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Subsurface Gravel Wetlands for the Treatment of Stormwater

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University of New Hampshire Stormwater Center

NJASLA 2012 Annual Meeting and Expo
Atlantic City, NJ
29-31 January 2012

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Gregg Hall ● 35 Colovos Road ● Durham, New Hampshire 03824-3534
603.862.4024 ● http://www.unhsc.unh.edu

Dedicated to the protection of water resources through effective stormwater management

- Research and development of stormwater treatment systems
- To provide resources to stormwater communities currently involved in design and implementation of Phase II requirements

- Brief introduction to subsurface gravel wetlands and their hydraulic performance.
- Water quality performance, especially nutrient nitrogen
- Design aspects
- Plants
- Costs and comparisons
- Case studies

Gravel Wetland

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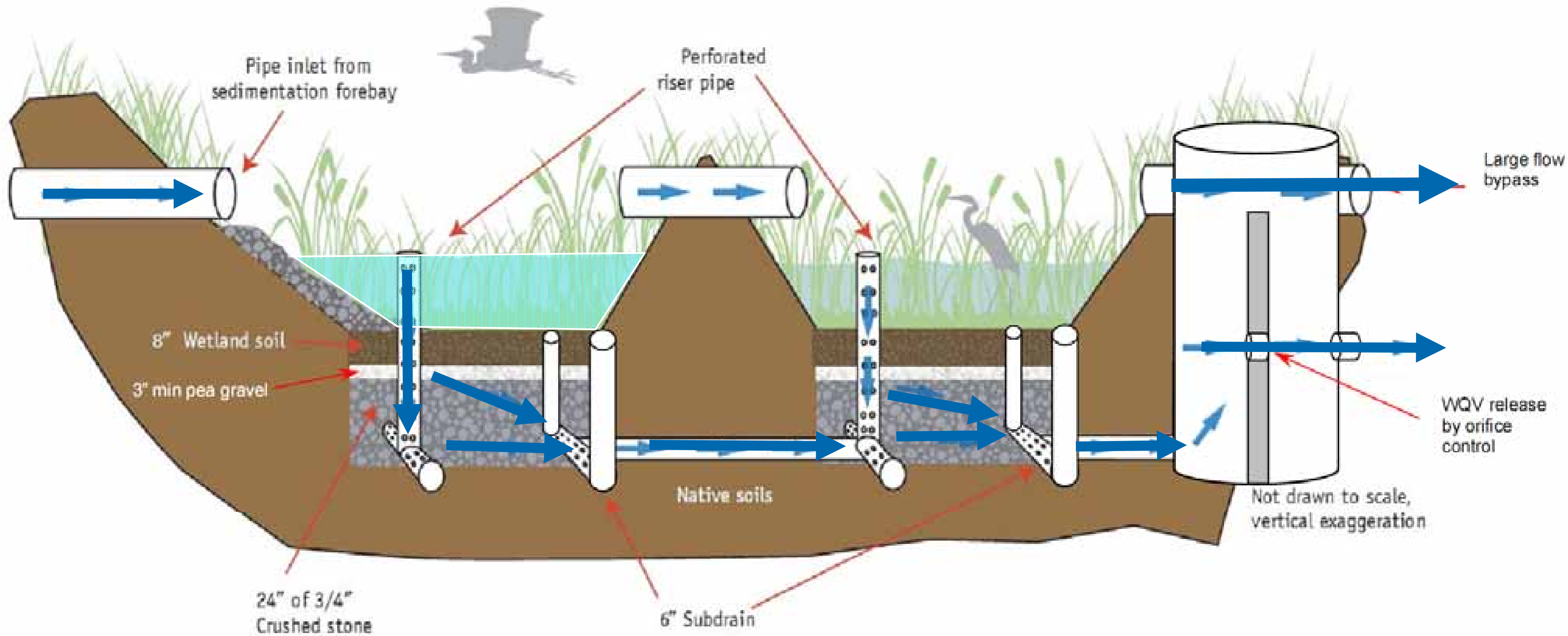
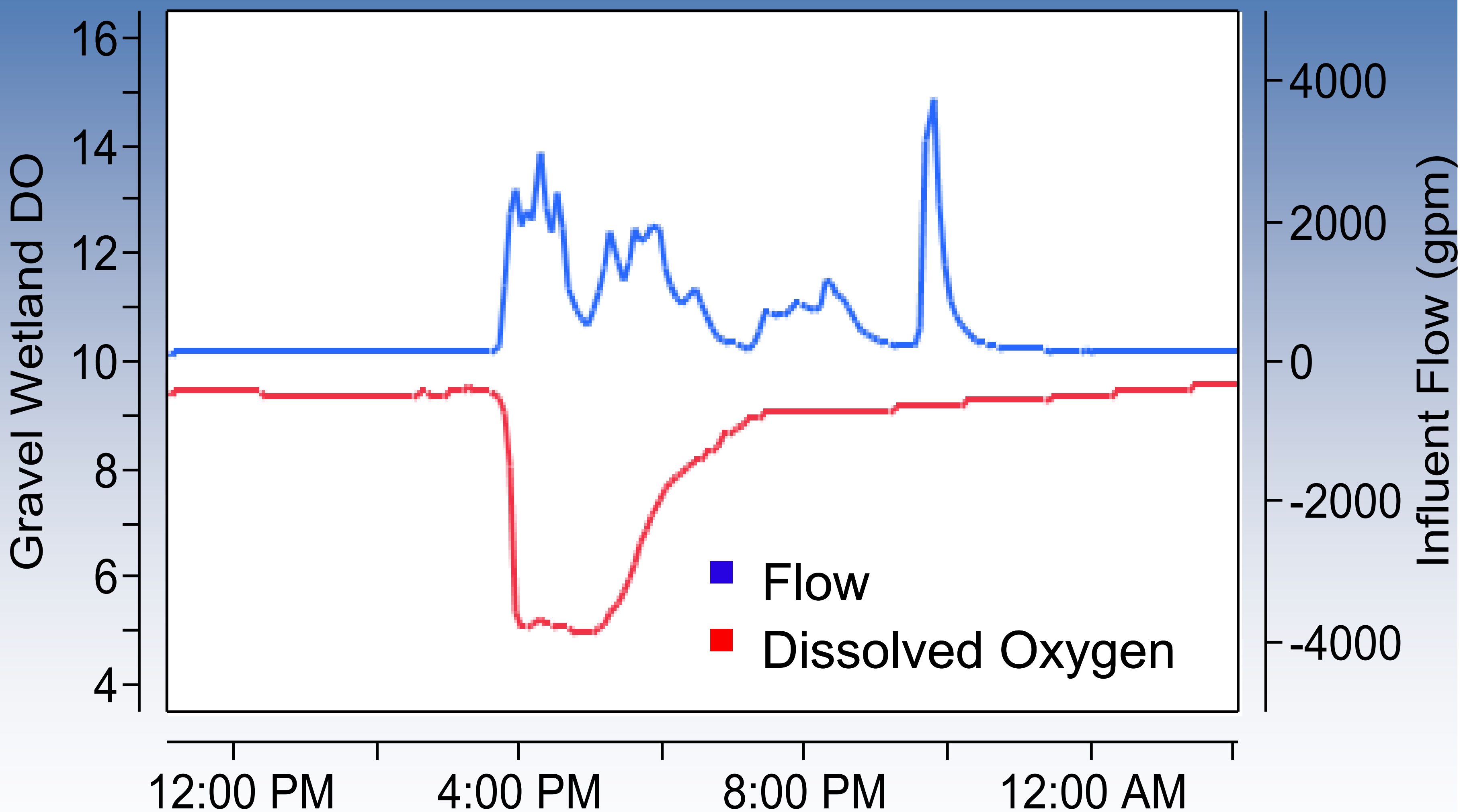
Subsurface Gravel Wetland



Design Sources:
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.

Dissolved Oxygen in Gravel Wetland Effluent



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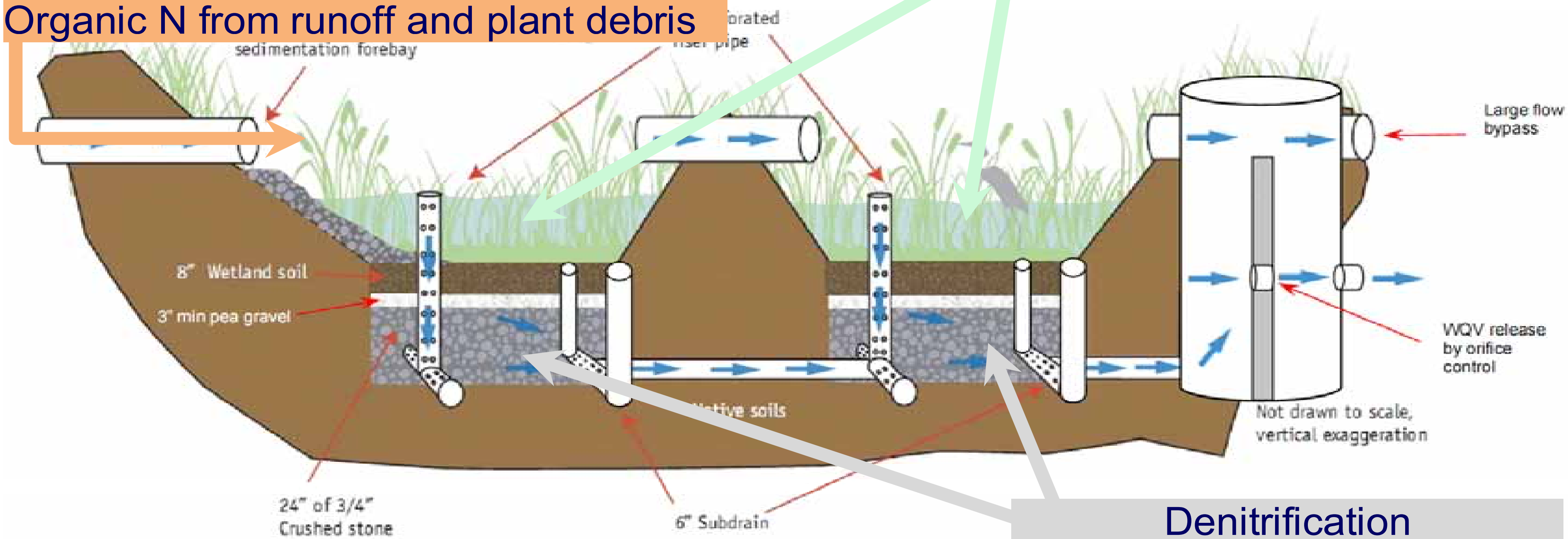
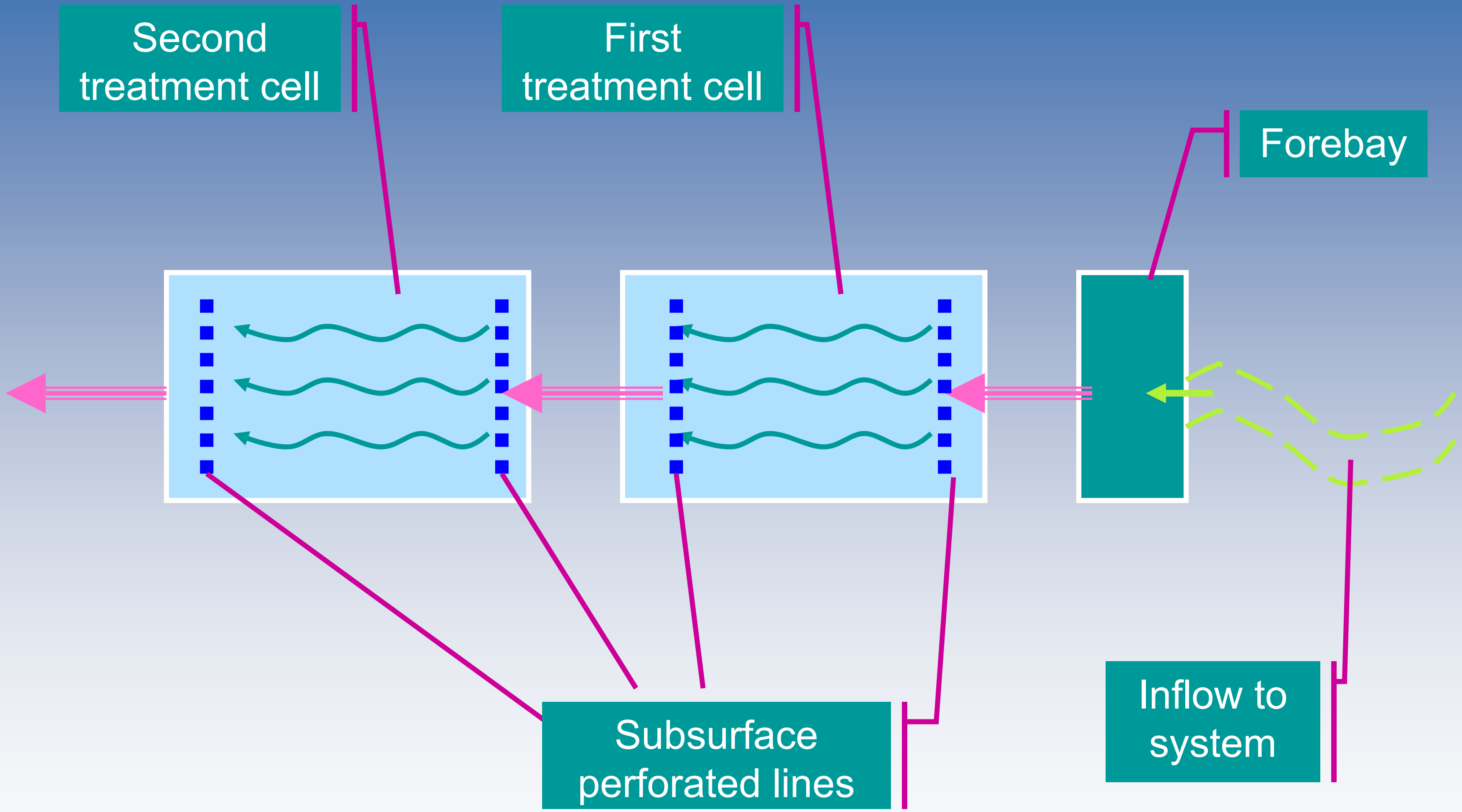
Nitrification
$NH_4 \rightarrow N0_2 \rightarrow NO_3$
Aerobic Zone
Forebay and surface of wetland

Influent
Organic N from runoff and plant debris



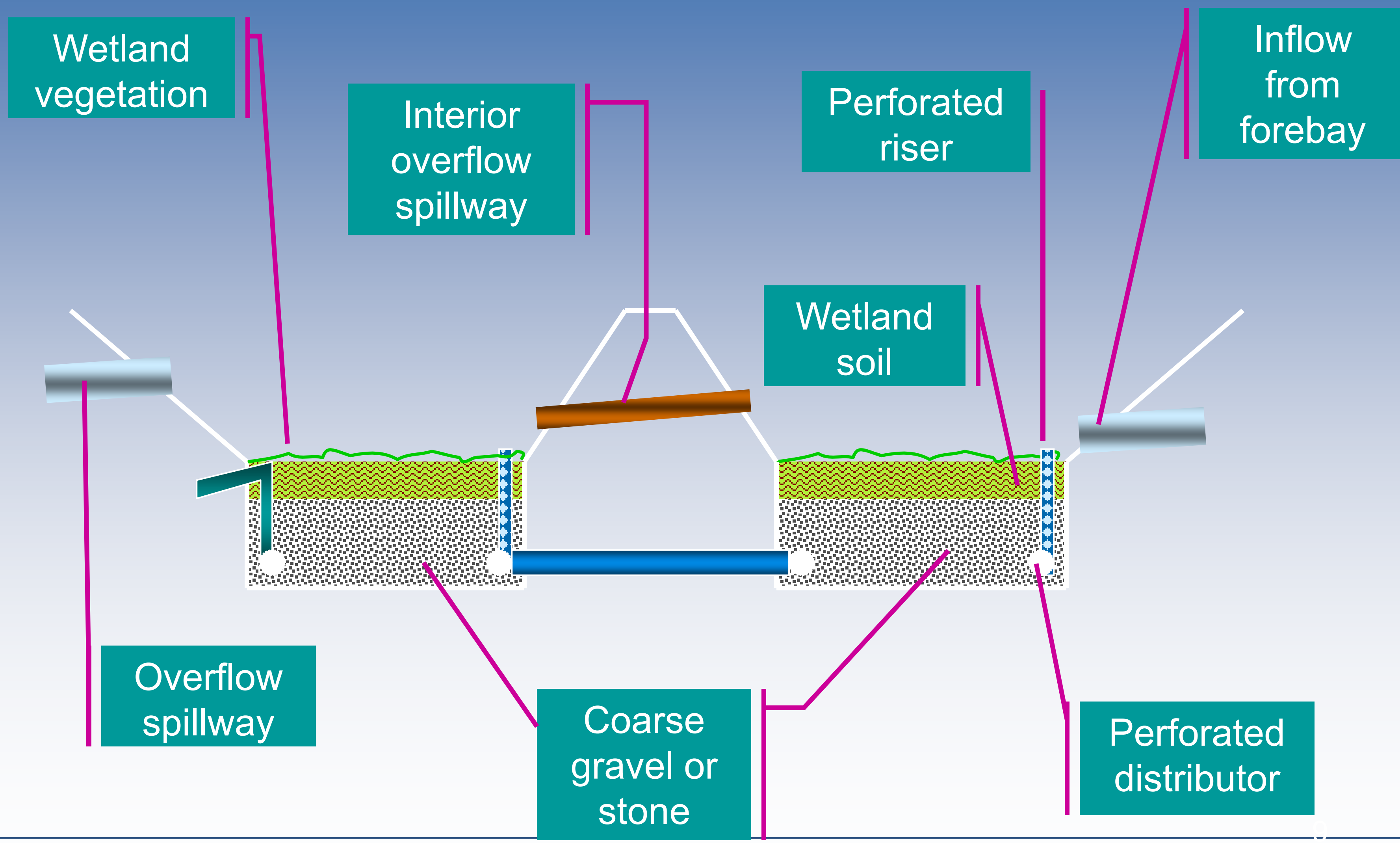
Denitrification
$\rightarrow N_2$ (gas)

Anaerobic Zone
Subsurface gravel

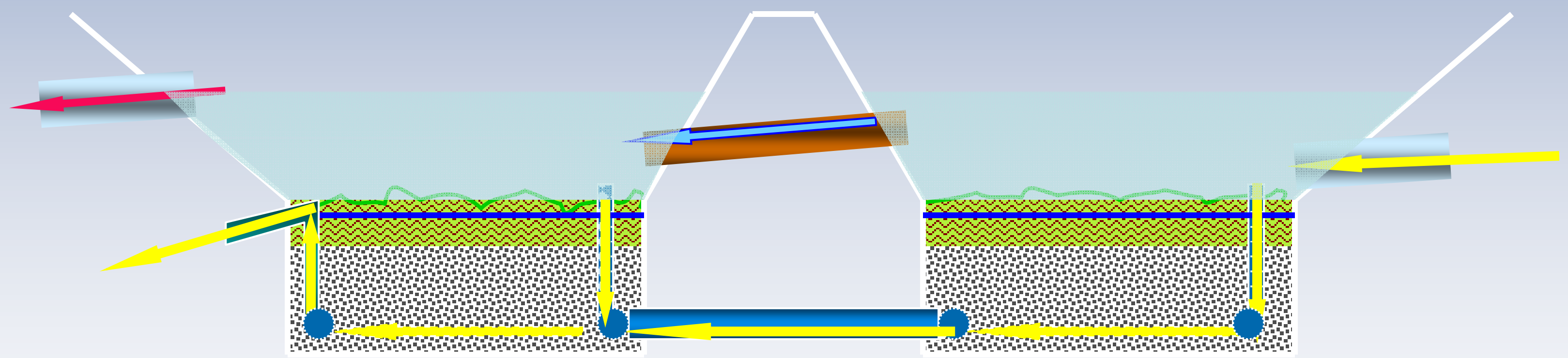


Second treatment cell
First treatment cell
Forebay
Subsurface perforated lines
Inflow to system

