Green Infrastructure: Sustainable Stormwater Management

ES 44, THAYER SCHOOL OF ENGINEERING

DARTMOUTH COLLEGE

MAY 14, 2019

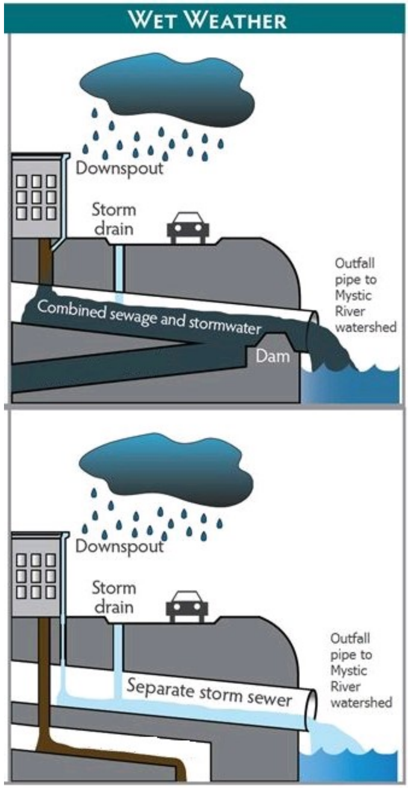
KEVIN DAHMS, D' 12, TH '13

WATER RESOURCES ENGINEER

BIOHABITATS, INC.

Biohabitats

OVERVIEW



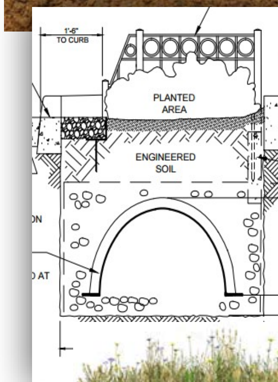
mysticriver.org/csos/

www.watershedcouncil.org/bioswale.html

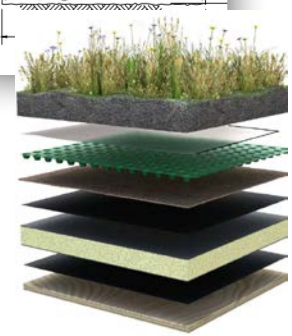
www.lastormwater.org

www.cookjenshel.com/green-roofs

www.a1soils.com



NYC DEP



mikosguesthouse.com/green-roof-layers-explained

NYC Environmental Protection

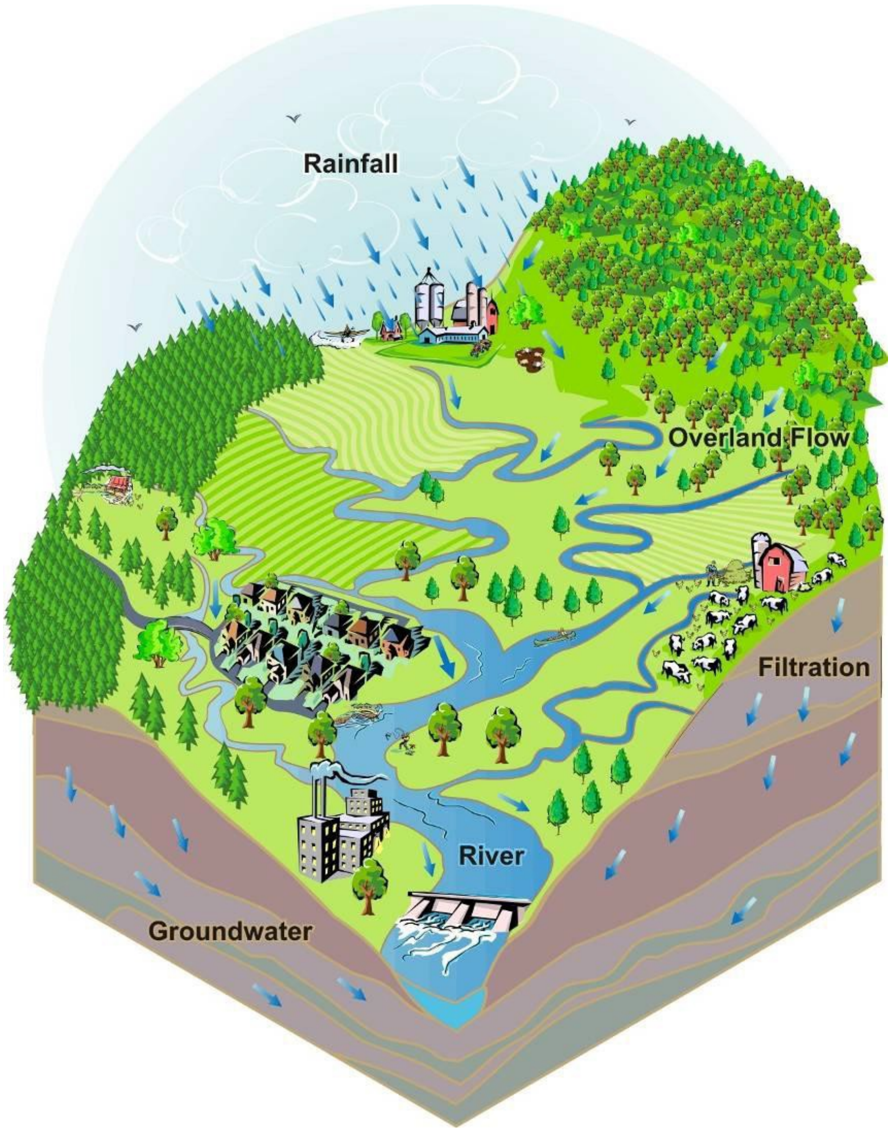
Yale School of Forestry & Environmental Studies

Biohabitats HUDSON RIVER BIOREGION

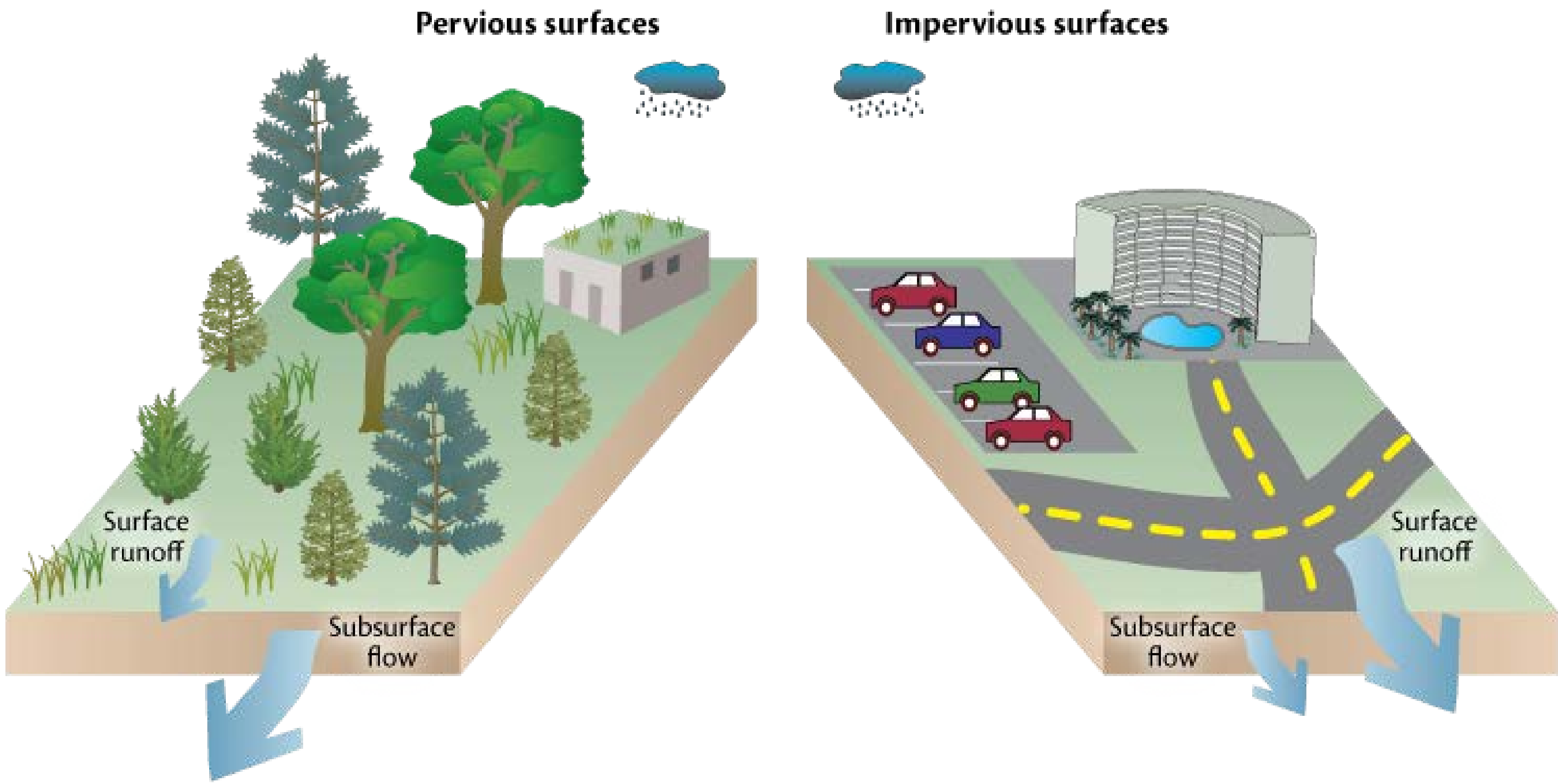
PROBLEM STATEMENT | GREEN INFRASTRUCTURE | DESIGN CONSIDERATIONS | CASE STUDIES

WATERSHED BASICS

A watershed is an area of land where all water that falls onto it (rain) and drains off of it (overland, through rivers and stream, and underground as groundwater) goes to a common outlet.

