Performance and Design of Subsurface Gravel Wetland Systems for Stormwater Management

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Historic Perspective

Wetlands First Used for Wastewater

- First emerged as a wastewater treatment technology in Western Europe based on research commencing in the 1960s (vertical flow) and further developed and expanded through 1980s.
- Early developmental work in the United States commenced in the early 1980s

US Wastewater Implementation

- ca 1980’s
- Advantages
  - Subsurface water prevention of mosquitoes
  - Odor minimization
  - Elimination of the risk of public contact with the partially treated wastewater
- Secondary or tertiary treatment of wastewater
- Believed to be ineffectual for CSOs

Aliases

- Rock reed filters
- Vegetated submerged bed (VSB) wetlands,
- Shallow horizontal flow wetlands

For Wastewater Design

- Originally suggested that systems have a high aspect ratio (L:W) to ensure maintenance of plug flow conditions and high levels of performance (BOD removal). A common recommendation indicated that the L:W should be at least 10:1. EPA performance study found that no penalty for aspect ratio. What is important is **plug flow**.
- Hydraulic loading rates of 3-14 cm/d
- Hydraulic residence time of 1-6 days (for BOD removal) – 1 to 2 days is effective
- Plant material might account for ten percent or less of the nitrogen- removed by the system
- Media depth in most of the beds in the U.S. is about 0.6 m (2 ft), but in most cases, plant roots have been observed to penetrate only to 0.3 m (1 ft) or less

Reed, 1995

For Stormwater

- 1977 EPA report discussed use of *surface wetland* for stormwater treatment in MN pilot study
- First reported SGW study for stormwater runoff 1987 Lake Tahoe
  - Good removals for: nitrate, iron, TSS, turbidity
  - Asserted denitrification through anaerobiosis
  - N removal depends on detention time
  - No flow measurements, so RE based on mean monthly concentrations

Reuter, Djohan and Goldman, 1992

For Stormwater

- SGW in FL to treat runoff from 121-acre industrial site – showed great removal for sediment, fecal coliforms, and nutrients
- Wetland vegetation had no discernible influence on pollutant removal
- Rock surfaces themselves were more important in pollutant removal, by creating a large substrate area for growth of epilithic algae and microbes, reducing flow rates, and providing more contact surfaces.

Egan, T.J. S. Burroughs and T. Attaway. 1995

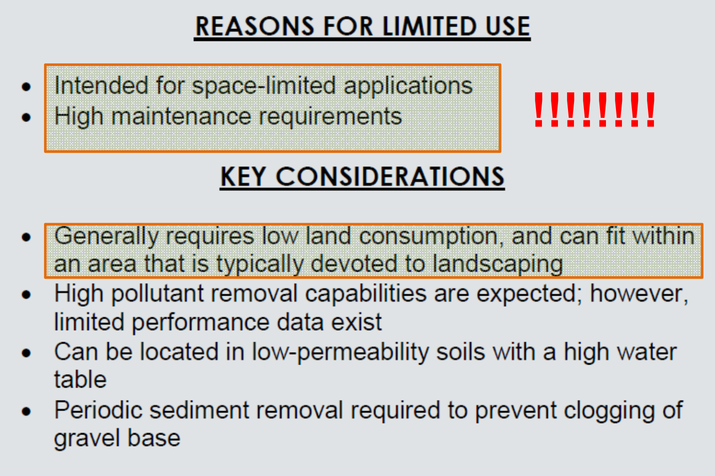
A common reference

- 1996 CWP *Design of Stormwater Filtering Systems*

2001 GA Stormwater Management Manual Volume 2

- **LIMITED APPLICATION STRUCTRUAL STORMWATER CONTROLS**
- **Referenced** Center for Watershed Protection; Roux Associates Inc.)

Continue to find 1990's info



REASONS FOR LIMITED USE

- Intended for space-limited applications
- High maintenance requirements

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KEY CONSIDERATIONS

- Generally requires low land consumption, and can fit within an area that is typically devoted to landscaping
- High pollutant removal capabilities are expected; however, limited performance data exist
- Can be located in low-permeability soils with a high water table
- Periodic sediment removal required to prevent clogging of gravel base

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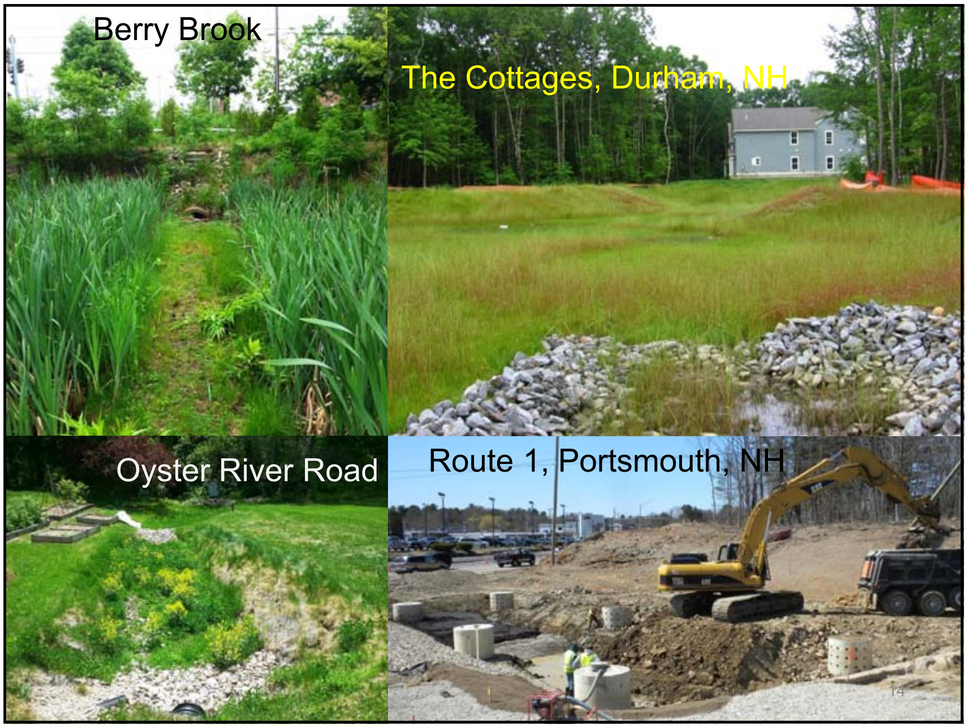
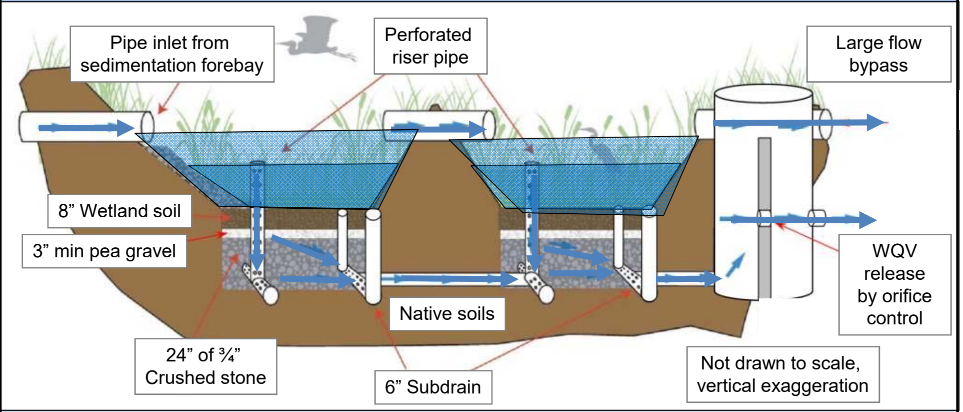
FUNCTIONALITY AND PERFORMANCE

Subsurface Gravel Wetland #1 at UNH



UNHSC Subsurface Gravel Wetland



Pipe inlet from sedimentation forebay

Perforated riser pipe

Large flow bypass

8" Wetland soil

3" min pea gravel

WQV release by orifice control

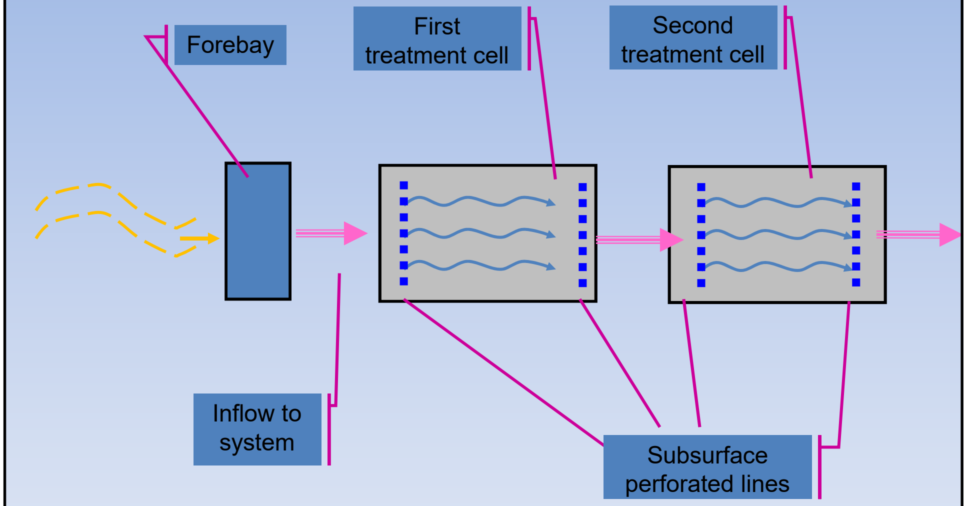
Native soils

24" of ¾" Crushed stone

6" Subdrain

Not drawn to scale, vertical exaggeration

Design Sources:
UNHSC, Roseen, R. M., Ballestero, T. P., and Houle, J. J. (2008). "UNHSC Subsurface Gravel Wetland Design Specifications." University of New Hampshire Stormwater Center, Durham, NH.
Claytor, R. A., and Schueler, T. R. (1996). Design of Stormwater Filtering Systems, Center for Watershed Protection, Silver Spring, MD.
Georgia Stormwater Management Manual, Volume 2: Technical Handbook, August 2001, prepared by AMEC Earth and Environmental, Center for Watershed Protection, Debo and Associates, Jordan Jones and Goulding, Atlanta Regional Commission.



