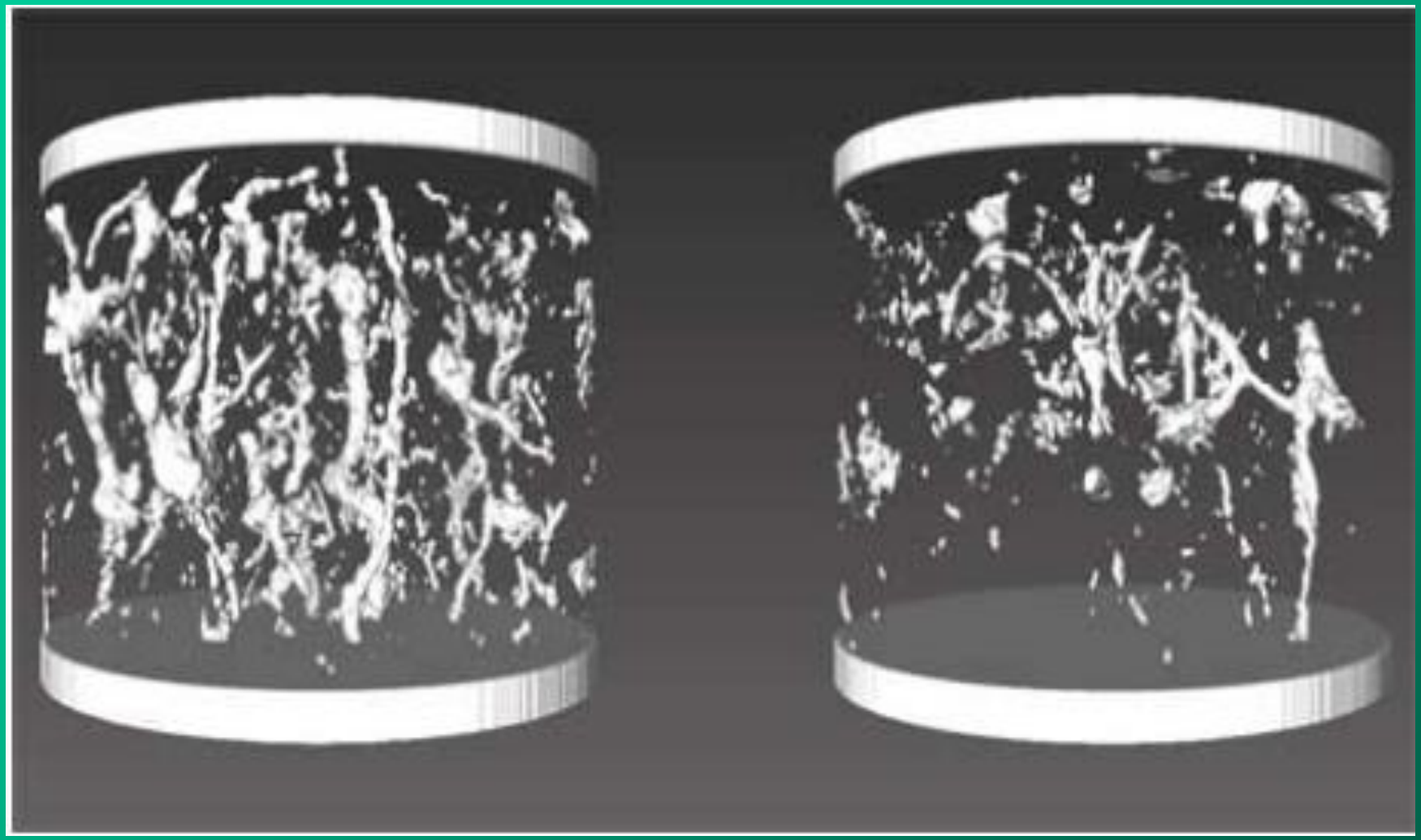

Ap
Bt1
Bt2
2Bt3
2Cr


Pit #2
ft
0
1
2
3
4
5
6
Ap
Bt1
Bt2
2Bt3
2Cr
2R
Weak structure with common very fine roots. The pores are well connected so permeability is fairly rapid.
No roots observed in the soil matrix but very few within the root channels, stronger structure with much lower pore connectivity. Pore shape changed from irregular open to irregular and closed.
Increasing density and rock fragment content with depth. Roots observed only between cracks between peds. Pore shape changed to low continuity vesicular pores
Lithologic Discontinuity of differing parent material. Very firm consistence and low pore continuity results in low infiltration.
Paralithic contact. Weathered bedrock with fines between fractured bedrock. Some porosity, but not much.
Refusal @ 52"
Shaley Sandstone Bedrock
Low
Medium
High
Estimated Infiltration

Pore Space


Any soil texture at ideal Bulk Density
Air
Water
Organic Matter
Mineral
25%
25%
5%
45%
Bulk Density = 1.33 g/cc = 83.0 pcf
Well Graded Soil at Peak Bulk Density
Air
Water
Organic Matter
Mineral
1%
25%
5%
45%
Bulk Density = 1.96 g/cc = 122.4 pcf
Poorly Graded Soil at Peak Bulk Density
Air
Water
Organic Matter
Mineral
10%
25%
5%
45%
Bulk Density = 1.70 g/cc = 106.1pcf





M. Lamandé, et.al 2013

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Estimated Water Retention

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814/867-5086

$$\theta(h) = \theta_r + \frac{\theta_s - \theta_r}{[1+(\alpha h)^n]^{1-1/n}}$$

van Genuchten (1980)