The UNH SC Subsurface Gravel Wetland Design

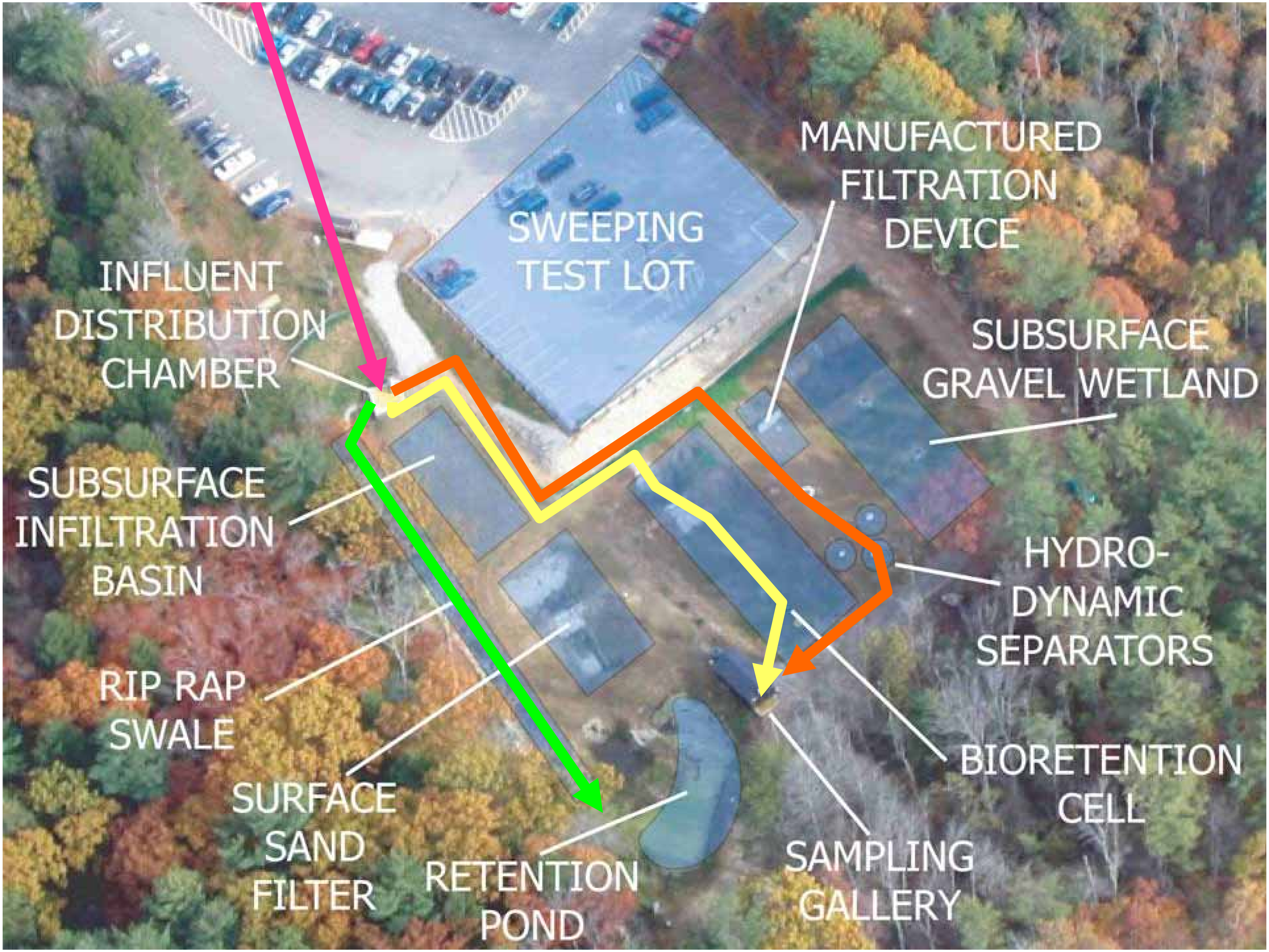


Flow Through the Subsurface Gravel Wetland Design



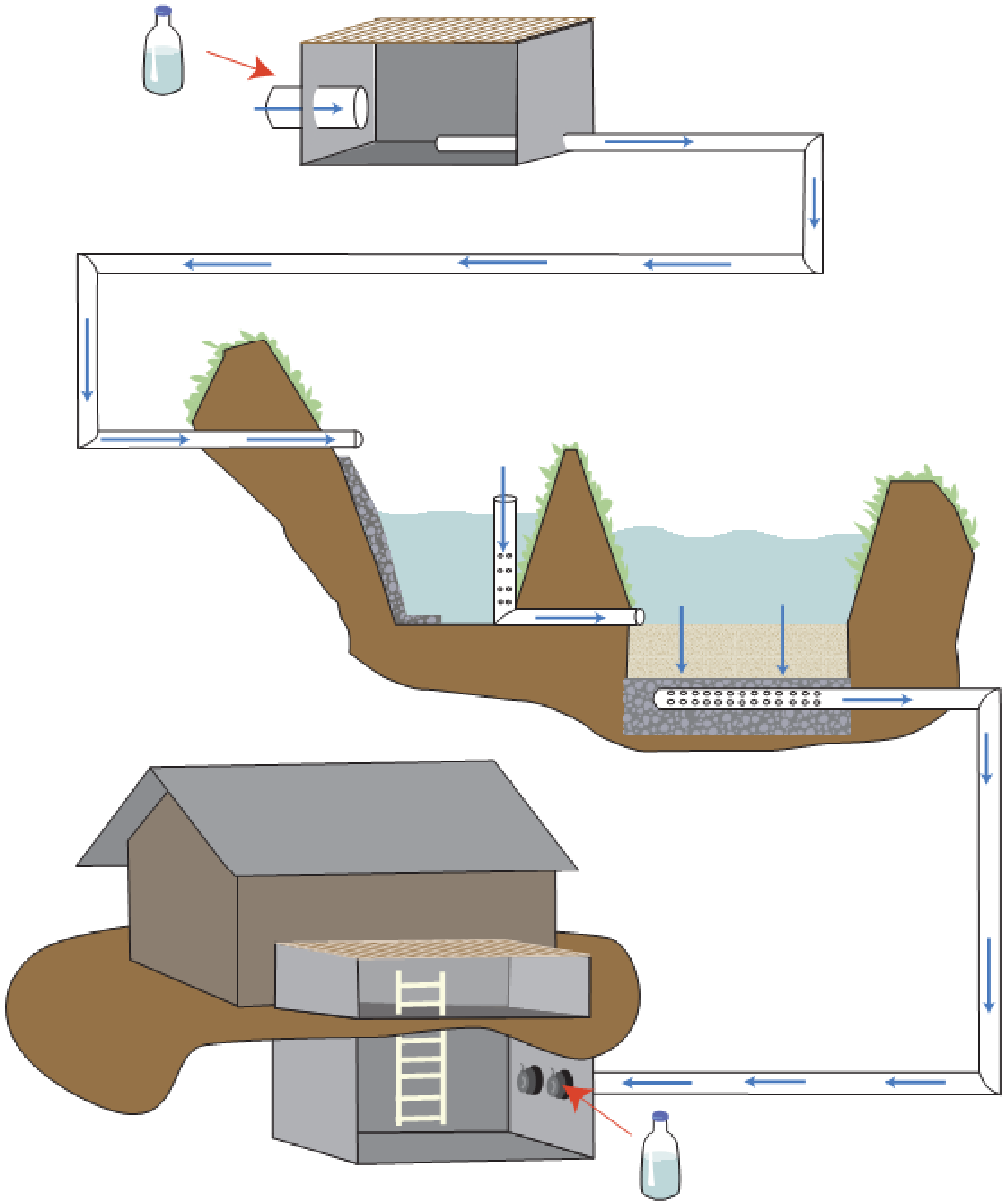
BMP Performance Monitoring

Research Field Facility at UNH
Tc ~ 19 minutes


SWEEPING TEST LOT
MANUFACTURED FILTRATION DEVICE
INFLUENT DISTRIBUTION CHAMBER
SUBSURFACE GRAVEL WETLAND
SUBSURFACE INFILTRATION BASIN
HYDRO-DYNAMIC SEPARATORS
RIP RAP SWALE
BIORETENTION CELL
SURFACE SAND FILTER
RETENTION POND
SAMPLING GALLERY

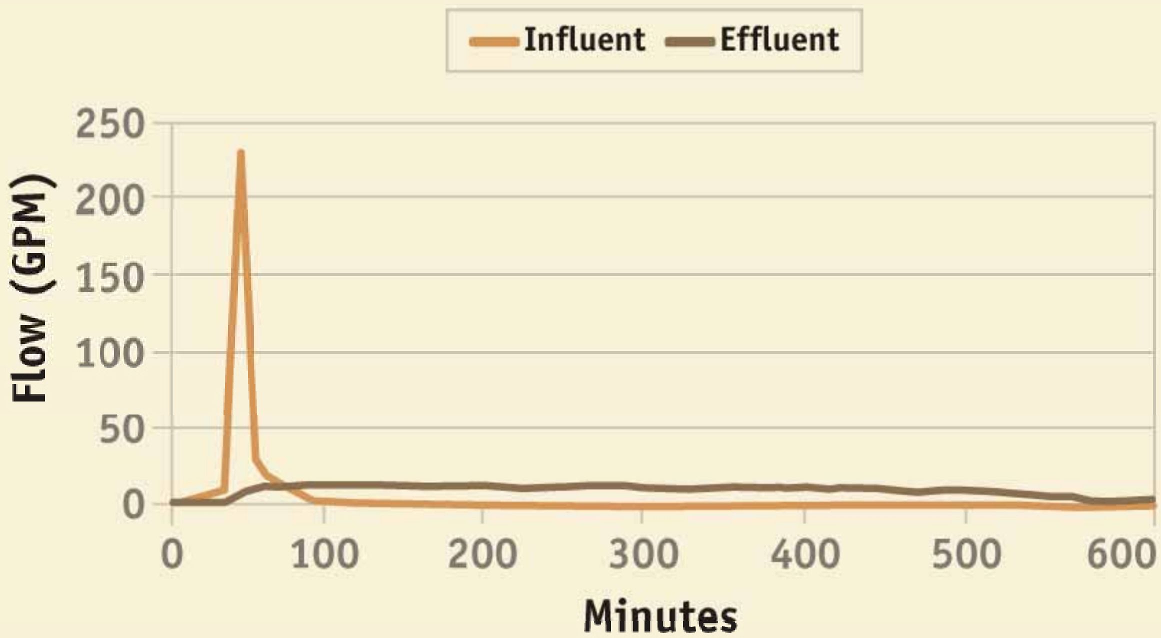
Parallel Performance Evaluation

- Each system uniformly sized to treat 1" runoff for 1 acre of impervious area
- WQV=3300 cf
- Q_{wqv}=1 cfs
- Uniform contaminant loading
- Uniform storm event characteristics
- Systems lined for mass balance
- Long term record of hydrology and contaminants



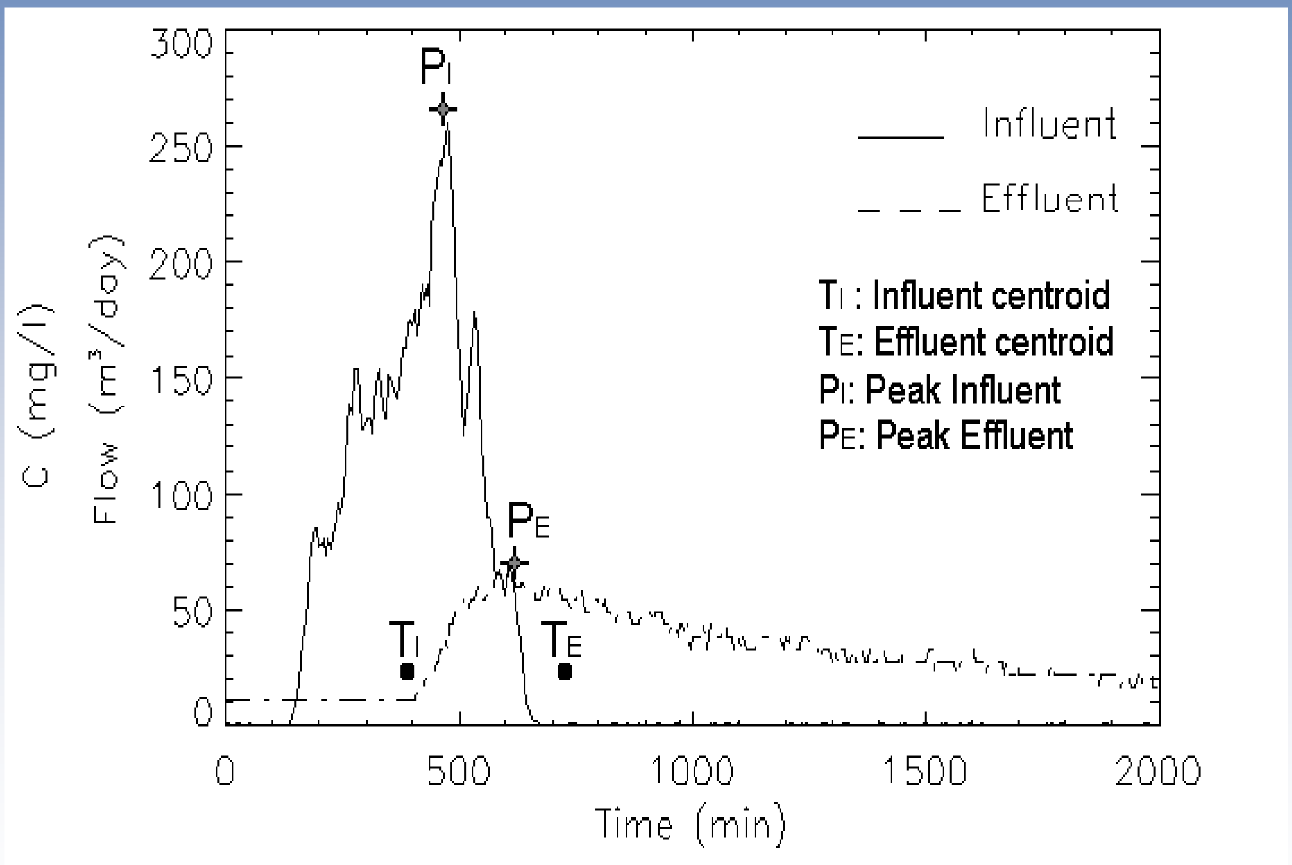
Subsurface Gravel Wetland Hydraulic Performance