Forebay

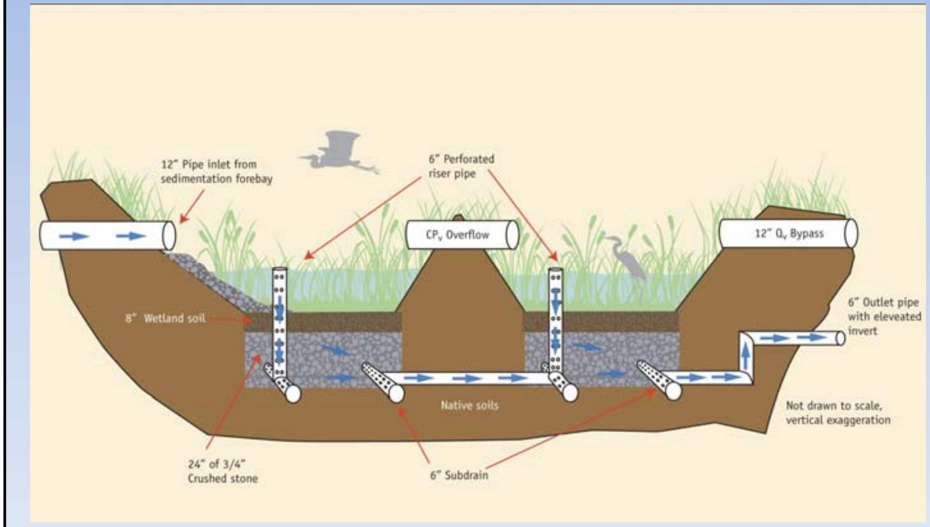
First treatment cell

Second treatment cell

Inflow to system

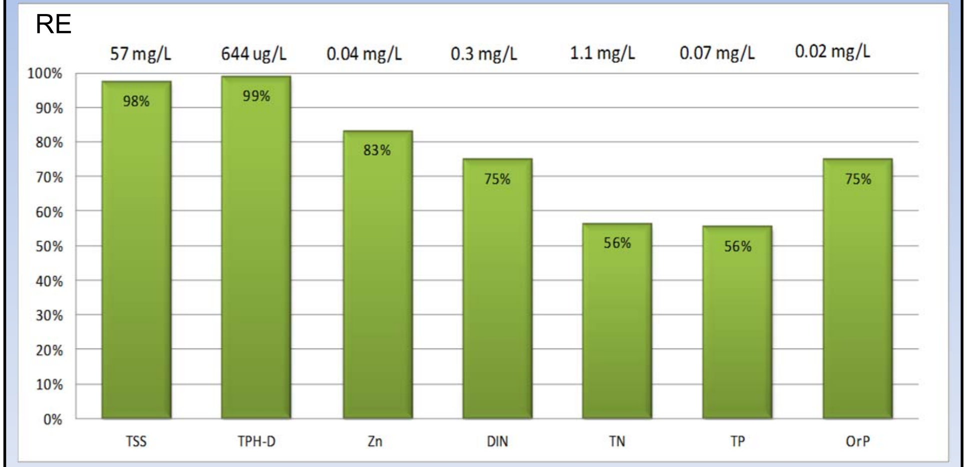
Subsurface perforated lines

Subsurface Gravel Wetland Components

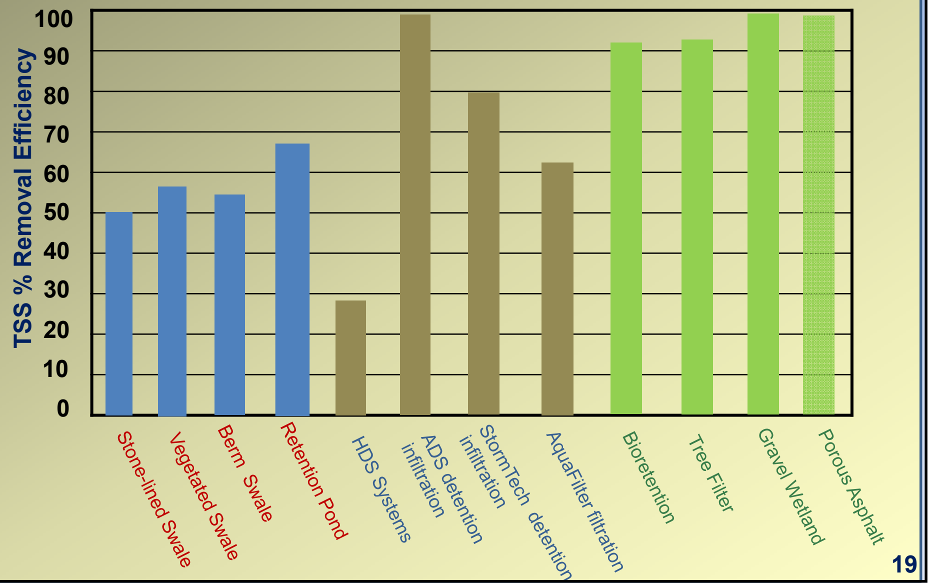


Subsurface Gravel Wetland MedianRemoval Efficiencies

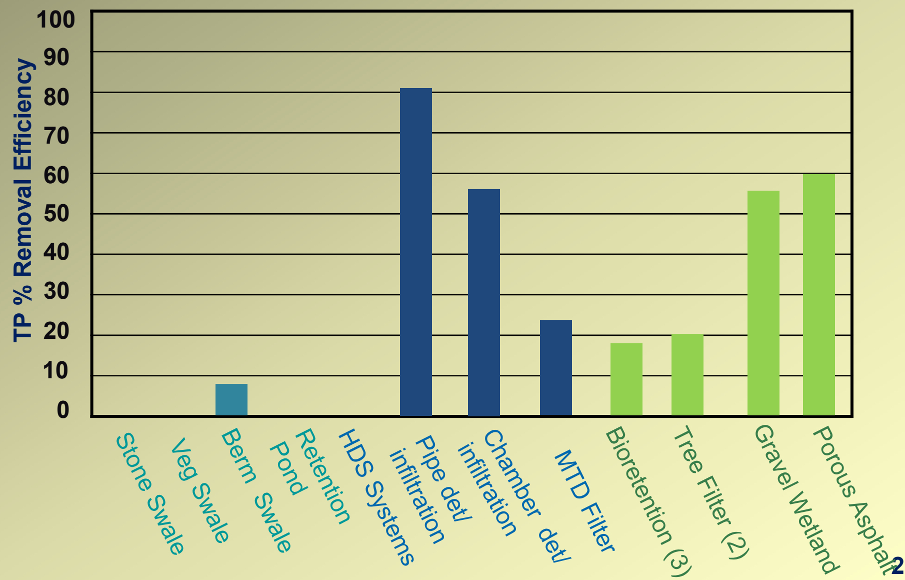
6 years of data with Influent EMC medians



