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The Principles of Green Infrastructure and Low Impact Development

Jason Wright, PE

Points we'll be covering…

- Hydrologic principles
- The GI/LID Process
- GI/LID Implementation/Practices
- Retrofitting Existing Development

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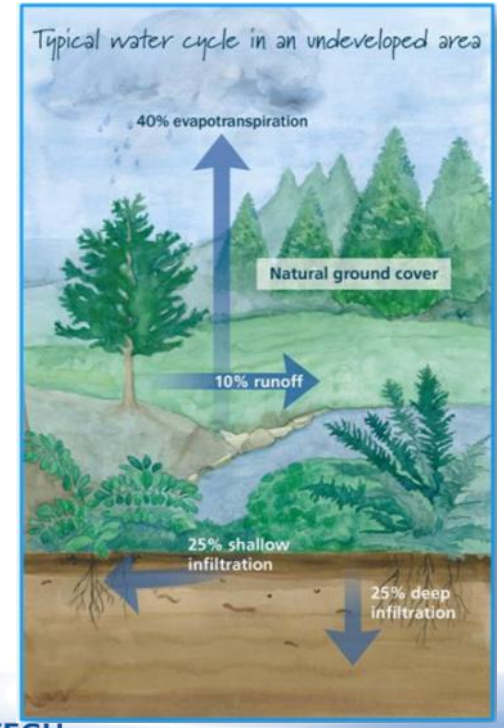
Development Impacts: Runoff Volume

Typical pre-development conditions:

Runoff = 10%

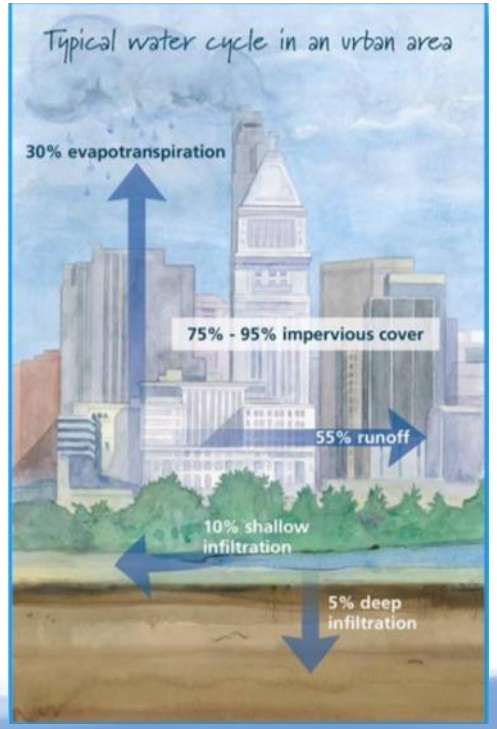
Infiltration = 50%



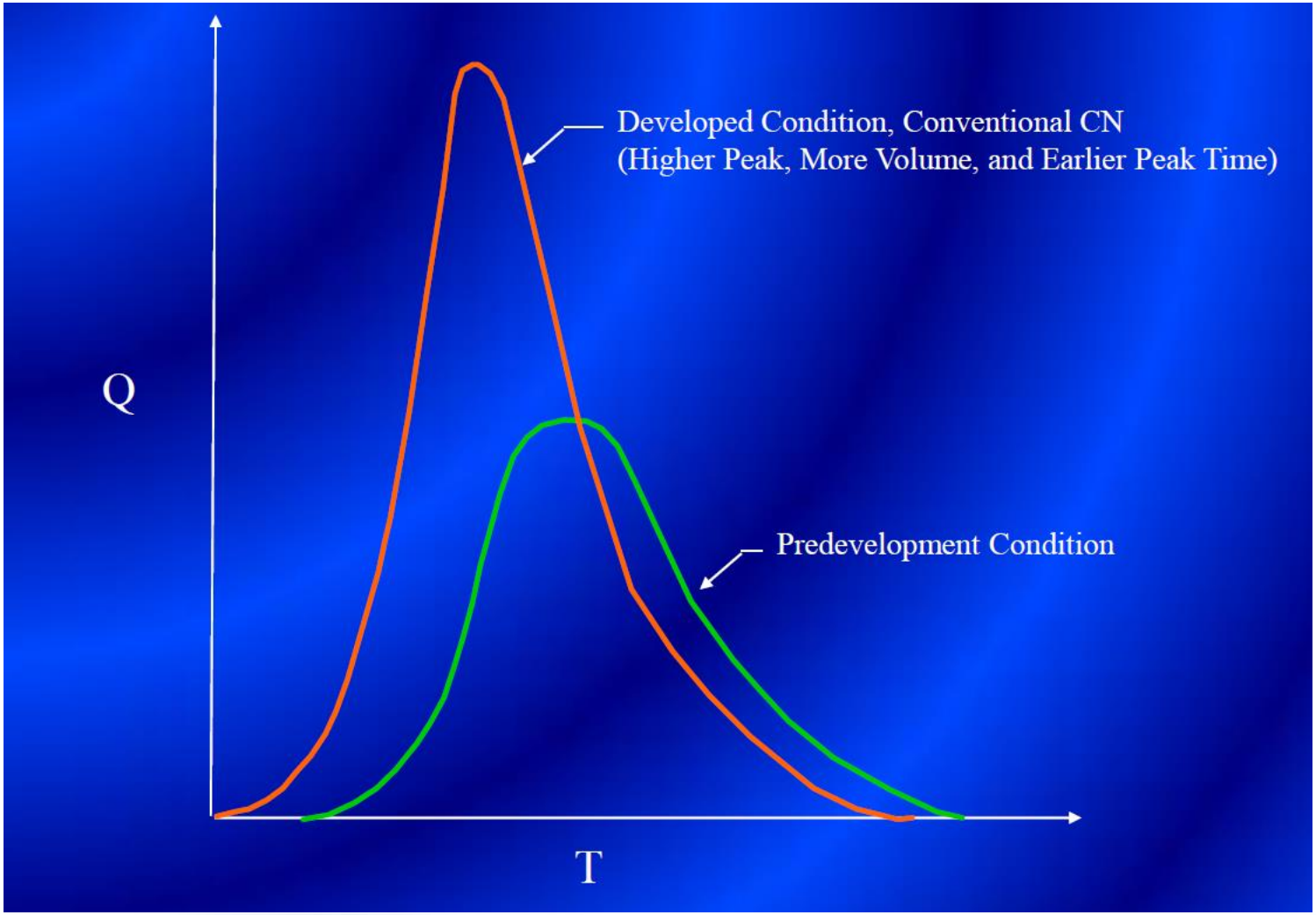
Typical post-development conditions:

Runoff = 55%

Infiltration = 15%



Increased Run-off Changes Stream Flow Characteristics



Increased Run-off Changes Stream Flow Characteristics

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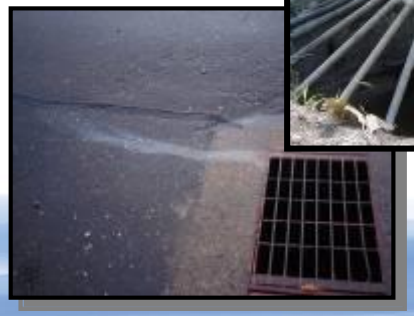
Pollutants in Stormwater Discharges

Nutrients
Pathogens
Sediment
Toxic Contaminants
Oil and Grease
Thermal Stress

Increased quantity

Decreased quality

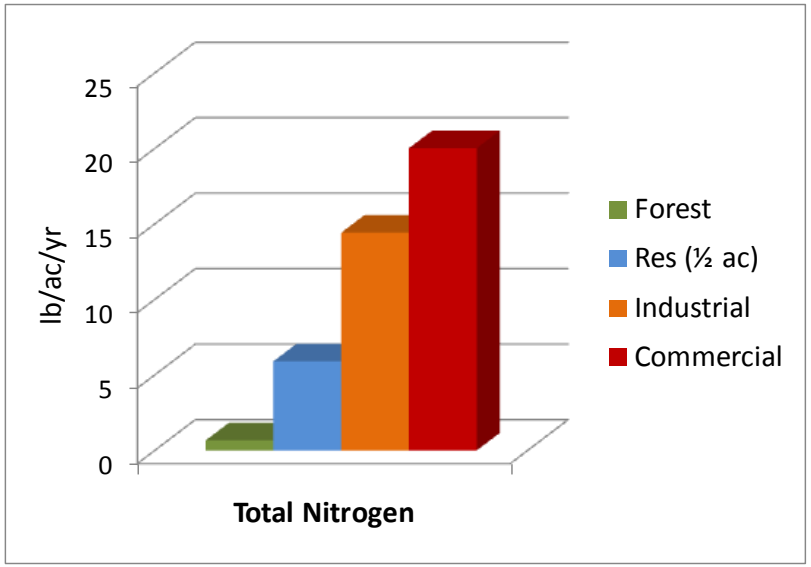


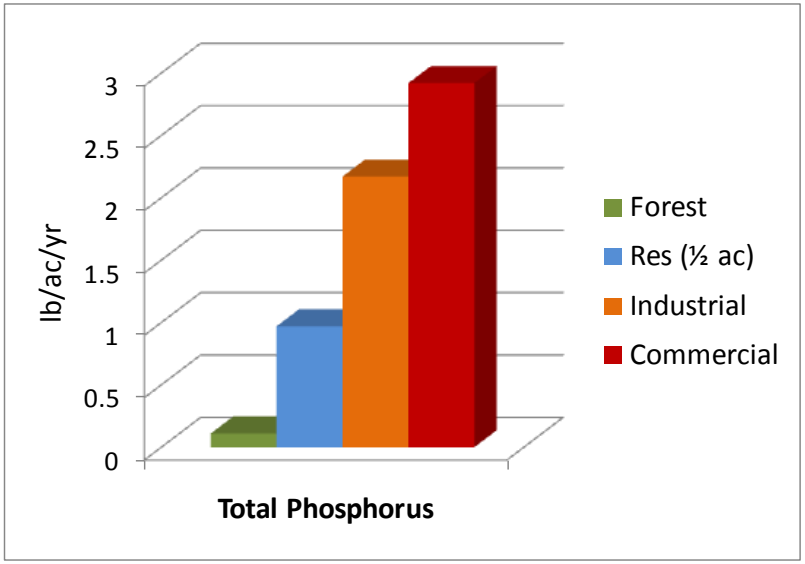
Discharges

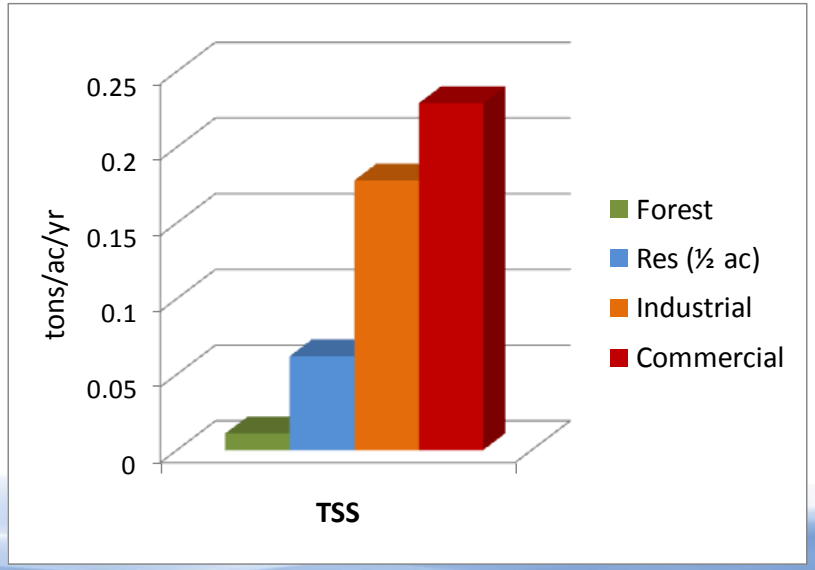
OPENING
FALL 2004
CENTEX
CONSTRUCTION COMPANY

Charlotte-Mecklenburg
Storm Water Services

Development Impacts: Overland Pollutant Loading

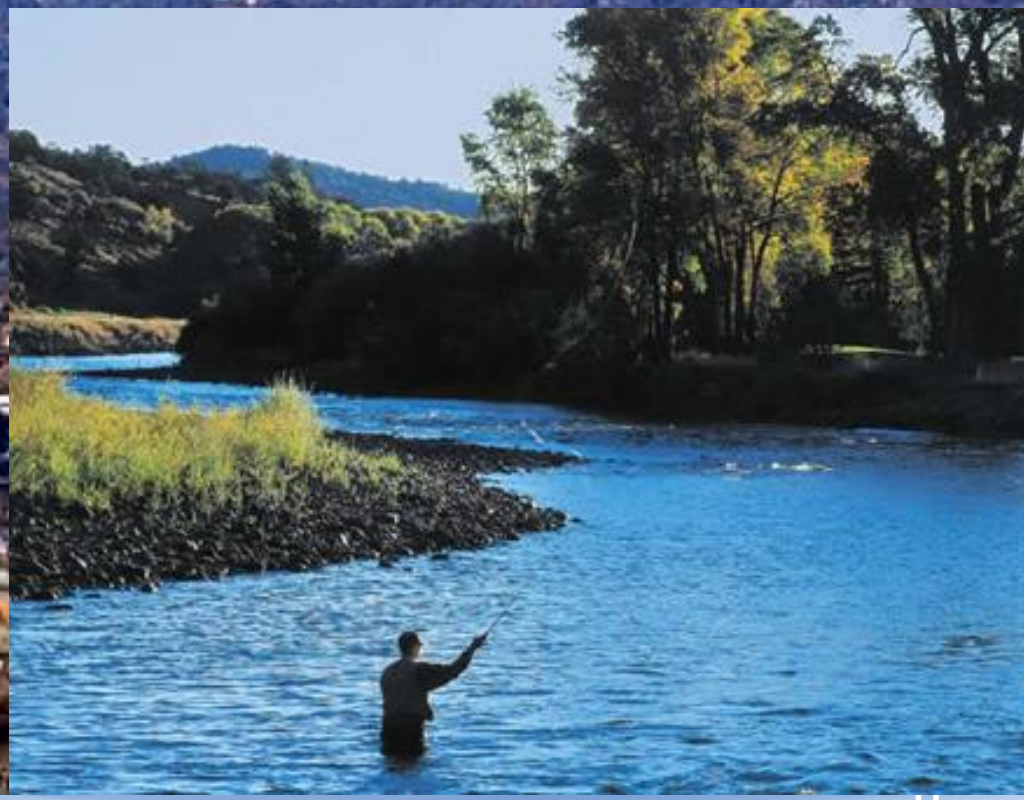






Effects of Water Pollution

Source: www.emnrd.state.nm.us



www.royallyflushed.com-500

Effects of Water Pollution

Source: earthjustice.org

Effects of Water Pollution

mstecker.co

Effects of Water Pollution

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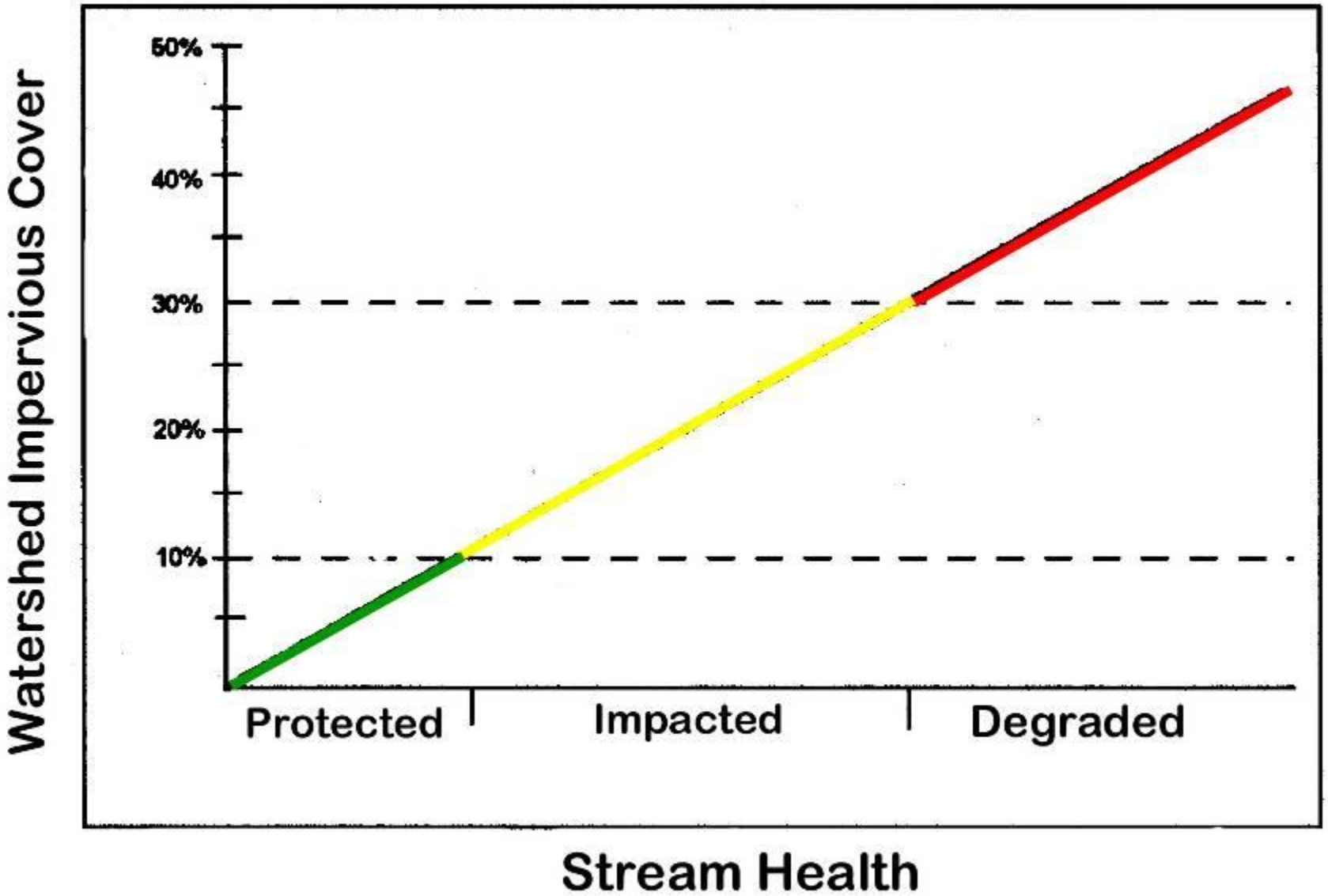
http://www.nature.org/ourinitiatives/regions/northamerica/unitedstates/newmexicol