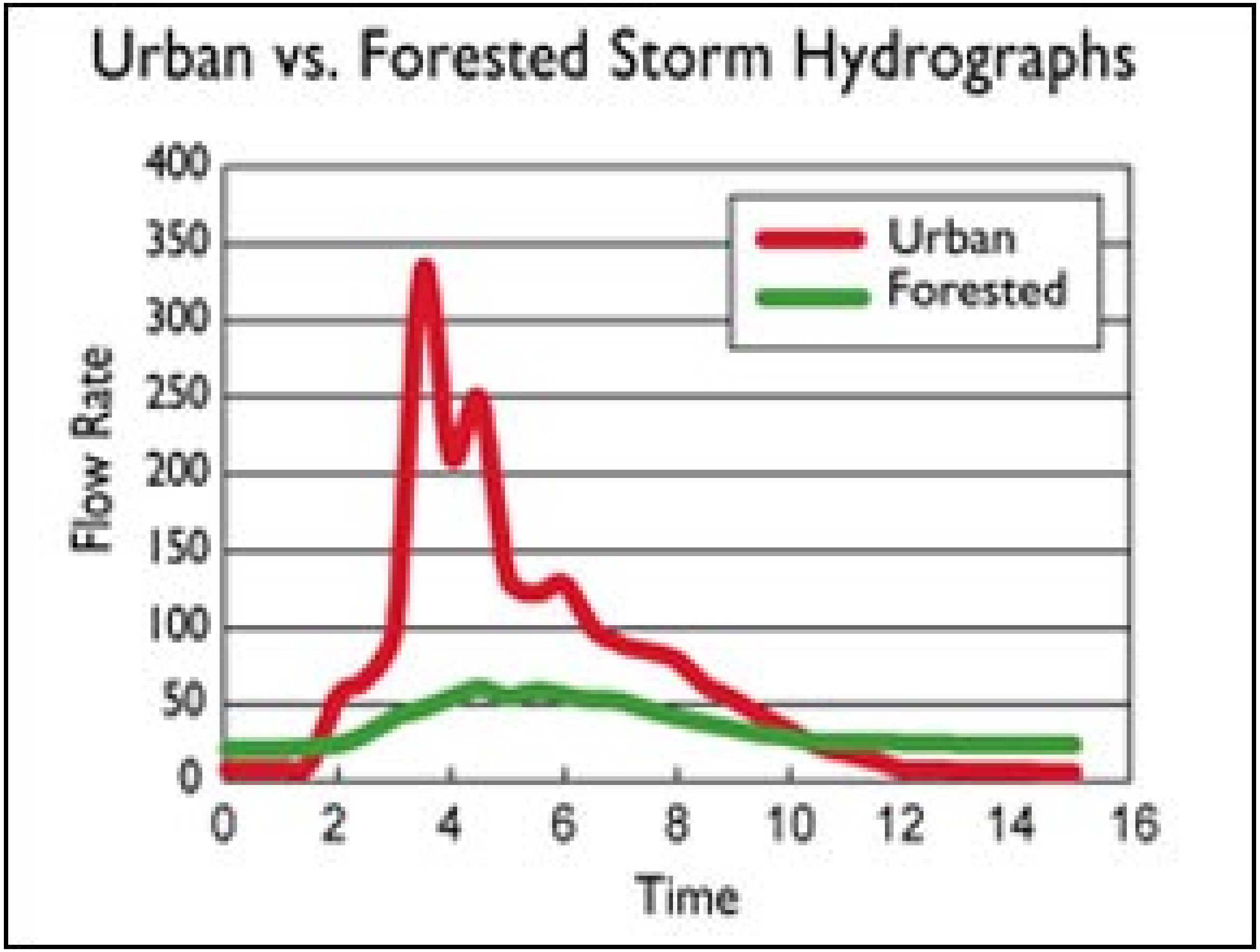


Mannahatta, 2009



http://www.mdcoastalbays.org/bayissues-stormwater-management

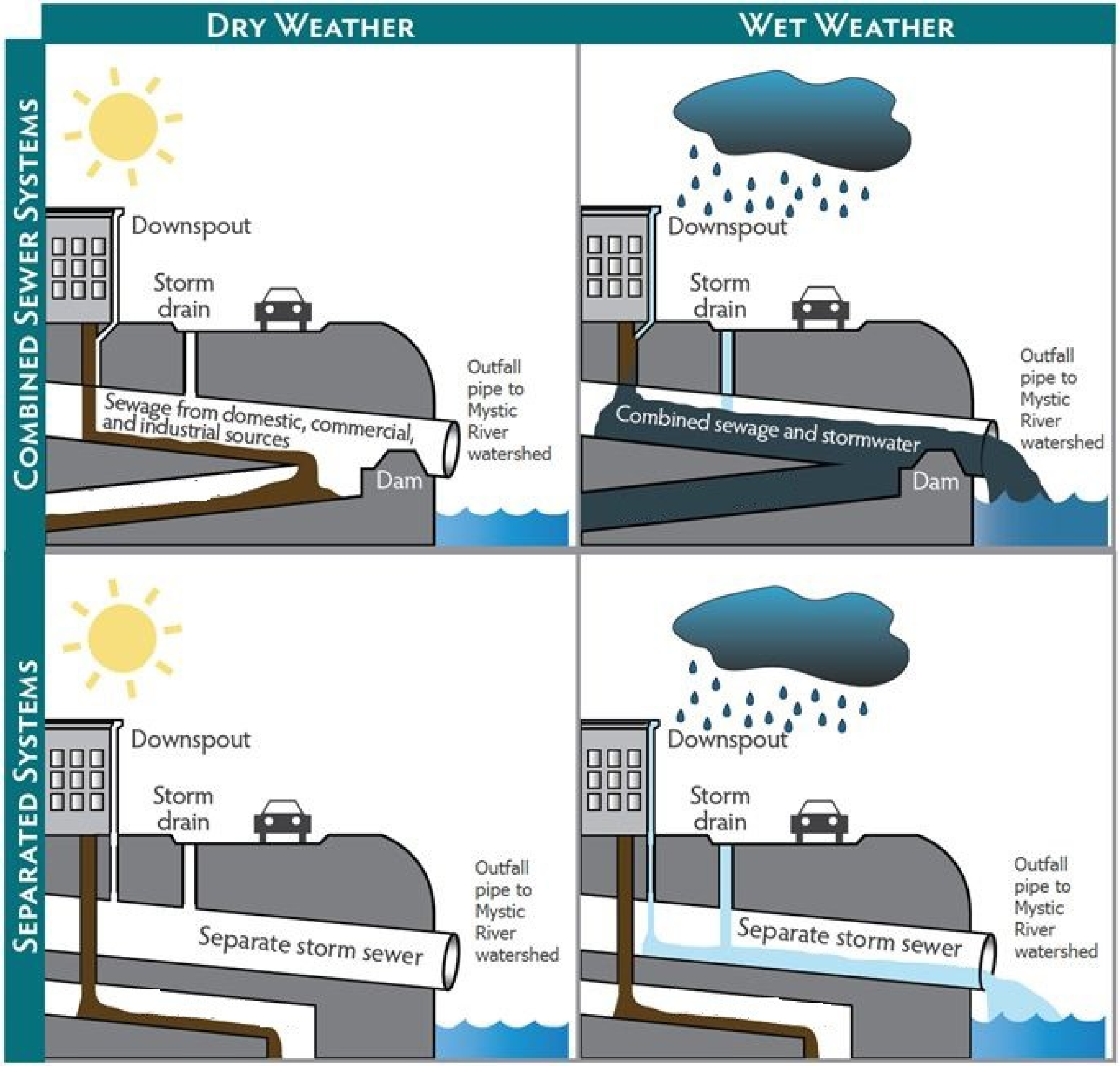
URBAN STREAM SYNDROME



https://uwcm-geog.wikispaces.com/Drainage+Basins+and+Flooding

COMBINED SEWER OVERFLOWS (CSOs)

https://mysticriver.org/csos/



WATER QUALITY

https://www.quora.com/What-is-eutrophication

http://cahnrs.wsu.edu/

www.fondriest.com

TRADITIONAL SOLUTIONS

http://www.estormwater.com/

https://my.spokanecity.org

GREEN STORMWATER INFRASTRUCTURE (GSI)

OTHER NAMES

Low Impact Development

SW Best Management Practices

Sustainable Storm Water System

PRIMARY GOALS

Reduce effective impervious surface

Capture runoff at the source

Restore natural flows

Filter water through soil and vegetation

http://livingarchitecturemonitor.com/

GSI

<u>DESIGN TYPES</u>

Cisterns and other detention

Green Roofs

Porous Pavement

Bioretention

Other (wetlands, sand filters, ponds, etc.)

