Pennypack Creek Watershed Act 167 Study

Progress Report
October 19, 2010

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Modeling and and GIS Development Assistance:
Philadelphia Water Department – Office of Watersheds

Pennypack Act 167 Meeting

October 19, 2009

Progress Report Topics

1)Act 167 Report Format

2)Current Stormwater Problems

3)Modeling and Scenarios

4) Opportunities for Improvement

5) Criteria and Standards (Ordinance)

Report Format

- ❑Runoff Characteristics
- ❑Stormwater Problems
- ❑Modeling and Scenarios
- ❑Recommended Improvements
- ❑Model Ordinance

Runoff Characteristics

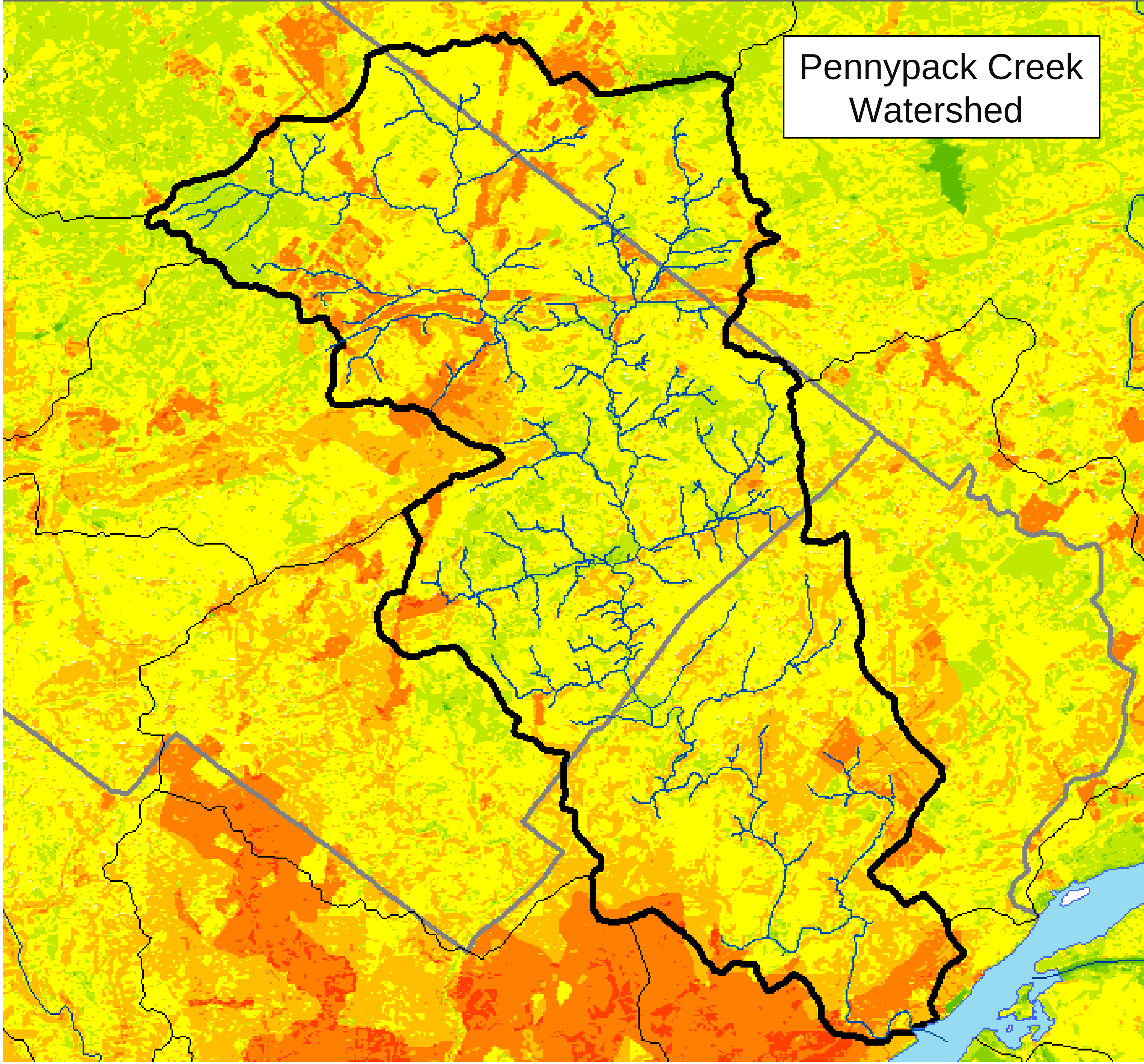
Flash Flood Potential Index

Recently Developed by
National Weather Service

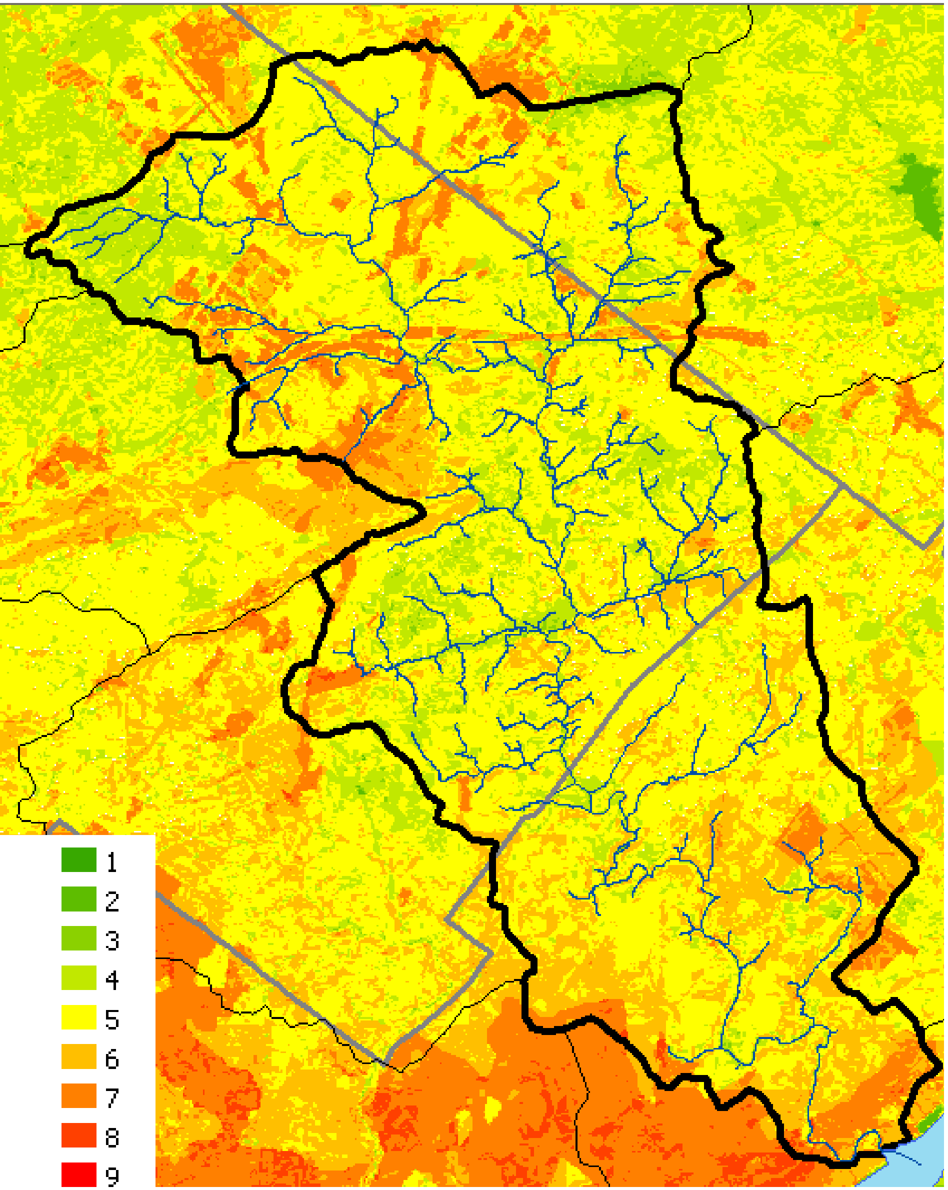
Based on analysis of
*Forest Density
*Slope
*Land Cover
*Soils

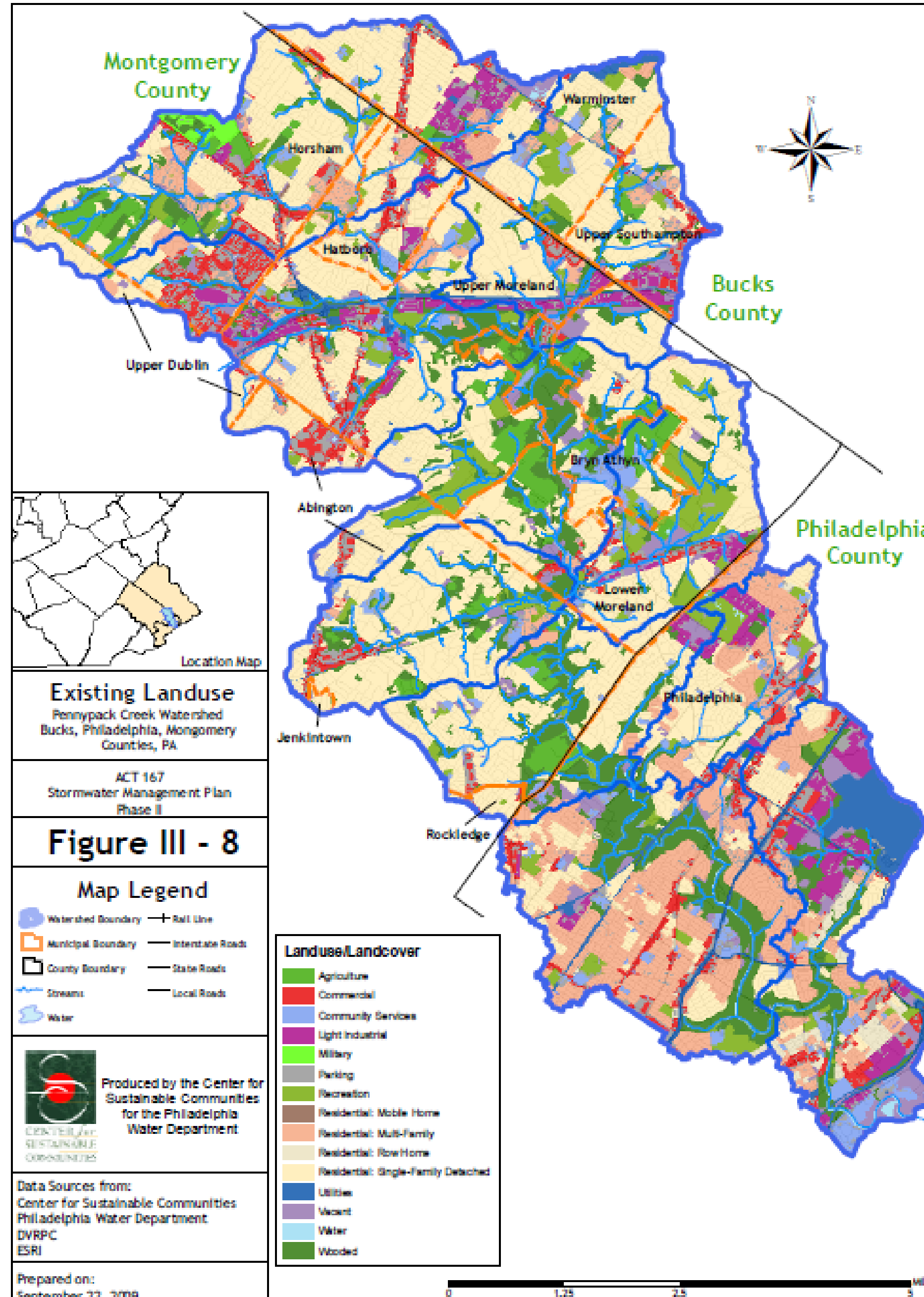
1 Lowest
2
3
4
5
6
7
8
9 Highest

Prepared by
NOAA
National Weather Service
Index Provided
Courtesy of
Raymond Kruzdlo
WFO Mt. Holly



Flash Flood Potential is Strongly Related to Land Use and Impervious Cover





Approximately 35% of the Pennypack Watershed is is impervious.