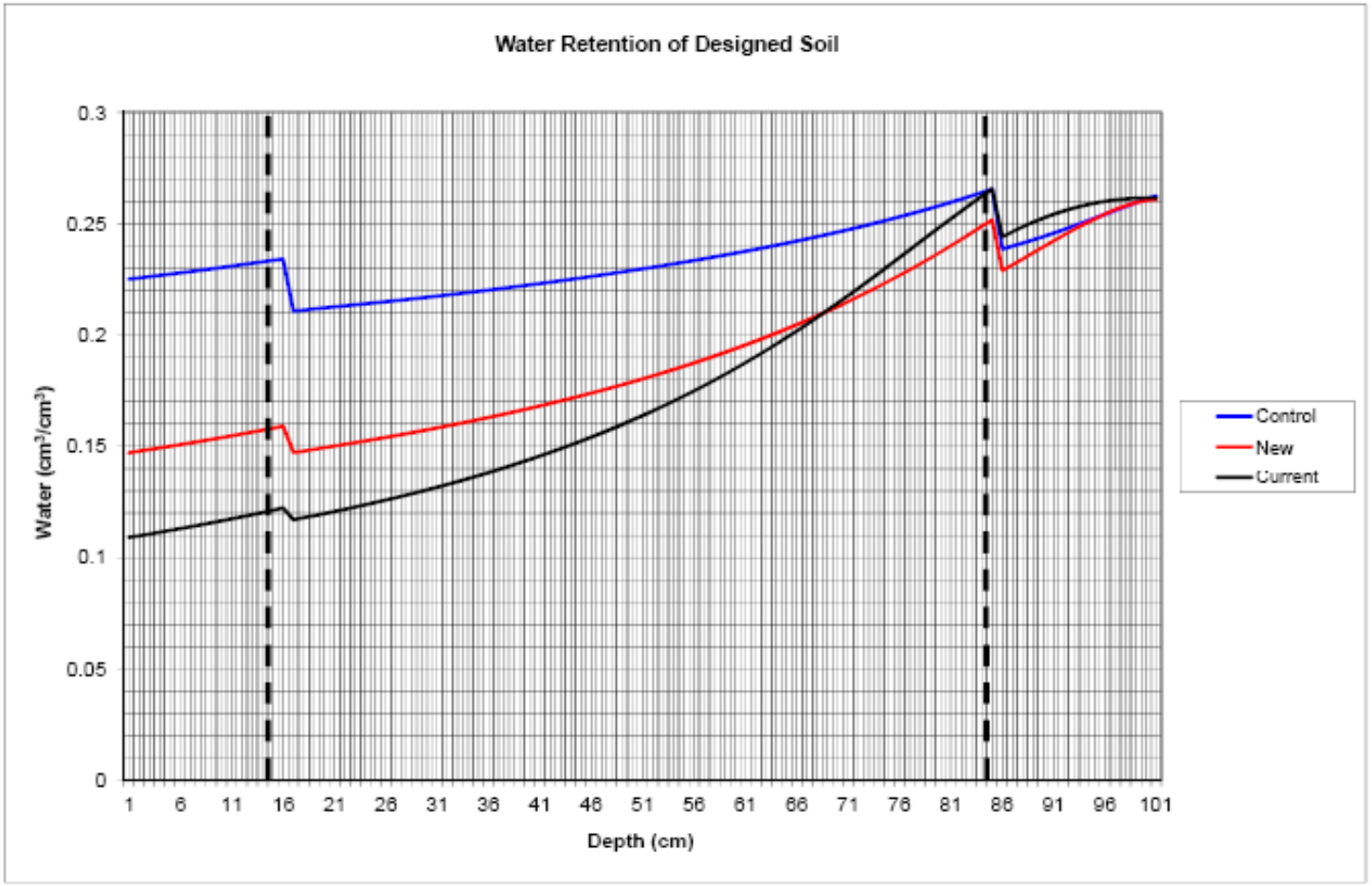
Description: Total Water Retention for Entire Profile

Average Water Held Under Steady State

Water Held Ap	0.229656
Water Held B	0.173851
Water Held C	0.247355
Total (percent)	17.58621

This chart shows the variation between the three mixes if the soil profile is uniform with no variations in compation assuming that the soils all compact equally. Which they do not.

The upper depth is run at a BD of 1.65 g/cc, the next depth from 15 cm to 83 cm was run at 1.85g/cc and the lower depth was run at 2.0 g/cc



Control = 62.2% Sand, 26.5% silt, 11.3% clay
New = 81% sand, 12% silt, 7% clay
Current = 91.1% sand, 3.2% silt, 6.7% clay

Estimated Water Retention

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$$\theta(h) = \theta_r + \frac{\theta_s - \theta_r}{[1+(\alpha h)^n]^{1-1/n}}$$

van Genuchten (1980)

Description: Total Water Retention for Entire Profile

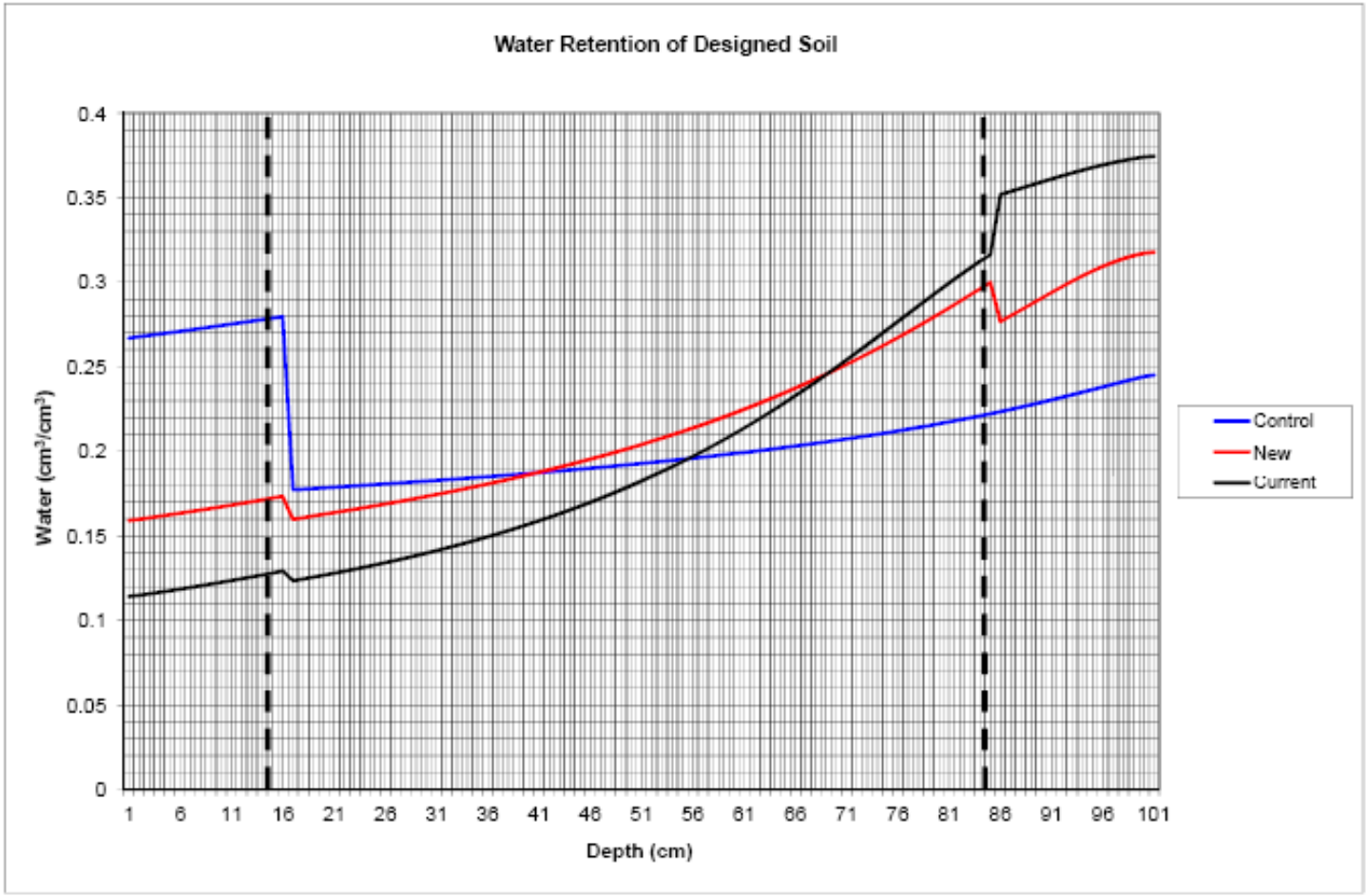
Average Water Held Under Steady State

Water Held Ap	0.273557
Water Held B	0.195446
Water Held C	0.300584
Total (percent)	20.33888

This graph shows what happens when each mix is compacted to its maximum density just below the surface.

The "Control" mix actually has less total water retention in the entire soil profile than the sand based mixes.

The "control" went from 1.4 g/cc in the surface to 2.1 g/cc in the next two layers. Since the sand based soils do not compact above 1.75 g/cc they hold more water within the entire soil profile.