Mississippi Watershed Management Organization

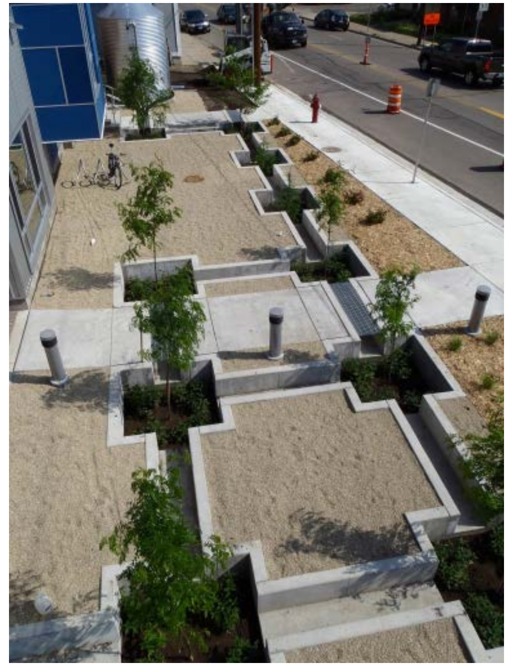


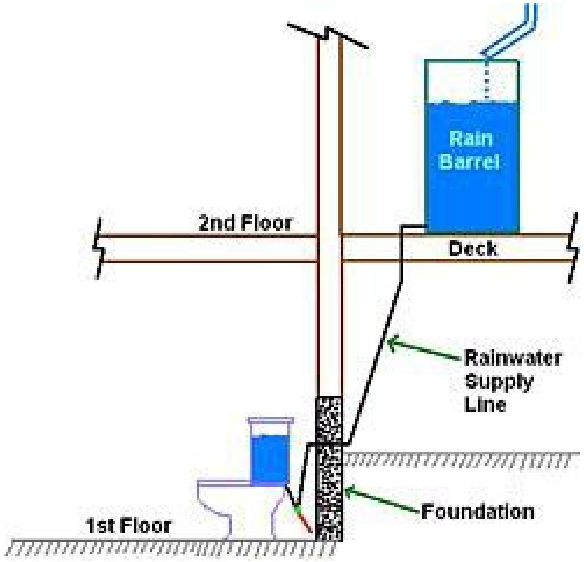
Photo Credit: JJ Harrison

https://sailorstales.files.wordpress.com/2015/08/img_6746-3 rain-garden.jpg

Moorefarmsbg.org

DETENTION AND STORAGE SYSTEMS

https://www.pinterest.com/explore/rain-barrels/



http://www.reuk.co.uk/

www.streamnologies.com

TYPES

Rain barrel

Cistern and reuse

Stormwater chambers

DESIGN FACTORS

- Contributing drainage area (roof vs. parking lot)
- Volume based capacity but peak flow reduction
- Available capacity with subsequent storm events
- Low profile
- Relatively easy installation, but maintenance?

GREEN ROOFS

TYPES

Extensive (< 4” media depth)

Intensive (> 4” media depth)

Stormwater management

Decorative

Rooftop Farms

http://www.greenroofs.com/

http://www.greenrooftechnology.com/

www.grassroofcompany.co.uk

GREEN ROOFS

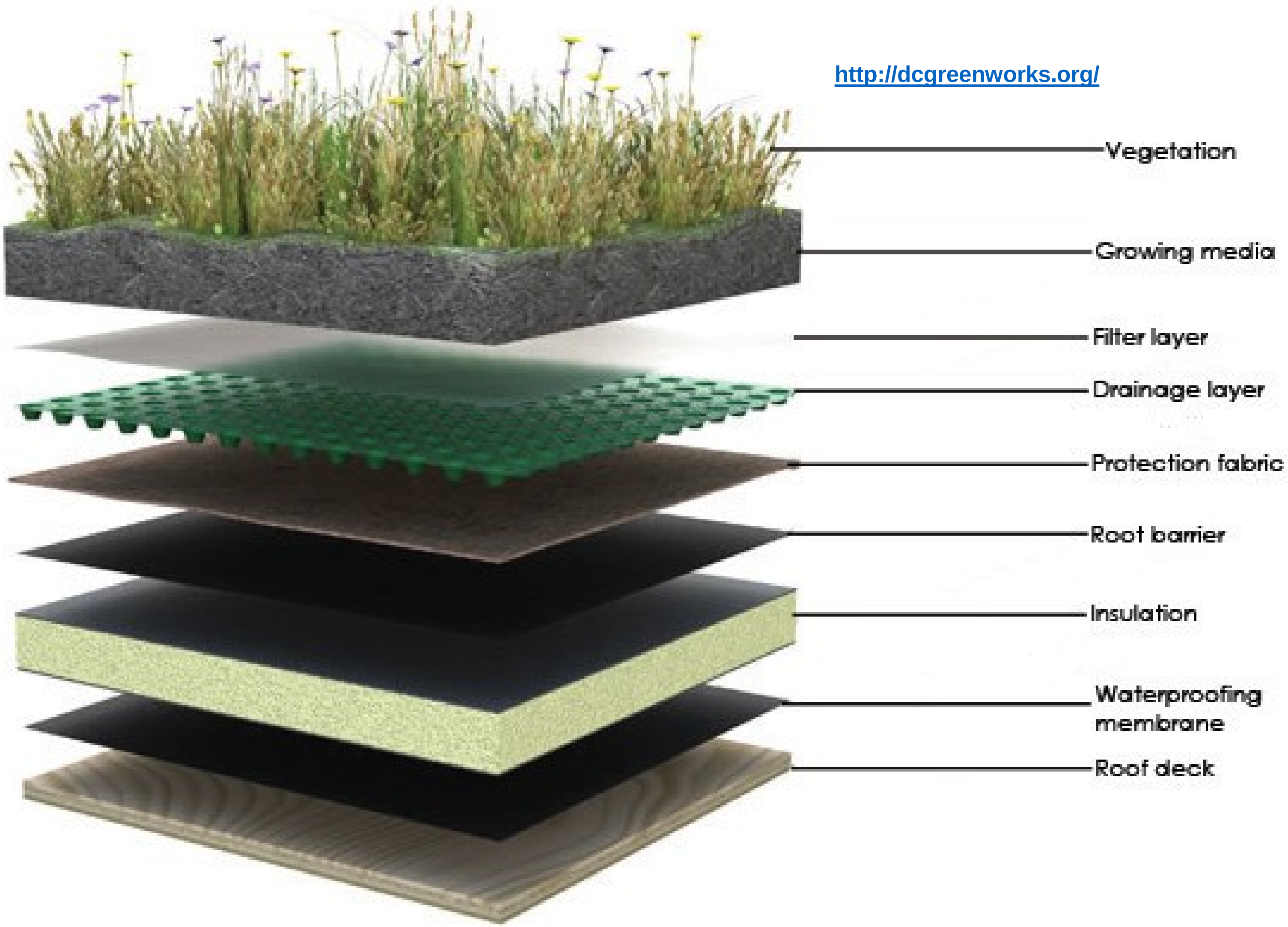
DESIGN FACTORS

Building Factors
- Max loading capacity of roof
- Roof membrane
- Access for maintenance
- Existing drain locations

Green Roof Factors
- Media type/depth
- Vegetation selection
- Establishment of vegetation
- Non-vegetative boundary