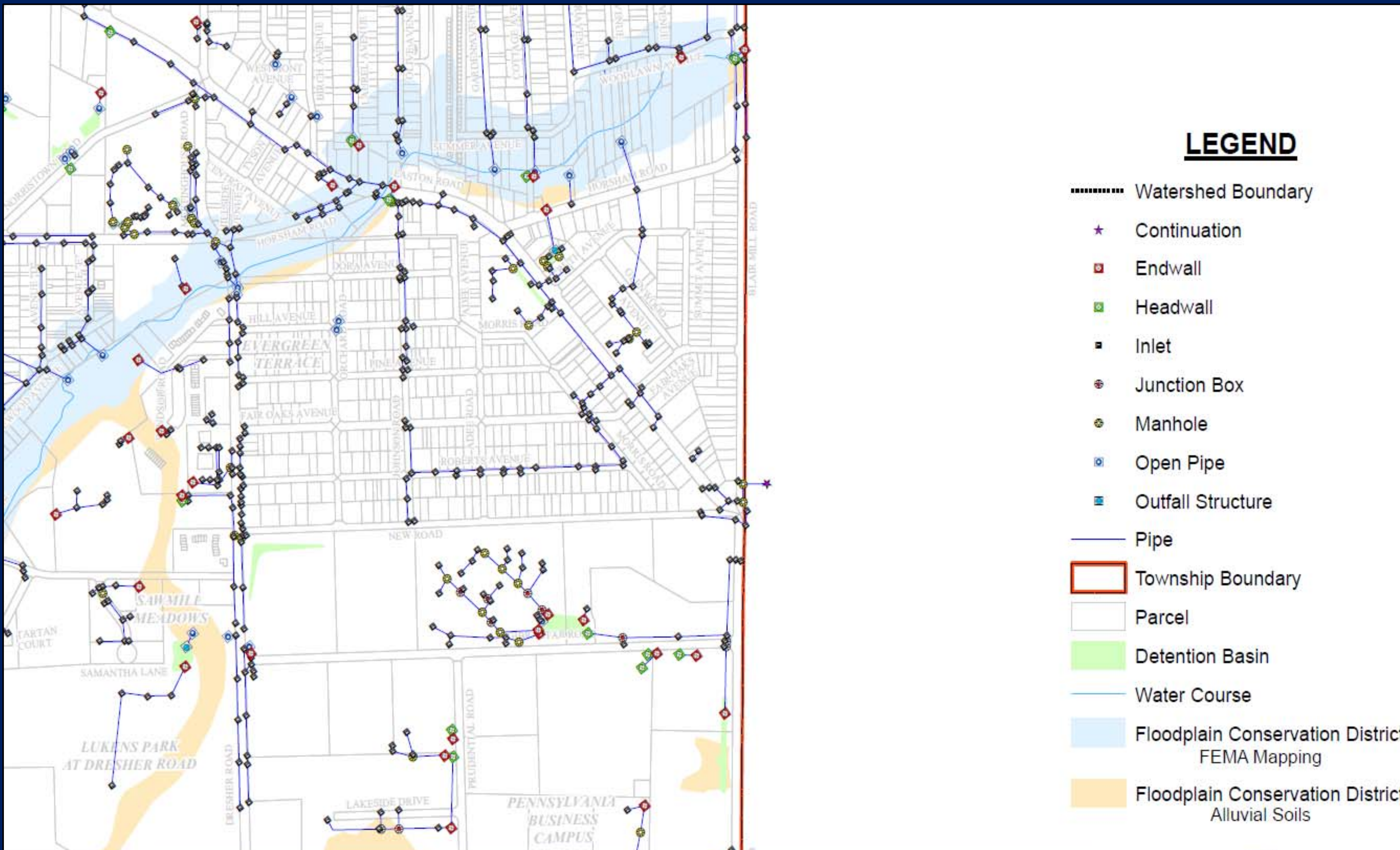
Land use change in the Pennypack has increased runoff volume and peak flows for a given storm and encroached into floodplains.

Design Storm Rainfall Totals

Design rainfall was based on the upper limit of the 90% confidence interval from NOAA Atlas 14 for the 24 hour Type II storm.

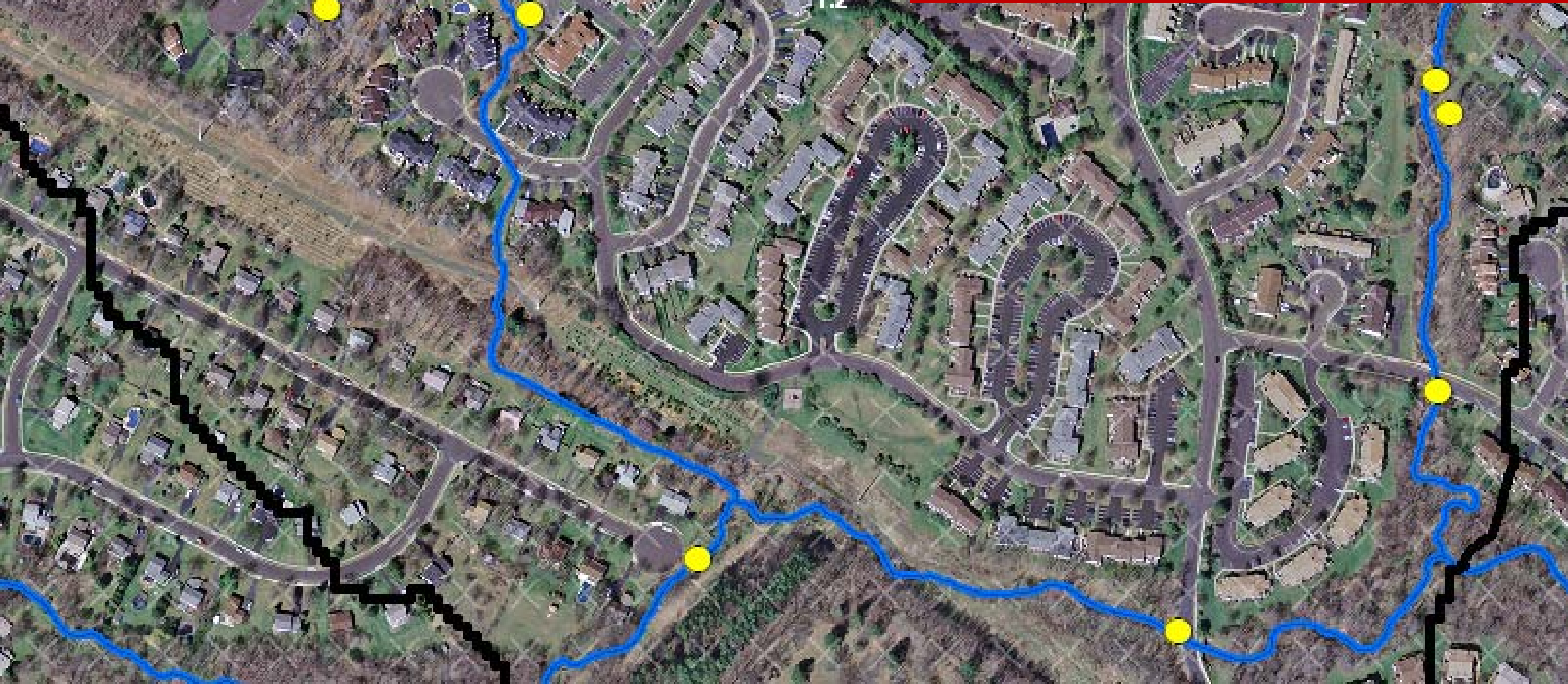
Storm Frequency	Total Precipitation (in)
1-Yr	2.98
2-Yr	3.60
5-Yr	4.55
10-Yr	5.35
25-Yr	6.50
50-Yr	7.50
100-Yr	8.60
500-Yr	11.61

In addition to land use change, stormwater collection has changed the pathways and timing of runoff.



Stormwater System Map Provided by Horsham Township

Stormwater collection and discharge affects drainage throughout the watershed.
It is estimated that 70 percent of the watershed is covered by some form of stormwater collection.



Stormwater Problems

Stormwater Problems in the Pennypack Watershed

- Water Quality Impairment
- Erosion
- Flood Damage

Water Quality Impairment
Section 303 (d) – Clean Water Act

Four Designated Use Categories

- Aquatic Life
- Water Supply
- Fish Consumption
- Recreation

Summary of 303 (d) List Impairments In the Pennypack Watershed

Impairment	Total Miles
Agriculture	0.4
Industrial/Municipal Point Source	9.5
Residential Runoff	7.3
Urban Runoff	61.8

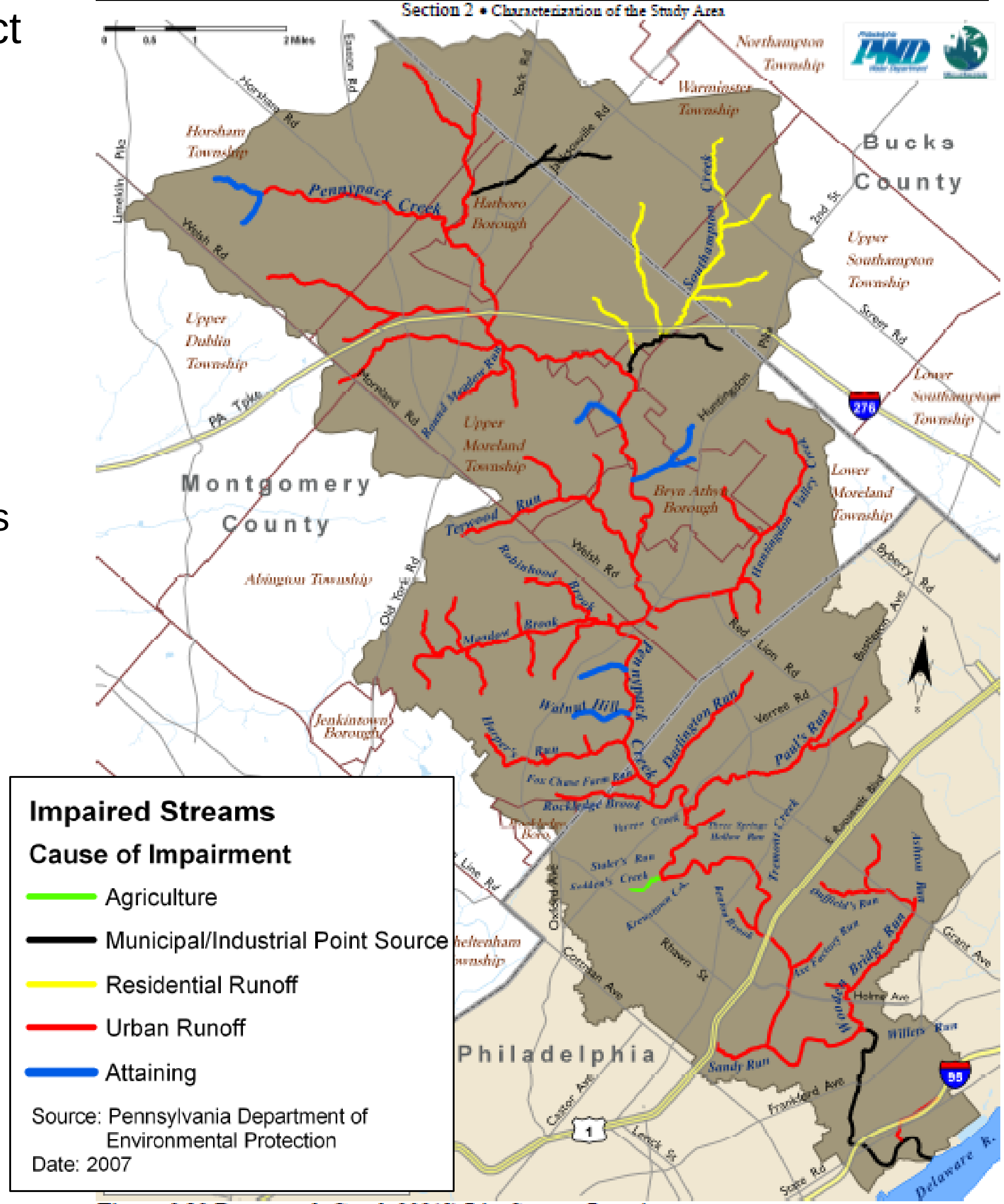
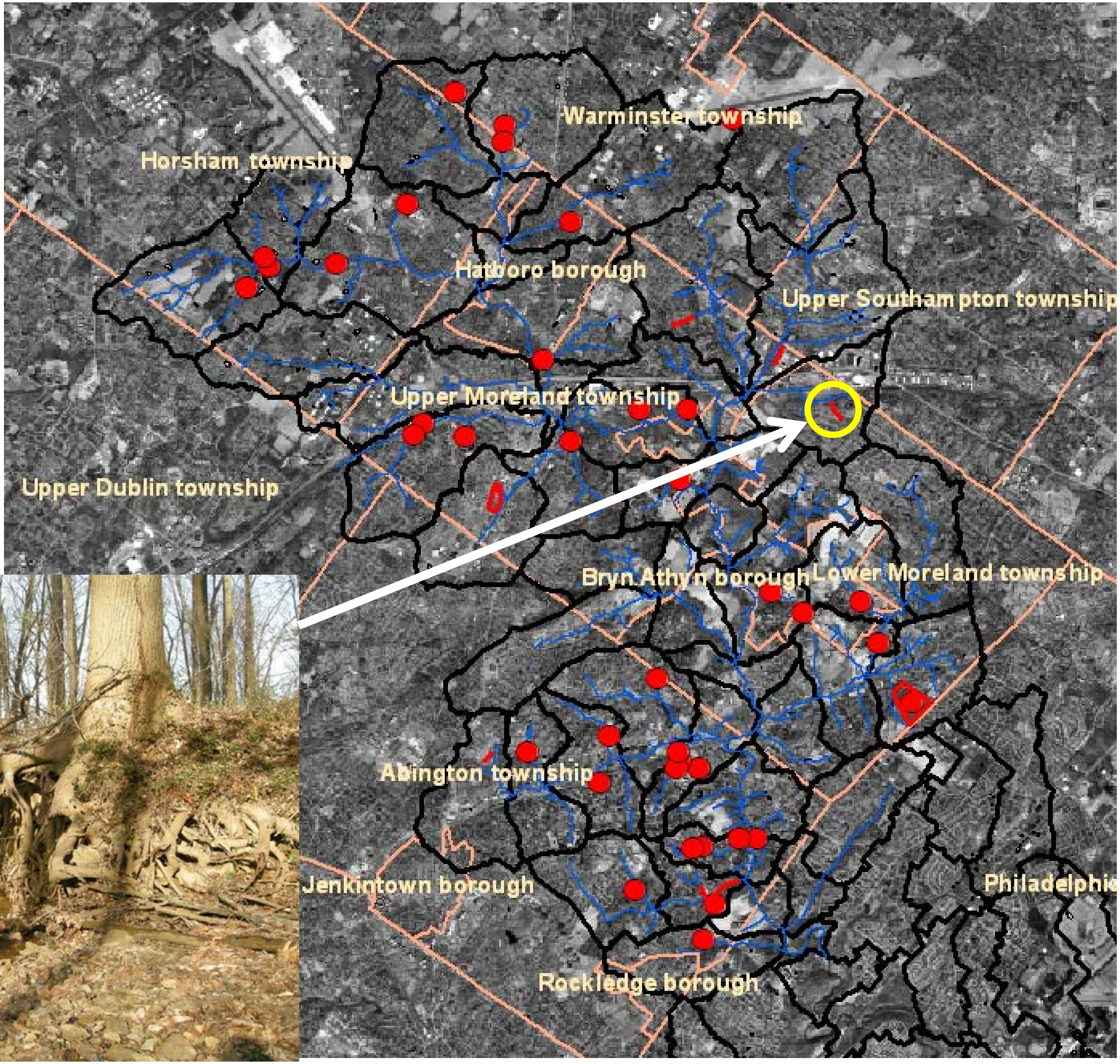