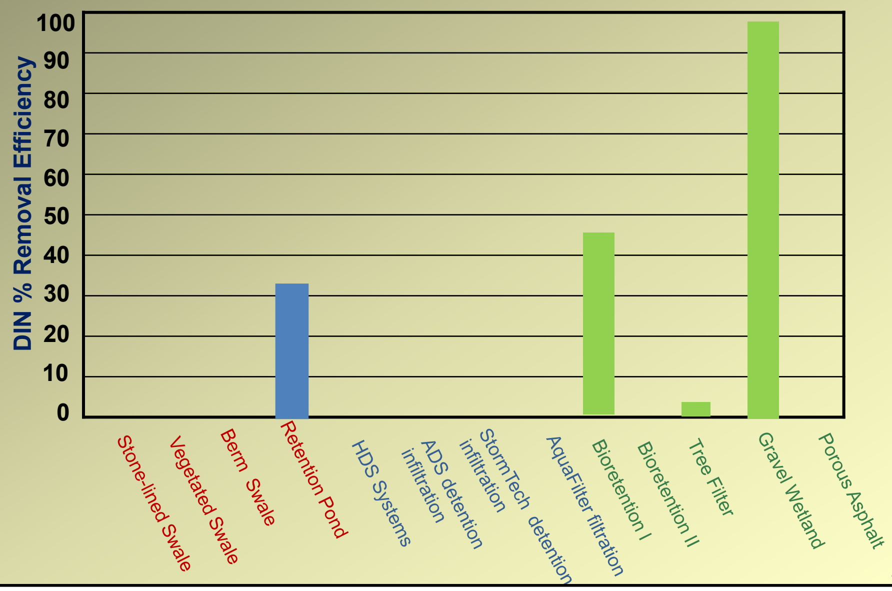
TSS Removal Efficiencies



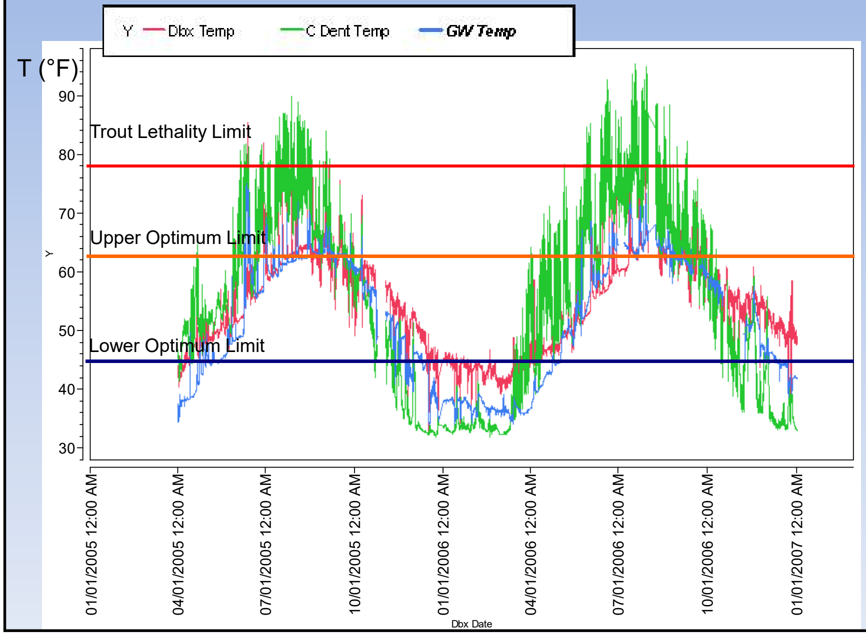
TP Removal Efficiencies



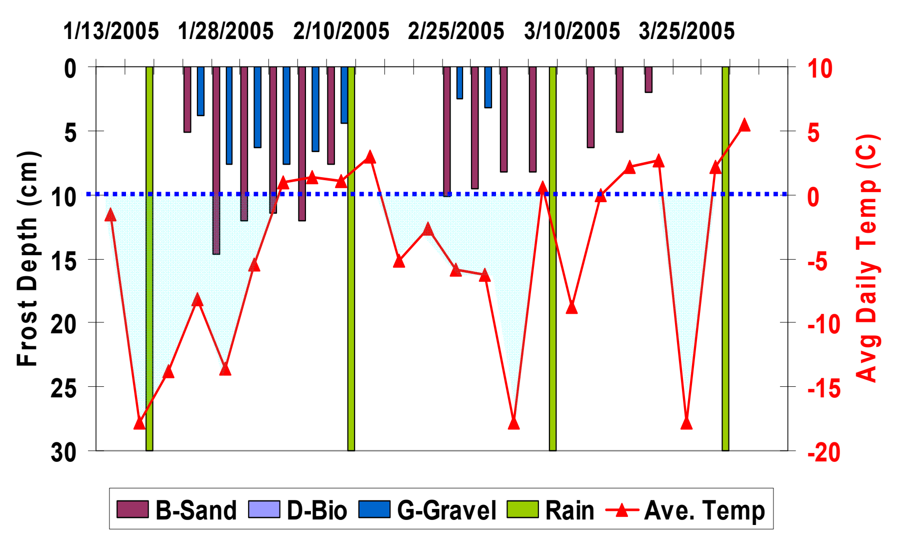
DIN Removal Efficiencies



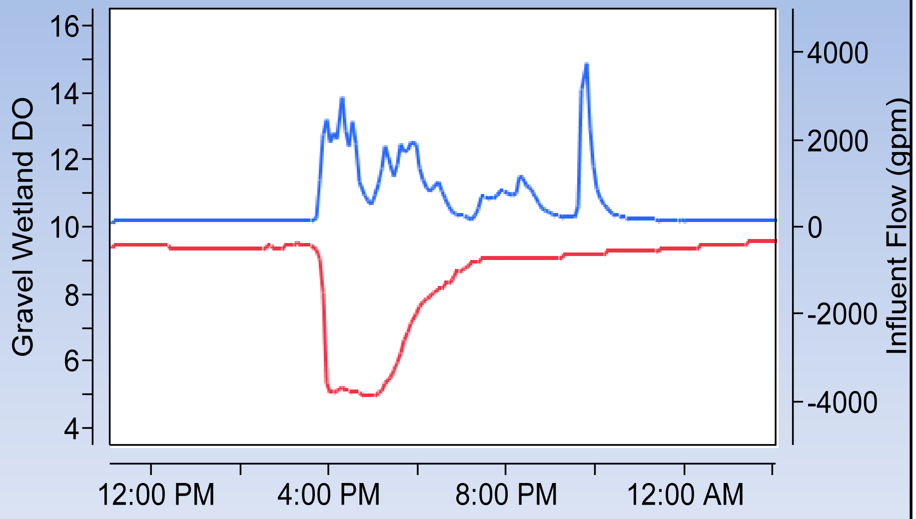
Thermal Impacts



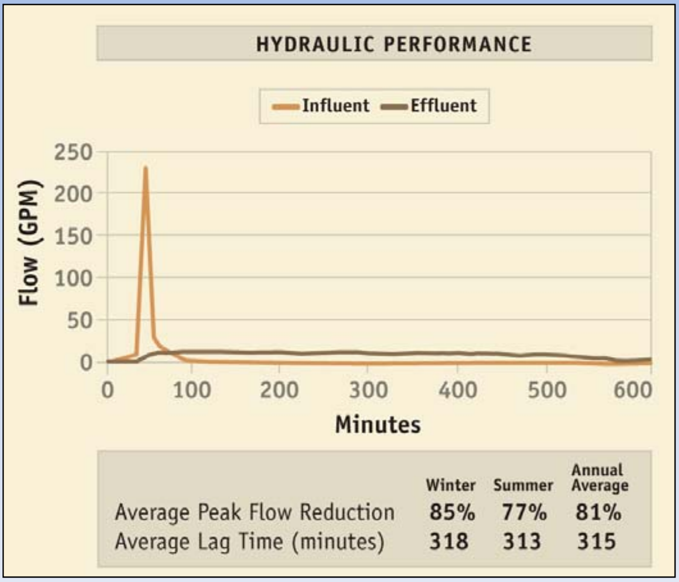
Filter Media Frost Penetration



Dissolved Oxygen in Gravel Wetland Effluent



Subsurface Gravel Wetland Hydraulic Performance



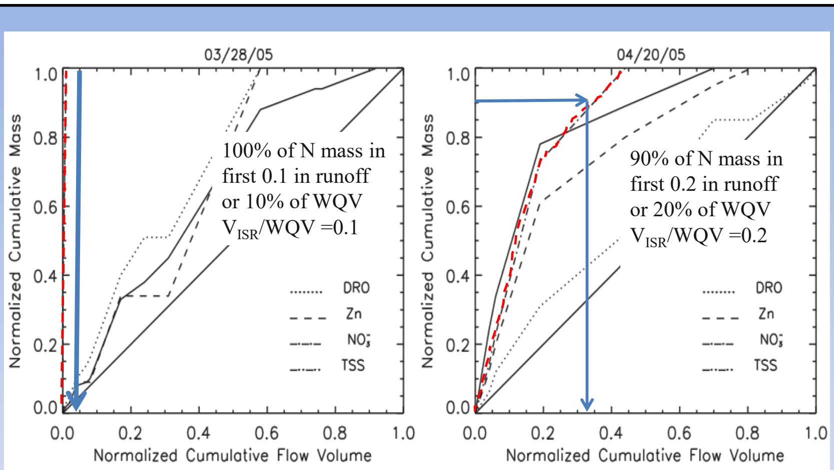
	Winter	Summer	Annual Average
Average Peak Flow Reduction	85%	77%	81%
Average Lag Time (minutes)	318	313	315

Unit Operations & Processes (UOPs) in the Gravel Wetland

- Physical Operations
- Biological Processes
- Chemical Processes
- Hydrologic Operations

Gravel Wetland Report Card

category	uop	target	"grade"
hydrologic	flow alteration	divert flow	✓
	volume reduction		
physical	sedimentation	sediment	✓
	enhanced sedimentation	sediment	
	filtration	sediment	✓
biological	microbial	nitrogen	✓+
	vegetative	nitrogen phosphorus	✓+
chemical	sorption	phosphorus	✓

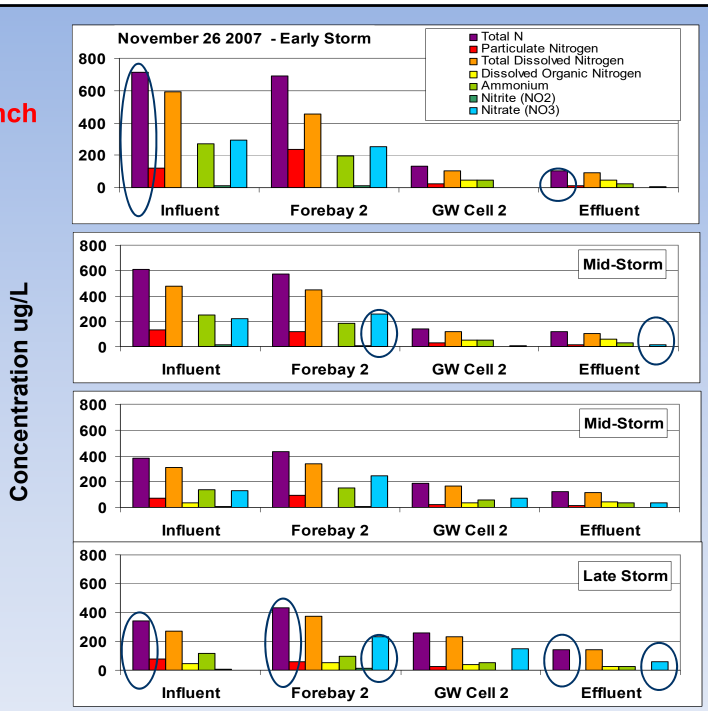


100% of N mass in first 0.1 in runoff or 10% of WQV V_{ISR}/WQV =0.1

90% of N mass in first 0.2 in runoff or 20% of WQV V_{ISR}/WQV =0.2

Mass loading for DRO, Zn, NO3, TSS as a function of normalized storm volume for two storms: (a) a large 2.3 in rainfall over 1685 minutes; (b) a smaller 0.6 in storm depth over 490 minute. DRO=diesel range organics, Zn= zinc, NO3= nitrate, TSS= total suspended solids

0.79 inch storm



NITROGEN

Nitrogen in Stormwater

- In Stormwater Nitrogen is dominated by organic forms in rural areas but shifts toward DIN in urban environments
- Organic N is highly reactive and can change forms in soils due microbial and fungal activity
- Microbial decomposition of organic matter produces reduced NH_3 which is treated commonly through biological oxidation (nitrified) to NO_2/NO_3 and then treated by biological reduction anaerobically to N_2

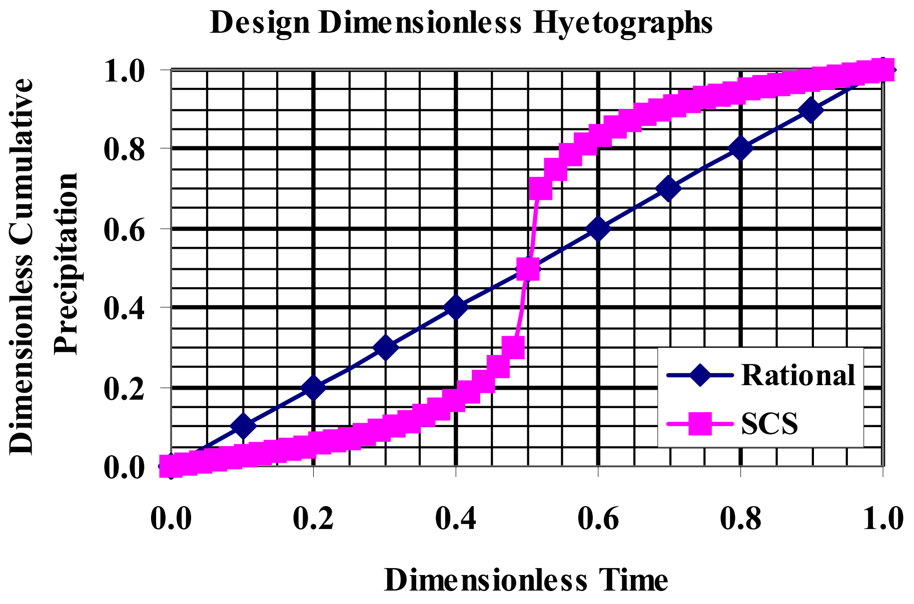
Source	TN (mg/L)	Organic – N (mg/L)	DIN (NO3) (mg/L)	Organic - N	Dissolved Inorganic - N (NO3)
UNHSC Data	1.10	0.79	0.31	72%	28%
Driscol, et al 1990	2.63	1.79	0.84	68%	32%
NURP, 1983	2.64	1.90	0.74	72%	28%