Relationship of Impervious Cover to Stream Health

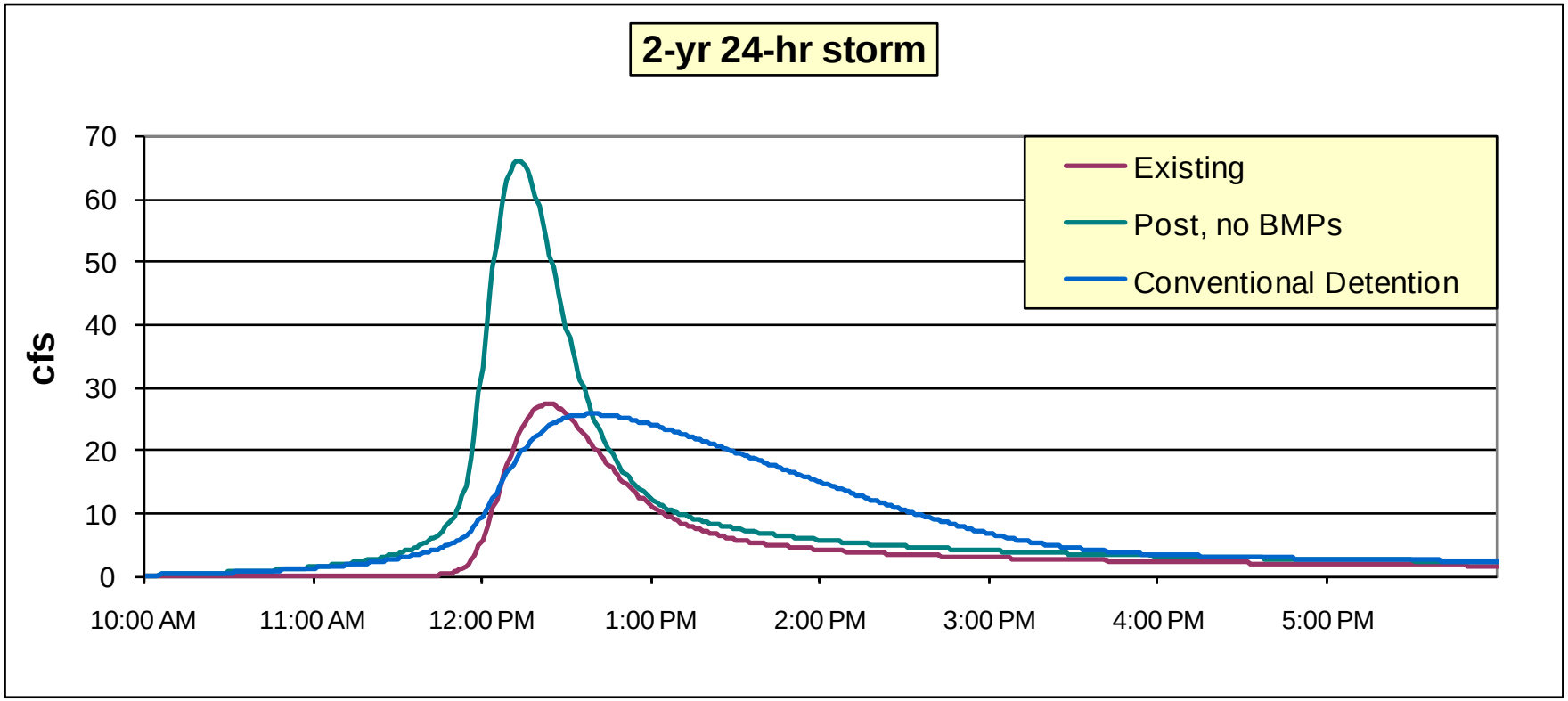


Center for Watershed Protection

Traditional Thinking

- Old wisdom: Treating the first inch of runoff and managing the peaks of stormwater is enough.
- Now we know it's not.

Changes in Flow



Low Impact Development Concepts

How do we make this…

function more like this?

Low Impact Development Concepts

Can we make this…

function more like this?

“Green” Stormwater Guiding Principles

1. Manage stormwater runoff both at the source and at the surface.

2. Use plants and soil to slow, filter, cleanse, and infiltrate runoff.

3. Design facilities that are simple, low-cost, and aesthetically enhance the community.

What is Green Infrastructure?

- Site Design and Green Infrastructure Principles
  - Reducing impervious surfaces
  - Disconnecting impervious areas
  - Conserving natural resources
  - Using cluster/consolidated development
  - Using xeriscaping and water conservation practices

Green Infrastructure Site Design

Reduce Impervious Surfaces

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Green Infrastructure Site Design

Conventional “Fat” Street

Source: NCSU-BAE

Green Infrastructure “Skinny” Street

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Green Infrastructure Site Design

Impervious Area Disconnection

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Downspout Disconnect Programs – Recent Research on City of Durham Rain Catcher's Program

Experiment Design

Graphic design by Andrew Anderson

Durham Downspout Disconnect – 2013 Findings (NCSU)

Site	Mean Percent Reduction
1A	54.7
1B	79.7
2A	86.7
2B	88.2
3A	94.2
3B	66.9
4A	69.6
4B	99.0
Mean/ Median	**79.9/ 83.2**

- Results in substantial volume reduction (even in tight soils)
- Is inexpensive BMP ($40)
- Potential for widespread on-site stormwater treatment
- Reasonable to assign stormwater credits

What measures reduce runoff to more natural conditions?

- Low impact development/green infrastructure practices…
  - Trees
  - Natural areas and open space
  - Bioretention
  - Raingardens
  - Vegetated swales
  - Permeable paving
  - Green roofs

Photo courtesy Summer Waters,UA

Drivers for watershed restoration/improvement plans….

- Total Maximum Daily Loads
- Combined Sewer Overflows (CSOs) and Separate Sewer Overflows (SSOs)
- Drinking water supply enhancement
- Brownfields
- Climate change

Drivers for watershed restoration/improvement plans….

- Xeric Climates are the fastest growing areas in the US
  - (US Census Bureau 2005)
- ½ water use in Utah and S. California is irrigation

(Erickson et al 2002, Salt Lake City 2010)

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Domingo Baca Inlet to North Diversion Channel

Source: City of Albuquerque

North Diversion Channel Outfall to Rio Grande

Source: City of Albuquerque

Question:
How far is it from the North Diversion Channel Outfall downstream to the Drinking Water Project Diversion Dam?

Points we'll be covering…

- Hydrologic principles
- The LID Process
- LID Implementation/Practices
- Retrofitting Existing Development

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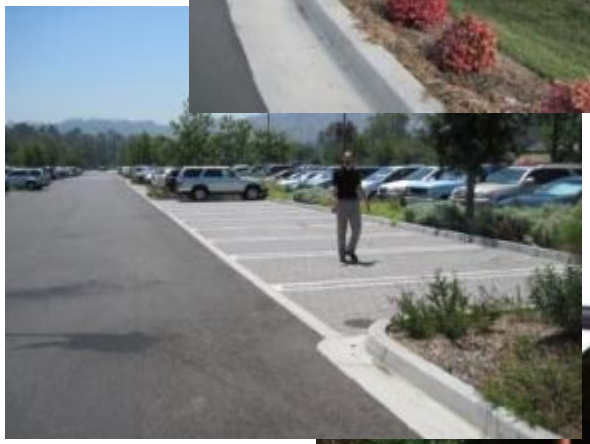
LID Implementation / Practices

- Bioretention
  - Bioswales
  - Infiltration Trench
  - Planter Boxes
- Permeable Pavement
- Water Harvesting
  - Cisterns
  - Rain Barrels
- Green Roofs/Living Roof
- Vegetated Swales



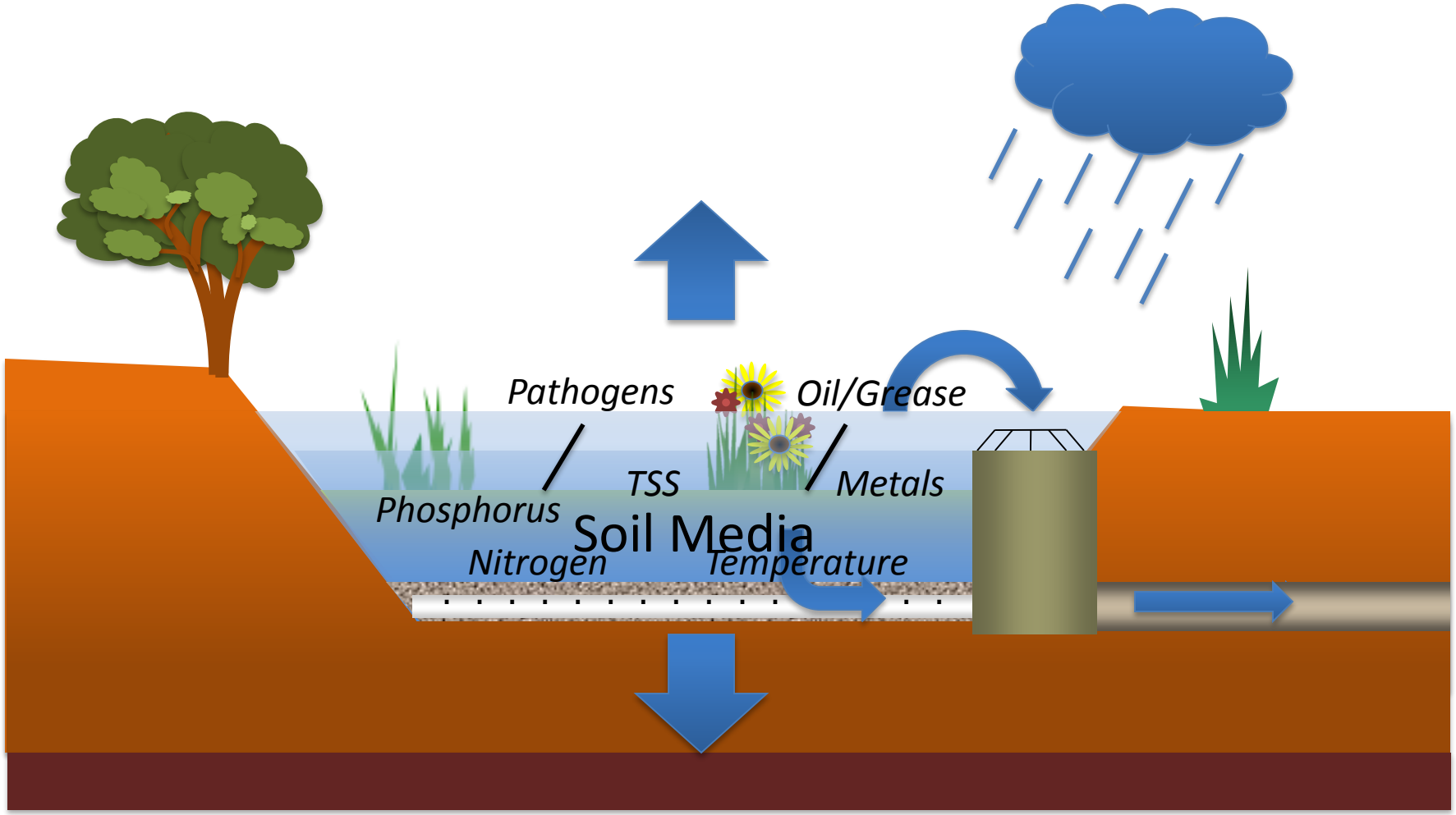
LID Implementation / Practices

Structural BMPs	Hydrologic controls			Removal processes					
	Storage/detention or flow attenuation	Infiltration	Evapotranspiration	Settling	Filtration	Sorption	Bioaccumulation	Biotransformation/ phytoremediation	Other (e.g., photolysis; volatilization)
Bioretention	+	(+)	o	o	+	o	+	+	(o)
Bioswale	(+)	(+)	o	o	o	o	o	o	(o)
Permeable pavement	+	(+)	–	–	+	–	–	–	–
Infiltration trench	+	+	(o)	o	+	o	–	–	–
Planter boxes	+	(+)	o	o	+	o	(+)	(+)	(o)
Sand filter	o	(o)	–	–	+	(o)	–	–	(o)
Vegetated filter strip	–	+	+	o	o	o	–	–	–
Vegetated swale	(o)	(o)	o	+	+	–	–	–	–
Cisterns/rain barrels	+	–	–	–	–	–	–	–	–

Note: ( ) optional function; + major function; o secondary function; – insignificant function

LID Implementation / Practices - Bioretention

LID Implementation / Practices - Bioretention



Source: NCSU BAE

LID Implementation / Practices - Bioretention

Landscaped Areas/Open Space

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LID Implementation / Practices - Bioretention

Parking Lots

LID Implementation / Practices - Bioretention

Rights-of-Way

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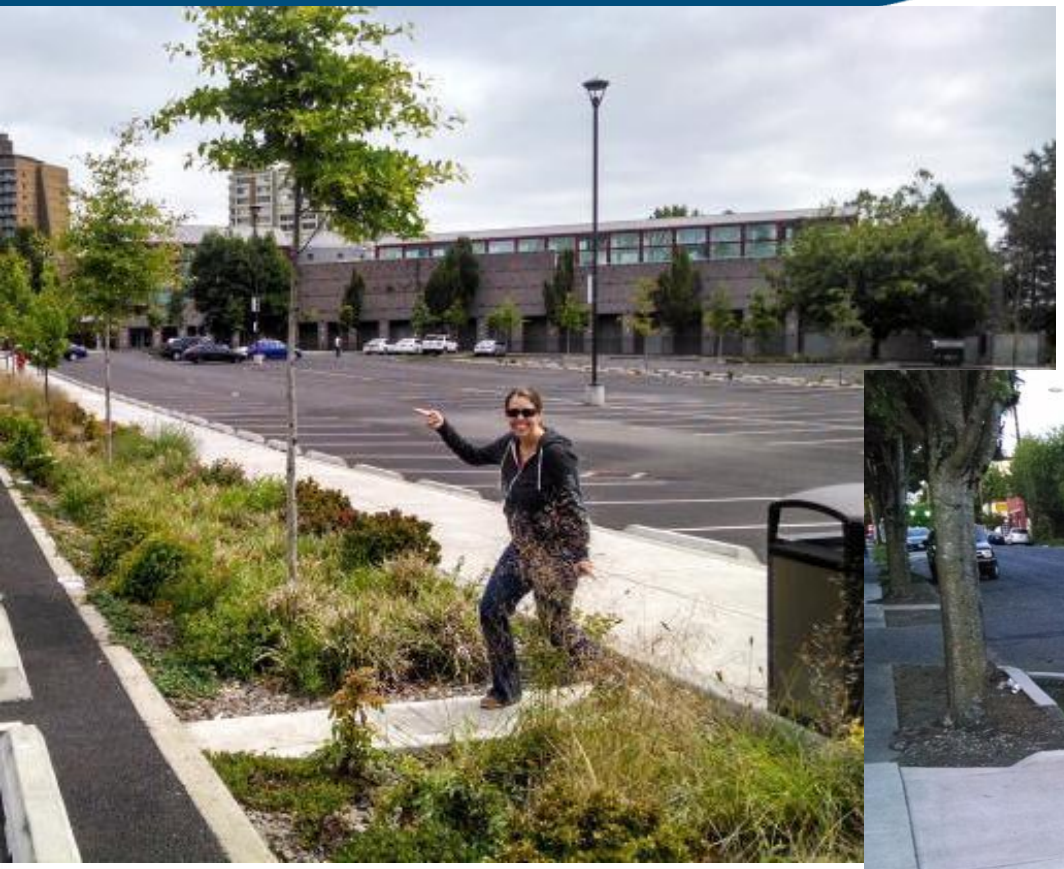
LID Implementation / Practices - Bioretention