Figure 2.10 Pennypack Creek 303(d) List Stream Impairments

Reference: Table 2.12 and Figure 2.10 of the Comprehensive Characterization Report for the Pennypack Creek Watershed – Philadelphia Water Department, 2009

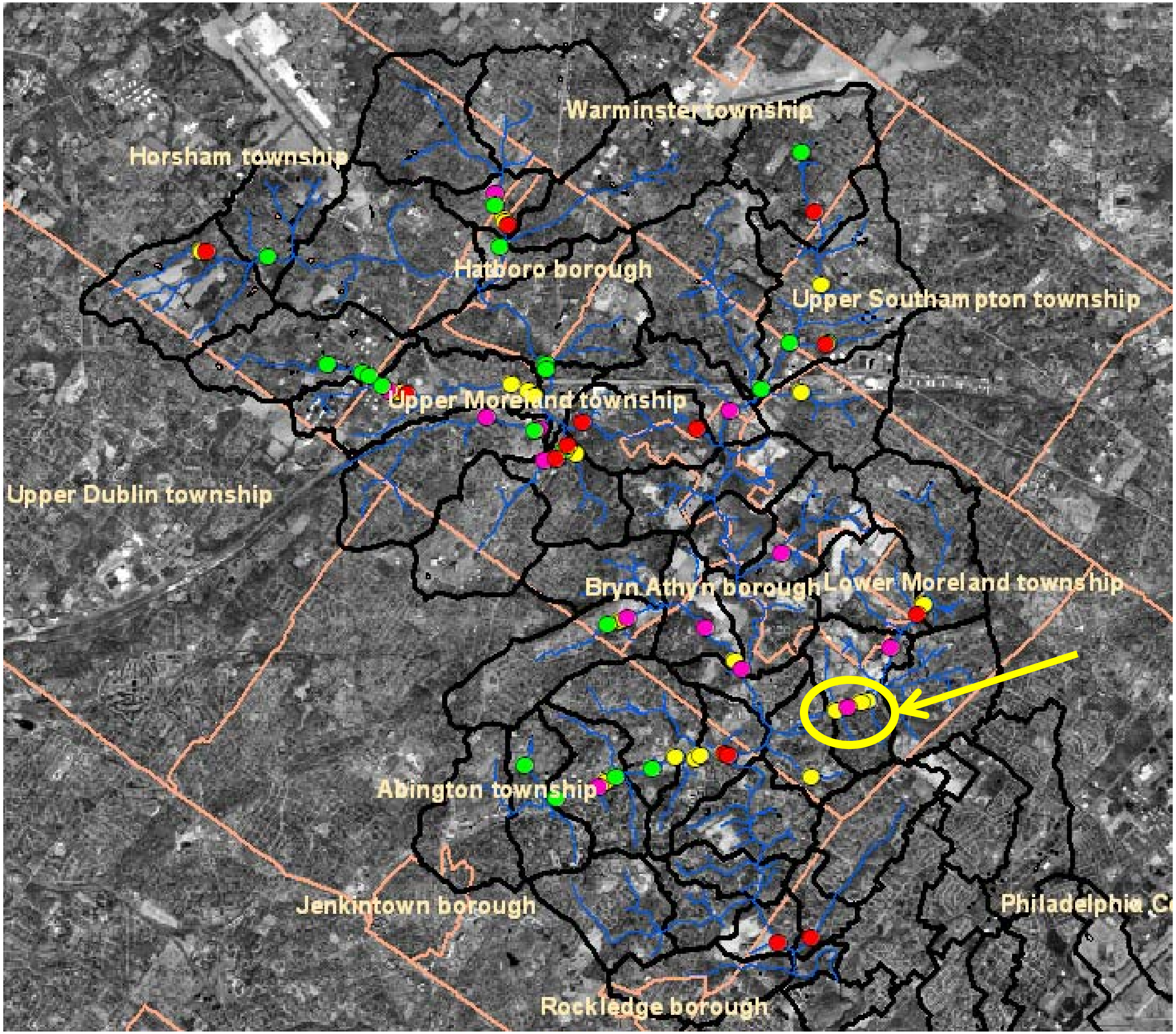
Erosion Problem areas Identified from Field observations



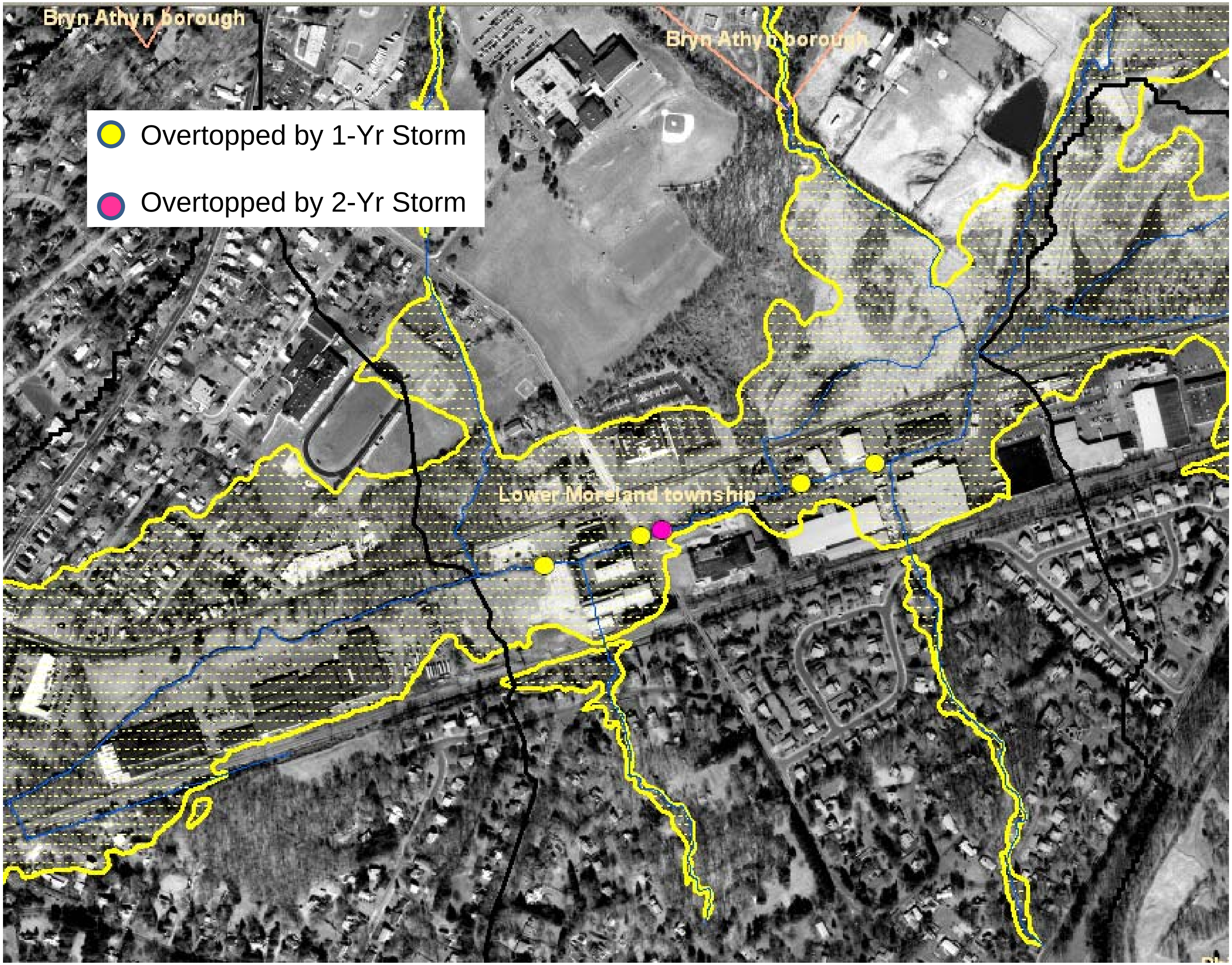
Bridges Most Frequently Flooded

Overtopped By:

- ≥ 1-Yr Storm
- ≥ 2-Yr Storm
- ≥ 5-Yr Storm
- ≥ 10-Yr Storm



Obstructions restrict flow and raise upstream flood elevations

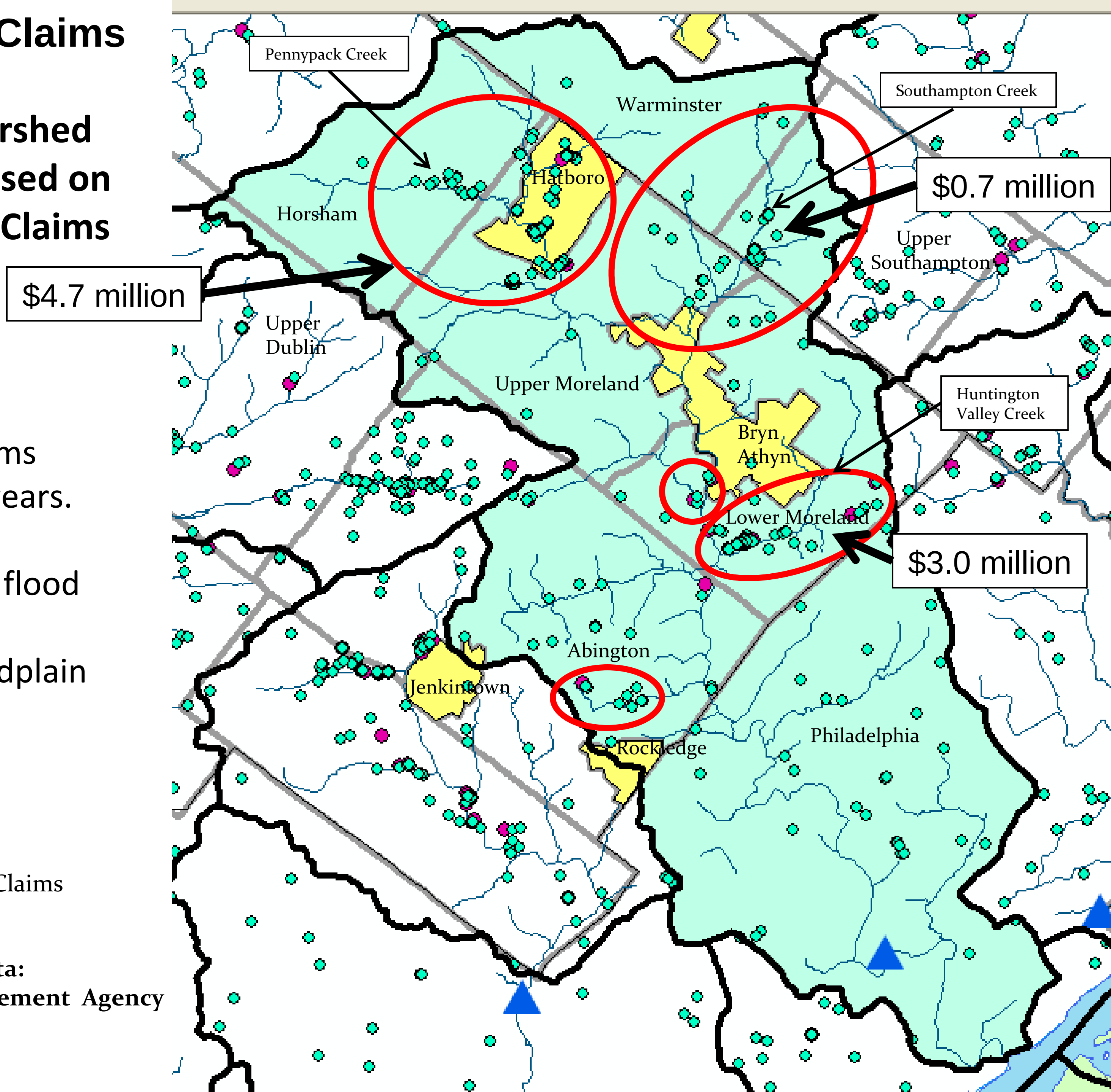


Flood Insurance Claims

Pennypack Watershed Damage Areas Based on Flood Insurance Claims 1978 to 2007

This slide shows areas with the highest density of flood insurance claims during the past 30 years.

It does not show all flood damage locations because not all floodplain residents purchase flood insurance.



