Maintaining Healthy Watersheds

Created by 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."

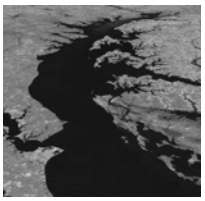
Captain John Smith 1607 writing about the Chesapeake Bay Watershed which was 95% Forested.

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 Watershed Today



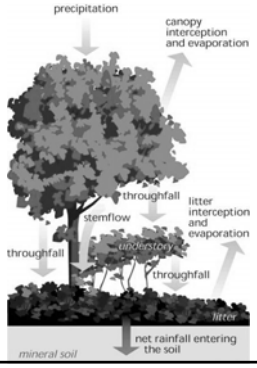
By the late 1970's, forest land made up 60% of the watershed, and began to decline.

During the past 20 years, urban & suburban development an average of 100 acres of forest have been lost daily.

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

- **Over 12,200 miles of streams in PA are polluted**
- **Over 3,000 miles of streams in PA are impaired due to stormwater runoff**

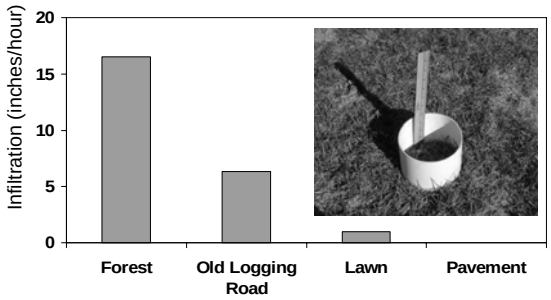
Forests Clean, Store and Regulate Water



- **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)**

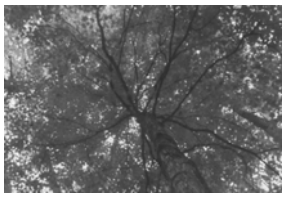
Water Infiltration Rates

(initial rates in dry soils)



Rainfall Interception by Tree Canopies

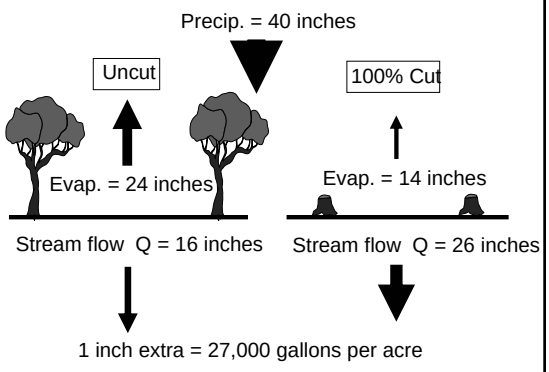
- **Average interception of rainfall by tree canopy cover ranges from 6-17% for forested settings.**
- **In one study, a 32 ft tall tree intercepted 327 gallons.**
- **Existing canopy in Dayton, Ohio reduced runoff by 7% and could be increased to 12% through planting more trees.**



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**

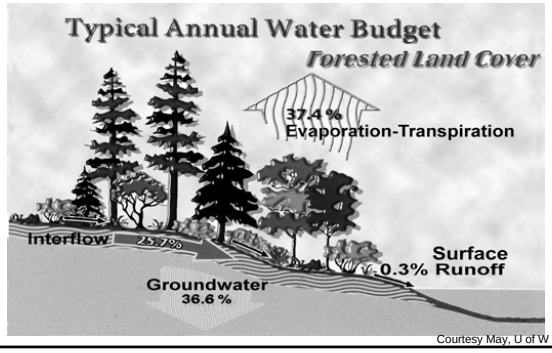
Vegetation Also “Consumes” Water



2006 Chesapeake Bay Executive Council Directive

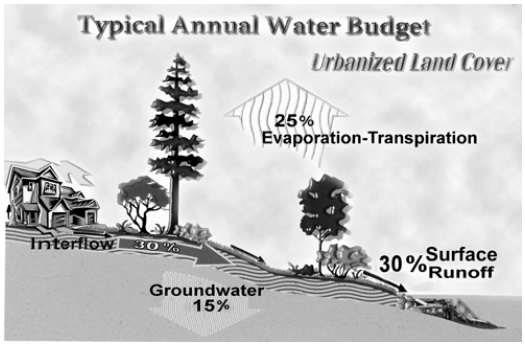
- “Forests are the most beneficial land use for protecting water quality, due to their ability to capture, filter and retain water, as absorb pollution from the air.”
- “Forests are also essential to the provision of clean drinking water to over 10 million residents of the watershed and provide valuable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