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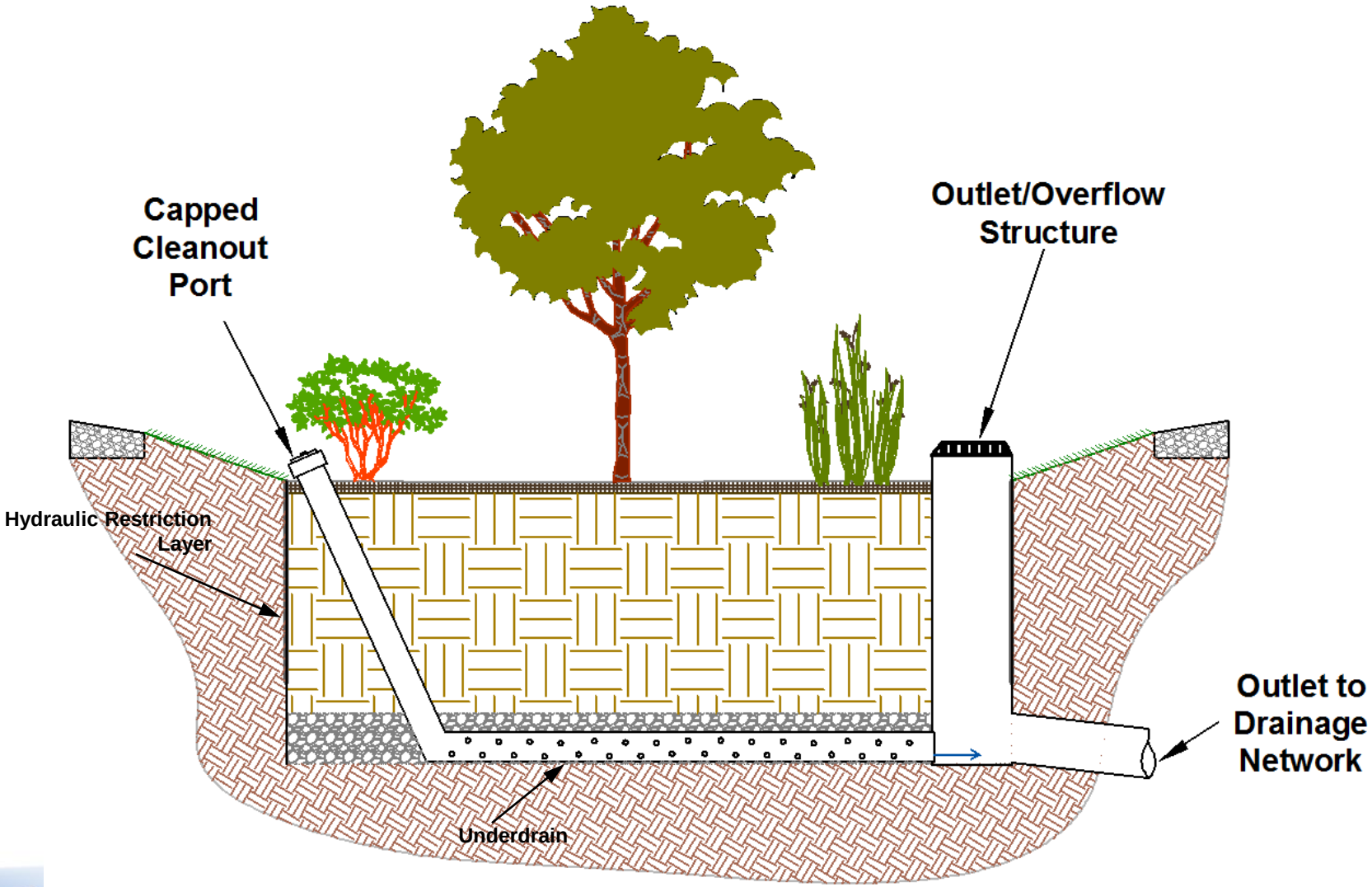
LID Implementation / Practices - Bioretention



LID Implementation / Practices - Bioretention

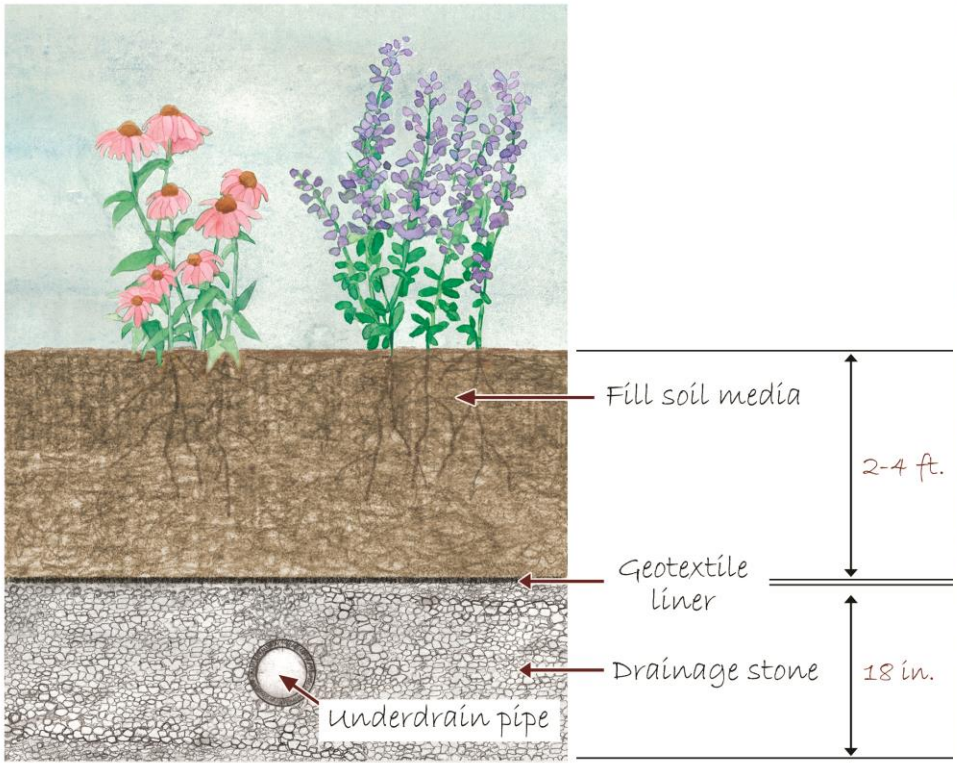
Underdrain (required if subsoil infiltration rate < 0.5 in/hr)	4 inch schedule 40 PVC pipe with perforations (slots or holes) every 6 inches.
No underdrain	If design is fully infiltrating, ensure that subgrade compaction is minimized.
Impermeable liner	If non-infiltrating (per geotechnical investigation), use an impermeable clay layer, geomembrane liner, or concrete (Required in Edwards Aquifer Recharge Zone, Barrett 2005)
Lateral hydraulic restriction barriers	Use geomembrane or concrete to restrict lateral flows to adjacent subgrades, foundations, or utilities.

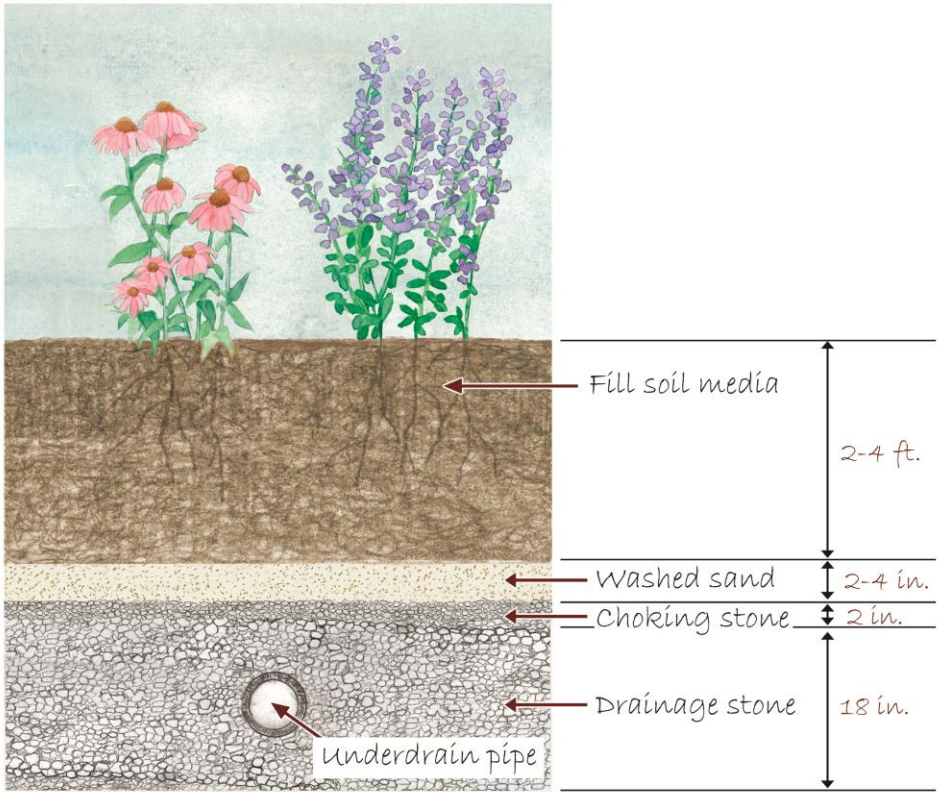
Geotechnical Investigation

- The infiltration rate of the soils at the potential subgrade
  - (ASTM D 3385 *Standard Test Method for Infiltration Rate of Field Soils Using Double-Ring Infiltrometer,* or a comparable method)
- The depth and texture of subsoils
- The depth to the seasonal high groundwater table
- Structural capacity of soils (if surface BMP, such as cistern or planter box, is intended)
- Presence of expansive clay minerals
- Presence of compacted or restrictive layers
- Underlying geology (especially presence of karst geology or shallow bedrock)
- Proximity to steep slopes

LID Implementation / Practices - Bioretention

- Underdrains
  - Natural soils < 0.5 in/hr
  - Infiltrate below the surface in 12 to 24 hours

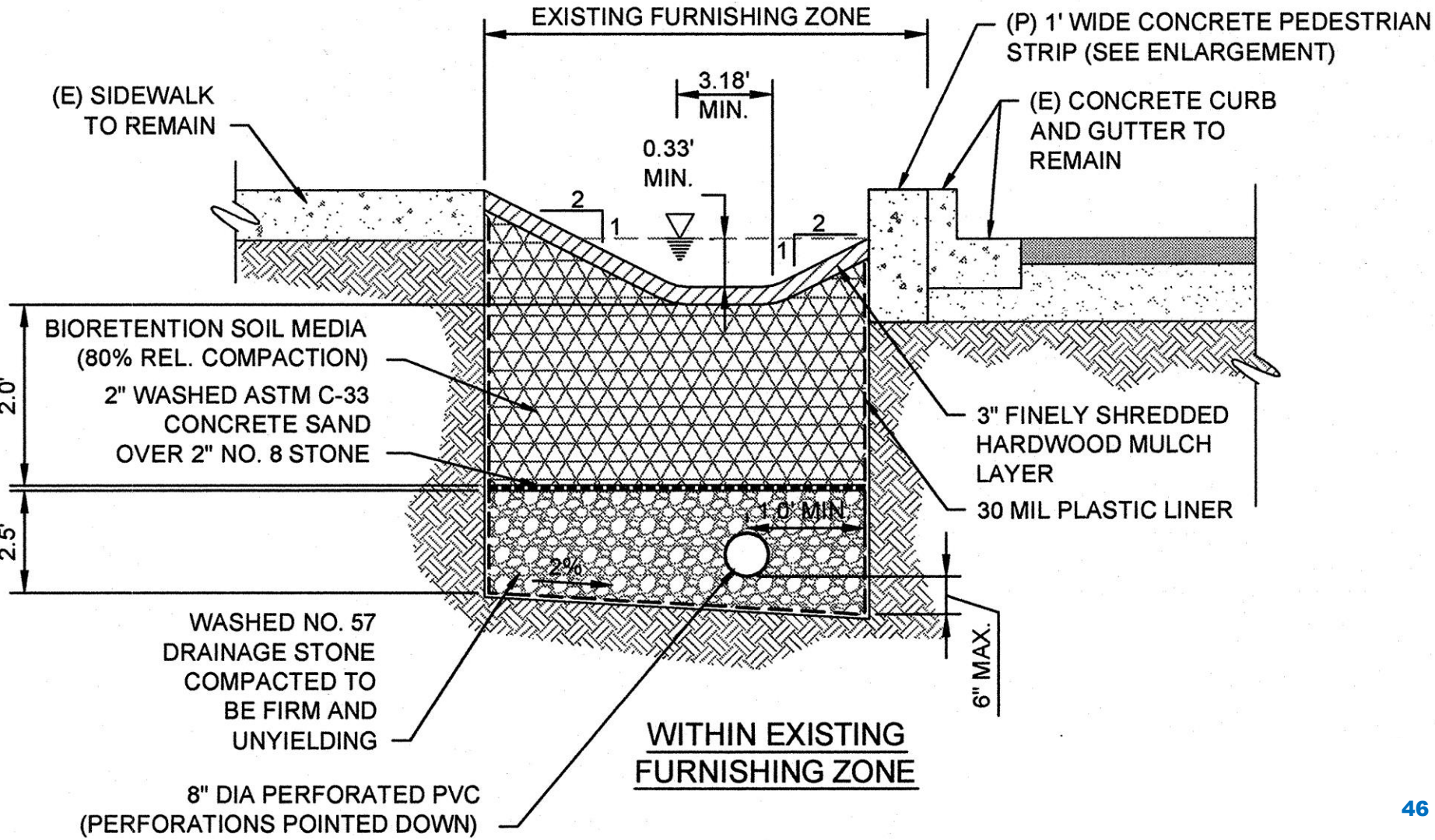




LID Implementation / Practices - Bioretention

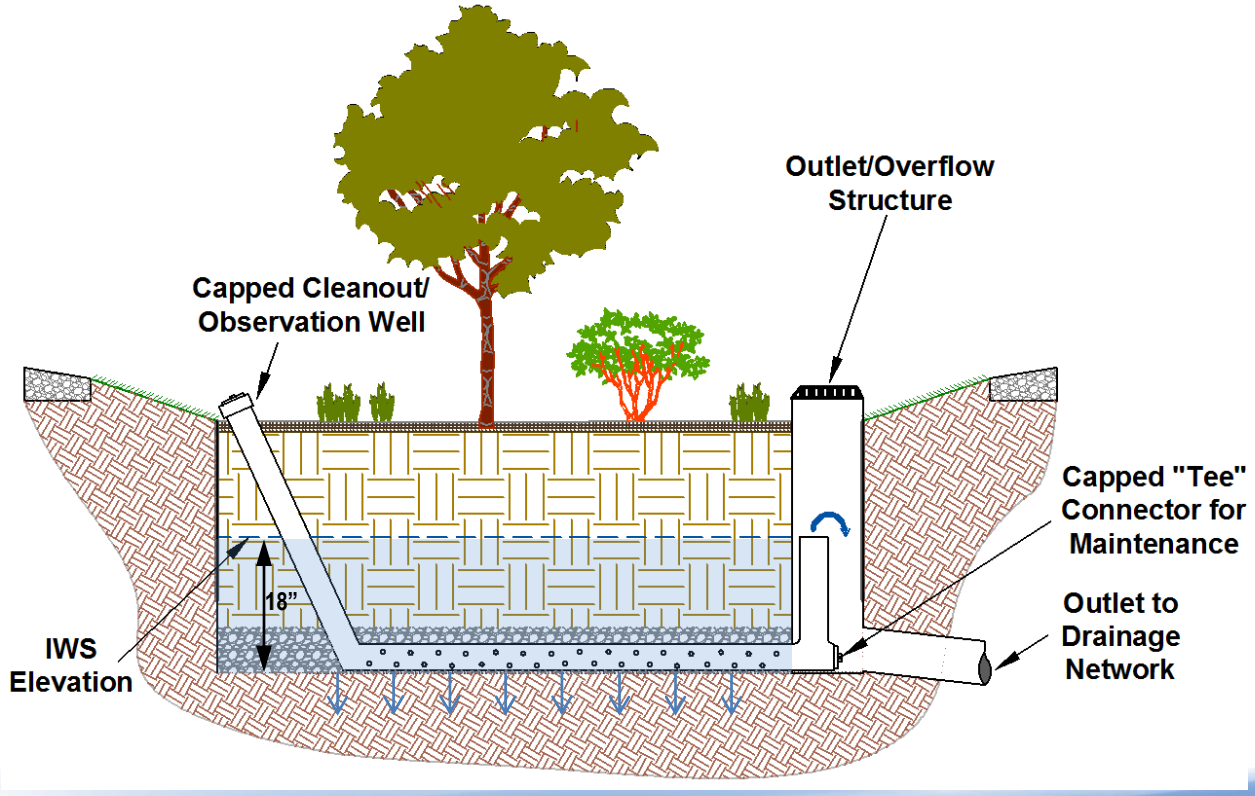
- Hydraulic Restriction Layers
  - 30 mil PVC Liner (ASTM D-7176)
  - Concrete
  - Clay (Bentonite)

LID Implementation / Practices - Bioretention



LID Implementation / Practices - Bioretention

Internal water storage (IWS)	If using underdrain and infiltration, elevate the outlet to create a sump for additional moisture retention to promote plant survival and enhanced treatment. Top of IWS should be greater than 18 inches below surface.