- Flood Insurance Claim
- Repeat Flood Insurance Claims

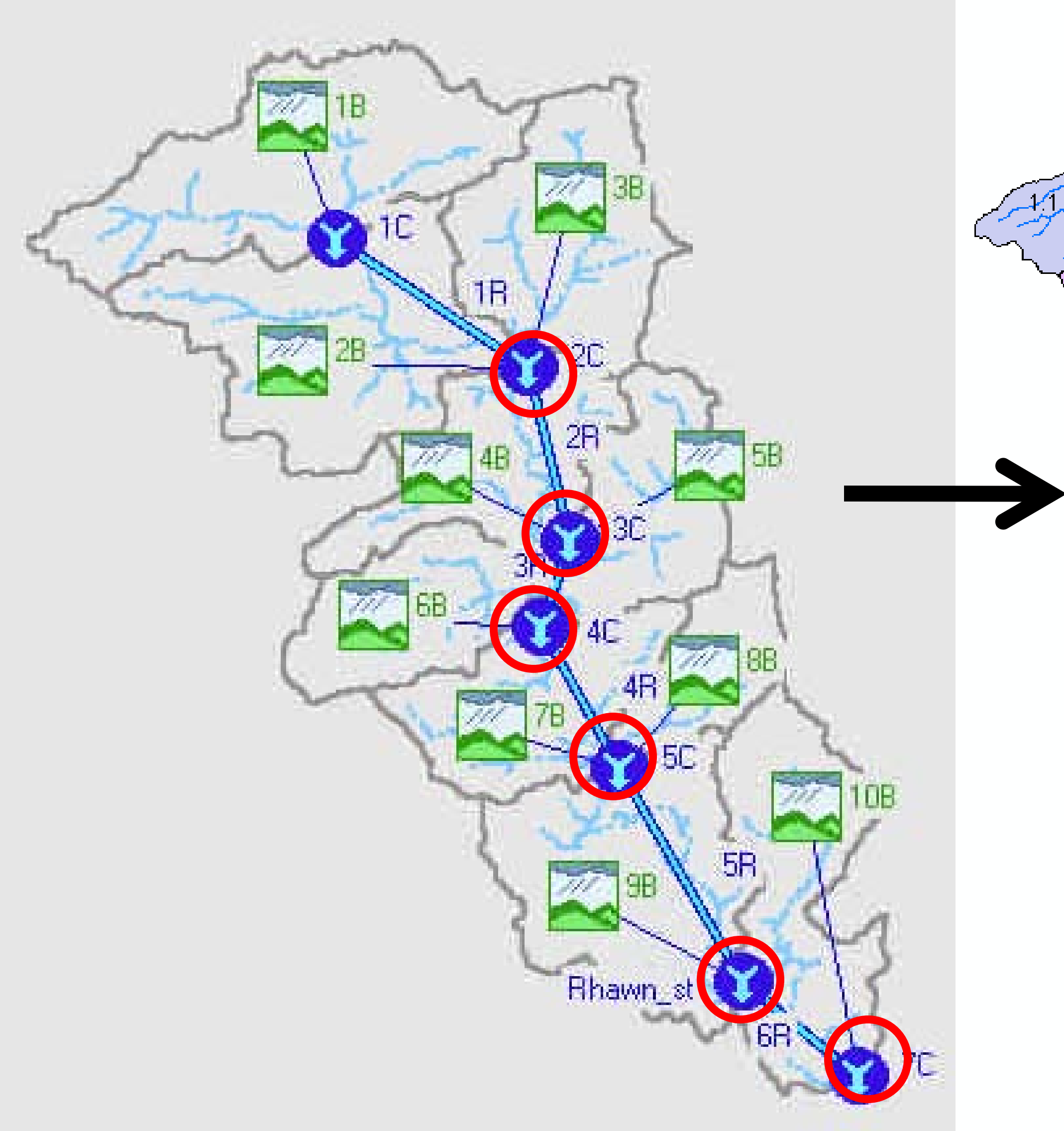
Source of Flood Claims Data:
Federal Emergency Management Agency

Model Development

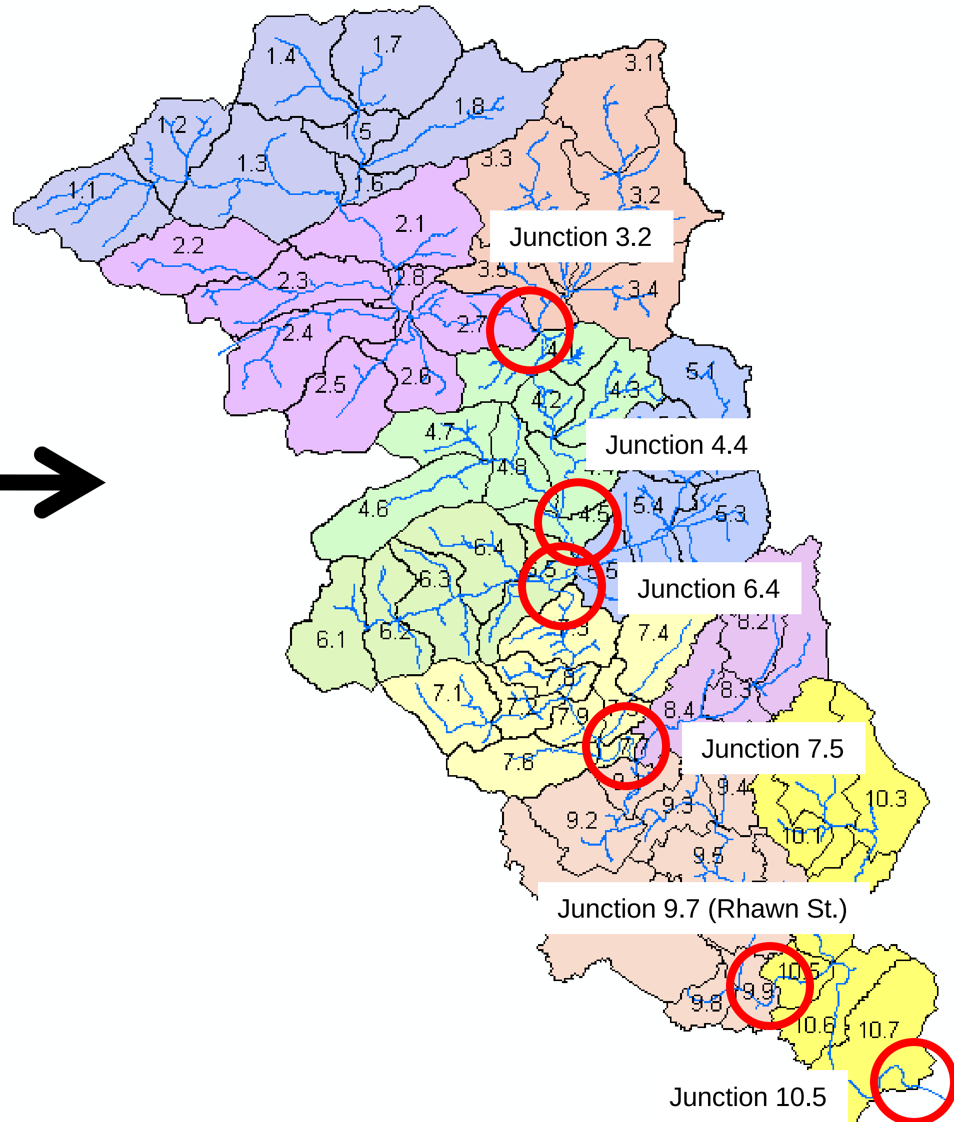
Model Development

Temple's recent Flood Insurance Study model was used as a starting point to develop a more detailed model with 68 subbasins.

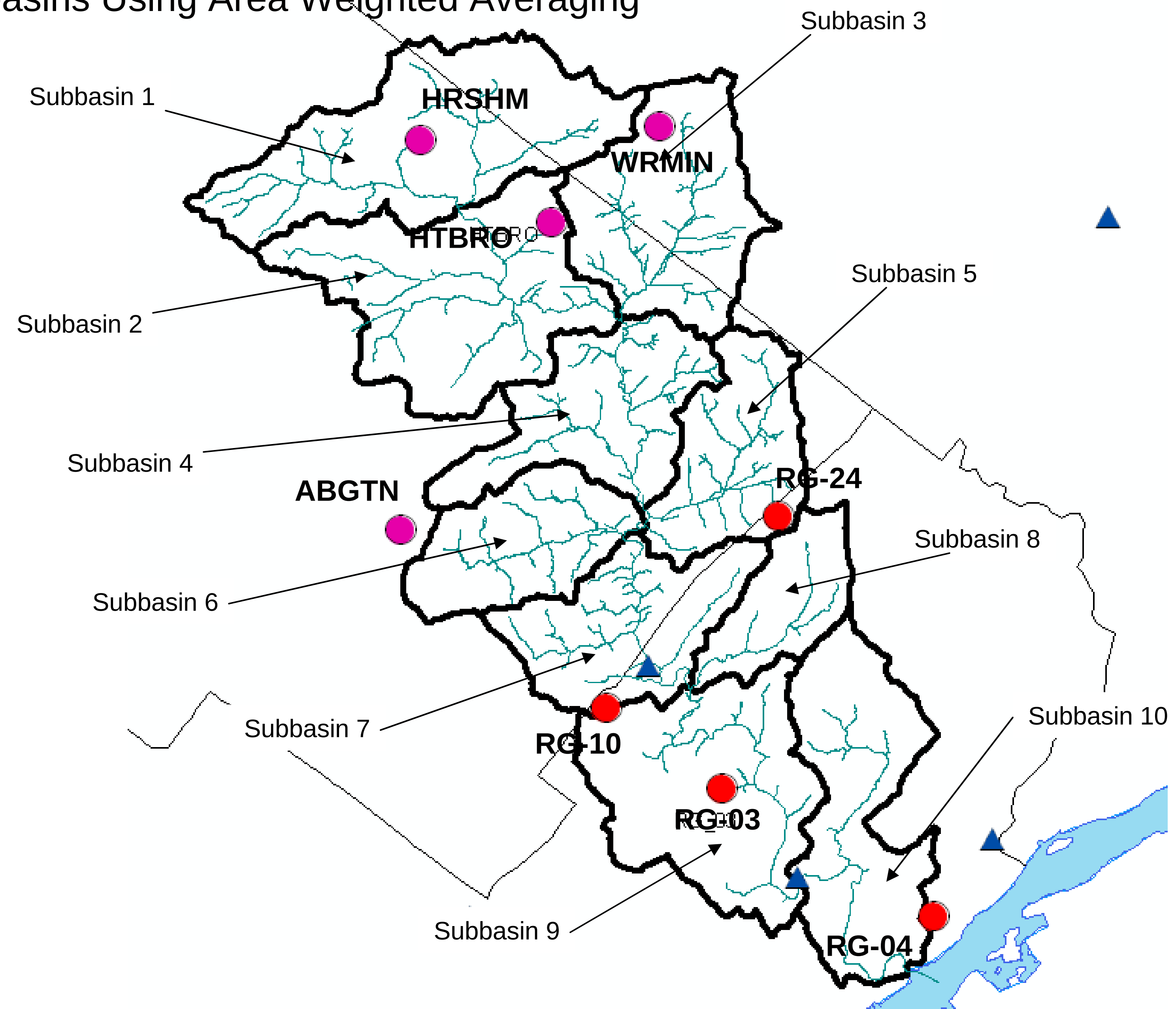
Original 10 Subasin Model



Detailed Model – 68 Subasins



Rain Observed at Stations was Distributed Over the 10 Subasins Using Area Weighted Averaging



Thiessen Polygons Used for Precipitation Gage Weighting

Weightings for Precipitation Gages

Weightings are the fractions of a subasin that are assigned to a particular gage

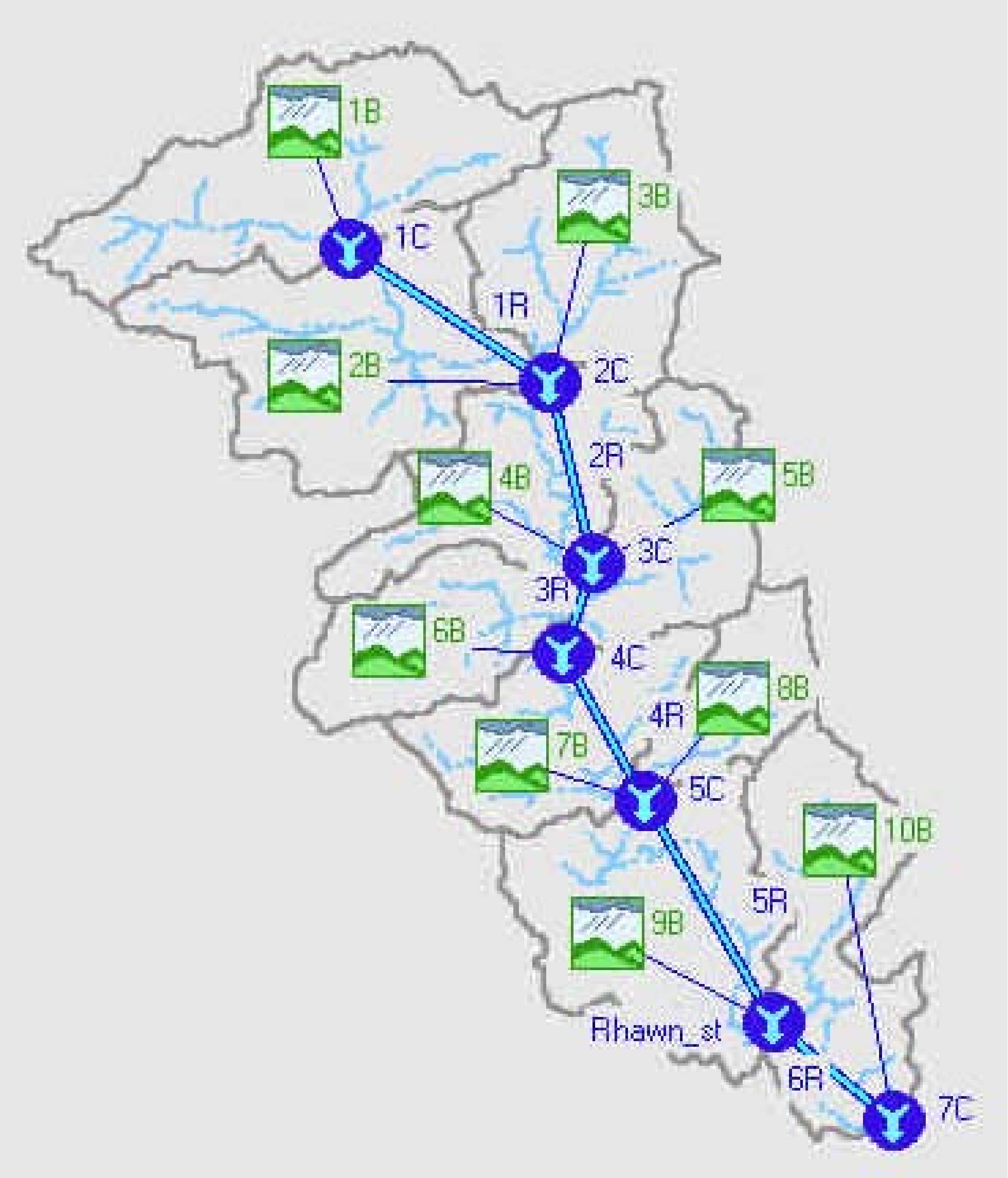
Precipitation Gages

		HRSHM	WRMIN	HTBRO	ABGTN	RG3	RG10	RG24	RG4
Subbasin 1		0.789	0.128	0.083					
Subbasin 2		0.281		0.569	0.150				
Subbasin 3			0.582	0.418					
Subbasin 4				0.361	0.308			0.332	
Subbasin 5								1.000	
Subbasin 6					0.828		0.093	0.079	
Subbasin 7					0.025		0.752	0.222	
Subbasin 8						0.082	0.086	0.832	
Subbasin 9						0.814	0.186		
Subbasin 10						0.360		0.101	0.539

*The model was run for 2007 and 2008 rainfall events.