Phosphorous in Stormwater

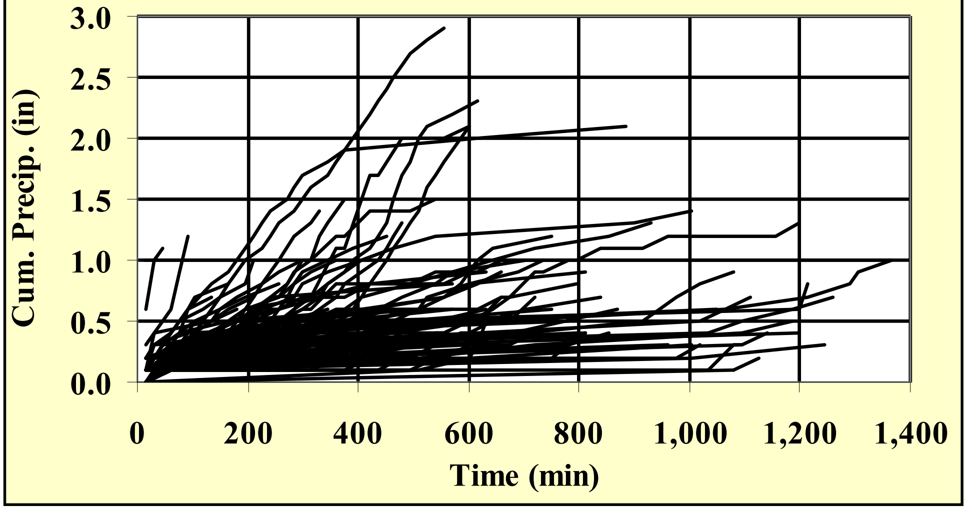
- In Stormwater, Phosphorus is dominated by particulate forms consisting of organic and inorganic species ionically bound to particles or in colloidal organic compounds
- Particulate P is highly reactive and can change forms in soils due to pH and microorganism activity

Source	TP (mg/L)	Ortho-Phosphate (mg/L)	Particulate/Colloidal P (%)	Dissolved inorganic P (Ortho-Phosphate)
UNHSC Data	.08	.02 (detected in 2 out of 50 events)	97%	3%
Sansalone, et al 2010	NR	NR	67% - 75 %	0.25% – 0.33%
NURP, 1983	0.20	.08	60%	40%

Modeling Hydrology



Sampling of Observed Hyetographs
Durham, NH NOAA Gage



Performance analysis of two relatively small capacity urban retrofit stormwater controls

Sizing Details

System	WQV ft^3 (m^3)	Actual WQV ft^3 (m^3)	% of normal design	Rain Event in (mm)	Sizing Method
SGWSC	7,577 (214.6)	720 (20.4)	10%	0.10 (2.5)	Static
IBSCS	1,336 (37.8)	310 (8.8)	23%	0. 23 (5.8)	Dynamic

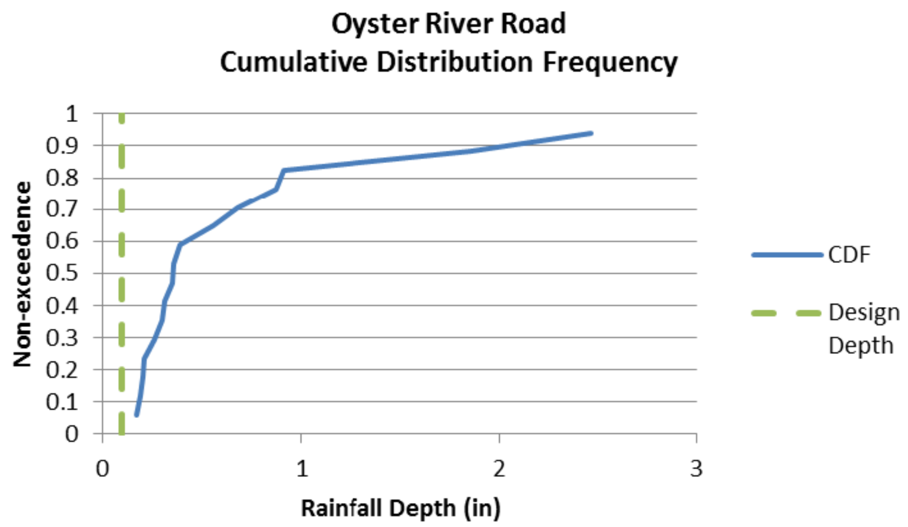
$$WQV = \left(\frac{P}{12}\right) x\ IA$$

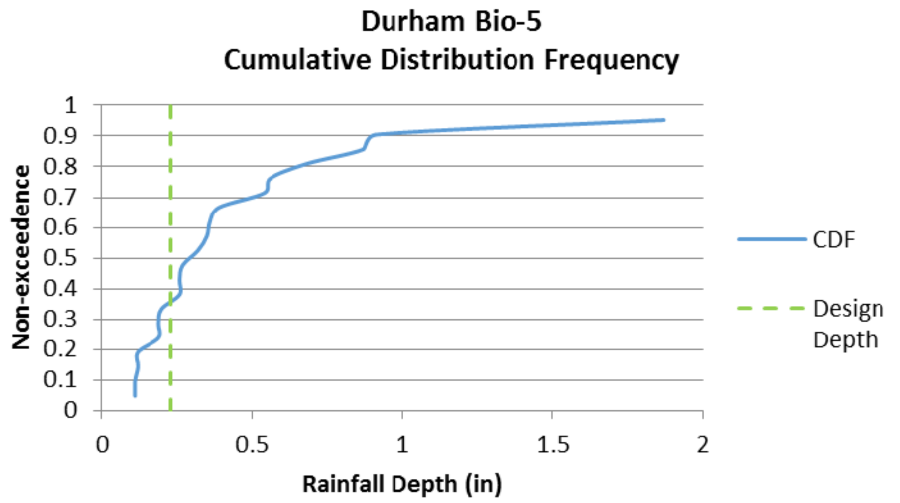
Dynamic Bioretention Sizing

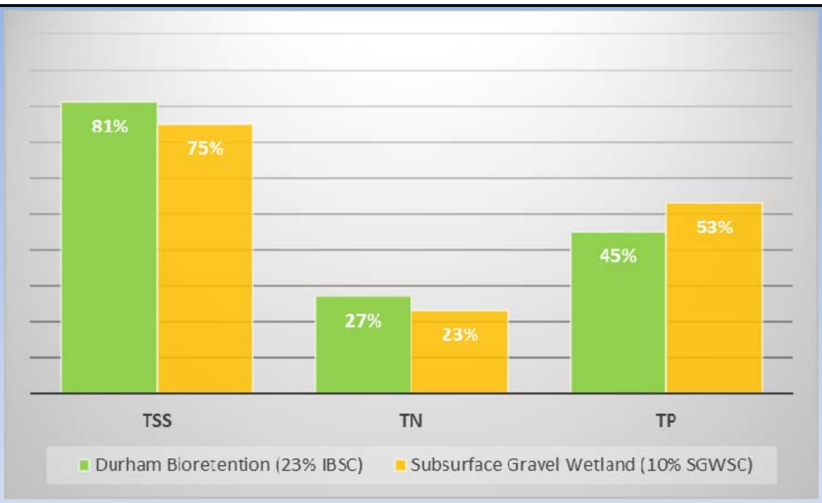
$$Af = Vwq * \frac{df}{(i(hf + df)tf)}$$

Static SGW System Sizing

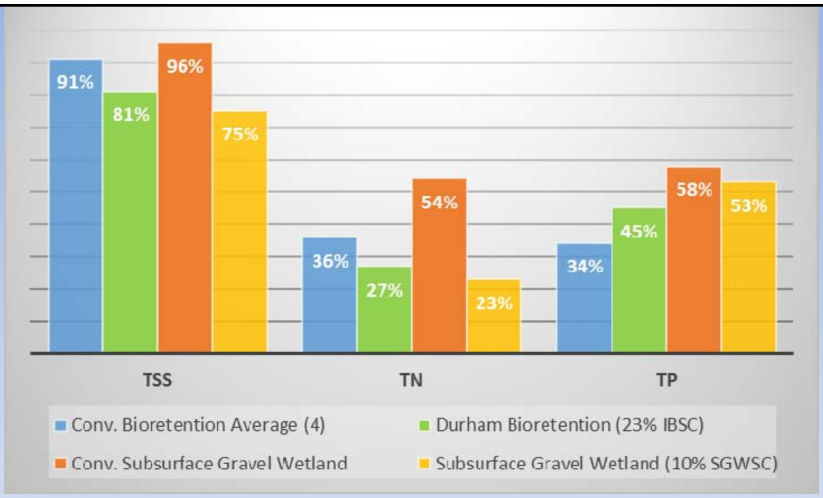
$$Q = CdA\sqrt{2gh}$$


Oyster River Road
Cumulative Distribution Frequency
Non-exceedence
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
Rainfall Depth (in)
CDF
Design Depth


Durham Bio-5
Cumulative Distribution Frequency
Non-exceedence
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.5
1
1.5
2
Rainfall Depth (in)
CDF
Design Depth



System	TSS	TN	TP
Durham Bioretention (23% IBSC)	81%	27%	45%
Subsurface Gravel Wetland (10% SGWSC)	75%	23%	53%



System	TSS	TN	TP
Conv. Bioretention Average (4)	91%	36%	34%
Durham Bioretention (23% IBSC)	81%	27%	45%
Conv. Subsurface Gravel Wetland	96%	54%	58%
Subsurface Gravel Wetland (10% SGWSC)	75%	23%	53%

Stormwater Management Design - 70.5 acre Ultra-Urban Drainage Area

Sizing Comparison of Capital Costs and Relative Phosphorus Load Removal Efficiency

