Stormwater Management

The Role of Trees and Forests

PENNSTATE

1855

Vincent Cotrone
Penn State Extension Urban Forester

A Forested Watershed

"It is a beautiful and delightsome land with clear rivers and brooks running into a faire Bay … there is little grass, but for that which grows in the marshes, for this country is completely overgrown with trees."

***Captain John Smith 1607 writing about the Chesapeake Bay Watershed which was 95% Forested*.**

Streams in Pennsylvania 1753

- “Our runs dry up apace; several which formerly would turn a fulling mill are now scarcely sufficient for the use of a farm. The reason for which is this, when the rain that fell was detained by these interruption and so had time to insinuate into the earth and contribute to the springs and runs. But now the country is clear’d, the rain as fast as it falls in naked fields, fills and choaks the springs, and makes shoals and sandbanks in our creeks and rivers; and hence several creeks mentioned by Mr. Penn to be navigable are no longer so”

By 1895, more than two-thirds of Pennsylvania’s 27 million acres of forests had been cleared.

Chesapeake Bay Today

In the late 1970's, forest land made up 60% of the Chesapeake watershed.

1982-1997, more than 750,000 acres of forest lost to development, an average of 140 acres/day.

More than 50% of Pennsylvania's streamside forests are now disturbed or degraded, and more continue to be lost.

From 1990 to 2000, population grew by 8% while impervious surfaces grew by 41%.

- Over 12,200 miles of streams in PA are polluted
- 4,170 miles of these streams are impaired due to storm water runoff

Forest Conversion

76,800 acres of impervious cover and 232,500 acres of turf cover created each year, or nearly 1% of Bay watershed per year

Traditional Lawnscapes

- **Over 100 million tons of fertilizer are applied to residential lawns and gardens annually.** (Audubon stat)
- **70 million pounds of synthetic pesticides are used on lawns each year – 10 times the rate/acre used by farmers.** (*Redesigning the American Lawn by F. Herbert Bormann, Diana Balmori, Gordon T. Geballe, Yale University Press, 1993*
- **Conversion from forest understory and leaf litter to turf, the mean infiltration rate went from 12.4 in/hr to 4.4 in/hr in a North Carolina watershed**
  (Kays, 1980)

Storm water often washes chemicals off turf grass areas

Urbanizing Watersheds

Increased impervious surfaces means:

- Increased storm water
- Flooding:
  - More frequent floods
  - Flash floods
  - Severe flooding
- Droughts
  - Reduced Groundwater Recharge
  - Low flow/Drying of Streams

Impact on Streams

Impervious surfaces challenge healthy streams with:

Non-point source pollution

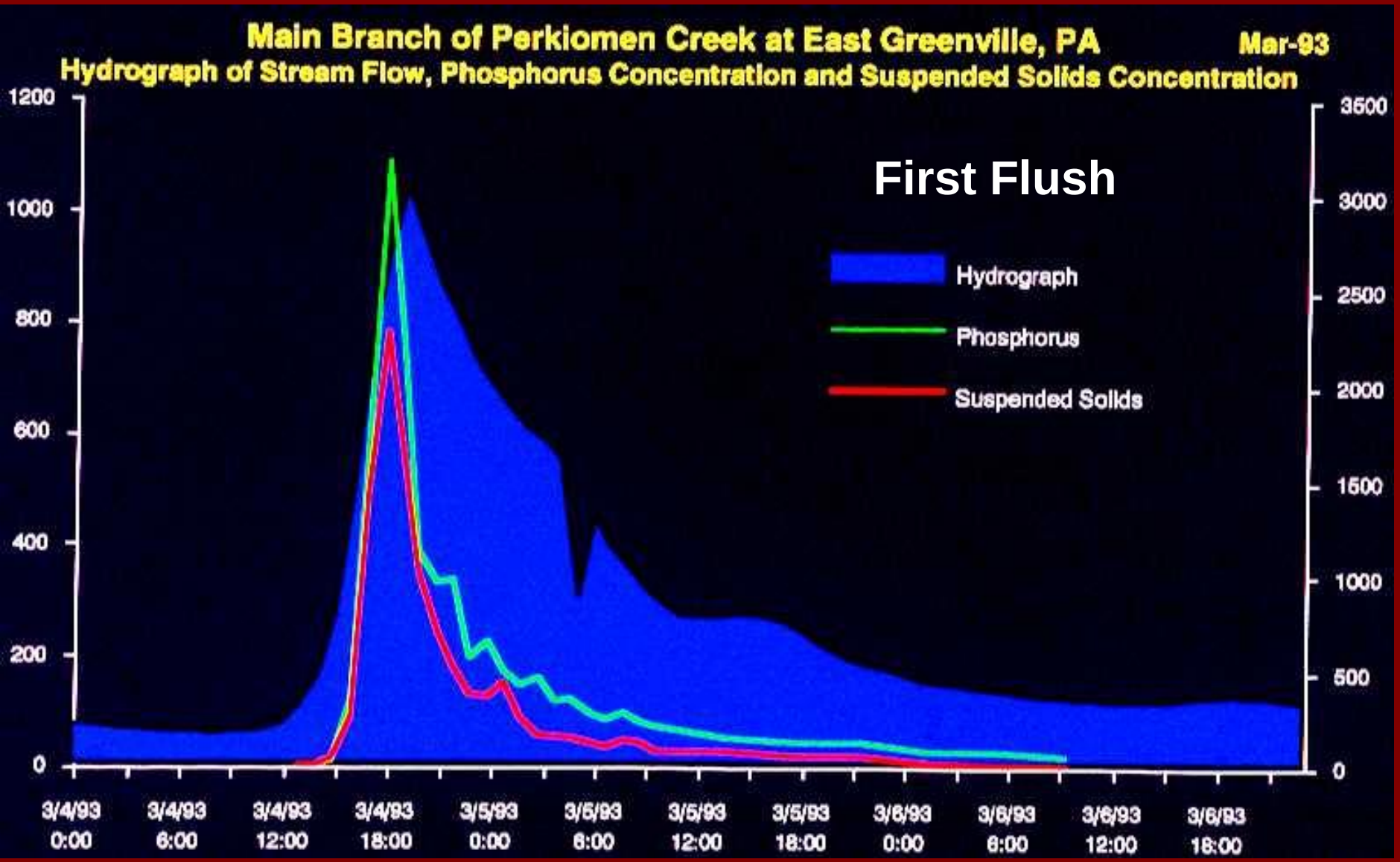
Streambank erosion & channelization

More Extremes: Floods to Dry

Parking Lots and Water Quality

One acre of Parking produces 40 times the runoff from an acre of forest.

- **Parking is the fastest growing land use – approximately 7 spaces for every registered automobile.**
- **Parking lots accumulate pollutants from vehicles & the atmosphere: petroleum hydrocarbons and trace metals (cadmium, copper, lead, zinc)**
- **Increased NPS Water Pollution**

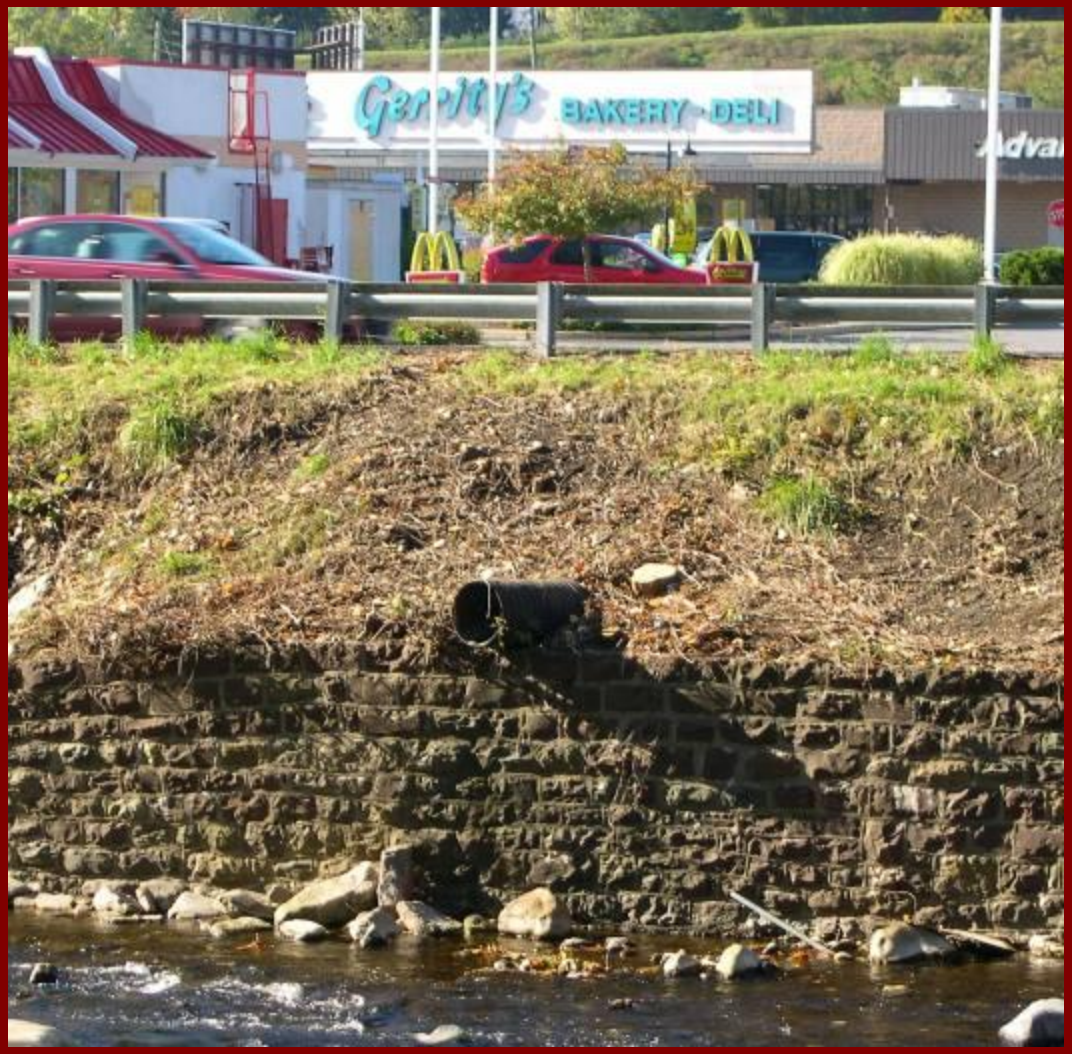

Main Branch of Perkiomen Creek at East Greenville, PA
Mar-93
Hydrograph of Stream Flow, Phosphorus Concentration and Suspended Solids Concentration
First Flush
Hydrograph
Phosphorus
Suspended Solids
1200
1000
800
600
400
200
0
3500
3000
2500
2000
1500
1000
500
0
3/4/93 0:00
3/4/93 6:00
3/4/93 12:00
3/4/93 18:00
3/5/93 0:00
3/5/93 6:00
3/5/93 12:00
3/5/93 18:00
3/6/93 0:00
3/6/93 6:00
3/6/93 12:00
3/6/93 18:00

Detention Basins Designed to Manage Quantity with Little Effect on Water Quality

Stormwater Discharged to Streams and the Chesapeake Bay

- Over 75% of rainfall does not infiltrate the ground in urban areas as result of impervious areas, and soil compaction

- Urban land accounts for only 7% of the landscape in the watershed, But contributes
  - 11% N and 17% P from non-point sources
  - 20% N and 20% P from point sources



Stormwater Pollutants

Category	Examples
Metals	Zinc, Cadmium, Cooper, Chromium, Arsenic, Lead
Organic Chemicals	Pesticides, Oil, Gasoline, Grease
Pathogens	Viruses, Bacteria, Protozoa
Nutrients	Nitrogen, Phosphorus
Biochemical Oxygen Demand	Grass clippings, Fallen Leaves, Hydrocarbons, human and animal waste
Sediment	Sand, Soils, Silts
Salts	Sodium Chloride, Calcium Chloride

Pesticides Found in Stormwater

Pesticide Name	Human Health/Environmental Effects
2,4-D	Lymphoma in humans; testicular toxicant in animals
Chlorpyrifos (Dursban)	Neurotoxicant; highly toxic to birds, aquatic organisms, and wildlife
Diazinon	Neurotoxicant; highly toxic to birds, aquatic organisms, and wildlife
Dicamba	Neurotoxicant; reproductive toxicity in animals; association with lymphoma in some human studies
MCPA (Methoxane)	Low toxicity to non-toxic in test animals, birds, and fish; suspected gastrointestinal, liver and kidney toxicant
MCPP (Mecoprop)	Slightly to moderately toxic; some reproductive effects in dogs; suspected cardiovascular, blood, gastrointestinal, liver, kidney and neurotoxicant.