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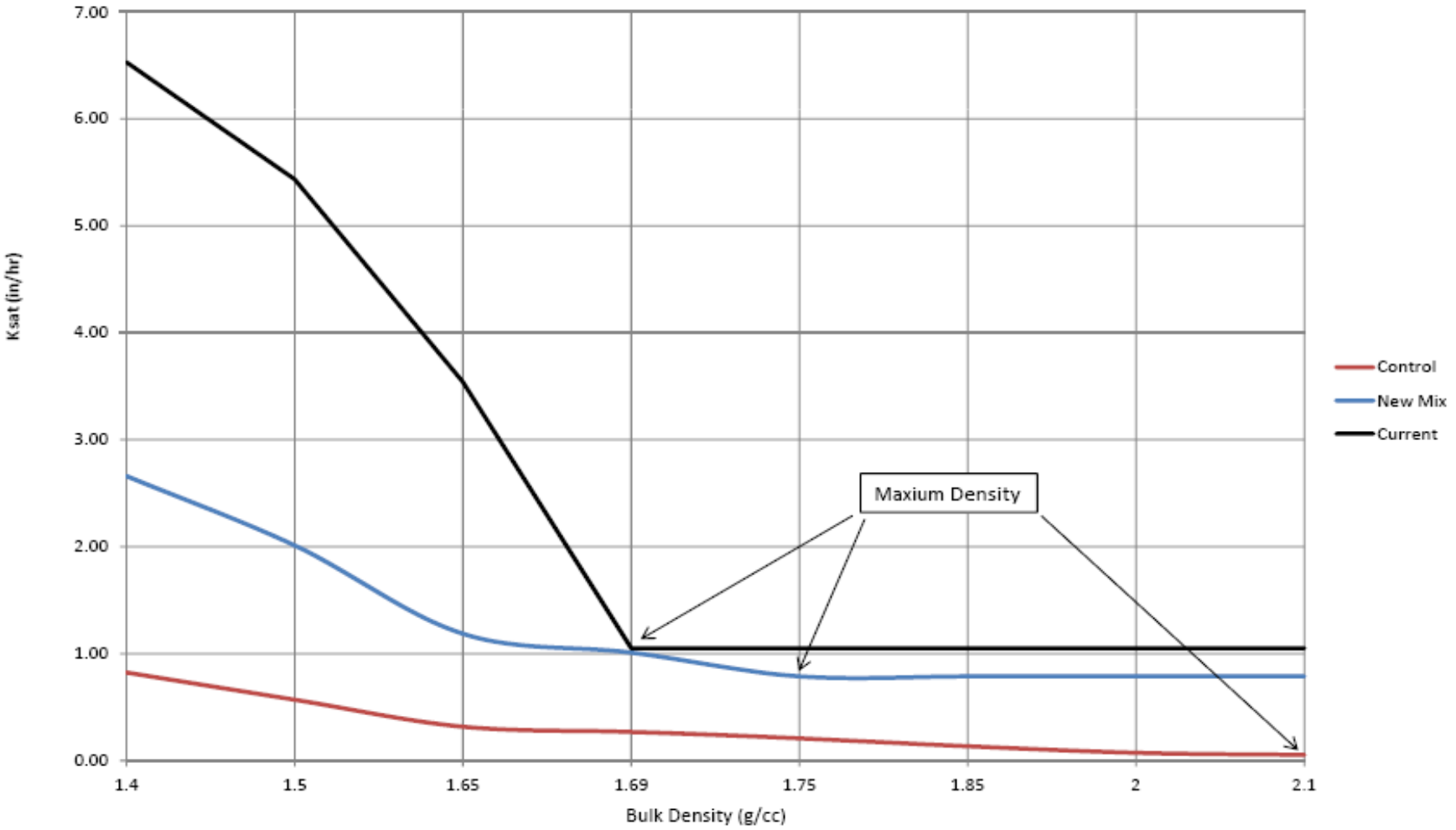
Saturated Hydraulic Conductivity vs. Density



Control = 62.2% Sand, 26.5% silt, 11.3% clay
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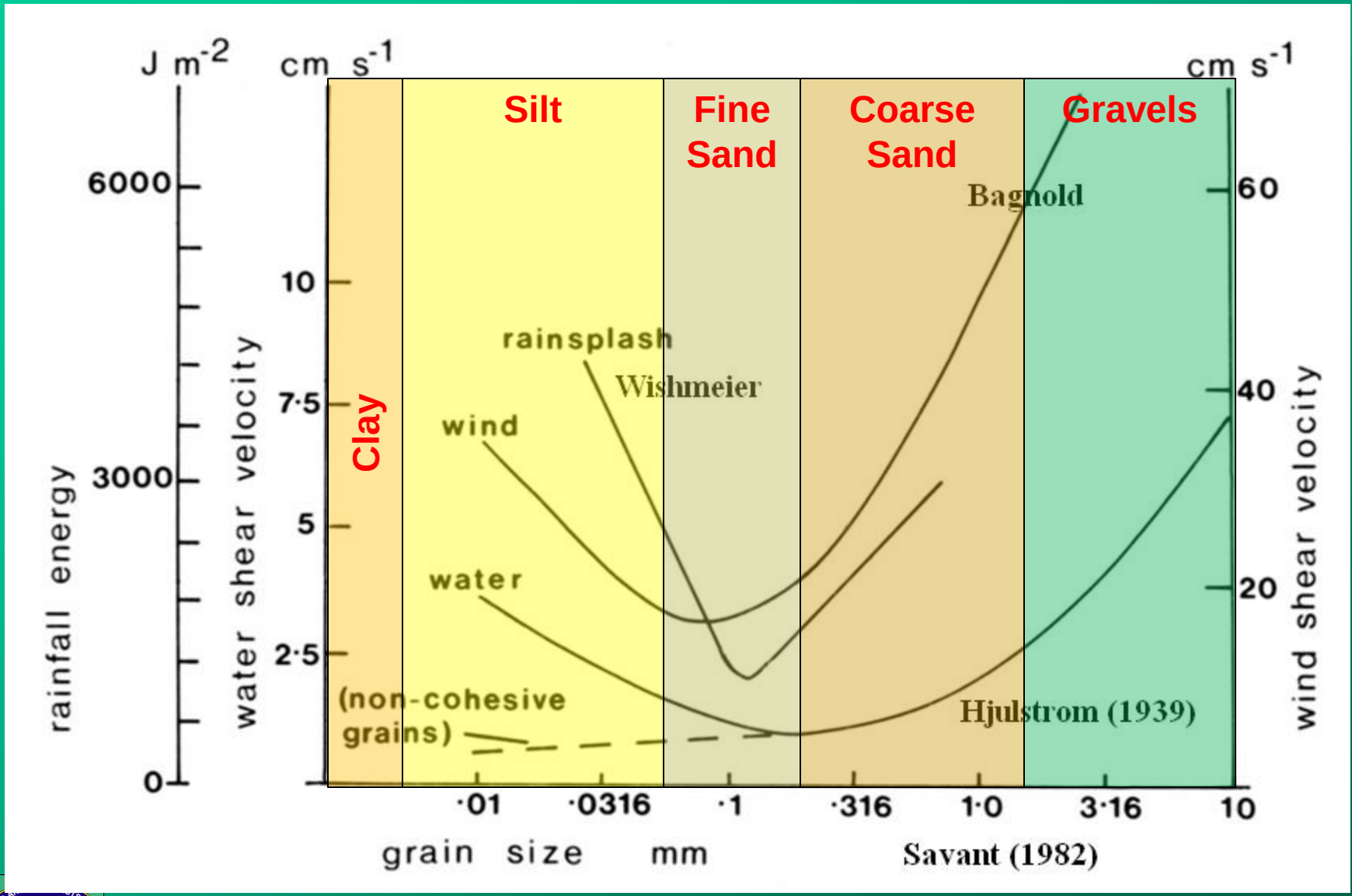
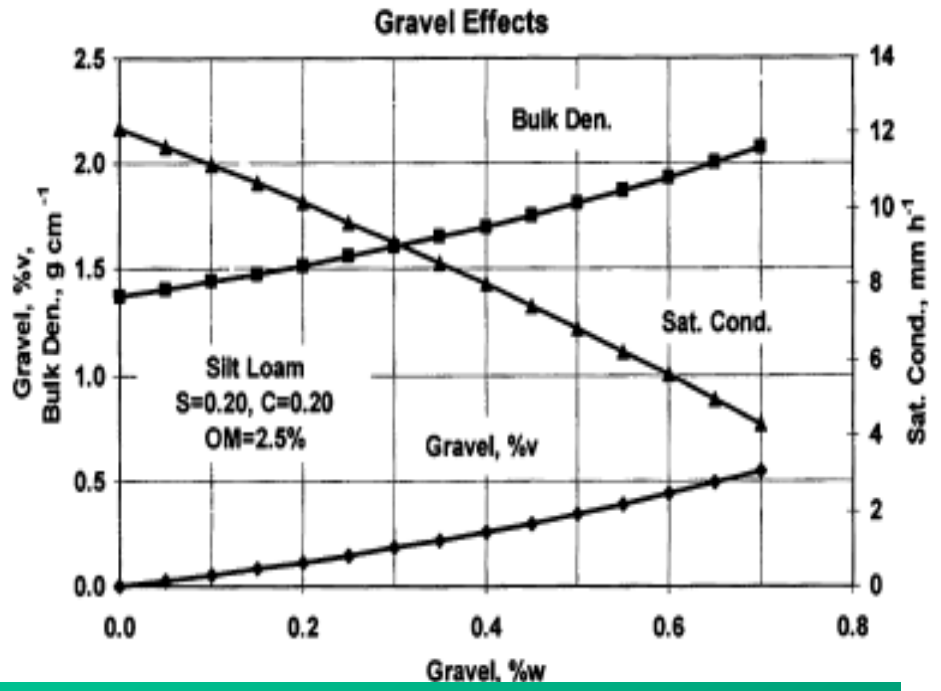
Current = 91.1% sand, 3.2% silt, 6.7% clay

