Storm Water Management Using Geosynthetics

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GeoStorage Corp.

Storm Water Management Using Geosynthetics

EPA Fact Sheet
Underground Retention/Detention

United States Environmental Protection Agency | Office of Water Washington, D.C. | EPA 832-F-01-005 September 2001

EPA

Storm Water Technology Fact Sheet

On-Site Underground Retention/Detention

DESCRIPTION

One of the major components of storm water management is flow control, particularly in newly-developed areas where buildings, parking lots, roads, and other impervious surfaces replace open space. As imperviousness increases, there is less area available for infiltration, and the amount of runoff increases. This may cause streams to be more prone to flash floods. Many municipalities now require newly-developed areas to maintain pre-development runoff conditions and to implement measures to capture or control the increase in peak runoff for a design storm event.

Several different types of storm water Best Management Practices (BMPs), including retention/detention ponds, storm water wetlands, and underground storage structures, can provide storm water volume control. These BMPs capture flow and retain it until it infiltrates into the soil (storm water retention) or release it slowly over time, thereby decreasing peak flows and associated flooding problems (storm water detention). Several of these options, including storm water wetlands and large detention ponds, require relatively large land areas, making them less of an option in areas where land costs are high or where land availability is a problem. In many of these areas, such as parking lots for malls or other developed sites in highly urbanized areas, storing storm water underground on the site may be the best option.

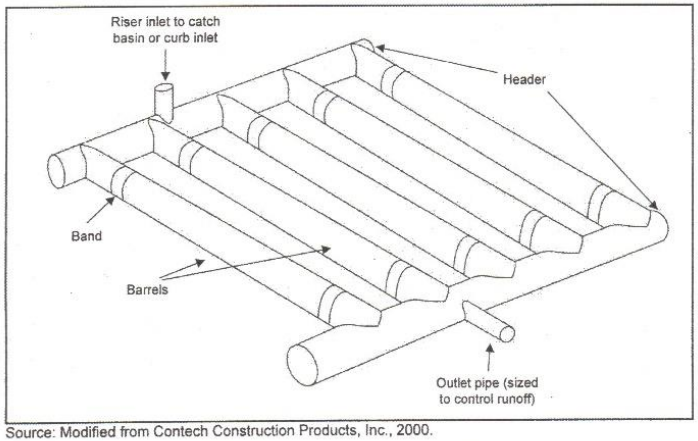
Underground storm water retention/detention systems capture and store runoff in large pipes or other subsurface structures (see Figure 1). Storm water enters the system through a riser pipe connected to a catch basin or curb inlet and flows into a series of chambers or compartments for storage. Captured runoff is retained throughout the storm event, and can be released directly back into surface waters through an outlet pipe. Outlet pipes are sized to release stored runoff at pre-development flow rates. This ensures that there is no net increase in peak runoff and that receiving waters are not adversely impacted by high flows from the site. Some systems are also designed to exfiltrate stored runoff into the surrounding soil, where it helps to recharge the groundwater table.

Underground retention/detention systems can be constructed from concrete, steel, or plastic materials. Each material has advantages and disadvantages and specific applicabilities, which are discussed in the following sections.

APPLICABILITY

Underground retention/detention systems are primarily used in newly-developed areas where land cost and/or availability are major concerns. They are not usually designed for retrofit applications. Most systems are built under parking lots or other paved surfaces in commercial, industrial, and residential areas. Perforated underground retention systems that release stored storm water into the subsoil are recommended only for areas with well-drained soils and where the water table is low enough to permit recharge. Some pretreatment such as sediment traps or sand filters may be necessary for infiltration to eliminate sediment and other solids that could clog the system.

On-site underground retention/detention systems provide peak runoff flow control and can store storm water for future release back into the environment. However, they are not designed specifically to enhance water quality; therefore, other storm water BMPs may be required to provide storm water treatment. Underground retention/detention systems are often used in "treatment trains," which consist of a number of storm water BMPs that provide both storm water treatment and storage. For example, storm water entering the underground detention structure in Hauge Homestead Park in Everett, Washington, is first collected from a parking area through a catch basin, then flows through a series of vegetated swales, then into a storm water pipe with a sump, all of which filter out sediment and pollutants before the runoff reaches the detention chambers. Runoff is then released into a pond at a controlled rate, where further pollutant removal occurs (City of Everett, Washington, Department of Parks and Recreation, 2000).



Source: Modified from Contech Construction Products, Inc., 2000.

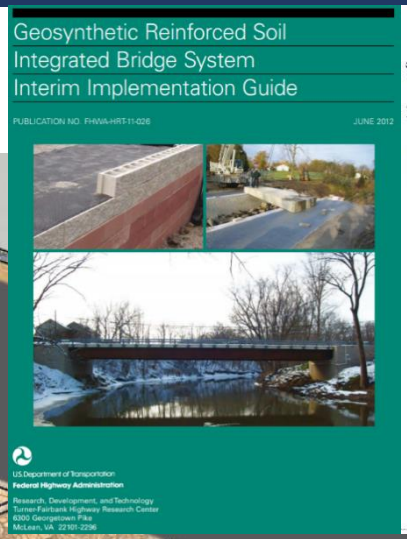
FIGURE 1 SCHEMATIC OF PIPE-BASED UNDERGROUND STORM WATER DETENTION SYSTEM

ADVANTAGES AND DISADVANTAGES

This Section presents the overall advantages and disadvantages of on-site underground retention/detention systems. The advantages and disadvantages of specific designs and construction materials (concrete, steel, plastic) for underground retention/detention systems are discussed in the Design section.

Advantages

- The primary advantage of the on-site underground storm water retention detention system is that it captures and stores runoff, thus helping meet the requirement to maintain pre-development runoff conditions at newly-developed sites
- These systems are ideal for highly urbanized areas, particularly in areas where land is expensive or may not be available for ponds or wetlands.
- These systems can be installed quickly. For example, construction and installation of a 6' by 4' by 156' concrete system was installed under a car dealership in Tennessee in 3 days (Sherman Dixie Concrete Industries, Inc., 2000).