Gizmodo.com

GREEN ROOFS - COMPONENTS



http://dcgreenworks.org/

POROUS PAVEMENT

TYPES

Porous Asphalt
Permeable Concrete
Interlocking Pavers
Grass Pavers

DESIGN FACTORS

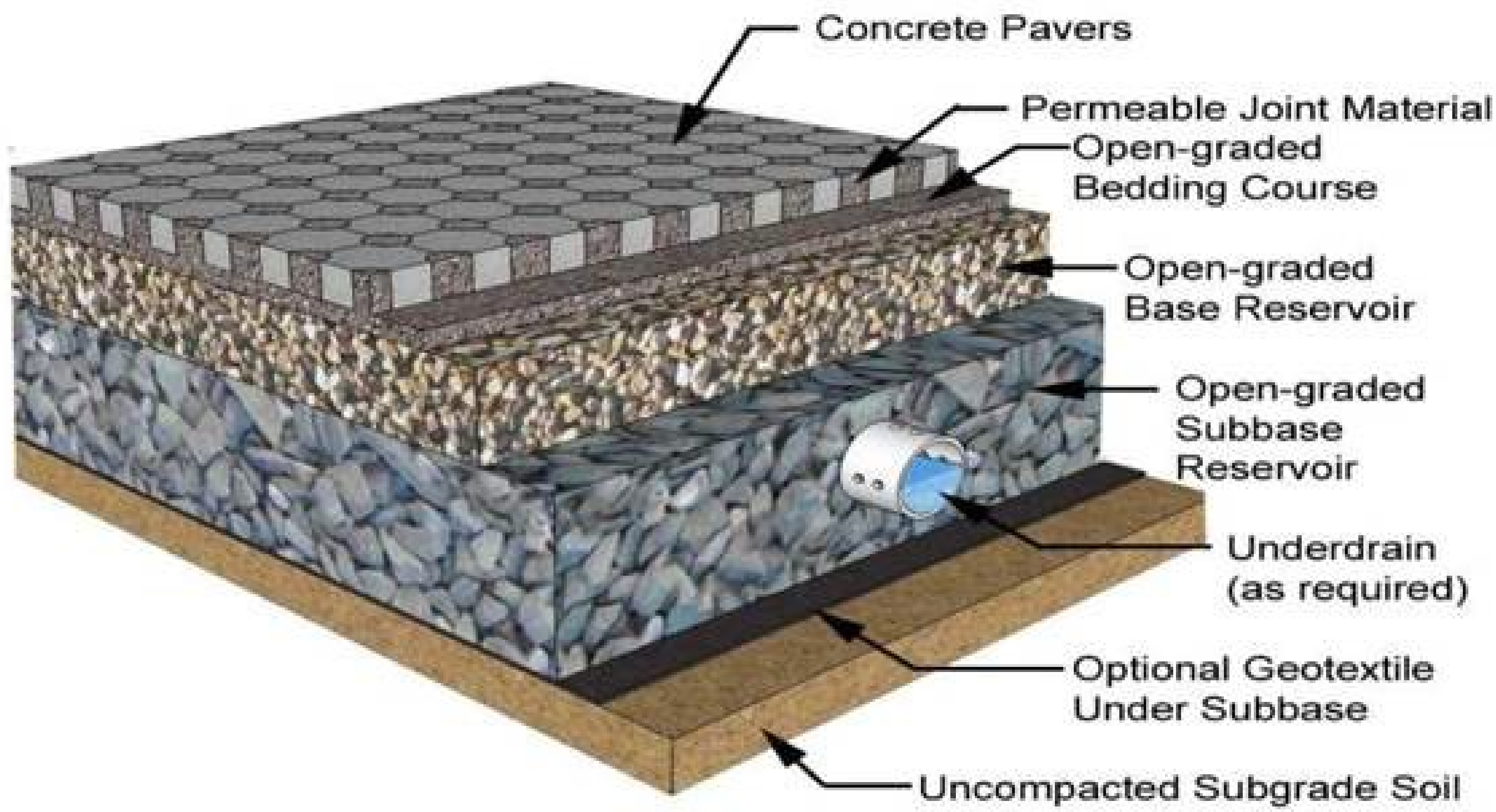
- Vehicle and pedestrian loading
- Aesthetics
- Maintenance

www.lastormwater.org

http://www.perviouspavement.org/

www.wolfpaving.com

POROUS PAVEMENT - COMPONENTS



Source: Smith, D. 2006. Permeable Interlocking Concrete Pavement-selection design, construction and maintenance. Third Edition. Interlocking Concrete Pavement Institute. Herndon, VA.

BIORETENTION

<u>TYPES (i.e. other names)</u>

Bioswales
Rain Gardens
Biofilters
Vegetated Buffers
Infiltration Tree Pits

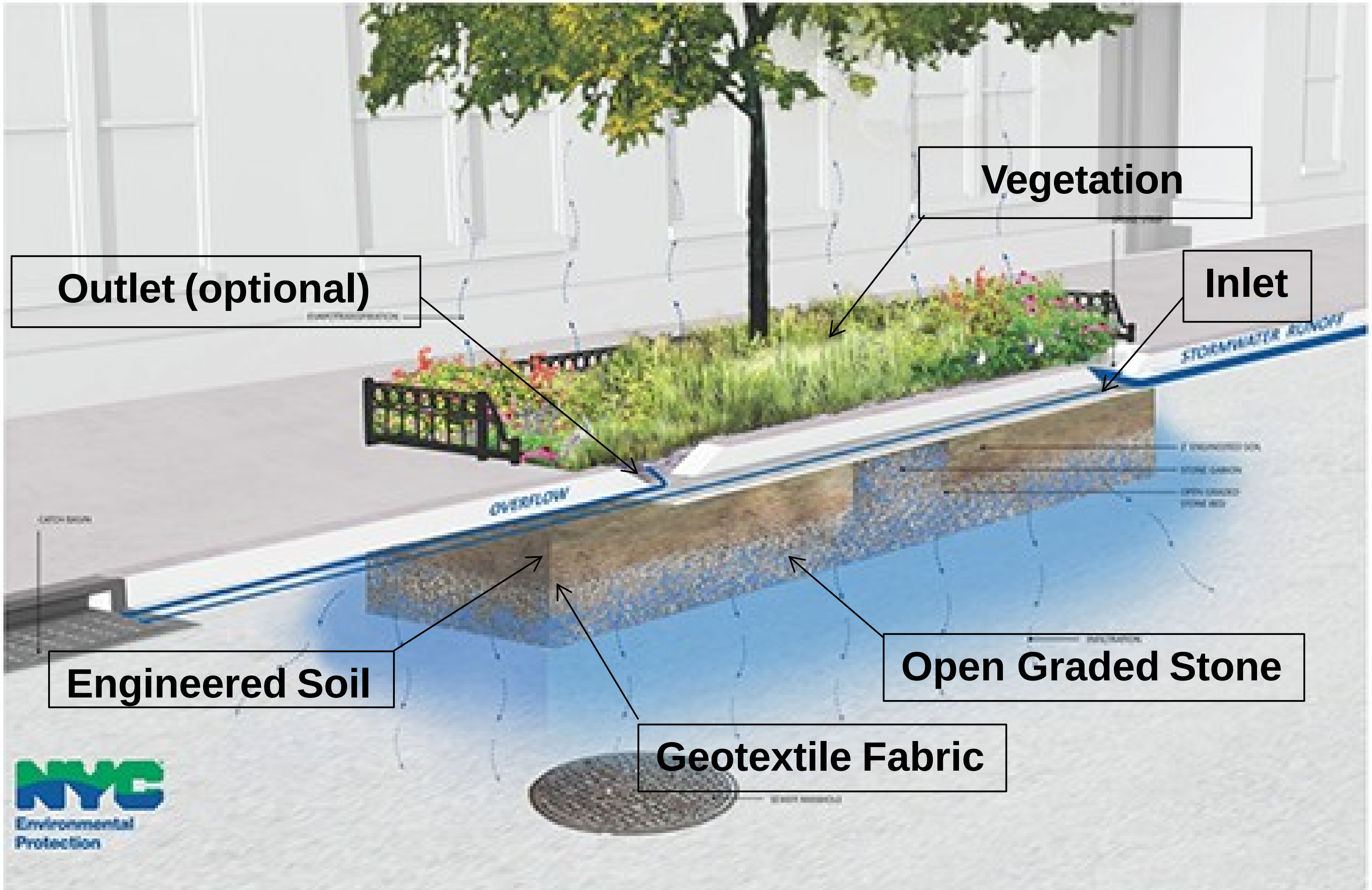
<u>DESIGN FACTORS</u>

- Contributing drainage area
- Existing subsoil conditions
- Engineered soil layers
- Pretreatment material/area
- Vegetation selection
- Grading
- Inlet/outlet location
- Maintenance

Bercy Chen Studio - Pintrest

Anna Marshall, Save the Sound

BIORETENTION - COMPONENTS



DESIGN CONSIDERATIONS

General Considerations

Volume and Flow Reduction

Water Quality Improvement – two ways…

DESIGN CONSIDERATIONS - GENERAL

Aesthetics

- Vegetation selection
- Ponding vs. well drained
- Tree guard and other accessory components
- Paver style and type

Site Constraints

- Existing grading of site
- Utilities and critical infrastructure
- Physical obstructions (utility poles, signs, structures)
- Proximity to building line
- New construction vs. retrofit (existing uses)

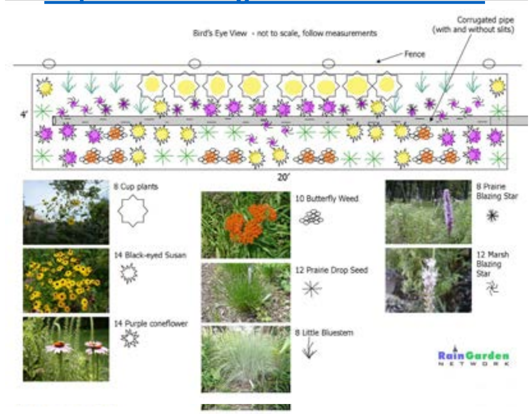
Maintenance

- Sediment/floatables trap
- Maintenance access
- Maintenance equipment
- Frequency of required maintenance activities

Cost

- Bioretention - **Variable**
- Porous Pavement - **Variable**

http://www.raingardennetwork.com



http://www.restorationdesigngroup.com

www.svrdesign.com

AESTHETIC

VEGETATION

Native vs. Ornamental

Ability to withstand drought & inundation

PONDING VS. WELL DRAINED

Is it publicly visible?

Mosquito breeding (48 or 72 hour rule)

OTHER ACCESSORIES

Tree guard/curb type

Furniture / Furnishings

Signage – educational, audience?

Access – paths, stone strip for pedestrians?

US EPA

Yale Hixon Center

SITE CONSTRAINTS

<u>EXISTING GRADING</u>

Divert to GSI before drains

Pull off from existing drains

Cover drains and install backup

<u>UTILITIES & INFRASTRUCTURE</u>

≥ 3’ from all main electric lines (NYC)

≥ 3’ from all gas mains (NYC)

≥ 6’ from all sewer and water mains (NYC)

<u>PHYSICAL OBSTRUCTIONS</u>

Buildings, retaining walls

Utility poles, street furnishings

Doorways and entrances

<u>EXISTING USES</u>

New development is much easier

Retrofit should blend with existing use

Parking lot vs. Courtyard vs. Playground

Underground utilities in NYC - www.balkanplumbing.com

NYC sidewalks are busy w/ people, signs, posts, and everything else
Crownheights.info

MAINTENANCE – *Perhaps most overlooked consideration*

<u>PRETREATMENT</u>

Grates, screens, settling basins

Gravel strips

Stiff vegetation

<u>MAINTENANCE ACCESS</u>

Paths to access without compaction

Make most vulnerable parts accessible

Can equipment (vacuum truck) access?