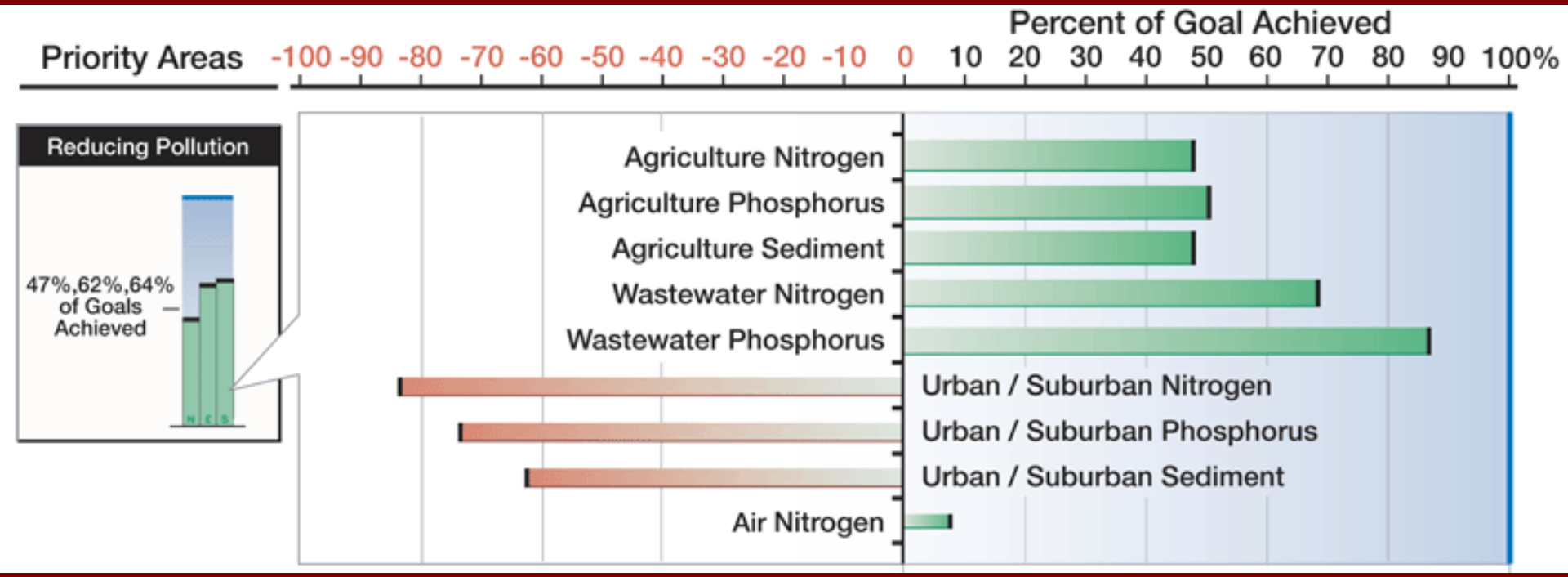
Sources: T.R. Schueler, quot;Urban Pesticides: From the Lawn to the Stream,quot; Watershed Protection Techniques, vol. 2, no. 1, Fall 1995, pp. 247, 250 and Extoxnet: Extension Toxicology Network Pesticide Information Profiles, http://ace/orst.edu/info/extoxnet, and Environmental Defense Fund, Scorecard Chemical Profiles, http://www.scorecard.org/chemical-profiles

Urban Nutrient Loads Are Fast Becoming a Big Slice of the Bay Pie

Year	Total N	Total P
1985	2%	5%
2000	9%	15%
2005	**19%**	**30%**
2030	**??**	**??**

Only Bay nutrient load sector where we are seeing reverse progress In load reductions- source OIG (2007)

Urban Nutrient Loads Are Fast Becoming a Big Slice of the Bay Pie



Only Bay nutrient load sector where we are seeing reverse progress
In load reductions- source OIG (2007)

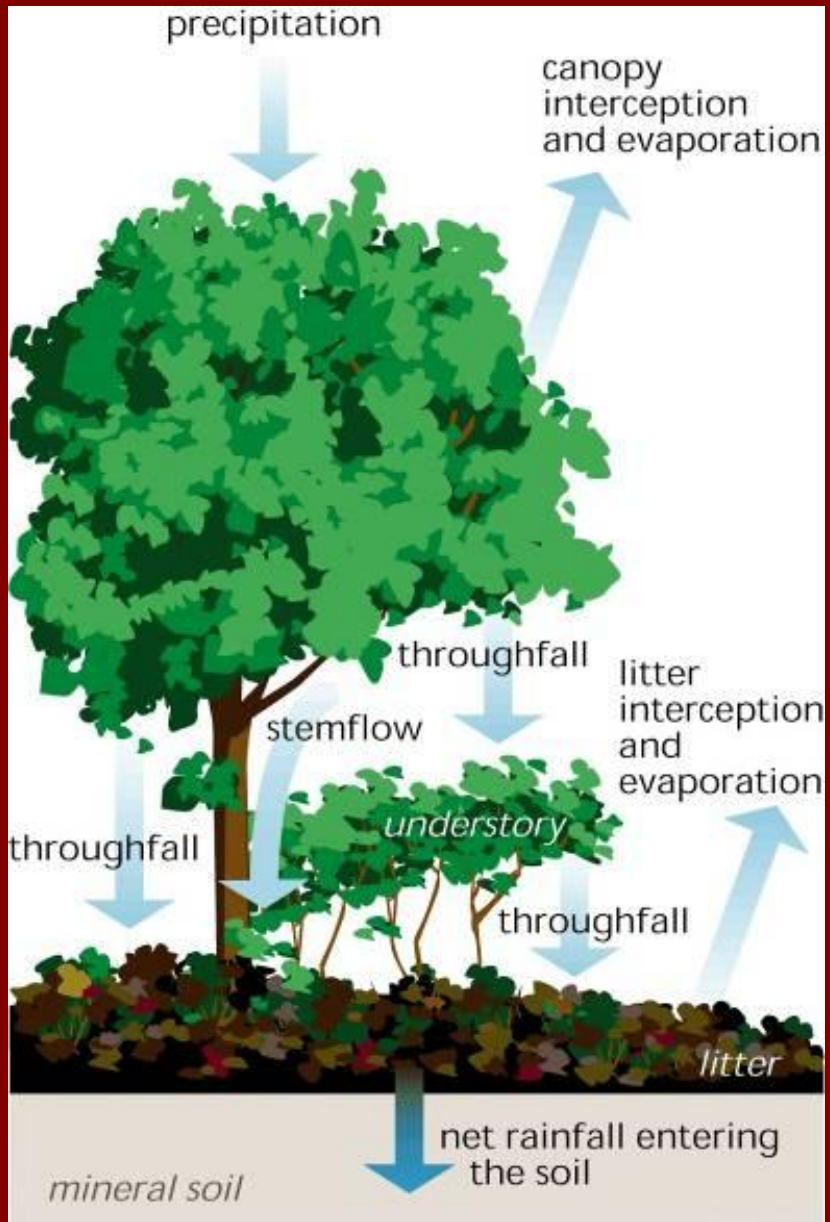
2006 Chesapeake Bay Executive Council Directive

- “Forests are the most beneficial land use for protecting water quality, due to their ability to capture, filter and retain water, as absorb pollution from the air.”
- “Forests are also essential to the provision of clean drinking water to over 10 million residents of the watershed and provide valuable ecological services and economic benefits including carbon sequestration, flood control, wildlife habitat, and forest produces.”

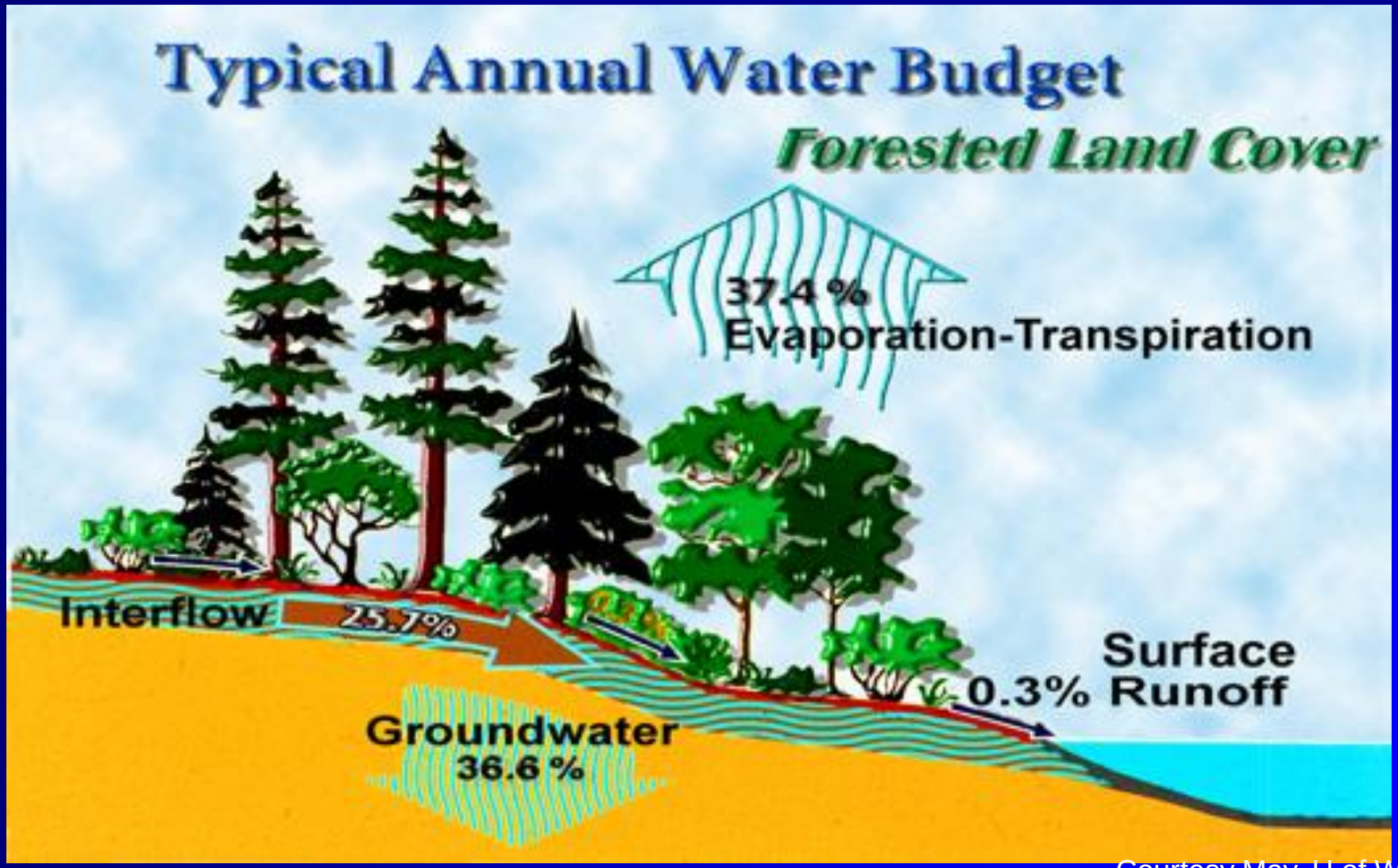
Trees Reduce Stormwater

- Interception in the Canopy
- Infiltration into Soils
- Consumption by Vegetation
- Pollutant Removal & Phytoremediation
- Soil Stabilization
- Streamside Buffers