HYDRAULIC PERFORMANCE



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

Hydraulic Efficiency

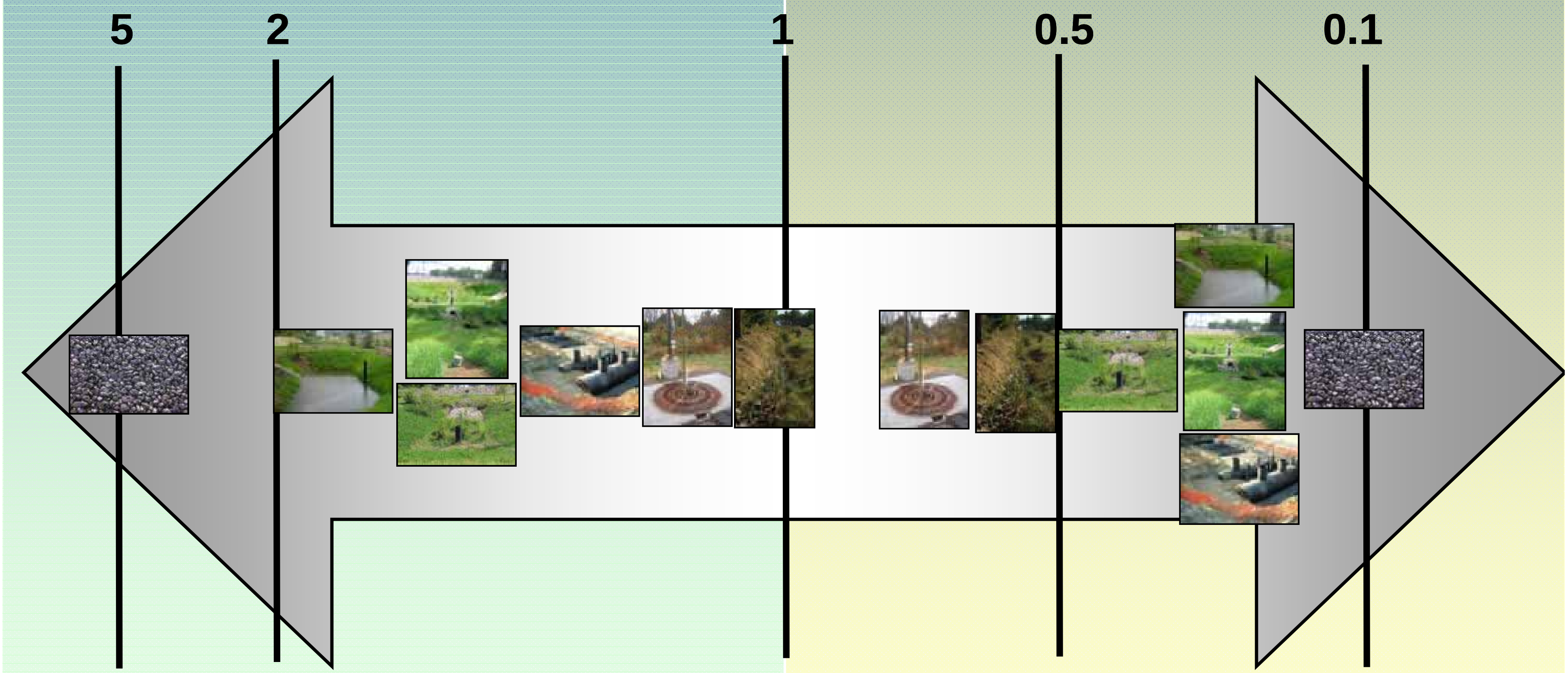


$$k_p = \frac{P_E}{P_I} \leq 1$$

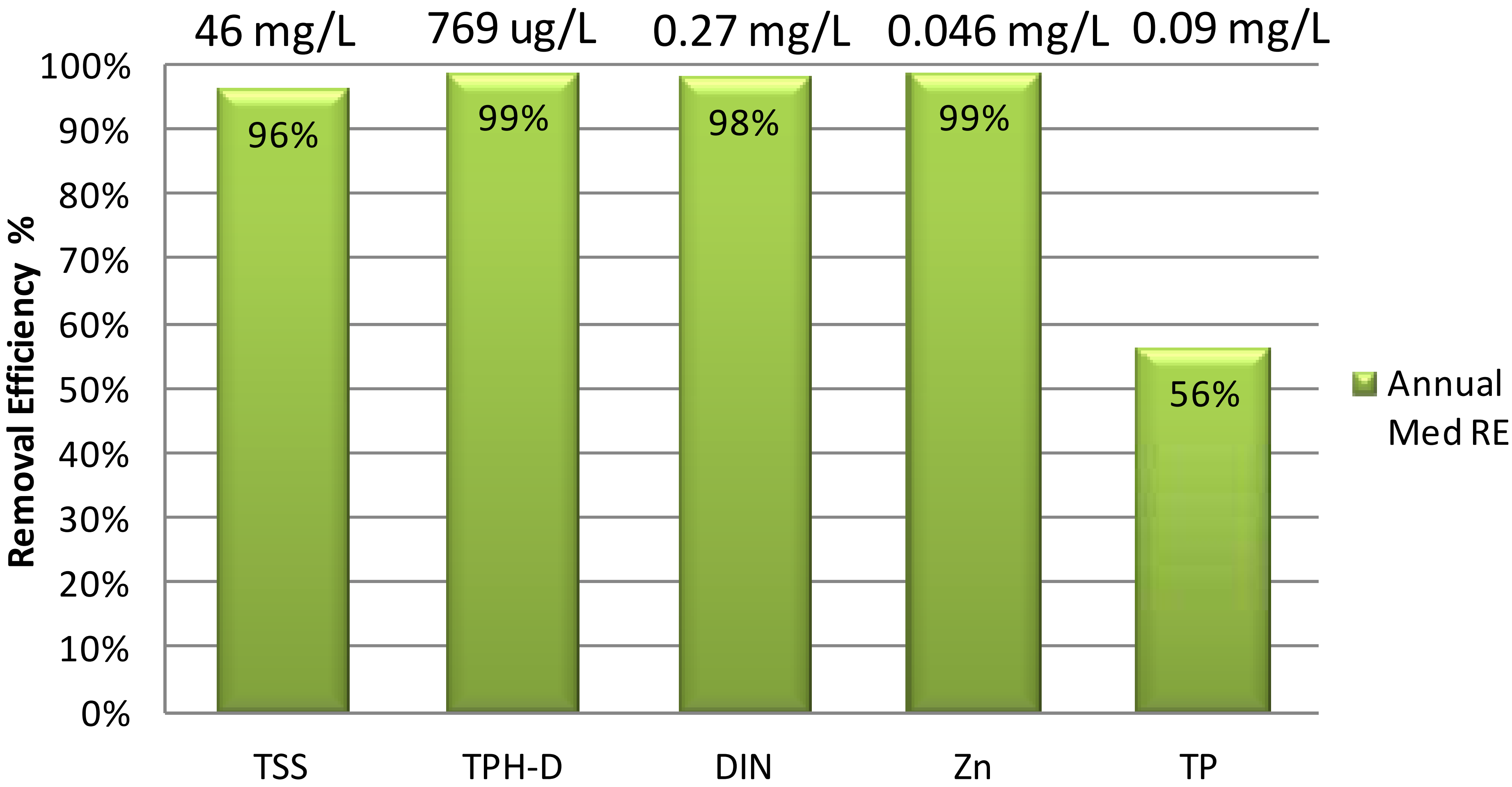
$$k_L = \frac{T_E}{T_I} \geq 1$$

Hydraulic Performance

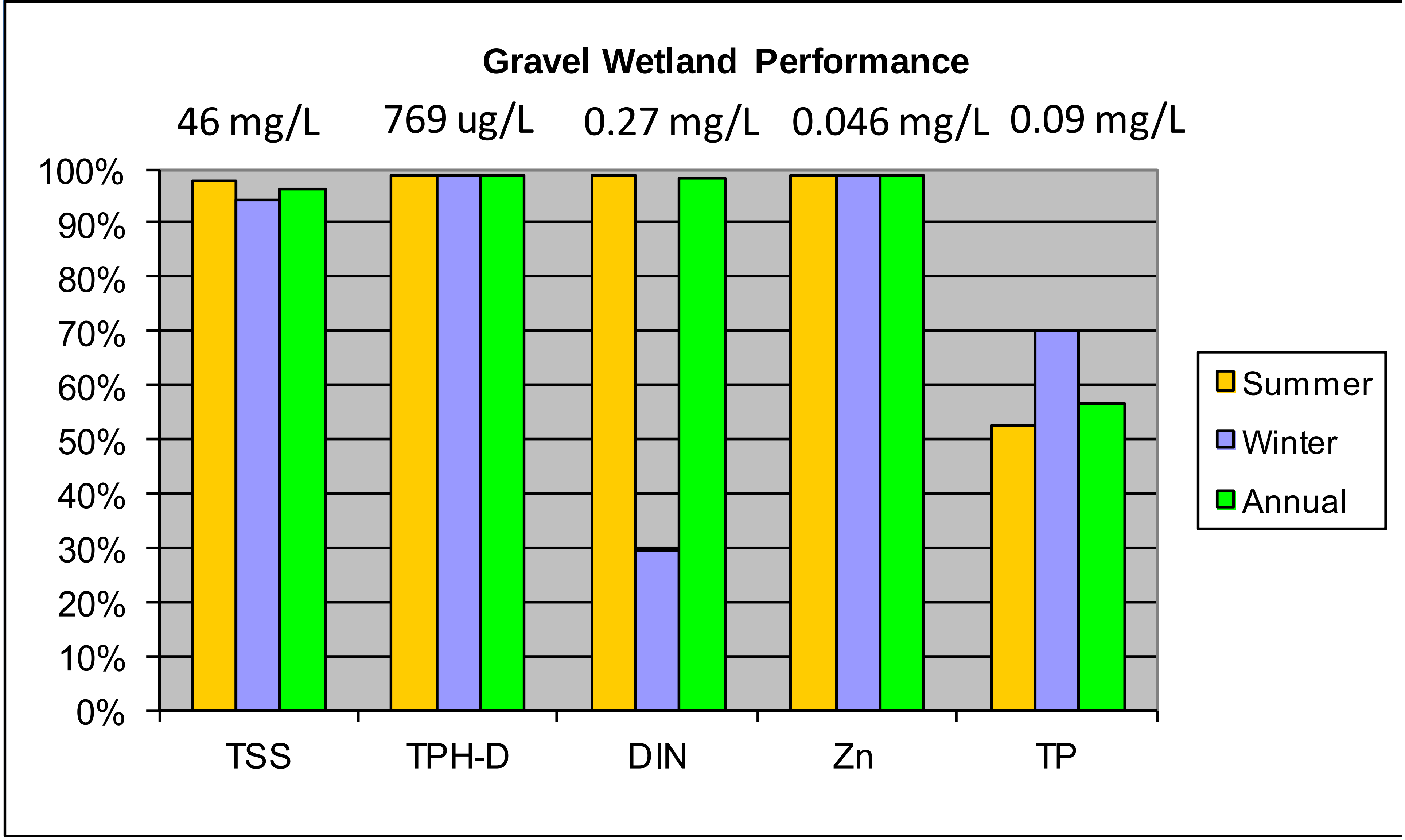
Lag Time (k_L) | Peak Reduction (k_P)



