Green Build-Out Model:

Quantifying the Stormwater Management Benefits of Trees & Green Roofs in the District of Columbia

Michael P. Sullivan, LimnoTech

Outline of Presentation

- Project Background
- Background on Sewer Systems in Washington, DC
- Opportunities for Green Infrastructure in Washington, DC
- The Green Build-out Model
- Benefits and Key Findings

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Project Background

- EPA Water Quality Cooperative Grant
- Grant Partners
  - Casey Trees
  - LimnoTech
  - Advisory Team
- Used DC WASA's Mike Urban Model (H&H)

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Green Infrastructure Opportunity in DC

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Hypothesis

Washington, DC: 2005

Washington, DC: 2025

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Grant Objectives

- **Quantify** the city-wide contribution that trees and green roofs could make towards reducing stormwater runoff and the frequency of discharges to the rivers in DC
- **Identify policy recommendations** to facilitate implementation of trees and green roofs as stormwater controls

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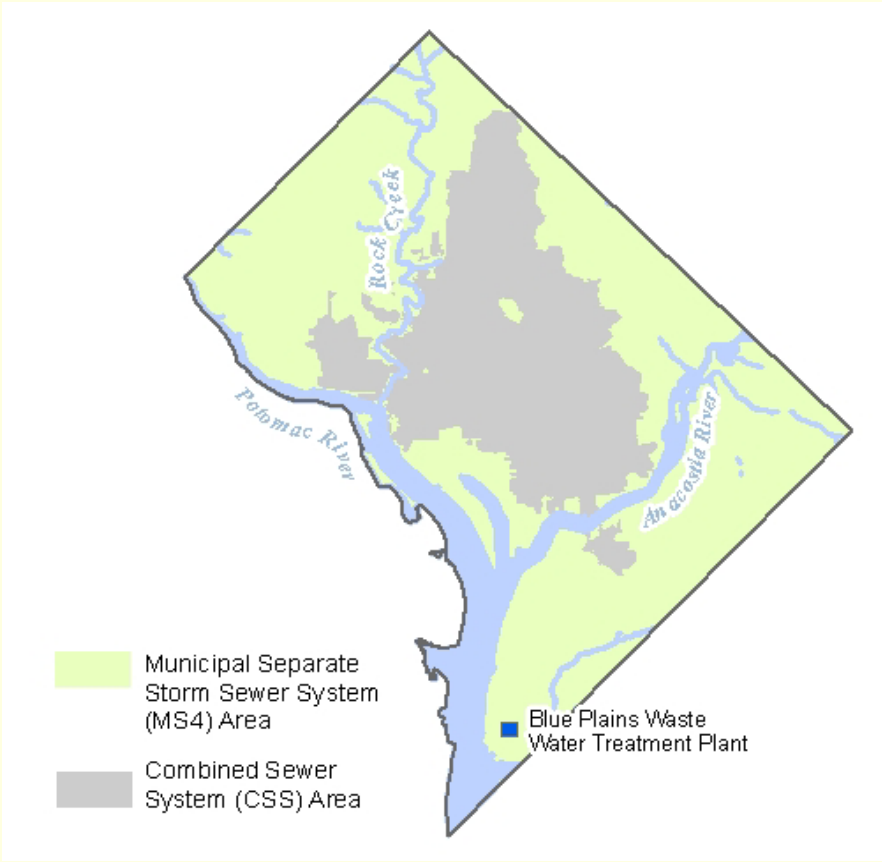
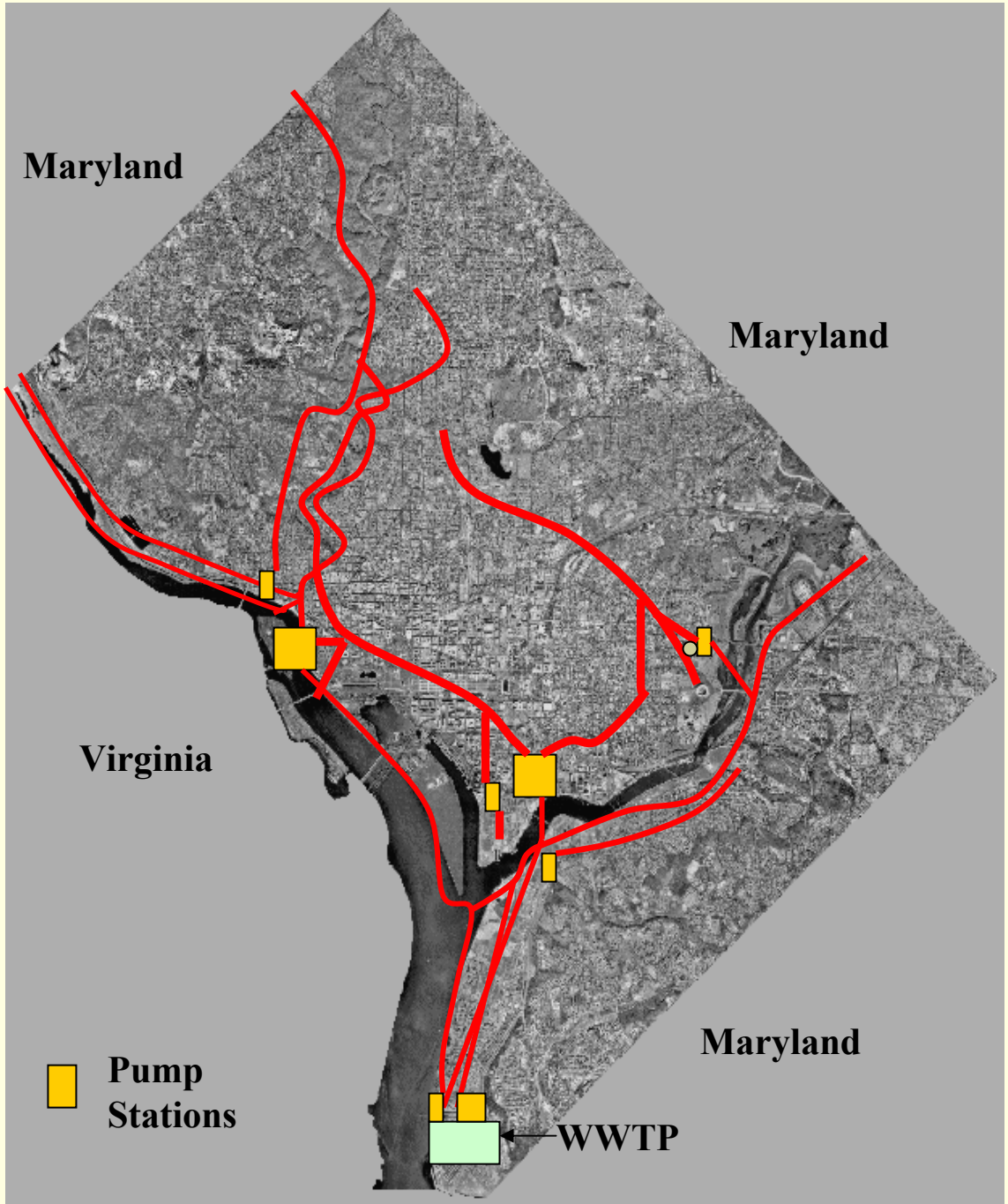
Background on Sewer Systems in Washington, DC

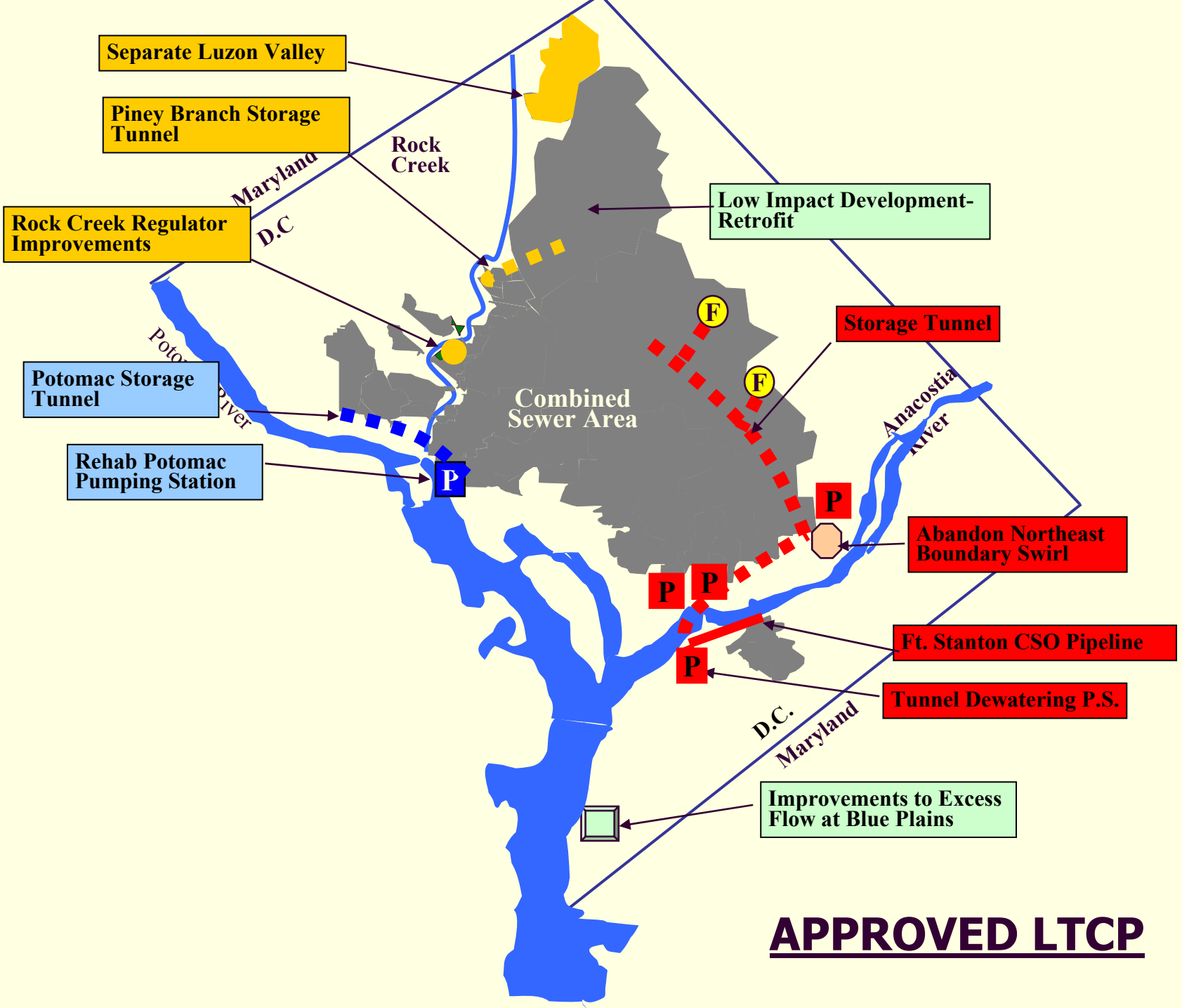
Background



- Two distinct systems
  - CSS (WASA)
  - MS4 (DC DOE)
- Outfalls to Anacostia River, Potomac River, Rock Creek
- All waters impaired from stormwater runoff and CSOs, Upstream Sources
- Many TMDLs
- WASA has an approved LTCP for CSOs

Major Interceptors





APPROVED LTCP

Blue Plains Wastewater Treatment Plant

- Largest advanced wastewater treatment plant in the world
- Capacity:
  - 370 mgd annual average
  - 1076 mgd wet weather
    - 740 mgd full treatment
    - 336 mgd excess flow treatment
- Current average flow is 334 mgd.
- Serves about 2 million people in DC, MD and VA.