- Trees used in bio-rentention areas filter and consume stormwater that would otherwise carry pollutants to our streams

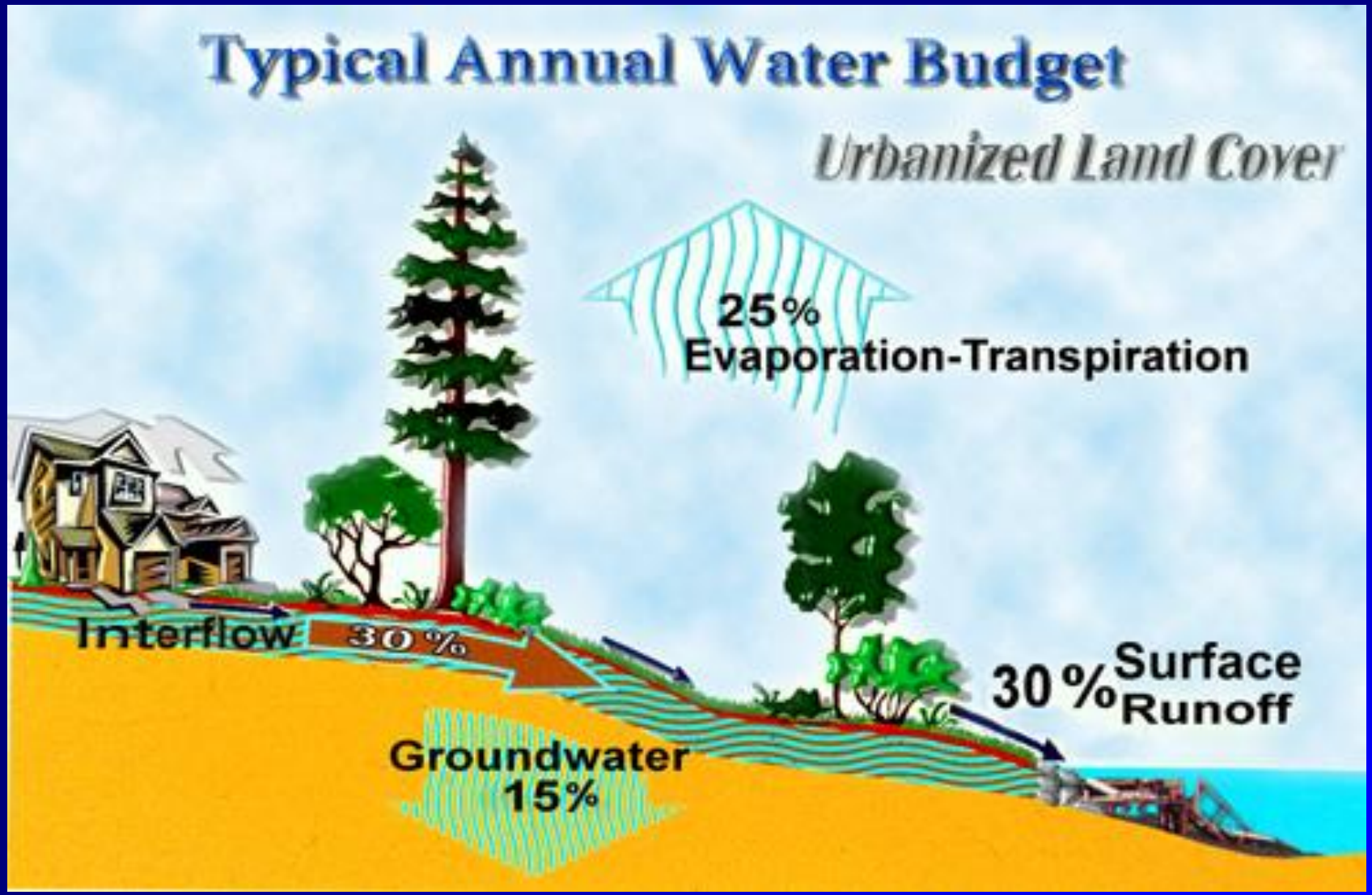


Hydrology Under Natural Conditions



Courtesy May, U of W

Developed Conditions

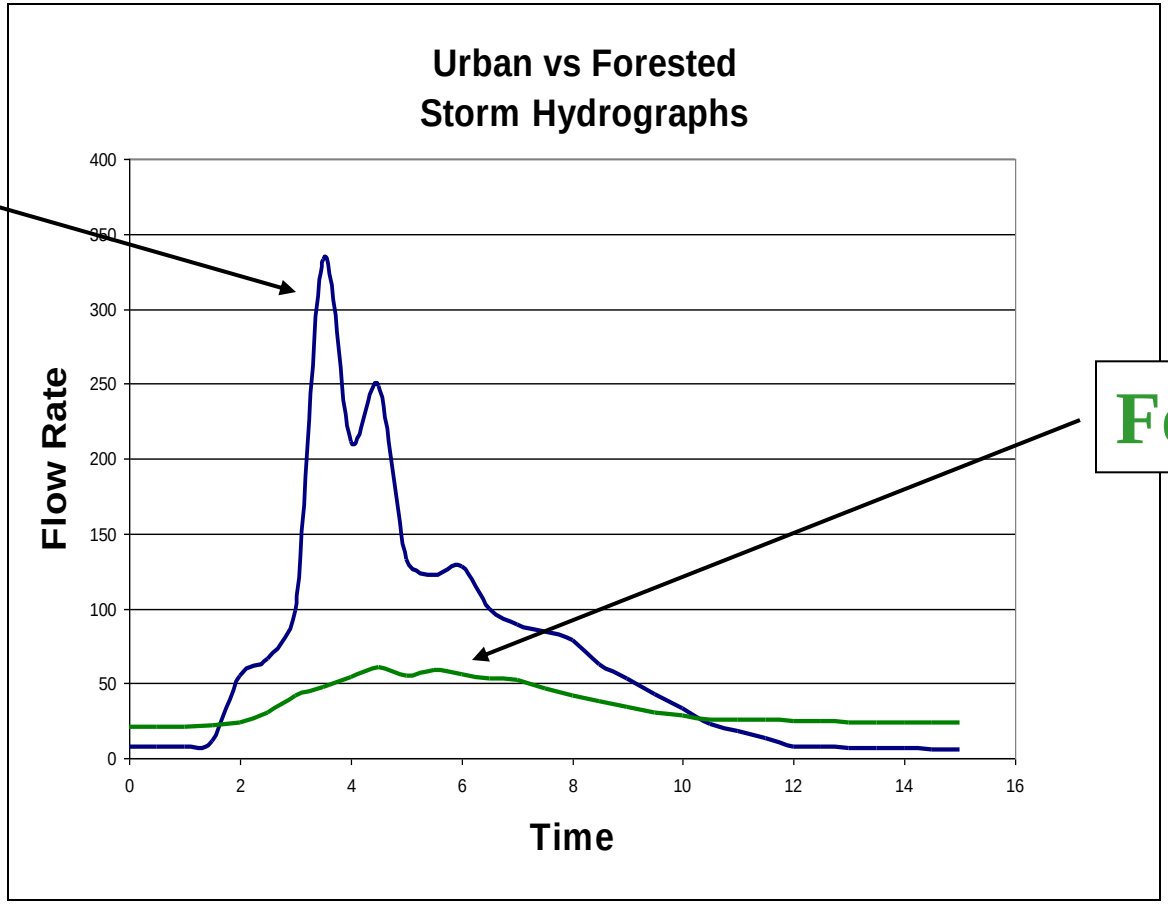


Courtesy May, U of W

The Urban Storm Hydrograph

Greater Peaks & Volume

Urban



Forested

Rainfall Interception by Tree Canopies

- Average interception of rainfall by tree canopy cover ranges from 10-40% for forested settings.
- Interception:
  mature deciduous
  500 to 760 gallons per year

  mature evergreen
  4,000 gallons per year.
- In one study, existing canopy in Dayton, Ohio reduced runoff by 7% and could be increased to 12% by planting more trees.

1 inch of rainfall per acre is equal to 27,000 gallons of stormwater

Rainfall Interception by a Tree

- **Callery Pear -**
  - ***9 yrs old, 28 ft tall, 19 ft crown diameter, 276 sq ft crown projection area, 1,923 sq ft leaf area, 446 sq ft stem area.***
- **0.5 inches of rain**
- **Total precipitation in crown projection area = 86.1 gallons**
- **Total tree interception = 58.1 gal gallons or 67% of the rain falling within the canopy**

USDA Forest Service Research at the Western Center for Urban Forestry, Davis, CA

Interception By Species

20 Year Old Trees

- **Crabapple** **144 gal/yr**
  22ft tall x 21ft spread
- **Kwanzan Cherry** **312 gal/yr**
  17ft tall x 17ft spread
- **Red Oak** **767 gal/yr**
  40ft tall x 27ft spread
- **Red Maple** **1,014 gal/yr**
  29ft tall x 24ft spread
- **Zelkova** **1,624 gal/yr**
  38ft tall x 34ft spread
- **White Pine** **786 gal/yr**
  32ft tall x 20ft spread
- **Hackberry** **1,394 gal/yr**
  47ft tall x 37ft spread

Source: USDA FS PSW-GTR-202 August 2007 & PSW-GTR-199

NYC Street Tree Interception

Average Interception by Species
London Plane – 2,875 gal/yr
Silver Maple – 2,948 gal/yr

- New York City's street trees intercept rain, reducing stormwater runoff by 890.6 million gallons annually, with an estimated value of $35.6 million.
- Citywide, the average tree intercepts 1432 gallons of stormwater each year, valued at $61 per tree.

Source: **NEW YORK CITY, MUNICIPAL FOREST RESOURCE ANALYSIS April 2007 , Peper, McPherson, Simpson, et.al.**

Pittsburgh Stratum Project

- **$334,600 in stormwater reduction savings (42 million gallons) annually. ($11.29/tree)**

Forests Clean, Store and Regulate Water

- **Forests filter and regulate the flow of water.**
- **The forest floor acts as an enormous sponge, typically absorbing up to 18 inches of precipitation before gradually releasing it into natural channels and watercourse (sub-surface flows)**

Source: Your Water- A Forest Product, Green America series, 1986

Rainfall Infiltration
Natural Areas are Giant Sponges!