<u>EQUIPMENT</u>

What equipment will be used?

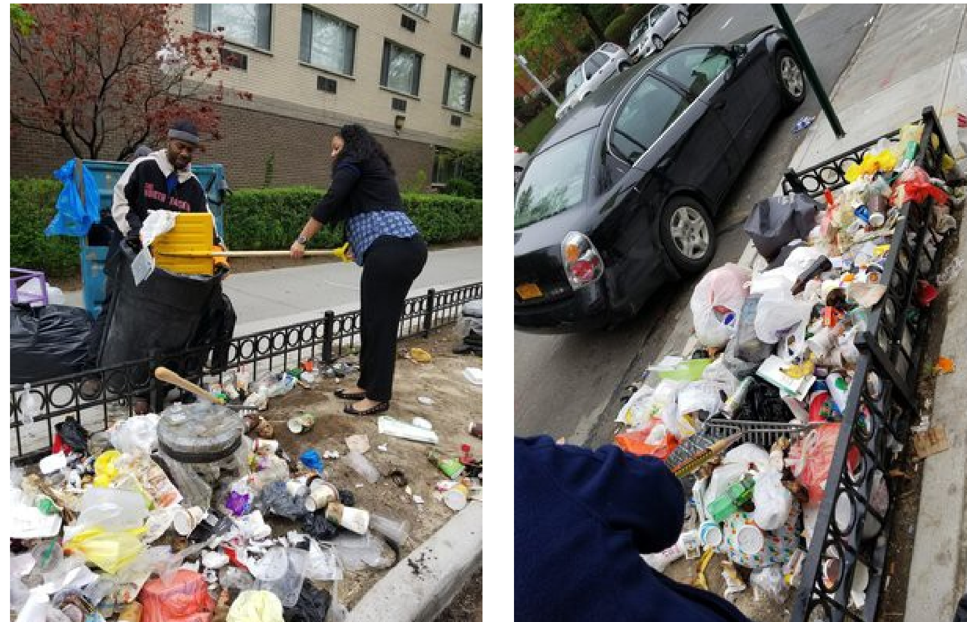
Manual vs. mechanical

<u>FREQUENCY OF MAINTENANCE</u>

Clear maintenance schedule

Robust record keeping

Adaptive management



Bioswale filled with trash - Queens Examiner

Clogged porous pavement - Charter Enterprises Inc.

COST

SOME RANGES

Bioretention (per sq. ft.) = $16 - $250 (Ohio EPA vs. NYC DEP)

Porous Pavement (per sq. ft.) = $7 - $26 (UMD vs. Ohio EPA)

SCALE

Individual practice vs. site scale vs. neighborhood scale

Mechanical construction vs. manual labor

Retrofit vs. new development

IMPORTANT CONSIDERATIONS

Cost per sq. ft. – often what is sited

Cost per volume managed – difficult to know upfront

WQ benefit is difficult to quantify

Should include O&M in costs to owner

BREAK?

DESIGN PROCESS

Management Goal

↓

Contributing Drainage Area

↓

Existing Soil Conditions

↓

Engineered Media Components

↓

GI Practice Size

MANAGEMENT GOAL: WATER QUALITY VOLUME (WQV)

From CT DEEP Stormwater Manual = Manage First 1" of Runoff (first flush)

WQV = (1")(R)(A)/12

WQV = cubic ft.

R = volumetric runoff coefficient = 0.05+0.009(I)

I = percent impervious cover

A = site area in sq. ft.

http://www.ct.gov/deep/lib/deep/water_regulating_and_discharges/stormwater/manual/Chapter_7.pdf

DESIGN CONSIDERATIONS: VOLUME/FLOW REDUCTION

Green Stormwater Infrastructure Volume Managed

Total Volume Managed = Storage Volume + Infiltration Volume

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Ignore evapotranspiration for now...

DESIGN CONSIDERATIONS: VOLUME/FLOW REDUCTION

Green Stormwater Infrastructure Volume Managed

Total Volume Managed = Storage Volume + Infiltration Volume

Storage Volume → Storage in soil + Storage in stone

Infiltration Volume → Infiltration Rate x Storm Duration (6 hrs)

DESIGN CONSIDERATIONS – REDUCE RUNOFF

Goal

- Volume or flow rate (cf, cfs)
- % impervious surface reduction (%, sf)
- Depth of rainfall (in)

Contributing Drainage Area

- Area (sf), account for imperviousness (%)
- Based on topography and site grading
- Locate GI at low point to capture entire area

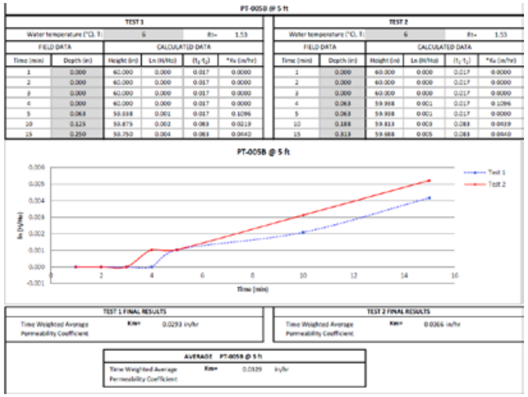
Existing Soil

- Perform soil borings/infiltration tests
- Infiltration Rate, 5 in/hr good, ≥ 0.15 in/hr acceptable (NYC)
- Bedrock and shallow groundwater
- Sand vs. Clay?

Engineered Media

- % void space
- Sandy soil mix – assume 25% voids
- Stone drainage layer (optional) – assume 50% voids

NYCDEP



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DESIGN CONSIDERATIONS: VOLUME/FLOW REDUCTION

Green Infrastructure Volume Managed

Total Volume Managed = Storage Volume + Infiltration Volume

Storage Volume ↓

Storage in soil
+
Storage in stone

Infiltration Volume ↓

Infiltration Rate x Storm Duration (6 hrs)

THAYER PARKING LOT EXAMPLE

MANAGEMENT GOAL

Manage 100% of 1” of runoff from contributing drainage

CONTRIBUTING DRAINAGE AREA

Site Area = 30,000 SF

% impervious = 98%

INFILTRATION RATE

5 in/hr

ENGINEERED MEDIA

Soil depth = 2 ft.

Soil void space = 25%

Stone depth = 3 ft.

Stone void space = 50%

Ponding depth = 3 in.

THAYER PARKING LOT EXAMPLE

WQV = (1”)(R)(A)/12

A = site area in sq. ft. = ?
I = ? **(percent not decimal)**
R = volumetric runoff coefficient = 0.05+0.009(I)
WQV = cubic ft. = ?

Total Volume Managed = Storage + Infiltration

Storage in soil = cf per sf = ?
Storage in stone = cf per sf = ?
Ponding storage = cf per sf = ?
Infiltration (6 hrs) = ft = ?

What is required GI footprint (sf)?

THAYER PARKING LOT EXAMPLE

WQV = (1”)(R)(A)/12

A = site area in sq. ft. = **30,000 sf**
I = **98%**
R = volumetric runoff coefficient = 0.05+0.009(I) = **0.932**
WQV = cubic ft. = **2,330 cf**

Total Volume Managed = Storage + Infiltration

Storage in soil = cf per sf = ?
Storage in stone = cf per sf = ?
Ponding storage = cf per sf = ?
Infiltration (6 hrs) = ft = ?

What is required GI footprint (sf)?

THAYER PARKING LOT EXAMPLE

WQV = (1”)(R)(A)/12

A = site area in sq. ft. = **30,000 sf**
I = **98%**
R = volumetric runoff coefficient = 0.05+0.009(I) = **0.932**
WQV = cubic ft. = **2,330 cf**

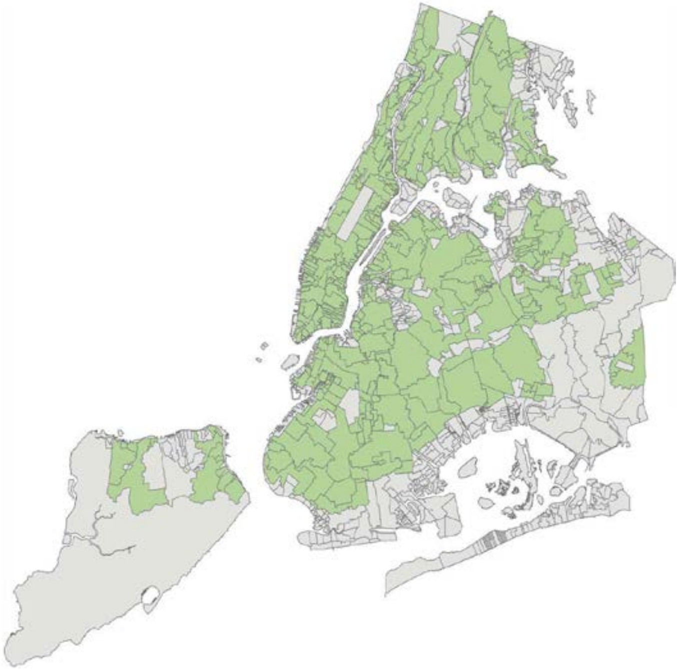
Total Volume Managed = Storage + Infiltration

Storage in soil = cf per sf = **2 ft. x 0.25 = 0.5 cf/sf**
Storage in stone = cf per sf = **3 ft. x 0.5 = 1.5 cf/sf**
Ponding storage = cf per sf = (**3/12) ft = 0.25 cf/sf**
Infiltration (6 hrs) = ft = ? = **(5/12) ft x 6 hr = 2.5 ft**

Required area of GSI = 491 sq. ft.