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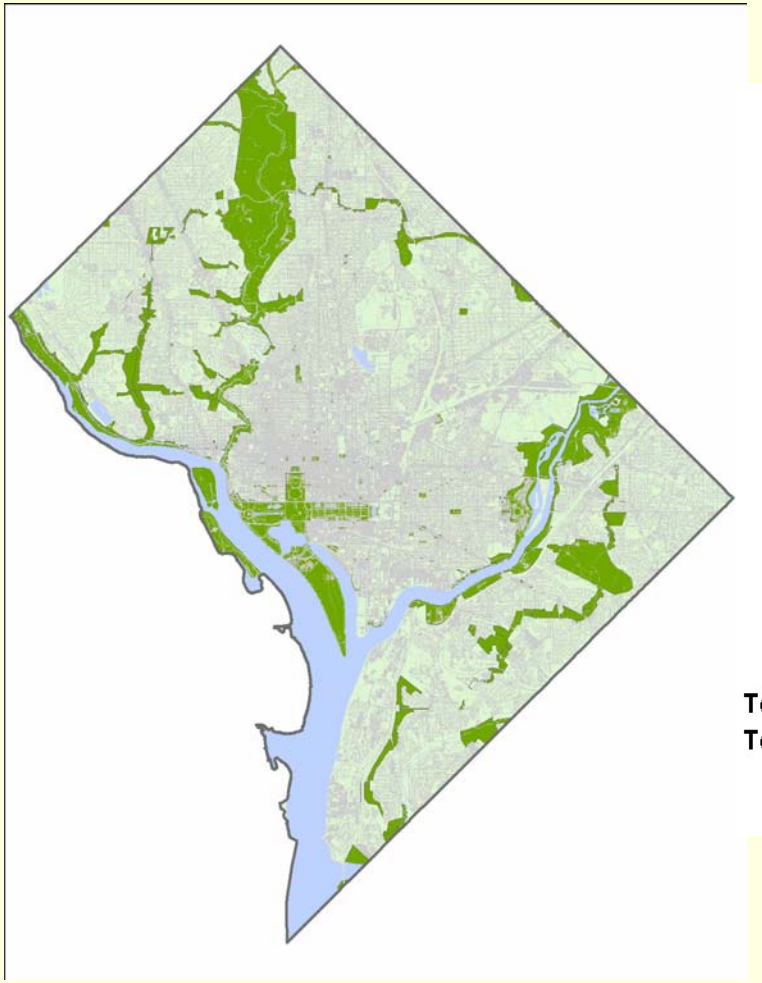
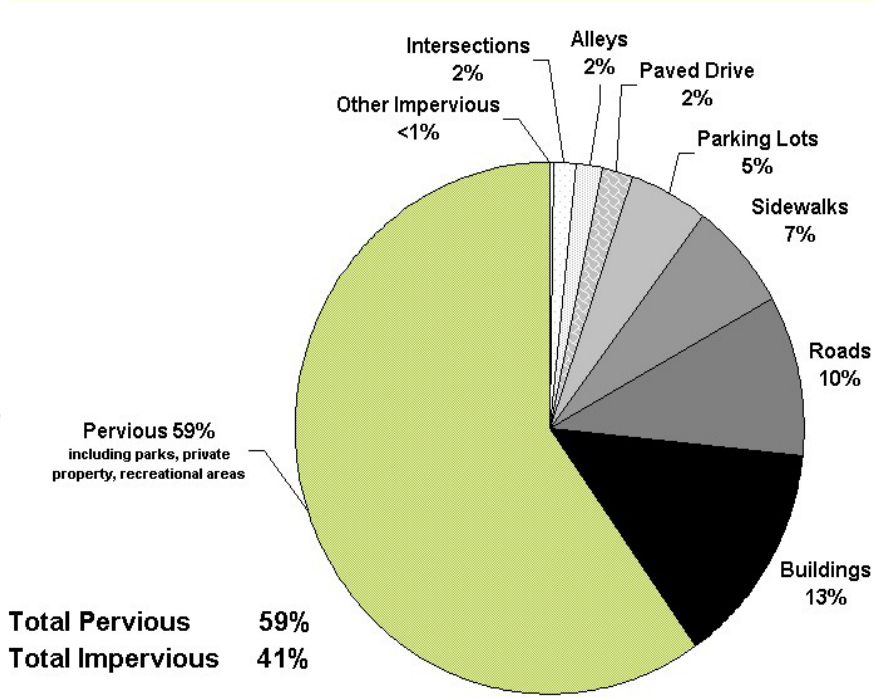
Existing Land Use In Washington, DC:





Total Pervious	59%
Total Impervious	41%

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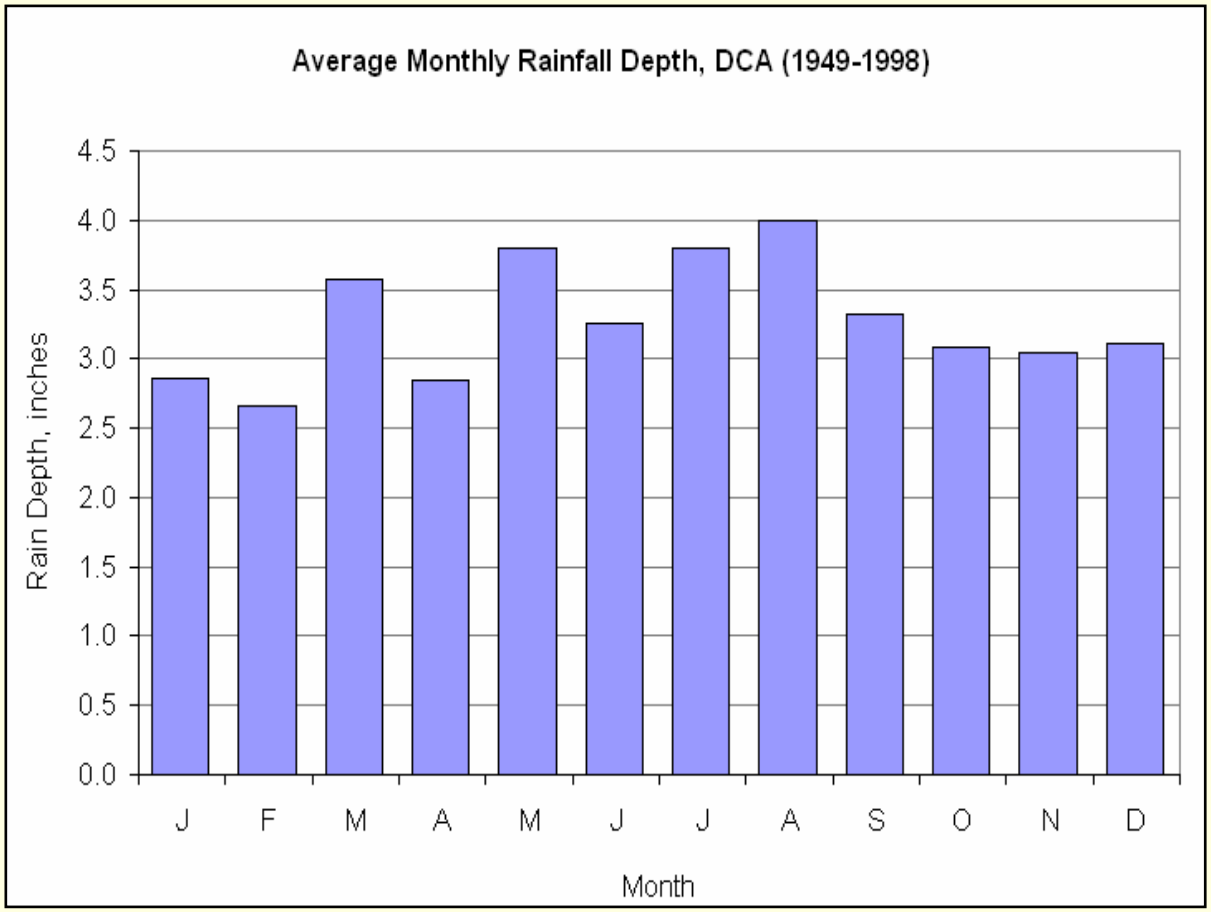
Average Precipitation in Washington, DC



- Monthly precipitation fairly constant from month to month
- Annual average precipitation ~ 39 inches

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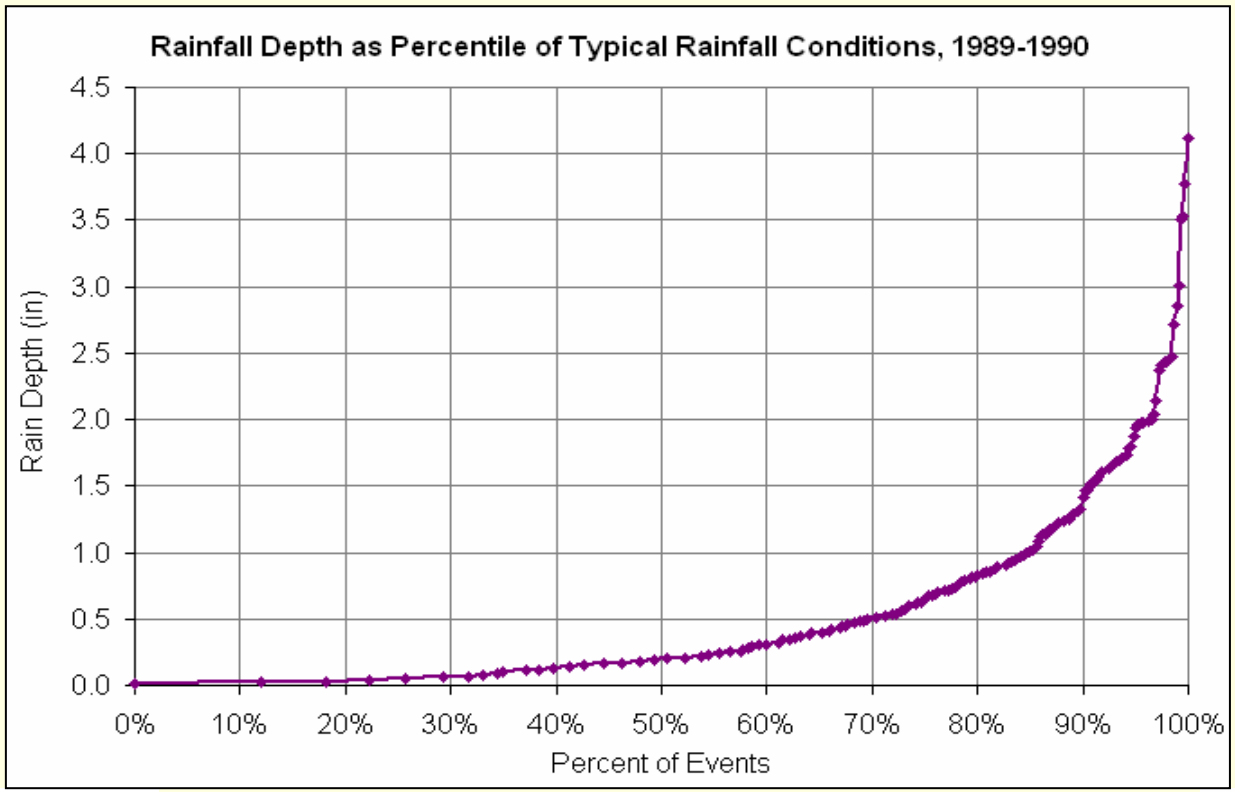
Precipitation: Cumulative Frequency