When forest understory/ leaf litter was converted to turf in a North Carolina watershed, the mean infiltration rate went from 12.4 in/hr to 4.4 in/hr. (Kays, 1980)

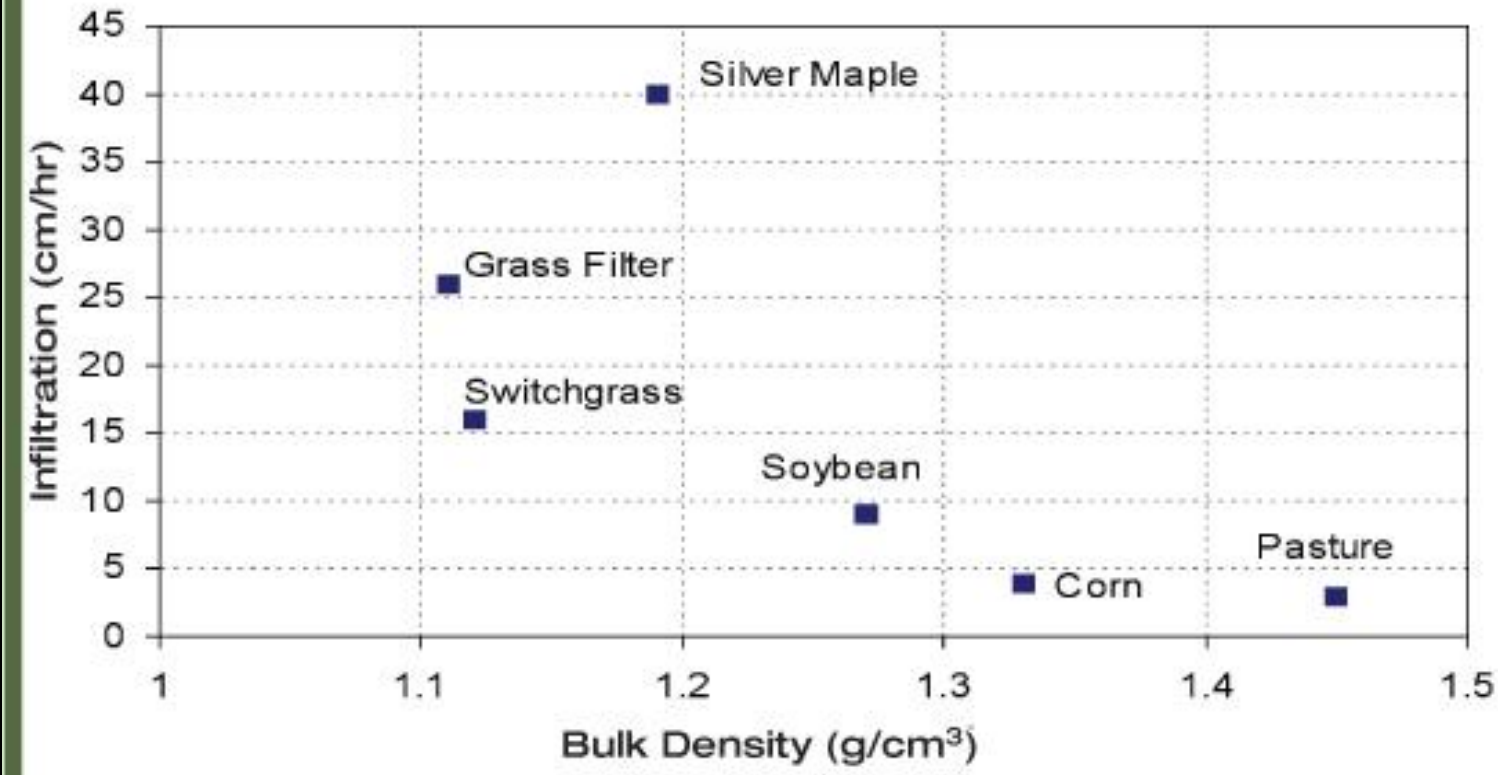
Hourly Infiltration Rates

Table 2. Average hourly infiltration rates from multispecies buffer (adapted from Bharati et al. 2002)

Treatment	Jun	Aug	Oct/Nov	Avg
		(cm/hr)		
Silver Maple	38	46	30	38
Grass Filter	29	20	25	25
Switchgrass	27	8	21	19
Bean	8	9	13	10
Corn	3	5	3	4
Pasture	2	4	3	3
Sandy Loam				1.1*
Silty Clay Loam				0.3*

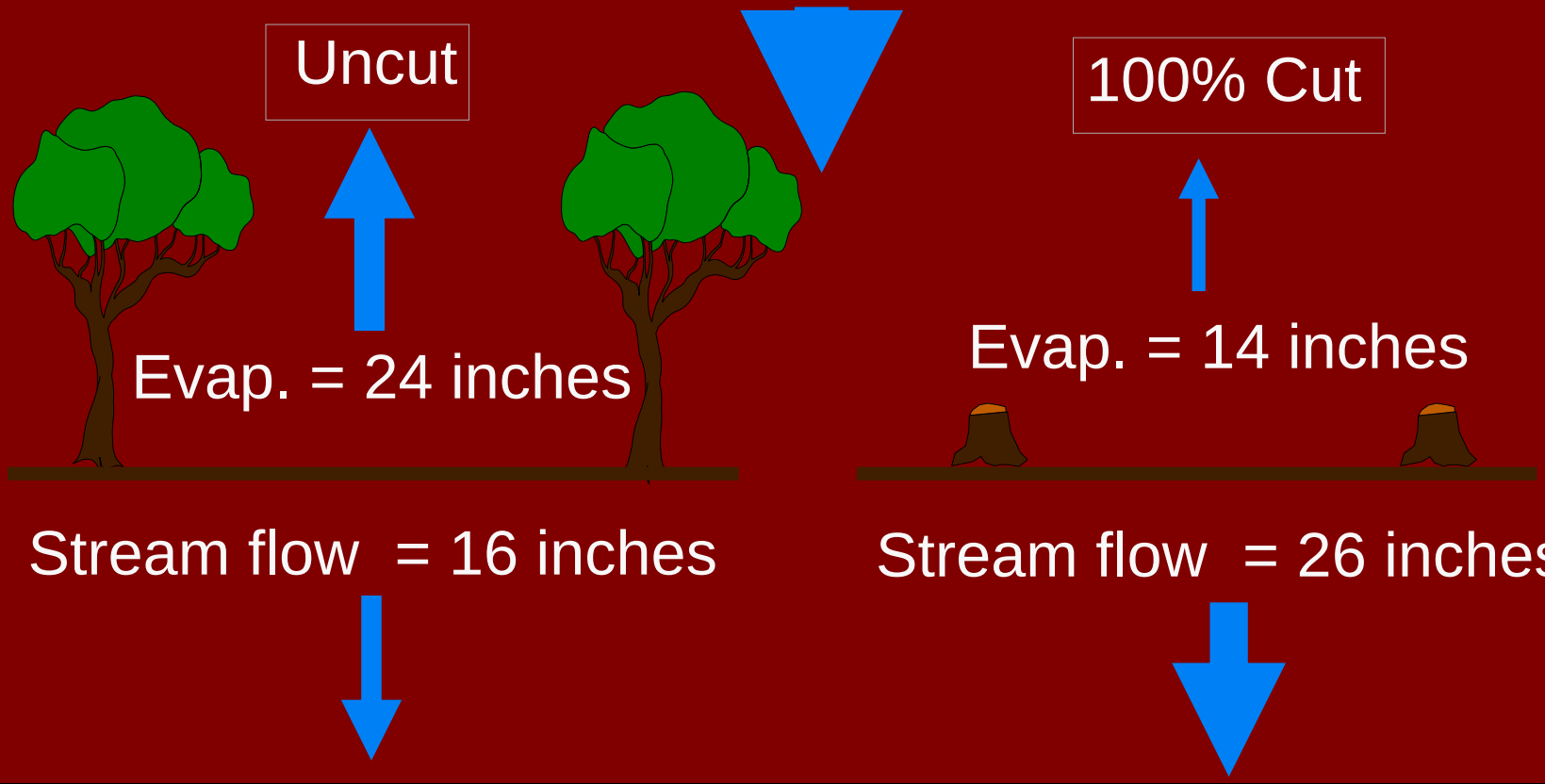
Infiltration Rates

Figure 4. Comparison of measured hourly infiltration rates and soil bulk density under multispecies buffer, crops, and grazed pasture (from Bharati et al. 2002)



Vegetation "Consumes" Water

Annual Precipitation for PA = 40 inches



- **A large oak tree can transpire 40,000 gallons (151,000 liters) per summer or 79 gallons per day. (Thomas 2000)**
- **A mature maple tree can transpire 65-140 liters per summer day (Cermak et.al., 2000)**

Phytoremediation

- Plants remove contaminates from soil and water such as metals, pesticides, solvents, oils, hydrocarbons, etc.

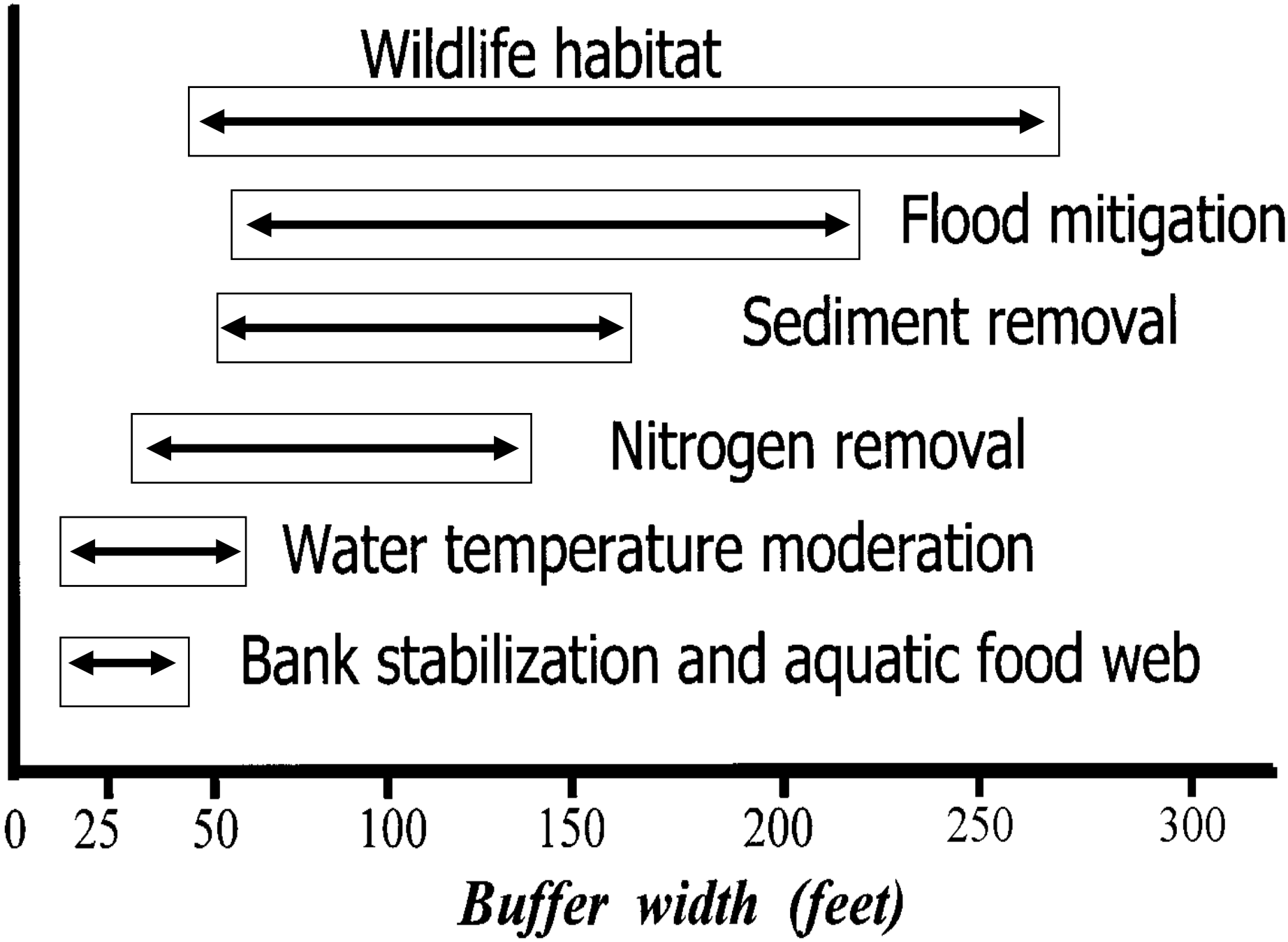
- In one study, a single sugar maple growing roadside removed 60mg of cadmium, 140mg of chromium, 820mg of nickel, and 5200mg of lead in a single growing season (Coder, 1996)