Hydrology Under Natural Conditions



Courtesy May, U of W

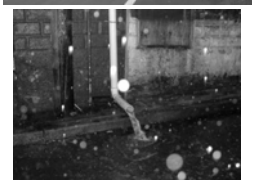
Developed Conditions



Courtesy May, U of W

Urbanizing Watersheds

- **Increased**
  - **Impervious Surfaces**
    - **Roads, roofs, pools, sidewalks, parking lots**
  - **Storm water**
  - **Flash Flooding**
  - **Peak Flow**
  - **Floodplain development**

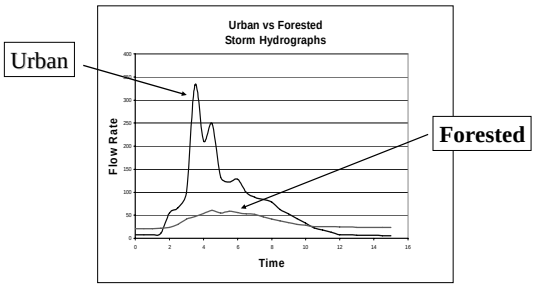


Impact of Stormwater / Impervious Area

- More Extreme Droughts
- Lower Low Stream Flows
- More Frequent & Severe Flooding
- Less Groundwater Recharge
- Water Quality Impacts

The Urban Storm Hydrograph

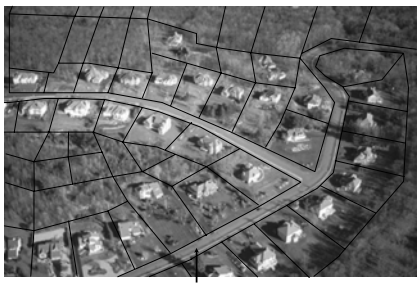
Greater Peaks & Volume



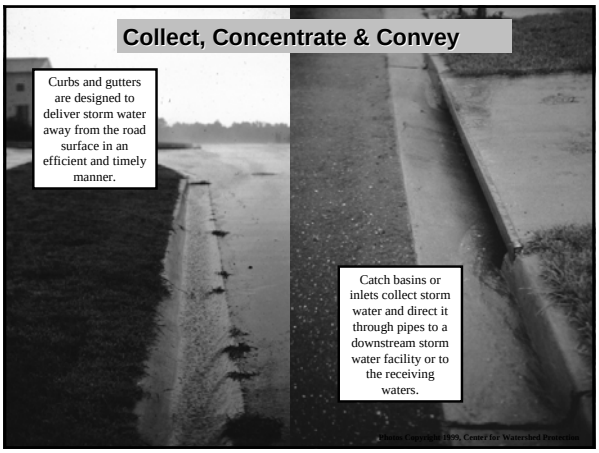
Forestland Dynamics

Road

Fragmentation

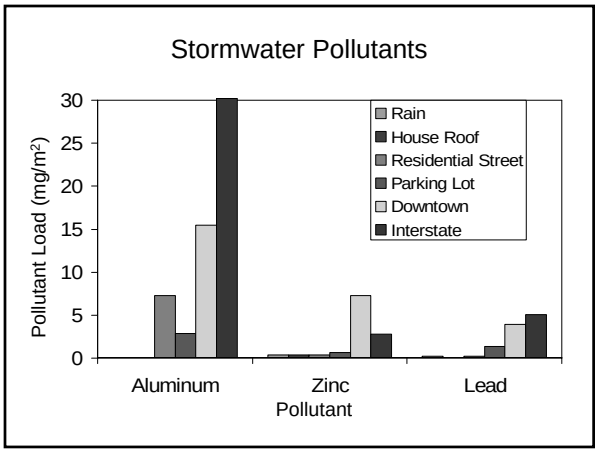


Road



Stormwater Discharged to Streams

- **<u>Nutrient Loads</u> Stormwater is contributing:**
  - **8.4 % of the nitrogen**
  - **10.8% of the phosphorus to waterways**