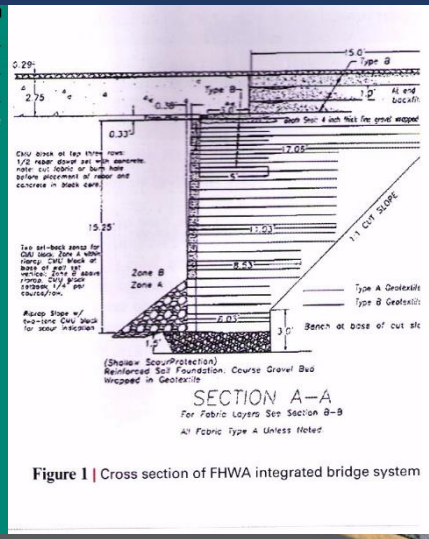


Figure 1 | Cross section of FHWA integrated bridge system

Reinforced Concrete Roof Slab

Geogrid

Reinforced Stone Berm

Stormwater Inlet Pipe

Drainage Rock

Outlet Pipe

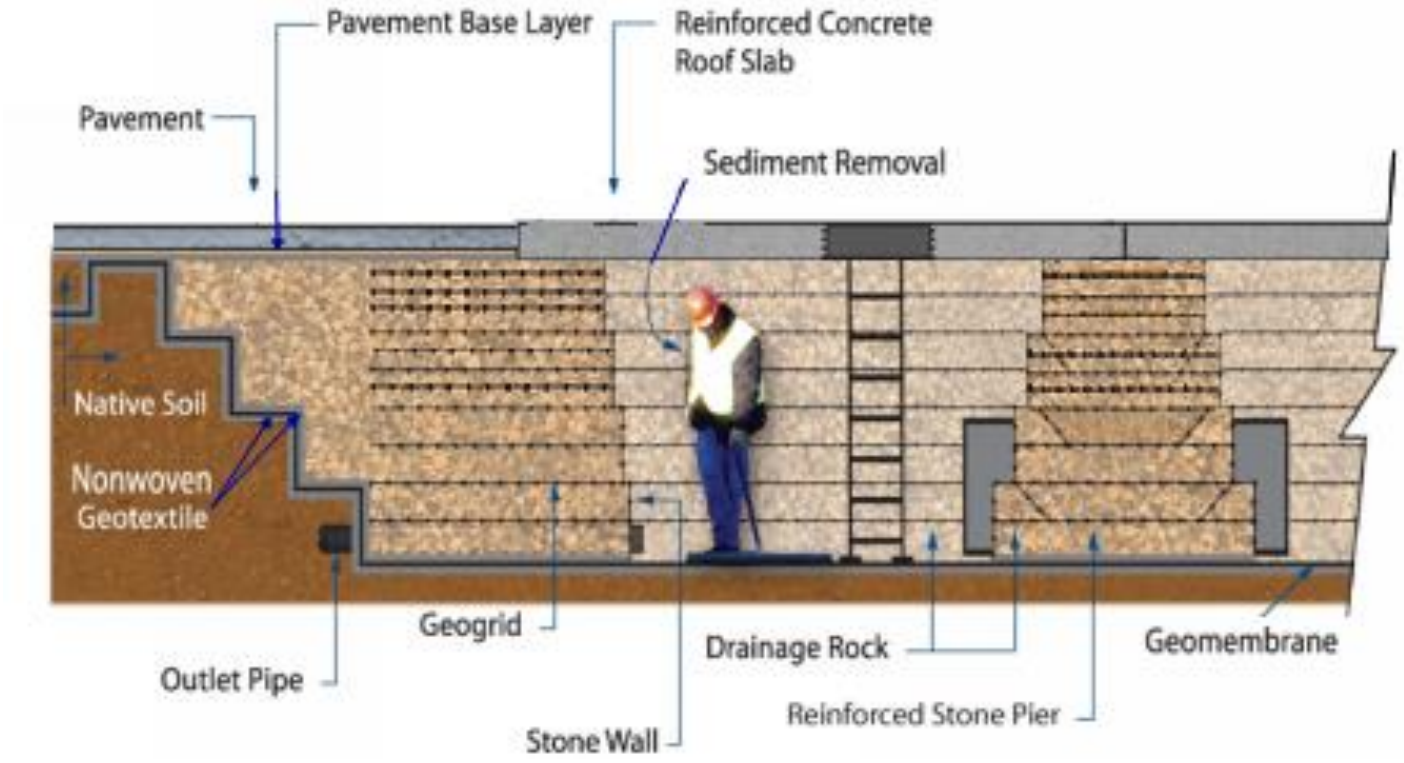
Nonwoven Geotextile

Geomembrane

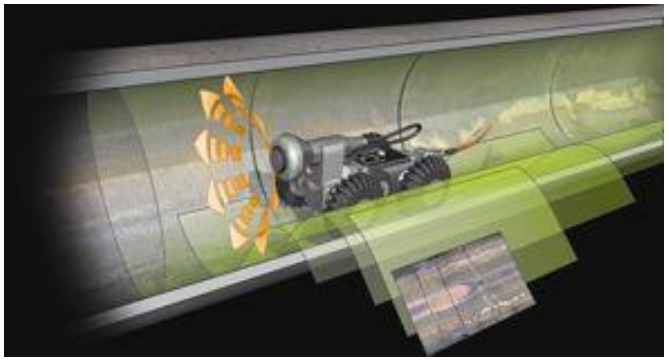
Nonwoven Geotextile

- FHWA Integrated Bridge Design
- Bridge Seat Bearing Capacity:

13 Tons/SF (limit of testing equipment) – no failure



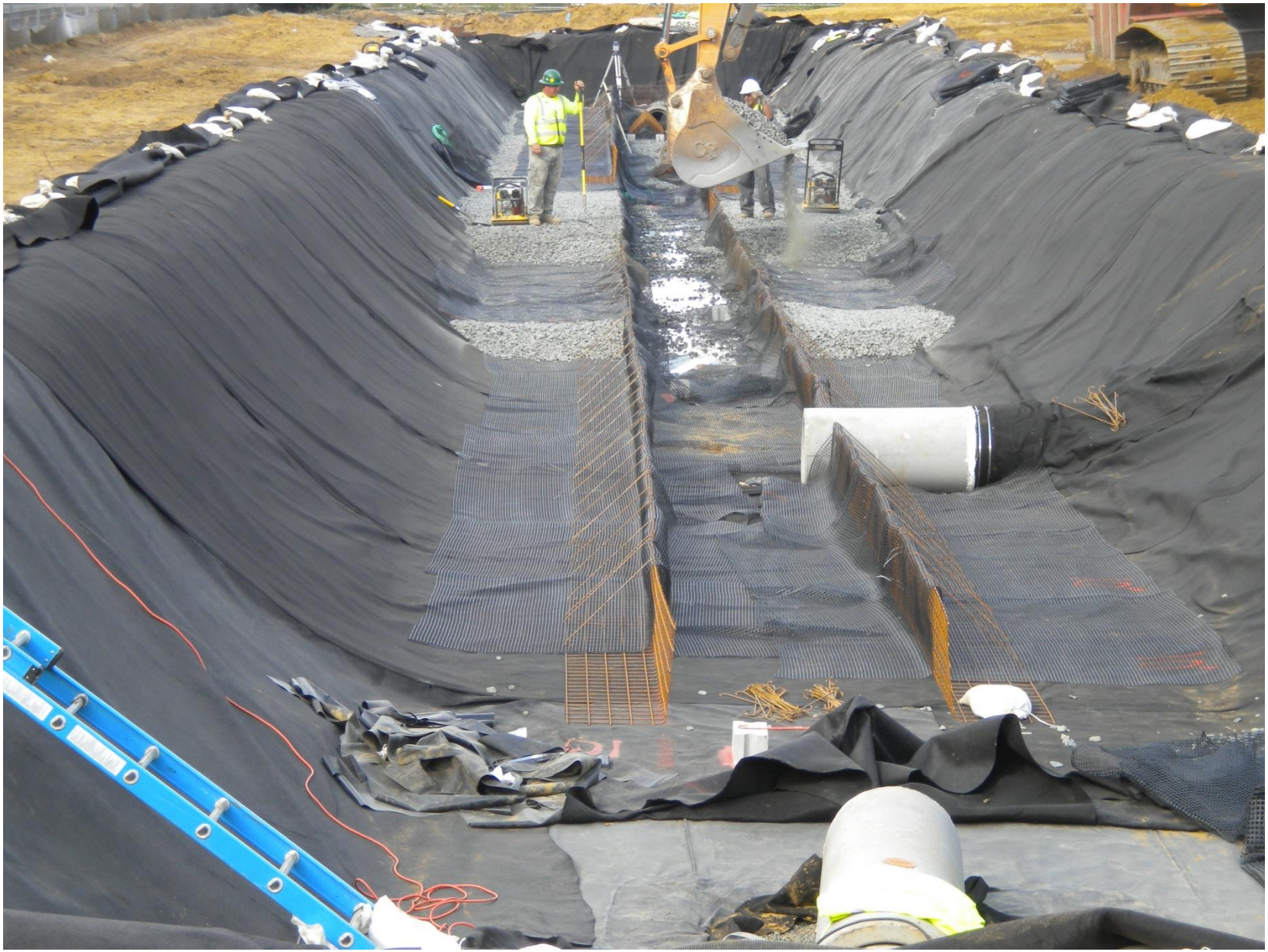
Stormwater Retention System	Total Amount of CO_2
Plastic Stormwater Modules	29,340
Corrugated Plastic Pipe	186,174
Corrugated Steel Pipe	571,227
Corrugated Arch Chambers	28,578
Underground Chamber w/Geosynthetics	25,470



Infiltration vs Detention

Fabricated Geomembrane Applications:

- Contaminated Sites (Urban Infills)
- Karst Geology (Sinkholes)
- Highly Porous Geology (Bedrock with cracks)
- Rainwater Harvesting
- Stomwater Treatment Applications (GeoStorage Sand Filters)



CET
Bobcat
T190

Bobcat
NO OUTLET

GOVBERG
WELLS FARGO

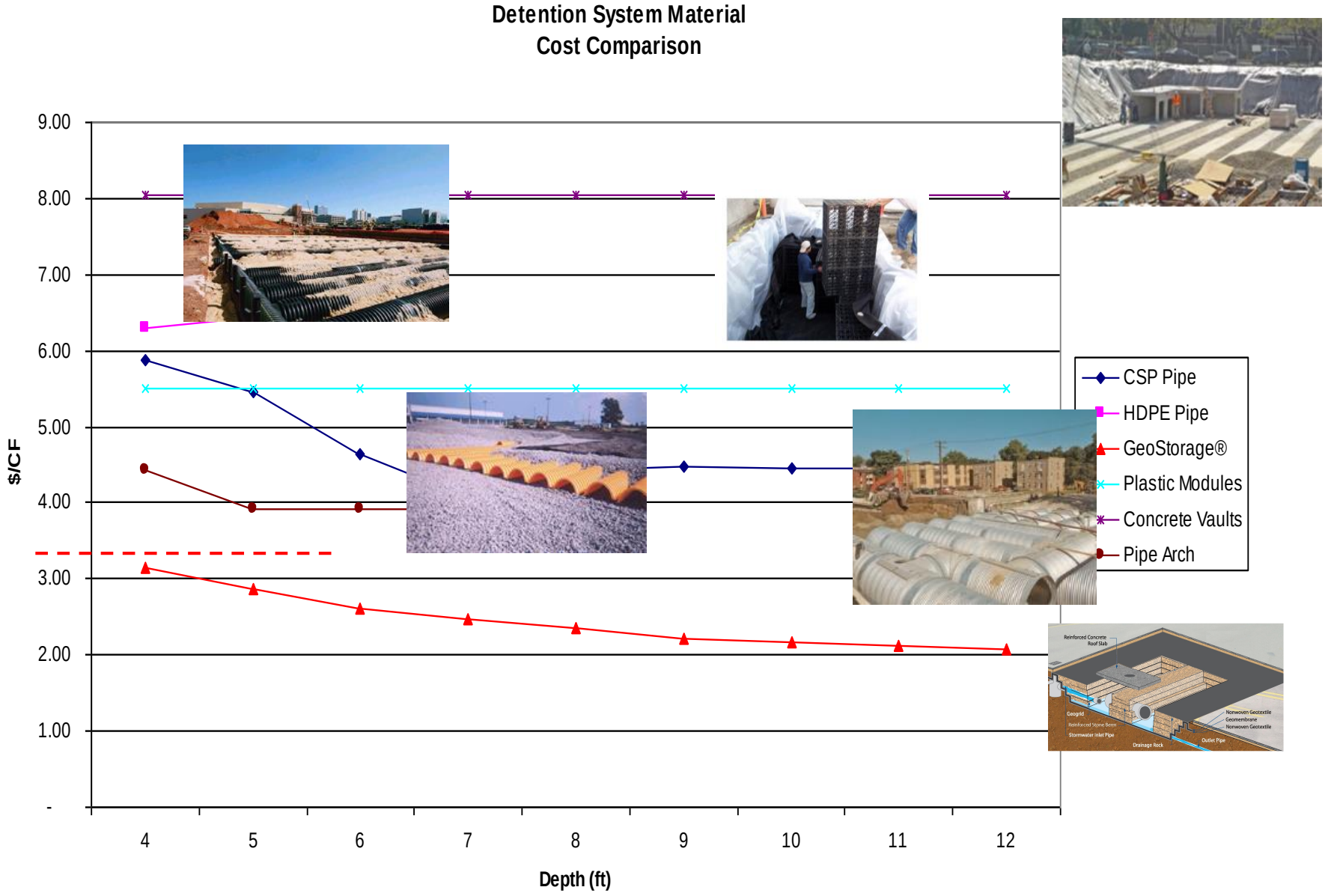
BRUTE

3'-9"