Riparian or Streamside Forests

The Link Before Water and Land

Stream Health is Dependent on Woody Vegetation

- **Sediment Filtering**
- **Nitrogen and Phosphorus Removal**
- **Stream Bank Stability**
- **Shade and Temperature Modification**
- **Aquatic Habitat and Leaf Food**
- **Reduced Stream Velocity & Down Stream Flooding**


Wildlife habitat
Flood mitigation
Sediment removal
Nitrogen removal
Water temperature moderation
Bank stabilization and aquatic food web
0
25
50
100
150
200
250
300
Buffer width (feet)

Research with the USDA Forest Service

UFORE
Urban Forest Effects Model

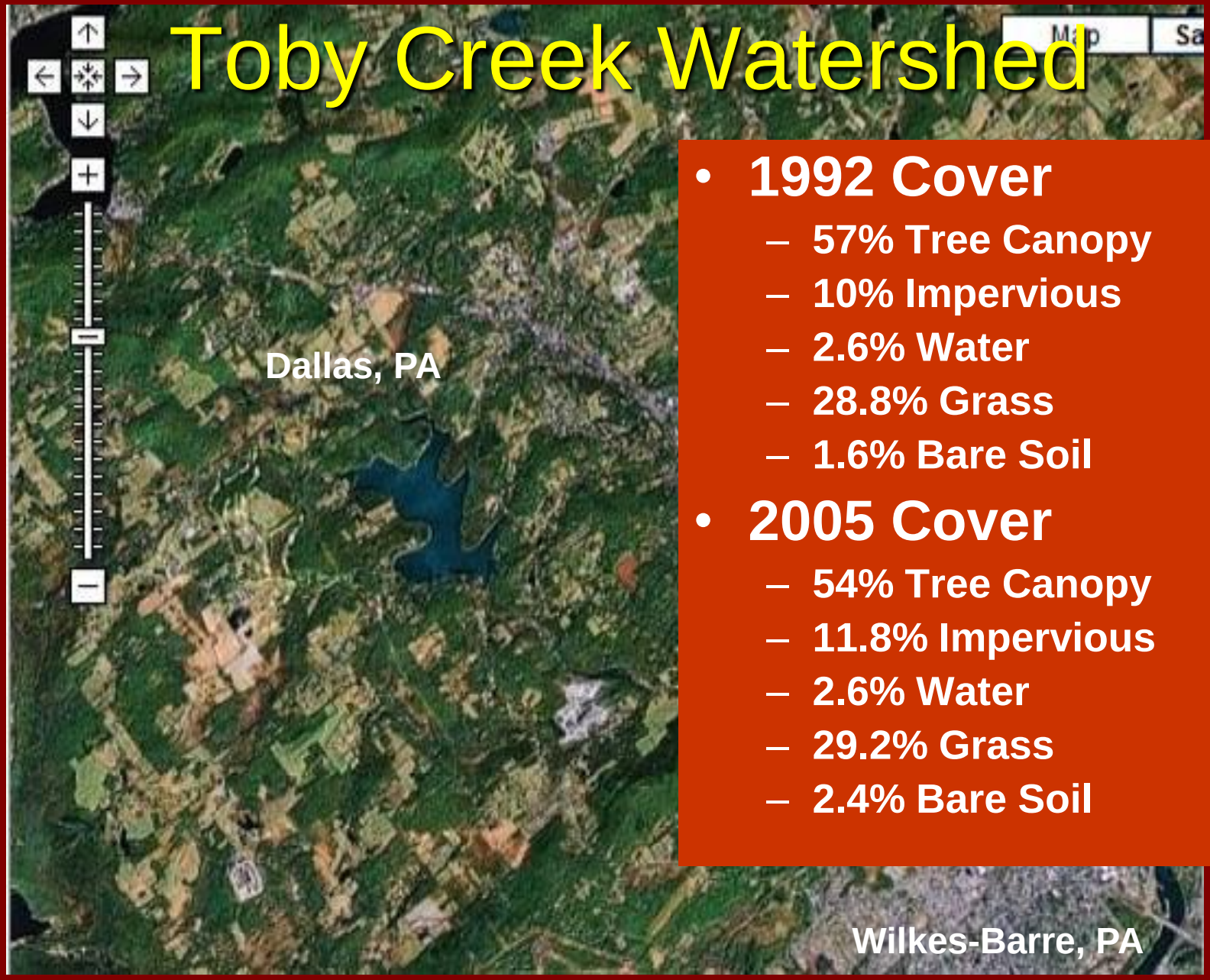
Tree Canopy & Water Quality Study on Toby Creek

UFORE Hydro Study in NEPA Started May 2006

Toby Creek Watershed – suburban Wilkes-Barre, a small urbanizing watershed with good canopy cover, but impacted stream.

i-Tree

Toby Creek Watershed

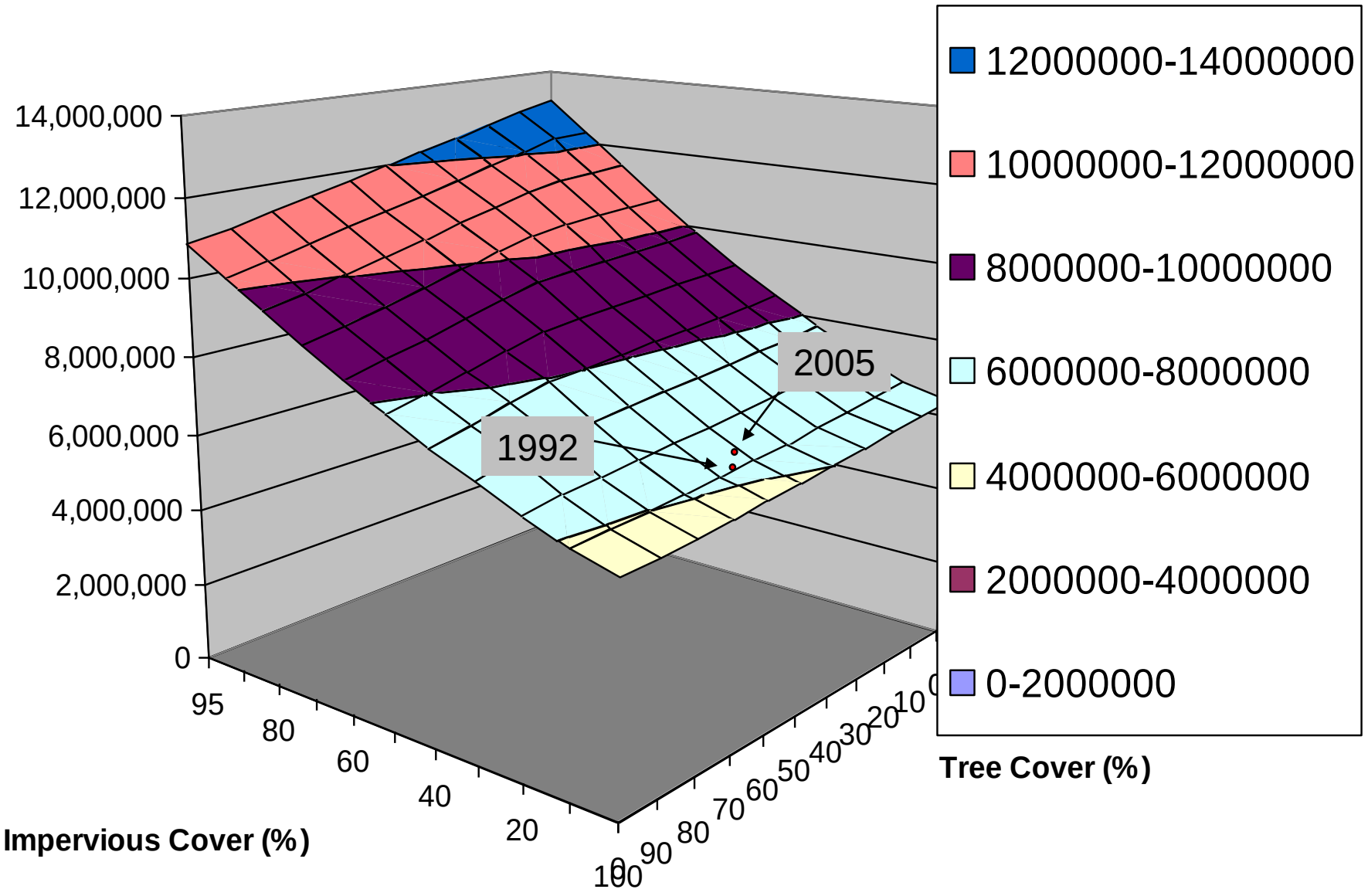


- **1992 Cover**
  - 57% Tree Canopy
  - 10% Impervious
  - 2.6% Water
  - 28.8% Grass
  - 1.6% Bare Soil
- **2005 Cover**
  - 54% Tree Canopy
  - 11.8% Impervious
  - 2.6% Water
  - 29.2% Grass
  - 2.4% Bare Soil

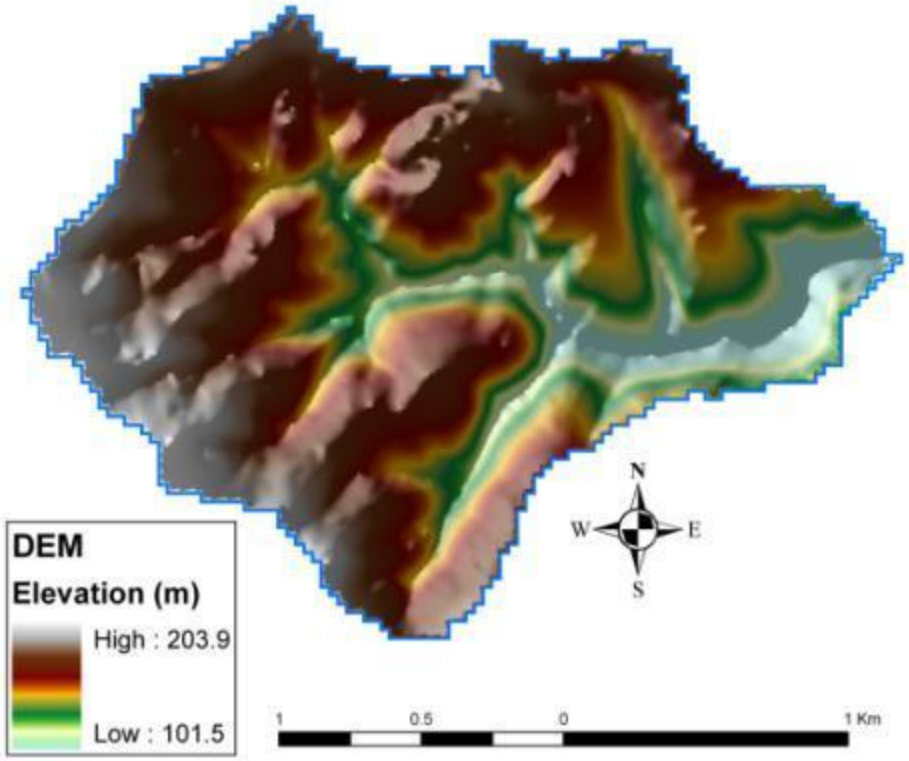
Runoff Changes

Runoff Change Using 1992 Precipitation Data			
	1992 (m^3)	**2005 (m^3)**	**% Change**
Total Runoff	6,505,666	6,628,993	1.90%
Largest Storm	(1 inch rainfall in May)		
Total Runoff	414,264	421,472	1.74%
Peak 1hr Runoff	14,607	15,090	3.31%
Peak 4hrs Runoff	49,317	50,820	3.05%