GSI CASE STUDIES – MY EXPERIENCE

NYCDEP



YALE FES

Yale School of Forestry & Environmental Studies

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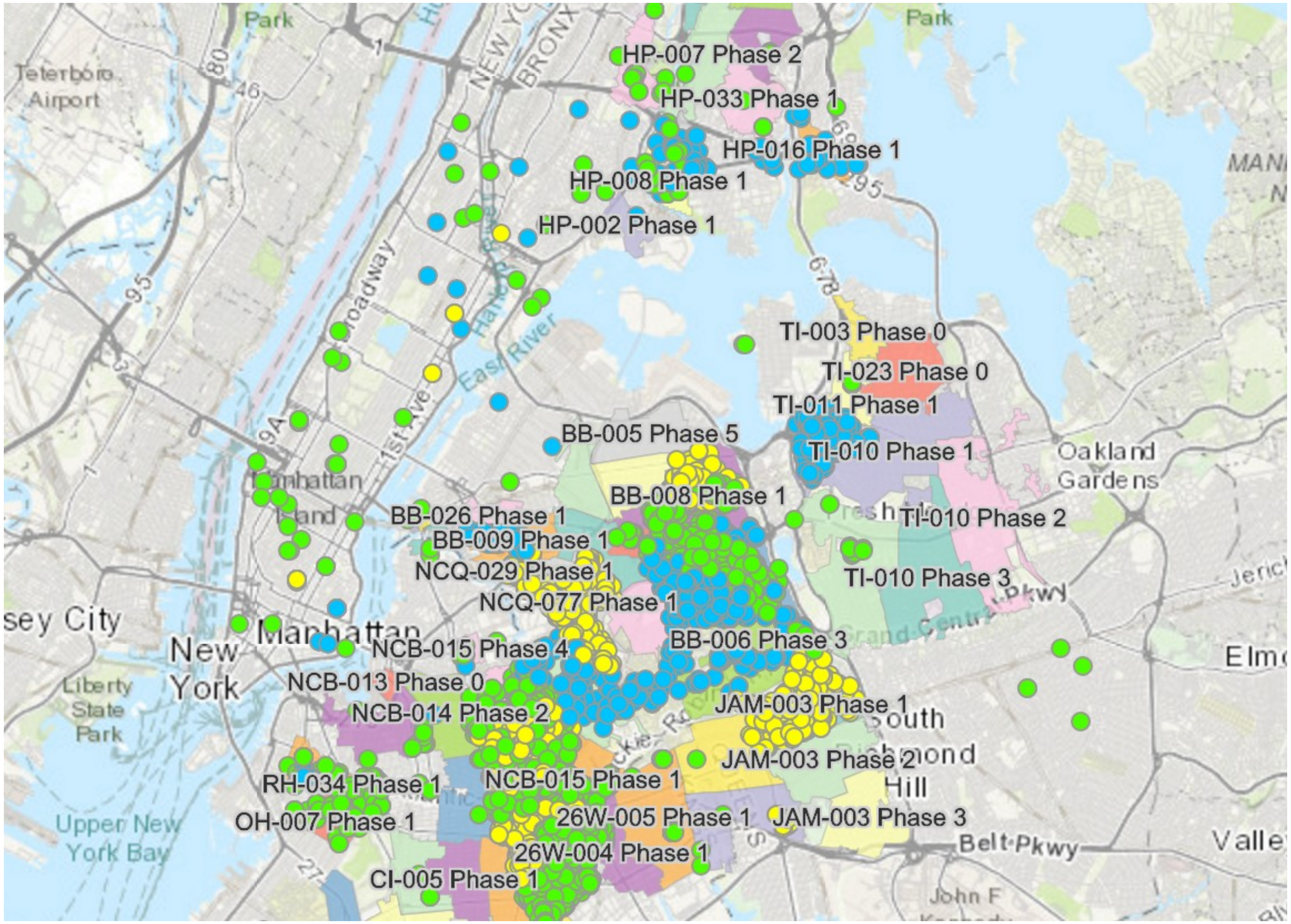
NYC GREEN INFRASTRUCTURE PROGRAM



NYC DEP Interactive Map - [Here]

NYC GREEN INFRASTRUCTURE PROGRAM

NYC GREEN INFRASTRUCTURE PROGRAM

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Credit: NYC DEP

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Credit: NYC DEP

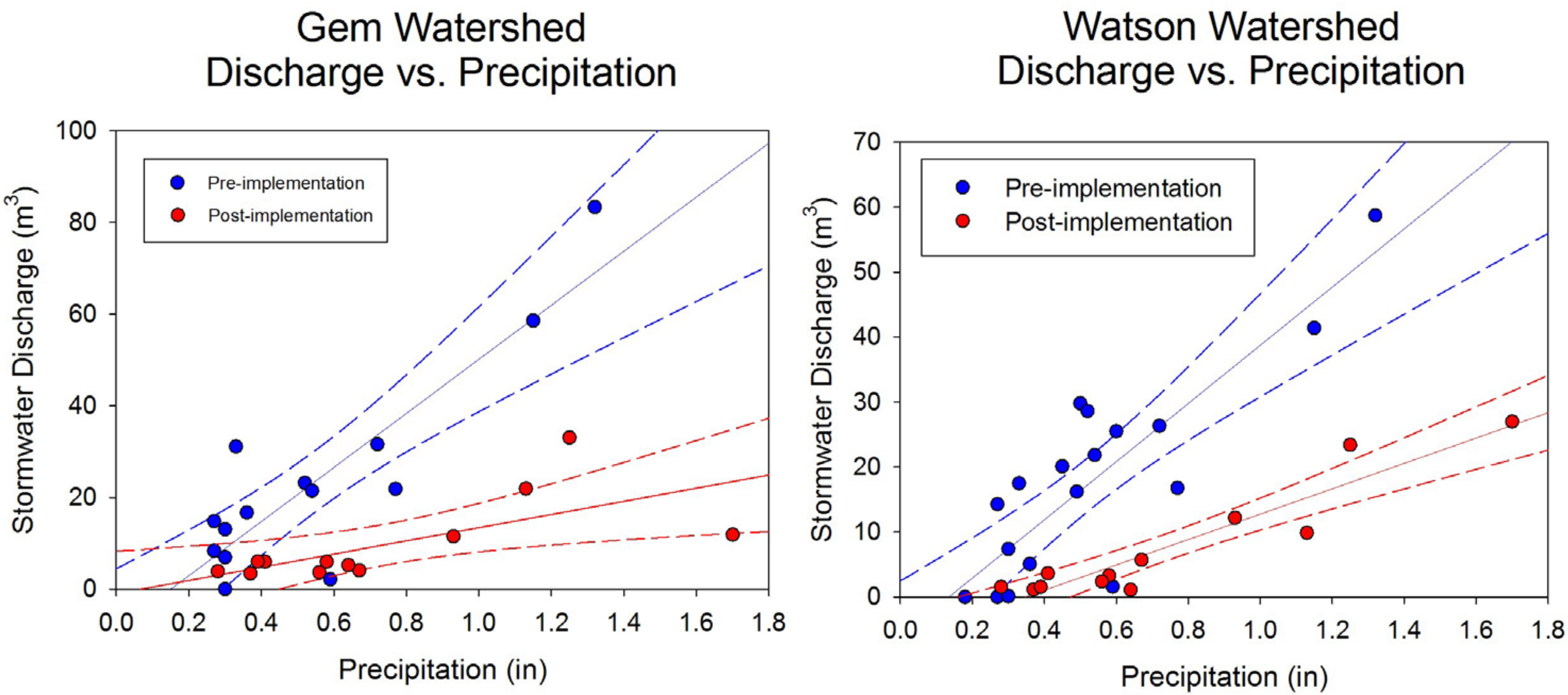
YALE SCHOOL OF FORESTRY & ENVIRONMENTAL STUDIES

MESc. Thesis.
Before and after sewershed study
Volume reductions in storm sewer
Water quality improvements
Inform City-wide initiative

Taking samples at study site – Photo credit Leana Weissberg

Flooding at train station – Photo credit Melissa Bailey

BIOSWALES WORK!