MERION GOLF CLUB
East Course

MERION GOLF CLUB
East Course

Detention system Material Cost Comparison



Deep Profile

Low Profile with Large Available Footprint

ENGINEERING ESTIMATES
May, 2007

1. Material prices based on a rectangular system with double manifolds and 8 each pipe runs @ 150' each
2. Minimizing fabrication reduces $/cf (fewer, longer pipe runs)
3. Prices include freight within 200 miles of plant and diameter ≤ 96"

Does not include structural backfill costs

Diameter	Aluminized 16 gage	Aluminized 12 gage	Galvanized 16 gage	Galvanized 12 gage
24"	$8.47	$12.71	$7.76	$11.55
30"	$6.88	$10.58	$6.28	$9.63
36"	$5.70	$9.13	$5.19	$8.29
42"	$4.95	$7.88	$4.52	$7.15
48"	$4.24	$6.86	$3.86	$6.23
54"	n/a*	$6.11	n/a*	$5.53

*Gage possible but not recommended.

1" Corrugation:

Diameter	Aluminized 16 gage	Aluminized 12 gage	Galvanized 16 gage	Galvanized 12 gage
60"	$3.83	$6.13	$3.49	$5.56
66"	$3.47	$5.57	$3.15	$4.60
72"	$3.19	$5.12	$2.92	$4.62
78"	$2.94	$4.72	$2.70	$4.29
84"	$2.75	$4.40	$2.51	$3.98
90"	$2.57*	$4.11	$2.34*	$3.73
96"	$2.42*	$3.91	$2.20*	$3.54
102"	n/a*	$3.66	n/a*	$3.32
108"	n/a*	$3.47	n/a*	$3.16
114"	n/a*	$3.30	n/a*	$2.99
120"	n/a*	$3.14	n/a*	$2.86

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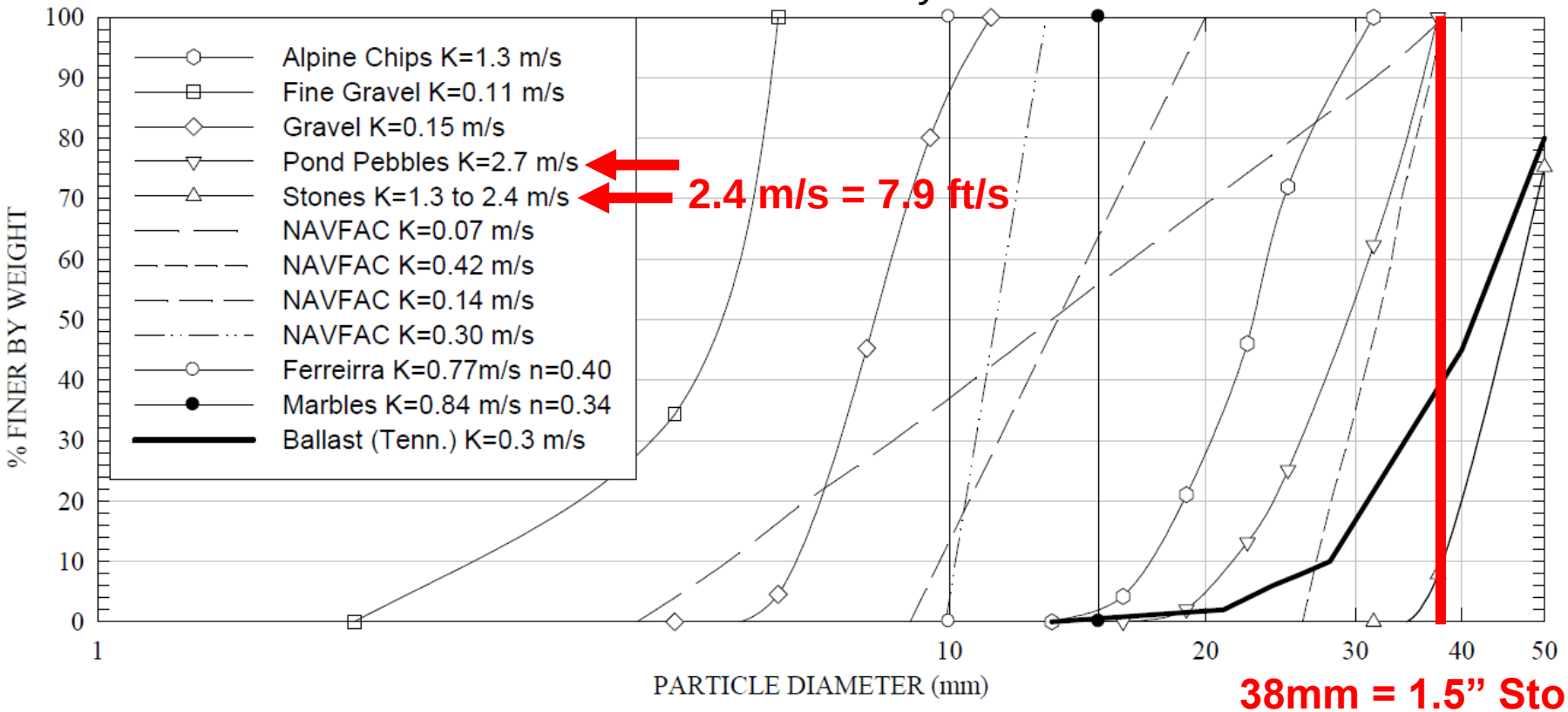
Storage Cost In Stone:
$18/Ton / 2000lbs x 100 PCF
= $.90/CF
$.90/CF / 40% Porosity

= **$2.25 CF of Storage**

GeoStorage Stone Backfill

Porosity = 40% Min.

Coeffecient of Permeability = 7.9 ft/sec



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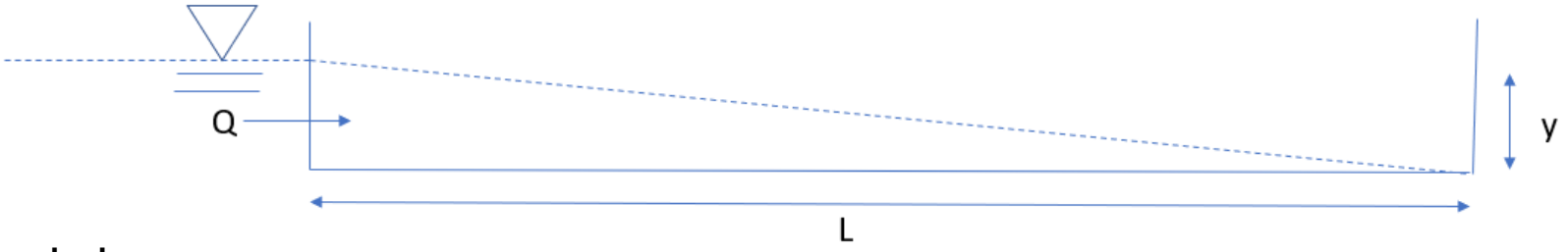
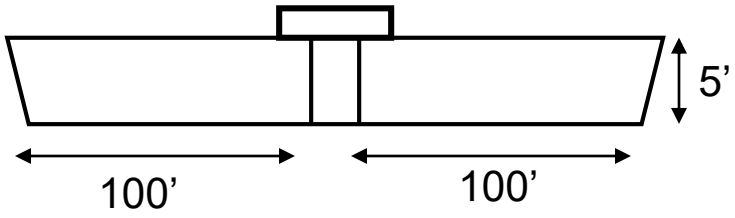
Darcy's Law Geosynthetic System



Darcy's Law
Q=KIA
Q= Flow Rate (CFS)
K= Hydraulic Conductivity ft/sec
I=hydraulic Gradient = y/L
A= Area (SF)

Q = KIA
K= 7.9 ft/sec
Y = 5 ft
L = 100 ft
I = 5 ft / 100 ft = .05 ft/ft
A = 5 ft^2
Q = (7.9 ft/sec) x (.05 ft/ft) x 5 SF = 2.0 CF/sec / LF

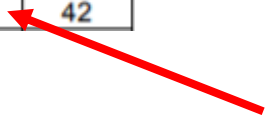


Example:

$Q_{100\ yr\ storm\ event}$ = **50 CFS**
Chamber Wall req. = 50 CFS/ 2.0 CFS/ft = 25 ft
Chamber Ends: 2 ends x 5.25' = 10.5 ft
14.5 ft
Chamber Length req = 14.5 ft / 2 walls = **8 LF**