Toby Creek Watershed

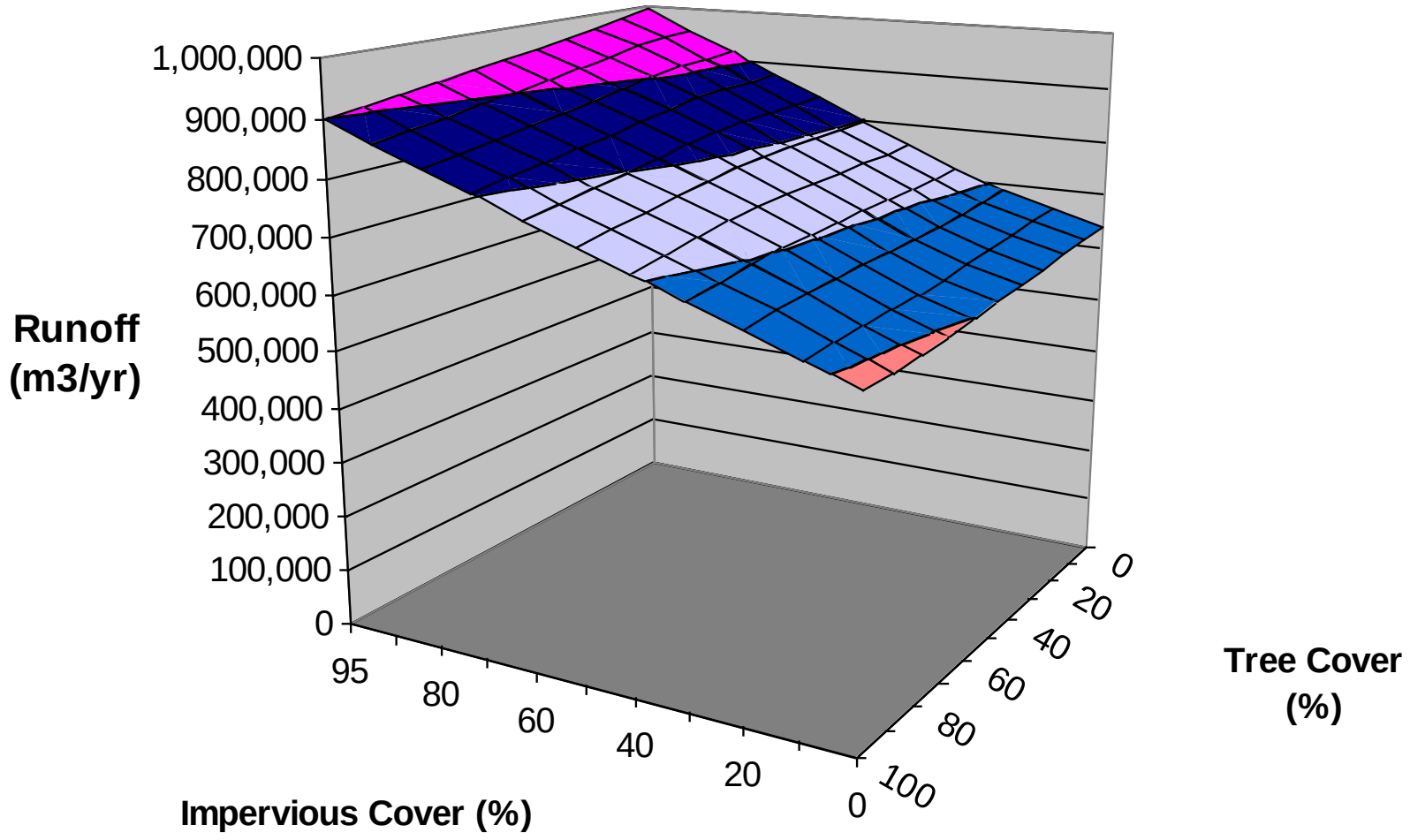


Baisman Run



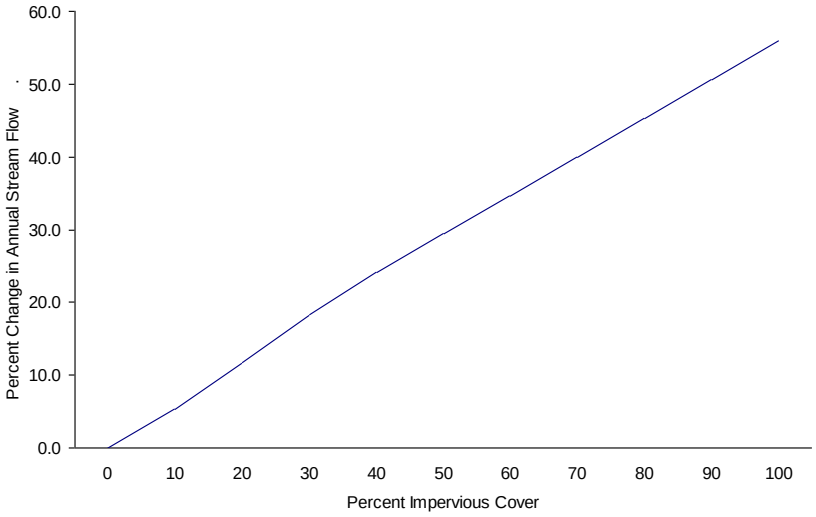
Watershed Area (m2)	**3,844,800**
Percent Impervious cover	**0.2**
Percent Tree Cover	**68.7**
Percent of Tree Cover over Impervious Area	**5**
Percent Water Cover	**0**
Average Tree Leaf Area Index (LAI)	**3.5**
Percent Shrub Cover	**7.8**
Percent Grass Cover	**20**
Percent Evergreen Trees	**4.2**
Percent Evergreen Shrubs	**21**
Shrub LAI	**3.9**
Leaf on Day	**80**
Leaf off Day	**294**

Baisman Run

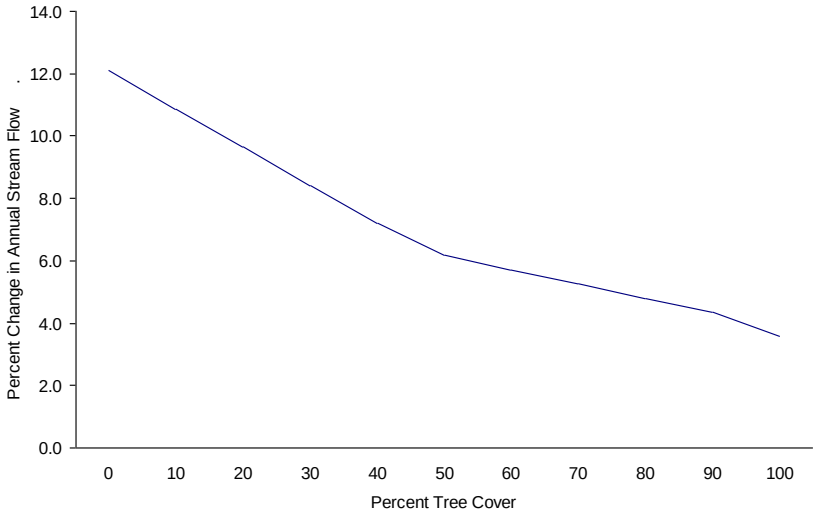

1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
Runoff (m3/yr)
95
80
60
40
20
0
Impervious Cover (%)
0
20
40
60
80
100
Tree Cover (%)