Best Management Practice Size	Depth of Runoff Treated from Impervious Area (in)	*Storage Volume Cost ($/ft³)	**Total Phosphorus Removal Efficiency (%)
Subsurface Gravel Filter - Minimum Size	0.35	$1,016,912	62%
Subsurface Gravel Filter - Moderate Size	0.5	$1,452,732	80%
Subsurface Gravel Filter - Full Size	1.0	$2,905,463	96%

*Storage Volume Cost estimates provided by EPA-Region 1 for Opti-Tool methodology, 2015-Draft

**Total Phosphorus %RE based on Appendix F Massachusetts MS4 Permit

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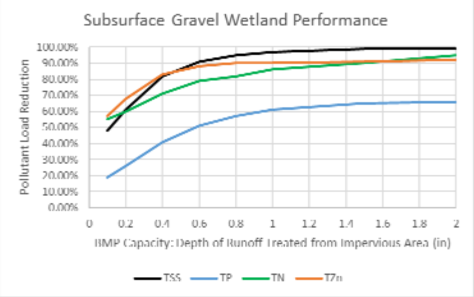
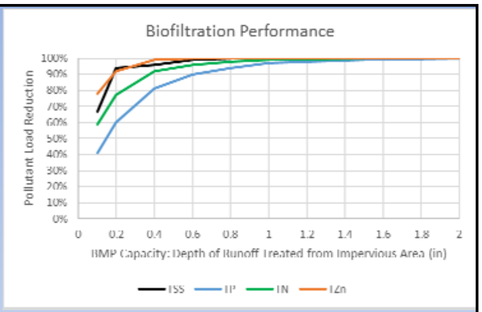




physical storage capacity - runoff depth from IA (in)

Analyte	Depth txt	Modeled RE	Measured RE
TSS	0.1	48	75
TZn	0.1	57	75
TN	0.1	55	23
TP	0.1	19	53

Analyte	Depth txt	Modeled RE	Measured RE
TSS	0.23	70	81
TZn	0.23	88	86
TN	0.23	60	27
TP	0.23	35	45

Column Study of Nutrient Removal

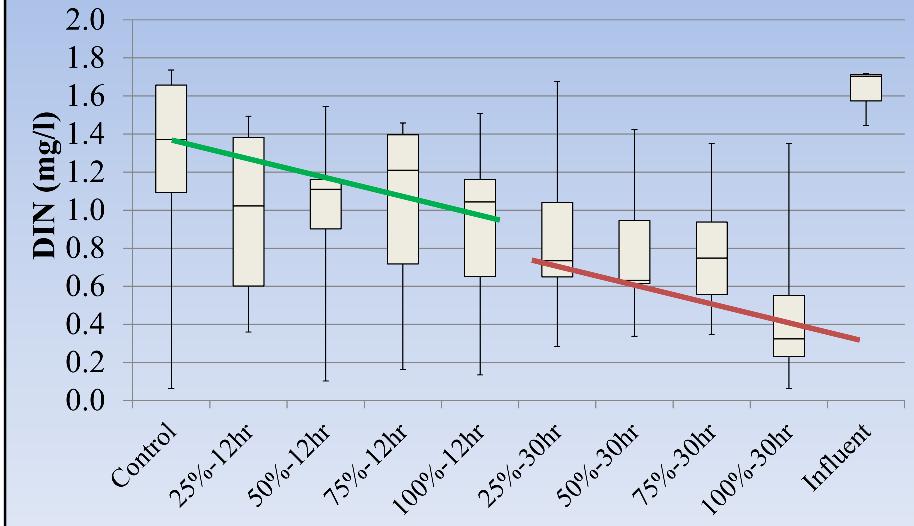
- Amendments for Phosphorus
  - Alum sludge
  - Zero valent iron
  - Limestone sand
  - Electric blast furnace slag
- Internal storage volume for nitrogen
- Effect of compost

Phase 1: Nitrogen

Column #	Soil Mix and saturation zone size	Notes
T1-N0	UNHSC BSM with no saturation zone (control)	• Drainage to filter ratio 80:1 • Soil depth in columns: 24” • 12 hour drain time • Soil tested: UNHSC mix
T1-N1	UNHSC BSM with 25% WQV	
T1-N2	UNHSC BSM with 50% WQV	
T1-N3	UNHSC BSM with 75% WQV	
T1-N4	UNHSC BSM with 100% WQV	
T1-N5	UNHSC BSM with 25% WQV	• Drainage to filter ratio 80:1 • Soil depth in columns: 24” • 30 hour drain time • Soil tested: UNHSC mix
T1-N6	UNHSC BSM with 50% WQV	
T1-N7	UNHSC BSM with 75% WQV	
T1-N8	UNHSC BSM with 100% WQV	

- Size ISR
- Retention Time

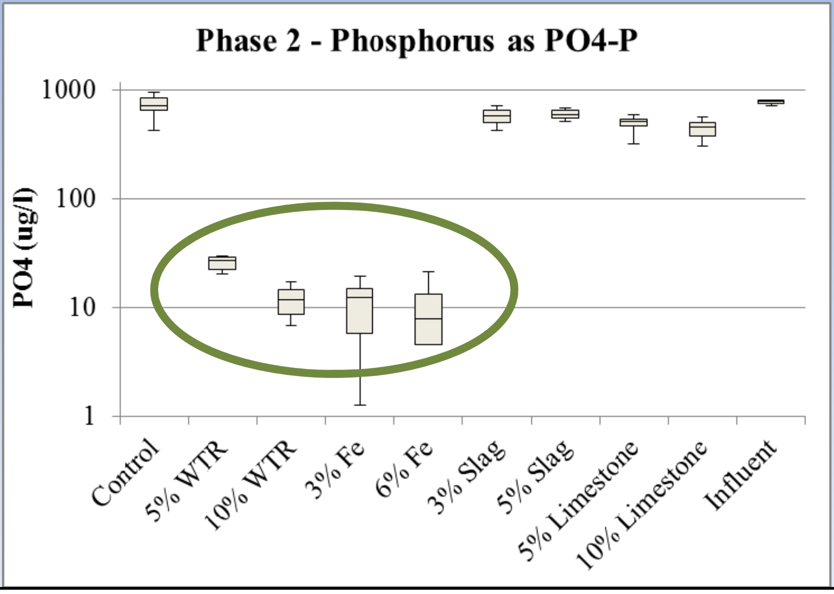
Nitrogen Results



Phase 2: Phosphorus

Column #	Soil Mix	Notes
T2-P0	UNHSC BSM (control)	- Drainage to filter ratio 80:1 - Soil depth in columns: 24” - 24 hour drain time - Soil tested: UNHSC mix
T2-P1	UNHSC 95% BSM + 5% WTR	
T2-P2	UNHSC 90% BSM + 10% WTR	
T2-P3	UNHSC 97% BSM+3% Fe_2	
T2-P4	UNHSC 94% BSM+6% Fe_2	
T2-P5	UNHSC 97% BSM+3% Slag	
T2-P6	UNHSC 95% BSM+5% Slag	
T2-P7	UNHSC 95% BSM +5% Limestone	
T2-P8	UNHSC 90% BSM +10% Limestone	

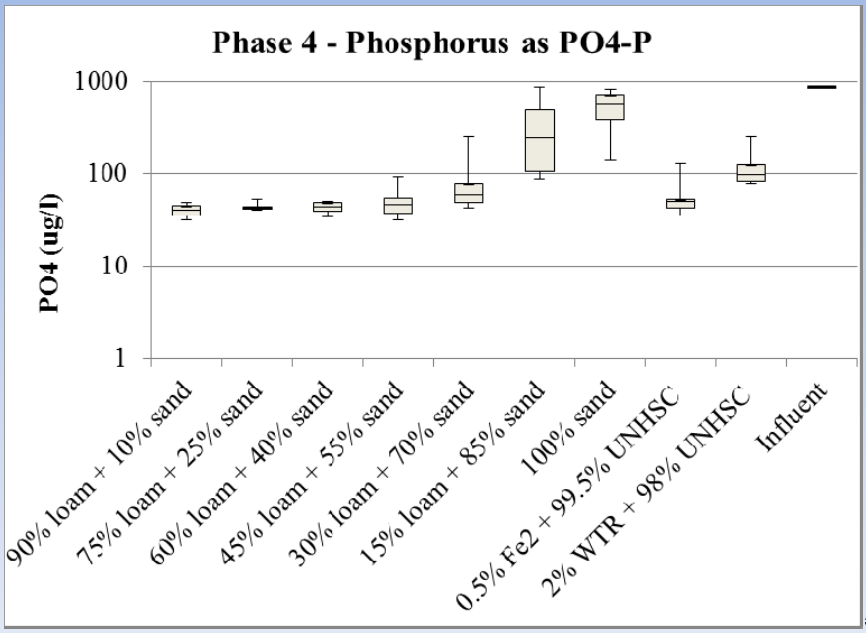
Phosphorus Results



Phase 3: Phosphorus Optimization

Column #	Soil Mix	Notes
T4-P1	90% Stantec loam + 10% sand	• Drainage to filter ratio 25:1 • Soil depth: 12” • Percentage of amending materials was based on test results from Phases 2 and 3
T4-P2	75% Stantec loam + 25% sand	
T4-P3	60% Stantec loam + 40% sand	
T4-P4	45% Stantec loam + 55% sand	
T4-P5	30% Stantec loam + 70% sand	
T4-P6	15% Stantec loam + 85% sand	
T4-P7	100% sand	
T4-P8	0.5% Fe_2 + 99.5% UNHSC mix	
T4-P9	2% WTR + 98% UNHSC mix	

Optimization Results



Conclusions - the obvious!