SOIL EROSION



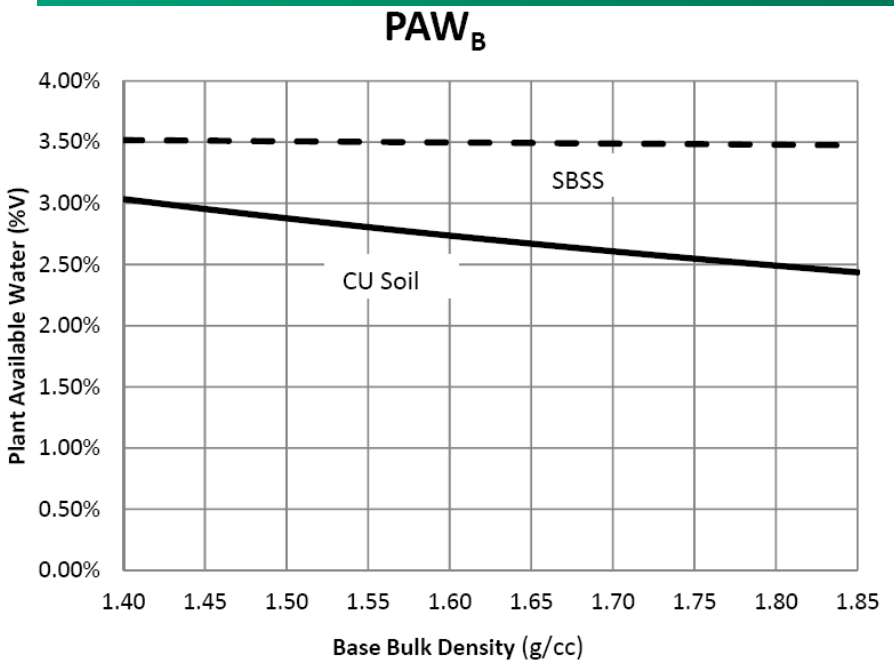


(Saxton & Rawls, 2006)