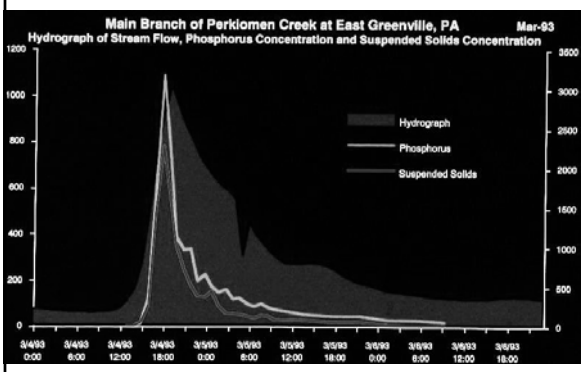
Designing for the Automobile Parking Lots

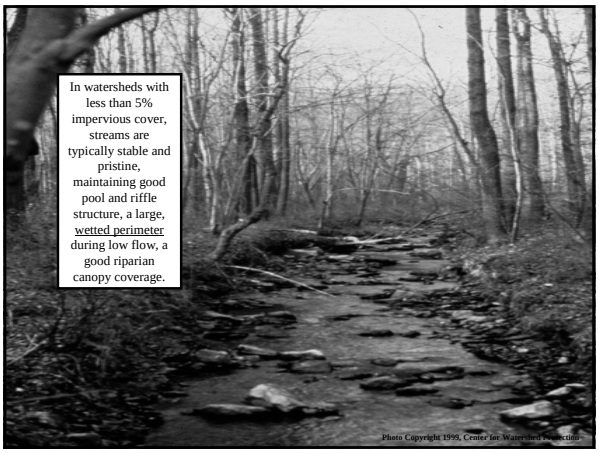
- Fastest Growing Land Use – 7 spaces for each registered car.
- Parking lots occupy between 10-20% of the land in our cities
- Significant sources of heat, visual blight, air and water pollutants

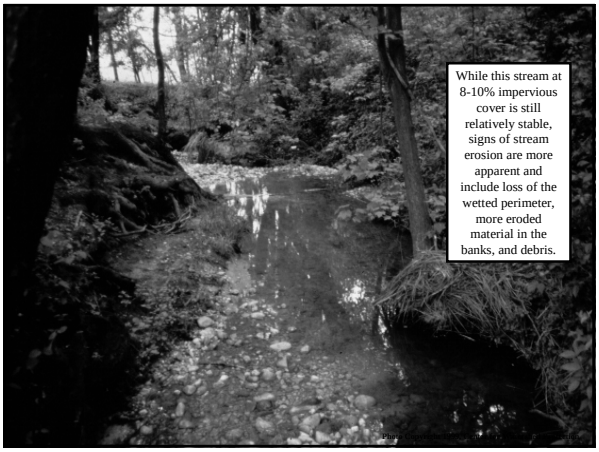
Parking Lots and Water Quality

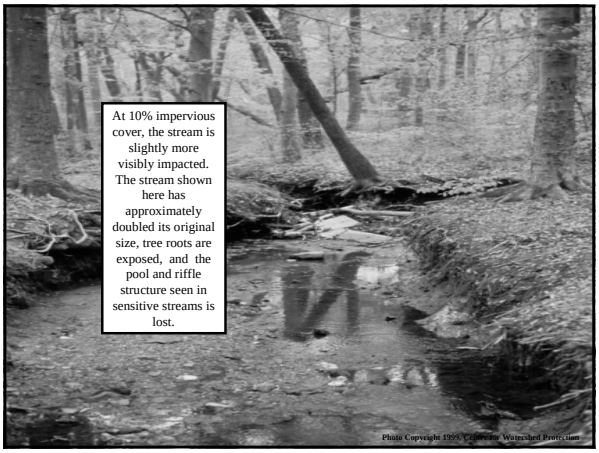
- Increased Impervious Surface – Storm water – Flash Flooding
- Increased streambank erosion & channalization
- Increased NPS Water Pollution
- Parking lots accumulate pollutants deposited from the atmosphere and produce greater levels of petroleum hydrocarbons and trace metals (cadmium, copper, lead, zinc)