- Compost leaches nutrients
- Filters are superior at sediment removal
- Hydraulic loading ratio and retention time have a large influence on performance

Conclusions – the promising…

- Modified bio systems show remarkable improvements to DIN and Ortho-P removals in the lab and in the field: ~ 60 - >90%
- Nitrogen removal is less media dependent and improves with ISR and with longer retention
- Loam has an excellent P-sorp capacity and should be incorporated in higher proportions in BSM

Conclusions – the curious…

- Details regarding BSM components are vague at best
- If optimal RE are to be achieved designs should be fine tuned and systems maintained

Performance Comparisons

Subsurface Gravel Wetland System Design and Sizing

Design Criteria

- Water Quality Volume (WQv)
- Channel Protection Volume (Q_2)
- Extreme Storm Volume (Q_{10})

WQV

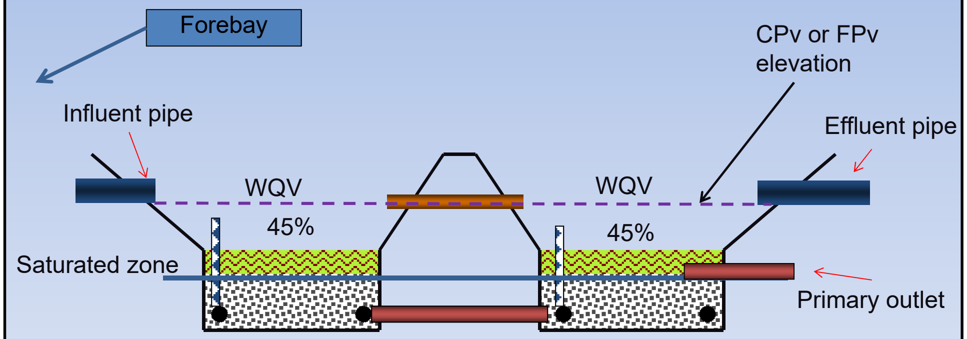
- In NH and many other jurisdictions, the WQV is a static sizing criteria meaning it is the calculated volume resulting from the WQ storm depth (1 inch in 24 hrs) across the drainage area (1 acre parking lot = 3,300 cf). Across the northeast US, the WQV varies form 1 to 1.3 inches.
- A GI filter systems typically need to provide storage and treatment for the WQV as if it were delivered instantaneously.

Static vs Dynamic

- Static – water volume instantaneously into system thus system must be able to hold the entire WQV before it is processed
- Dynamic – water enters and leaves the system at the same time

For the same WQV, dynamically-sized systems are smaller

Generic Cross-Section



Design Criteria

- Water Quality Volume (WQv)
  - Based on a rainfall frequency analysis for a given area.
  - Rainfall frequency spectrum will determine the rainfall depth corresponding to 90% of total depth annual rainfall.
  - Economic sizing and treats > 90% of the annual storm events (first inch of large storms also treated

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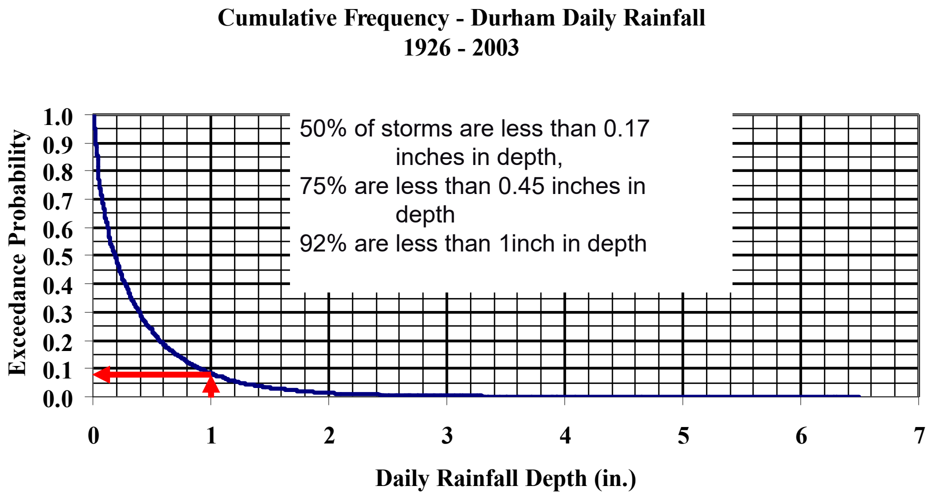
92 % of daily precipitation is 1-inch or less



50% of storms are less than 0.17 inches in depth,
75% are less than 0.45 inches in depth
92% are less than 1inch in depth

Calculating the WQV

WQV = (P1)(Rv)(A)

P1 = 90% Rainfall Event (inches)
(typically 0.75 to 1.25 inches)

Rv = dimenshionless runoff coefficient:
Rv = 0.05+ 0.9(I)

I = percent impervious cover draining to the structure converted to decimal form

A = total site area draining to the structure

Calculating WQV

WQV = (P1)(Rv)(A)

WQV = (1 in) (0.05+0.9(.95)) (1 acre)
= **0.91** ac-in

X 43,560 ft^2/acre X 1ft/12 in =**3,285** ft^3

Critical Design Elements

1.) Pretreatment: Can be hydrodynamic separators, swales, or other basin that is capable of holding 5-10% of the WQV.

2.) Two Treatment Cells: -45% of the WQV held in each of 2 treatment cells ABOVE GROUND. Not the volume of internal storage reservoir.

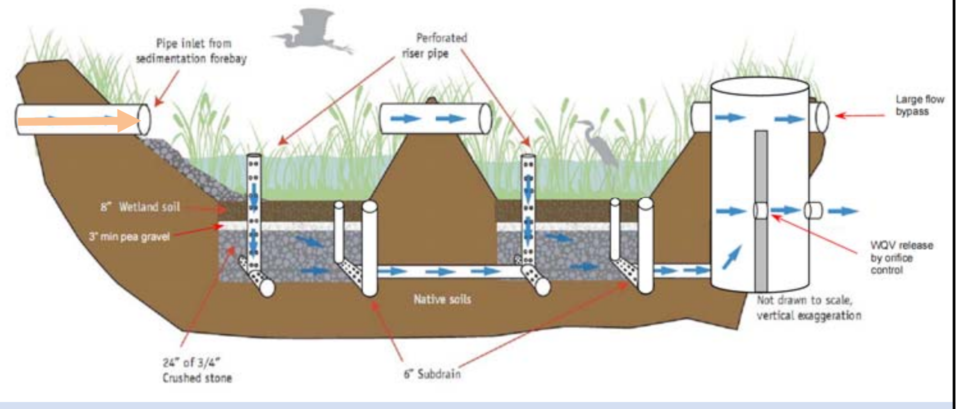
3.) Travel length through the gravel should be a minimum of 15 ft

4.) No Geotextile between soil and crushed stone

5.) Underlying soils should have low permeability (hydraulic conductivity ≤ 0.03 ft/day), may need a liner if not

Subsurface Gravel Wetland

1) Sedimentation Forebay



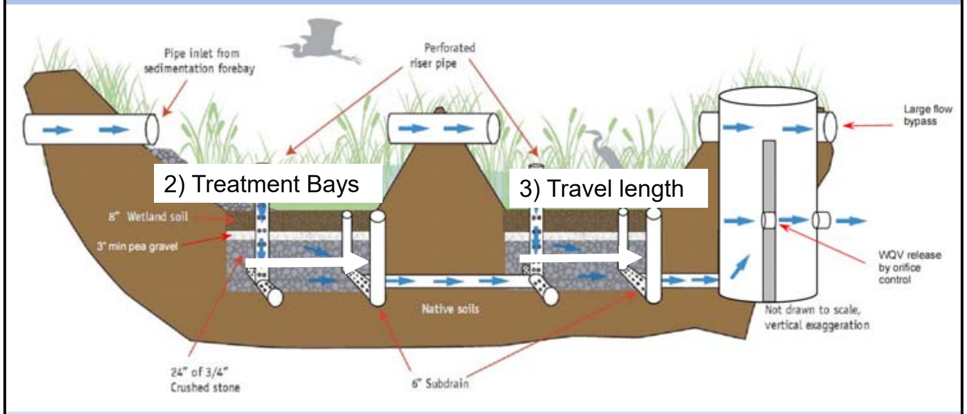
Critical Design Elements: Pretreatment

1.) Pretreatment: remove large solids and floating debris

- Pretreatment is highly recommended.
- Can be manufactured systems, swales, or other basin (forebay) that is capable of holding upwards of 10% of the WQV.
- Plunge pool in excess of 1 m in depth

Example forebay volume: 0.10 X 3,285 ft^3 = 329 ft^3

Subsurface Gravel Wetland



Critical Design Elements: Treatment Cells

2) Two Treatment Cells: 45% (NJ 50%) of the WQV held in each of 2 treatment cells ABOVE GROUND.

Ex: $0.45 \times 3{,}285\ ft^3 = 1{,}480\ ft^3$

3) Travel length through the gravel layer should be a minimum of 15 ft

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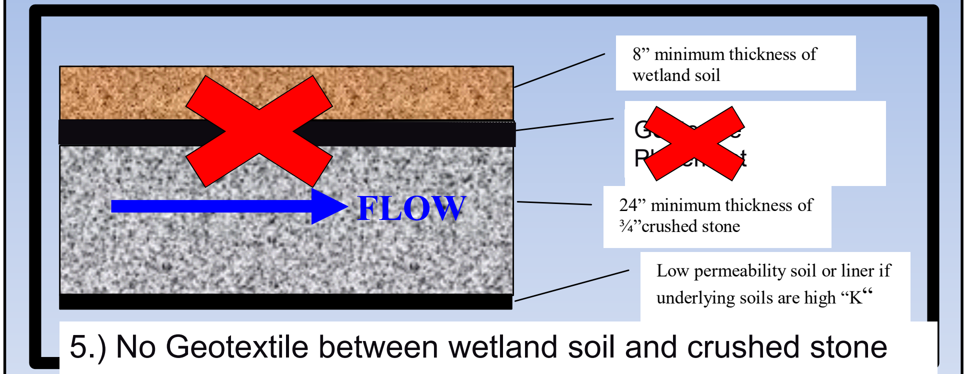
Critical Design Elements: Treatment Cells

4) Depth of ponding

- forebay 2- 4 ft common range
- SGW cells 6 – 18-in. preferable (depends on vegetation)