Coarse Fragment Content on Saturated Conductivity

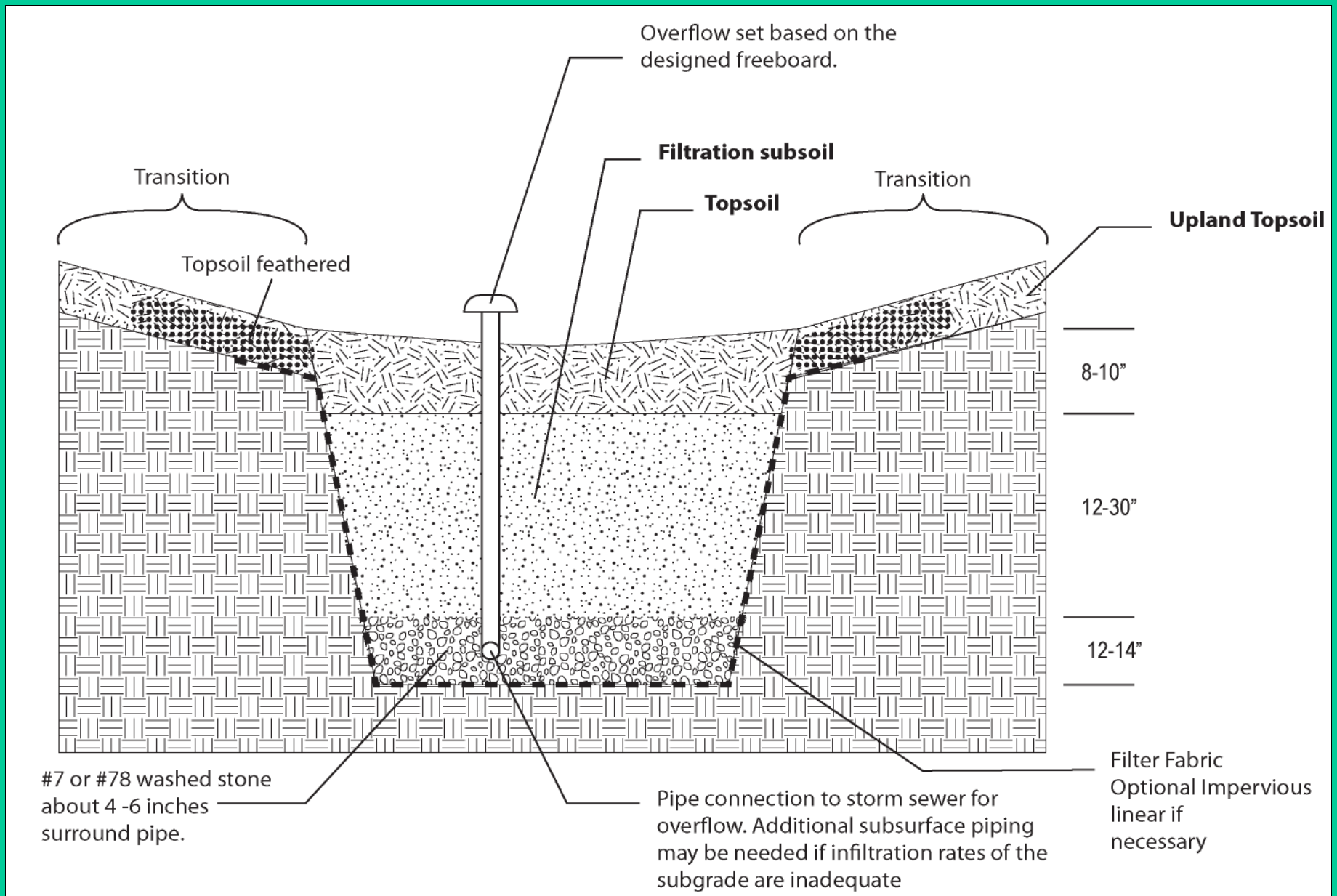
Estimated Plant Available Water

for bulk soil of CU soil with a clay loam and 86% coarse fragments versus a SBSS sand with 6.9% coarse fragments over a range of bulk densities.



Rain Gardens

CASE STUDIES



Infiltration Rain Garden Profile

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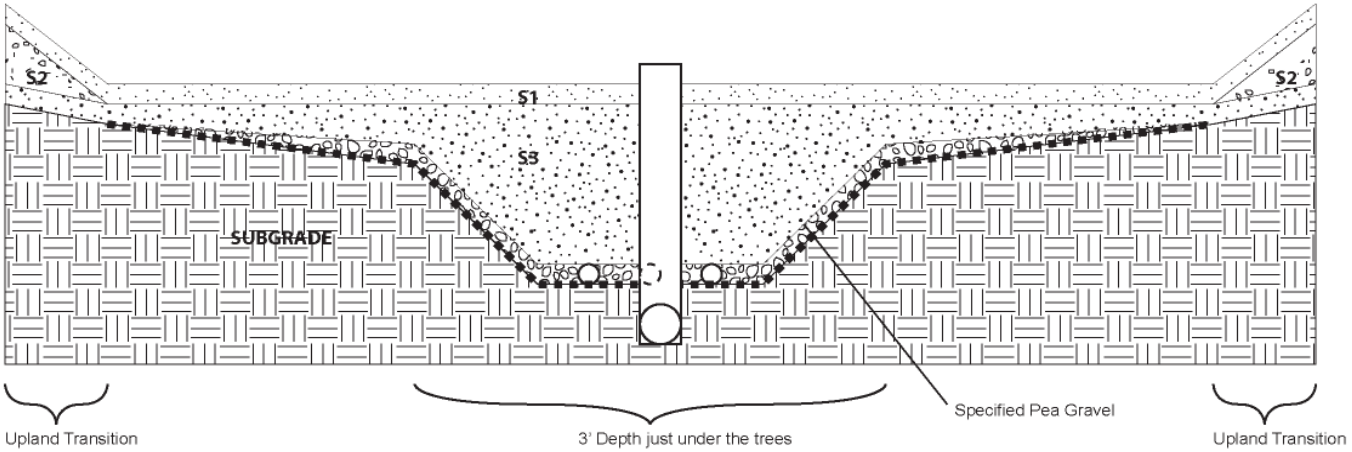
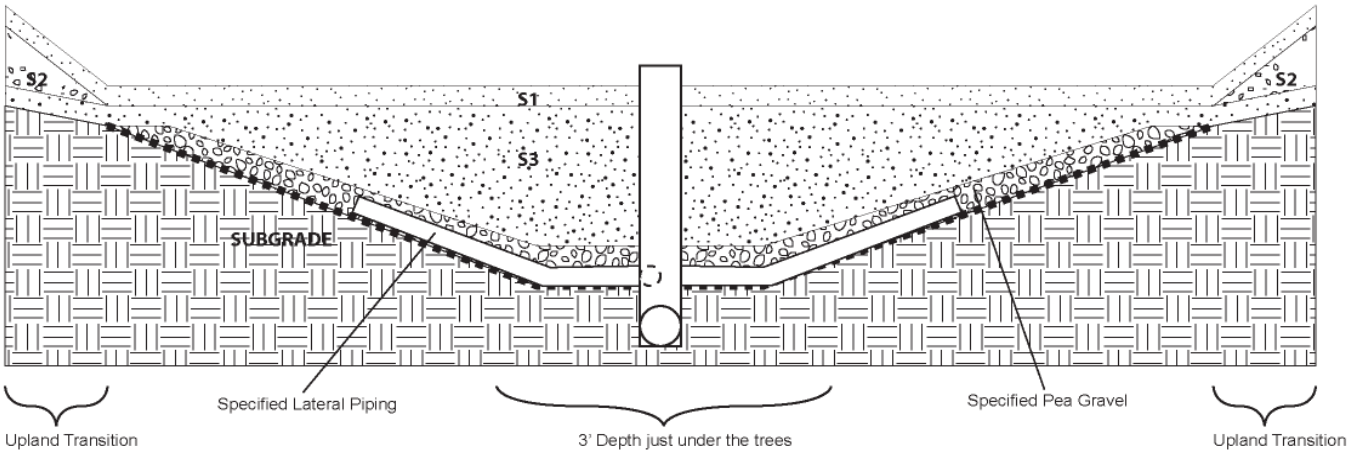
Standard Details

Date:

June 30 , 2012





B

Bio-Retention Basin (Large w/ trees)

Scale = Not to Scale

Chemistry Building – Princeton University

Before Plugs - 2010

Day after Hurricane Irene- 2011

Michael Van Valkenburgh Associates

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Phipps Conservancy - Pittsburgh