HDPE Pipe Perforation Specifications

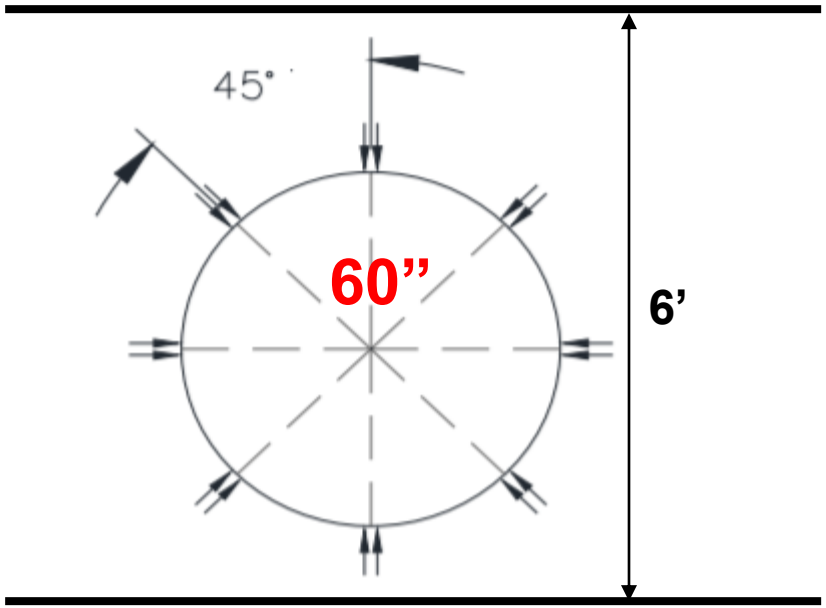
Nominal I.D.		Perforation Type	Maximum Slot Length or Diameter		Maximum Slot Width		Minimum Inlet Area	
in	mm		in	mm	in	mm	in^2/ft	cm^2/m
*4	100	Slot	0.875	22	0.125	3	1.0	21
*6	150	Slot	0.875	22	0.125	3	1.0	21
*8	200	Slot	1.18	30	0.125	3	1.0	21
*10	250	Slot	1.18	30	0.125	3	1.0	21
12	300	Circular	0.313	8	-	-	1.5	32
15	375	Circular	0.313	8	-	-	1.5	32
18	450	Circular	0.313	8	-	-	1.5	32
24	600	Circular	0.313	8	-	-	2.0	42
30	750	Circular	0.375	9.5	-	-	2.0	42
36	900	Circular	0.375	9.5	-	-	2.0	42
42	1050	Circular	0.375	9.5	-	-	2.0	42
48	1200	Circular	0.375	9.5	-	-	2.0	42
54	1350	Circular	0.375	9.5	-	-	2.0	42
60	1500	Circular	0.375	9.5	-	-	2.0	42



Flow Rate Through Pipe Perforations

$$Q_{perforations} = B \times C \times A_{perforation} \sqrt{2gh} \qquad \text{(Equation 7.3)}$$

where $Q_{perforations}$ is the capacity of flows through the perforations
B is the blockage factor (0.5–0.75)
C is the orifice coefficient (about 0.6)
A is the area of the perforation
h is depth of water over the collection pipe.



Q = .5 x .6 x 2”/144”/ft^2 x SQR (2 x 32.2ft/sec^{2}x 1’)
Q = .033 CFS/LF

Example:
$Q_{100\ yr\ storm\ event}$ = 50 CFS
Pipe Length = 50 CFS/ 0.033 CFS/ft = 1,516 ft

Note: Hydraulic Head (h) is set at 1 ft to stay as consistent as possible with the free-flowing hydraulic modeling software. The water level in the upstream manhole will sit 1 ft above the water in the pipe/stone.

Low Profile GeoStorage Systems Caveats

- Expensive Stone (e.g. Long Island, southern Florida).
- Small Footprint
- Export Site – “Expensive” Concrete Vaults

  should be Cost effective, particularly if material is contaminated.

Stormwater Treatment

United States Environmental Protection Agency | Office of Water Washington, D.C. | EPA 832-F-99-048 September 1999

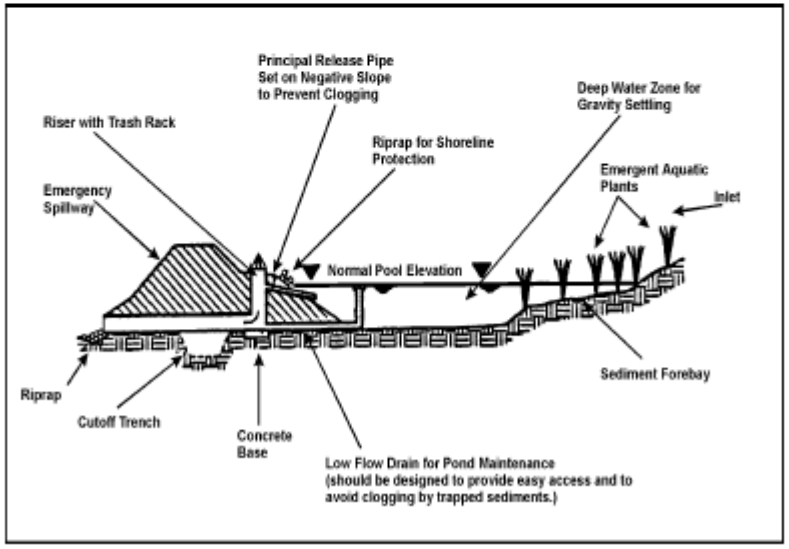
EPA

Storm Water Technology Fact Sheet
Wet Detention Ponds

DESCRIPTION

Wet detention ponds are storm water control structures providing both retention and treatment of contaminated storm water runoff. A typical wet detention pond design is shown in Figure 1. The pond consists of a permanent pool of water into which storm water runoff is directed. Runoff from each rain event is detained and treated in the pond until it is displaced by runoff from the next storm.

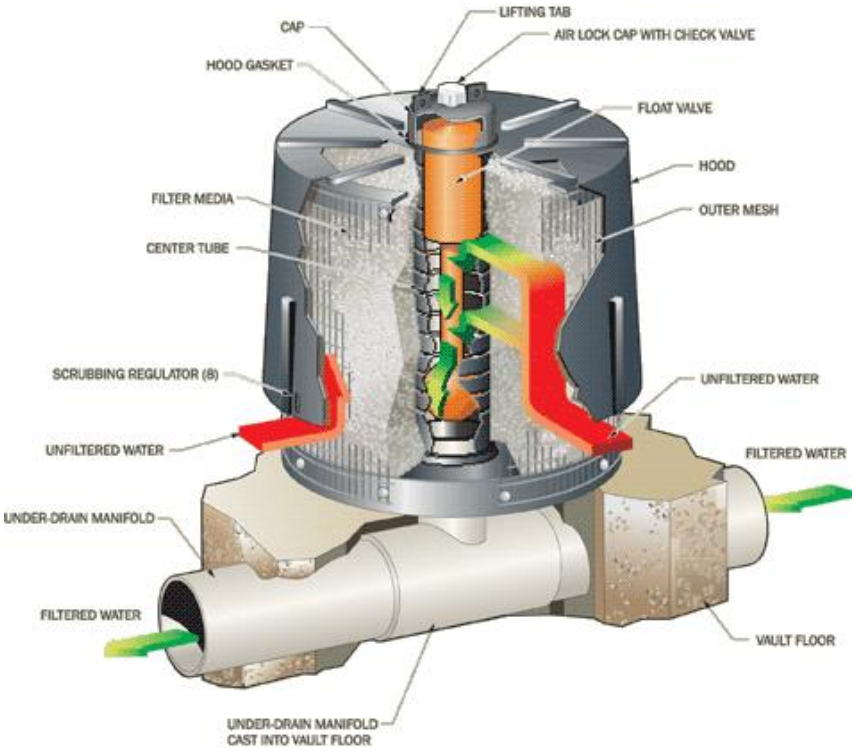
By capturing and retaining runoff during storm events, wet detention ponds control both storm water quantity and quality. The pond's natural physical, biological, and chemical processes then work to remove pollutants. Sedimentation processes remove particulates, organic matter, and metals, while dissolved metals and nutrients are removed through biological uptake. In general, a higher level of nutrient removal and better storm water quantity control can be achieved in wet