- 70% of rain events are less than 0.5 inches
- 85% of rain events are less than 1 inch



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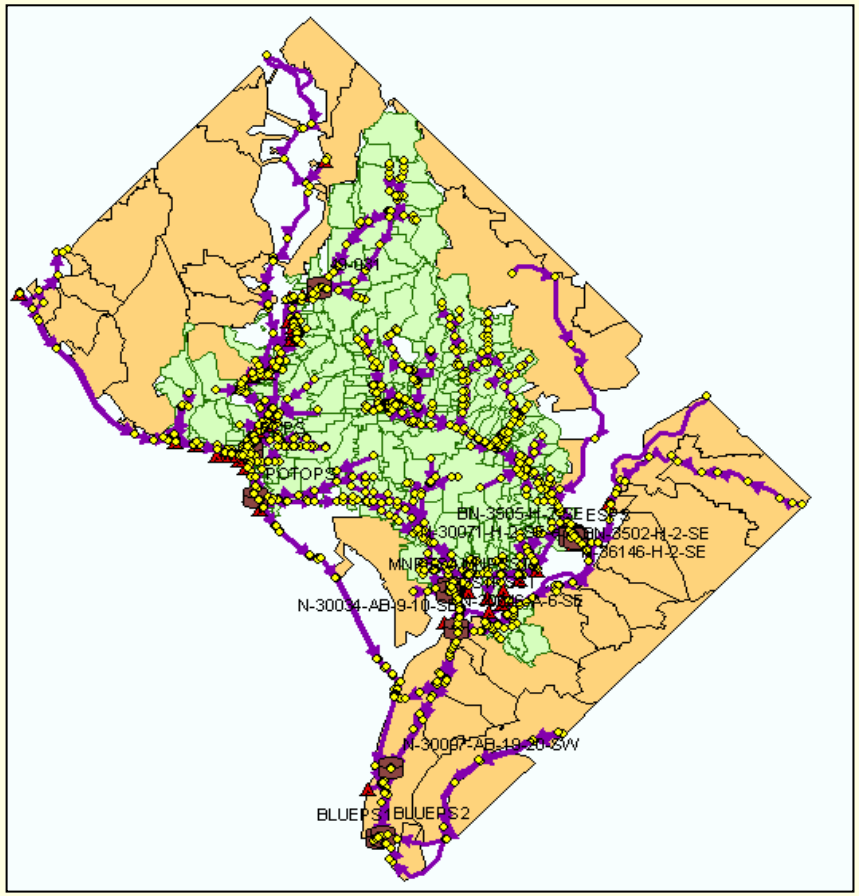
Study Objectives



- Add Green Infrastructure to Mike Urban Model (MOUSE)
  - MS4 area
  - Green component
- Quantify runoff reductions at different coverage scenarios
  - Intensive Greening Scenario
    - Physically possible
  - Moderate Greening Scenario
    - More practical

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Opportunities for Green Infrastructure In Washington, DC

Opportunities Evaluated Under the Grant

- Expand Tree Cover
- Build Larger Tree Boxes
- Retrofit More Green Roofs

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Tree Cover Over Streets

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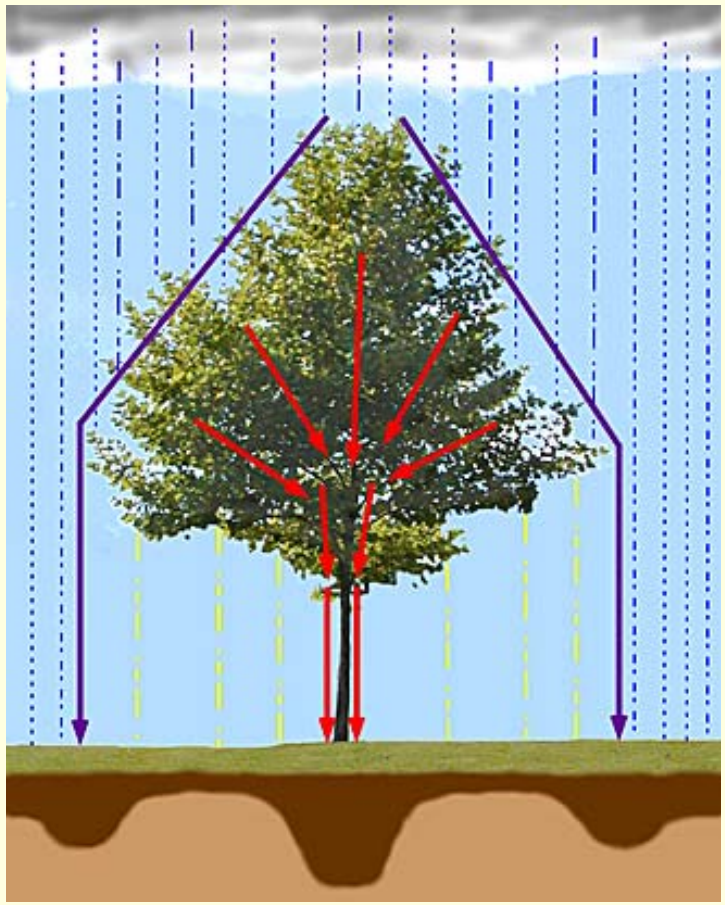
Tree Hydrology

Precipitation = Interception + Stem Flow + Throughfall + Canopy Drip



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Interception Storage

Generally, 10-35% of annual precipitation is intercepted

- Difference between precipitation above canopy & precipitation below canopy
- Includes
  - Precip stored on canopy
  - Evaporation
- Varies with
  - Leaf type
  - Canopy structure
  - Wind speed
  - Radiation
  - Temperature
  - Humidity
  - Seasonality

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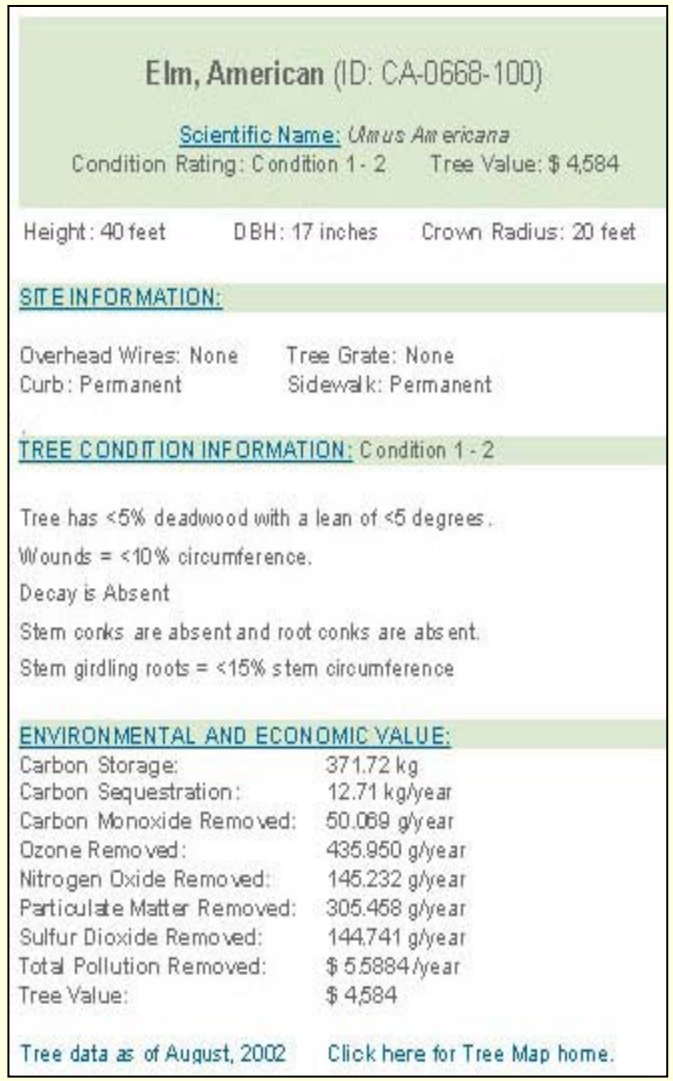
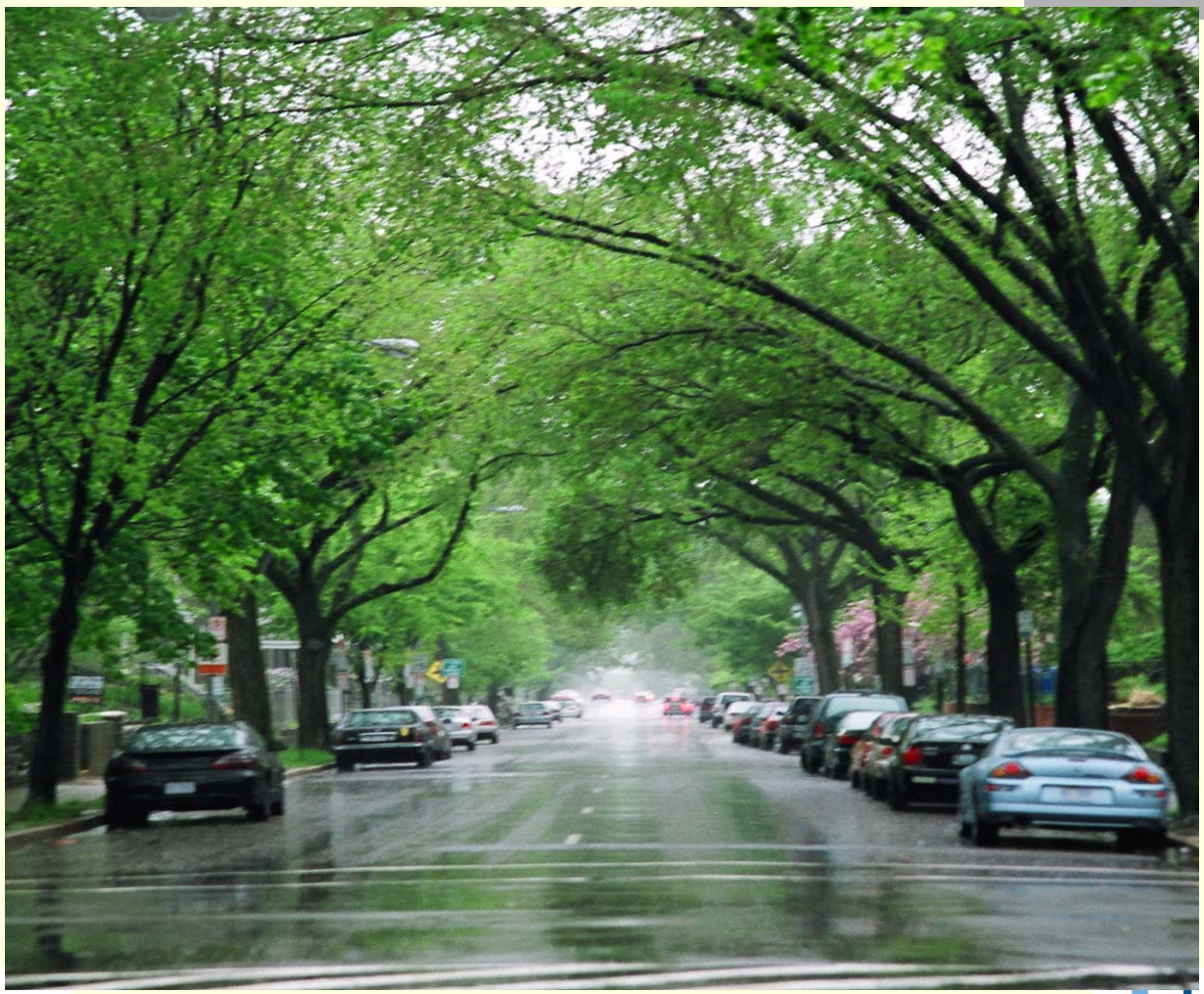
Casey Trees GIS Street Tree Map