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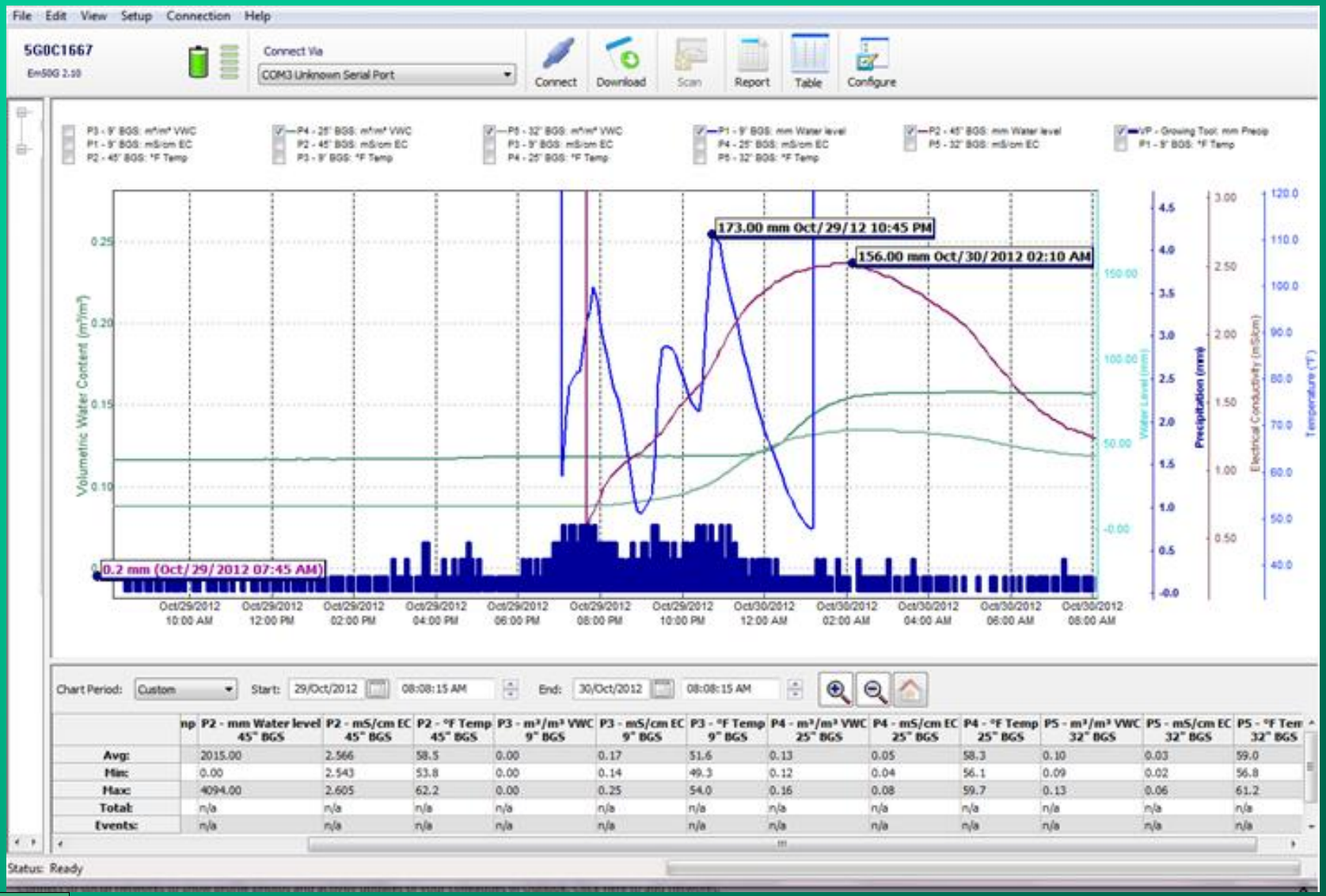
Phipps Conservancy - Pittsburgh



	np	P2 - mm Water level 45" BGS	P2 - mS/cm EC 45" BGS	P2 - °F Temp 45" BGS	P3 - m³/m³ VWC 9" BGS	P3 - mS/cm EC 9" BGS	P3 - °F Temp 9" BGS	P4 - m³/m³ VWC 25" BGS	P4 - mS/cm EC 25" BGS	P4 - °F Temp 25" BGS	P5 - m³/m³ VWC 32" BGS	P5 - mS/cm EC 32" BGS	P5 - °F Tem 32" BGS
Avg:		2015.00	2.566	58.5	0.00	0.17	51.6	0.13	0.05	58.3	0.10	0.03	59.0
Min:		0.00	2.543	53.8	0.00	0.14	49.3	0.12	0.04	56.1	0.09	0.02	56.8
Max:		4094.00	2.605	62.2	0.00	0.25	54.0	0.16	0.08	59.7	0.13	0.06	61.2
Total:		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Events:		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Shoemaker Green – University of Pennsylvania

Shoemaker Green – University of Pennsylvania

Penetration resistance of the Bio-retention basin

*In lbs/in^2

Bed	0 – 6”	6 – 12”	12 – 24”	24”+
Bio-Retention Basin	100	150	250	300
	125	150	250	250
	100	150	225	200
	75	150	150	275
	50	175	275	300
	50	50	50	50
	50	100	175	250
	50	125	150	275
	50	50	50	50
	55	75	150	300

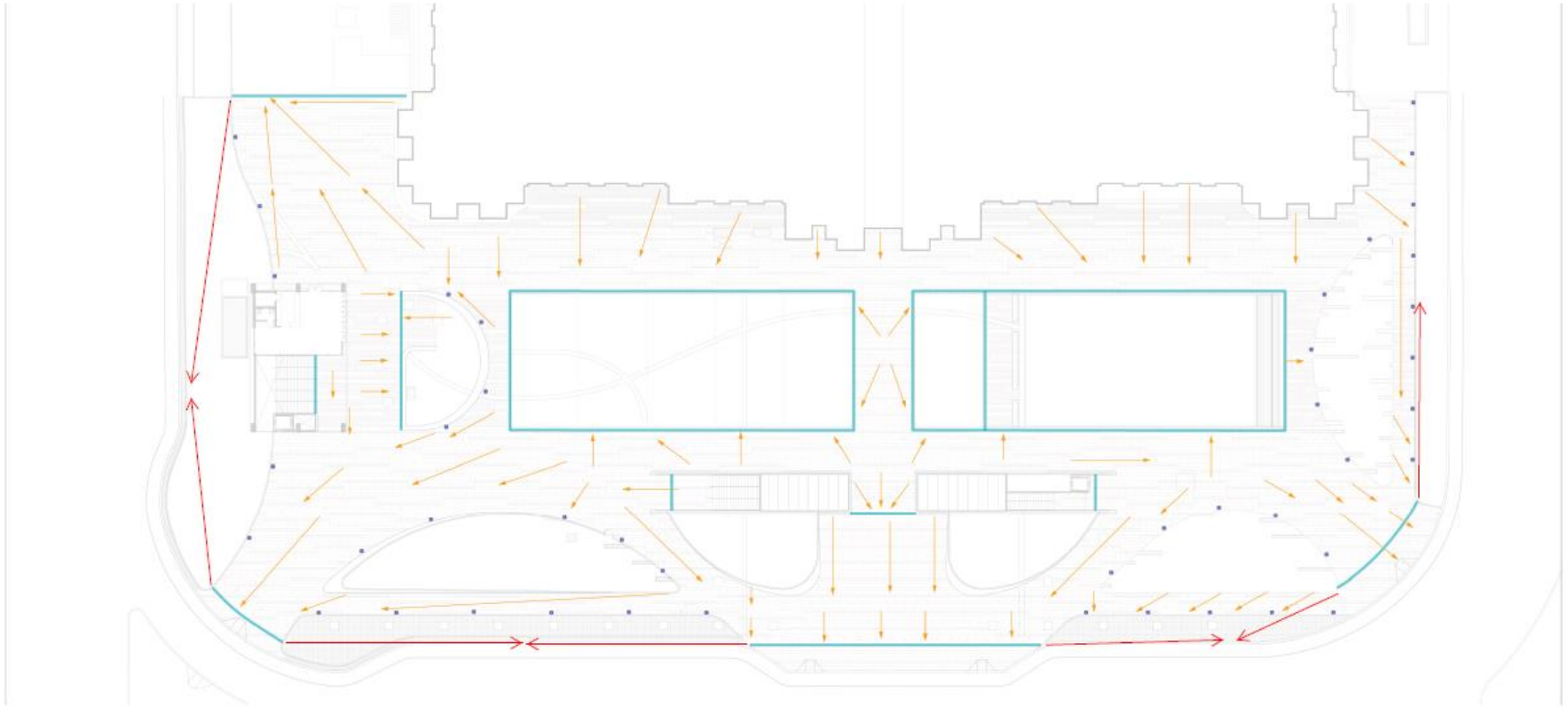
Infiltration Rate of the Bio-retention basin