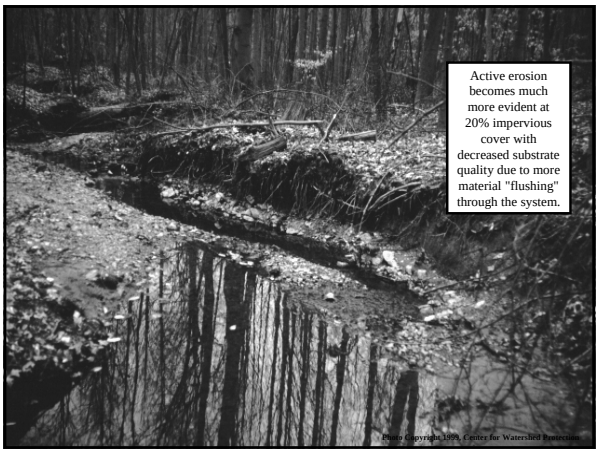
Recipe for Stormwater Soup : 1 acre parking mix in 3" of rain
Produces: 3-5 lbs of Heavy metals in runoff
81,000 gallons of Stormwater
Ten times the Nitrogen from an acre of forest

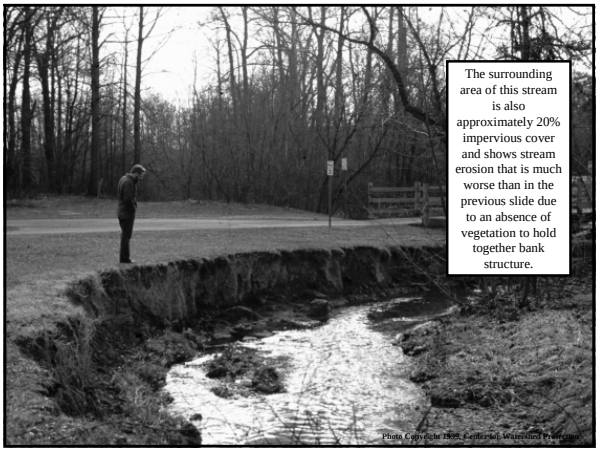


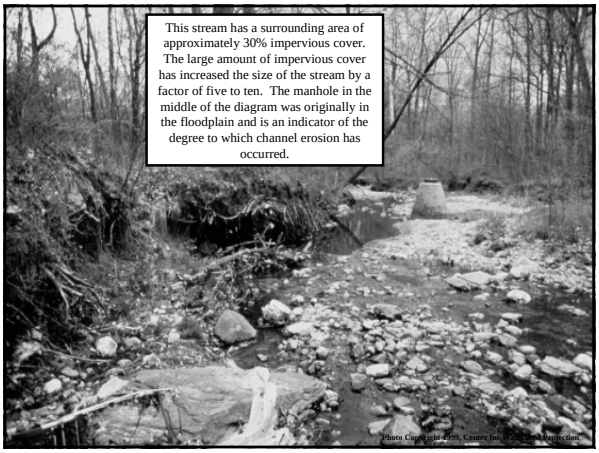

In watersheds with less than 5% impervious cover, streams are typically stable and pristine, maintaining good pool and riffle structure, a large, wetted perimeter during low flow, a good riparian canopy coverage.
Photo Copyright 1999, Center for Watershed Protection

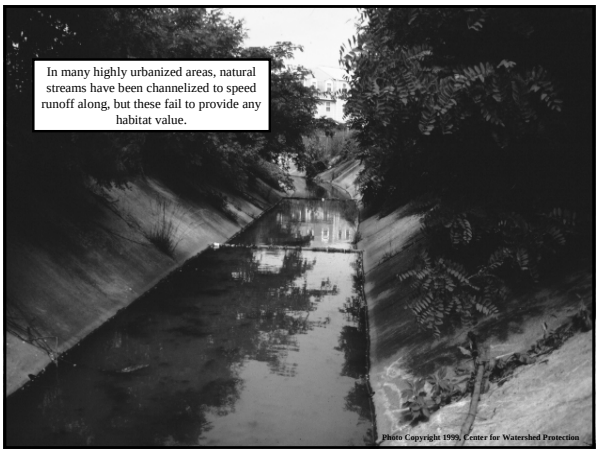

While this stream at 8-10% impervious cover is still relatively stable, signs of stream erosion are more apparent and include loss of the wetted perimeter, more eroded material in the banks, and debris.