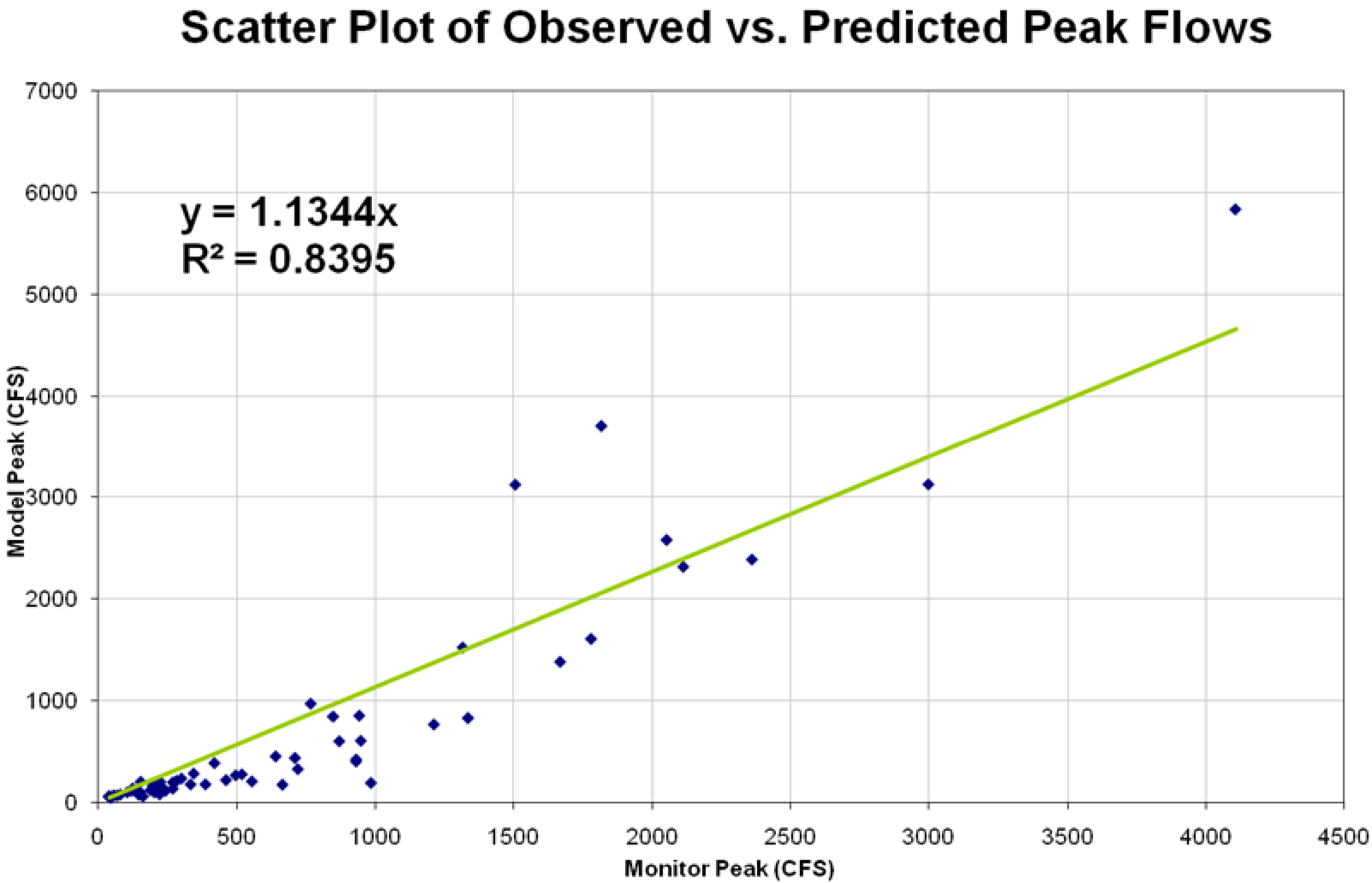
*60 different events were modeled.

*Predicted peak flow and volume from the model were compared to observed data at the USGS gaging station at Rhawn Street.



Test Results for Sixty Precipitation Events – 2007-2008

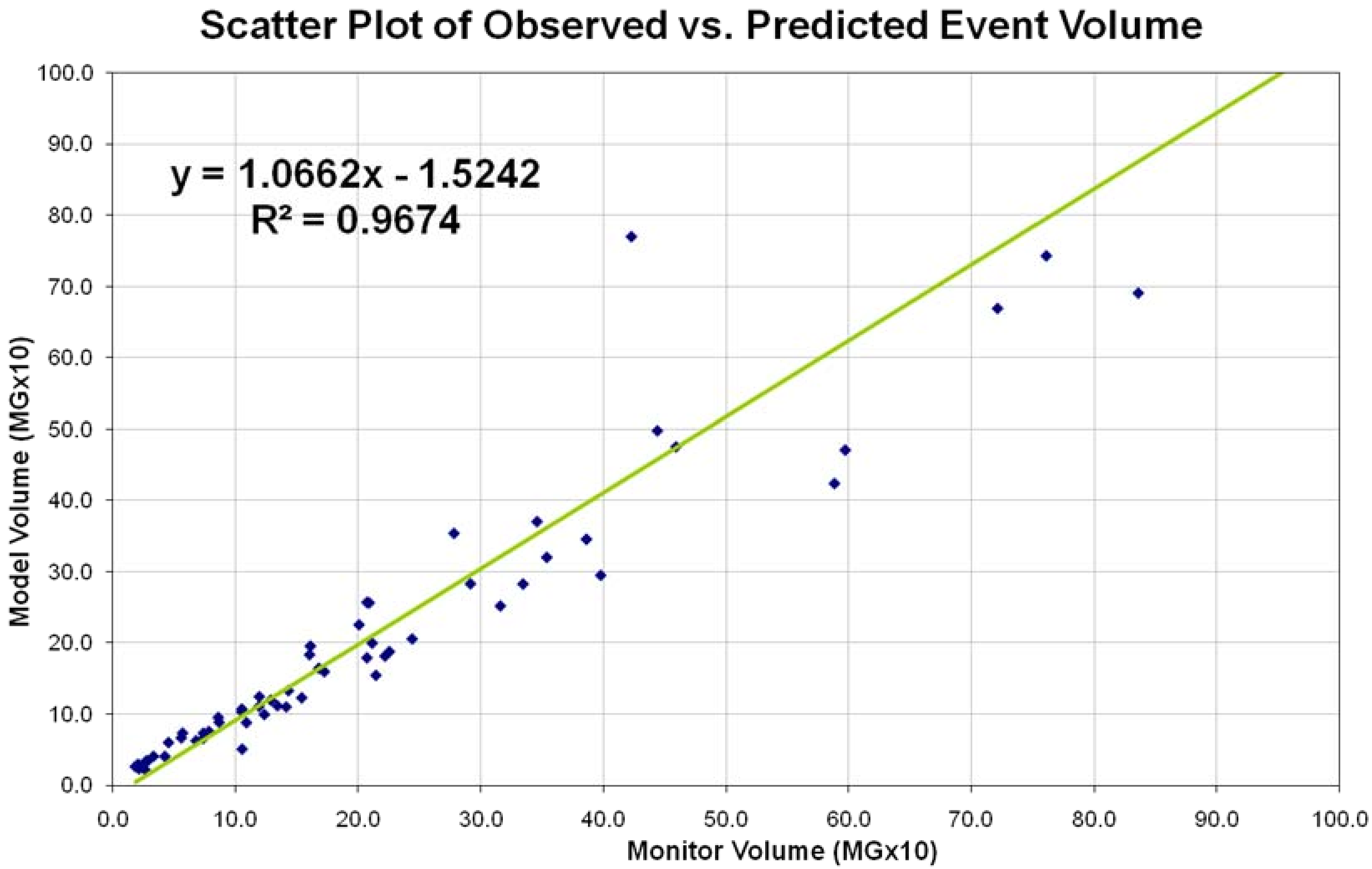
The model output for each of 60 events and compared to Observed Data



Observed flow at USGS Stream Gage at Rhawn Street

Analysis of results was performed by the Philadelphia Water Department

Test Results for Sixty Precipitation Events – 2007-2008



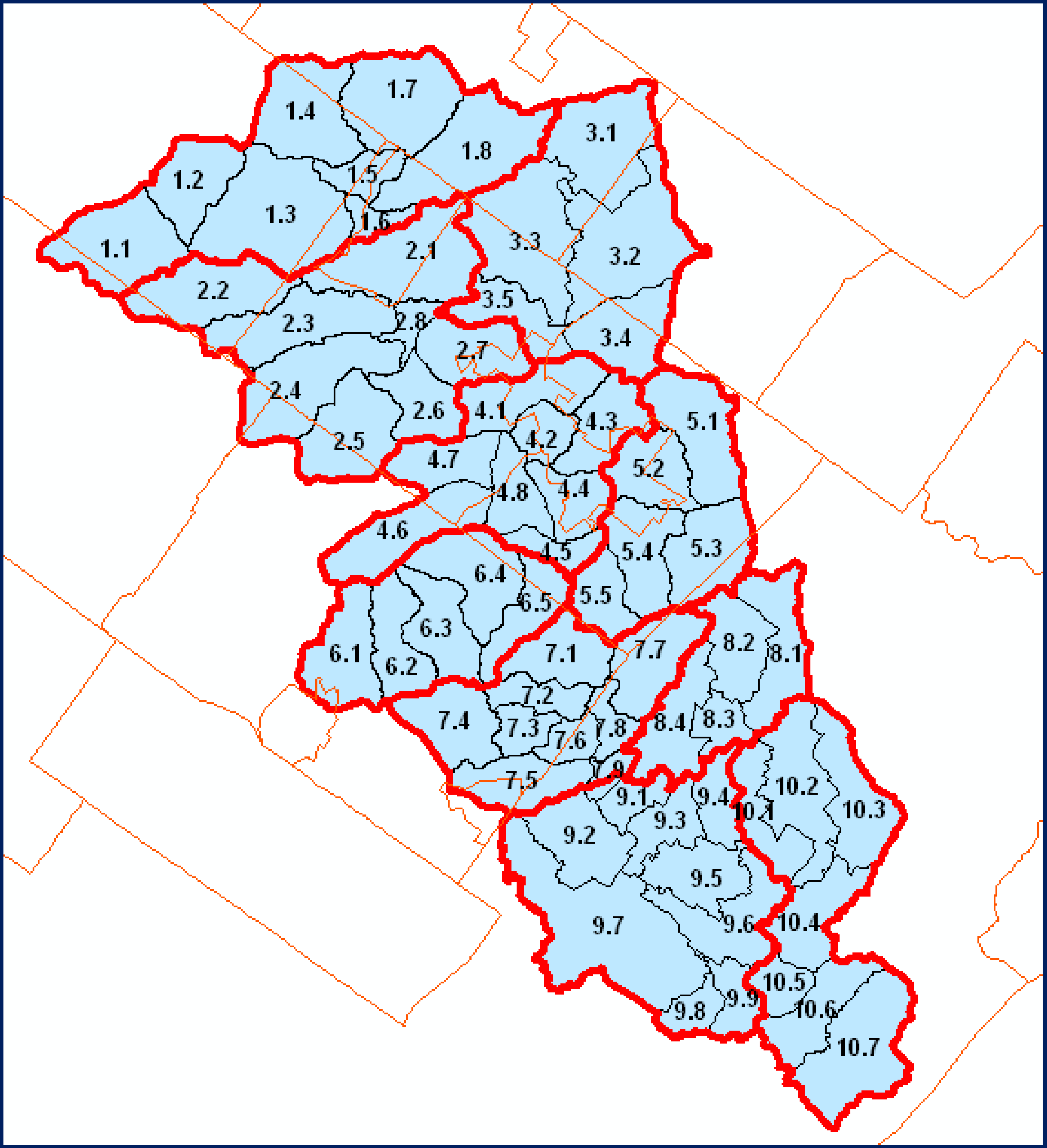
Observed volume at USGS Stream Gage at Rhawn Street