Casey Trees interactive “Tree Map”
www.caseytrees.org

Tree Cover Over Streets



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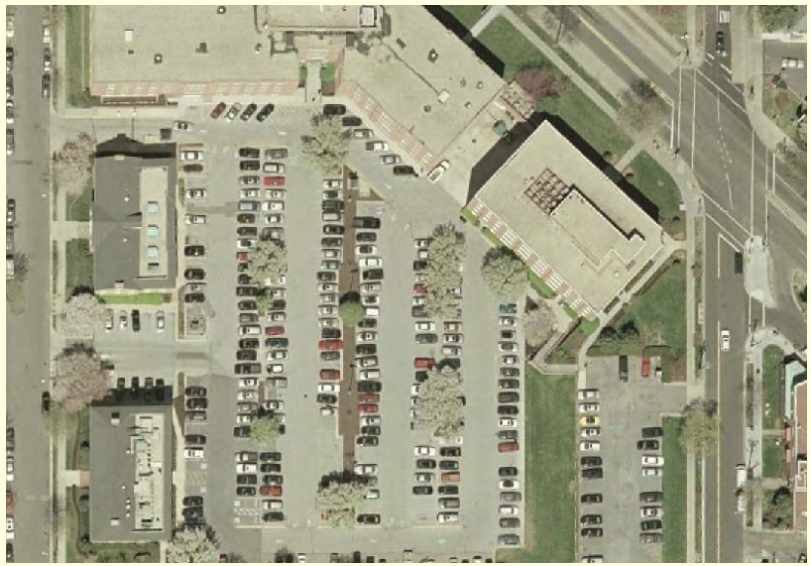
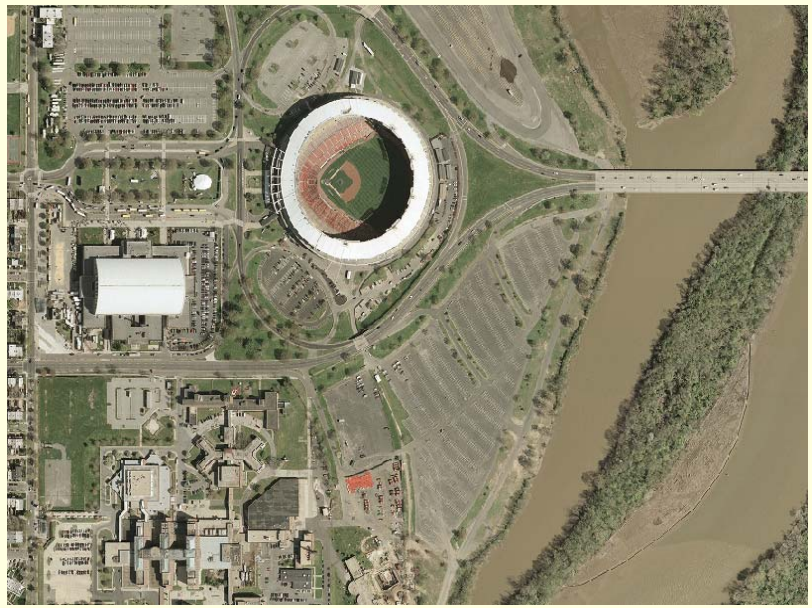
Tree Cover Over Parking Lots





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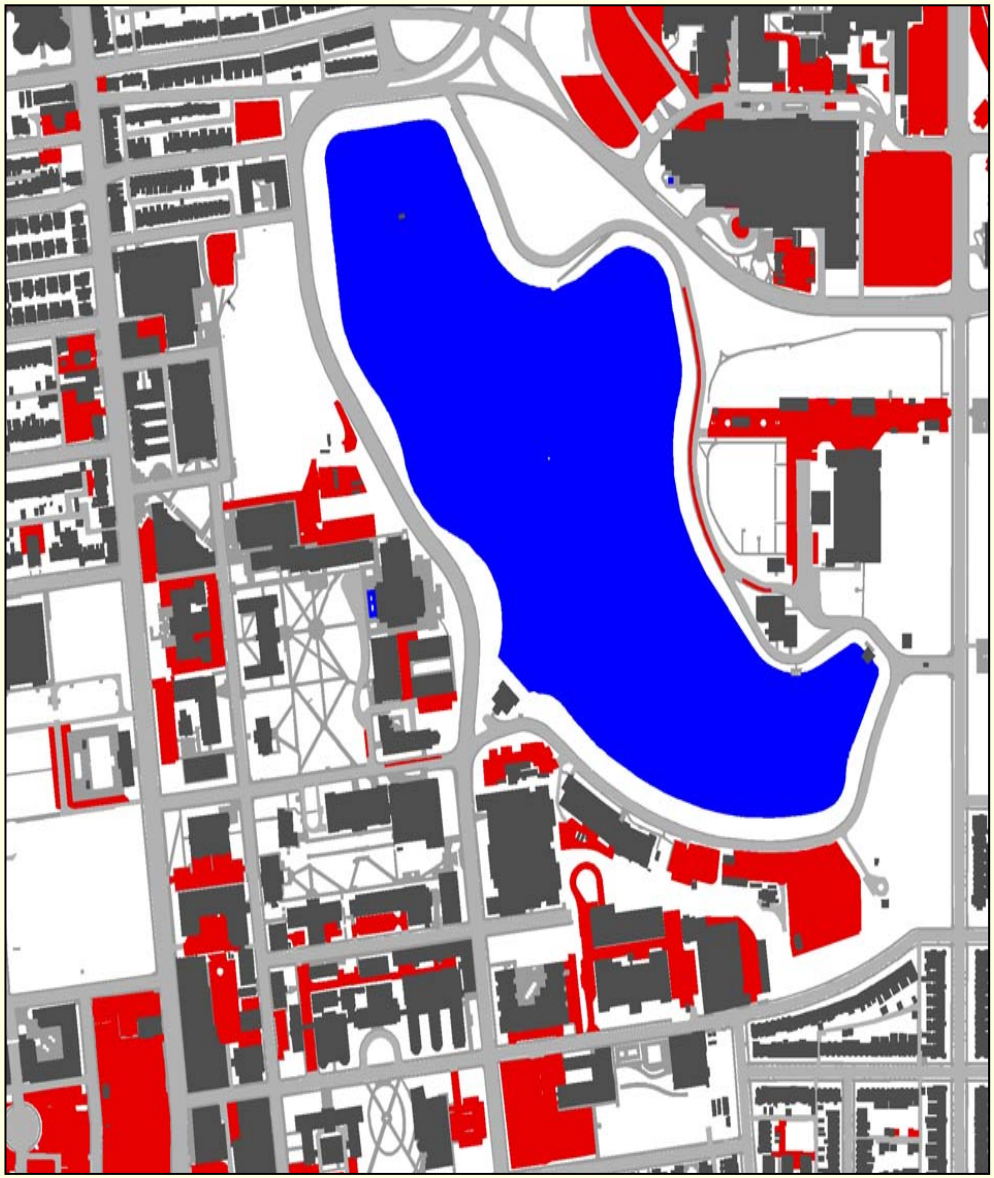
GIS Allows us to Focus in on Parking Lots



Parking lots in red
In Neighborhood surrounding a reservoir

Tree Cover Over Parking Lots

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Build Larger Tree Boxes

- Building larger tree boxes reduces impervious area and gives trees a better chance to survive.
- The average tree box in much of DC is 3 feet by 5 feet.
- Increase tree box size in downtown area from 3x5 to 6x20.
- Changes 105 sf of impervious area to pervious area per tree space.

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Retrofit More Green Roofs

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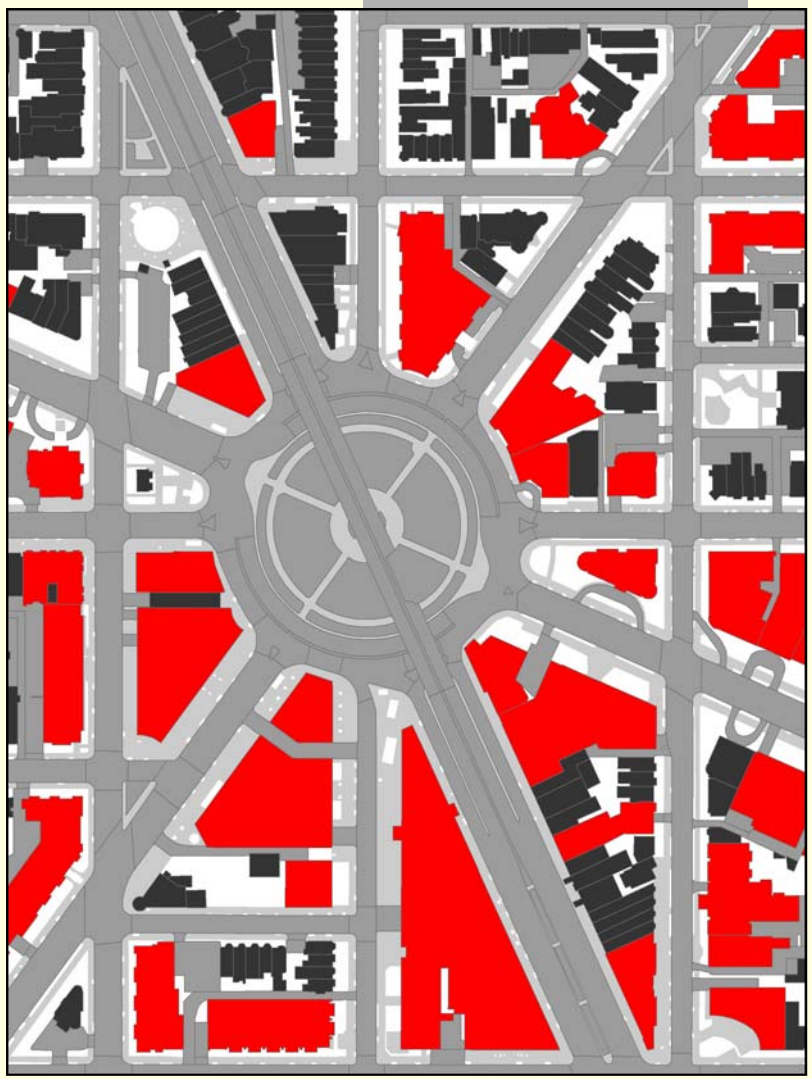
GIS Allows us to Focus in on Building Footprints

- Buildings in red are greater than 5,000 sq ft in area.