At 10% impervious cover, the stream is slightly more visibly impacted. The stream shown here has approximately doubled its original size, tree roots are exposed, and the pool and riffle structure seen in sensitive streams is lost.
Photo Copyright 1999, Center for Watershed Protection


Active erosion becomes much more evident at 20% impervious cover with decreased substrate quality due to more material "flushing" through the system.
Photo Copyright 1999, Center for Watershed Protection


The surrounding area of this stream is also approximately 20% impervious cover and shows stream erosion that is much worse than in the previous slide due to an absence of vegetation to hold together bank structure.
Photo Copyright 1999, Center for Watershed Protection


This stream has a surrounding area of approximately 30% impervious cover. The large amount of impervious cover has increased the size of the stream by a factor of five to ten. The manhole in the middle of the diagram was originally in the floodplain and is an indicator of the degree to which channel erosion has occurred.
Photo Copyright 1999, Center for Watershed Protection



1993 Chesapeake Bay Executive Council Directive

- "We now recognize that forests along waterways, also known as 'riparian forests', are an important resource that protects water quality and provides habitat and food necessary to support fish survival and reproduction. Used as buffers, riparian forests provide a means of helping us achieve our restoration goals in the tributaries."
- The governors of PA, VA, MD, NY agree to restore 2,010 miles of new riparian forest buffer by the year 2010.

Riparian Forest Functions

- **Nitrogen and Phosphorus Removal - Similar to wetlands, they serve as filters, sinks, and transformers of nutrients.**
- **Studies in Maryland showed reductions of up to 88% of nitrate and 76% of phosphorus after agricultural runoff passed through a forest buffer.**

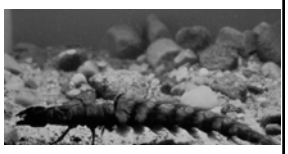
Riparian Forest Functions

Shade and Temperature - forests moderate stream temperatures and levels of dissolved oxygen. Critical for fish and submerged aquatic vegetation, but also has water quality implications.

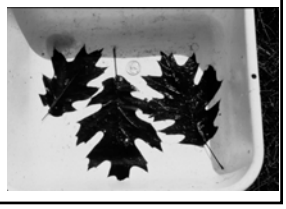
Temp. increases conversion of nutrients attached to solids to a soluble form. Stream temp. above 60 F increases phosphorus release from sediments.

Loss of forest shade = increased nutrients = algae bloom = low oxygen levels.

Riparian Forest Function



- **Habitat and leaf food - richly diverse ecosystem that supports many species and provides linear corridors for species migration, reducing fragmented gene pools, increasing biodiversity.**
- **100 foot wide streamside buffer that is 1 mile long provides 12 acres of habitat supporting over 50 species of wildlife.**
- **Woody debris in streams provide cover for fish and invertebrates, while leaves provide food for aquatic insects (part of the food web).**

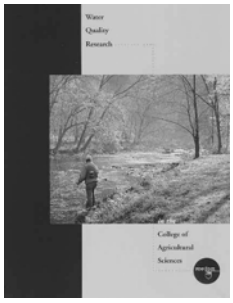


Riparian Forest Function

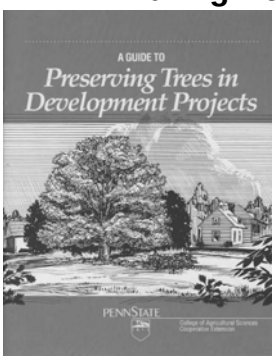
- **<u>Stream Channel Stability</u> - vegetation (especially woody) is essential for stabilizing streambanks. Stream velocity and erosion is reduced by roughness of edge. By slowing and dispersing flood waters, the down stream crest and damage is dramatically reduced.**

Streambank stabilization projects can cost $100/stream foot or $500,000 per mile of stream.

Working Towards Solutions



Preserving Existing Forests During Development



Working with Communities to Planting More Trees

- **Increasing Tree Canopy Cover in Existing Communities**

Many small communities in Northeastern PA are forming tree commissions and planting trees.

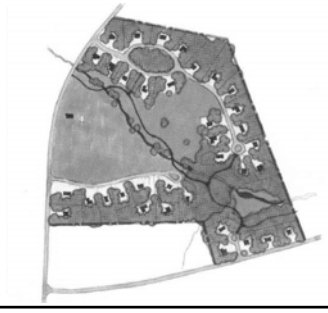
Since 1991, the PA Community Forestry Council has helped communities plant over 25,000 trees, with the help of grant funds.

In the past 3 years, Kingston has planted over 400 new street trees.