Analysis of results was performed by the Philadelphia Water Department

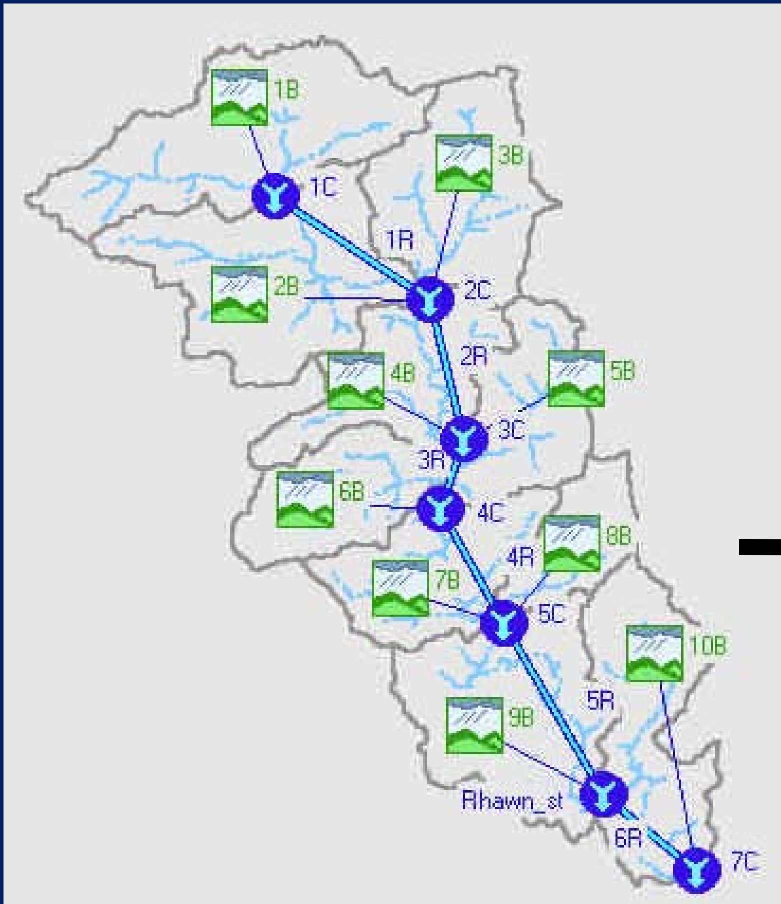
Model Inputs and Method

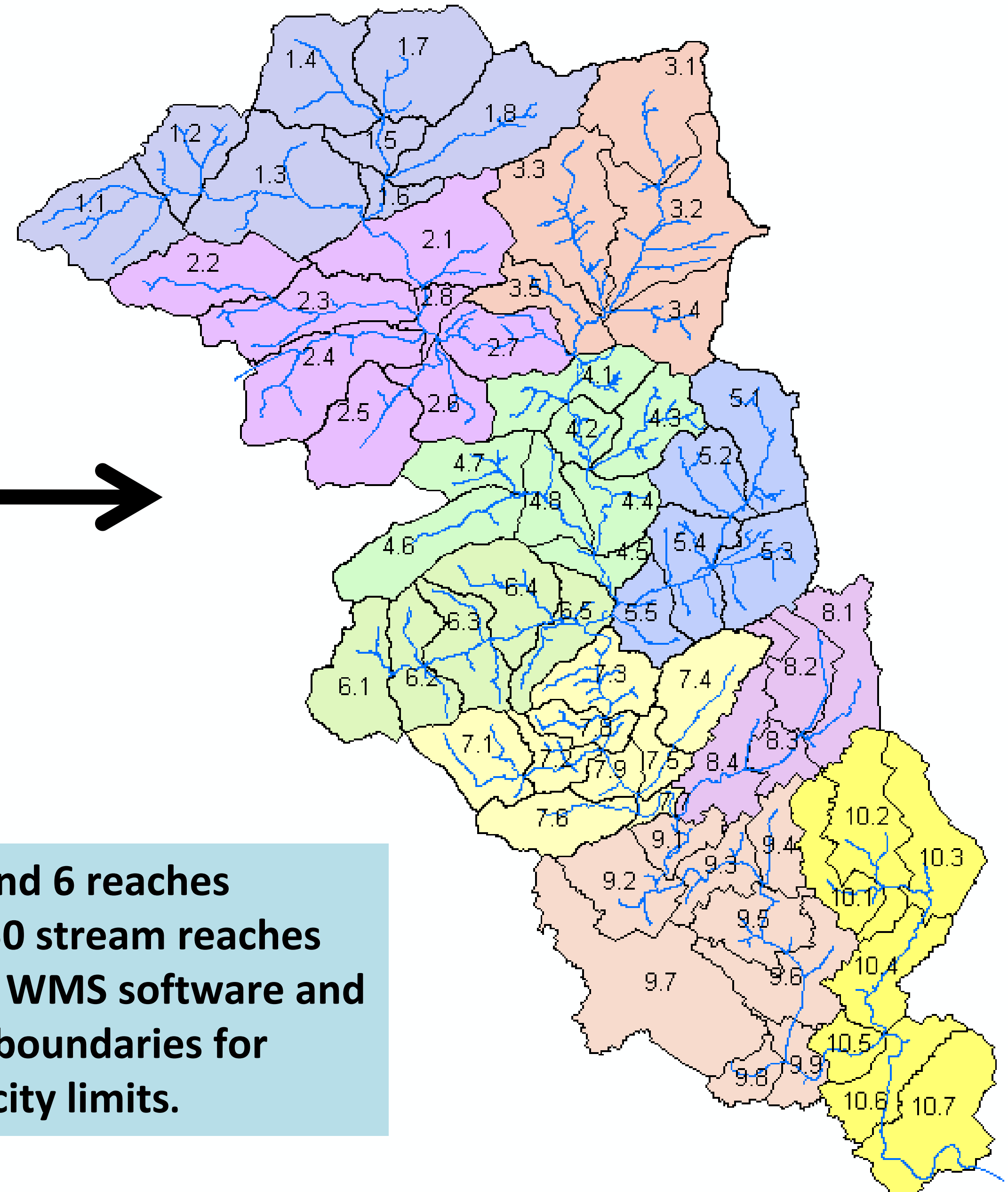
Pennypack Act 167 Hydrologic Model

New smaller subasins were grouped within the 10 larger subasins of the original model so that test comparisons could be made.



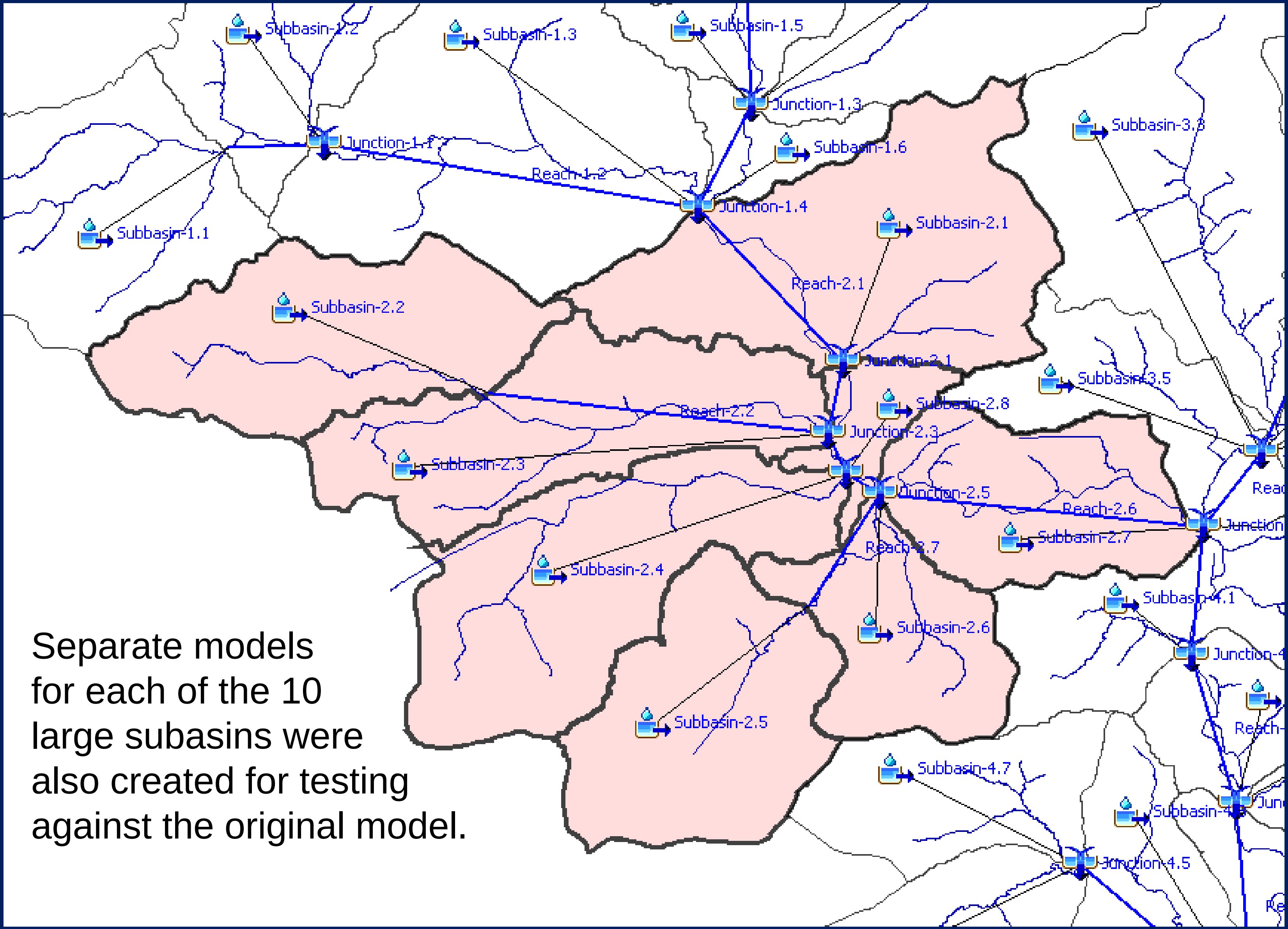
Pennypack Watershed Delineation for Detailed Model





- **The Original model had 10 subasins and 6 reaches**
- **The new model has 68 subasins and 50 stream reaches**
- **Small subasins were delineated using WMS software and were edited using ArcMap and PWD boundaries for sewer sheds within the Philadelphia city limits.**

The new hydrologic model was developed using HEC-HMS and the NRCS Curve Number Method for the 68 subasins

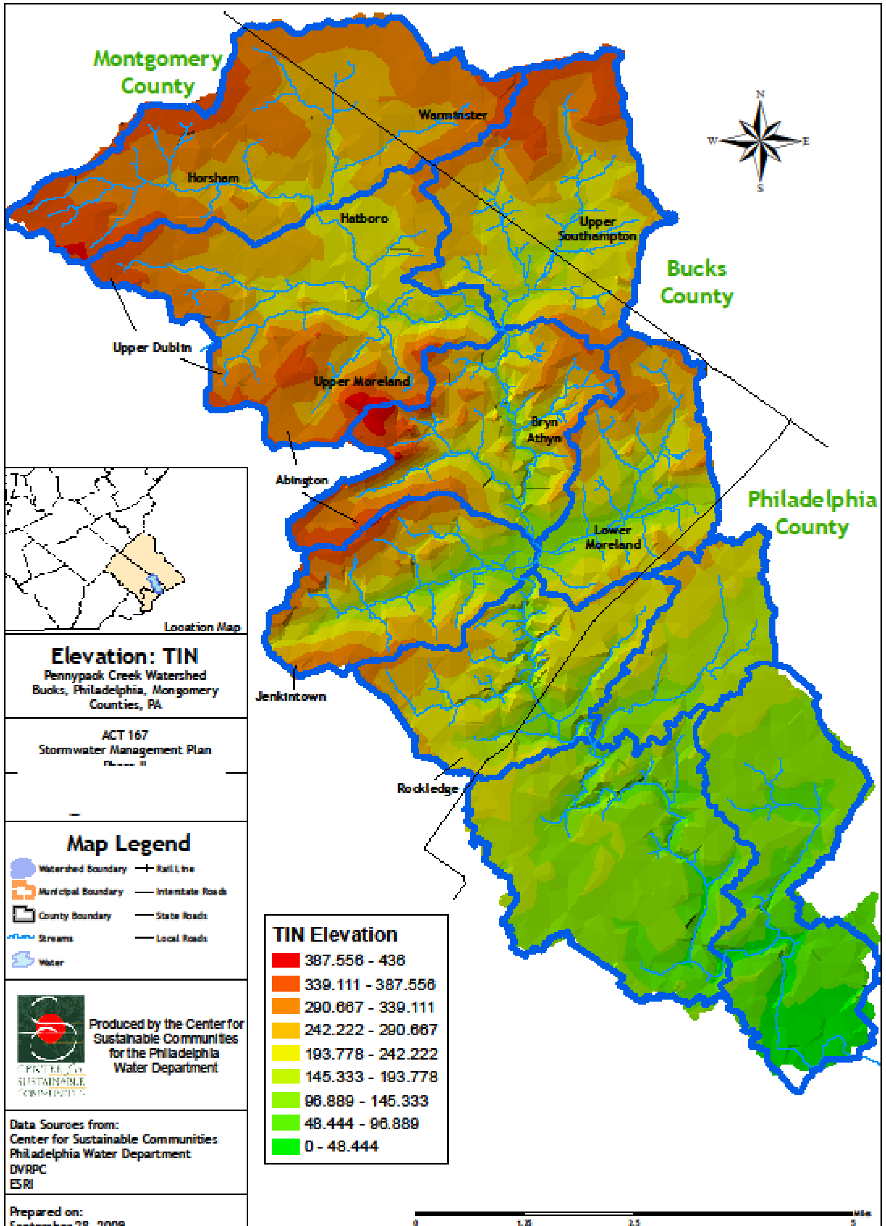


Separate models for each of the 10 large subasins were also created for testing against the original model.