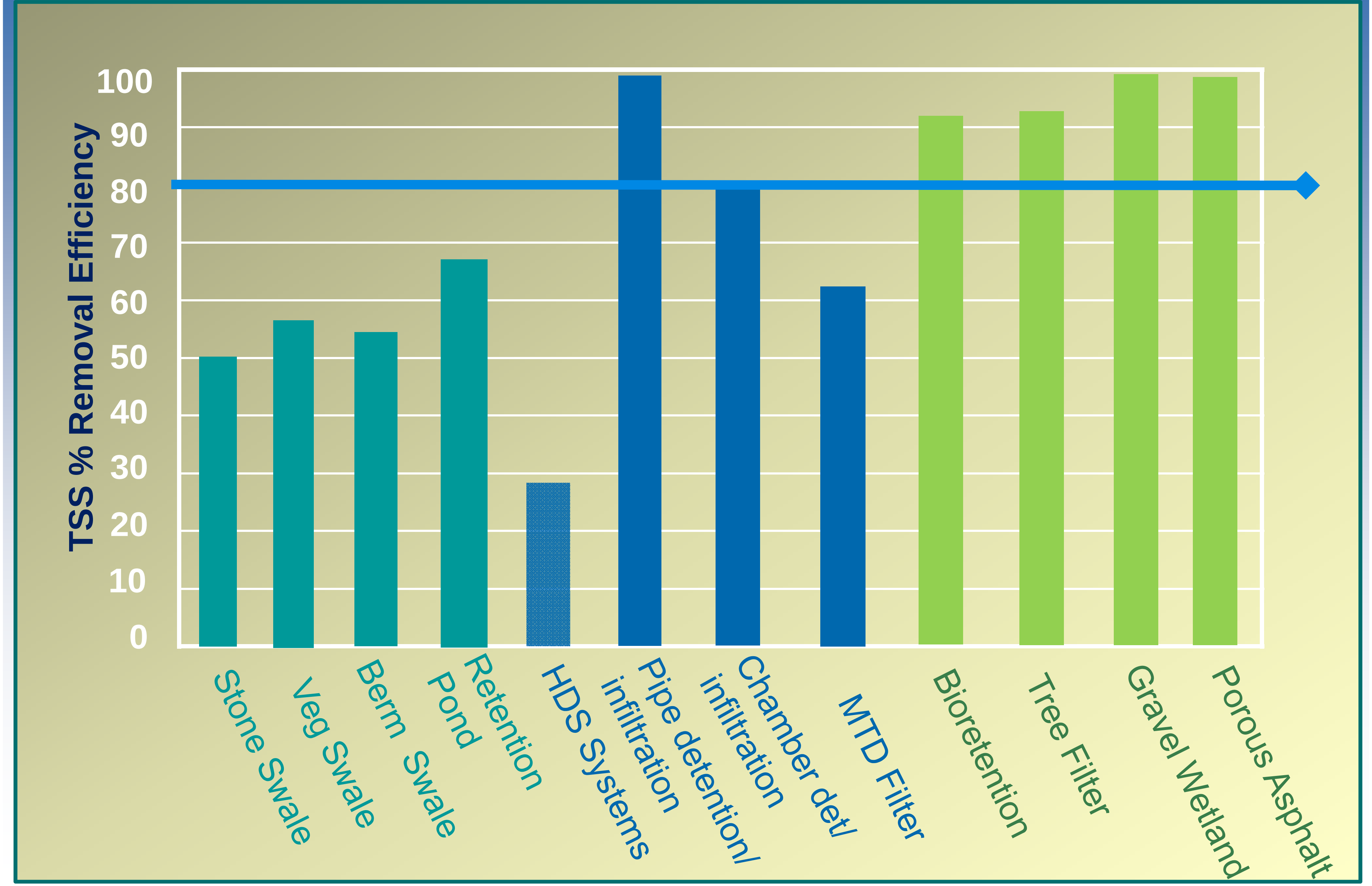
Gravel Wetland Performance



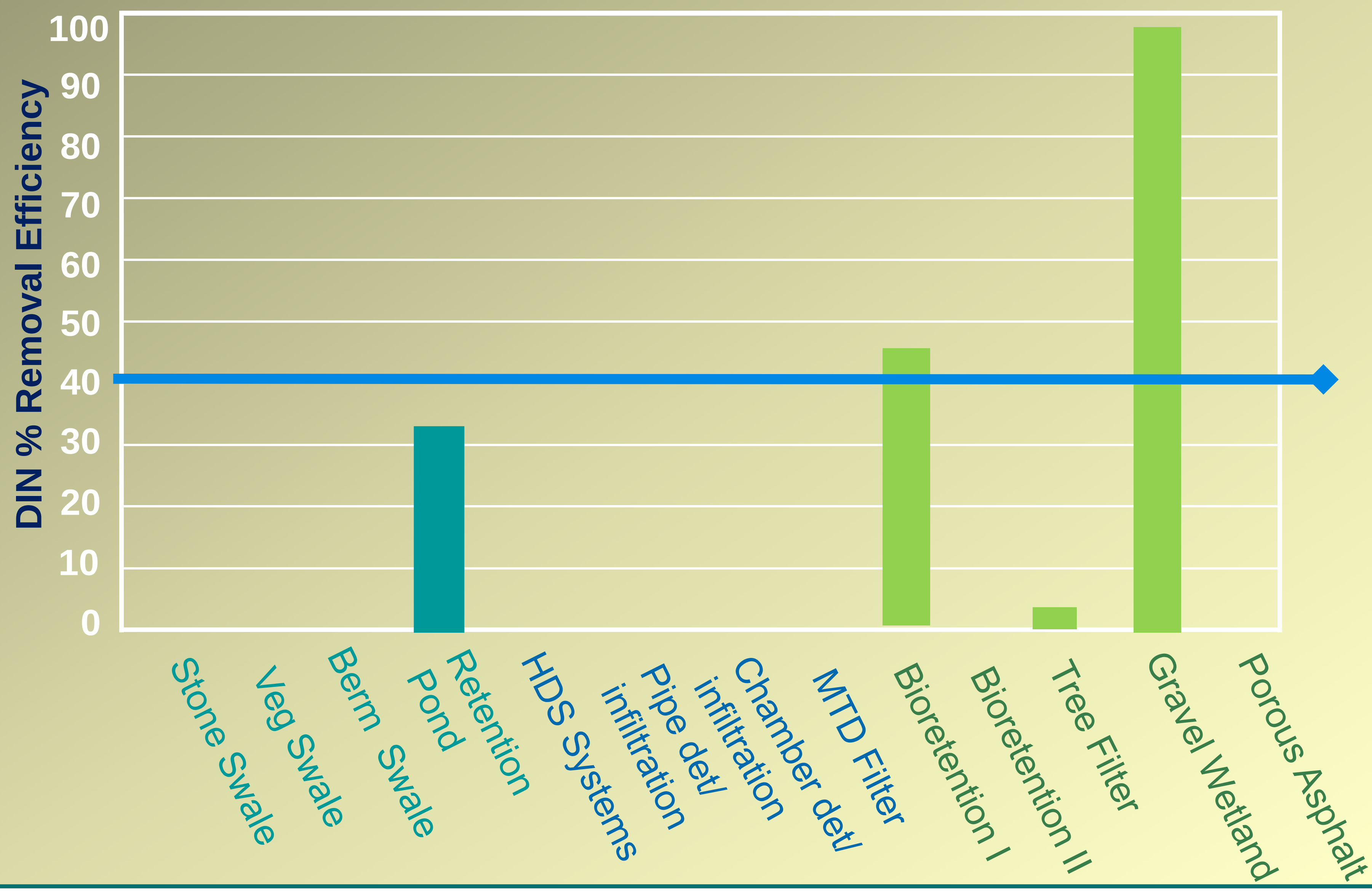
Seasonal Performance



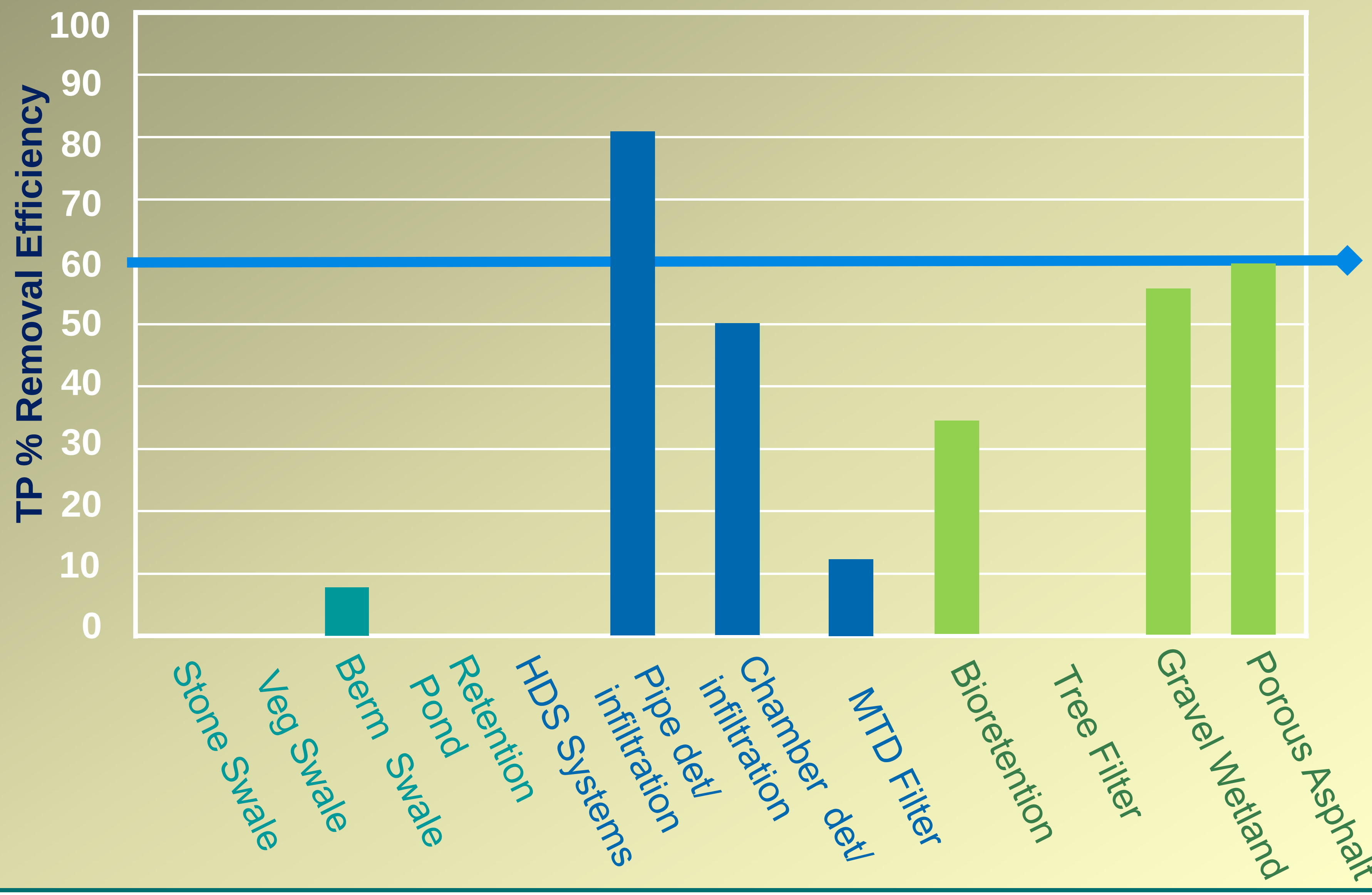
TSS Removal Efficiencies



DIN Removal Efficiencies



TP Removal Efficiencies



Unit Operations & Processes (UOPs) in the Gravel Wetland

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

Gravel Wetland Report Card

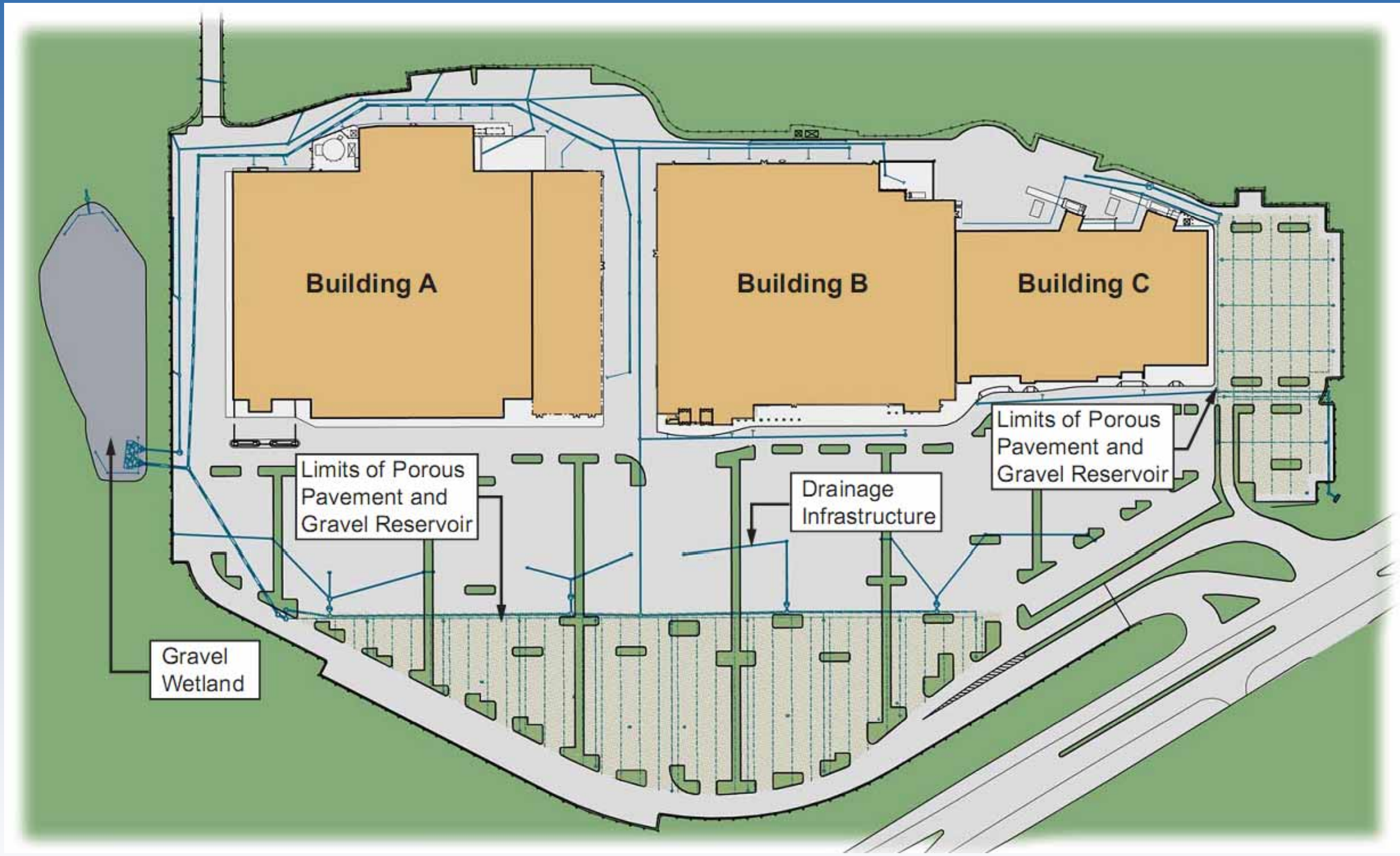
category	uop	target	"grade"
hydrologic	flow alteration	divert flow	✓
	volume reduction		
physical	sedimentation	sediment	✓
	enhanced sedimentation	sediment	
	filtration	sediment	✓
biological	microbial	nitrogen	✓+
	vegetative	nitrogen phosphorus	✓+
chemical	sorption	phosphorus	✓

Example Retrofit in the Northeast

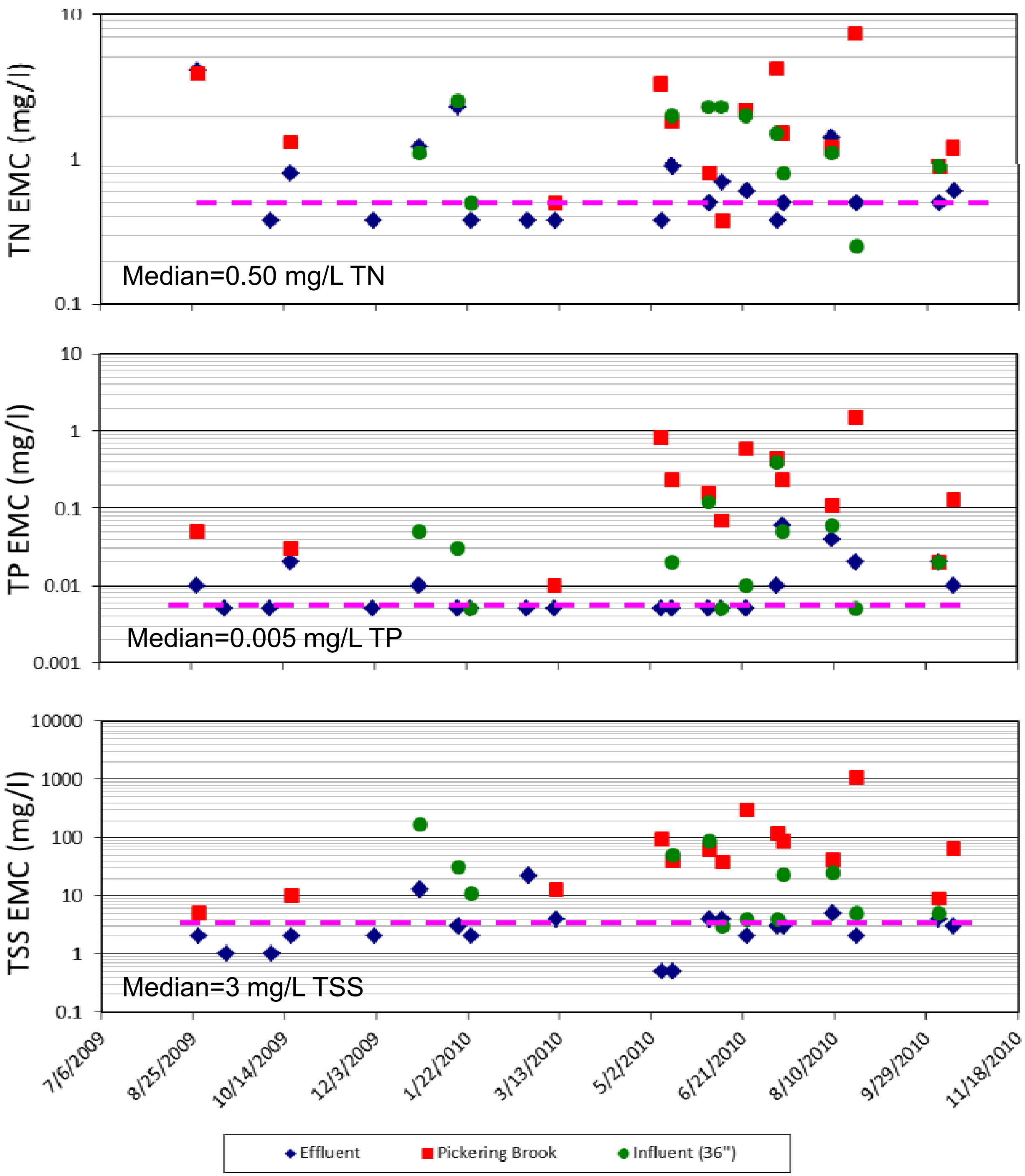
Greenland Meadows Commercial

- "Gold-Star" Commercial Development
- Cost of doing business near Impaired Waters/303D
- Saved $800k in SWM on costly piping and advanced SWM proprietary ($3.3M vs $2.5M)
- Brownfields site, ideal location, 15yrs
- Proposed site >15,000 Average Daily Traffic count on >30 acres

Site Design using LID and MTD



28 ac site, initially >95% impervious, now <10%EIC, with all drainage through filtration, expected to have minimal WQ impact except thermal and chloride



TN EMC (mg/l)
Median=0.50 mg/L TN
TP EMC (mg/l)
Median=0.005 mg/L TP
TSS EMC (mg/l)
Median=3 mg/L TSS
7/6/2009
8/25/2009
10/14/2009
12/3/2009
1/22/2010
3/13/2010
5/2/2010
6/21/2010
8/10/2010
9/29/2010
11/18/2010
Effluent
Pickering Brook
Influent (36")

Nutrient cycling

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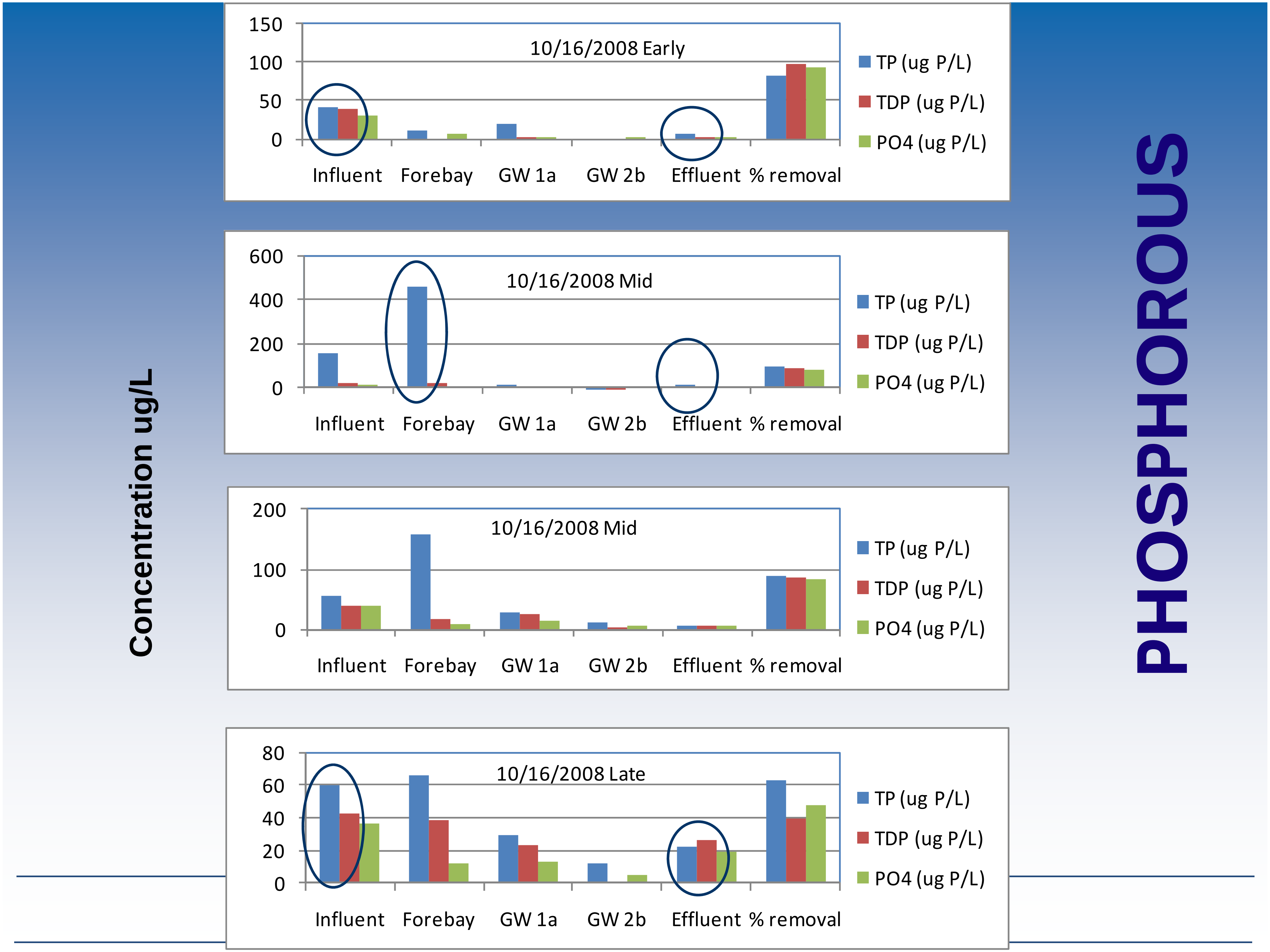
Phosphorous is typically in 3 forms:

- **Soluble Reactive Phosphorous.** SRP usually consists largely of the inorganic orthophosphate (PO_4) form of phosphorous. Measurements of orthophosphate are commonly used to quantify SP.
- **Soluble Unreactive or Soluble Organic Phosphorous.** SUP are organic forms of phosphorous and chains of inorganic phosphorous molecules termed polyphosphates.
- **Particulate Phosphorous.** PP contains all material, inorganic and organic, particulate and colloidal, that is captured on a 0.45-micron membrane filter.

SRP +SUP= soluble phosphorous (SP)

SP+PP=total phosphorous (TP)

PO4 + SUP+PP=TP


PHOSPHOROUS
Concentration ug/L
10/16/2008 Early
150
100
50
0
Influent
Forebay
GW 1a
GW 2b
Effluent
% removal
TP (ug P/L)
TDP (ug P/L)
PO4 (ug P/L)
10/16/2008 Mid
600
400
200
0
10/16/2008 Mid
200
100
0
10/16/2008 Late
80
60
40
20
0

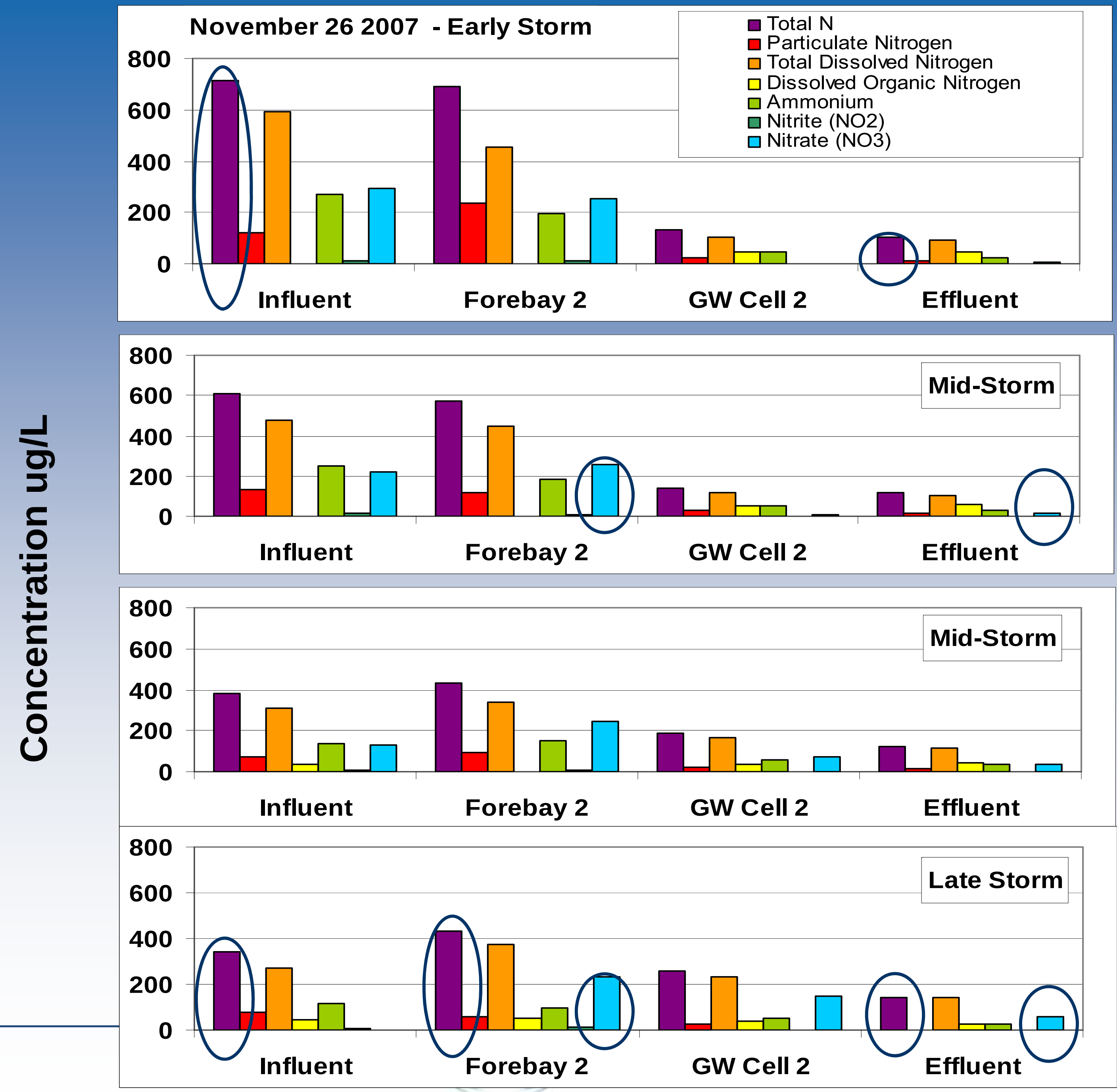
Nitrogen in Stormwater Water

- Systems must be vegetated, sedimentation plays a minor role
- Biologically-mediated conversion processes, whether aerobic or anaerobic. 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