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



Redesigning Parking Lots

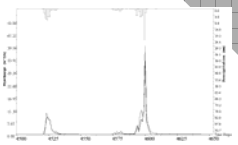
Trees Intercept Rainfall and Promoting Infiltration

PHOTO: TOM LIPTAN, PORTLAND, OR

Research with the USDA Forest Service

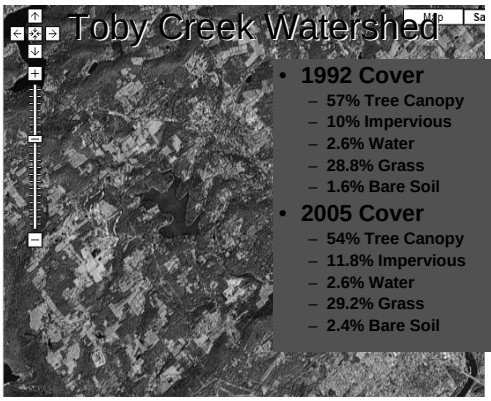
UFORE
Urban Forest Effects Model

Tree Canopy & Water Quality Study on Toby Creek



i-Tree

Toby Creek Watershed

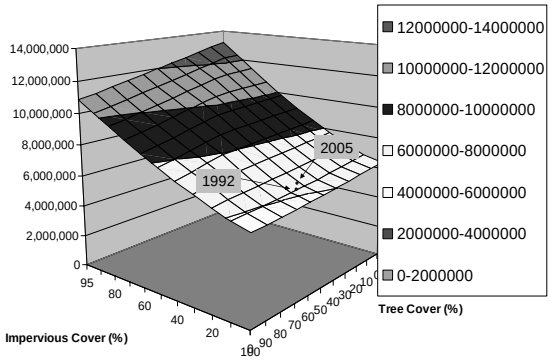


- **1992 Cover**
  - 57% Tree Canopy
  - 10% Impervious
  - 2.6% Water
  - 28.8% Grass
  - 1.6% Bare Soil
- **2005 Cover**
  - 54% Tree Canopy
  - 11.8% Impervious
  - 2.6% Water
  - 29.2% Grass
  - 2.4% Bare Soil

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



Water Quality Results (median national pooled EMC)

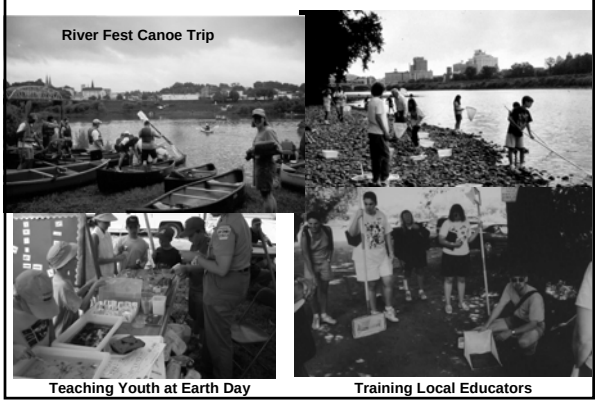
				Reduction (t/total hours)										
Watershed	Tree Canopy	Total % reduction	% per % canopy	TSS	BOD	COD	TP	Sol P	TKN	NO2 NO3	Cu	Pb	Zn	Total hours
Accotink	31.9	3.7	0.1	40.3	8.5	33.0	0.19	0.08	1.1	0.39	8.2	37.5	95.4	8760
Baisman Run	68.7	12.1	0.2	4.5	1.0	3.7	0.02	0.01	0.1	0.04	0.9	4.2	10.7	6600
Gwynns 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	5.7	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

Penn State Cooperative Extension

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

Watershed Education



Teaching Youth at Earth Day

Training Local Educators

Model Inputs

- **Hourly discharge data (USGS)**
- **Digital elevation map (USGS)**
- **Hourly weather and evaporation data**
  - **Evaporation data calculated from weather data**
- **Structural information on watershed (NCLD and UFORE data) e.g.,**
  - **Tree cover**
  - **Impervious cover**
  - **Shrub and grass cover**
  - **LAI**

Model Calibration

- **Auto calibrator (DOS Parameter Estimation (PEST) program)**
- **Iterative process**
- **Calibration results**
  - **Peak flow weighted (CRF1)**
  - **Base flow weighted (CRF2)**
  - **Balanced flow (peak and base) (CRF3)**