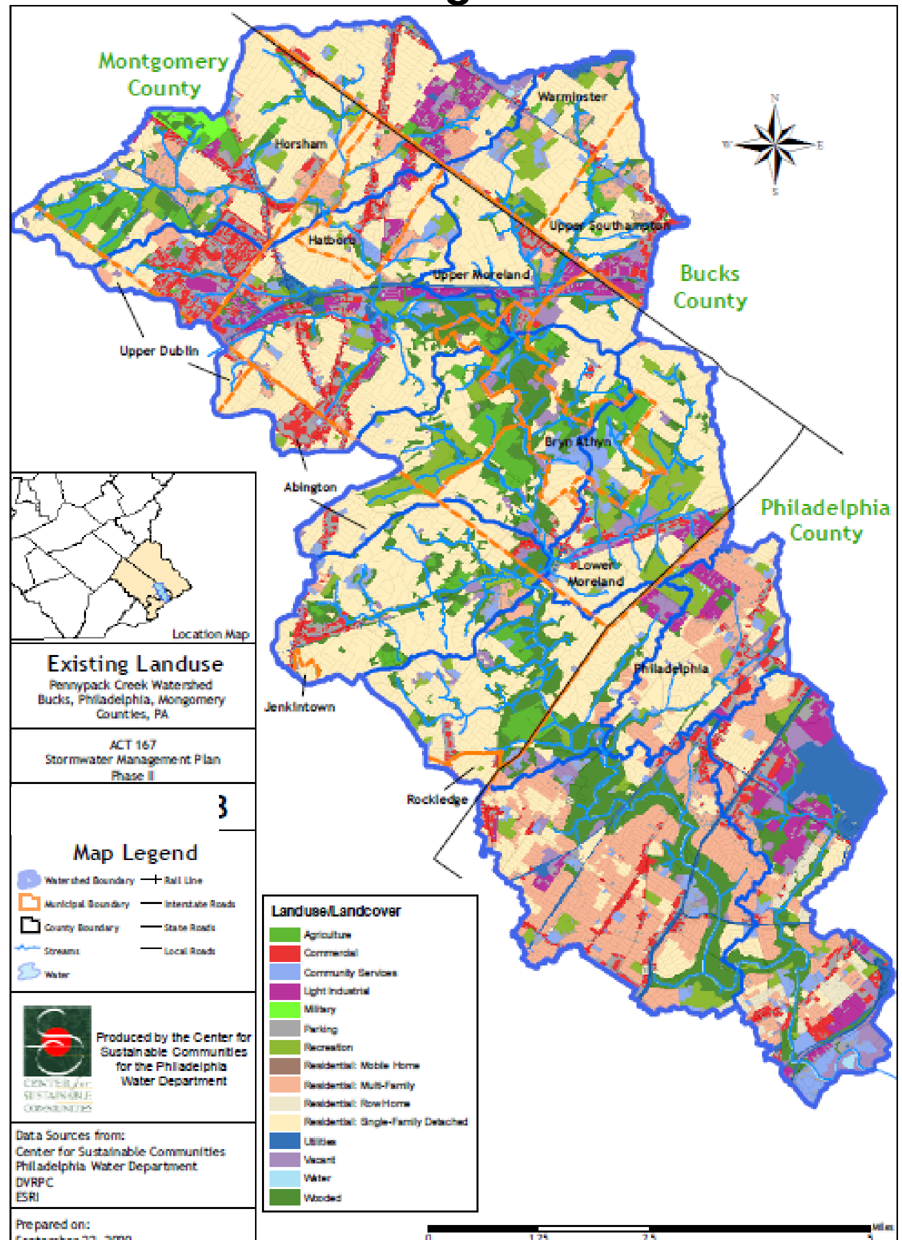
Physical Characteristics of the Pennypack Watershed