Baisman Run

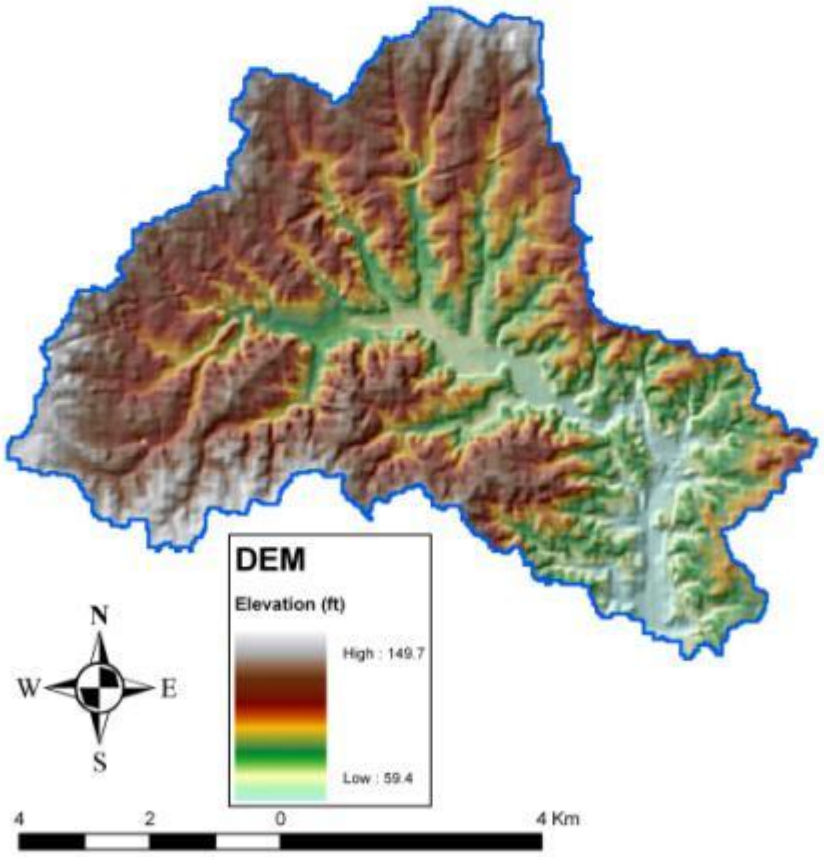
Canopy held at 70%



Impervious held at 10%



Accotink



Watershed Area (m2)	**61,910,100**
Percent Impervious cover	**21.3**
Percent Tree Cover	**31.9**
Percent of Tree Cover over Impervious Area	**10**
Percent Water Cover	**0.3**
Average Tree Leaf Area Index (LAI)	**3.5**
Percent Shrub Cover	**7.8**
Percent Grass Cover	**33.8**
Percent Evergreen Trees	**4.2**
Percent Evergreen Shrubs	**21**
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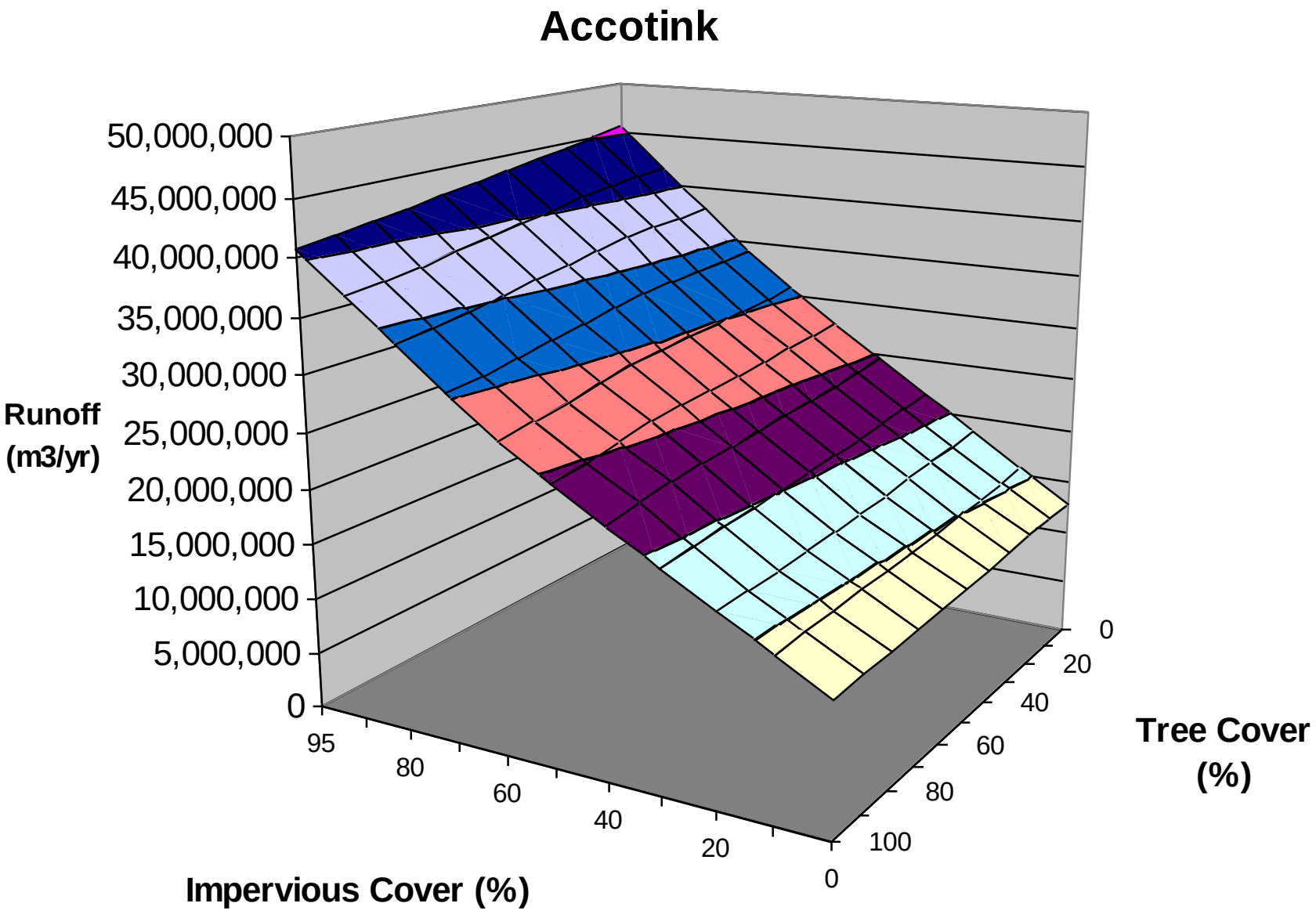
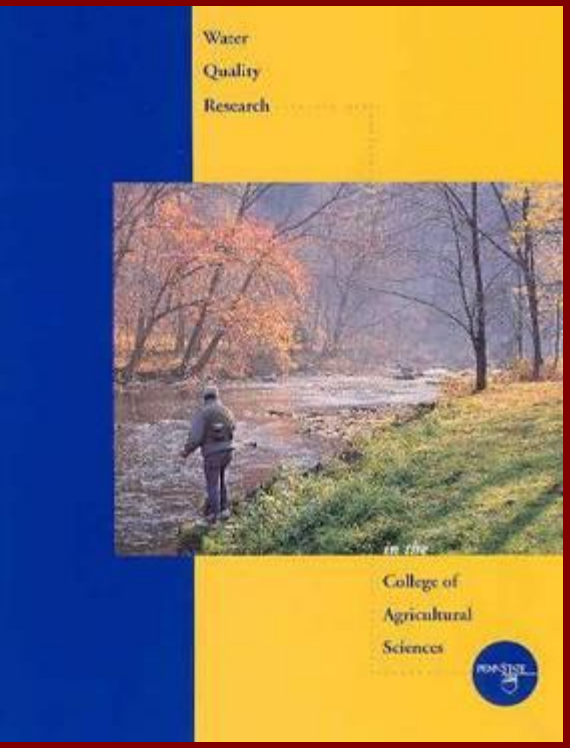

Accotink
50,000,000
45,000,000
40,000,000
35,000,000
30,000,000
25,000,000
20,000,000
15,000,000
10,000,000
5,000,000
0
Runoff (m3/yr)
95
80
60
40
20
0
Impervious Cover (%)
0
20
40
60
80
100
Tree Cover (%)

Water Quality Results (median national pooled EMC)

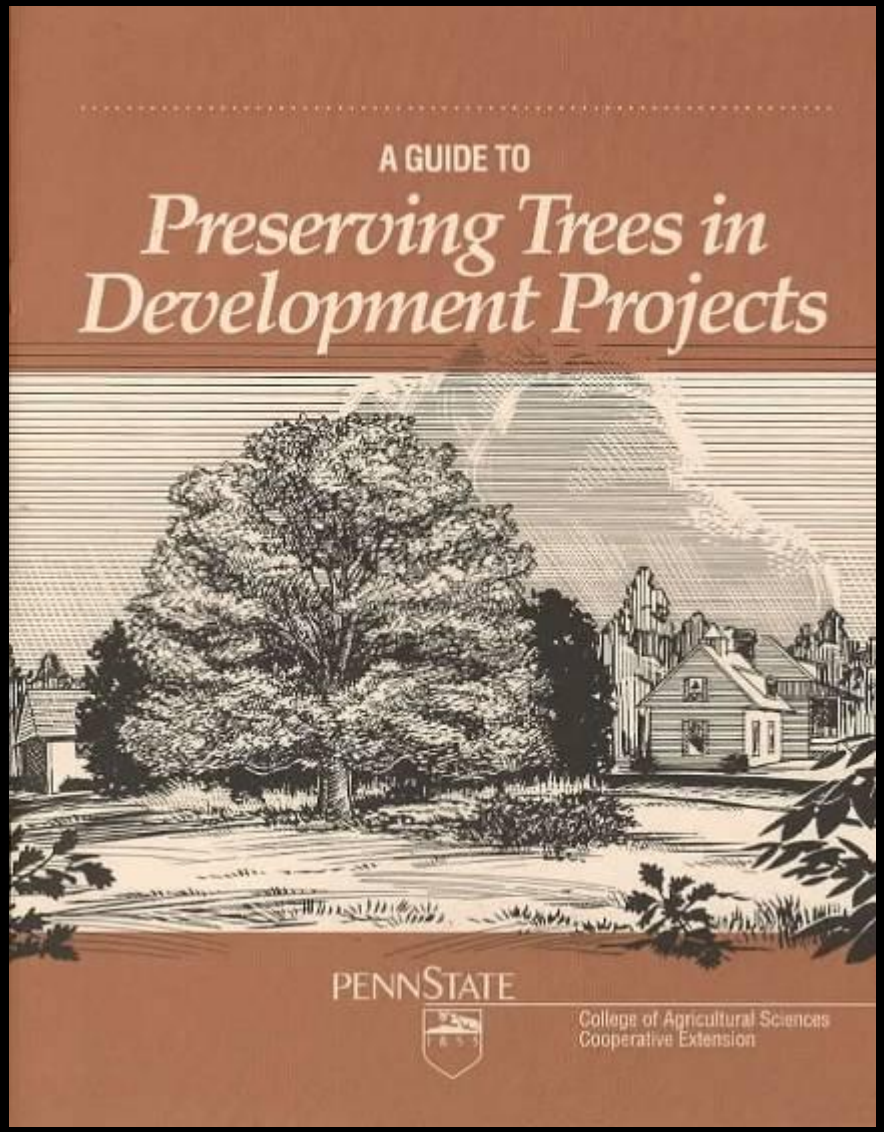
				Reduction (t/total hours)										
Watershed	Tree Canopy	Total % reduction	% per % canopy	TSS	BOD	COD	TP	Sol P	TKN	NO2 NO3	Cu	Pb	Zn	Total hours
Accotink	31.9	3.7	0.1	40.3	8.5	33.0	0.19	0.08	1.1	0.39	8.2	37.5	95.4	8760
Baisman Run	68.7	12.1	0.2	4.5	1.0	3.7	0.02	0.01	0.1	0.04	0.9	4.2	10.7	6600
Gwynns Falls	27.0	3.3	0.1	44.9	9.5	36.8	0.21	0.08	1.2	0.44	9.1	41.7	106.2	8760
Mill Creek	7.1	1.6	0.2	12.3	2.6	10.1	0.06	0.02	0.3	0.12	2.5	11.4	29.1	4008
Rock Creek	27.0	5.2	0.2	136.8	28.9	112.2	0.65	0.26	3.7	1.34	27.9	127.3	323.9	8760
Toby Creek	54.4	10.6	0.2	41.5	8.8	34.0	0.20	0.08	1.1	0.41	8.4	38.6	98.2	4416

Tree Canopy accounts for a 10.6% reduction in runoff

Working Towards Solutions



Preserving Existing Forests During Development



Conservation Subdivision Design/ Regulations

- **Local Watershed and Conservation Plans**
  - **Forest (Contiguous and Interior Habitat)**
  - **Streams (Corridors)**
  - **Wetlands**
  - **Habitats**
  - **Step Slopes**
  - **Buffers**
  - **Critical Areas**
  - **Parks**
  - **Scenic Areas**
  - **Trails**
  - **Shorelines**
  - **Difficult Soils**
  - **Ag Lands**
  - **Minerals**

Large and Small Scale

Promoting Low Impact Development

Conventional

Low Impact

Good Drainage

Functional Lanscape Design

Rain gardens

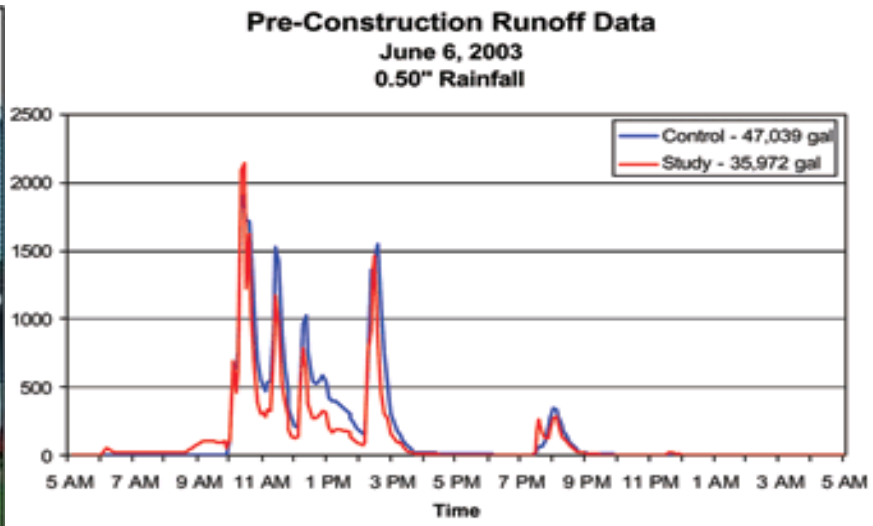
- Low - lying areas to collect rainwater
- Rain water is directed to these areas
- Contain water tolerant grass, shrubs and trees
- Water is retained and slowly seeps into the ground.

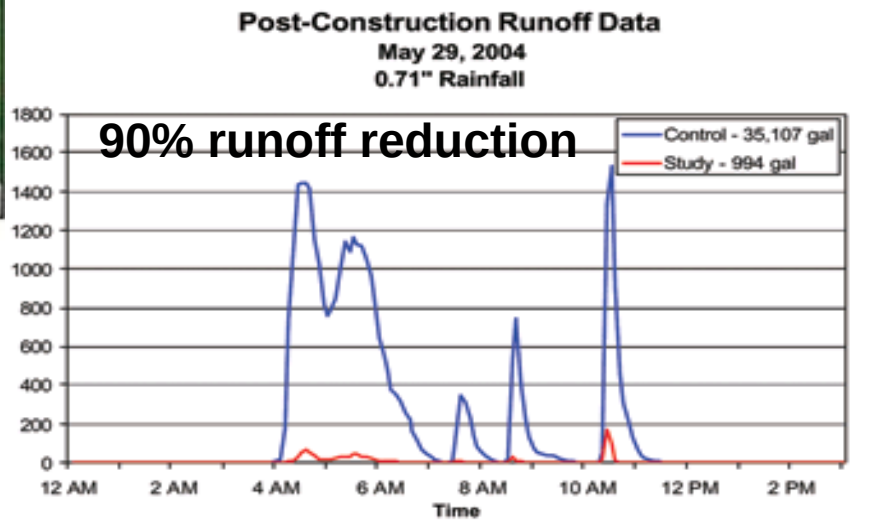
97% Runoff Volume Reduction
Land and Water, Sept/Oct. 2004

College of ENGINEERING VILLANOVA UNIVERSITY

Villanova Urban Stormwater Partnership

Burnsville, MN
17 gardens installed in '03 at $8/sq. ft.