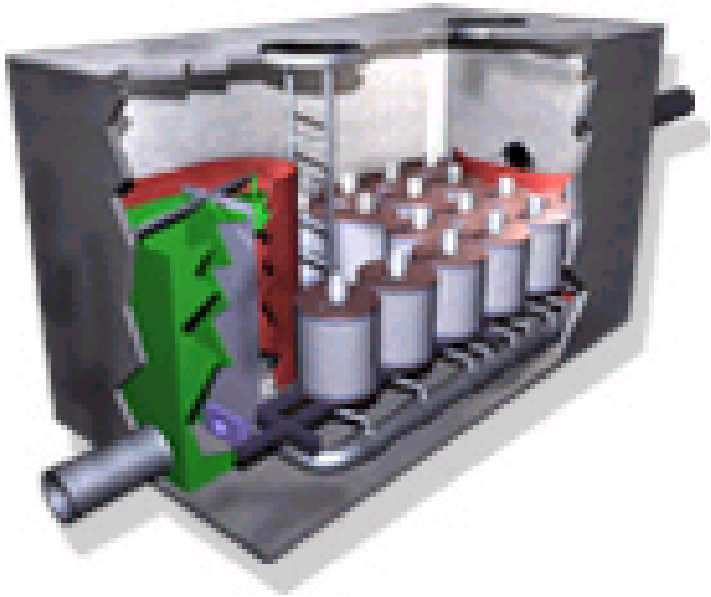


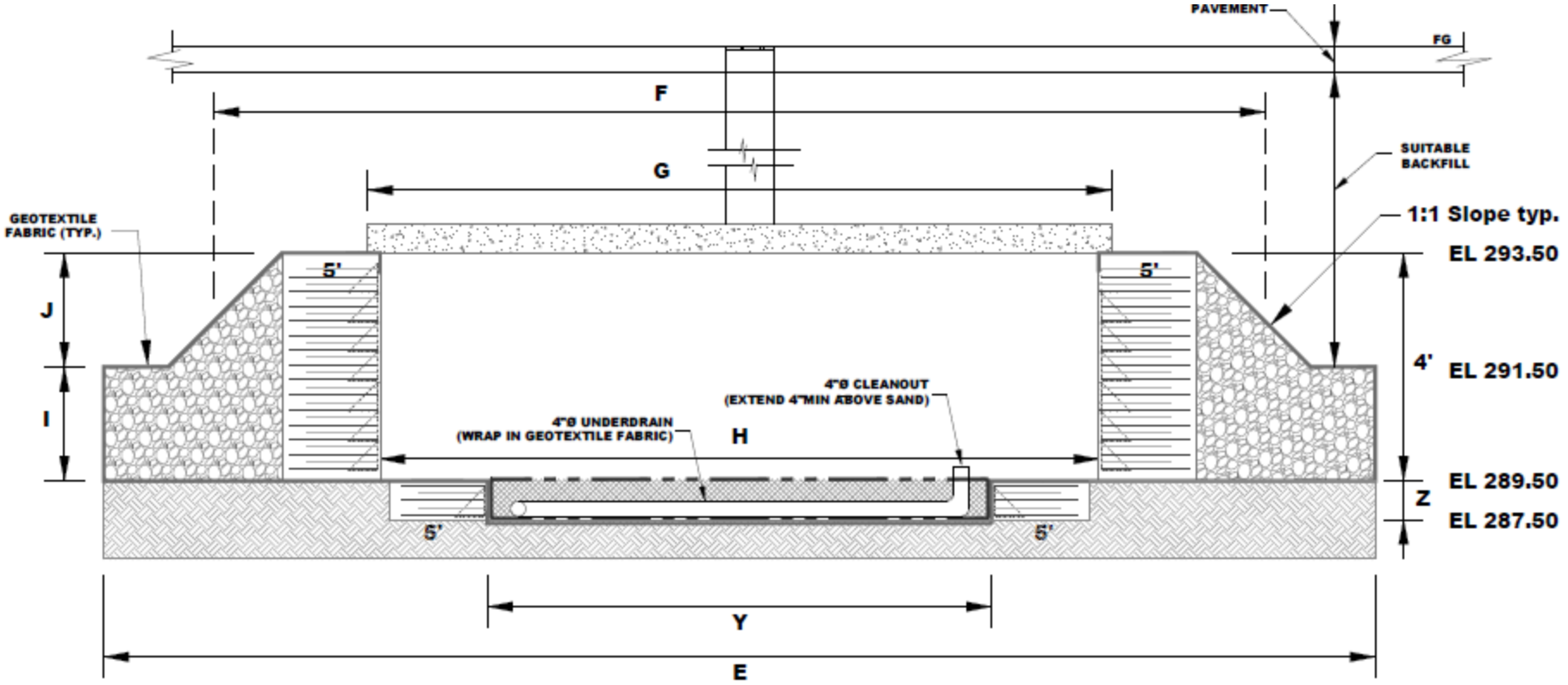
Source: Maryland Department of the Environment, 1986.

FIGURE 1 TYPICAL LAYOUT OF A WET DETENTION POND

Stormwater Filtration Systems






PAVEMENT
FG
F
G
SUITABLE BACKFILL
1:1 Slope typ.
GEOTEXTILE FABRIC (TYP.)
5'
5'
J
I
EL 293.50
4'
EL 291.50
4"Ø CLEANOUT
(EXTEND 4" MIN ABOVE SAND)
4"Ø UNDERDRAIN
(WRAP IN GEOTEXTILE FABRIC)
H
EL 289.50
Z
EL 287.50
5'
5'
Y
E

Sand Filter System

Sand Filter Installation

Geosynthetic Detention System Features

- Most Cost Effective
- FHWA 75+ Year Service Life[1]
- Robust design allows complete site access for construction equipment.
- Maximizes Flow into Stone (no choke point for stage storage analysis)
- Smallest Footprint (excl. Concrete Vault)
- Accessible for Inspection & Maintenance Crews
- Lowest Carbon Footprint
- A WQ Sand Filter can be included simply an inexpensively.

GeoStorage® Value:

Provides Engineers a design with FHWA design procedures and safety factors.
Not “manufacturer’s recommendations” based on an “FHWA HS-20 Truck Load Test”

Geotechnical Engineering Challenges in the Stormwater Management Market

United States Environmental Protection Agency | Office of Water Washington, D.C. | EPA 832-F-99-023 September 1999

EPA

Storm Water Technology Fact Sheet
Porous Pavement

DESCRIPTION

Porous pavement is a special type of pavement that allows rain and snowmelt to pass through it, thereby reducing the runoff from a site and surrounding areas. In addition, porous pavement filters some pollutants from the runoff if maintained.

There are two types of porous pavement: porous asphalt and pervious concrete. Porous asphalt pavement consists of an open-graded coarse aggregate, bonded together by asphalt cement, with sufficient interconnected voids to make it highly permeable to water. Pervious concrete consists of specially formulated mixtures of Portland cement, uniform, open-graded coarse aggregate, and water. Pervious concrete has enough void space to allow rapid percolation of liquids through the pavement.

The porous pavement surface is typically placed over a highly permeable layer of open-graded gravel and crushed stone. The void spaces in the aggregate layers act as a storage reservoir for runoff. A filter fabric is placed beneath the gravel and stone layers to screen out fine soil particles. Figure 1 illustrates a common porous asphalt pavement installation.

Two common modifications made in designing porous pavement systems are (1) varying the amount of storage in the stone reservoir beneath the pavement and (2) adding perforated pipes near the top of the reservoir to discharge excess storm water after the reservoir has been filled.

Some municipalities have also added storm water reservoirs (in addition to stone reservoirs) beneath the pavement. These reservoirs should be designed to accommodate runoff from a design storm and should provide for infiltration through the underlying subsoil.

APPLICABILITY

Porous pavement may substitute for conventional pavement on parking areas, areas with light traffic, and the shoulders of airport taxiways a runways, provided that the grades, subsoils, drainage characteristics, and groundwater conditions are suitable. Slopes should be flat or very gentle. Soils should have field-verified permeability rates of greater than 1.3 centimeters (0.5 inches) per hour, and there should be a 1.2 meter (4-foot) minimum clearance from the bottom of the system to bedrock or the water table.

ADVANTAGES AND DISADVANTAGES

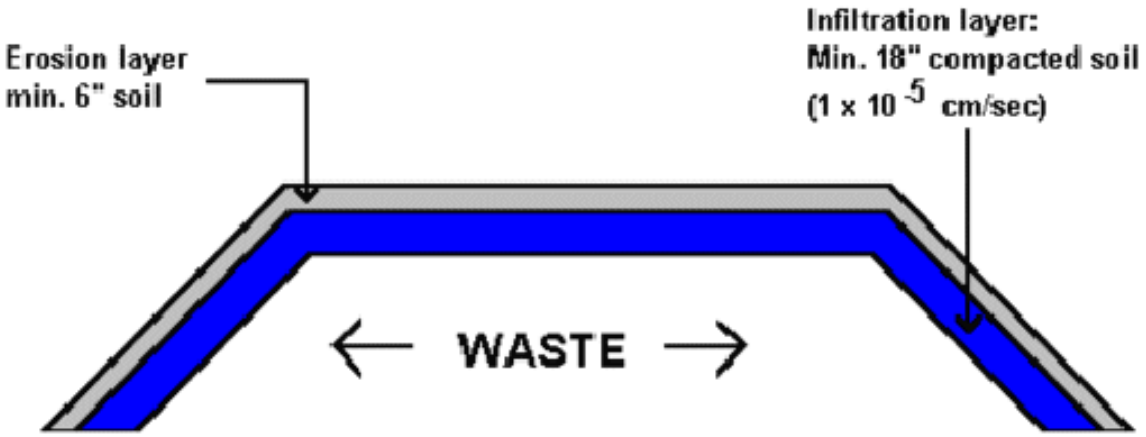
The advantages of using porous pavement include:

- Water treatment by pollutant removal.
- Less need for curbing and storm sewers.
- Improved road safety because of better skid resistance.
- Recharge to local aquifers.