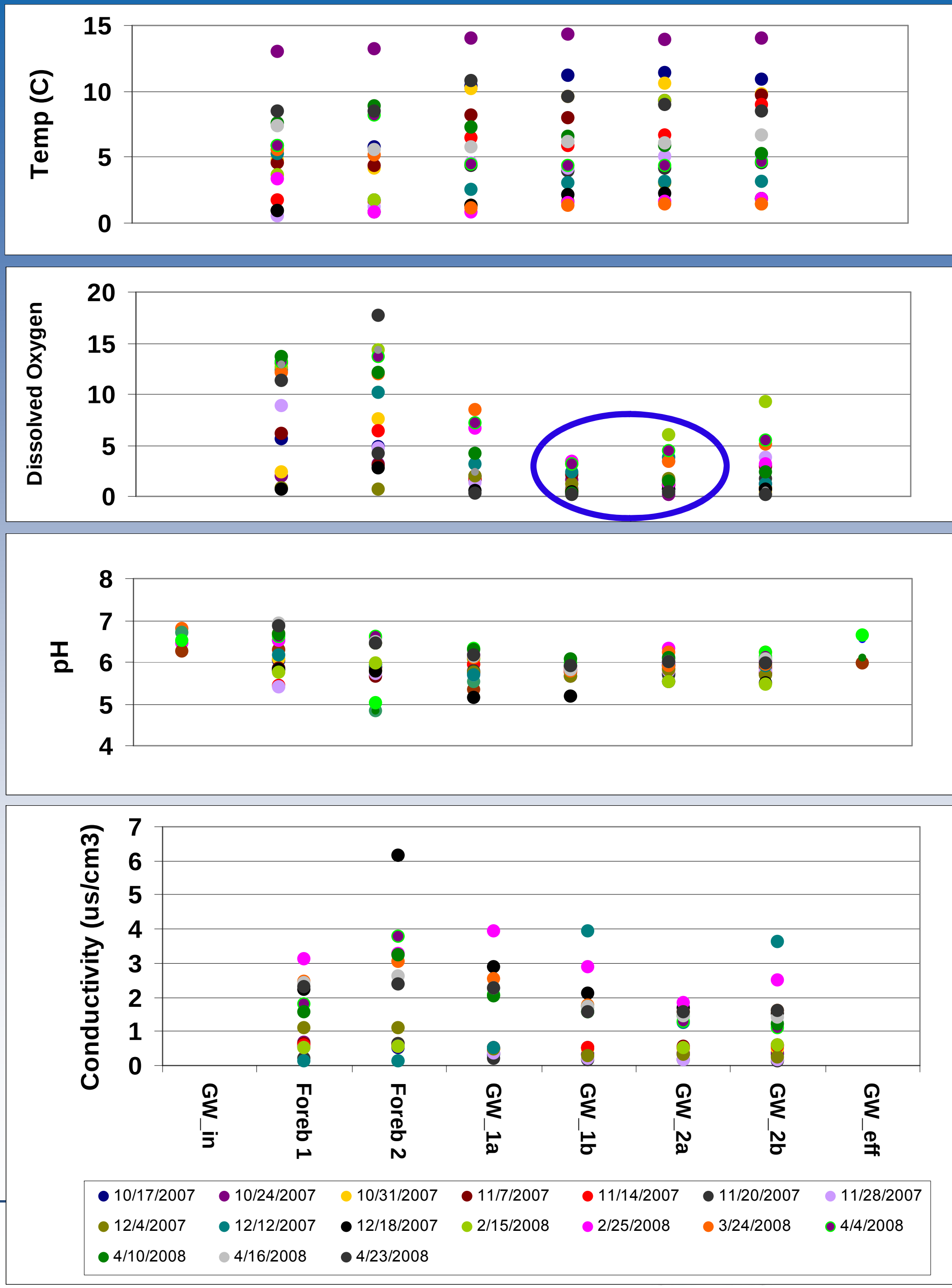
Organic N= TKN

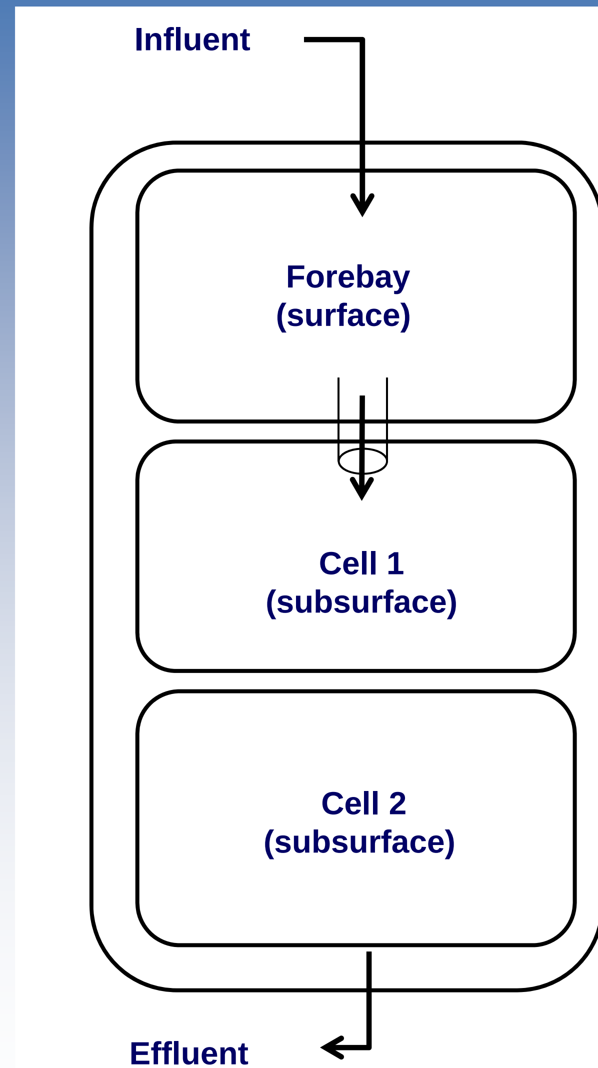
TN = Organic N+NH_3+NH_4+NO_2+NO_3

NITROGEN



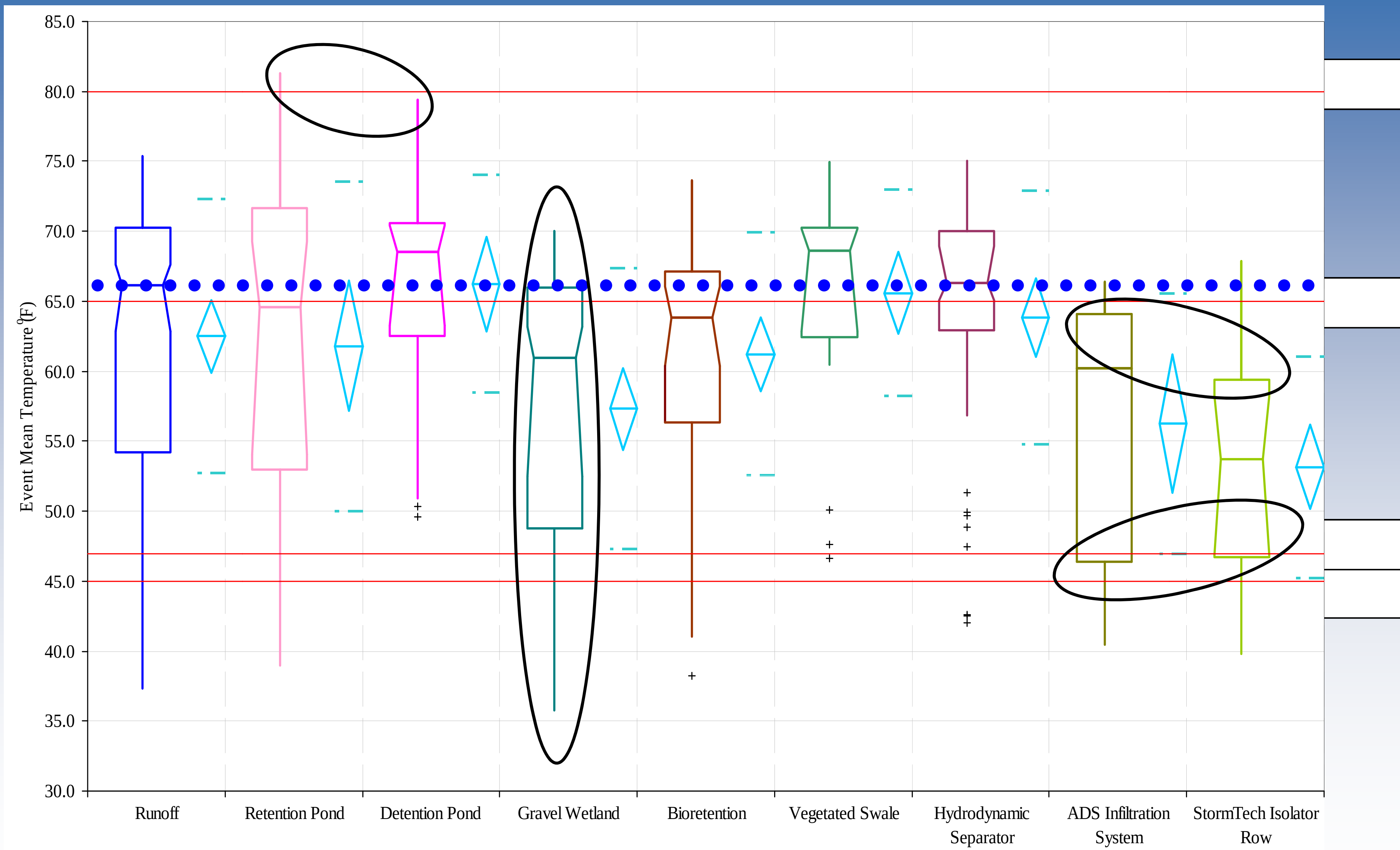
Concentration ug/L
November 26 2007 - Early Storm
Total N
Particulate Nitrogen
Total Dissolved Nitrogen
Dissolved Organic Nitrogen
Ammonium
Nitrite (NO2)
Nitrate (NO3)
800
600
400
200
0
Influent
Forebay 2
GW Cell 2
Effluent
Mid-Storm
Mid-Storm
Late Storm


Temp (C)
0
5
10
15
Dissolved Oxygen
0
5
10
15
20
pH
4
5
6
7
8
Conductivity (us/cm3)
0
1
2
3
4
5
6
7
GW_in
Foreb 1
Foreb 2
GW_1a
GW_1b
GW_2a
GW_2b
GW_eff
10/17/2007
10/24/2007
10/31/2007
11/7/2007
11/14/2007
11/20/2007
11/28/2007
12/4/2007
12/12/2007
12/18/2007
2/15/2008
2/25/2008
3/24/2008
4/4/2008
4/10/2008
4/16/2008
4/23/2008

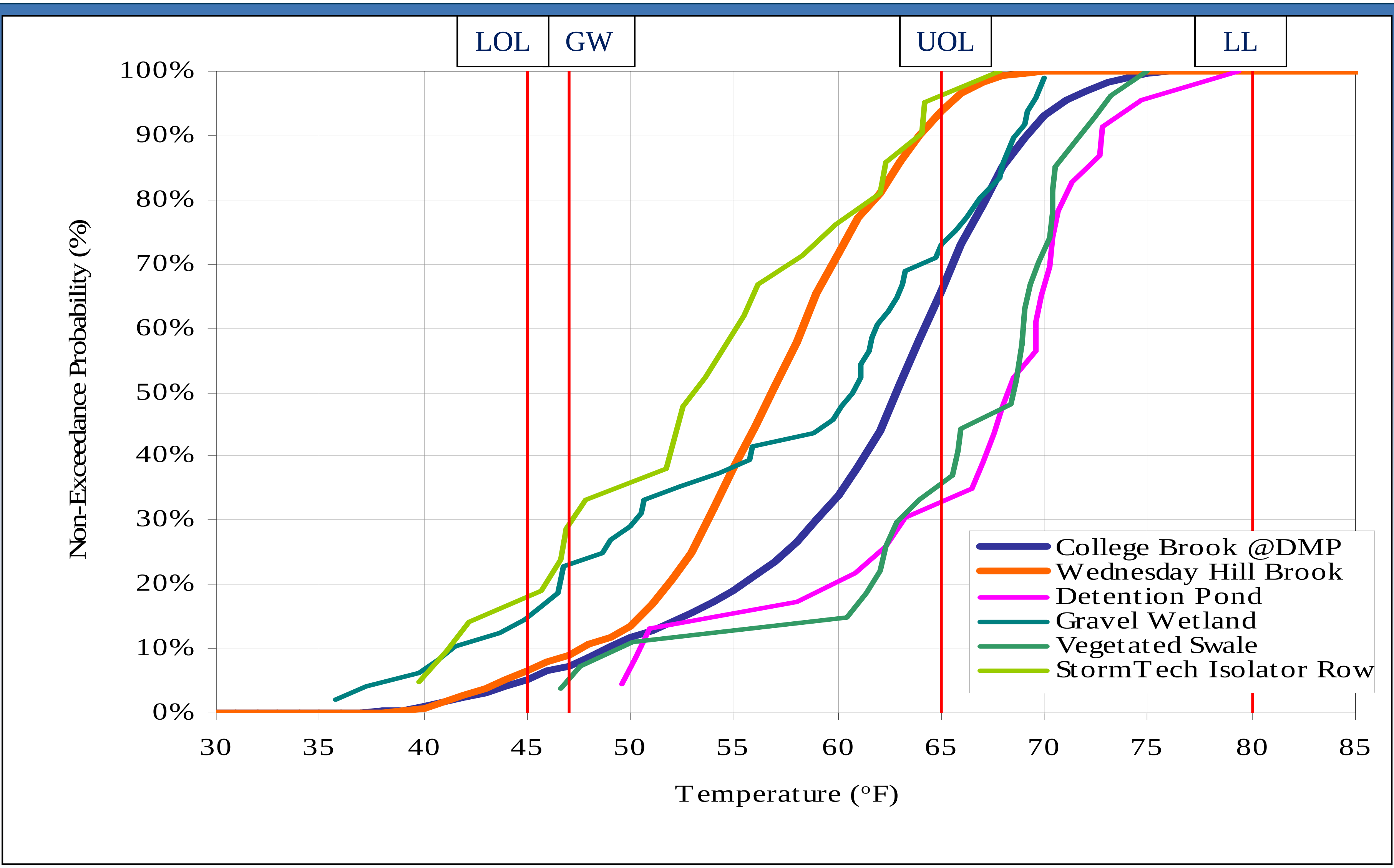

Influent
Forebay
(surface)
Cell 1
(subsurface)
Cell 2
(subsurface)
Effluent

Thermal Performance

Summer Quartile Assessment



Summer Natural Streams



Results

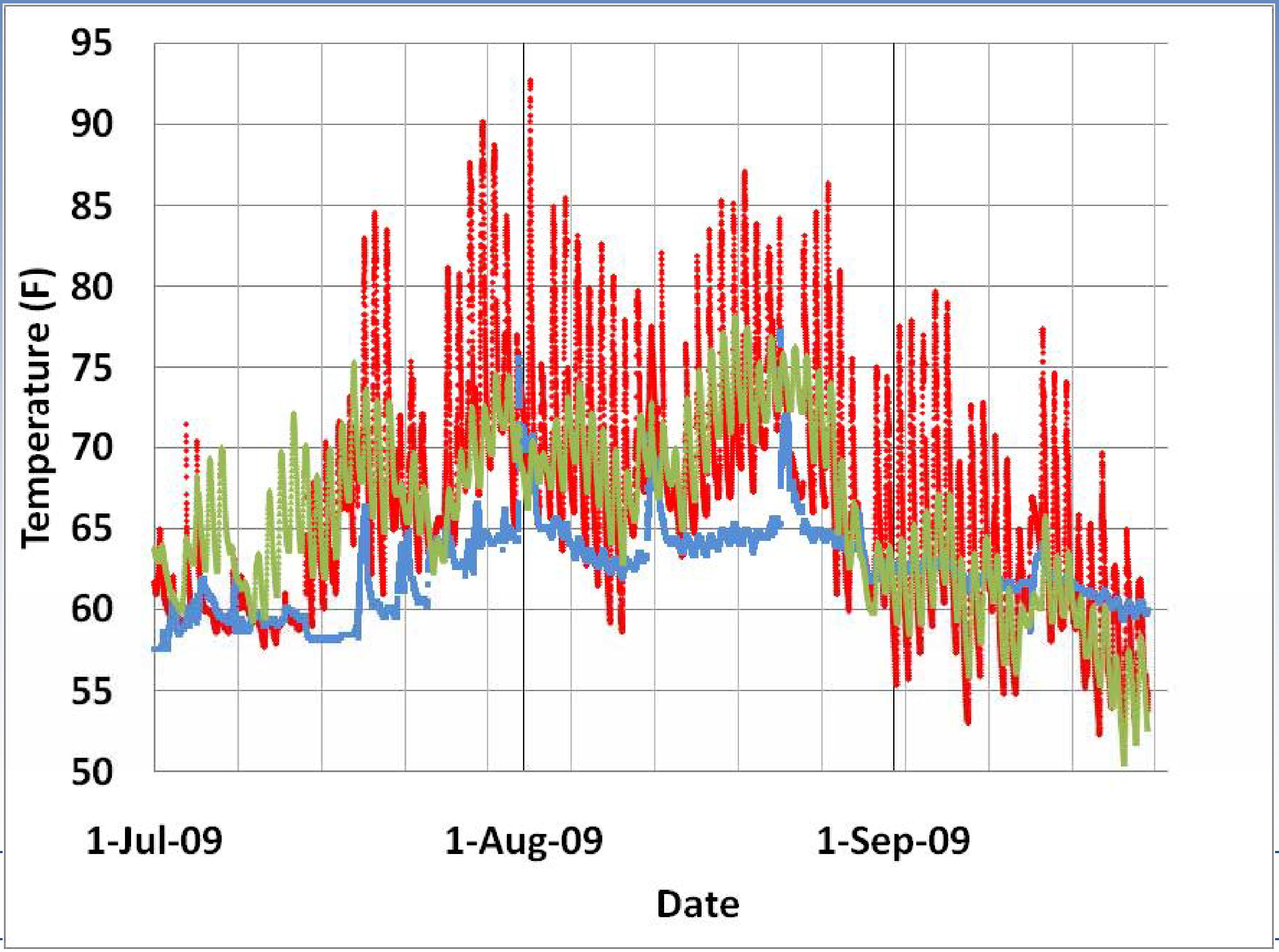
Annual Assessments		Runoff	Retention Pond	Detention Pond	Gravel Wetland	Bioretention	Vegetated Swale	HDS	ADS	STIR
EMT (°F)	Median	52.4	48.1	52.8	47.3	51.8	57.3	56.6	49.2	47.6
	Mean	53.5	50.9	52.3	48.7	51.9	54.8	54.1	51.5	49.0
	Standard Deviation	12.7	14.6	15.1	12.0	13.1	12.6	13.6	9.7	9.2
	Maximum	75.4	81.3	79.4	70.0	73.7	75.0	75.0	66.4	67.8
% Non-Exceedance UOL (65°F)		72.5%	79.0%	71.5%	87.0%	78.0%	72.5%	65.0%	95.0%	98.5%

Summer Assessments		Runoff	Retention Pond	Detention Pond	Gravel Wetland	Bioretention	Vegetated Swale	HDS	ADS	STIR
EMT (°F)	Median	66.2	64.6	68.6	60.9	63.9	68.6	66.3	60.3	53.7
	Mean	62.5	61.8	66.3	57.3	61.2	65.6	63.8	56.3	53.2
	Standard Deviation	9.8	11.8	7.8	10.1	8.7	7.3	9.1	9.3	7.9
Mean July Temperatures (°F)		67.1	77.9	72.2	66.0	67.7	70.3	69.0	63.4	58.5
% Non-Exceedance UOL (65°F)		42.0%	56.0%	37.0%	73.0%	58.5%	35.0%	34.0%	91.0%	96.0%