GW Cross-section



8” minimum thickness of wetland soil

24” minimum thickness of ¾”crushed stone

Low permeability soil or liner if underlying soils are high “K“

5.) No Geotextile between wetland soil and crushed stone

Graded Filter

$$D_{15,\,COARSE\ \ SUBLAYER} \le 5\ X\ D_{85,\,SETTING\ \ BED}$$

$$D_{50,\,COARSE\ \ SUBLAYER} \le 25\ X\ D_{50,\ SETTING\ \ BED}$$

Materials

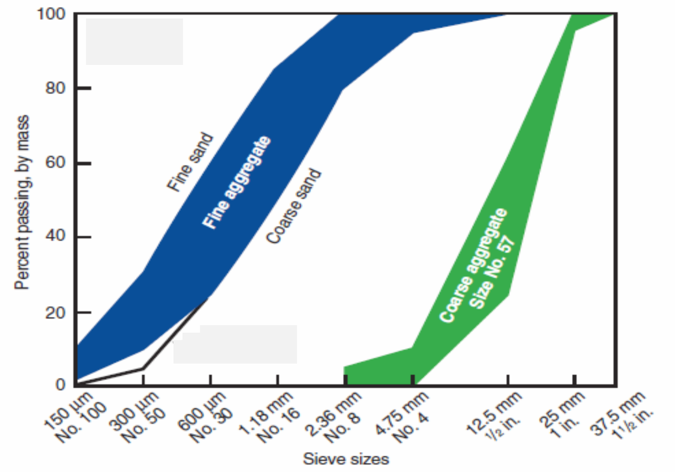
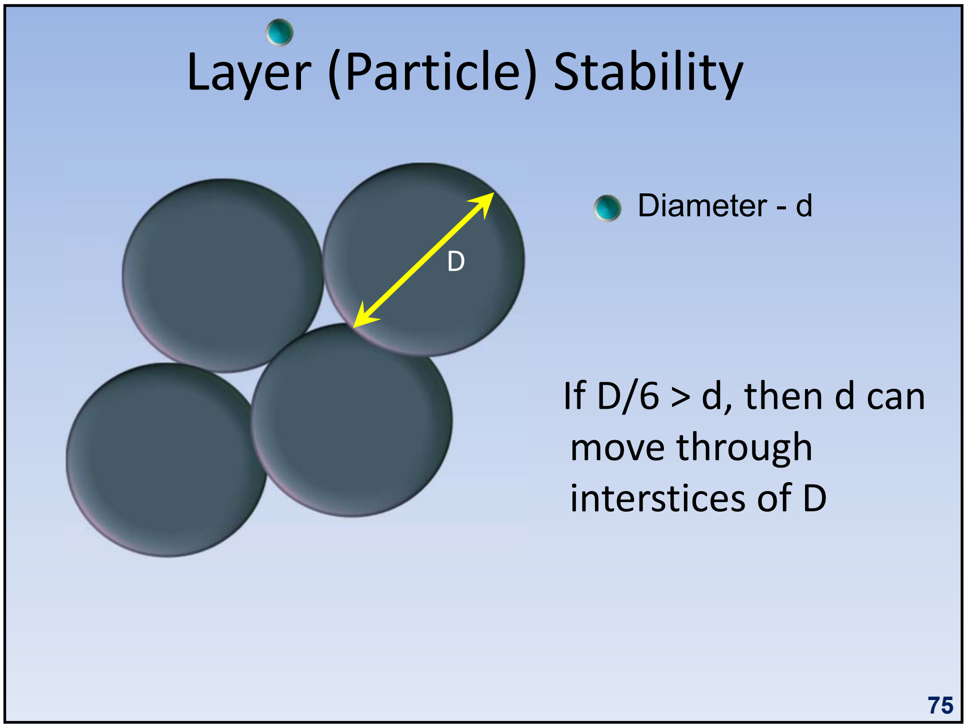


Fig. 5-6. Curves indicate the limits specified in ASTM C 33 for fine aggregate and for one commonly used size number (grading size) of coarse aggregate.



Layer (Particle) Stability

- Diameter - d

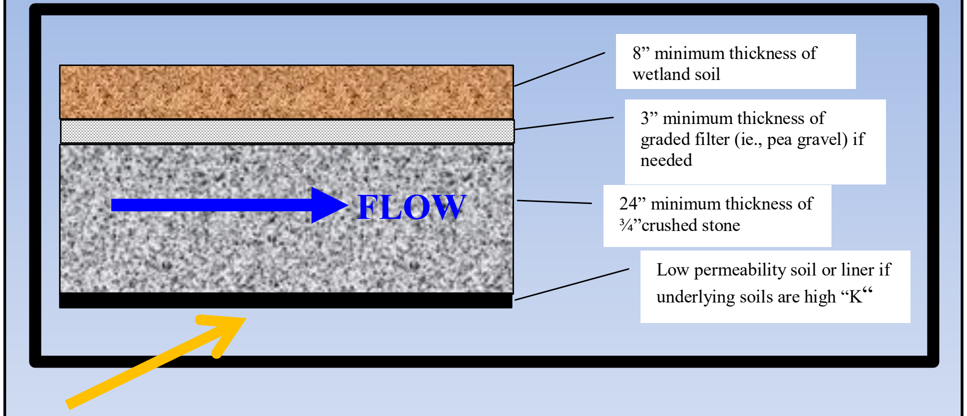
If D/6 > d, then d can move through interstices of D

Graded Filter Specification/Design

$$\frac{D_{15\ coarse}}{d_{85\ finer}} < 5 < \frac{D_{15\ coarse}}{d_{15\ finer}} < 40$$

Piping Permeability Uniformity

GW Cross-section



8” minimum thickness of wetland soil

3” minimum thickness of graded filter (ie., pea gravel) if needed

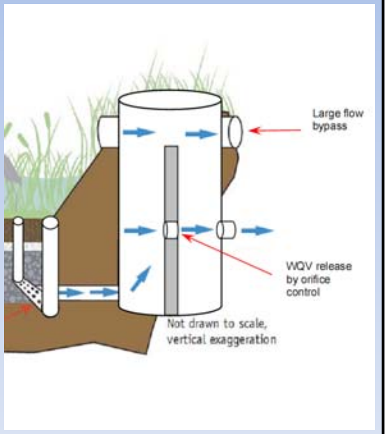
24” minimum thickness of ¾”crushed stone

Low permeability soil or liner if underlying soils are high “K“

6.) Underlying soils should have low permeability (hydraulic conductivity ≤ 0.03 ft/day.), if not use a compact soil liner or HDPE liner (≥ 30 mil).

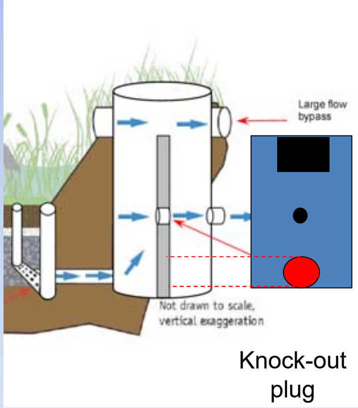
Hydraulic Outlet Structure

- The primary outlet invert shall be located 4-8” (10 cm) below the elevation of the wetland soil surface to control the system groundwater elevation.
- The primary outlet location must be open or vented and can be a simple pipe or structure and should be accessible for maintenance.



Hydraulic Outlet Structure

- An optional high capacity outlet below the primary outlet may be installed for maintenance.
- This maintenance port would be plugged during regular operation. This optional outlet allows for flushing of the treatment cells at higher flow rates and can be used to drain the system for maintenance or repairs.



Additional Details

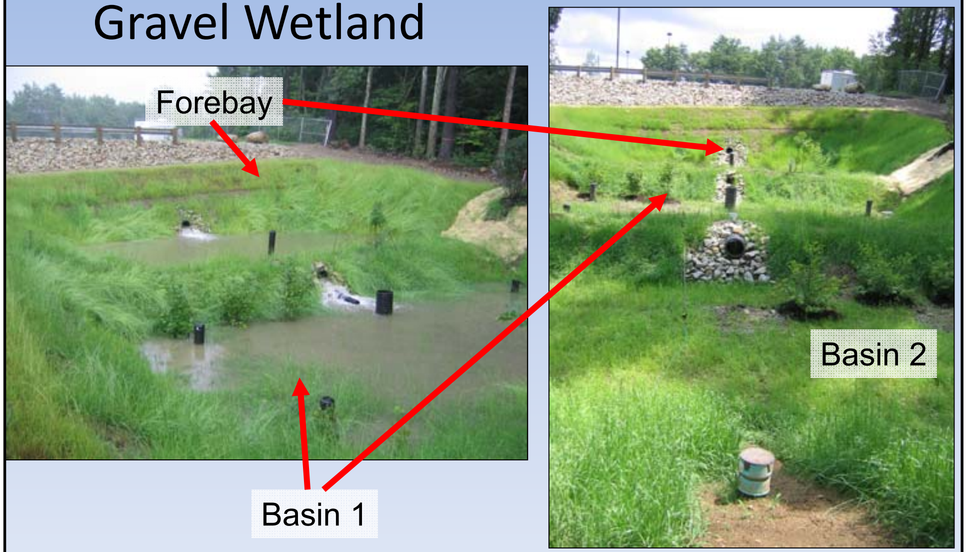
- The Bypass Outlet (emergency spillway, or secondary spillway) is sized to pass design flows (10-year, 25-year, etc.). This outlet is sized by using conventional routing calculations of the inflow hydrograph through the surface storage.
- Local criteria for peak flow reductions are then employed to size this outlet to meet those criteria.
- The primary outlet structure and its hydraulic rating curve are based on a calculated release rate by orifice control to drain the WQV in 24-48 hrs. For orifice diameter calculations refer to the NY Stormwater Manual (2001) or HDS 5 (FHWA, 2012) for details.

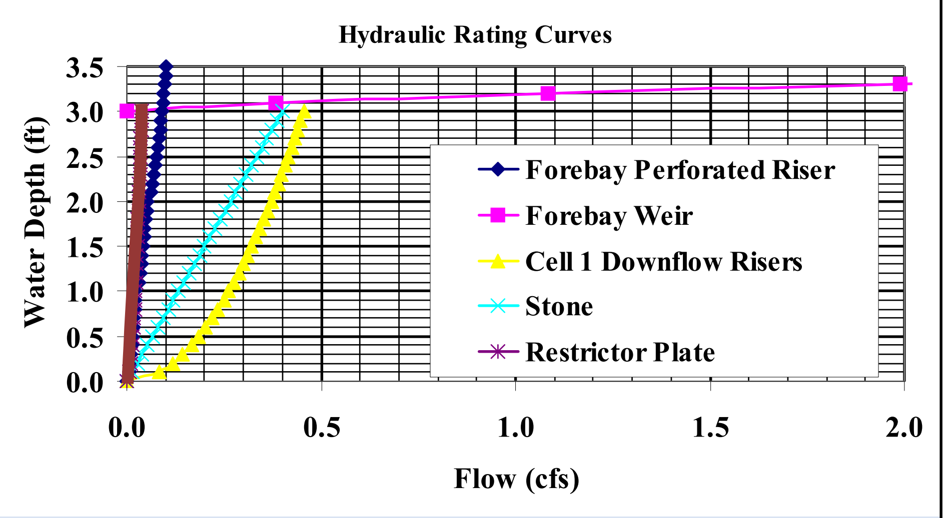
As with any GI, it is important to understand HOW your system design is anticipated to perform during larger-than-design events