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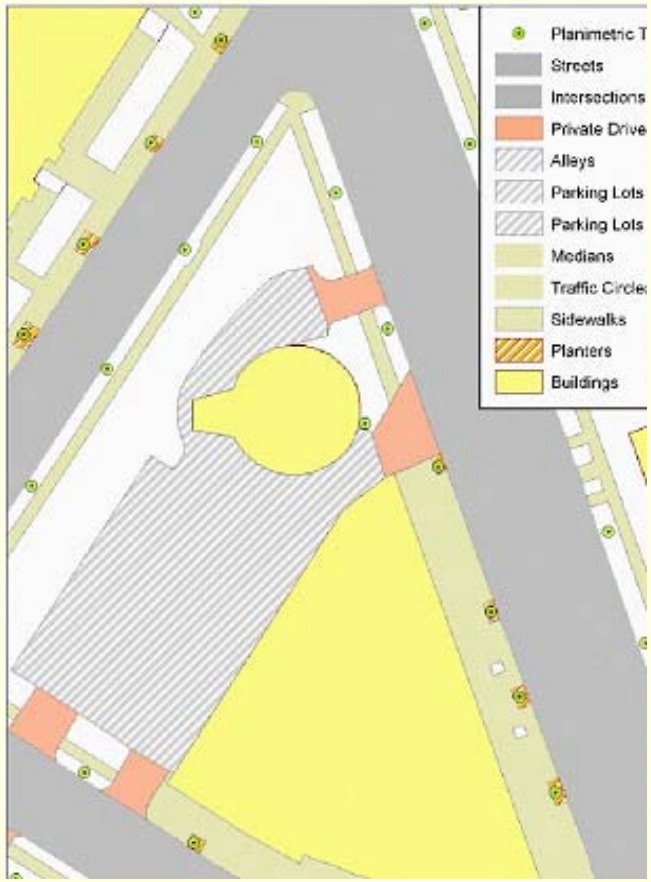
Land Use Example: Impervious Surfaces



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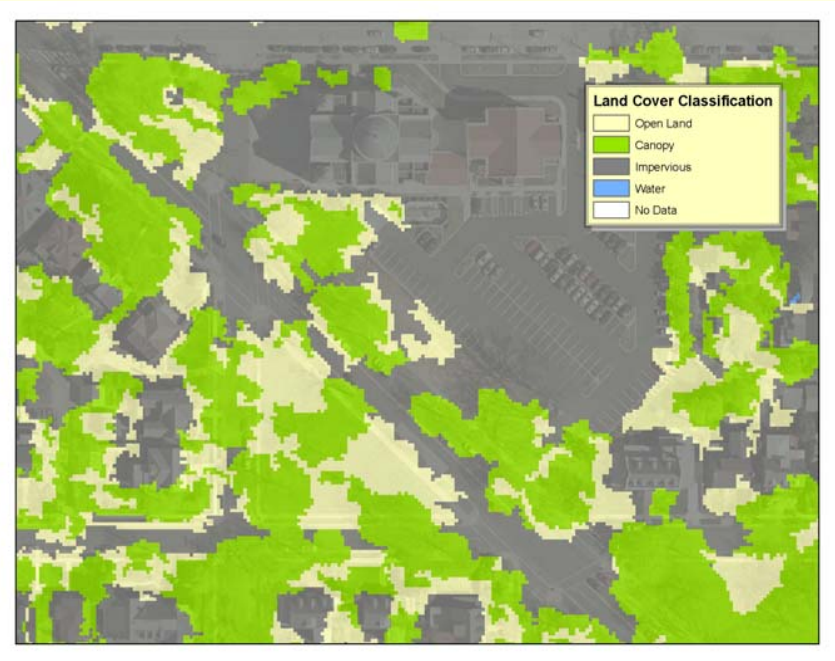
Land Cover Example: Trees



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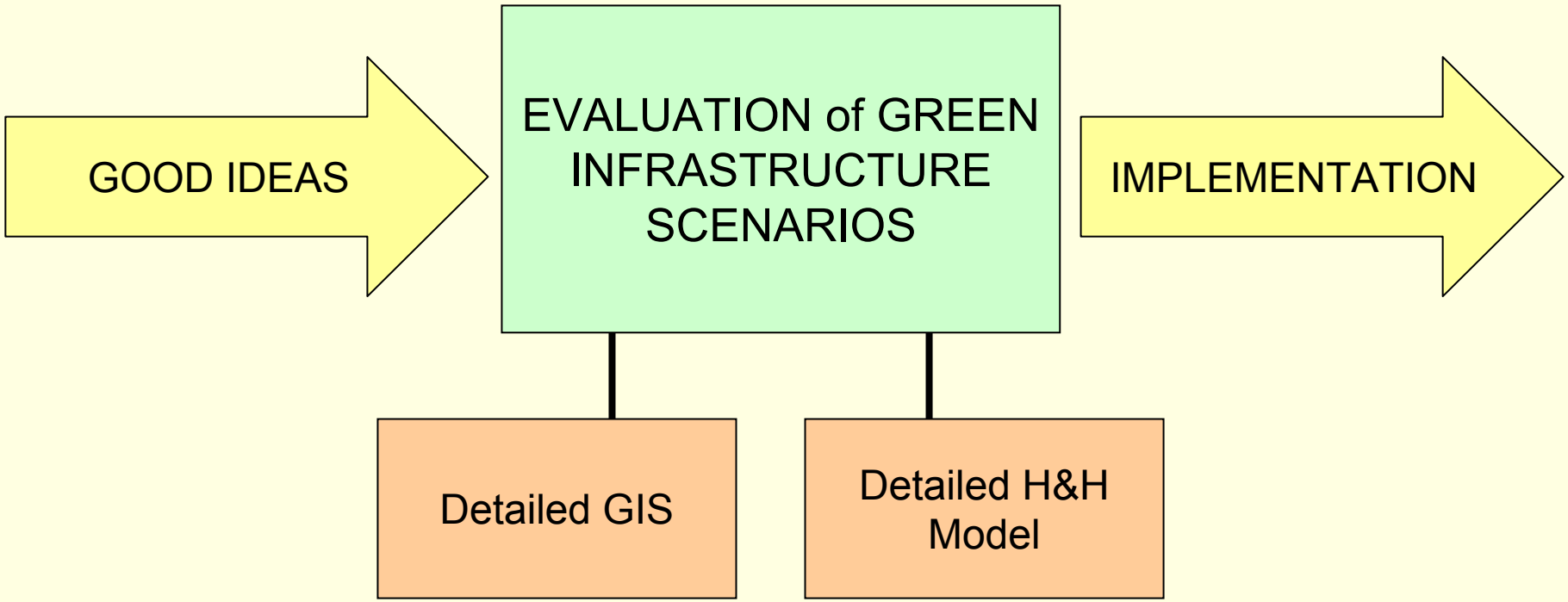
The Green Build-out Model

The Green Build-out Model



Basic Runoff Equation

- R = P – PET – S - I
  - R = Runoff
  - P = Precipitation
  - PET = Potential Evapotranspiration
  - S = Storage (trees, green roofs, etc)
  - I = Infiltration (for pervious areas only)

The Green Build-out Model

- Identified Rainfall
- Identified Potential Evapotranspiration
- Adjusted Hydrologic inputs to mimic green infrastructure (Particularly Storage)
- Made assumptions concerning coverage (distribution) of green infrastructure across DC
- Applied Green Build-out Model to moderate and intensive greening scenarios

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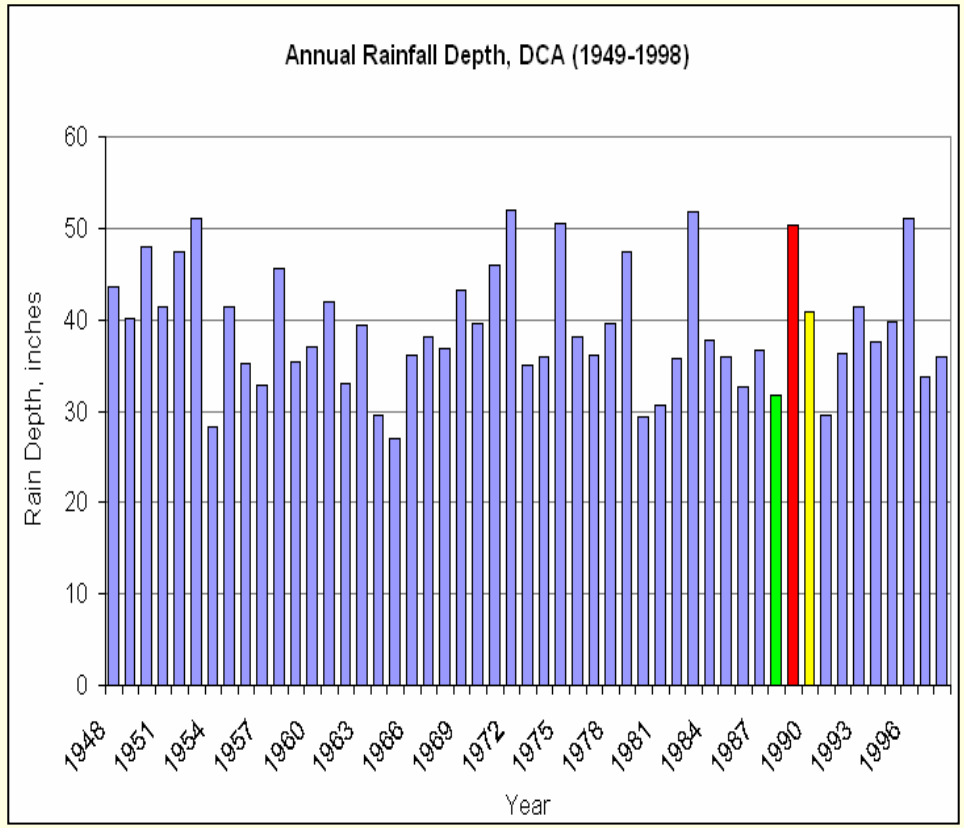
Rainfall: Model Input