LID Implementation / Practices - Bioretention

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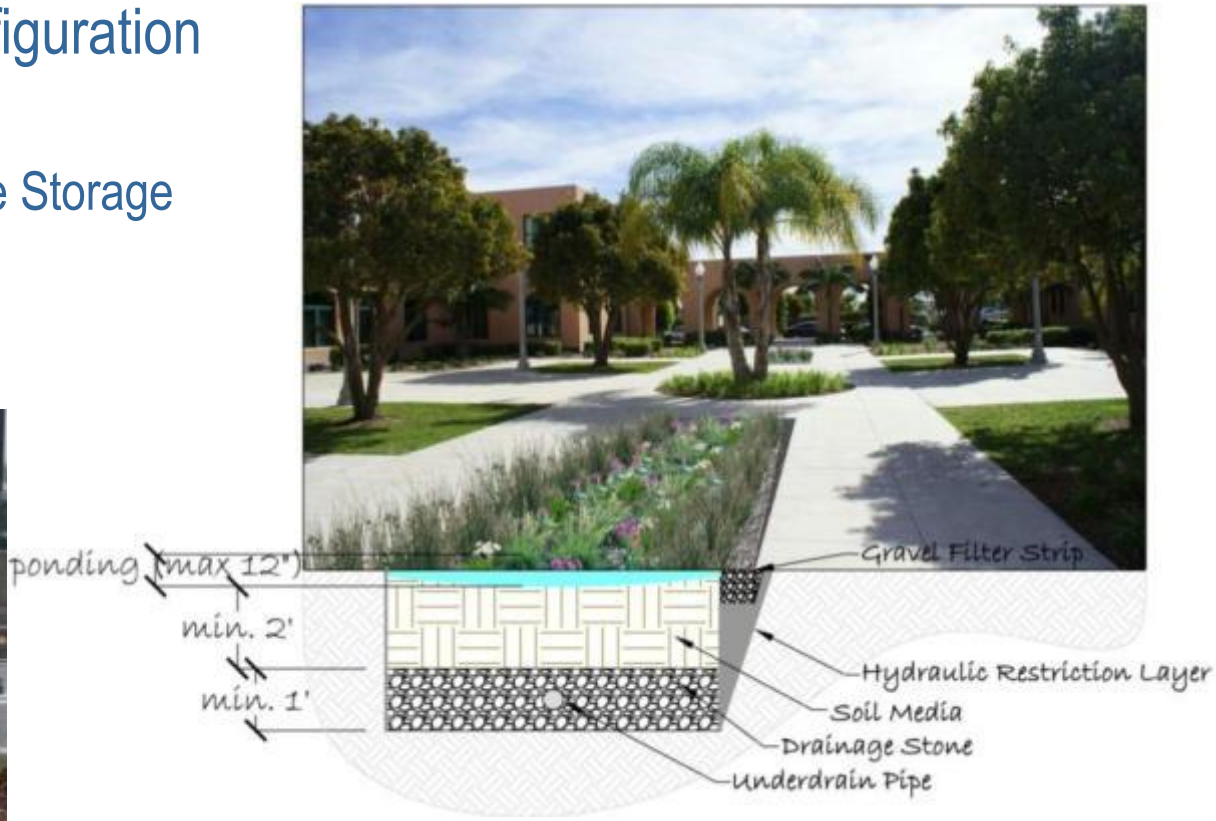
Raleigh, North Carolina. Source: Tetra Tech

Rocky Mount, North Carolina. Source: NCSU BAE

LID Implementation / Practices - Bioretention

- Calculate Surface Area
  - Function of BMP Configuration
    - Surface Storage
    - Soil Media/Subsurface Storage (30% porosity)



LID Implementation / Practices - Bioretention

$$D_{eq} = (D_{surface}) + (n_{media} \times D_{media}) + (n_{gravel} \times D_{gravel})$$

D_{eq} = equivalent depth of water stored in representative cross section

$D_{surface}$ = average depth of temporary surface ponding (maximum 18 inches)

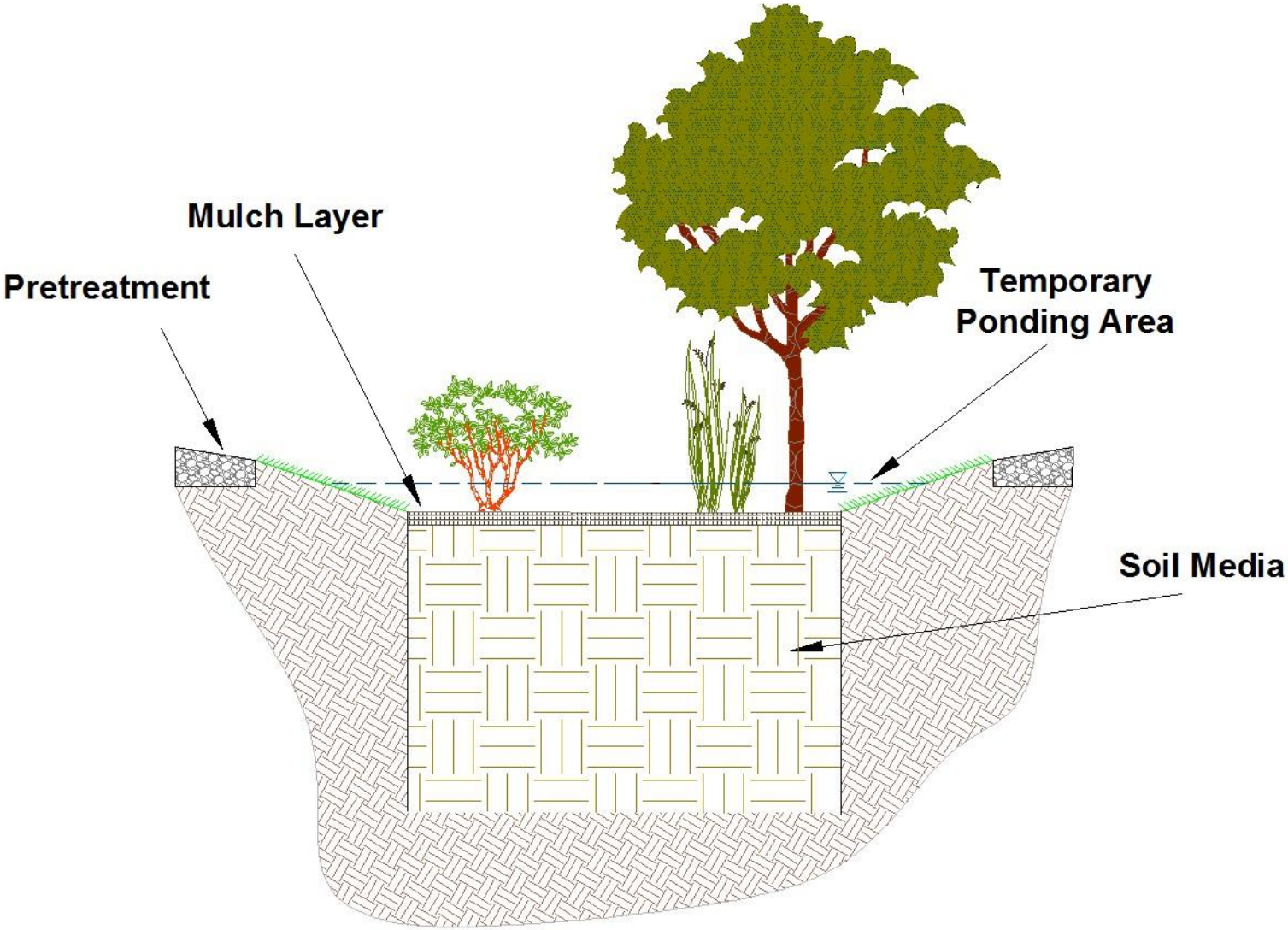
n_{media} = porosity of soil media (0.35 typically)

D_{media} = depth of soil media (2 to 4 feet)

n_{gravel} = porosity of gravel drainage layer (0.4 for no. 57)

D_{gravel} = depth of gravel drainage layer (1.5 feet max)

LID Implementation / Practices - Bioretention



LID Implementation / Practices - Bioretention

+ 4 Hours

+14 Hours

LID Implementation / Practices - Bioretention

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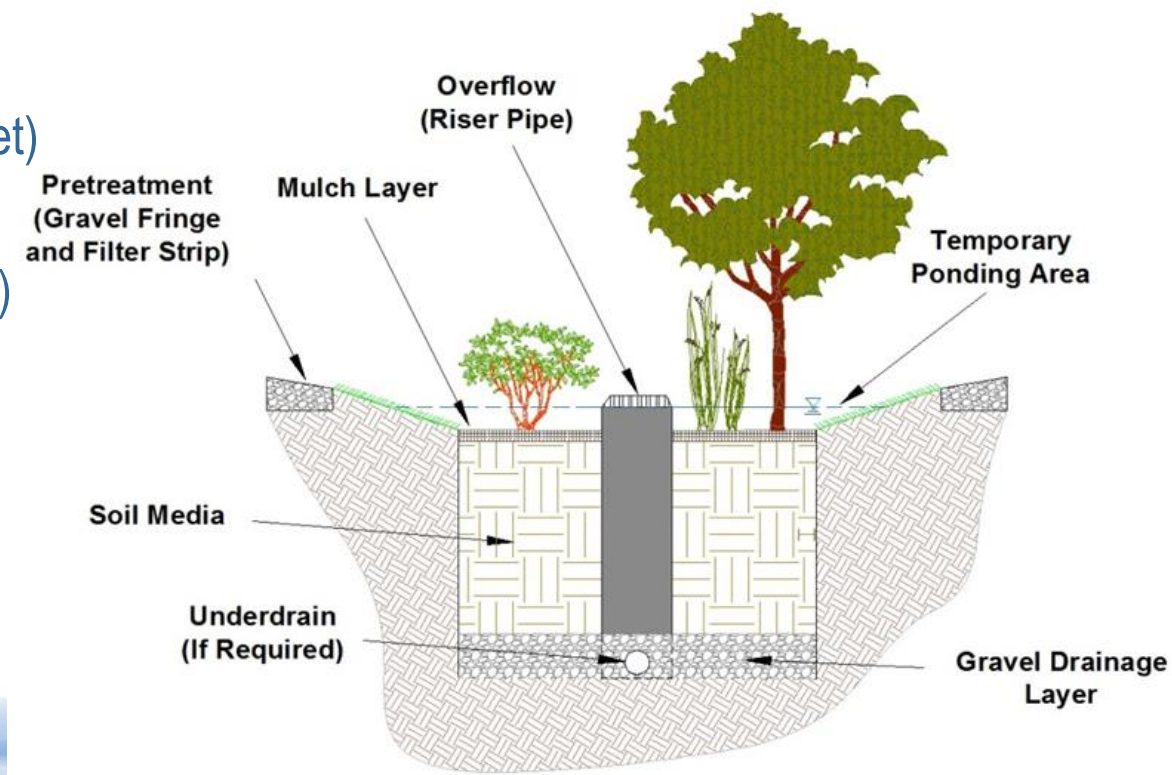
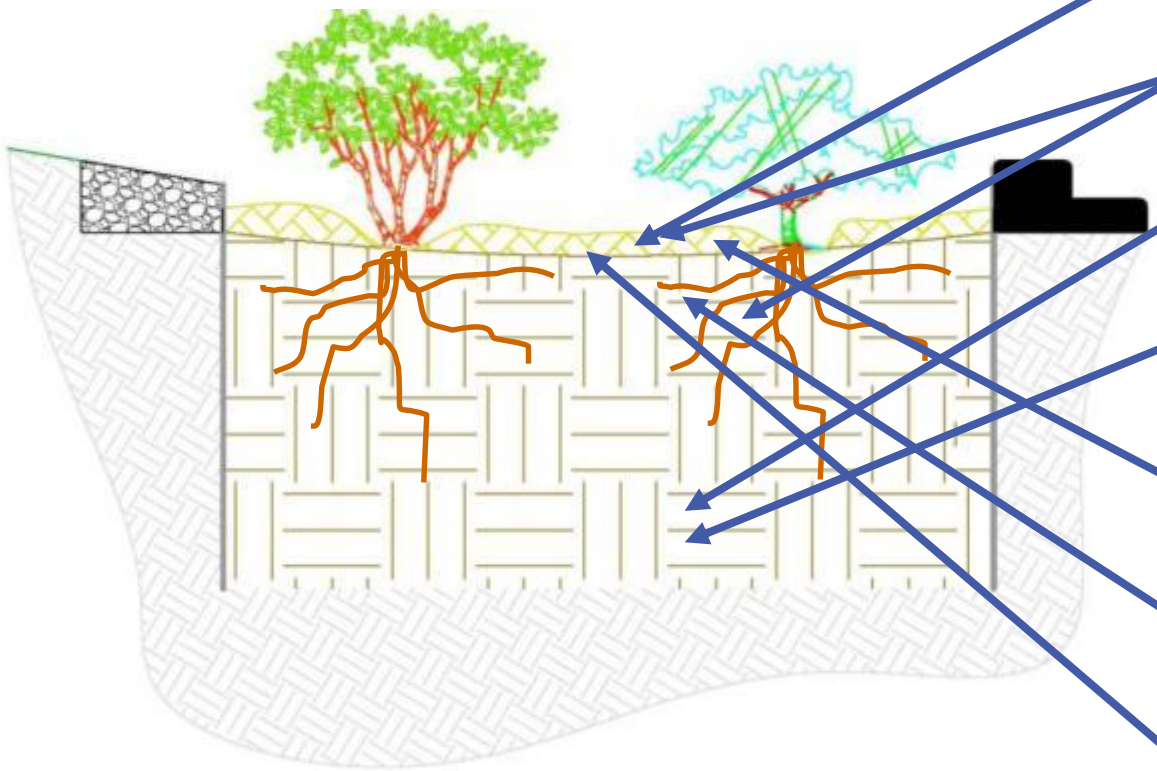


LID Implementation / Practices - Bioretention

- Soil Media Depth

Where are pollutants removed?