The use of porous pavement may be restricted in cold regions, arid regions or regions with high wind erosion rates, and areas of sole-source aquifers. The use of porous pavement is highly constrained, requiring deep permeable soils, restricted traffic, and adjacent land uses. Some specific

Minimum Allowable Infiltration Rate: 0.5 in/hour

Maximum Allowable
Infiltration Rate: 0.014 in/hour



Minimum Final Cover Requirements

40 CFR §258.60(a)

Figure 1

0.00001 CM / SEC X (1 IN / 2.54 CM) X (60 SEC / 1 MIN) x (60 MIN / 1 HOUR) = 0.014 in/hour

Permeability

0.00001 CM / SEC X (1 IN / 2.54 CM) X (60 SEC / 1 MIN) x (60 MIN / 1 HOUR) =

.014 IN / Hour << .5 IN / Hour

.5 IN / HOUR X (1 HOUR / 60 MIN) X (1 FT / 12 IN) = **7×10^{-4} FT / MIN**

TABLE 1
Typical Properties of Compacted Soils

Group Symbol	Soil Type	Range of Maximum Dry Unit Weight, pcf	Range of Optimum Moisture, Percent	Typical Value of Compression		Typical Strength Characteristics				Typical Coefficient of Permeability ft./min.
				At 1.4 tsf (20 psi)	At 3.6 tsf (50 psi)	Cohesion (as compacted) psf	Cohesion (saturated) psf	ϕ (Effective Stress Envelope Degrees)	Tan ϕ	
				Percent of Original Height						
GW	Well graded clean gravels, gravel-sand mixtures.	125 - 135	11 - 8	0.3	0.6	0	0	>38	>0.79	5×10^{-2}
GP	Poorly graded clean gravels, gravel-sand mix	115 - 125	14 - 11	0.4	0.9	0	0	>37	>0.74	10^{-1}
GM	Silty gravels, poorly graded gravel-sand-silt.	120 - 135	12 - 8	0.5	1.1	.....	.....	>34	>0.67	$>10^{-6}$
GC	Clayey gravels, poorly graded gravel-sand-clay.	115 - 130	14 - 9	0.7	1.6	.....	.....	>31	>0.60	$>10^{-7}$
SW	Well graded clean sands, gravelly sands.	110 - 130	16 - 9	0.6	1.2	0	0	38	0.79	$>10^{-3}$
SP	Poorly graded clean sands, sand-gravel mix.	100 - 120	21 - 12	0.8	1.4	0	0	37	0.74	$>10^{-3}$
SM	Silty sands, poorly graded sand-silt mix.	110 - 125	16 - 11	0.8	1.6	1050	420	34	0.67	$5 \times >10^{-5}$
SM-SC	Sand-silt clay mix with slightly plastic fines.	110 - 130	15 - 11	0.8	1.4	1050	300	33	0.66	$2 \times >10^{-6}$
SC	Clayey sands, poorly graded sand-clay-mix.	105 - 125	19 - 11	1.1	2.2	1550	230	31	0.60	$5 \times >10^{-7}$
ML	Inorganic silts and clayey silts.	95 - 120	24 - 12	0.9	1.7	1400	190	32	0.62	$>10^{-5}$
ML-CL	Mixture of inorganic silt and clay.	100 - 120	22 - 12	1.0	2.2	1350	460	32	0.62	$5 \times >10^{-7}$
CL	Inorganic clays of low to medium plasticity.	95 - 120	24 - 12	1.3	2.5	1800	270	28	0.54	$>10^{-7}$
OL	Organic silts and silt-clays, low plasticity.	80 - 100	33 - 21	.....	.....	.....	.....	.....	.....	.....
MH	Inorganic clayey silts, elastic silts.	70 - 95	40 - 24	2.0	3.8	1500	420	25	0.47	$5 \times >10^{-7}$
CH	Inorganic clays of high plasticity	75 - 105	36 - 19	2.6	3.9	2150	230	19	0.35	$>10^{-7}$
OH	Organic clays and silty clays	65 - 100	45 - 21	.....	.....	.....	.....	.....	.....	.....

.5 IN / HOUR X (1 HOUR / 60 MIN) X (1 FT / 12 IN) = **7×10^{-4} FT / MIN**

UNIFIED SOIL CLASSIFICATION SYSTEM

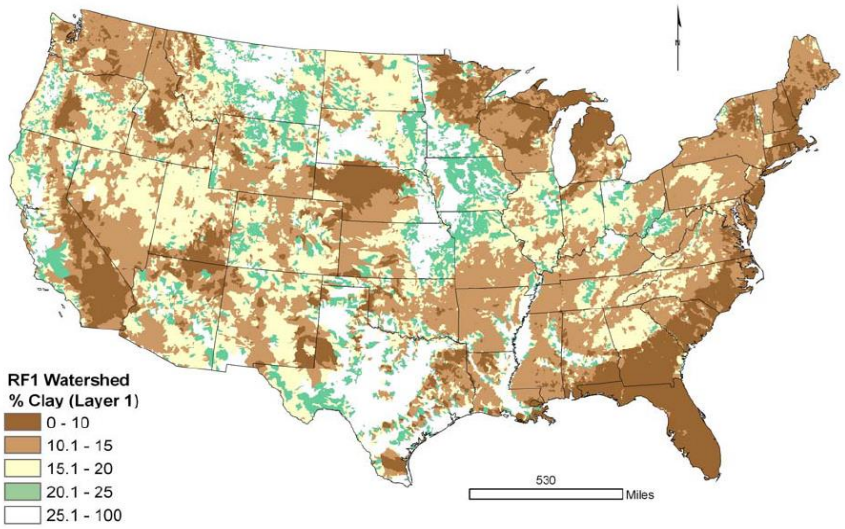
Criteria for Assigning Group Symbols and Group Names Using Laboratory Tests[A]					Soil Classification	
					Group Symbol	Group Name[B]
Coarse Grained Soils More than 50% retained on No. 200 sieve	Gravels More than 50% of coarse fraction retained on No. 4 sieve	Clean Gravels Less than 5% fines[C]	Cu ≥ 4 and 1 ≤ Cc ≤ 3[E]		GW	Well-graded gravel[F]
			Cu < 4 and/or 1 > Cc > 3[E]		GP	Poorly graded gravel[F]
		Gravels with Fines More than 12% fines[C]	Fines classify as ML or MH		GM	Silty gravel[F,G,H]
			Fines classify as CL or CH		GC	Clayey gravel[F,G,H]
	Sands 50% or more of coarse fraction passes No. 4 sieve	Clean Sands Less than 5% fines[D]	Cu ≥ 6 and 1 ≤ Cc ≤ 3[E]		SW	Well-graded sand[I]
			Cu < 6 and/or 1 > Cc > 3[E]		SP	Poorly graded sand[I]
		Sands with Fines More than 12% fines[D]	Fines classify as ML or MH		SM	Silty sand[G,H,I]
			Fines Classify as CL or CH		SC	Clayey sand[G,H,I]
Fine-Grained Soils 50% or more passes the No. 200 sieve	Silts and Clays Liquid limit less than 50	inorganic	PI > 7 and plots on or above "A" line[J]		CL	Lean clay[K,L,M]
			PI < 4 or plots below "A" line[J]		ML	Silt[K,L,M]
		organic	Liquid limit - oven dried / Liquid limit - not dried	< 0.75	OL	Organic clay[K,L,M,N] / Organic silt[K,L,M,O]
	Silts and Clays Liquid limit 50 or more	inorganic	PI plots on or above "A" line		CH	Fat clay[K,L,M]
			PI lots below "A" line		MH	Elastic Silt[K,L,M]
		organic	Liquid limit - oven dried / Liquid limit - not dried	< 0.75	OH	Organic clay[K,L,M,P] / Organic silt[K,L,M,O]
Highly organic soils	Primarily organic matter, dark in color, and organic odor				PT	Peat

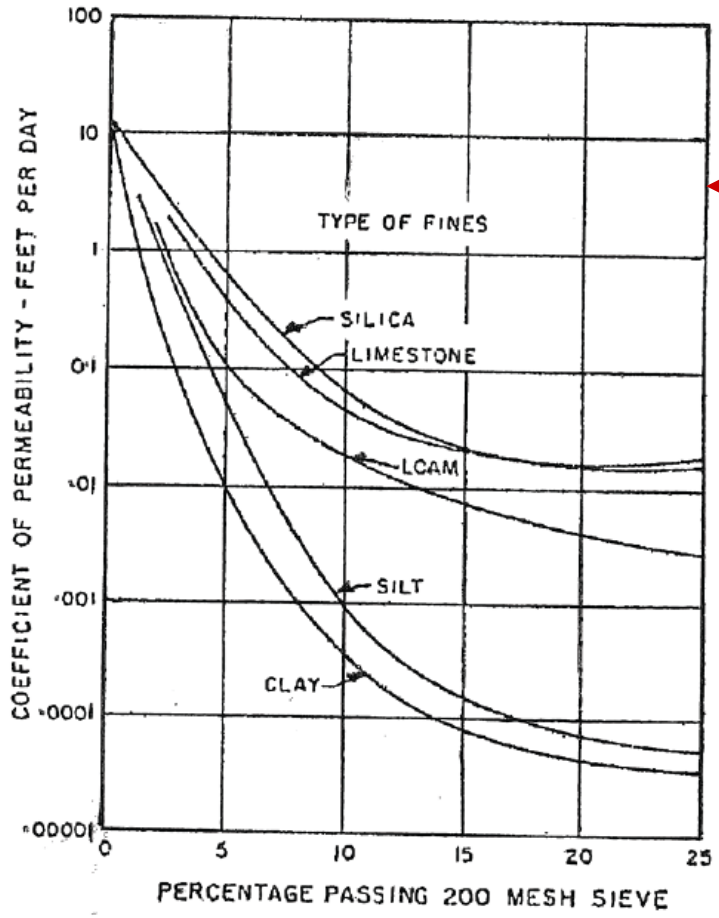
Table 4. Summary of Soil Data for Indicator Cities

Indicator City	Average Percent Clay	Average Percent Silt	Average Percent Sand
Albany, NY	17	43	40
Atlanta, GA	19	26	55
Boise, ID	17	41	43
Chicago, IL	24	57	20
Dallas, TX	38	35	27
Denver, CO	19	25	56
Kansas City, KS	27	66	7
Las Vegas, NV	12	16	72
Manchester, NH	6	33	61
Seattle, WA	10	31	59
Washington, DC	16	39	45