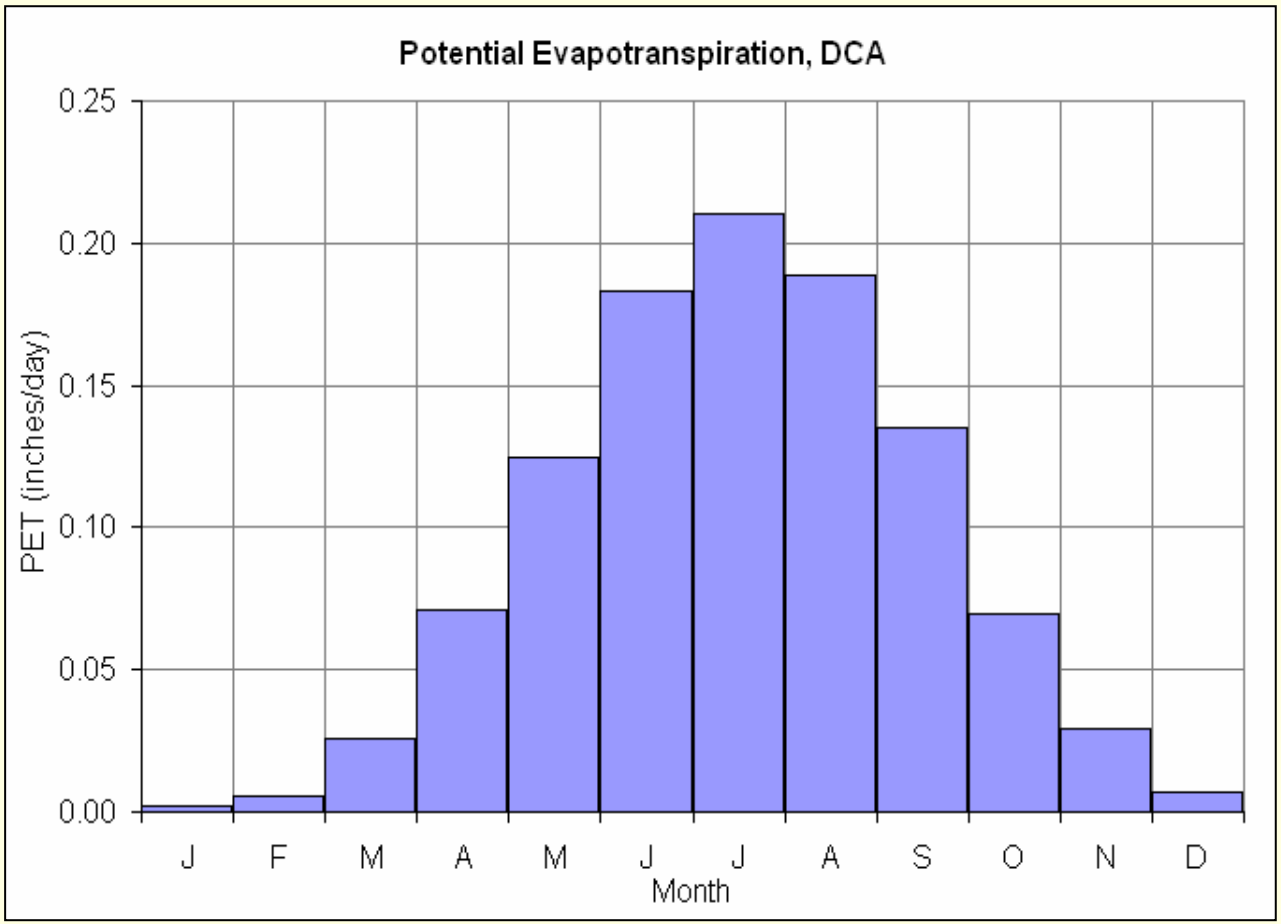
Rainfall drives the H&H Models

Model input was hourly time series for three years

1988 – dry year (green)
1989 –wet year (red)
1990 –average year (yellow)



Potential Evapotranspiration: Model Input



- PE served as loss mechanism for rainfall stored in tree canopy.
- The seasonal pattern mimicked loss of tree cover during the winter.

Storage: Model Input

- Storage on tree leaves developed with Leaf Area Index.
- Storage on roof tops depends upon roof medium.

Infiltration: Model Input

- No infiltration on impervious surfaces (streets, sidewalks, parking lots, etc.)
- Infiltration on pervious areas varies according to NRCS Soil Type (A,B,C, etc.)

Modeled Scenario

- **Baseline**: Existing condition that represents current tree cover and absence of green roofs.
- **Moderate Greening**: added trees and green roofs where it was practical and reasonable to do so.
- **Intensive Greening**: added trees and green roofs wherever it was physically possible.

Tree Cover Assumptions

Land Cover Type	Existing Tree Cover	Moderate Greening	Intensive Greening
Impervious			
Streetscapes (roads, sidewalks, intersections)	22%	25%	35%
Parking lots	7%	30%	50%
Paved drives	23%	50%	80%
Alleys	26%	35%	50%
Median islands, traffic islands, hidden medians, other	23%	30%	40%
Pervious			
Includes parks, open space, recreational areas, golf courses, soccer fields, cemeteries, front & back yards, school yards, etc	53%	57%	80%
TOTAL Tree Cover	**35%**	**40%**	**57%**

Types of Green Roofs

GREEN ROOF

- Extensive
- Medium <6 inches
- 3-4 inches, typical, in northeastern USA

ROOF GARDEN

- Intensive, semi-intensive
- Medium >6 inches
- 10-12 inches, typical

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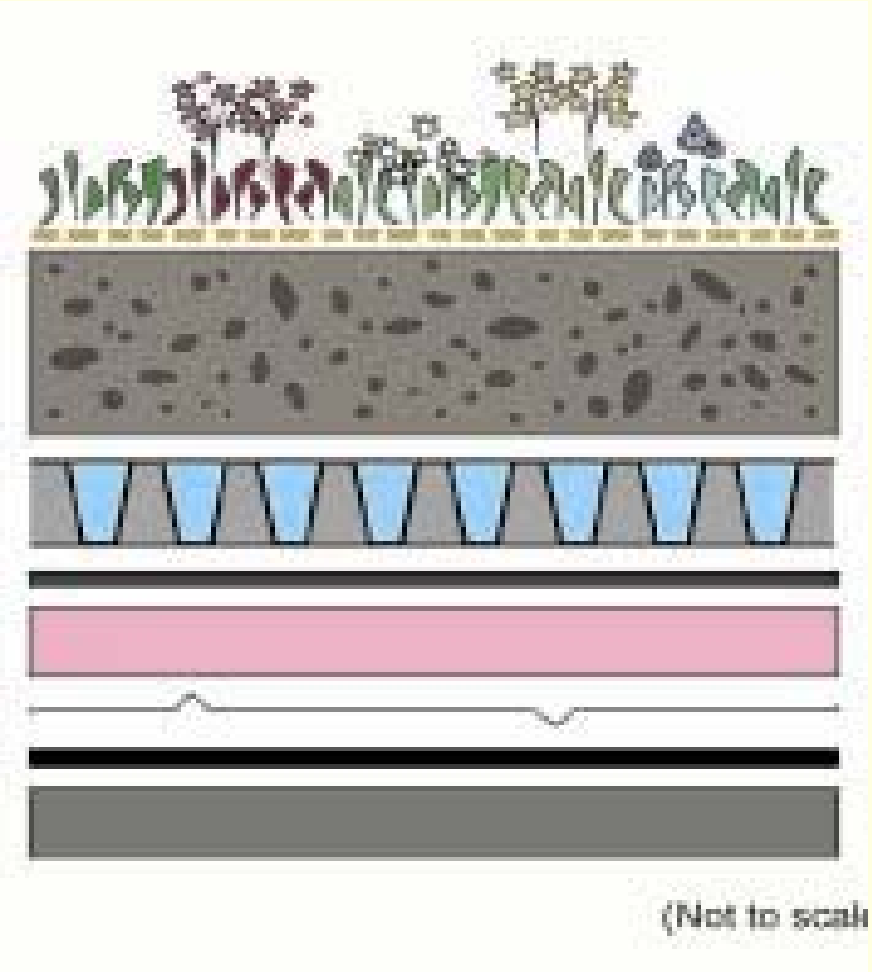
Profile of Green Roof



- Plants
  - Interception Storage
  - Evapotranspiration
- Soil media
  - Infiltration
  - Storage
- Drainage course
  - Storage
  - Drainage

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Green Roof Storage and Area Assumptions

Evergreen State College, Olympia, WA

- 1 inch storage
- All roofs = 3-4 inch growing media depth
- 75% rooftop cover
- Existing greenroof cover in DC = 0

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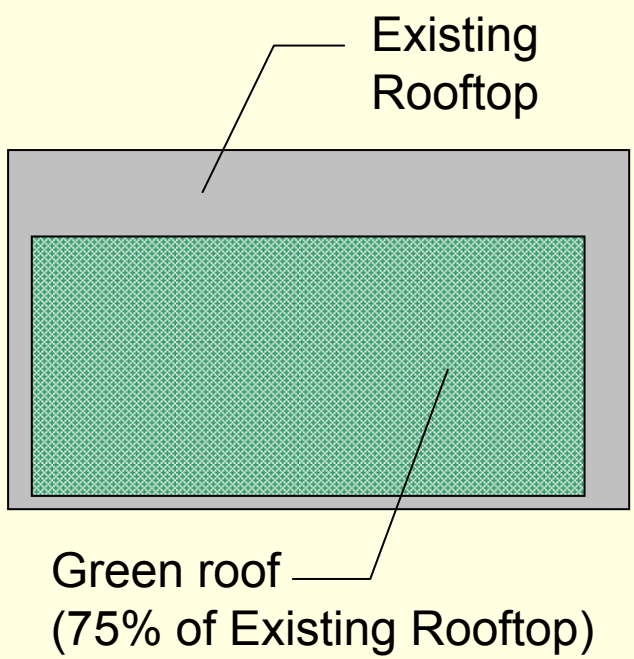
Building Coverage



- Green Roof Ready area
  - Space needed for HVAC, access, and maintenance
- Total bldg footprint area = 260 million sf
- Green Roof Ready area = 194 million sf