Modeling Hydrograph Movement Through Stormwater Management Systems

- Inflow Hydrograph
- Volume Characteristics of the System
- Outflow Structure Hydraulic Characteristics

Subsurface Gravel Wetland





Routing Method

- Storage Indication Routing Method

  Select time step for analysis

  Develop storage indication function

$$\frac{2S}{\Delta t}+O \quad \text{vs} \quad O$$

  Perform routing calculations

Simplified Routing

- Route inflow hydrograph by storage indication method employing only the outlet orifice and secondary spillway combined rating curves

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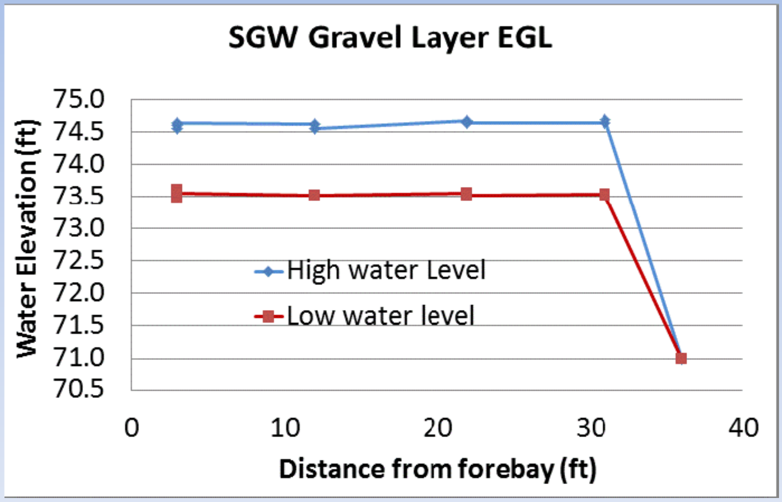
Simple works



Thorough Hydrologic Routing Through the Subsurface Gravel Wetland

- Route inflow hydrograph through forebay
  - Primary spillway – 6-in pipe with restrictive orifice
  - Secondary spillway
- Routed forebay outflow hydrograph through first cell
  - Primary spillway – outlet orifice
  - Secondary spillway – overflow between cells
- Route first cell outflow hydrograph through second cell
  - Primary spillway – outlet orifice
  - Secondary spillway

Wetland Soil

- The surface infiltration rates of the gravel wetland soil should be similar to a low hydraulic conductivity wetland soil (0.1-0.01 ft/day = 3.5×10^{-5} cm/sec to 3.5×10^{-6} cm/sec)).
- This soil may be manufactured using wood chips, sand, and some fine soils to blend to a high % organic matter content soil (>15% organic matter). Avoid using clay contents in excess of 15% because of potential migration of fines into subsurface gravel layer.
- Wetland soil must exclude any sticks, roots, stones, etc. that violate the suggested PSD
- $\geq$15% organic matter
- Clay content $\leq$ 15%
- Do not use geotextiles between the horizontal layers of this system as they will clog due to fines and may restrict root growth.

PSD and testing tolerances for wetland soil for the SGW system

US Standard Sieve Size in/mm	Percent Passing	Percent Passing Testing Tolerances
0.5/12.5	100	± 10.0
#10/2.00	90 - 75	± 5.0
#100/0.15	40-50	± 5.0
#200/0.075	25-50	± 5.0

Median particle size (D_{50}) of 0.15 mm and is a clay or silt loam

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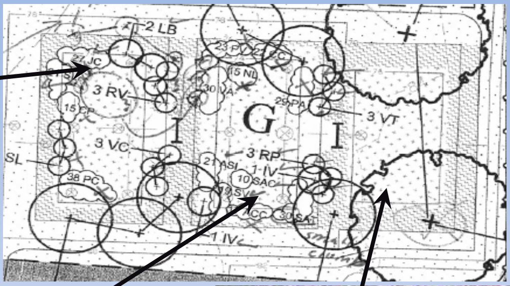
Wetland Vegetation

- Used New England Wetmix (wetland seed mix) from New England Wetland Plants Application Rate: 1 LB/2500 SQ. FT. (18 LBS/ACRE as a wet meadow seeding)
- http://www.newp.com
- Price: $125.00/LB
- Gravel wetland – mixed wetland grasses, reeds, herbaceous plants and shrubs growing vigorously. 100% cover, except for open water in forebay. Very few upland plants. Healthy, diverse wetland system.

Gravel Wetland

Sagittaria, Cattail, Juncus, grasses, areas with standing water



Bullrush (scirpus), aster, grasses, no standing water

Rush (juncus), cattail, grasses, open water

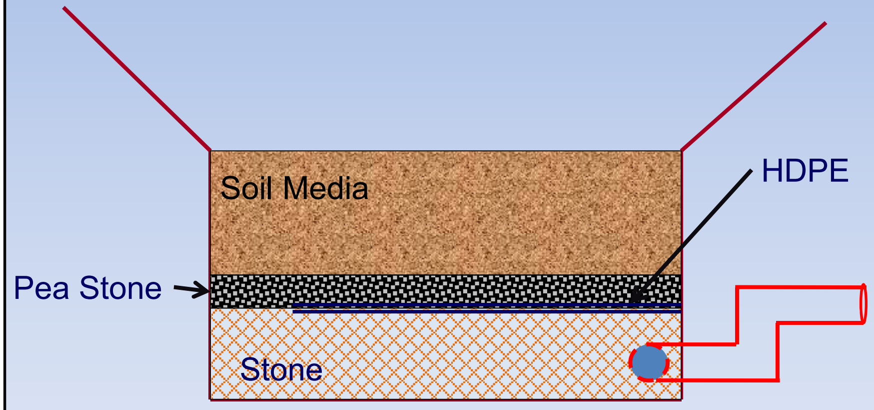
UNHSC – General Wetland Condition

- 53% of the planted species were still present (in areas that have not been re-constructed).
- Trees and shrubs had a high survival.
- Emergent obligate wetland species (e.g water lily, pickerelweed) survival was very low.
- All areas with standing water populated by Typha (cattail).
- No Phragmites, some Purple Loosestrife removed.
- Predominantly emergent marsh/wet meadow species.
- Some vertebrate wildlife species present; frogs and heron.

Hybrid Systems

- Bioretention with Internal Storage Volume

ISV Plumbing



GRADED FILTER
Setting Bed – Separation Layer

- Pea stone common
- Need to prevent piping of wetland soil down to stone layer
- Characteristics based on particle stability, layer permeability, uniformity

$$D_{15,\,COARSE\ \ SUBLAYER} \leq 5\ X\ D_{85,\,SETTING\ \ BED}$$

$$D_{50,\,COARSE\ \ SUBLAYER} \leq 25\ X\ D_{50,\ SETTING\ \ BED}$$

Underlayer Stone

- 4 in to feet of 1/2 –in to 1-in stone (No. 57 common)

Shallow for infiltration systems on high K soils or where no infiltration is desired, deeper for internal water storage and denitrification and/or interstorm infiltration

Internal Storage Volume

- Promotes denitrification
  - May need liner at base in high K soils
  - Thickness > 1 ft
  - Create plug flow through ISV (may require an internal, partial liner)
  - The longer the residence time, the better
    - > 1/3 of WQV
    - > 12 hours

Maximum Depth of Ponding

- 6 – 24 in.

Largely based on vegetation survival

Hydraulic outlet structures

- Choose which you prefer to control the system hydraulics
  - Soil media
  - Orifice/pipe

Inspection and Maintenance

4 - yr Forebay Maintenance - June 2008

Maintenance

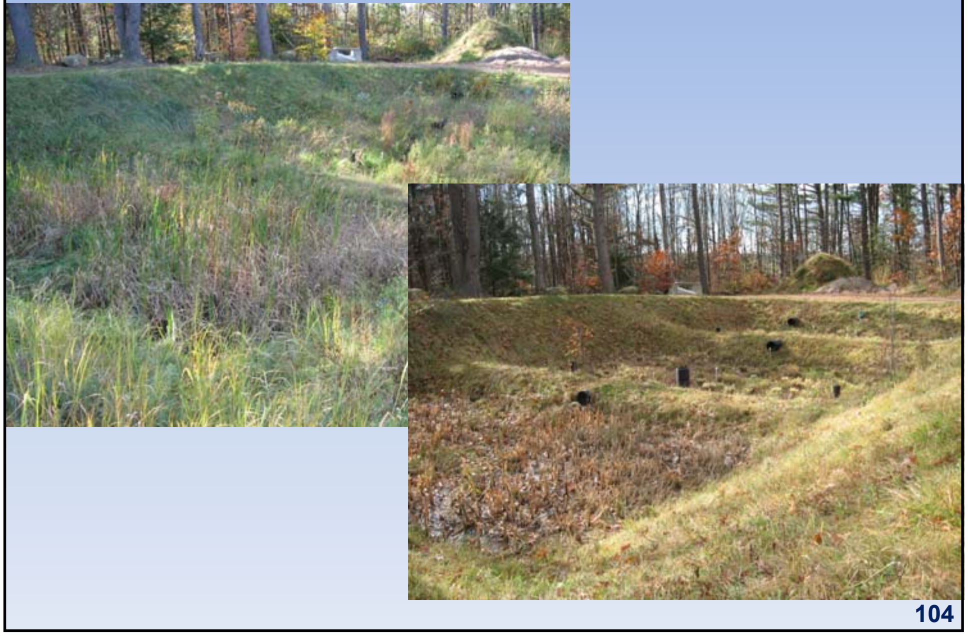
- The forebay to the gravel wetland, and probably all stormwater systems may become a source of contamination as the system ages—maintenance is essential

- Improved forebay designs would include a deeper pool of water in excess of a meter, or a deep sump catch basin or proprietary treatment device for removal of solids.

Maintenance

- Sediments and plant debris stored in the forebay may be re-suspended and released in subsequent storms. Routine maintenance is an important component in maintaining performance—2-3 year interval.

Current 3-yr Maintenance Plan



Questions?

Other Questions

- What is the max design ponding depth?

A: It depends on chosen plant communities and the possibility of driving water vertically through the wetland soil. Preferably = 18 in.

- Is the WQV storage in the system static or dynamically sized?

A: Static. Volume of storage above-ground is equal to the WQV. Draindown is controlled by the restrictive outlet hydraulics

Other Questions

- How important is the 2-cell treatment approach?

A: The primary benefit is the built-in redundancy should one of the cells need repair or maintenance.

- Is there a specific reason for the 15’ flow path?

A: Some of our tests with a horizontal flow gravel sluice verified this sizing based on performance.