TSS Soil Depth ≥ 24 inch

TP ≥ 24 inches

Temp ≥ 48 inches

TN ≥ 36 inches

Pathogens ≥ 24 inches

Metals ≥ 24 inches

Oil & Grease ≥ 24 inches

LID Implementation / Practices - Bioretention

- Soil Media Depth

Vegetation Root Depth Requirements

Vegetation	Depth (ft)	Comments
Grass	1.5 - 2.0	Minimum
Shrubs/Trees	2.5 - 3.0	Minimum
Shrubs/Trees	3.0 - 4.0	Optimum
Shrubs/Trees	> 4.0	Sufficient but Extra Cost

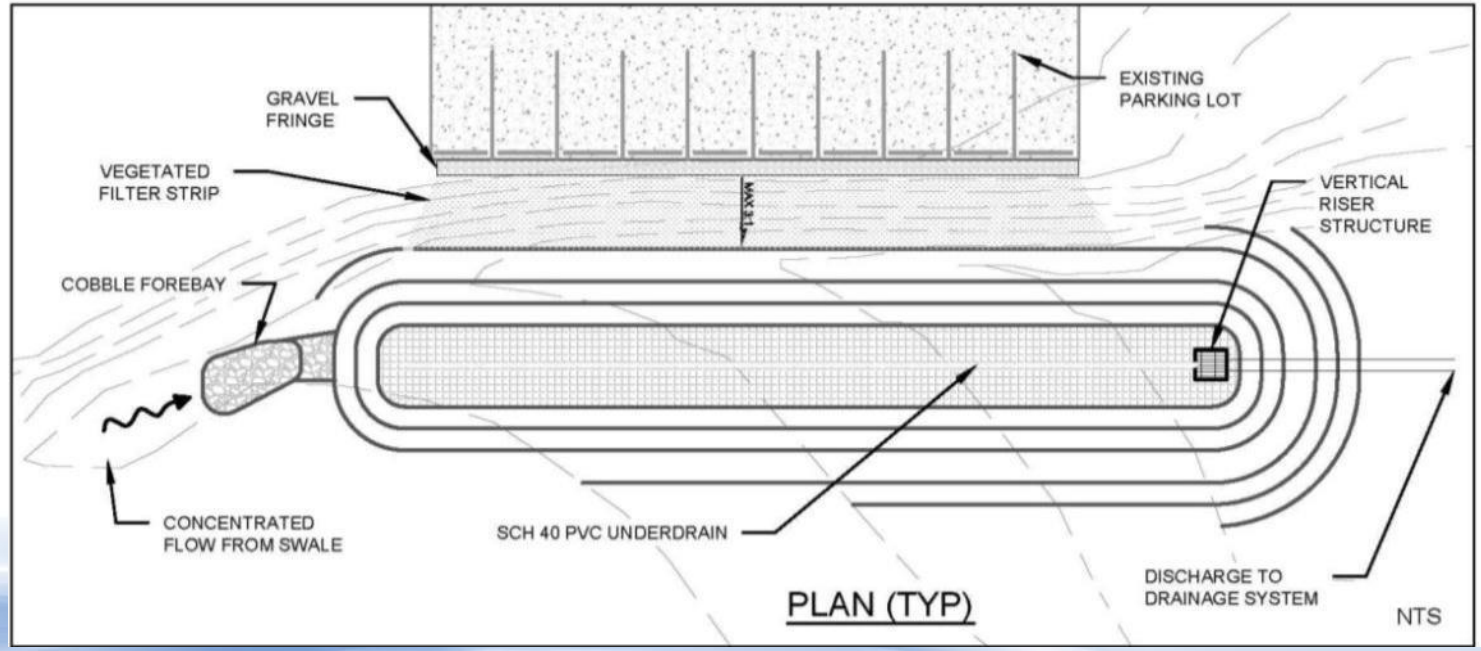
LID Implementation / Practices - Bioretention

$$A = \frac{V_{wq}}{D_{eq}}$$

A = required bioretention footprint (area)

V_{wq} = water quality treatment volume (based on the stormwater quality design standard)

D_{eq} = equivalent depth



LID Implementation / Practices - Bioretention

- Inlet Configuration
  - non-erosive sheet flow (1 ft/sec for mulch cells, 3 ft/sec for grass cells)
  - Filter Strips
  - Flow diversion

LID Implementation / Practices - Bioretention

- Inlet Configuration
  - Armored inlet, forebay, diversion structure

LID Implementation / Practices - Bioretention

- Inlet Configuration

LID Implementation / Practices - Bioretention

- Mulch and Vegetation
  - Double or triple shredded hardwood mulch

Bioretention Areas
(Mulch)

- Mulch And Vegetation
  - Hardwood Mulch fades and breaks down in intense sunlight
  - Landscaping stone an alternative

Photos courtesy Watershed Management Group

LID Implementation / Practices - Bioretention

- Mulch and Vegetation
  - Drought tolerant vegetation
  - Periodic inundation
  - Native species
- Consider size and appearance at maturity

Bioretention Areas
(Vegetation)

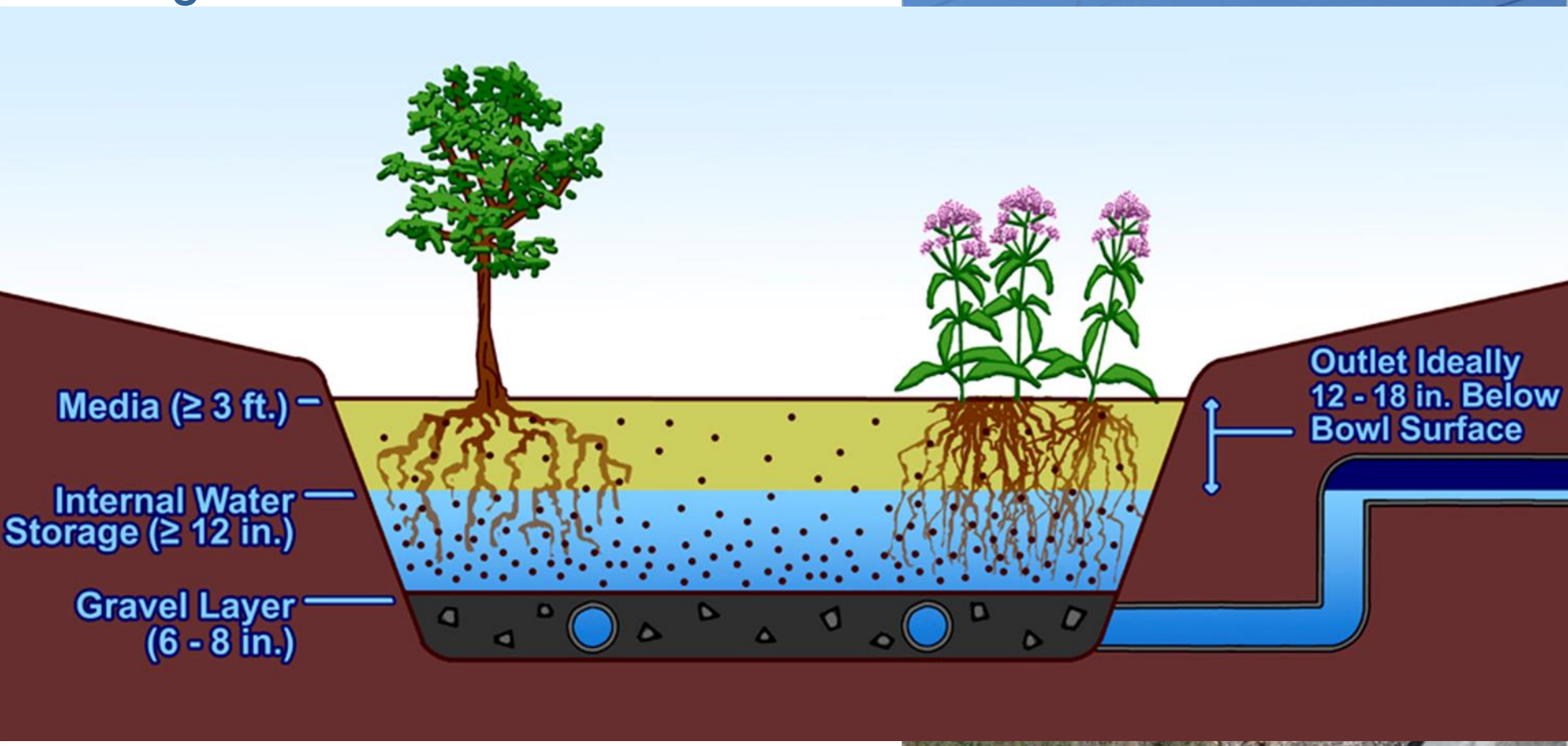
- Vegetation
  - Drought tolerant native vegetation
  - Phreatophytes
    - Large deep tap roots (> 100 ft)
    - Root system 4 to 9 times above ground biomass
      - Scrub Oak and Mesquite

Adapted from Houdeshel et al. 2012

Photos courtesy Watershed Management Group

Bioretention Areas
(Vegetation)

- Vegetation



Source: NCSU BAE

Photos courtesy Watershed Management Group

LID Implementation / Practices – Bio / Bioretention Swale

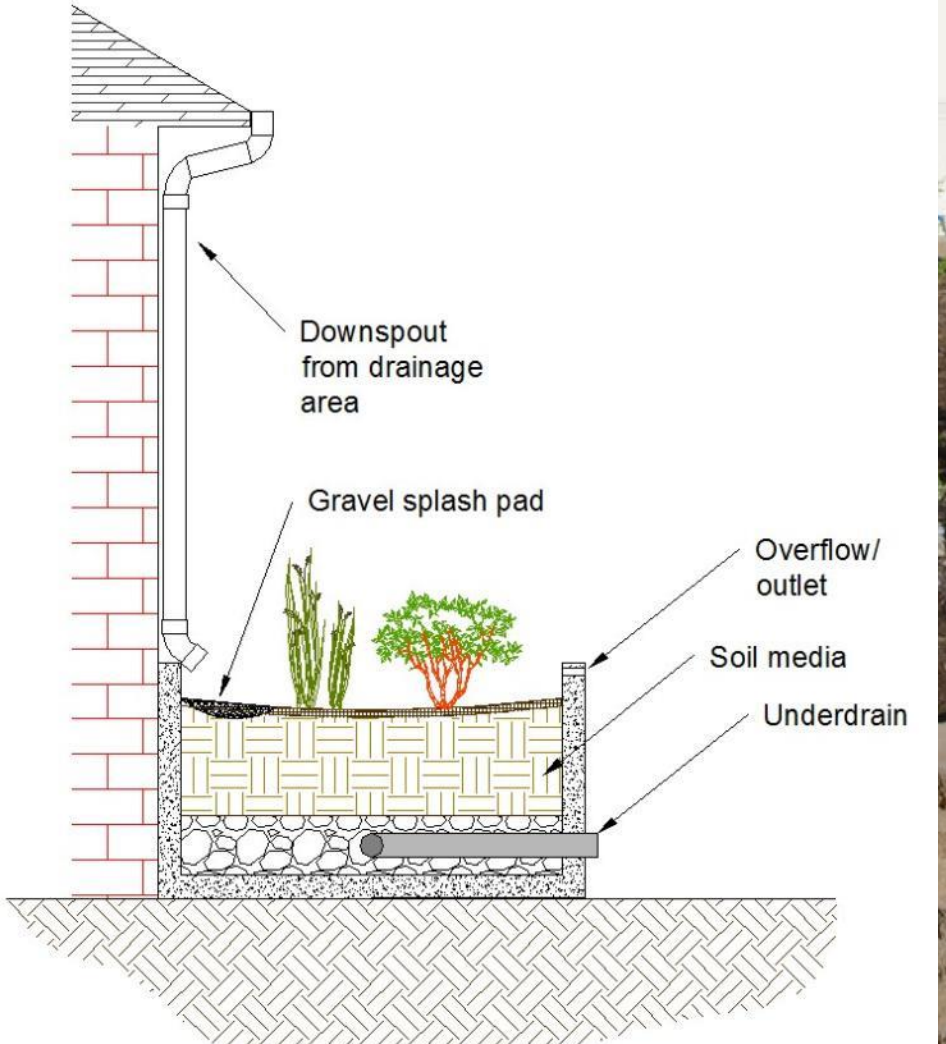
- Bioswales / Bioretention Swales

LID Implementation / Practices – Bio / Bioretention Swale

- Longitudinal Slope
  - Less that 2%
  - Less that 5% overall

LID Implementation / Practices – Bio / Bioretention Swale

- Flow Through Planter Boxes



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Green Infrastructure Implementation / Structural Practices - Bioretention

Pollutant	Typical literature removal efficiency	Median effluent concentration (mg/L unless otherwise noted)1	Minimum recommended media depth for treatment
Sediment	High	8.3	1.5 feet
Metals	High	TCd: 0.94 µg/L, TCu: 7.67 µg/L, TPb: 2.53 µg/L, TZn: 18.3 µg/L	2 feet
Hydro-carbons	High	N/A	N/A
Total phosphorus	Medium (-240% to 99%)	0.09	2 feet
Total nitrogen	Medium (TKN: -5% to 64%, Nitrate: 1% to 80%)	TN: 0.90, TKN: 0.60, NO2,3-N: 0.22	3 feet
Bacteria	High	Enterococcus: 234 MPN/ 100 mL, *E.coli*: 44 MPN/100 mL	2 feet
Thermal load	High	68–75 °F	4 feet

LID Implementation / Practices – Permeable Pavement

- Allows for rainfall infiltration
- Ideal for low traffic surfaces (driveways, parking lots, walk ways)
- Provides peak flow mitigation, volume storage, and some water quality improvement

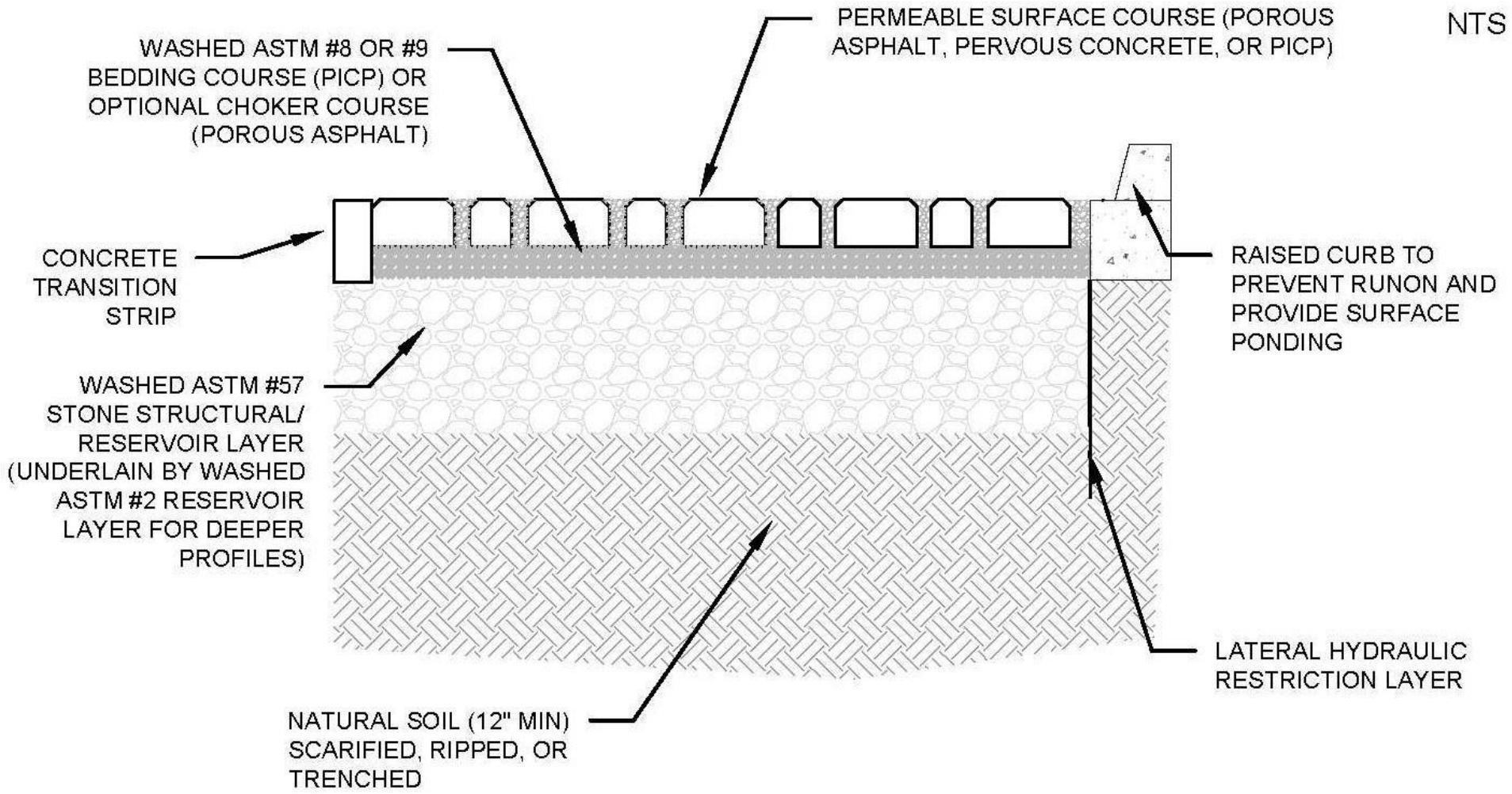
LID Implementation / Practices – Permeable Pavement