Note: Illustrates why flexible pipes require imported structural backfill

Figure D-2. Surface Soil Percent Clay Content





← ½"/ hour (7 X 10-4 ft / min)

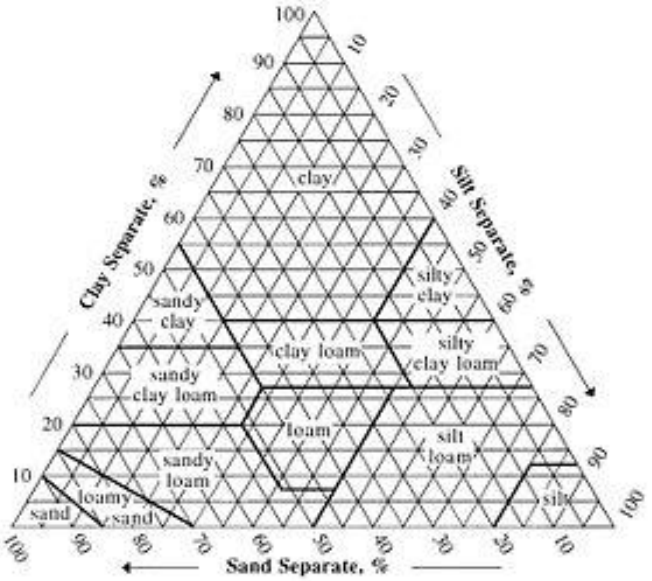
FIG 1 EFFECT OF FINES ON PERMEABILITY

(after BARBER et al, 1952)

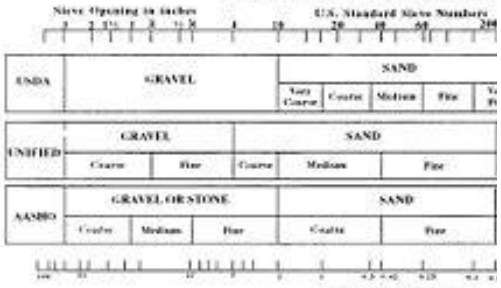
How should we classify soils for Stormwater Detention

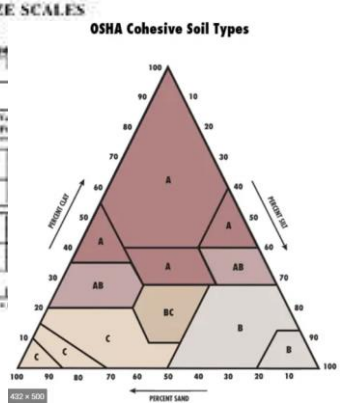
Rational Method:

Q = **CiA**. **Q** = Flowrate. C = Coefficient of Runoff. i = intensity of the storm. A = Area of the Catchment that the rainfall will runoff of.

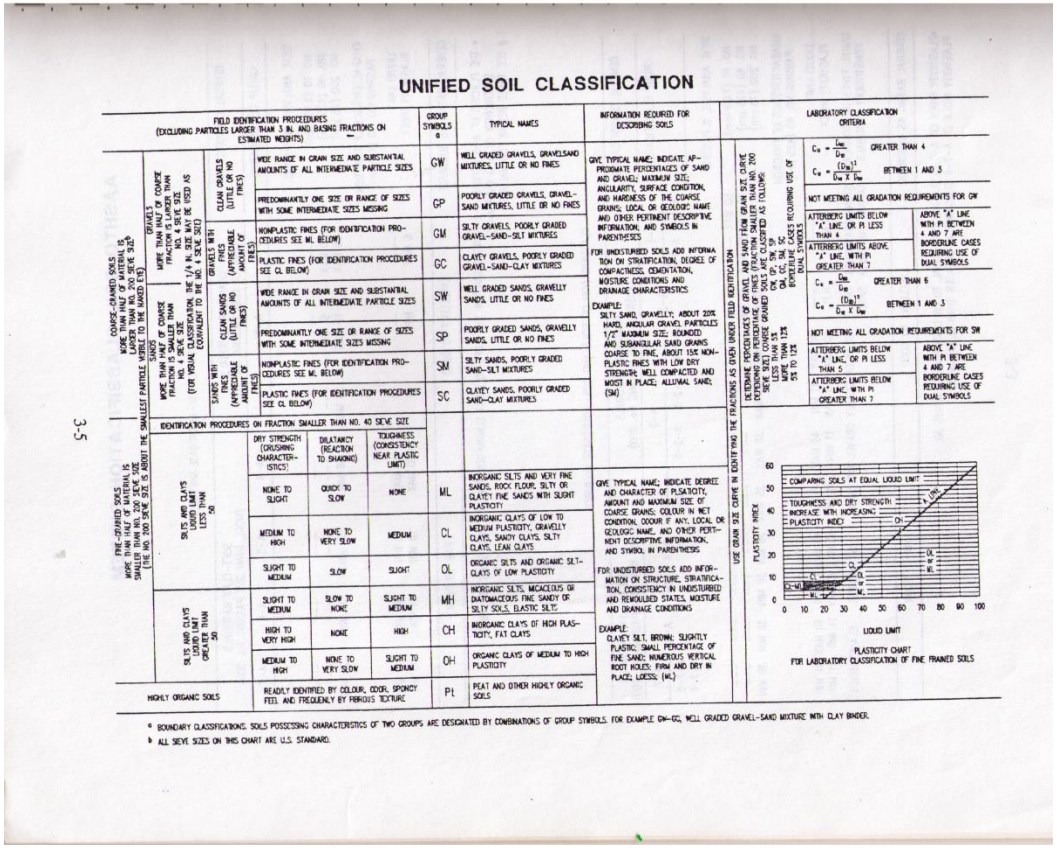


COMPARISON OF PARTICLE SIZE SCALES





USDA



UNIFIED SOIL CLASSIFICATION

Field Identification Procedures (Excluding particles larger than 3 in. and basing fractions on estimated weights)				Group Symbols	Typical Names	Information Required for Describing Soils	Laboratory Classification Criteria
Coarse-grained soils: more than half of material is larger than No. 200 sieve size	Gravels: more than half of coarse fraction is larger than No. 4 sieve size	Clean gravels (little or no fines)	Wide range in grain size and substantial amounts of all intermediate particle sizes	GW	Well graded gravels, gravel-sand mixtures, little or no fines	Give typical name; indicate approximate percentages of sand and gravel; maximum size; angularity, surface condition, and hardness of the coarse grains; local or geologic name and other pertinent descriptive information, and symbols in parentheses	$C_u = \frac{D_{60}}{D_{10}}$ Greater than 4; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3
			Predominantly one size or range of sizes with some intermediate sizes missing	GP	Poorly graded gravels, gravel-sand mixtures, little or no fines		Not meeting all gradation requirements for GW
		Gravels with fines (appreciable amount of fines)	Nonplastic fines (for identification procedures see ML below)	GM	Silty gravels, poorly graded gravel-sand-silt mixtures	For undisturbed soils add information on stratification, degree of compactness, cementation, moisture conditions and drainage characteristics. Example: Silty sand, gravelly; about 20% hard, angular gravel particles 1/2" maximum size; rounded and subangular sand grains coarse to fine, about 15% nonplastic fines with low dry strength; well compacted and moist in place; alluvial sand; (SM)	Atterberg limits below "A" line, or PI less than 4 / Atterberg limits above "A" line with PI greater than 7 — Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols
			Plastic fines (for identification procedures see CL below)	GC	Clayey gravels, poorly graded gravel-sand-clay mixtures		
	Sands: more than half of coarse fraction is smaller than No. 4 sieve size (for visual classification, the 1/4 in. size may be used as equivalent to the No. 4 sieve size)	Clean sands (little or no fines)	Wide range in grain size and substantial amounts of all intermediate particle sizes	SW	Well graded sands, gravelly sands, little or no fines		$C_u = \frac{D_{60}}{D_{10}}$ Greater than 6; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3
			Predominantly one size or range of sizes with some intermediate sizes missing	SP	Poorly graded sands, gravelly sands, little or no fines		Not meeting all gradation requirements for SW
		Sands with fines (appreciable amount of fines)	Nonplastic fines (for identification procedures see ML below)	SM	Silty sands, poorly graded sand-silt mixtures		Atterberg limits below "A" line, or PI less than 4 / Atterberg limits above "A" line with PI greater than 7 — Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols
			Plastic fines (for identification procedures see CL below)	SC	Clayey sands, poorly graded sand-clay mixtures		
Fine-grained soils: more than half of material is smaller than No. 200 sieve size (the No. 200 sieve size is about the smallest particle visible to the naked eye)	Identification procedures on fraction smaller than No. 40 sieve size						
	Silts and clays: liquid limit less than 50	Dry strength (crushing characteristics)	Dilatancy (reaction to shaking)	Toughness (consistency near plastic limit)			
		None to slight	Quick to slow	None	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity	Give typical name; indicate degree and character of plasticity, amount and maximum size of coarse grains; colour in wet condition, odour if any, local or geologic name, and other pertinent descriptive information, and symbol in parentheses. For undisturbed soils add information on structure, stratification, consistency in undisturbed and remolded states, moisture and drainage conditions. Example: Clayey silt, brown; slightly plastic, small percentage of fine sand; numerous vertical root holes; firm and dry in place; loess; (ML)
		Medium to high	None to very slow	Medium	CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	
		Slight to medium	Slow	Slight	OL	Organic silts and organic silty clays of low plasticity	
	Silts and clays: liquid limit greater than 50	Slight to medium	Slow to none	Slight to medium	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	
		High to very high	None	High	CH	Inorganic clays of high plasticity, fat clays	
		Medium to high	None to very slow	Slight to medium	OH	Organic clays of medium to high plasticity	
Highly organic soils		Readily identified by colour, odor, spongy feel and frequently by fibrous texture			Pt	Peat and other highly organic soils	

[a] Boundary classifications: Soils possessing characteristics of two groups are designated by combinations of group symbols. For example GW-GC, well graded gravel-sand mixture with clay binder.