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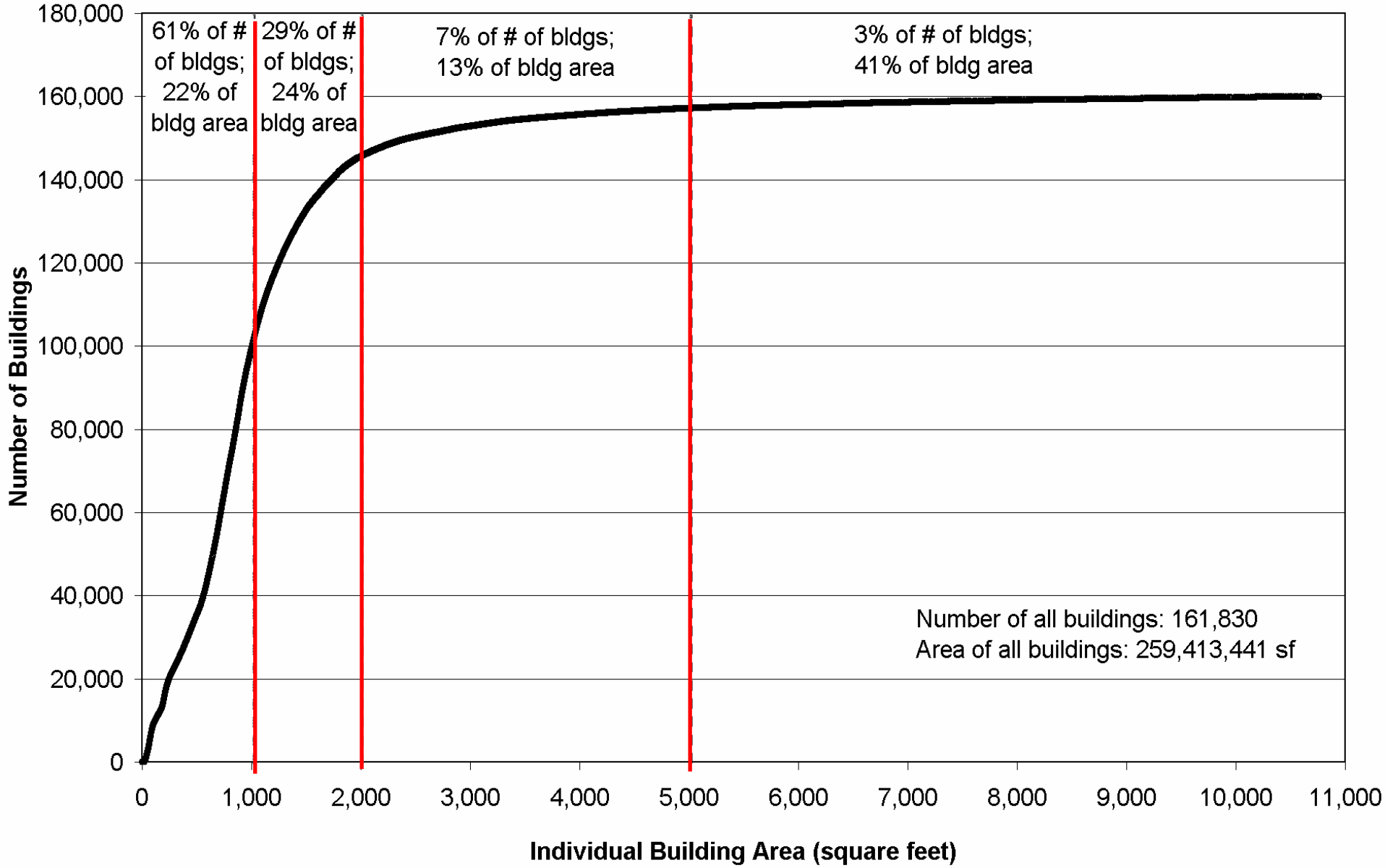
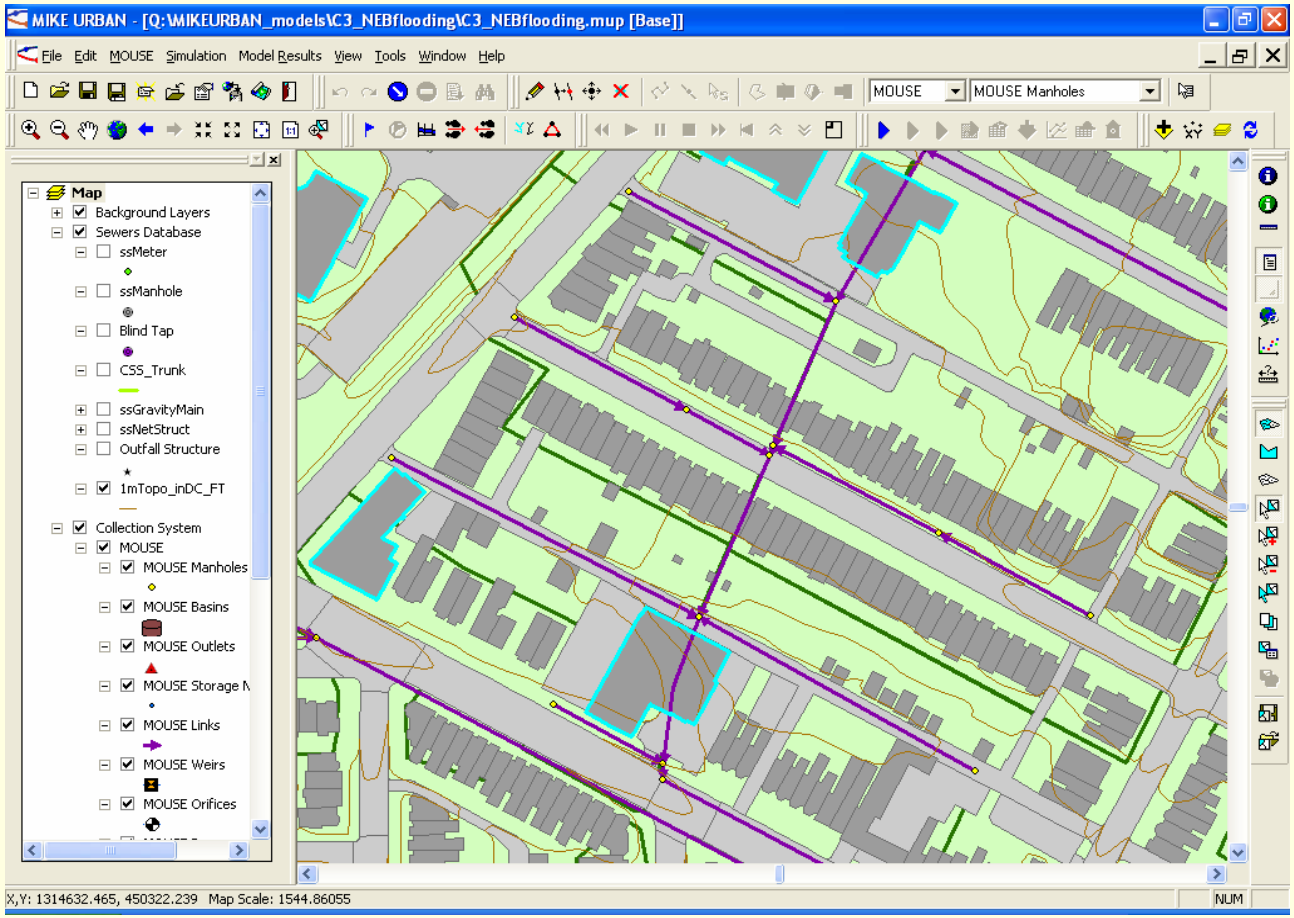
Distribution of Buildings in DC



Mike Urban: GIS integration

- Includes:
  - Roads
  - Buildings
  - Soils
  - Topography
  - Trees
  - Sewers
  - Other



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Green Roof Coverage Assumptions

Roof Type (size)	Existing Coverage	Moderate Greening Scenario[2]	Intensive Greening Scenario[2]
< 1,000sf	0%	2%	10%
1,000sf – 2,000sf	0%	6%	30%
2,000sf – 5,000sf	0%	10%	50%
> 5,000sf	0%	18%	90%
TOTAL	**0%**	**10.5% 20 million sf**	**53% 103 million sf**

Notes
1. These percentages are based on the building area (not the number of buildings)
2. The scenarios represent the building area that is “green roof ready”.

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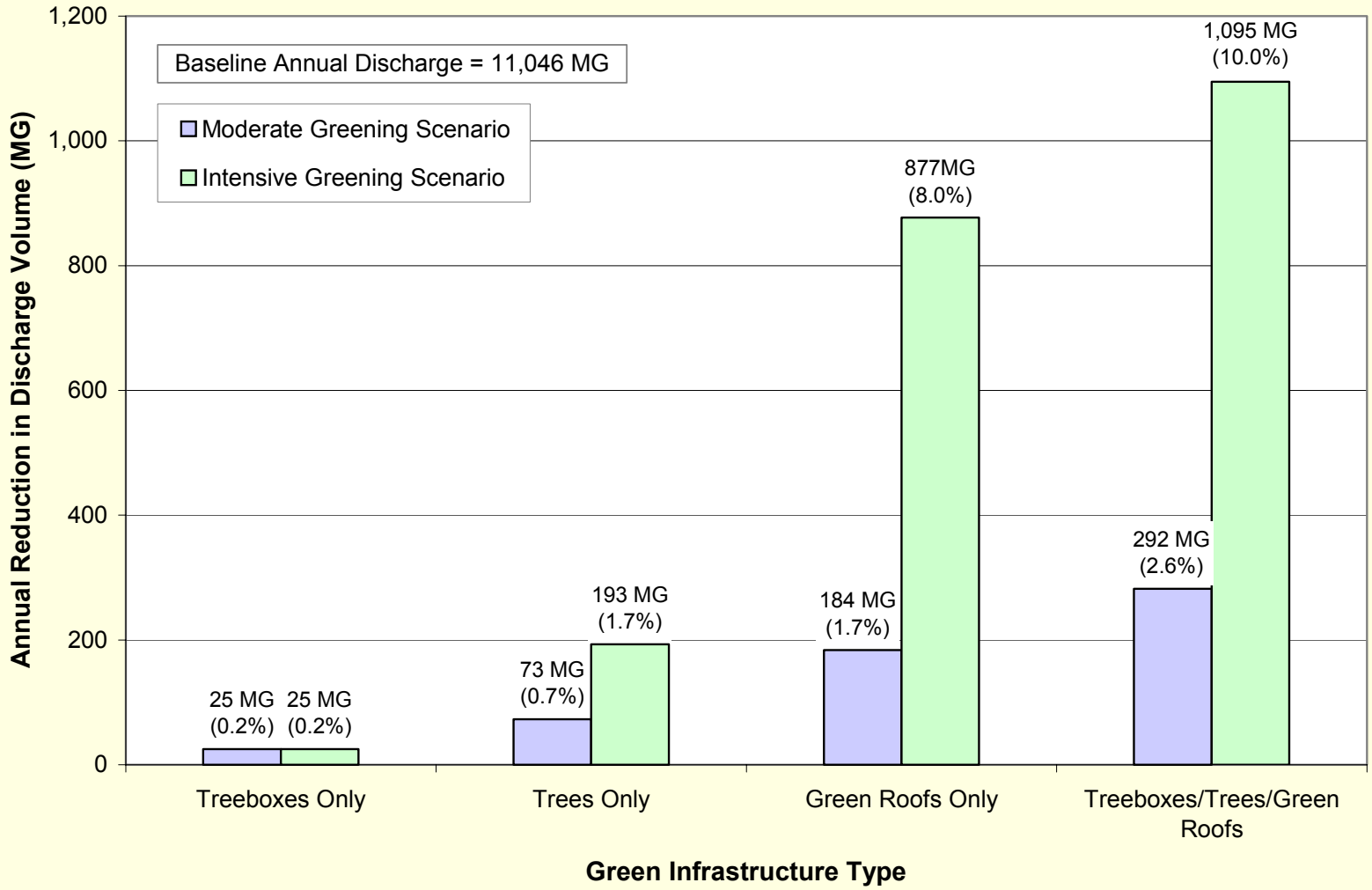
Benefits and Key Findings