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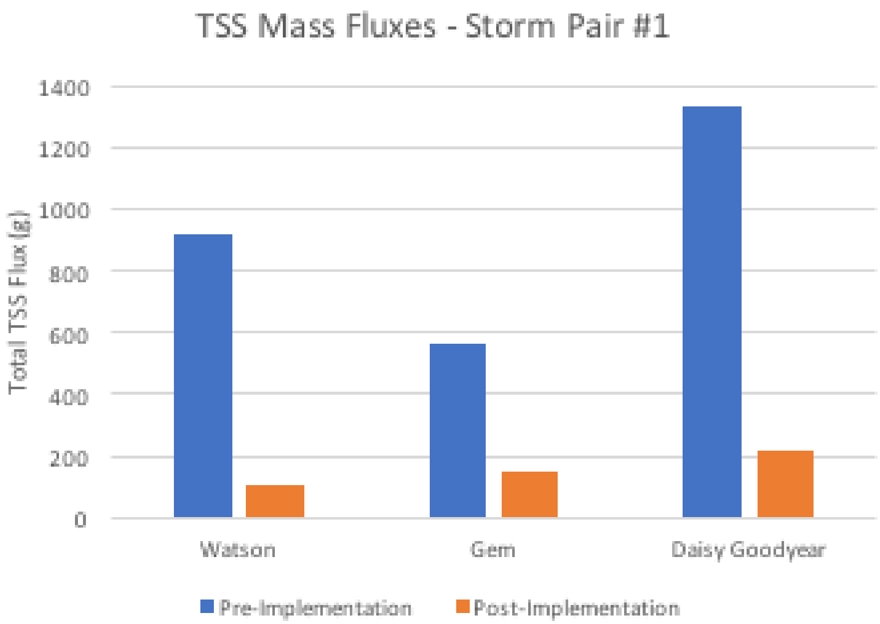