Photo Credit: Green Paving Solutions

Photo Credit: US EPA

LID Implementation / Practices – Permeable Pavement

LID Implementation / Practices – Permeable Pavement



LID Implementation / Practices – Permeable Pavement

Parking Lots

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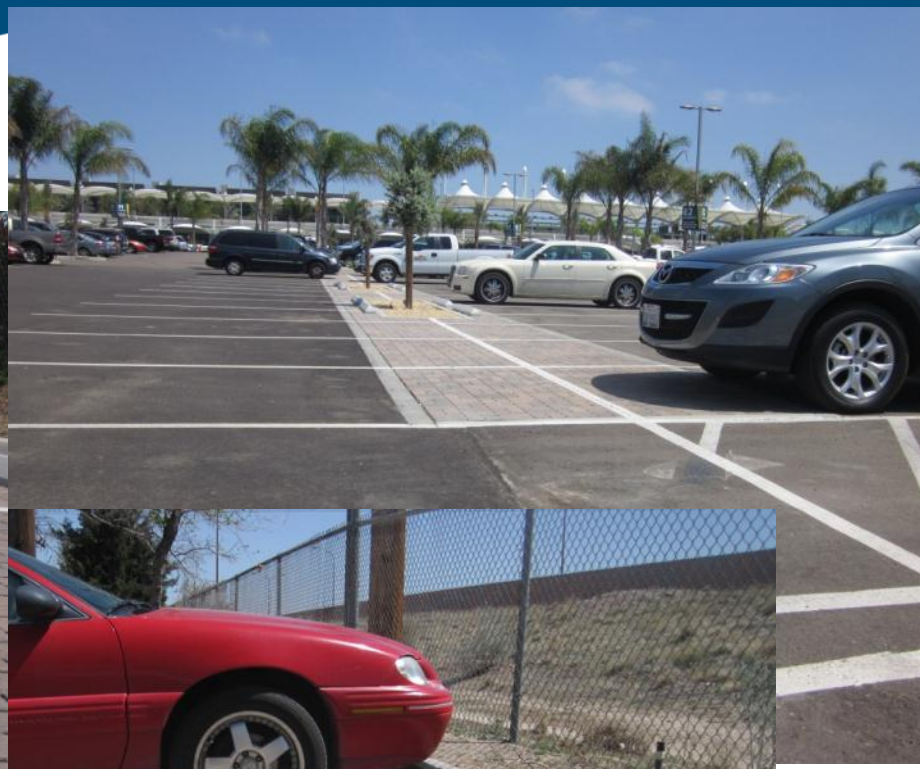
LID Implementation / Practices – Permeable Pavement



Parking Lots

LID Implementation / Practices – Permeable Pavement

Rights-of-Way

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LID Implementation / Practices – Permeable Pavement

Artistic Uses

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LID Implementation / Practices – Permeable Pavement

Driveways and Alleys

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LID Implementation / Practices – Permeable Pavement

Driveways and Alleys

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LID Implementation / Practices – Permeable Pavement

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LID Implementation / Practices – Permeable Pavement

LID Implementation / Practices – Permeable Pavement

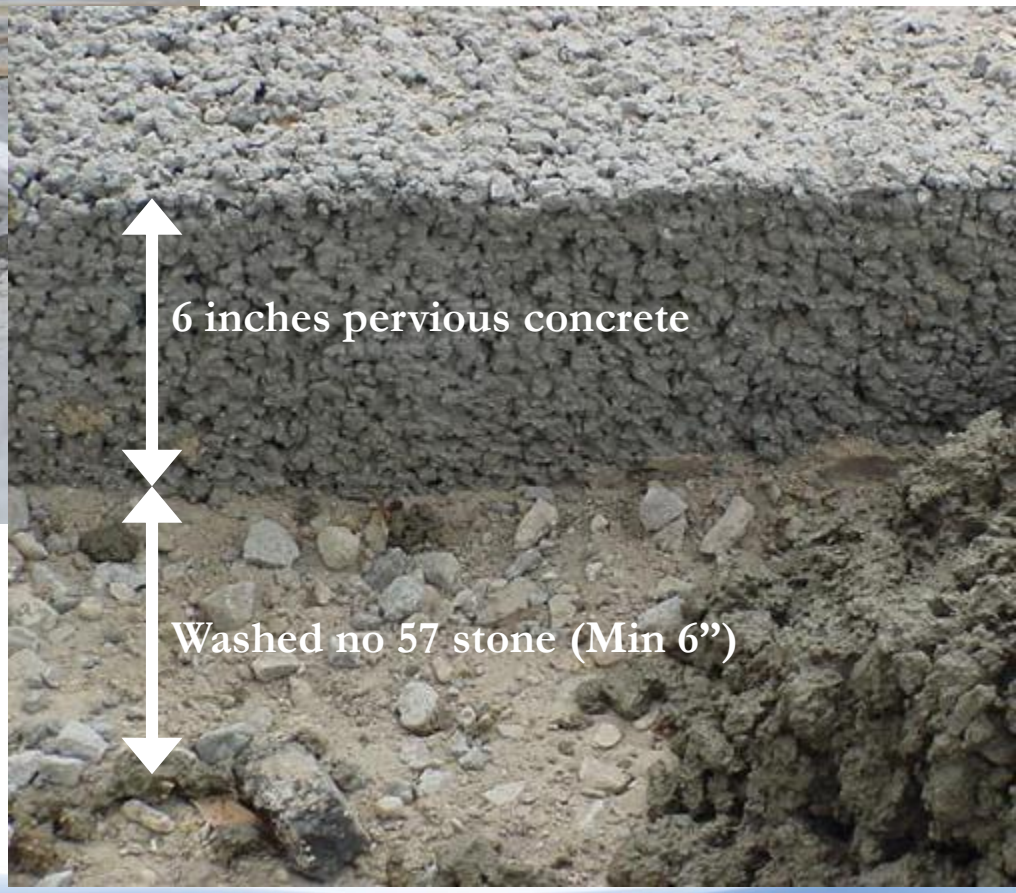
- Permeable Interlocking Concrete Pavers (PICP)
- Concrete Grid Pavers (CGP)
- Pervious Concrete
- Porous Asphalt
- Plastic Reinforcing Grids (PG)

LID Implementation / Practices – Permeable Pavement

PICP with gravel fill

PICP with sand fill

LID Implementation / Practices – Permeable Pavement



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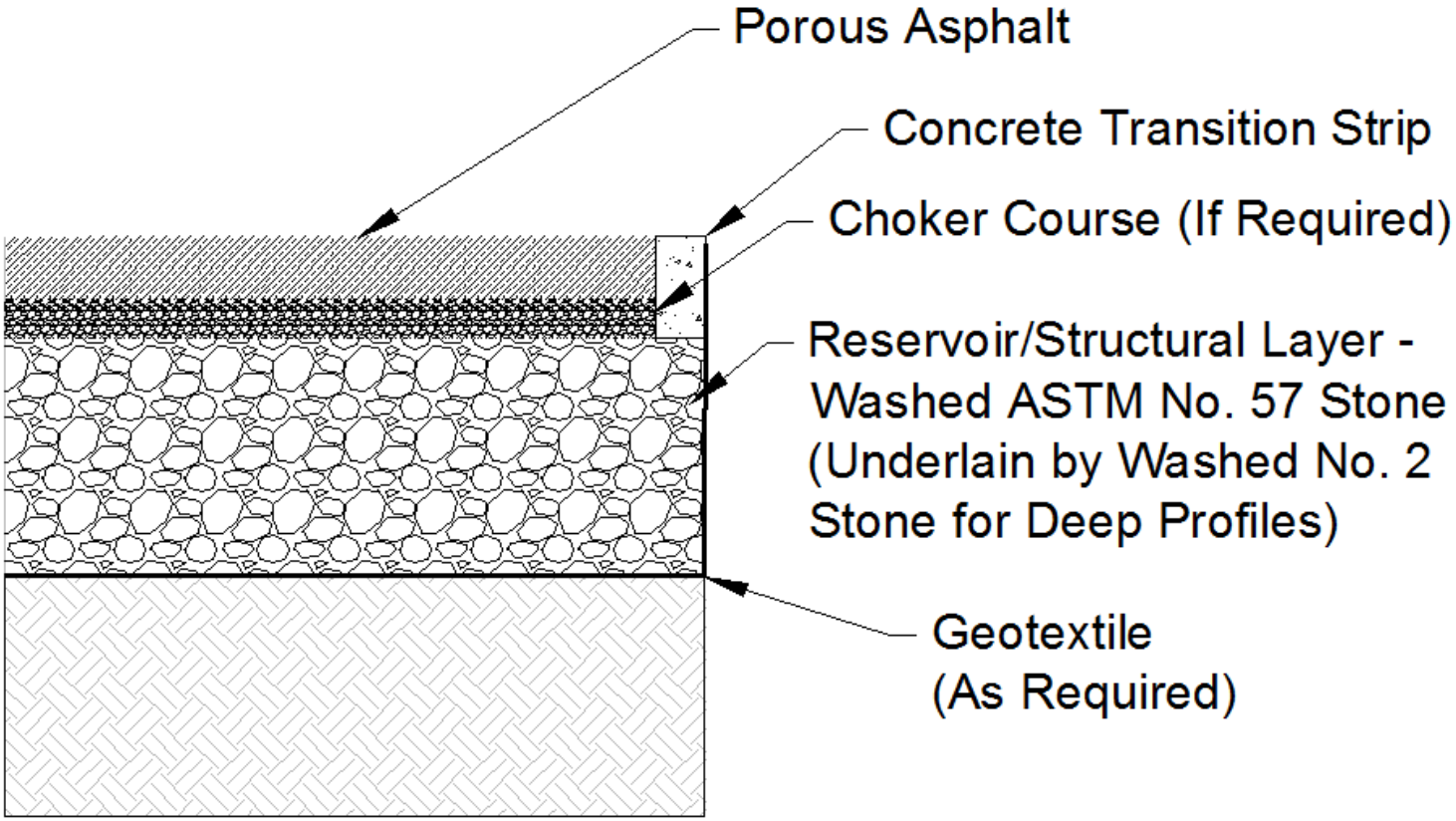


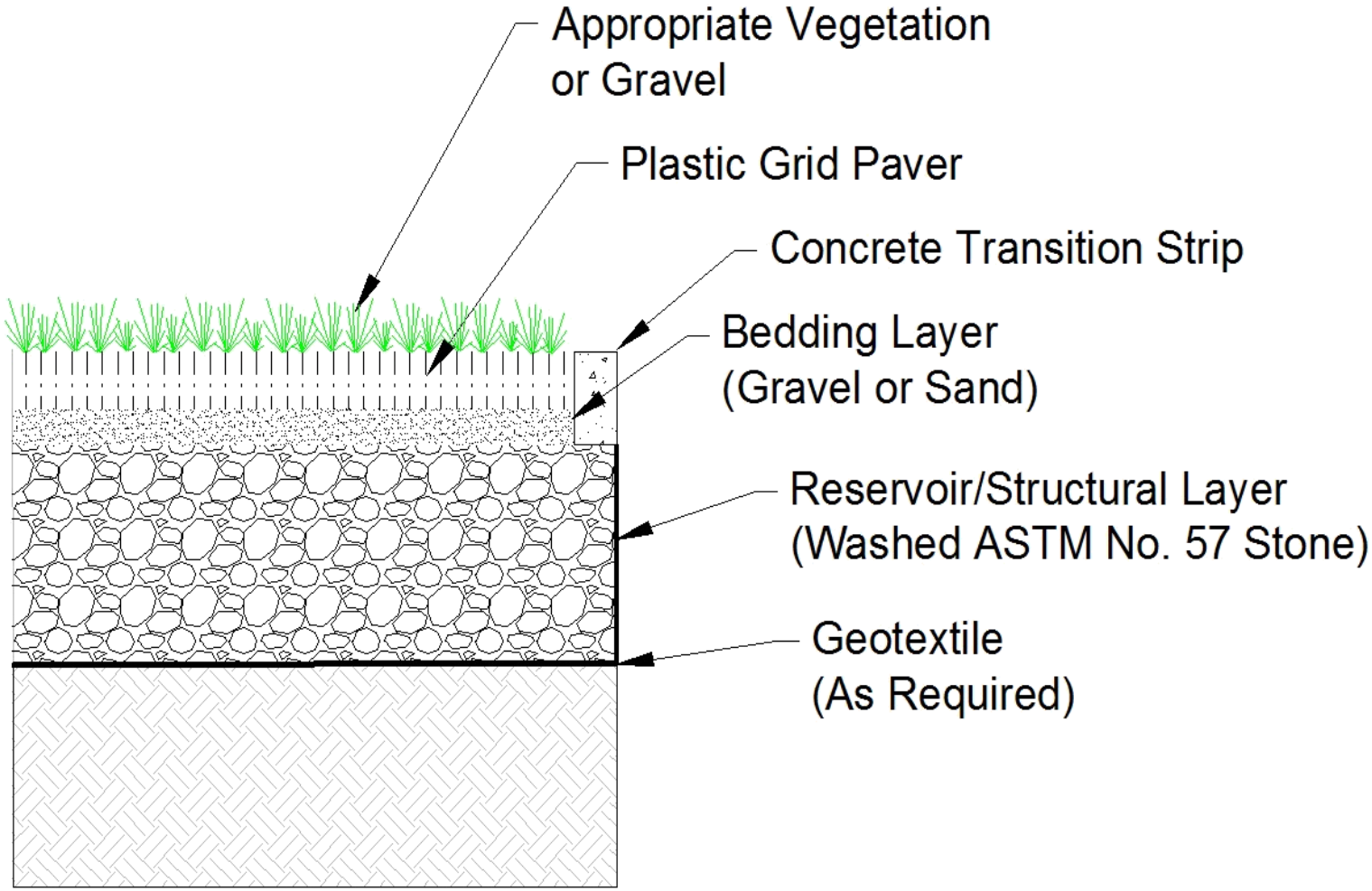
LID Implementation / Practices – Permeable Pavement