Rain Gardens

Increase Urban Tree Canopy

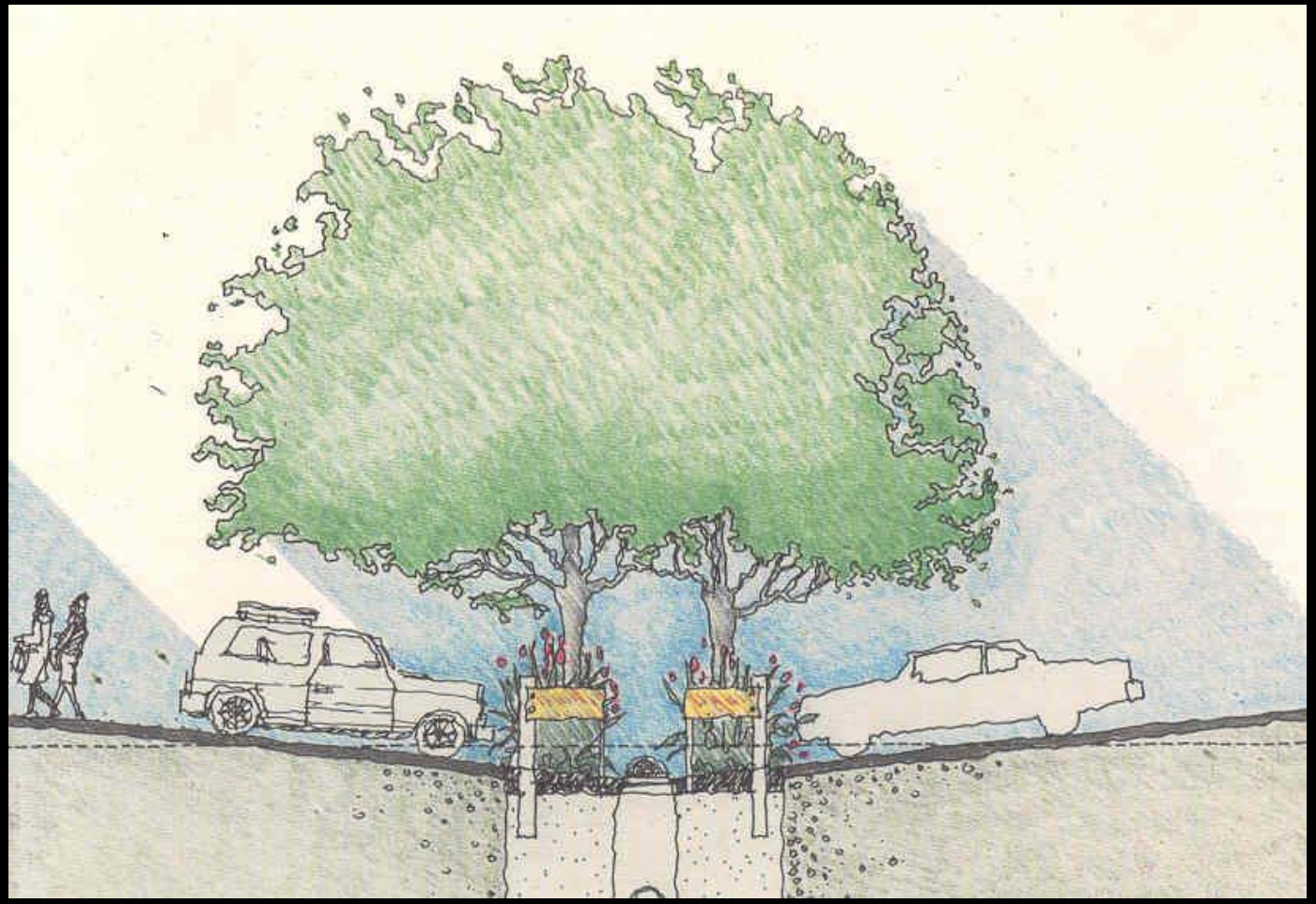
Urban Tree Interception rates exceeded 40% for small storm events, but were less than 4% for large storm events (Wang, Nowak, Endreny 2006).

Increasing canopy cover over impervious surface had the greatest effect on reducing runoff.

UFORE Hydro Study Dead Run, Baltimore, MD

Redesigning Parking Lots

Trees Intercept Rainfall and Promoting Infiltration



Parking Lot Infiltration


MAY 21 2001

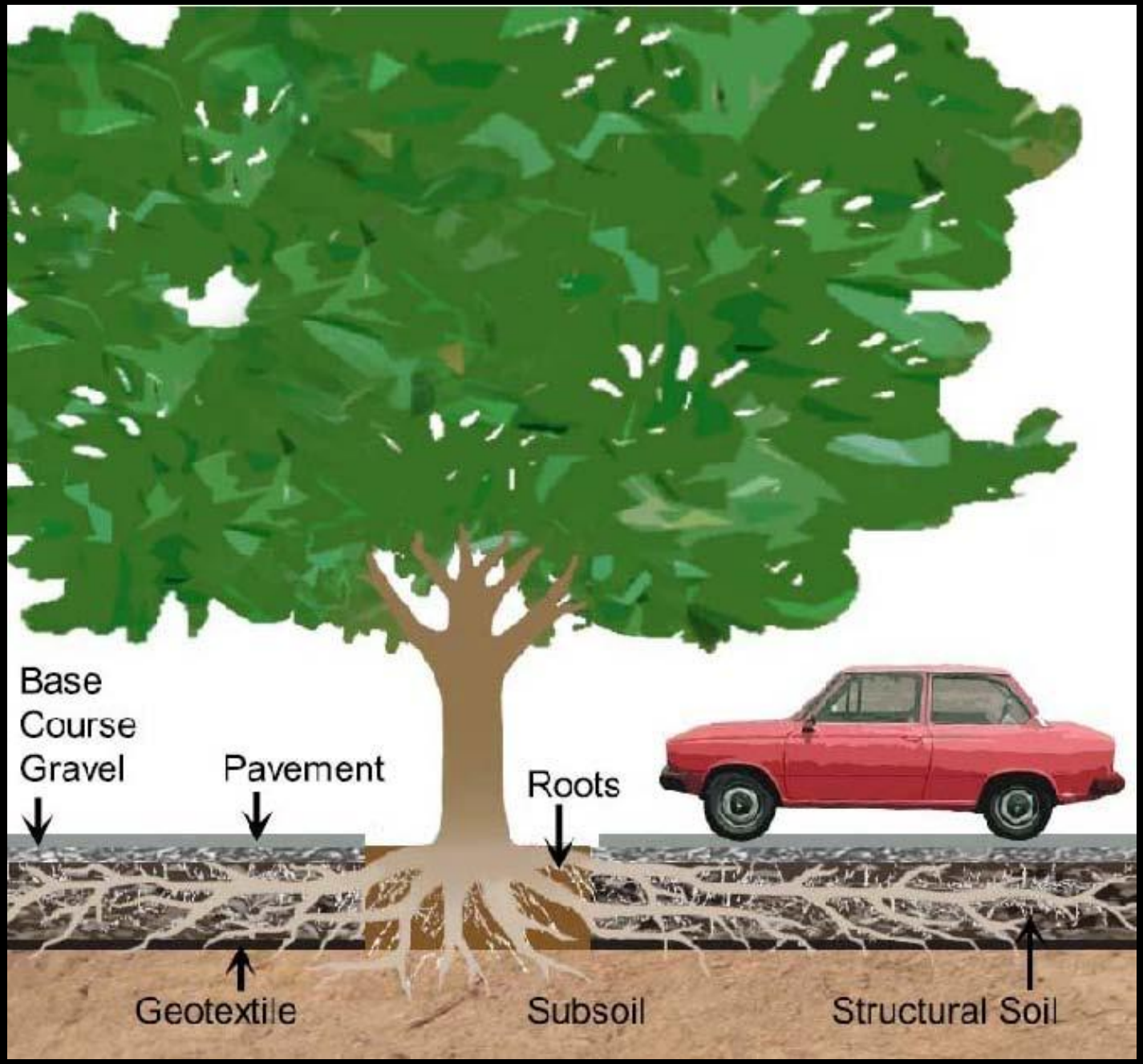
Structural Soils and Stormwater

Experiments using engineered soil mixes at Cornell and Virginia Tech showed that trees increased the infiltration rate by 27 times compared with unplanted controls.

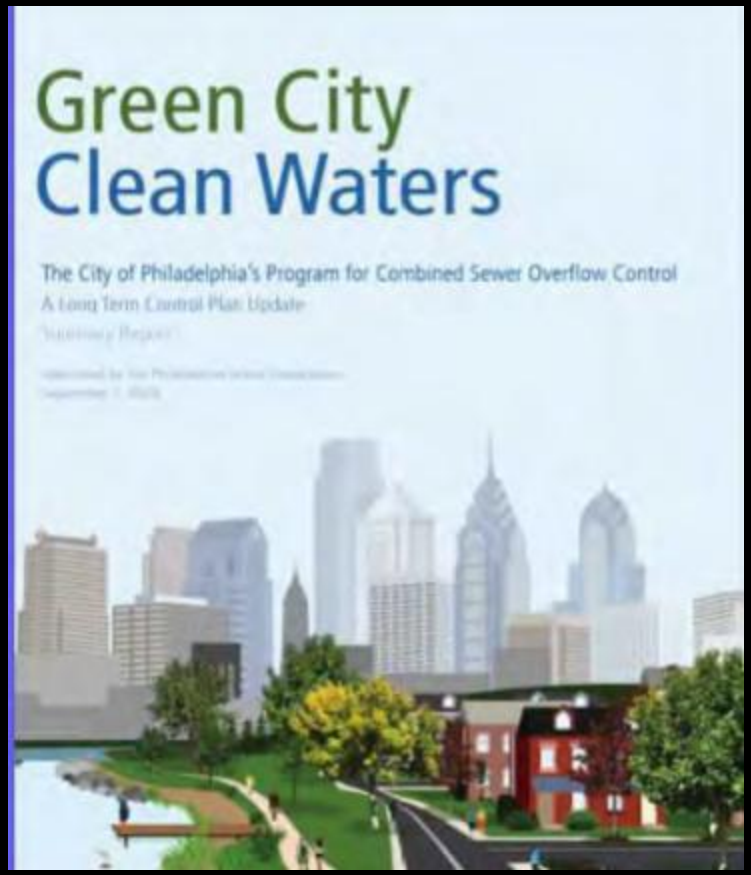
Using Porous Asphalt and CU-Structural Soil®

Cornell University

Urban Horticulture Institute
Cornell University
Department of Horticulture
134A Plant Science Building
Ithaca, NY 14853
www.hort.cornell.edu/UHI


Base
Course
Gravel
Pavement
Roots
Geotextile
Subsoil
Structural Soil

Green City, Clean Water Program – Philadelphia



- $290 million to restore & preserve stream corridors
- $320 million to upgrade water pollution plant
- $1.01 billion to Green 34% of the combined sewer area to manage stormwater at the source

For more information, visit www.phillywatersheds.org

Philadelphia Retrofits

Philadelphia Retrofits

Philadelphia Retrofits

Green Streets – Portland, WA

Challenges

- **Public/Municipal perception of Large canopy trees** – small canopy trees are being replanted
- **Riparian Buffers** – Lack of public understanding and still no statewide protection!
- **Engineers** – many still don't get it!
- **BMPs not installed properly**
- **Reducing impervious surfaces & turf conversion**
- **Need more data** on pollution removal by urban trees (by species) and evapotranspiration (by species & size class).

Penn State Cooperative Extension

Penn State is committed to affirmative action, equal opportunity, and the diversity of its workforce.

Vincent Cotrone
570-825-1701
vjc1@psu.edu
www.PATrees.org