[b] All sieve sizes on this chart are U.S. standard.

Use grain size curve in identifying the fractions as given under field identification.

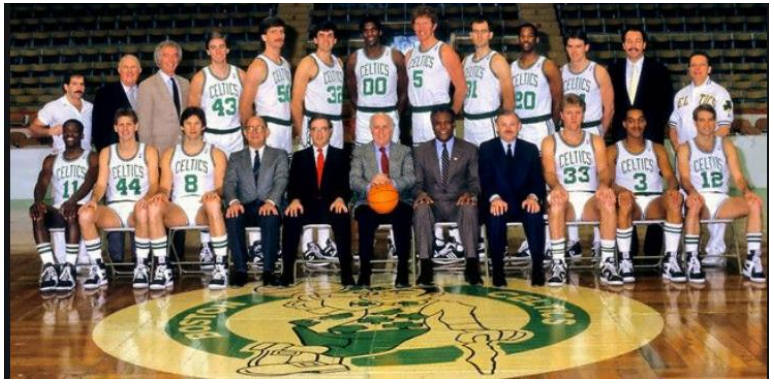
Determine percentages of gravel and sand from grain size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size) coarse grained soils are classified as follows: Less than 5% — GW, GP, SW, SP. More than 12% — GM, GC, SM, SC. 5% to 12% — Borderline cases requiring use of dual symbols.

3-5

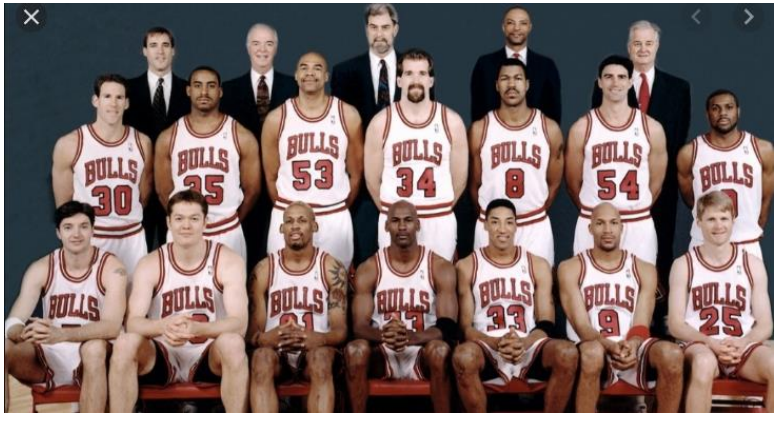
ASTM D-2487

All-Time Greatest NBA Championship Teams

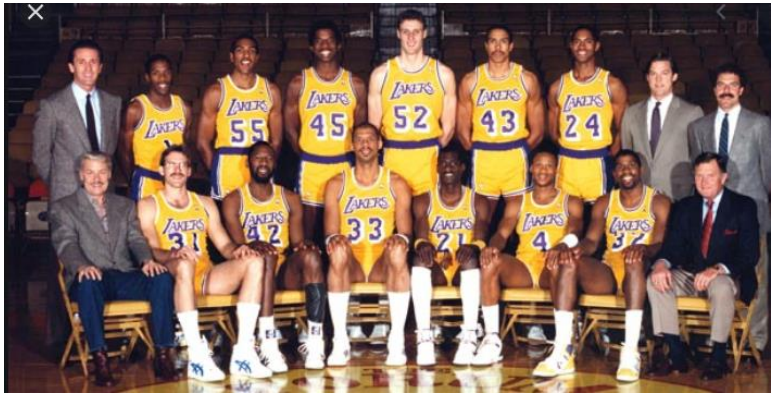
#1
‘86 Celtics



#2
’96 Bulls



#3
’87 Lakers



Questions?

Storm Water Management Using Geosynthetics

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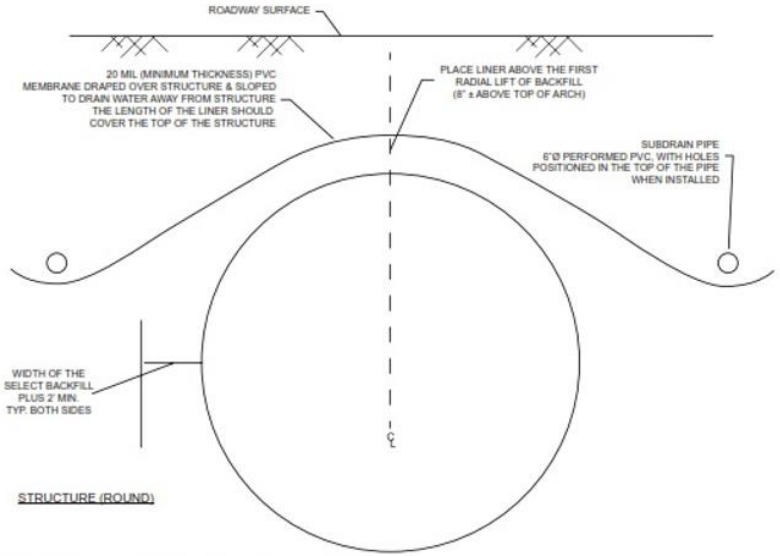


Figure 1. Nonpermeable PVC liner over culvert structure detail.

CMP Detention/Retention Systems Installation Guide

Open-graded fill is typically not used beyond the initial 18- to 24-inches because this type of fill often does not provide adequate confining restraint to the pipes. If a uniformly graded material

2019 Contech Geomembrane Solid Pipe Installation Detail where de-icing salts are used

https://www.conteches.com/knowledge-center/pdh-article-series/practical-design-considerations-that-can-extend-the-service-life-of-metal-buried-bridge-and-culvert-structures

Fully perforated CSP pipe has thirty 3/8" diameter holes per square foot,

Corrosion Protection

zinc corrodes approximately 1/10 to 1/40 the rate of steel depending on the environment…

http://www.galvanizeit.org/hot-dip-galvanizing/why-specify-galvanizing/corrosion-protection

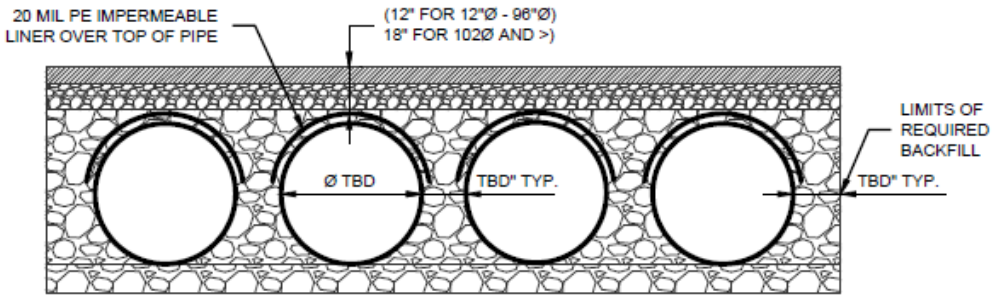
From - "Service Life Evaluation of Corrugated Steel Pipe..." Transportation Research Board 2003 Paper presented by Corrpro Companies Inc and sponsored by NCSPA (National Corrugated Steel Pipe Association): http://www.elzly.com/docs/Service_Life_Evaluation_of_Corrugated_Steel_Pipe_Storm_Water_Detention_Systems_in_the_Metropolitan_DC_Area.pdf

"In fact, some systems are developed with a slotted pipe (undesirable from a corrosion perspective as the edges corrode quicker than the coated material..."

GEOMEMBRANE BARRIER

A SITE'S RESISTIVITY MAY CHANGE OVER TIME WHEN VARIOUS TYPES OF SALTING AGENTS ARE USED, SUCH AS ROAD SALTS FOR DEICING AGENTS. IF SALTING AGENTS ARE USED ON OR NEAR THE PROJECT SITE, A GEOMEMBRANE BARRIER IS RECOMMENDED WITH THE SYSTEM. THE GEOMEMBRANE LINER IS INTENDED TO HELP PROTECT THE SYSTEM FROM THE POTENTIAL ADVERSE EFFECTS THAT MAY RESULT FROM THE USE OF SUCH AGENTS INCLUDING PREMATURE CORROSION AND REDUCED ACTUAL SERVICE LIFE.

THE PROJECT'S ENGINEER OF RECORD IS TO EVALUATE WHETHER SALTING AGENTS WILL BE USED ON OR NEAR THE PROJECT SITE, AND USE HIS/HER BEST JUDGEMENT TO DETERMINE IF ANY ADDITIONAL PROTECTIVE MEASURES ARE REQUIRED. BELOW IS A TYPICAL DETAIL SHOWING THE PLACEMENT OF A GEOMEMBRANE BARRIER FOR PROJECTS WHERE SALTING AGENTS ARE USED ON OR NEAR THE PROJECT SITE.



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