LID Implementation / Practices – Permeable Pavement

Porous Asphalt – Pervious Friction Course

Source: Texas DOT Construction Division

LID Implementation / Practices – Permeable Pavement

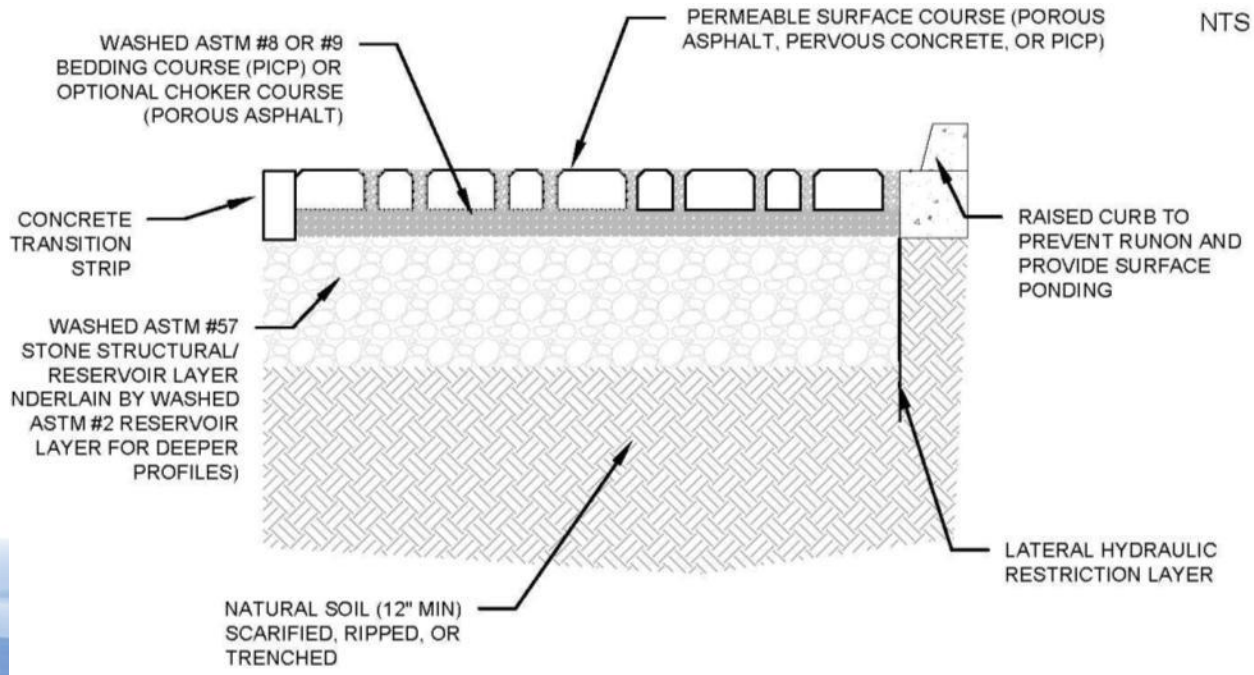


LID Implementation / Practices – Permeable Pavement

LID Impl

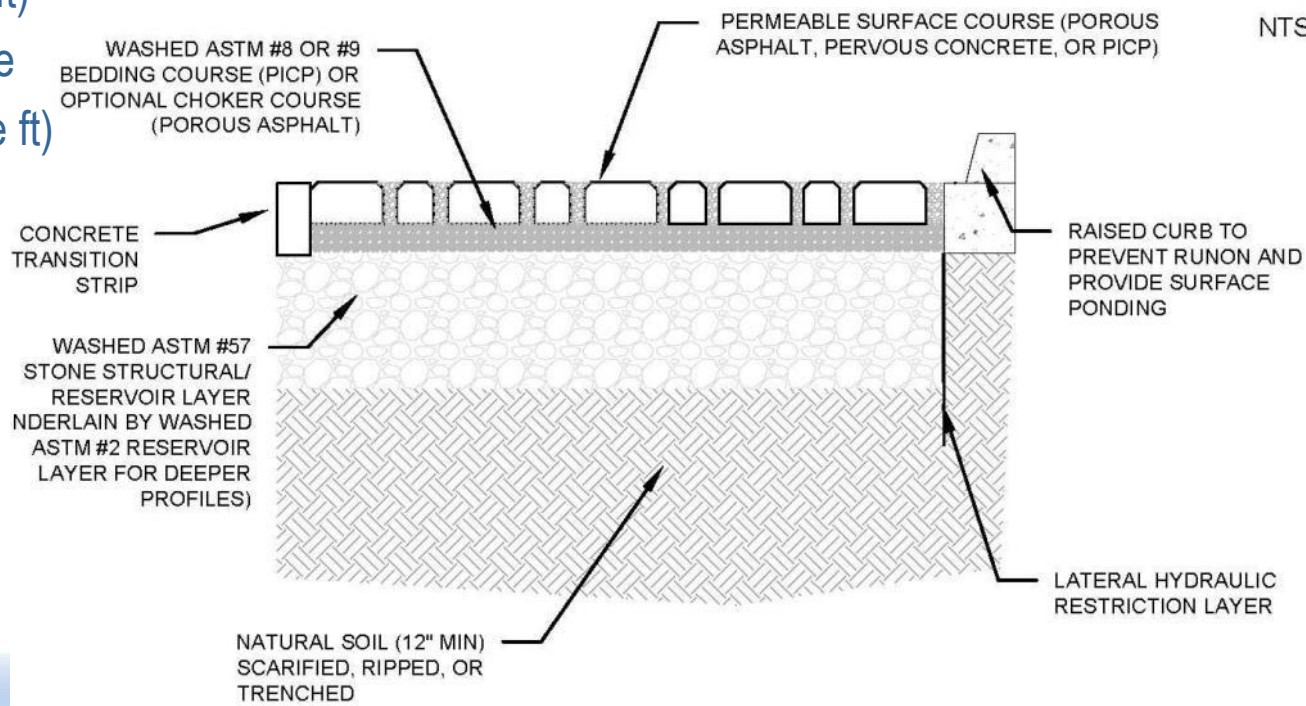
LID Implementation / Practices – Permeable Pavement

- PP must capture the stormwater quality design standard
  - Main variable is layer depth
- Account for contributing areas



LID Implementation / Practices – Permeable Pavement

- Store/Treat the stormwater quality design standard
  - within base and sub-base reservoirs
  - $d = V / A \times n$
  - d = Gravel Layer Depth (ft)
  - V = Water Quality Volume
  - A = Surface Area (square ft)
  - n = Porosity (0.3 to 0.4)



LID Implementation / Practices – Permeable Pavement

No. 57

No. 2

Washed Stone

Source: NCSU BAE

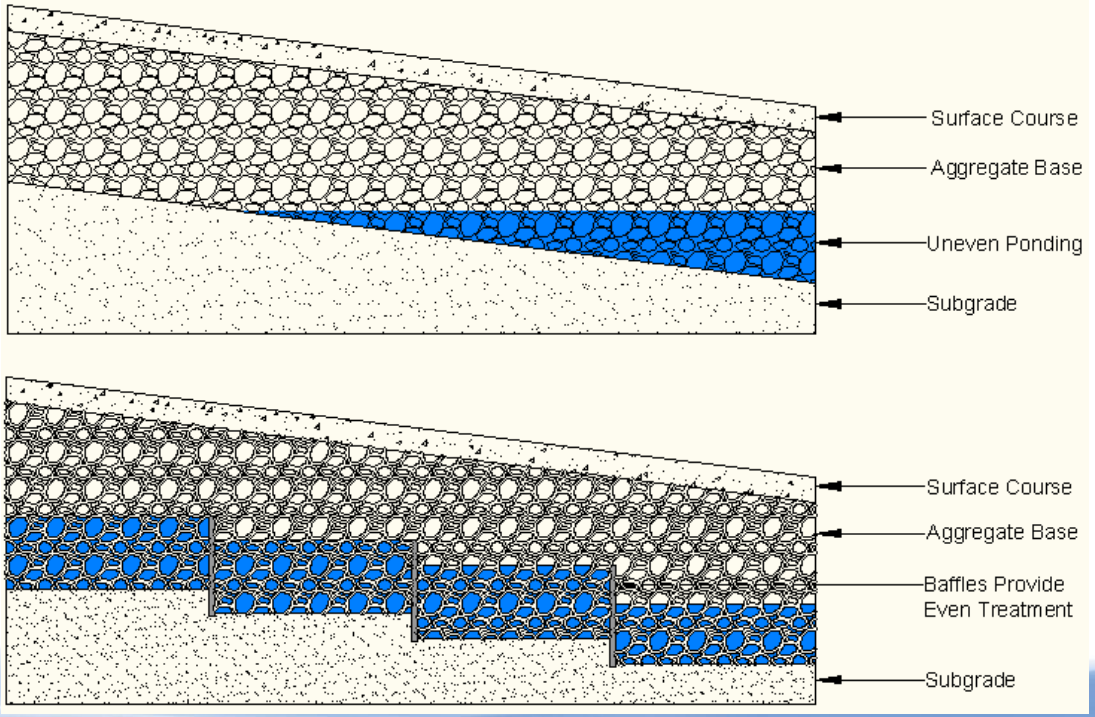
LID Implementation / Practices – Permeable Pavement

- Design
  - Total traffic
  - In situ soil strength
  - Environmental elements
  - Bedding and reservoir layer design

- AASHTO Guide for Design of Pavement Structures (1993)
- AASHTO Supplement to the Guide for Design of Pavement Structures (1998)
- AASHTO Flexible Pavement Method

LID Implementation / Practices – Permeable Pavement

- Consider slope in calculation



Source: NCSU BAE

LID Implementation / Practices – Permeable Pavement

Pollutant	Typical literature removal efficiency	Median effluent concentration (mg/L unless otherwise noted)[1]
Sediment	High[1] (32% to 96%)	13.2
Metals	High (65% to 84%)	TAs: 2.50µg/L, TCd: 0.25µg/L, TCr: 3.73 µg/L, TCu: 7.83µg/L, TPb: 1.86µg/L, TNi: 1.71 µg/L, TZn: 15.0 µg/L
Hydro-carbons	Medium (92% to 99%)	N/A
Total phosphorus	Low (20% to 78%)	0.09
Total nitrogen	Low (-40% to 88%)	TKN: 0.80, *$NO_{2,3}$-N: 0.71*
Bacteria	Medium	N/A
Thermal load	Medium	58–73 °F

LID Implementation / Practices – Living Roof

Intensive living roof

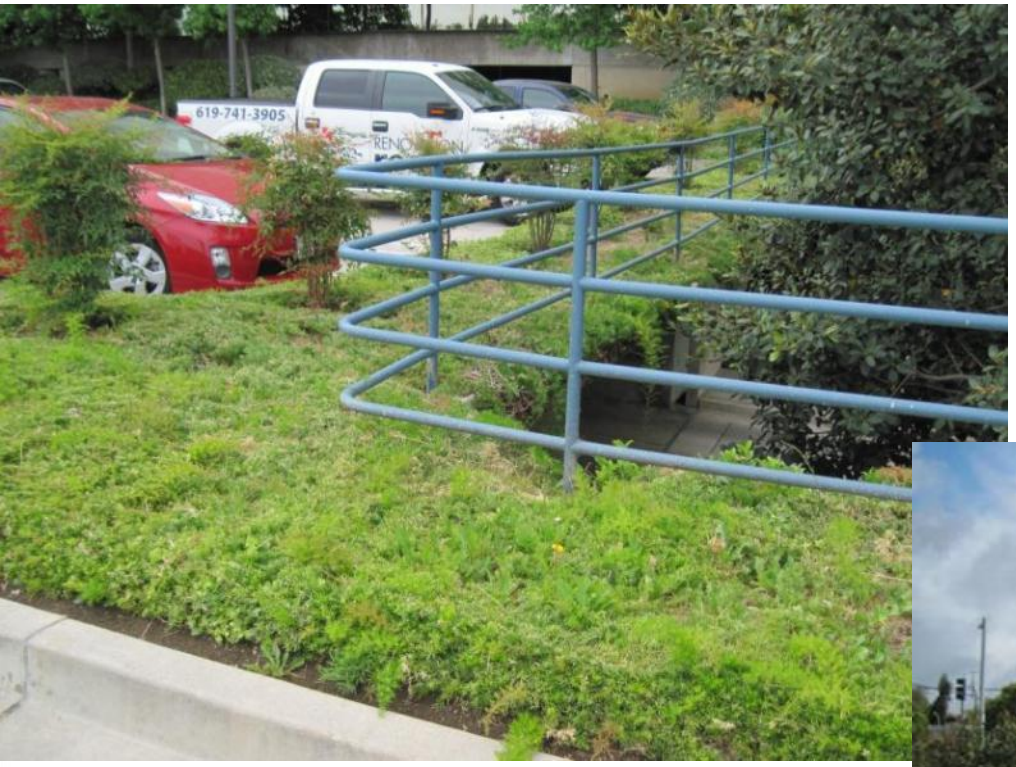
Extensive living roof

LID Implementation / Practices – Living Roof

LID Implementation / Practices – Living Roof

TETRA TECH

LID Implementation / Practices – Living Roof



TETRA TECH

LID Implementation / Practices – Living Roof

TETRA TECH

LID Implementation / Practices – Living Roof

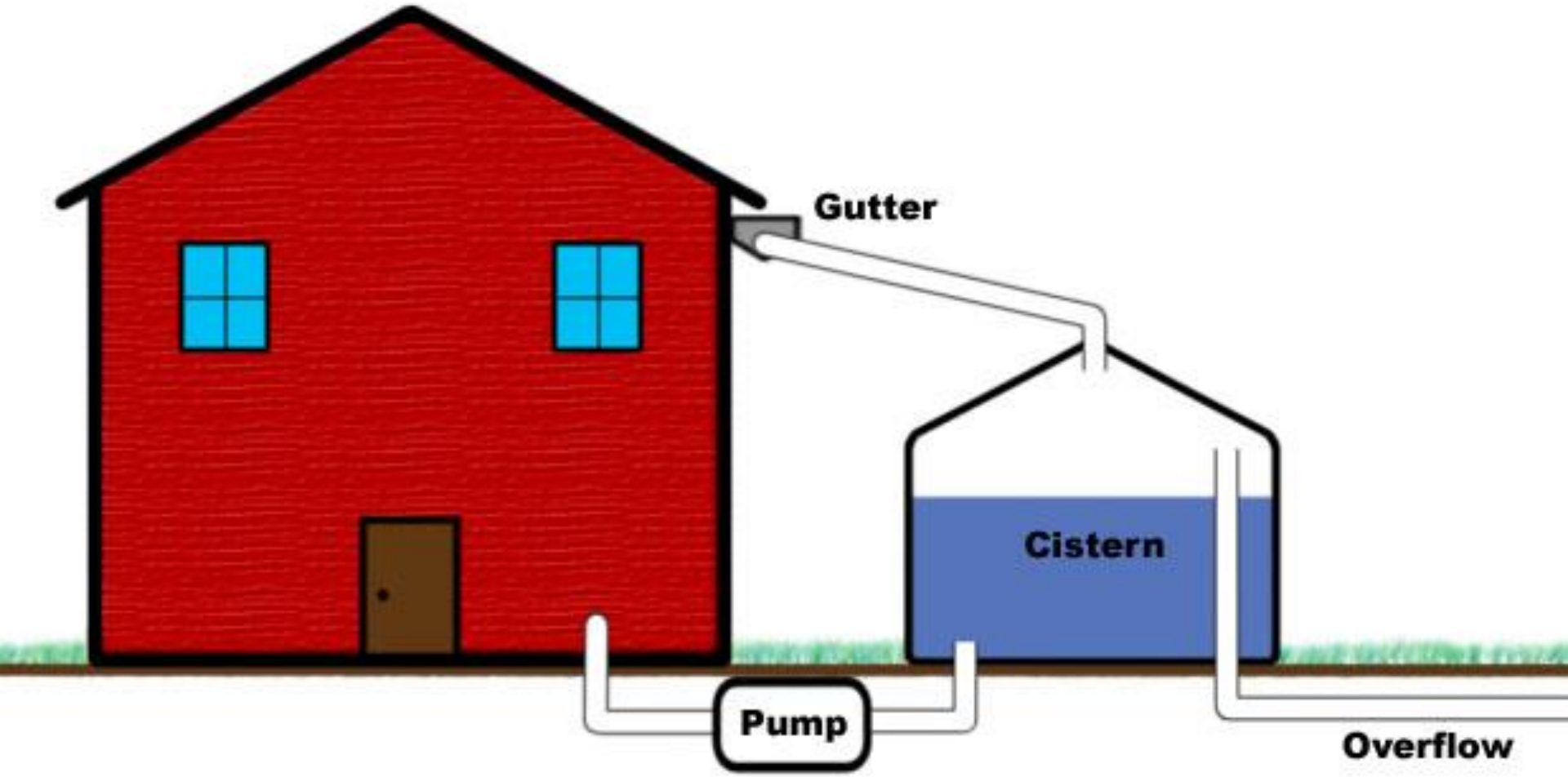
TETRA TECH

Green Infrastructure Implementation / Structural Practices – Living Roof

- Volume reduction
- Extended roof life span (due to additional sealing, liners, and insulation)
- Improved building insulation and energy use
- Reduction of urban heat island effects
- Opportunities for recreation and rooftop gardening
- Noise attenuation
- Air quality improvement
- Bird and insect habitat
- Aesthetics

Tolderlund 2010; Berndtsson 2010; Getter and Rowe 2006)