5 min	10 min	15 min	cm/hr	In/hr
2.5	5.4	8.2	32.8	12.9
1.9	4.0	6.2	24.8	9.8

Shoemaker Green – University of Pennsylvania

Andropogon

Dillworth Plaza



Dilworth Plaza

Proposed Drainage Plan

OLIN

December 16, 2010 L1.00

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Central Green

Construction Limitations

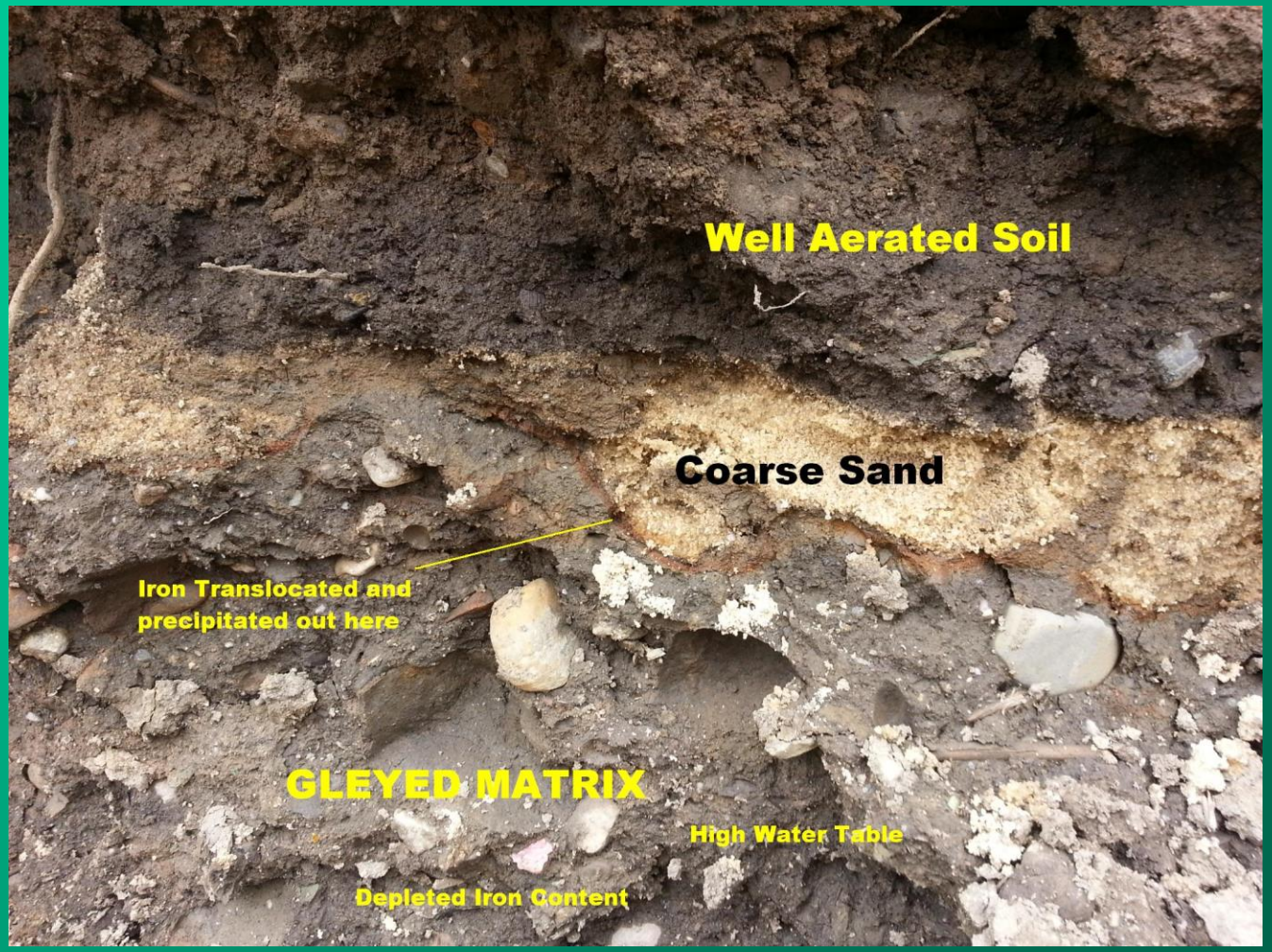
- Contaminated Site
- Fluctuating water table
- Limited Budget
- Making donated soils work for the site.
- Moderate site usage (lower than Shoemaker Green, DC Mall, or Central Park)

Solutions

- Bury the contaminated material with a “witness layer” (S3).
- Adjusting installation procedures and QC for less robust planting soils.
- Identifying those high use areas and adjusting planting soils and plants for those areas specifically.

The Meadow

Drainage Layer (S3) Functionality



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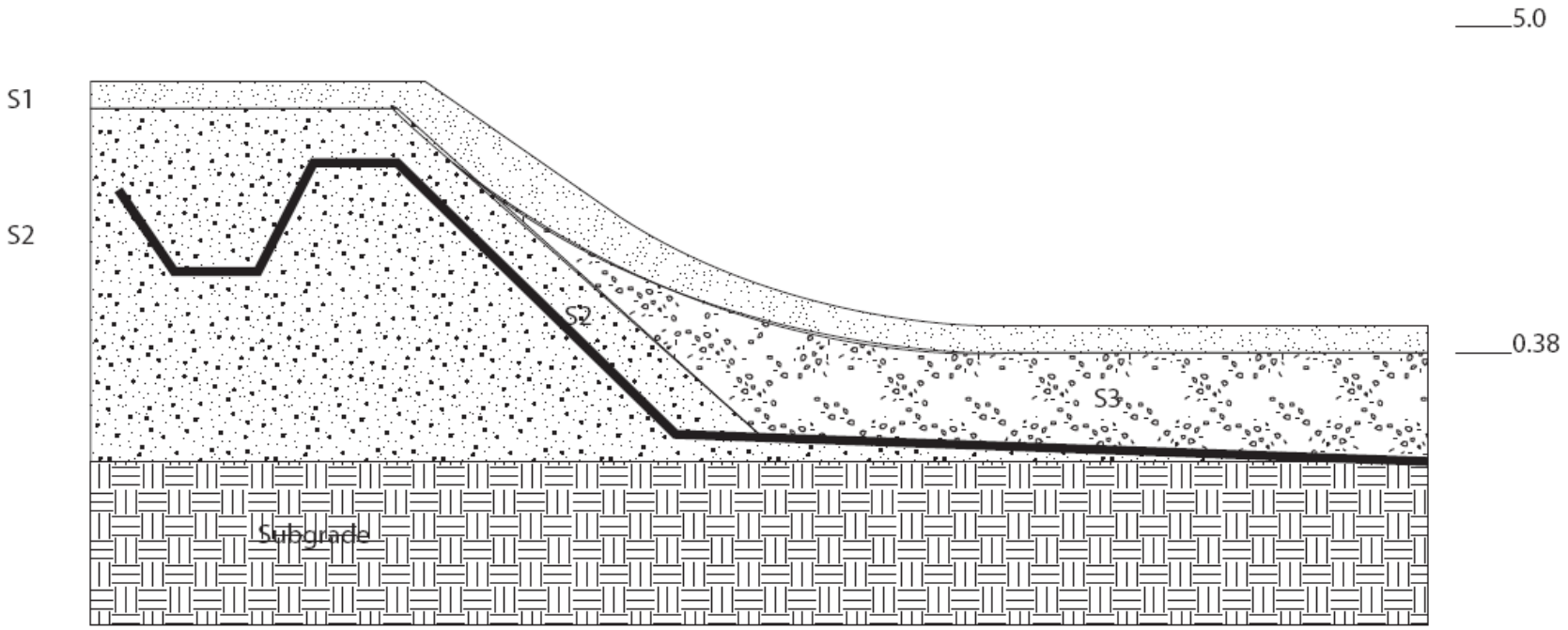
Central Green Bio-basin

Date:

5/27/15



A Bio-Basin Slope Detail

Scale = Not to Scale

S1 / Ap

Physical and Chemical Parameters: VE Topsoil Specifications.