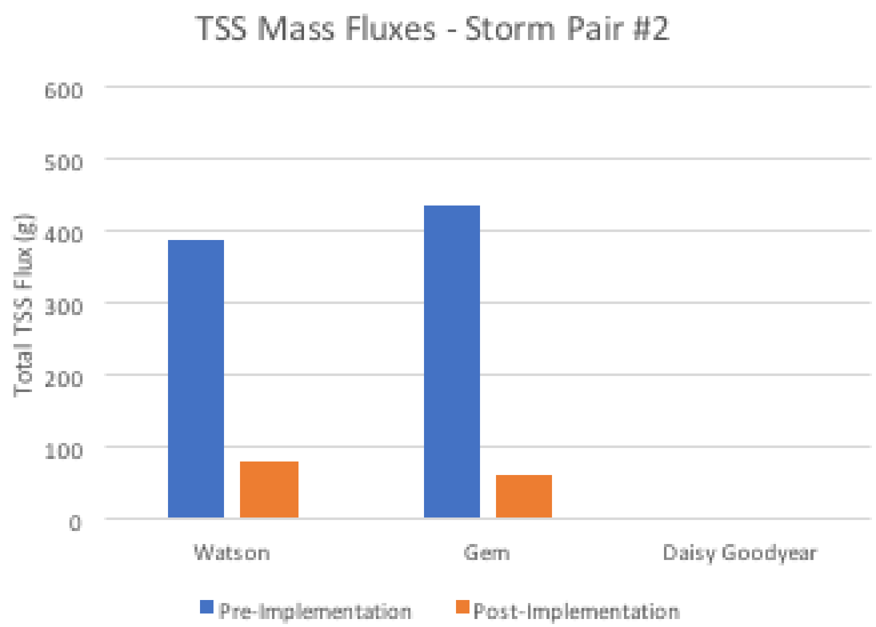

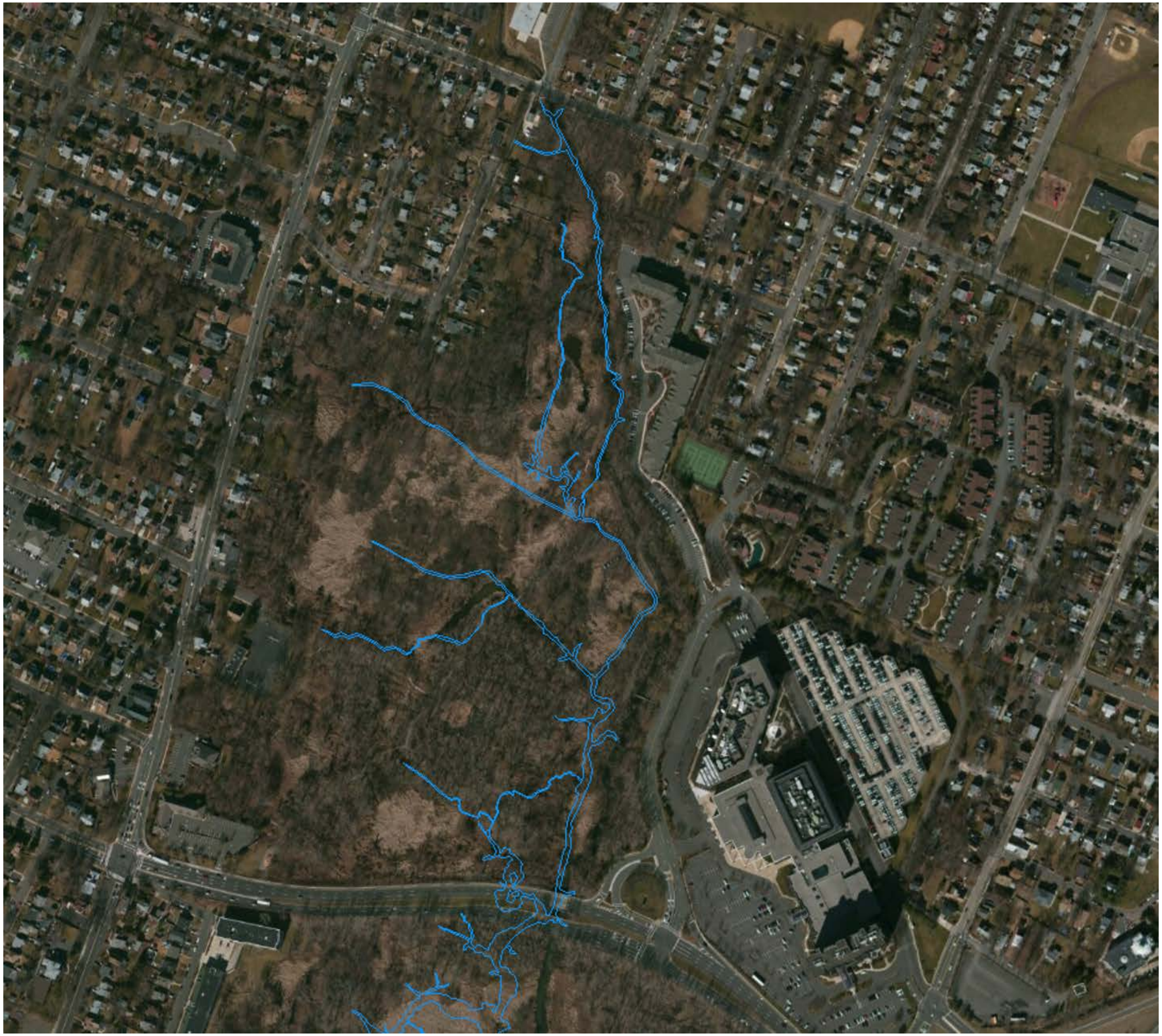

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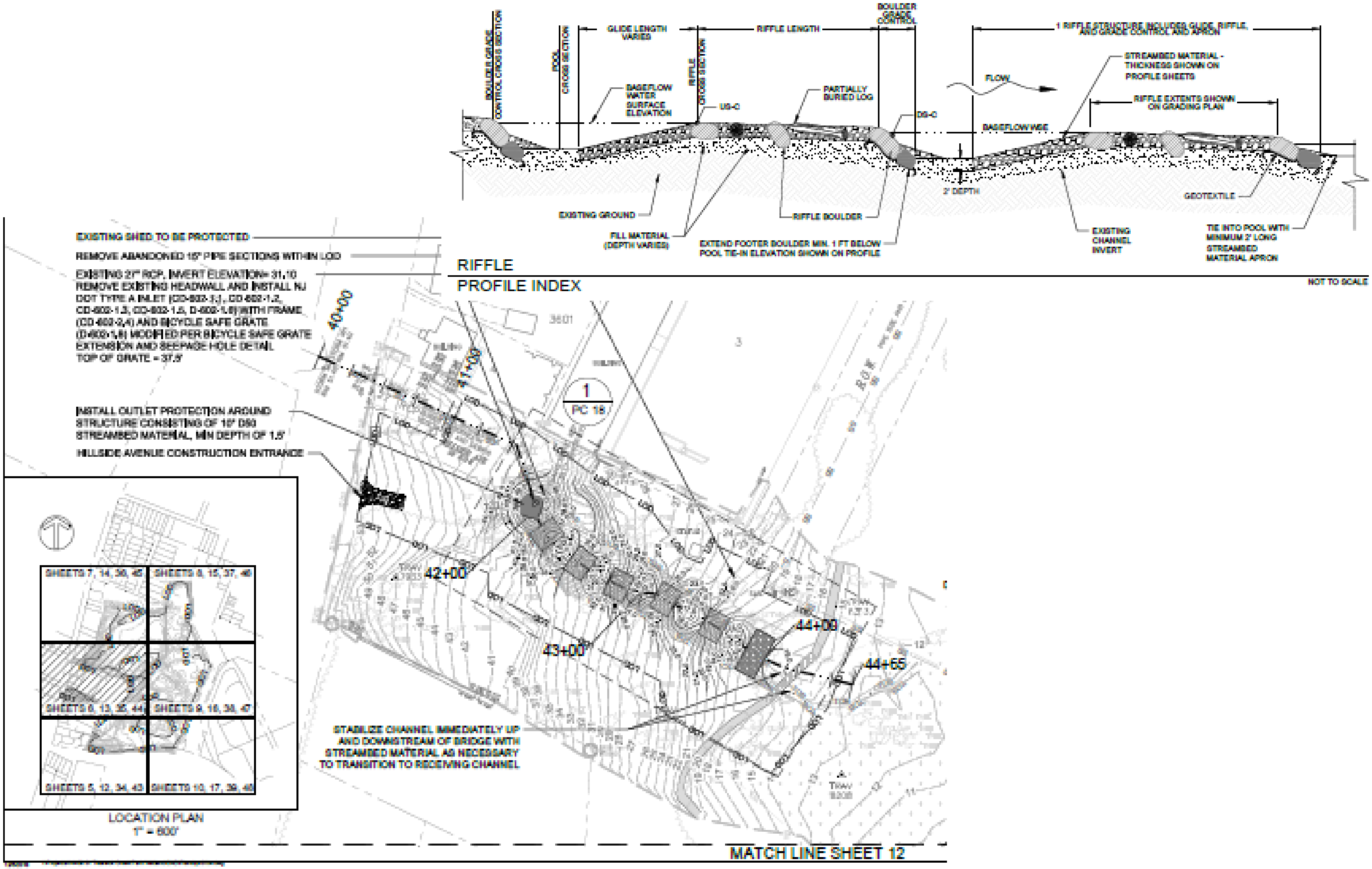
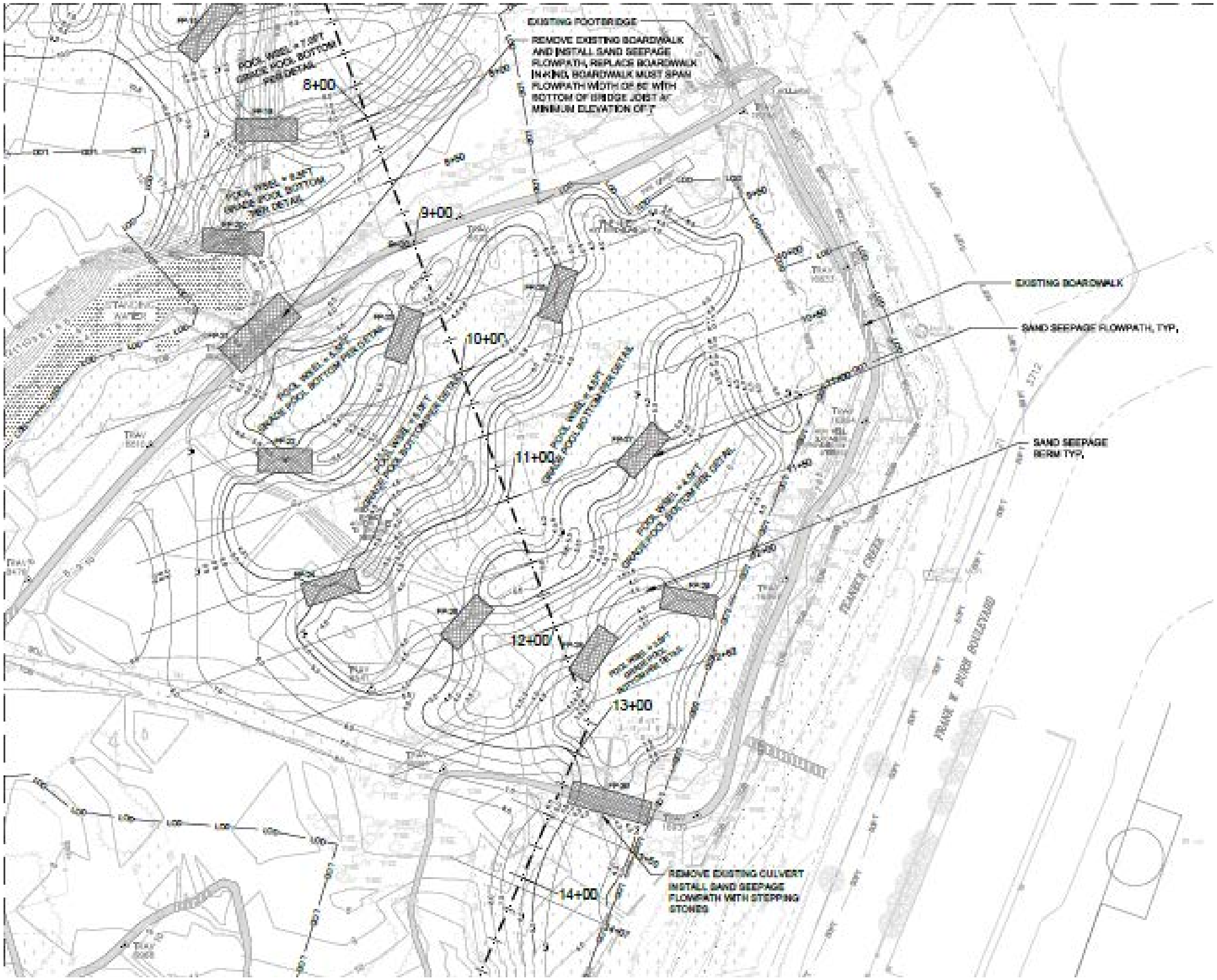



Biohabitats, Inc.

BIOHABITATS



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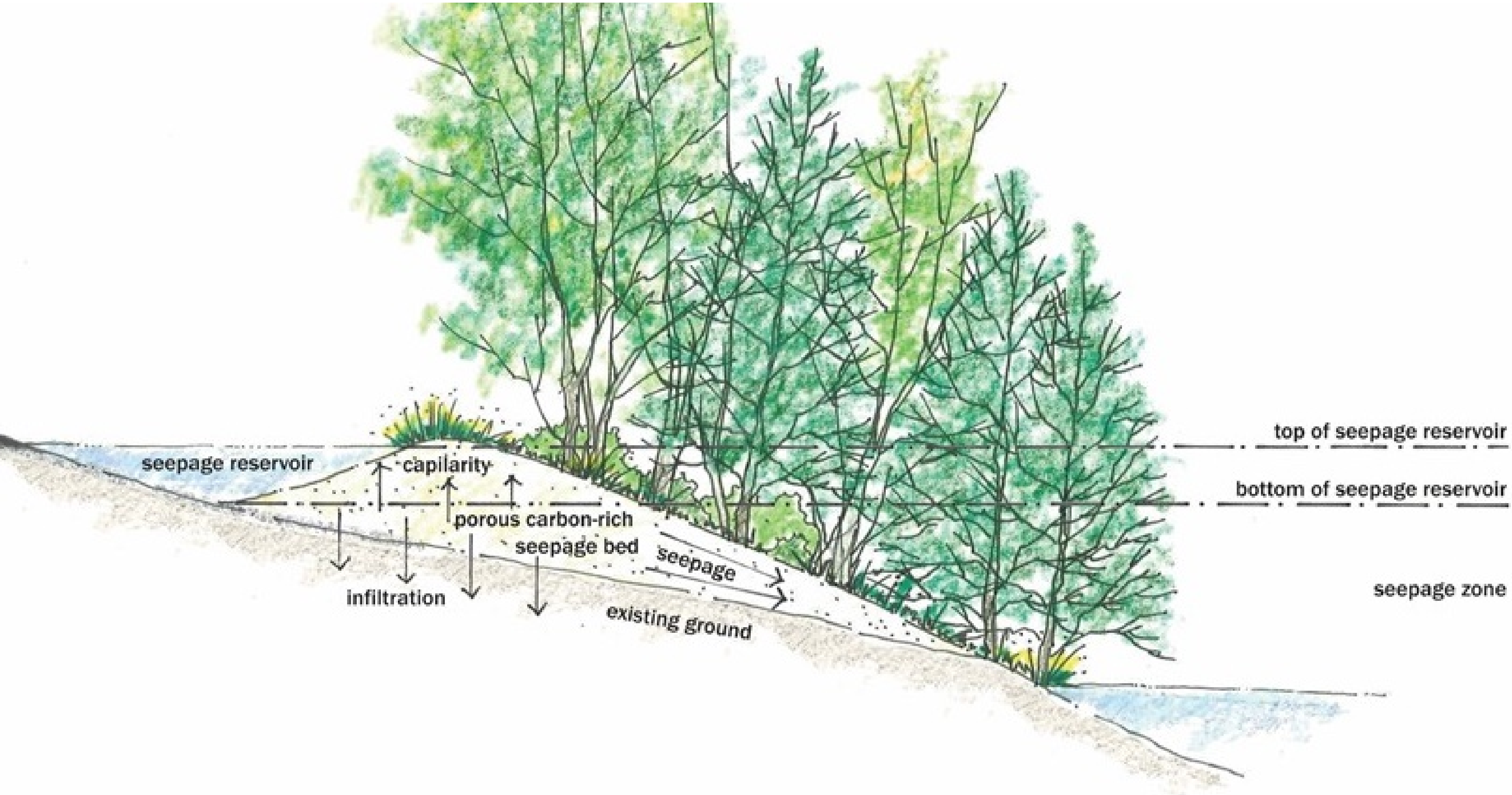

Thank You

Questions?

Contact: kdahms@biohabitats.com

Biohabitats