LID Implementation / Practices - Water Harvesting



LID Implementation / Practices - Water Harvesting

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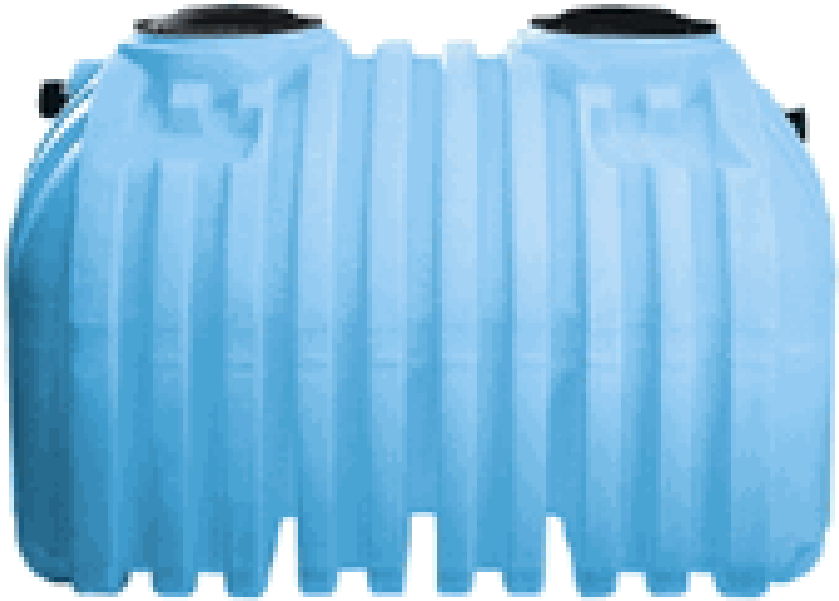
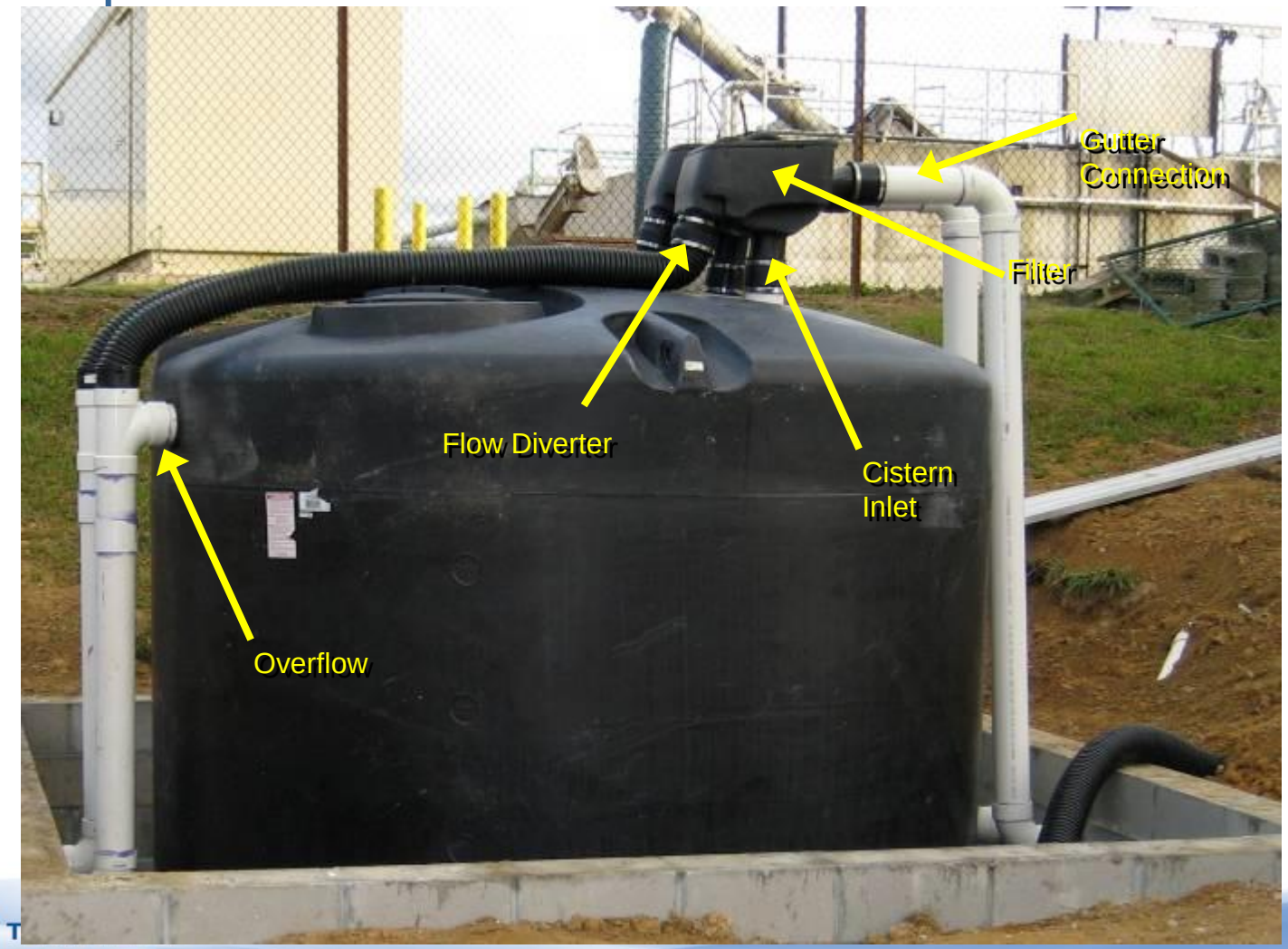


LID Implementation / Practices - Water Harvesting

LID Implementation / Practices - Water Harvesting

LID Implementation / Practices - Water Harvesting

System Components



LID Implementation / Practices - Water Harvesting

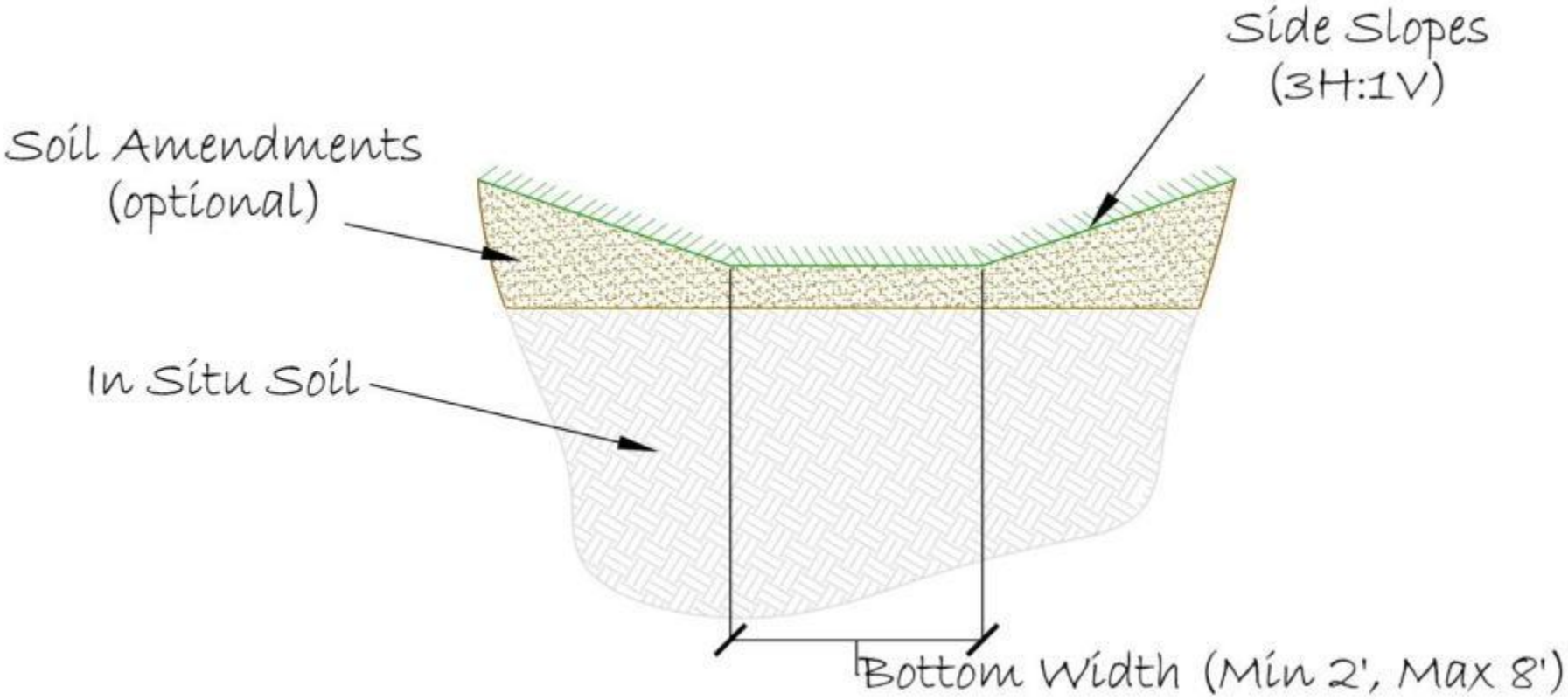
Source: Kathy DeBusk

LID Implementation / Practices - Water Harvesting

LID Implementation / Practices – Vegetated Swales

- More soil/water contact compared to pipes, more opportunity for infiltration
- Filtration of sediment and debris by the grass, especially when kept long
- Larger bottom widths result in lower velocities, shallower flow depths, more infiltration and filtration

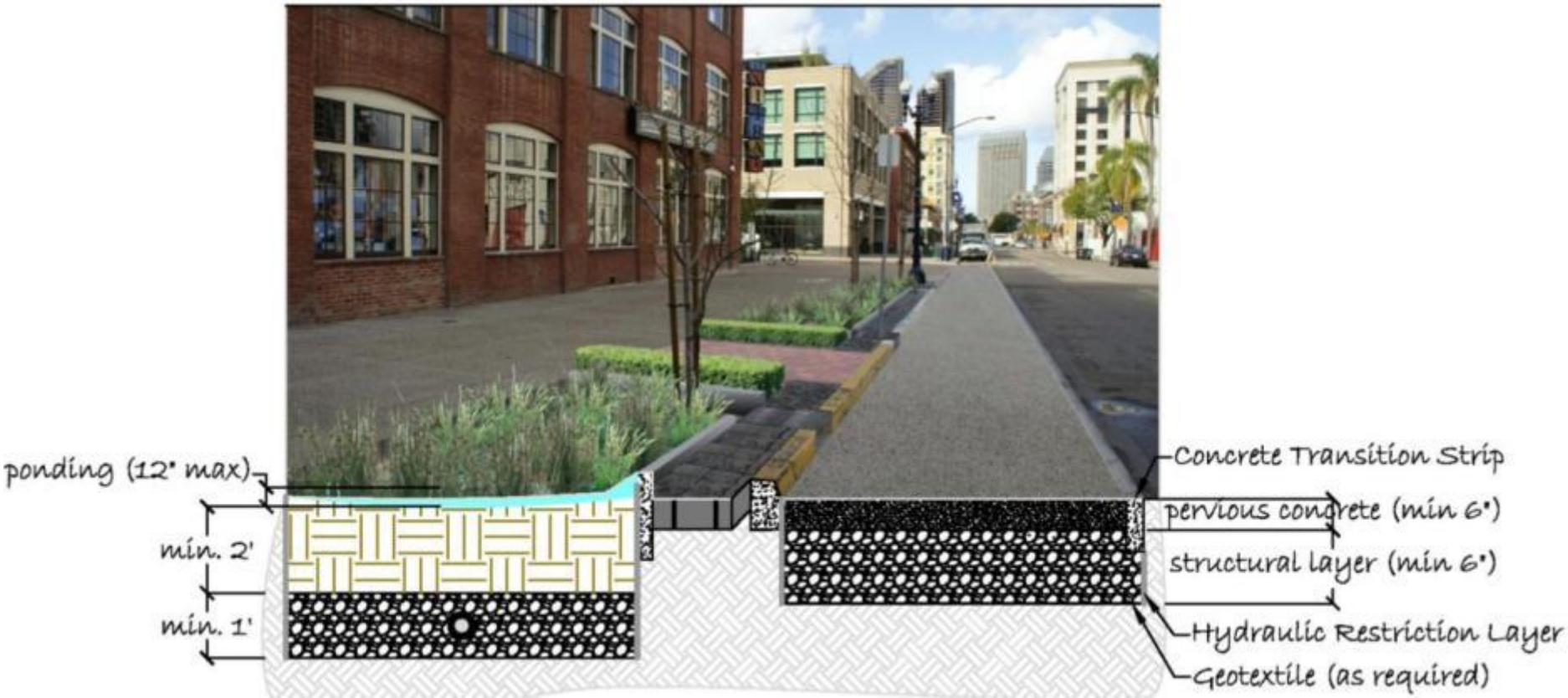
LID Implementation / Practices – Vegetated Swales



Green Infrastructure Implementation / Structural Practices – Vegetated Swales

Pollutant	Typical literature removal efficiency	Median effluent concentration (mg/L unless otherwise noted)[1]
Sediment	High (20% to 98%)	13.6
Metals	Medium	TAs: 1.17µg/L, TCd: 0.31µg/L, TCr: 2.32µg/L, TCu: 6.54µg/L, Pb: 2.02µg/L, TNi: 3.16µg/L, TZi: 22.9µg/L
Total phosphorus	Low	*0.19*
Total nitrogen	Low	TN: 0.71, TKN: 0.62, $NO_{2,3}$-N: 0.25
Bacteria	Low (typically exports pathogens)	E. coli: 4190 MPN/100 mL, Fecal coliform: 5000 MPN/100 mL

LID Implementation / Practices – Treatment Train



LID Implementation / Practices – Treatment Train

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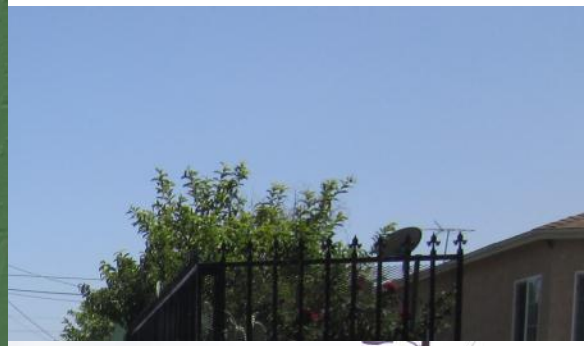
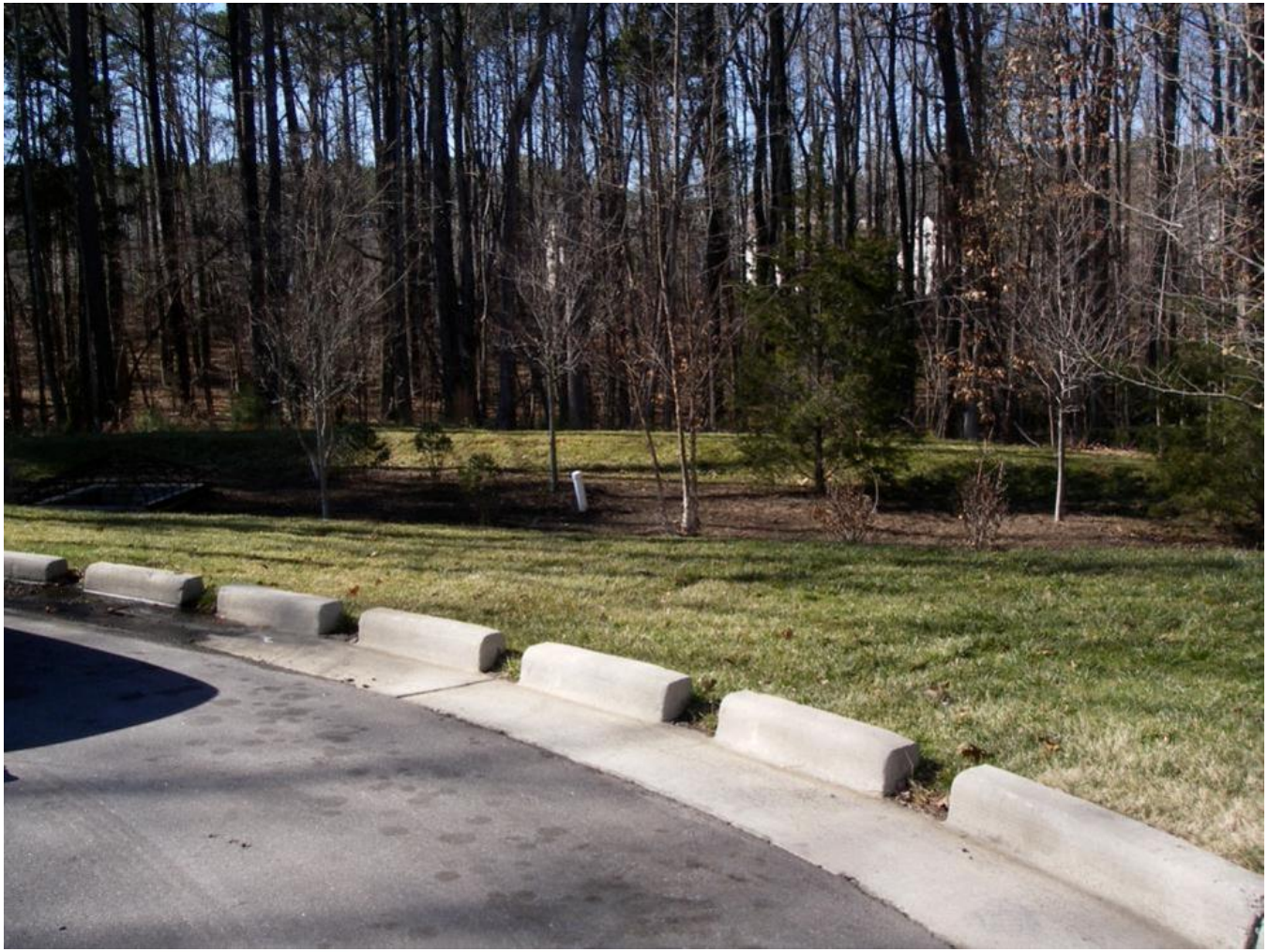


LID Implementation / Practices – Treatment Train



Questions and Discussion