Time Series Characteristics

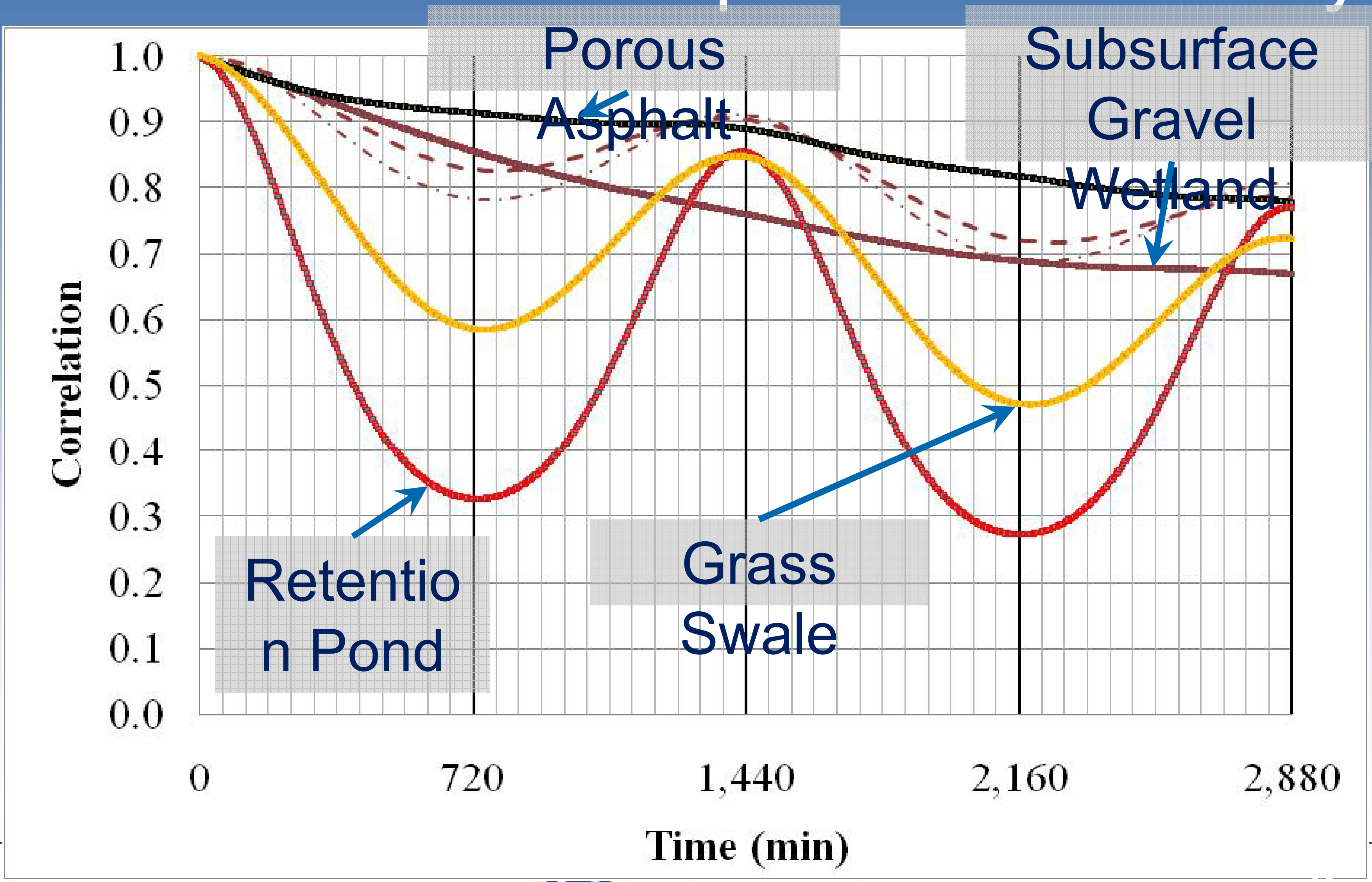
Subsurface Gravel Wetland (blue) Retention Pond (red)

Caldwell Brook (green)

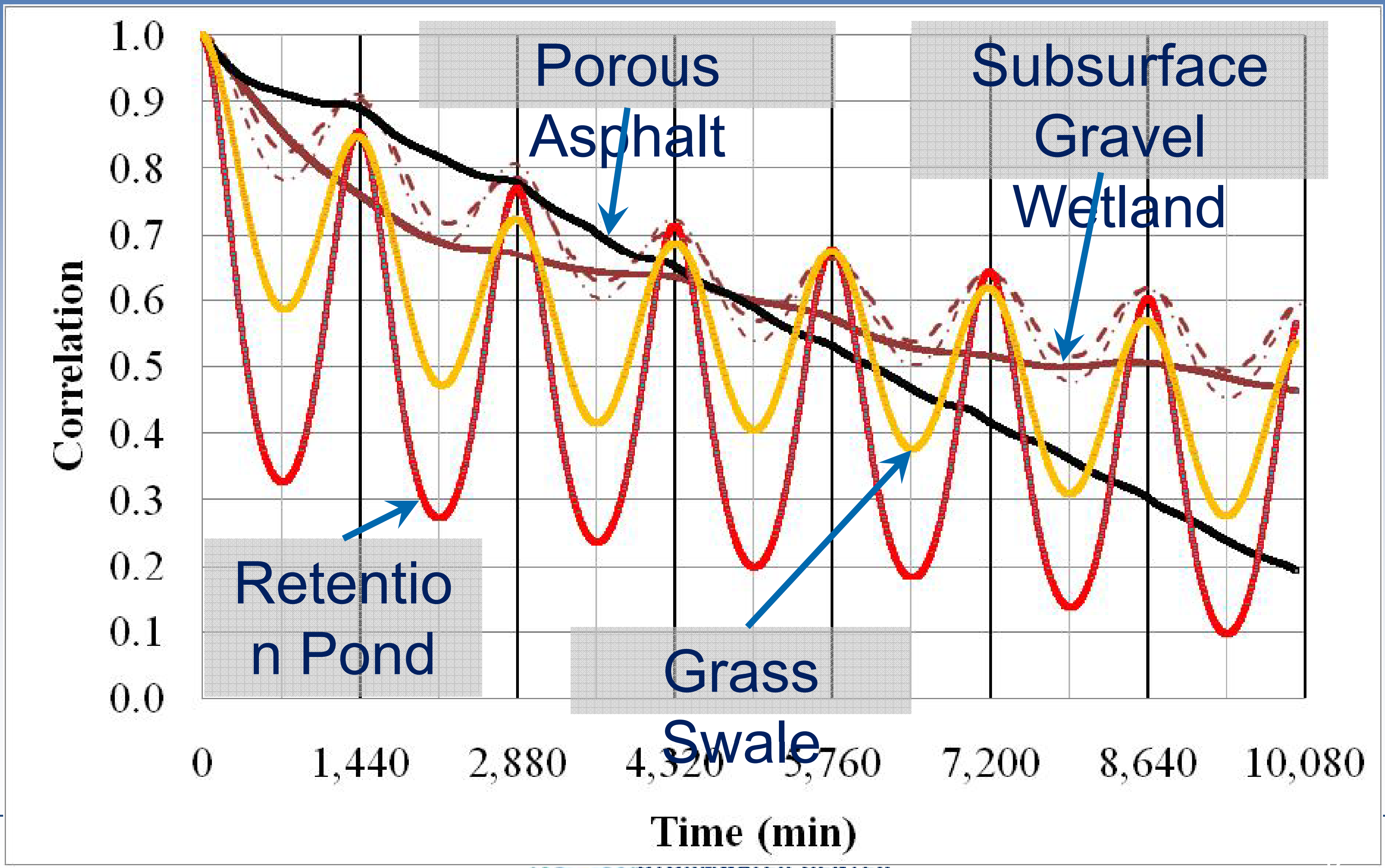


So When Stormwater Flows Into These Systems……Is it Memory Compatible?

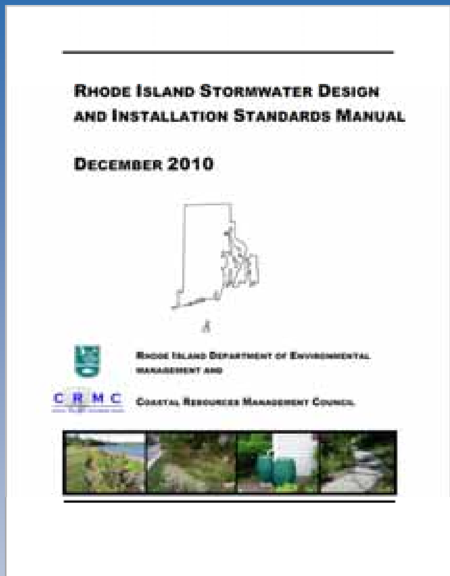
2009 Summer Temperatures – 2 days

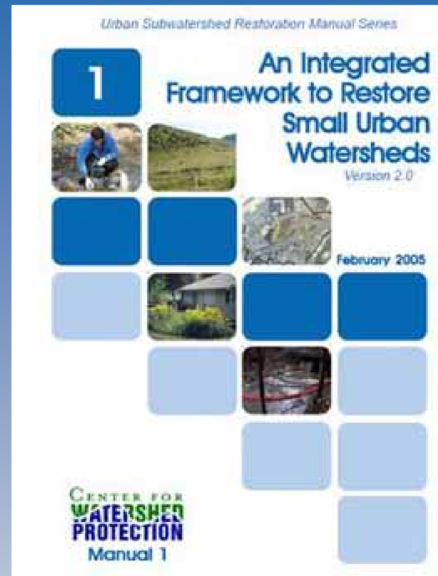


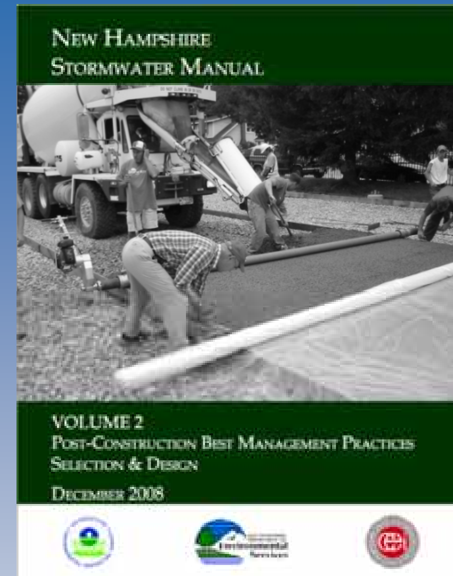
2009 Summer Temperatures – 7 days

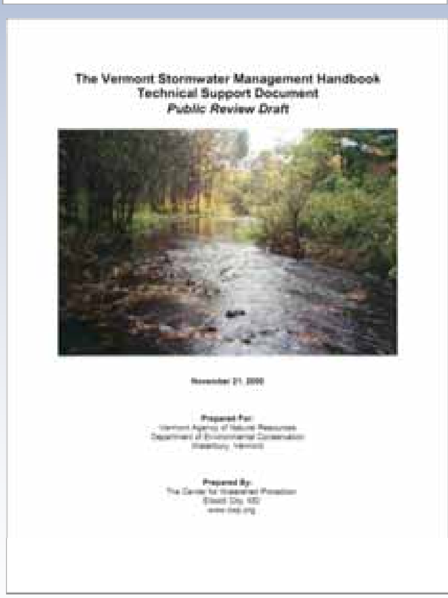


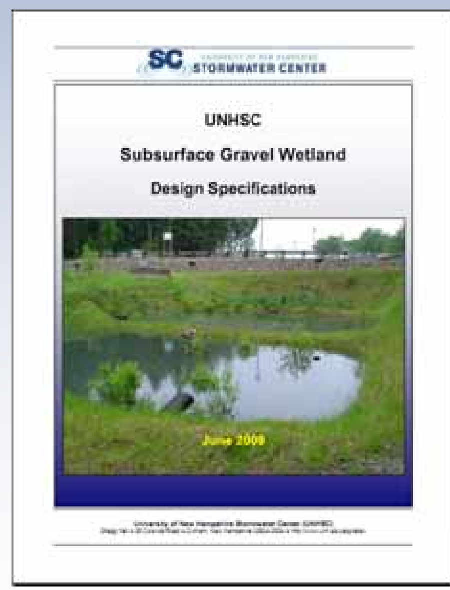
System Design
and
Sizing


Rhode Island Stormwater Design and Installation Standards Manual
December 2010
Rhode Island Department of Environmental Management and
CRMC
Coastal Resources Management Council


Urban Subwatershed Restoration Manual Series
1
An Integrated Framework to Restore Small Urban Watersheds
Version 2.0
February 2005
Center for Watershed Protection
Manual 1


New Hampshire Stormwater Manual
Volume 2
Post-Construction Best Management Practices Selection & Design
December 2008


The Vermont Stormwater Management Handbook
Technical Support Document
Public Review Draft


SC
Stormwater Center
UNHSC
Subsurface Gravel Wetland
Design Specifications
June 2009


New Jersey
Stormwater
Best Management Practices Manual
New Jersey Department of Environmental Protection
Division of Watershed Management

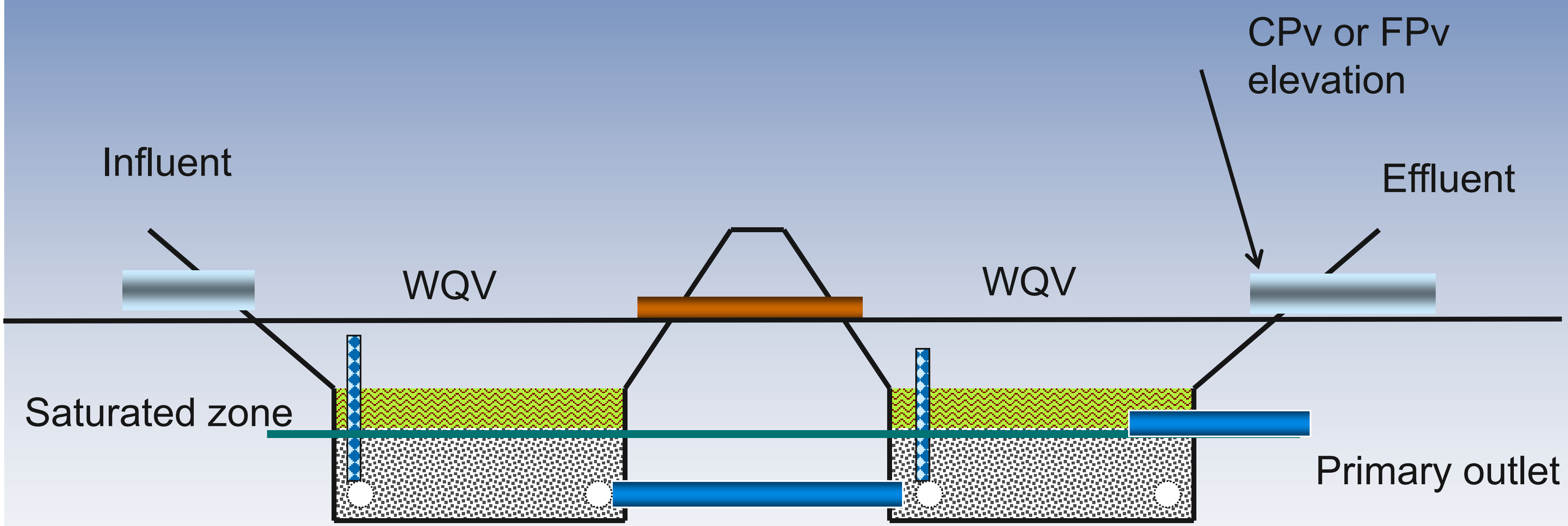
Design Criteria

- Water Quality Volume (WQv)
- Channel Protection Volume (Q2)
- Extreme Storm Volume (Q10)

WQV

- 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)
- In this case the system needs to provide storage and treatment for the WQV as if it were delivered instantaneously.

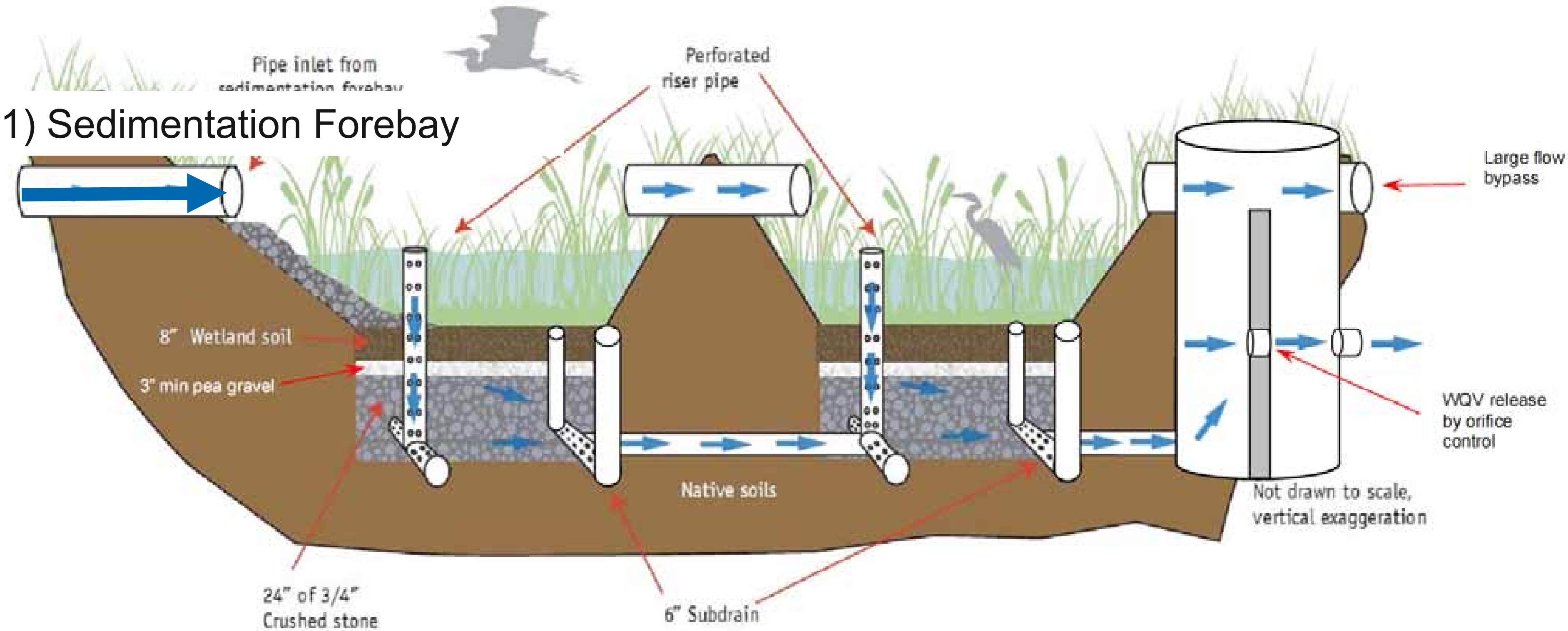
Generic Cross-Section



Critical Design Elements

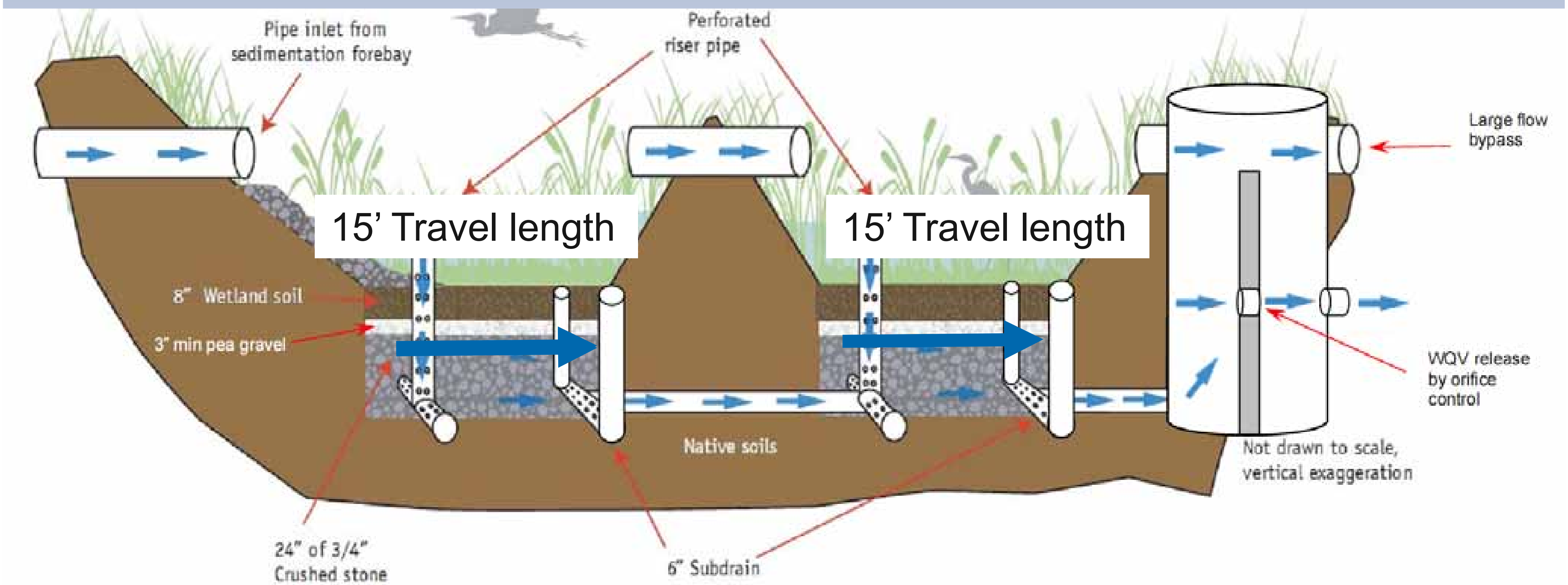
1. Pretreatment
2. Two Treatment Cells.
3. Flow path
4. Geotextile usage
5. Wetland soils
6. Subgrade soils
7. Liners
8. Materials
9. Inlet Structures
10. Outlet Structure