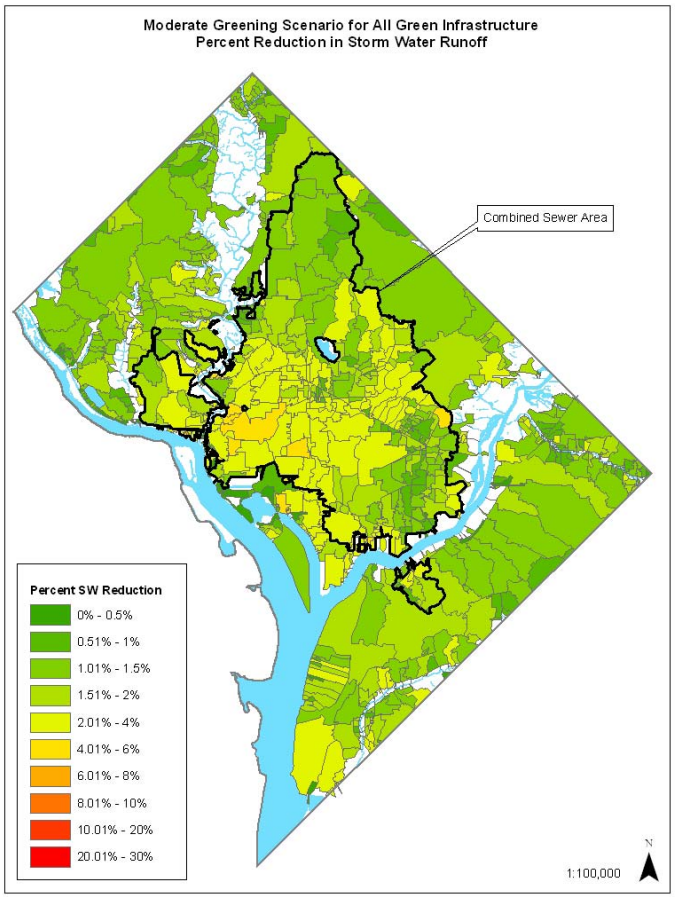
Summary of Stormwater Runoff and Sewer System Discharge Reductions

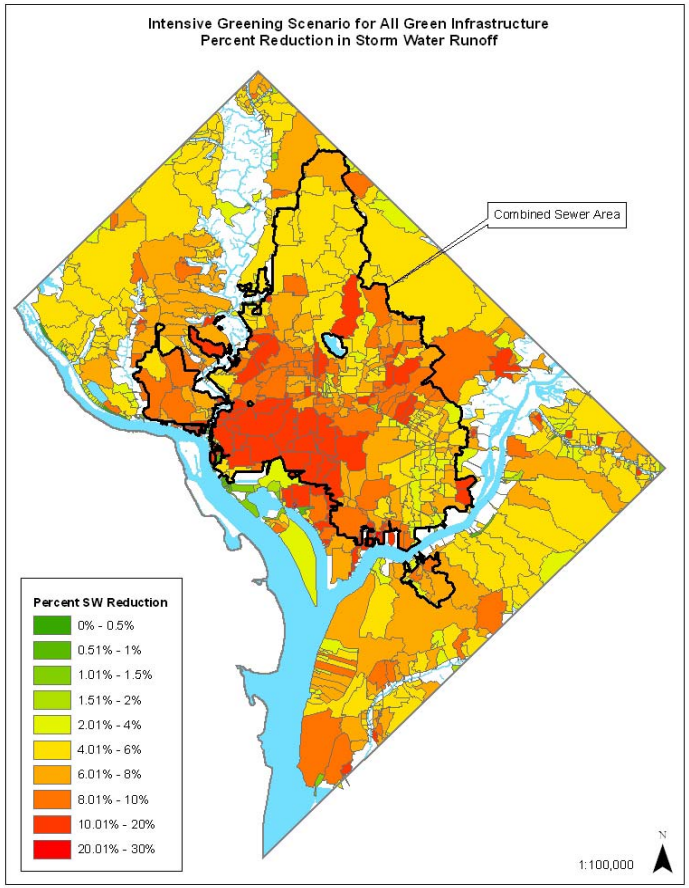
	Moderate Greening Scenario		Intensive Greening Scenario	
	MG	%	MG	%
Stormwater Runoff Reductions				
CSS	170	2.2	634	8.3
MS4	141	1.6	581	6.6
Entire Sewer System	311	1.9	1,216	7.4
Sewer System Discharge Reductions				
CSS	141	6.1	514	22.0
MS4	141	1.6	581	6.6
Entire Sewer System	282	2.6	1,095	10.0

Reduction in CSO and Stormwater Discharge to All Waterbodies



Runoff Reduction By Sewershed: Moderate vs. Intense Greening



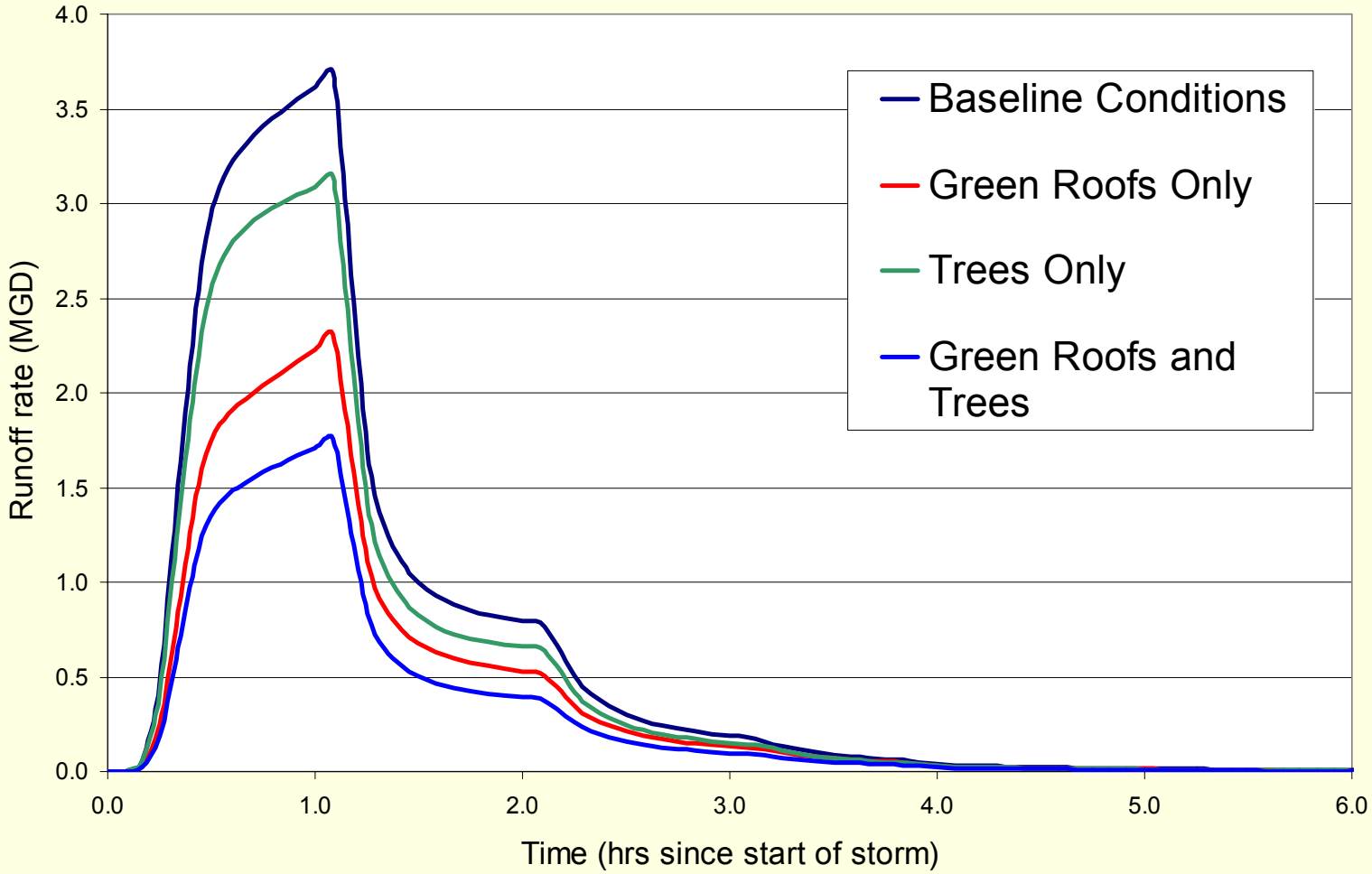


Hydrologic Relationships: Unit Area Reduction Factors

Type of Greening	Stormwater runoff volume reduction per unit area (MG/acre/year)	Acres required to achieve a one MG reduction in stormwater over an average year (acres/MG)
Green roofs	0.38960	2.5667
Trees over impervious areas	0.11117	8.9952
Trees over pervious areas (NRCS Soil Type D)	0.02210	45.249
Trees over pervious areas (NRCS Soil Type C)	0.00276	362.32
Trees over pervious areas (NRCS Soil Type A/B)	0.00008	12,500

- Can be used for quick planning calculations in the Washington, DC area or for other urban areas with similar climate conditions and rainfall distribution patterns

Peak Shaving: Best Case



Potential Operational Savings for DC Water and Sewer Authority

- Operational costs assumed to decrease proportionally for every gallon avoided
  - Utility costs for pumping (electricity)
  - Treatment costs
- Exploratory review of literature = $0.01/gallon
- Savings approximately $1.4 - $5.1 million/year

Pollutant Loading Benefits (reductions)

Pollutant	Intensive Greening Scenario	
	lbs reduced/year	% reduction
Total Suspended Solids	77,000	0.8%
Biochemical oxygen demand (BOD)	34,000	1.5%
Total phosphorous	340	0.6%
Total Kjeldahl nitrogen (TKN)	11,000	4.6%
Ammonia	3,400	4.1%
Copper	120	2.3%
Lead	180	1.8%
Zinc	3,100	16.1%

- Green roofs
  - Replaces pollutant contributions from conventional roofs
  - Highly effective at storing and filtering pollutants
- Conservative estimate of expected pollutant load reduction
  - Does not include pollutant scouring reductions from peak shaving

Overall Key Findings

- Substantial reduction in runoff & discharge volumes (Green Roofs are much more effective than Trees)
- Limited reduction in CSO frequencies
- Reduction in stormwater peak flow & velocity
- Operational savings in CSS
  - Less volume to be stored, pumped and treated
- Multiple other benefits for same investment
  - Air quality, urban heat island effect, energy, climate change, public health, social capital, economic development, aesthetics, urban ecology, etc

Grant Products

- Data Results Display Tool
- Mini-Model
- Final report documentation
  - www.caseytrees.org

Project won award from the
American Society of Landscape Architects

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Ongoing/Future Work

- Addition of other Green Infrastructure practices to Mike Urban Model for WASA (rain barrels, infiltration, porous pavement, bioretention, etc.)
- Development of guidance on incorporation of Green Infrastructure practices to existing SWMM applications
- Incorporation of other benefits assessments
  - Air quality
  - Urban heat island
  - Carbon
  - Aesthetics
  - Etc.

The End

QUESTIONS?

Extra Slides