	Sieve	Passing	Sub
fine gravel	10	80 – 100	73.7
medium sand	60	30 – 50	55.4
very fine sand	270	12 – 45	42.9
silt* (<0.05mm)		6 – 38%†	24.8%†
clay* (<0.002mm)		6 – 17%†	18.1%†

Property	Specified	Submitted
pH	5.5 - 7.5	7.4
CEC	20 -100 cmol/kg	24.6
Soluble Salts	< 1.5 mS/cm	2.93
SAR	< 5	N/A

† Percent of Whole Soil
N/A = Not Applicable; NR = Not Reported

Slightly more gravels than specified, will offset finer material passing #60 sieve.

PSU data weighted to reflect 100% whole soil percentages.

S2

Physical and Chemical Parameters: VE S2 material

Particle Size	Specified Ranges	Submitted
< 2.0 mm (#10)	95 – 100	55.1
> 1.0 mm (#18)	90 – 100	52.2
> 0.5 mm (#35)	65 – 85	46.2
> 0.25 mm (#60)	30 – 40	37.6
> 0.10 mm (#140)	15 – 25	26.8
> 0.05 mm (#270)	9– 15	21.0
> 0.002 mm (silt)	6 – 9%†	13.1%†
<0.002 mm (clay)	3 – 6%†	7.9%†

Property	Specified	Submitted
pH	5.5 – 7.0	8.3
CEC		20.6
Soluble Salts	< 1.5 mS/cm	0.25
SAR	< 5	
OM	< 1.0	0.6

NR=Not Reported; N/A=Not Applicable
† Whole soil percentage

S3

Physical and Chemical Parameters: S3 material – as per specifications

Particle Size	Specified Ranges	Submitted
< 2.0 mm (#10)	95 – 100	98.8
> 1.0 mm (#18)	80 – 95	91.2
> 0.5 mm (#35)	60 – 88	61.5
> 0.25 mm (#60)	10 – 40	15.0
> 0.10 mm (#140)	8 – 15	1.9
> 0.05 mm (#270)	1 – 10	1
> 0.002 mm (silt)	1 – 6%†	0.7%†
<0.002 mm (clay)	0 – 4%†	0.3%†

Property	Specified	Submitted
pH	5.5 – 7.0	7.1
CEC		0.6
Soluble Salts	< 1.5 mS/cm	0.03
SAR	< 5	
OM	< 1.0	0.0

NR=Not Reported; N/A=Not Applicable
† Whole soil percentage
PSU Data was weighted to reflect whole soil percent passing at 100%

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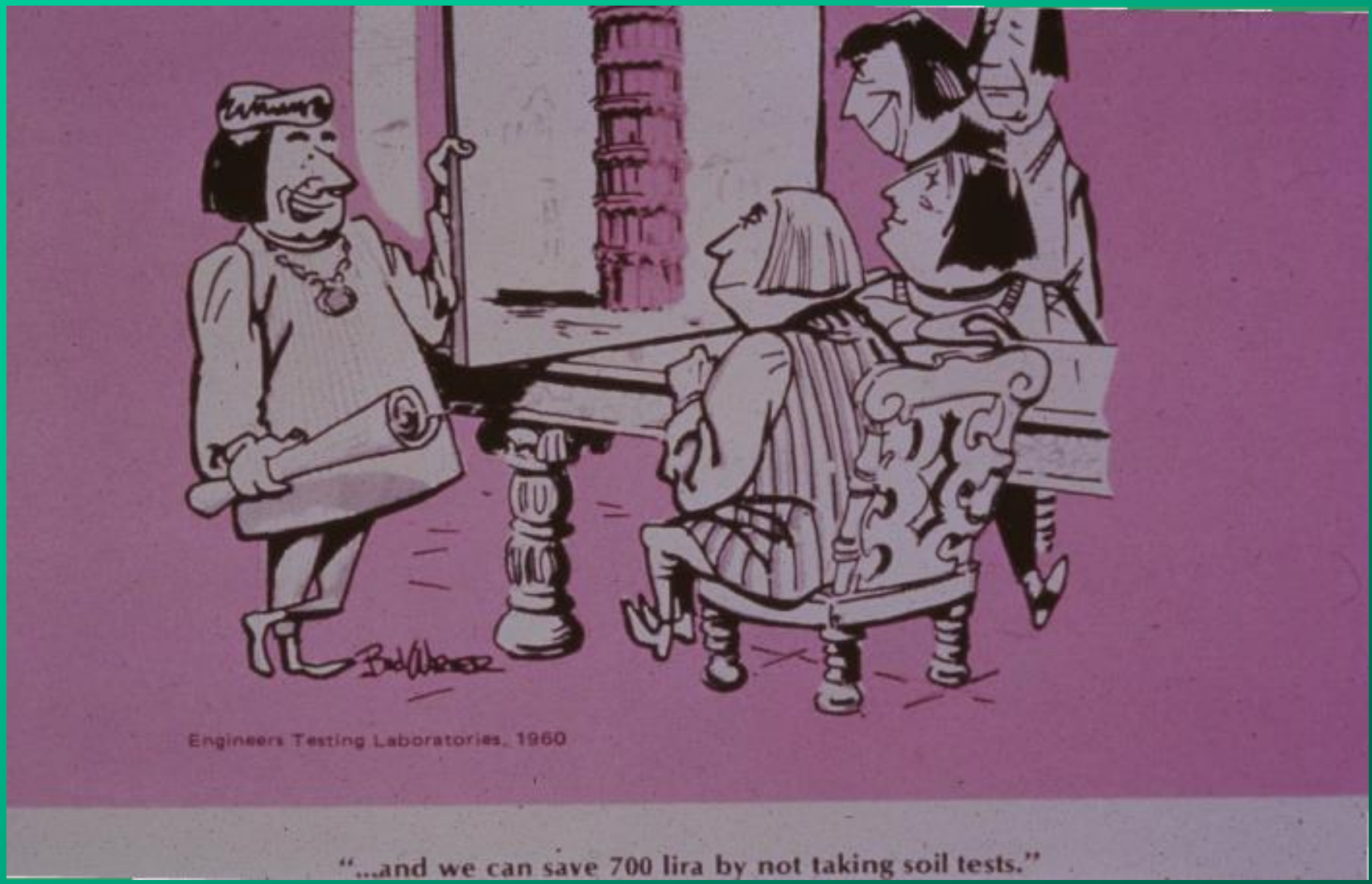

Engineers Testing Laboratories, 1960

"...and we can save 700 lira by not taking soil tests."