Subsurface Gravel Wetland

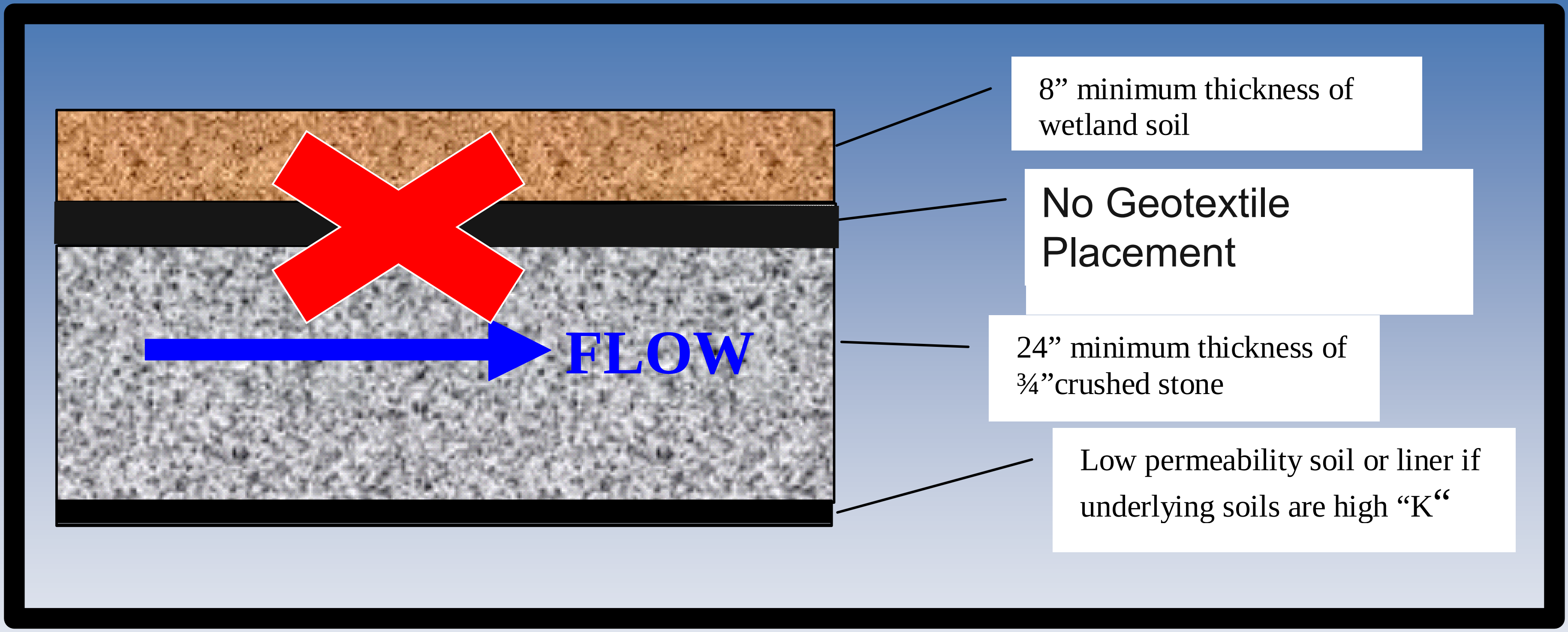


Flow Path

- Minimum flow path length through the gravel should be 15 ft per cell, 30 ft total
- Flow path is horizontal and distinct from most biofiltration



Geotextiles



- No Geotextile between soil and crushed stone, in replace use intermediate setting bed
- Do not use geotextiles between the horizontal layers of this system as they will clog due to fines and may restrict root growth.

Wetland Soil

- 8 in. (20 cm) minimum thickness of a wetland soil as the top layer.
- This layer is leveled (constructed with a surface slope of zero).
- 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 x 10^{-5} cm/sec to 3.5 x 10^{-6} cm/sec)).

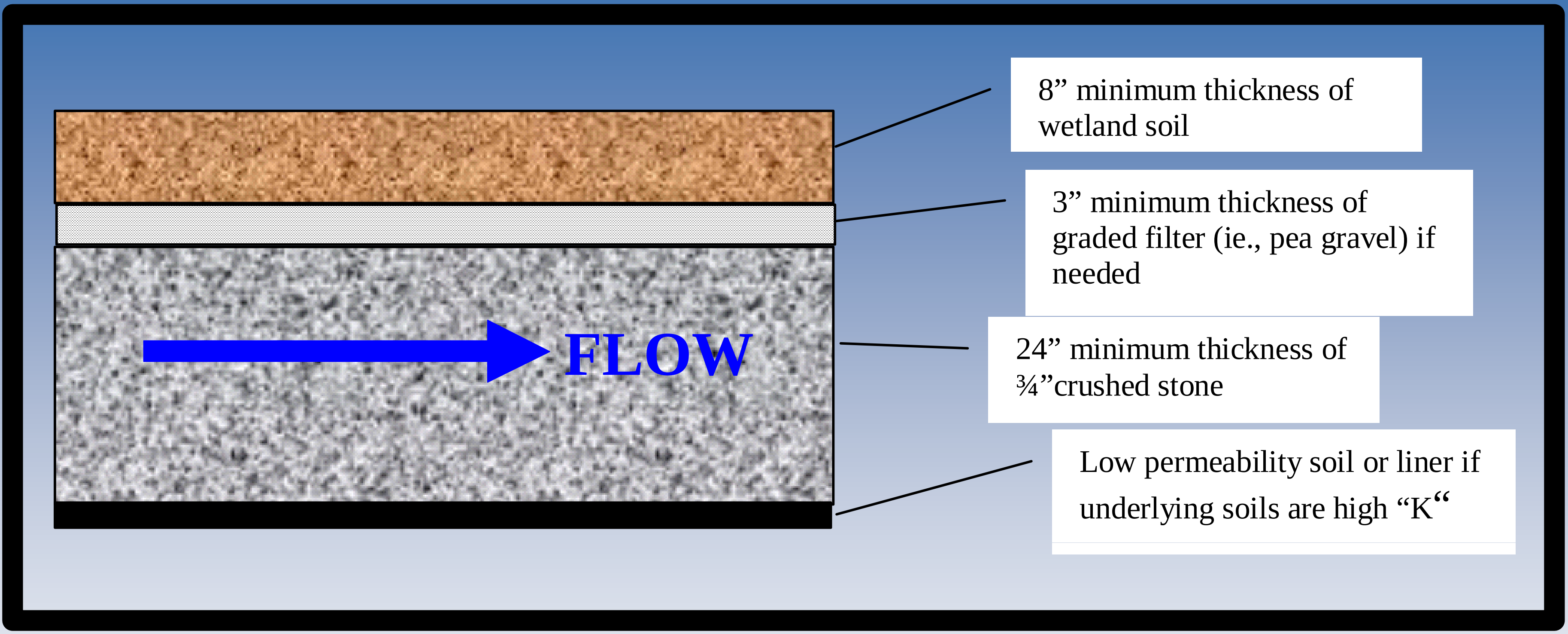
Wetland Soil

- This soil can be manufactured using existing topsoil, and compost, or 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.

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

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

Subgrade Soils



Subgrade Soils

- Underlying soils should have low permeability to maintain driving head and risk of groundwater contamination
- Hydraulic conductivity ≤ 0.03 ft/day
- If low permeability soils are present, use a compacted soil or HDPE liner.

Liners

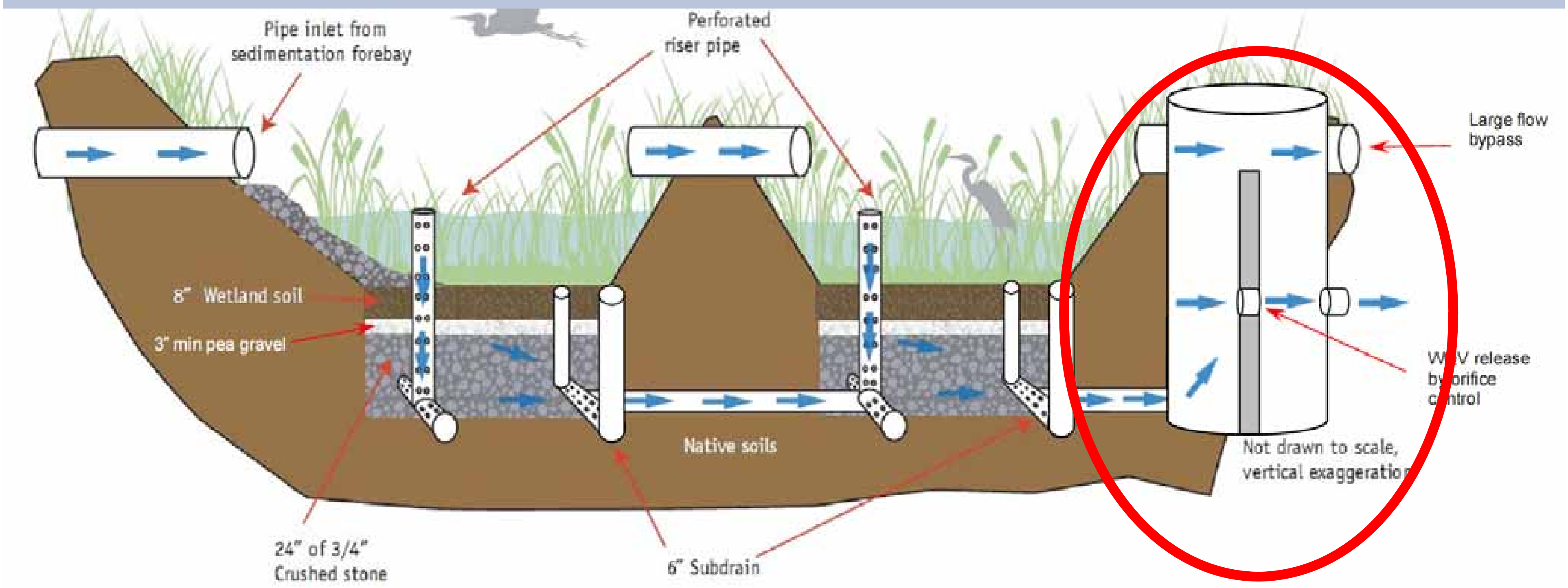
- Federal guidelines regulate groundwater protection standards.
- Liners can be used for sites where the infiltration is a concern (eg. high water table, bedrock karst sites and hot spots where hazardous materials may be handled).
- The use of Liners will preserve water quality through detention and filtration and will limit any infiltration.
- Liners can be made from HSG 'D' soils, HDPE, or clay

Reservoir Course

- 3 in. (8 cm) minimum thickness of an intermediate setting bed layer of a graded aggregate filter overtop the reservoir course
- Prevent the wetland soil from moving down into the gravel sub-layer through soil piping
- Material compatibility between layers needs to be evaluated.
- Reservoir course is constructed of ~0.75” angular stone (similar to ASTM#57)

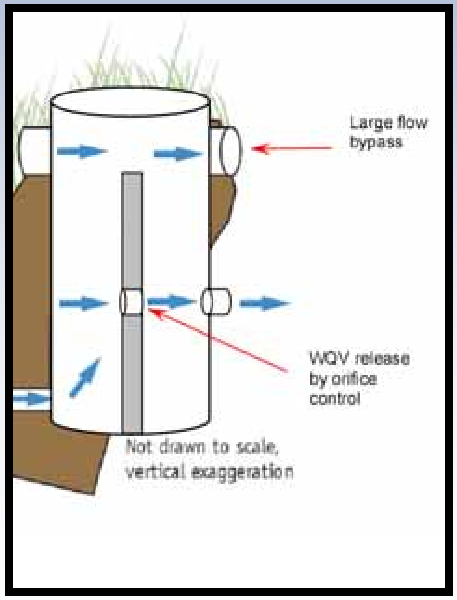
Outlet Structure

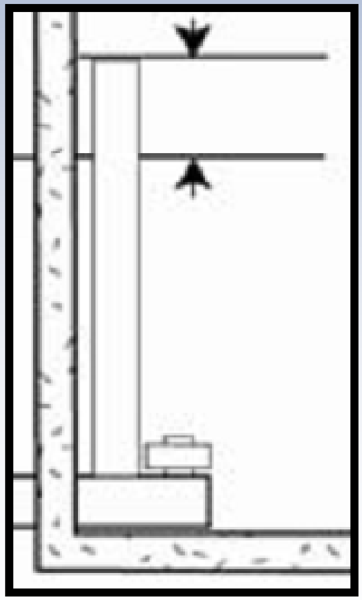
- Many options
- All will have WQV release and highflow bypass
- May include drainplug for maintenance

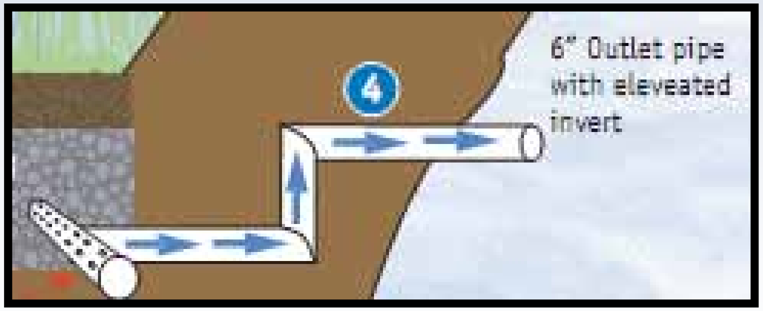


Outlet Structure

- Outlet Structure Options vary
  - Precast structure with weir wall
  - T-fitting with valve
  - Upturned elbow





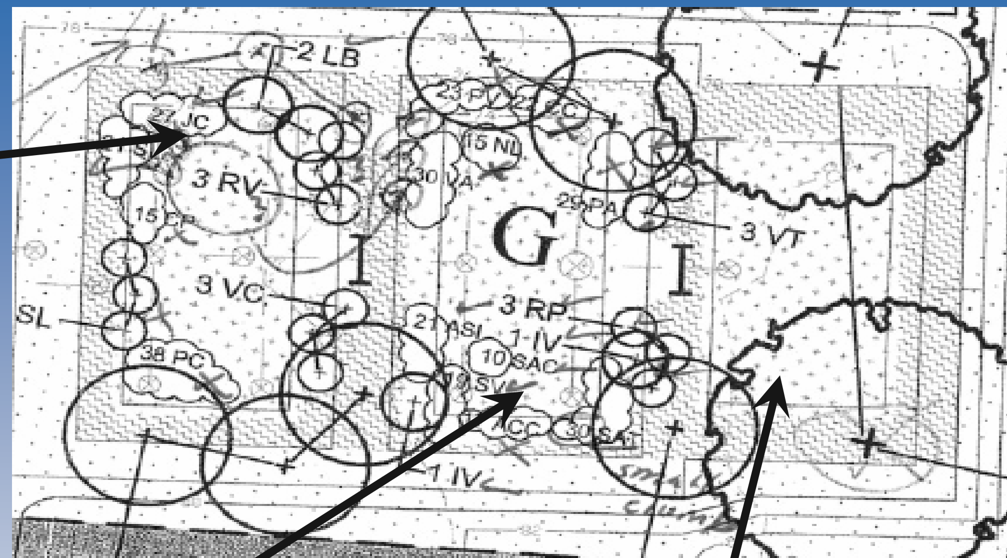


Wetland Vegetation

- 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

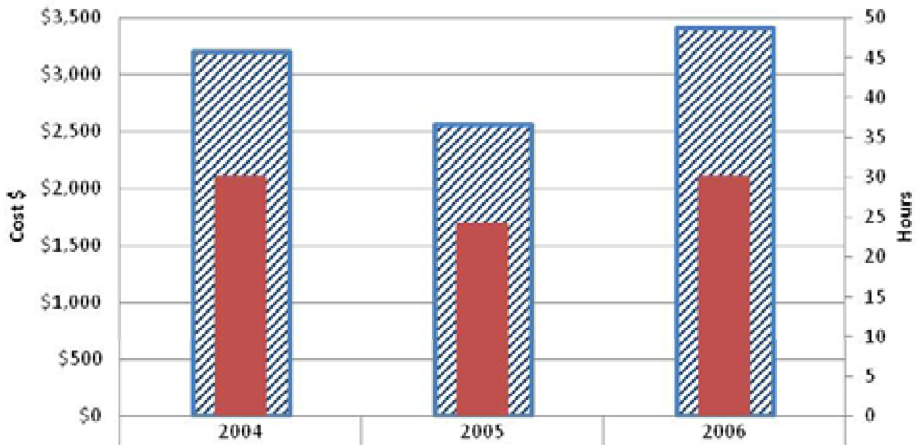
UNH SC – General Wetland Condition

- 53% of the planted species are 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.

Inspection and Maintenance

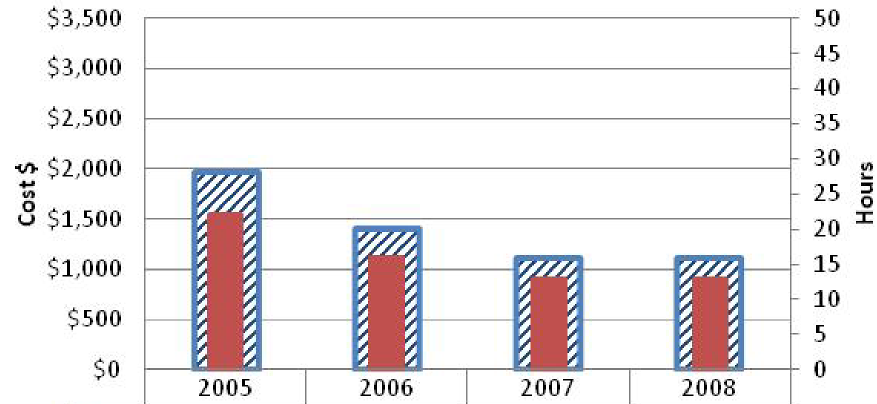
REACTIVE	PERIODIC
Episodic maintenance Cheap in short term Expensive in long term Most property damage	Can be expensive and wasteful Need statistics Simple administration
PREDICTIVE	**PROACTIVE**
Scientific basis Cost-effective Not applicable everywhere Administration more difficult	Can be cost-effective Expensive if overused Can have institutional implications

Retention Pond



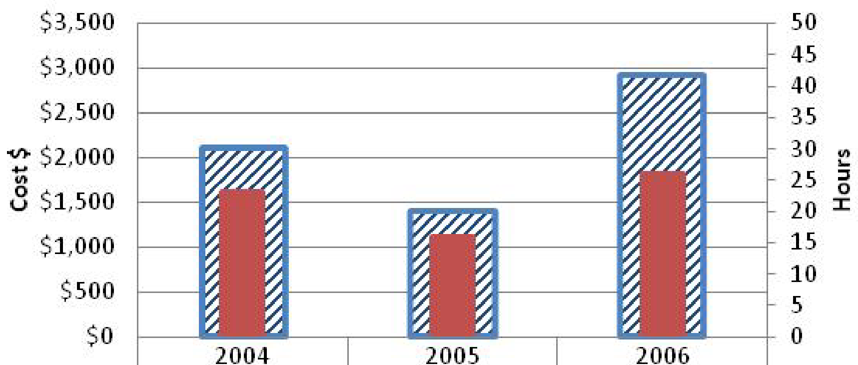
	2004	2005	2006
cost	3210.0	2560.0	3410.0
hr	30.0	24.0	30.0

Bioretention



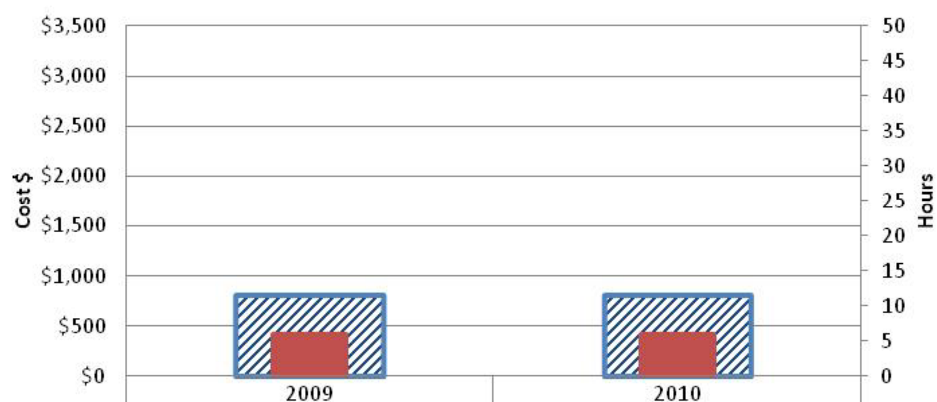
	2005	2006	2007	2008
cost	$1,970.0	$1,400.0	$1,115.0	$1,115.0
hr	22.0	16.0	13.0	13.0

Gravel Wetland



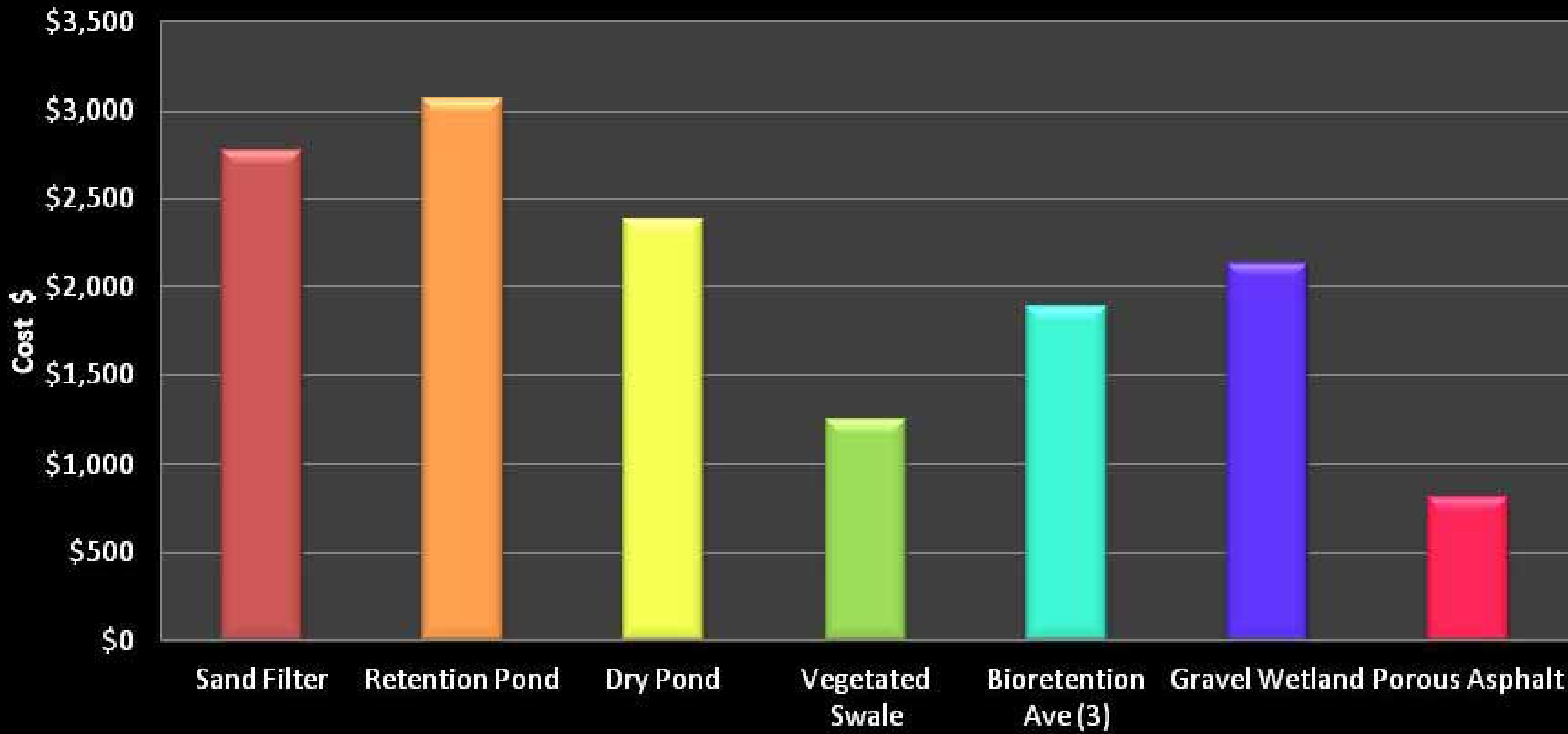
	2004	2005	2006
cost	$2,105.0	$1,400.0	$2,910.0
hr	23.0	16.0	26.0

Porous Asphalt

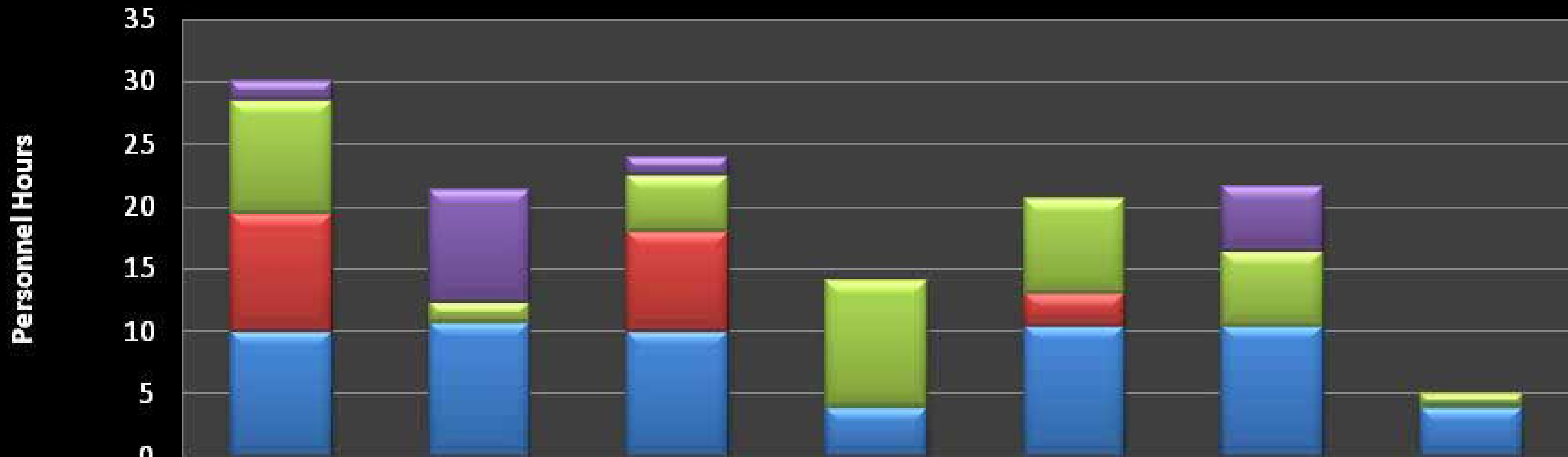


	2009	2010
cost	$810.0	$810.0
hr	6.0	6.0

Yearly BMP Maintenance (per acre treated)



BMP Maintenance/acre/yr by Catagory



	Sand Filter	Retention Pond	Dry Pond	Vegetated Swale	Bioretention (3)	Gravel Wetland	Porous Asphalt
Reactive	1.5	9	1.5	0	0	5	0
Proactive	9	2	4.5	10	8	6	1
Predictive	9.5	0	8	0	3	0	0
Periodic	10	11	10	4	10	10	4

4 - yr Forebay Maintenance - June 2008

Current 3-yr Maintenance Plan

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.

Materials and Installation Cost

Technology		Cost: $/Acre IC
Vegetated Swale	$	11,200.00
Retention Pond	$	13,700.00
Gravel Wetland	$	22,300.00
Bioretention		15,000 - 25,000
HDPE Chamber	$	34,000.00

Greenland Case Study

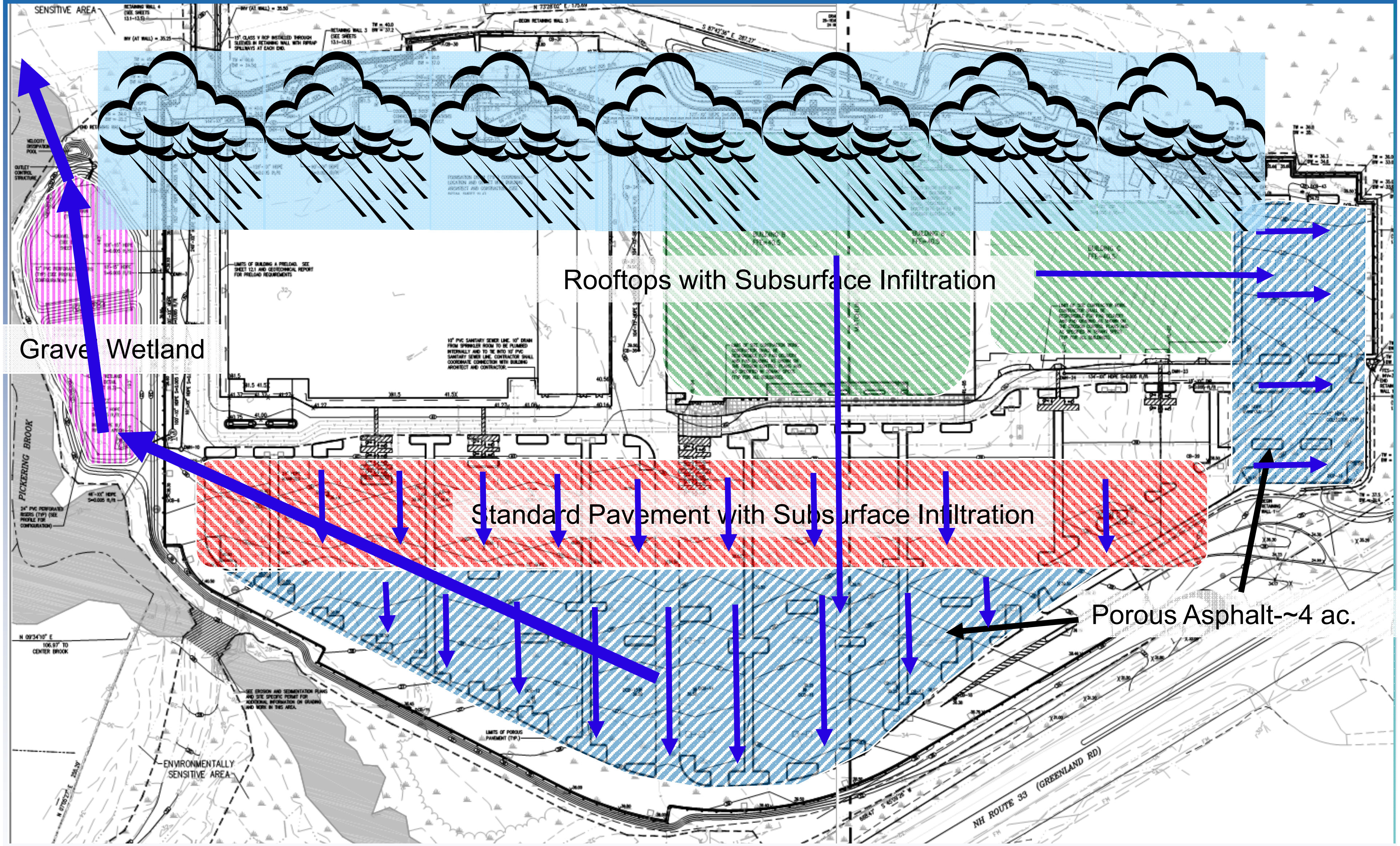
CASE STUDY: Greenland Meadows

Packard Development, Conservation Law Foundation, UNHSC (2005- Present)

- Protection of impaired waters—Pickering Brook
- >15,000 Average Daily Traffic count

Involves the use:

- daily street vacuuming
- a porous asphalt parking lot
- subsurface infiltration of rooftop runoff
- a gravel wetland
- Combined as a treatment train



Entire site is treated by filtration, either porous pavement, subsurface infiltration, or gravel wetland, or combination of methods



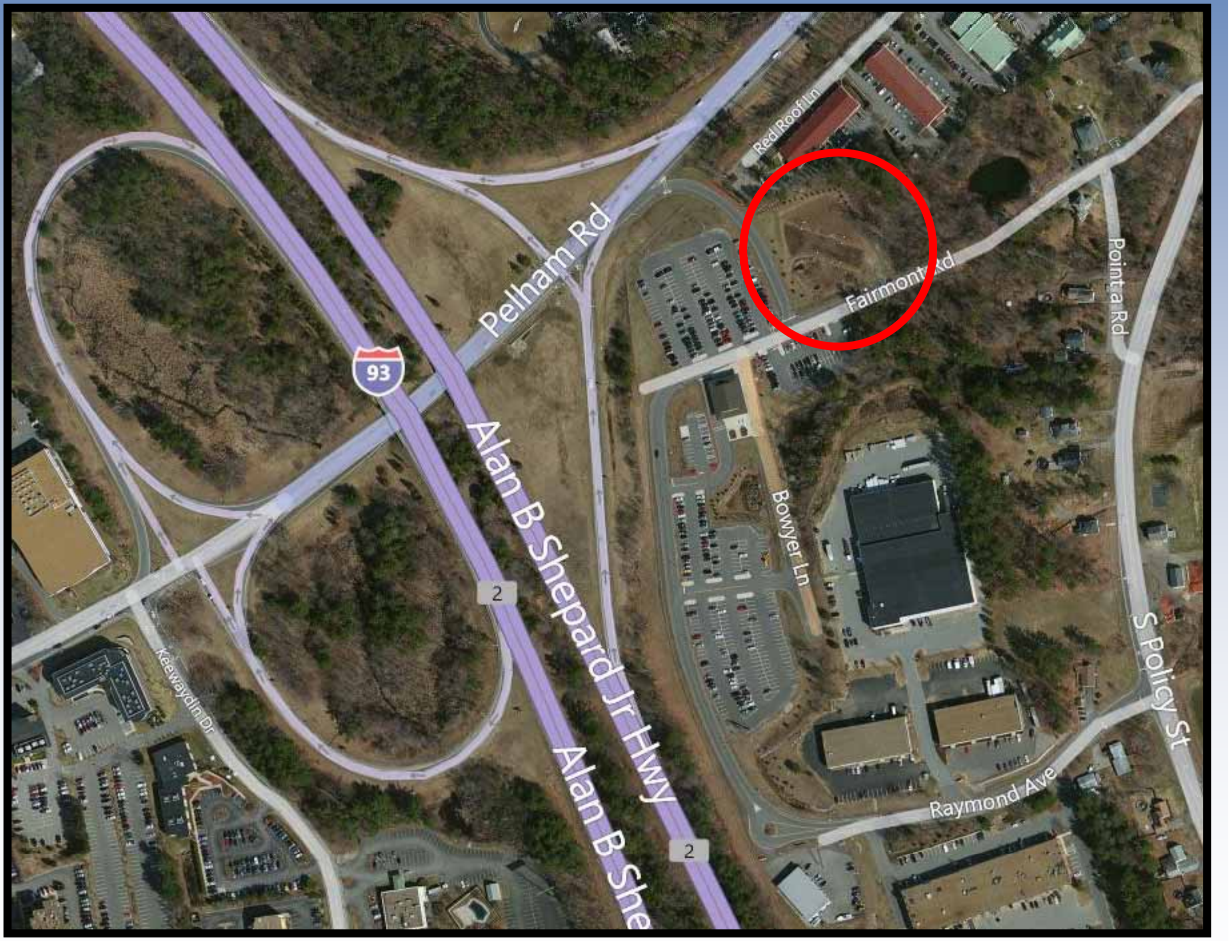

3 mos later

3 years later

Discharge to Impaired Water

TMDL Impaired Watershed

- NHDOT Exit 2 Park and Ride
- GW use for 401 WQ Certification
- Used widely by NHDOT on I-93 and Rt 16 Expansion



UNIVERSITY OF NEW HAMPSHIRE STORMWATER CENTER

NHDOT Install Exit 5

Funding

Funding is provided by the Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET) whose mission is to support the scientific development of innovative technologies for understanding and reversing the impacts of coastal and estuarine contamination and degradation.