Dense Development with Open Main Stem Corridor in Mid and Lower Reaches

Elevation

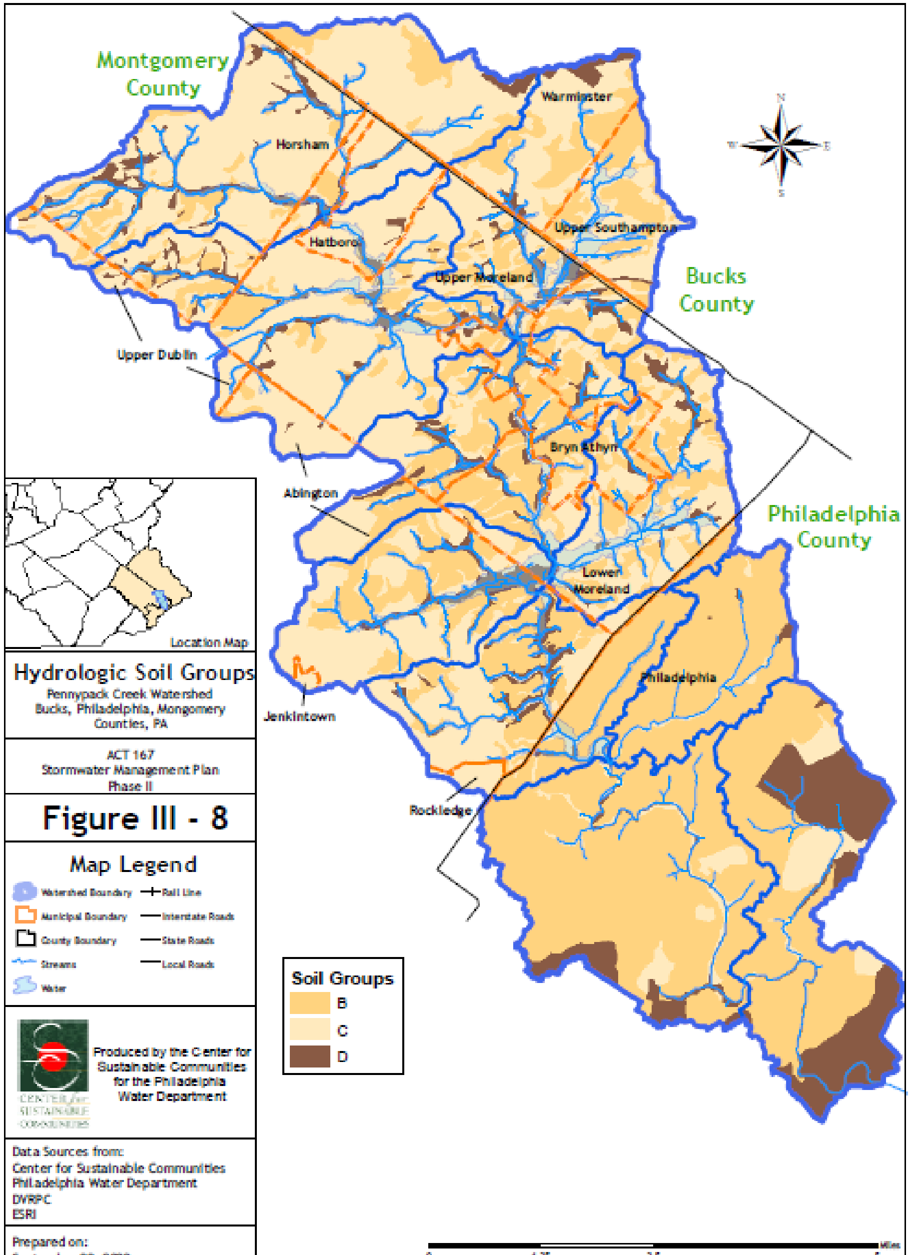


Existing Land Use

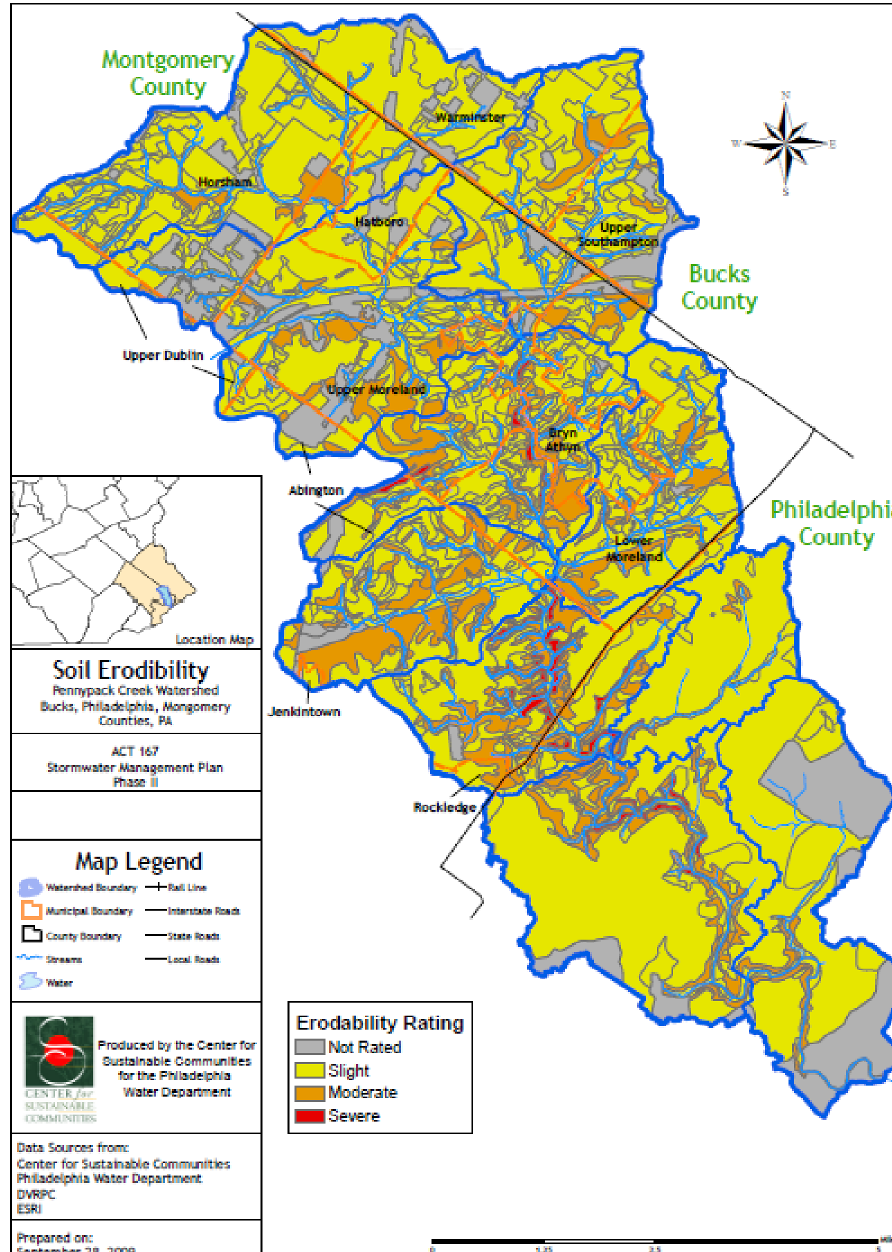


Physical Characteristics of the Pennypack Watershed

Hydrologic Soil Group



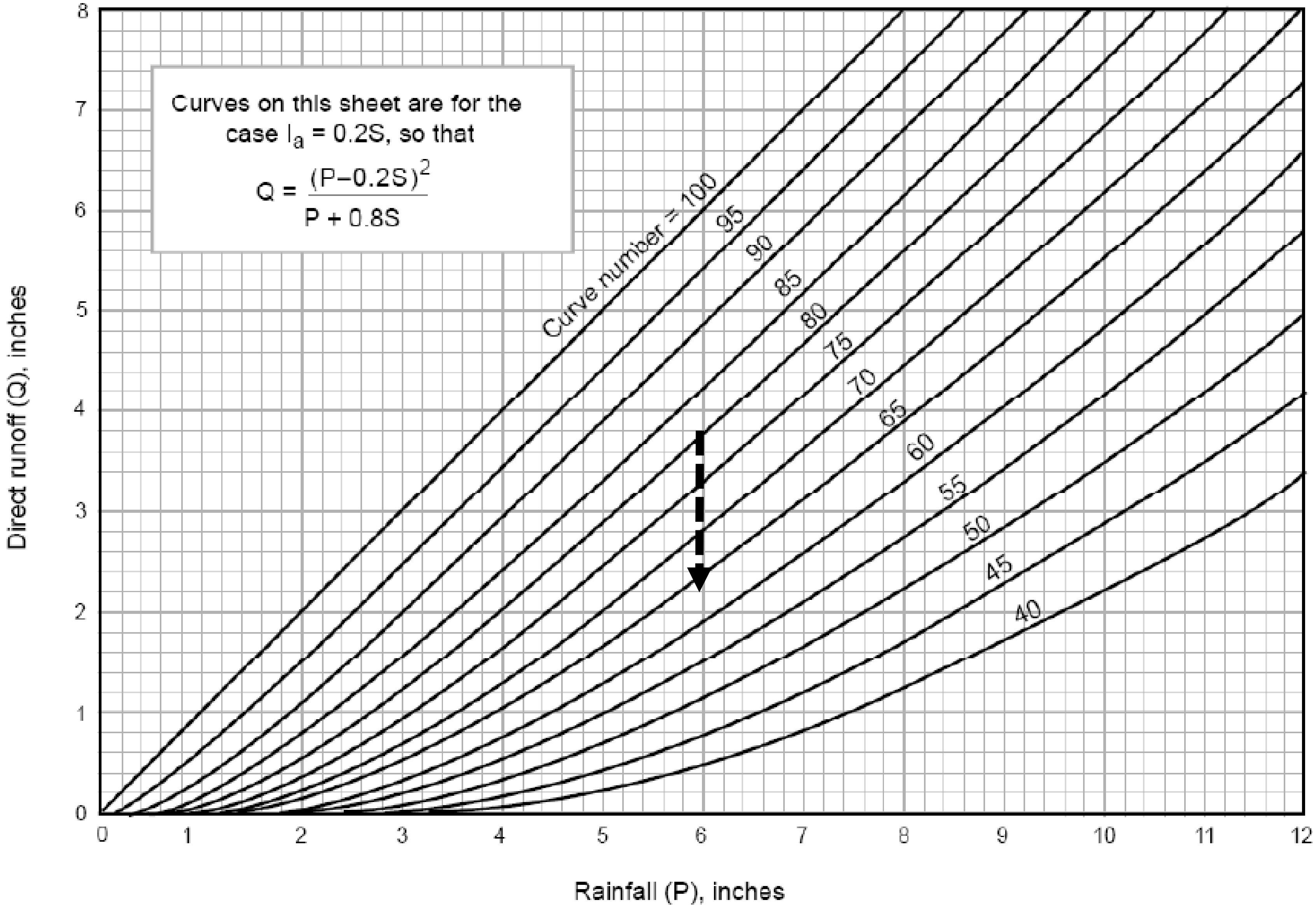
Soil Erodibility Rating



Curve Number Assignments

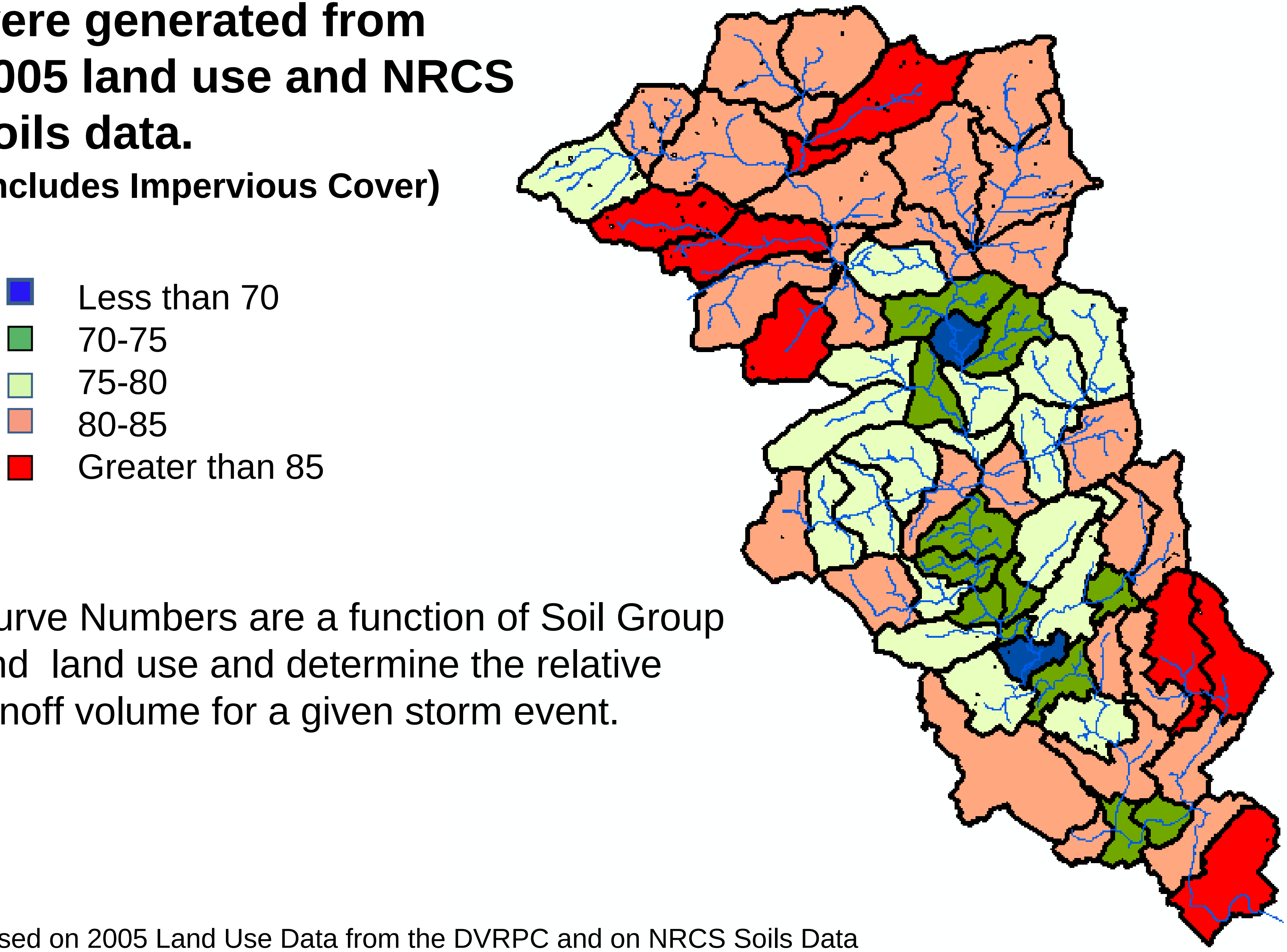
Landuse Description (2005 Data)	A	Hydrologic Soil Group B	C	D
"Residential: Single-family detached"	57	72	81	86
Agriculture	49	69	79	84
Wooded	36	60	73	77
Vacant	77	85	90	92
Water	100	100	100	100
Residential:Multi-Family	77	85	90	92
Parking	98	98	98	98
Residential:Row Home	77	85	90	92
Residential: Mobile-Home	77	85	90	92
Manufacturing:Light Industrial	81	88	91	93
Transportation	83	89	92	93
Utility	89	92	94	95
Commercial	89	92	94	95
Community Services	81	88	91	93
Military	63	77	85	88
Recreation	49	69	79	84

Figure 2: Solution of the NRCS runoff equation



Composite Runoff Curve Numbers were generated from 2005 land use and NRCS soils data.

(Includes Impervious Cover)



Curve Numbers are a function of Soil Group and land use and determine the relative runoff volume for a given storm event.

Based on 2005 Land Use Data from the DVRPC and on NRCS Soils Data

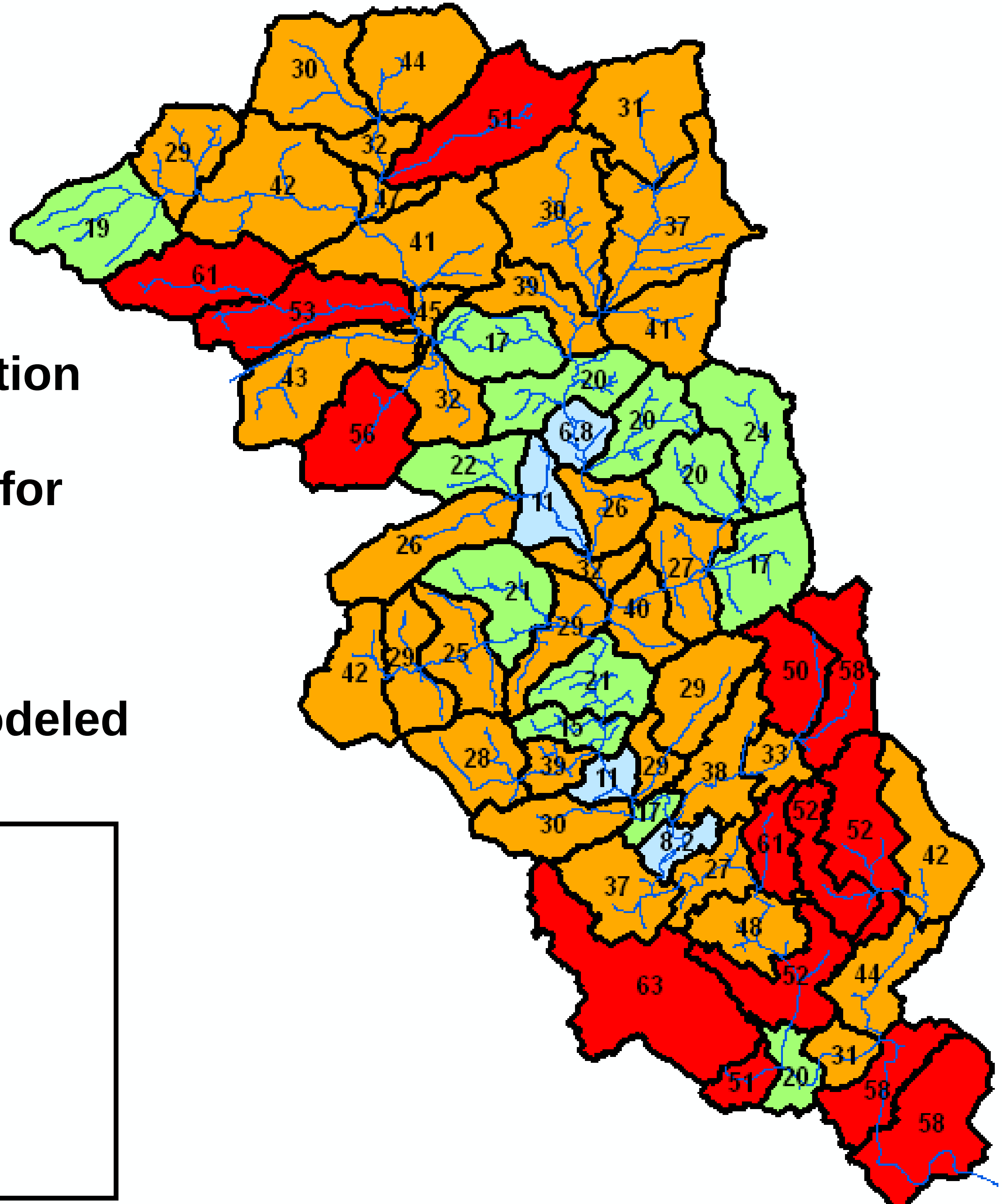
Percentage Impervious Cover for Land Uses

Land Use Type	% Impervious Cover
Commercial	85
Manufacturing	72
Residential Multi-Family	65
Residential Mobile Home	65
Residential Row Home	65
Residential Single Family	30
Parking	100
Utility	85

% Impervious Cover was estimated for each land use type and assumed to be directly connected.

This was used in combination with the composite CN to calculate the pervious CN for each subasin.

The % impervious and the pervious CN were then modeled in HEC-HMS.



Less than 15%

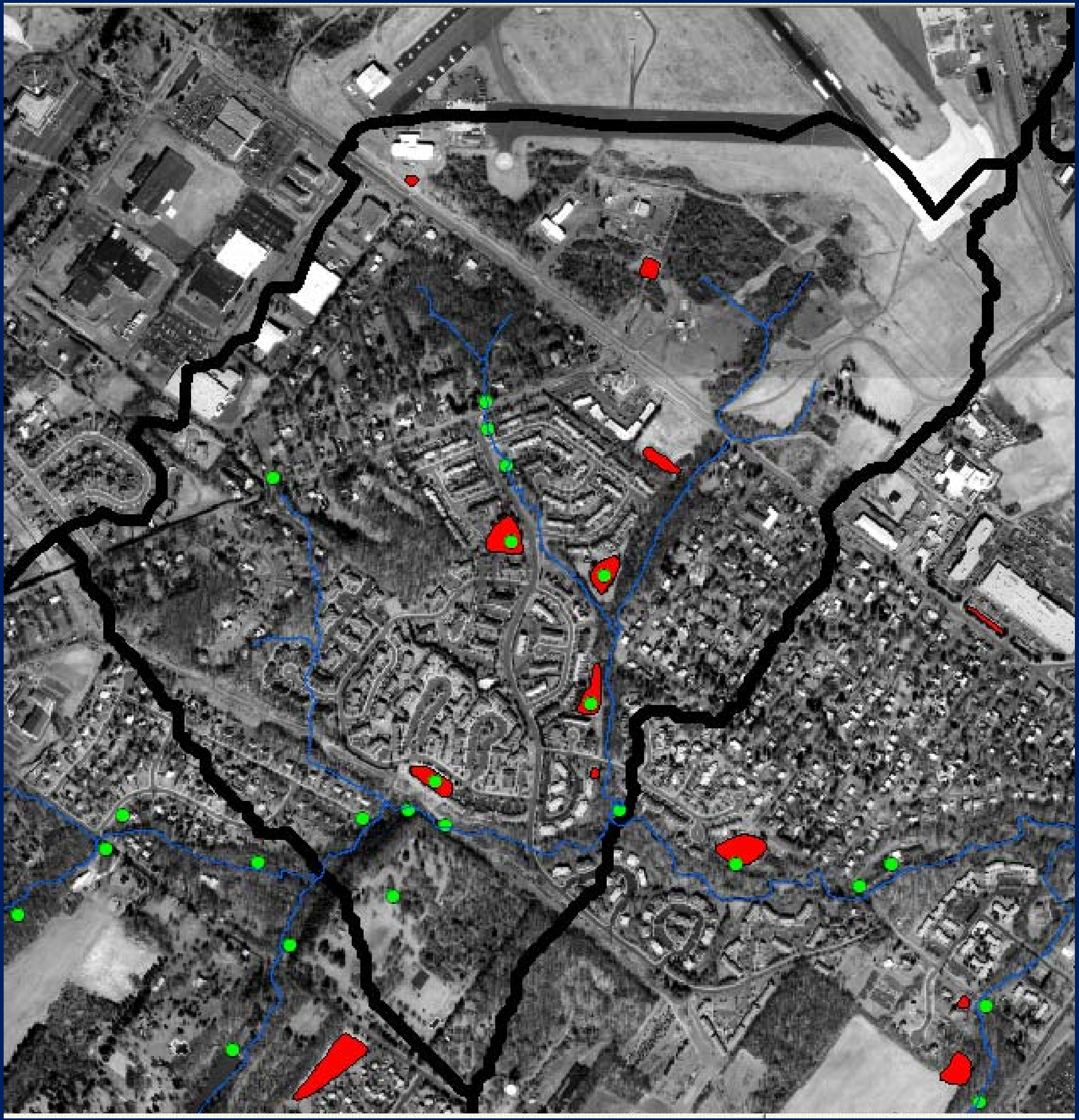
15% - 25%

25%-50%

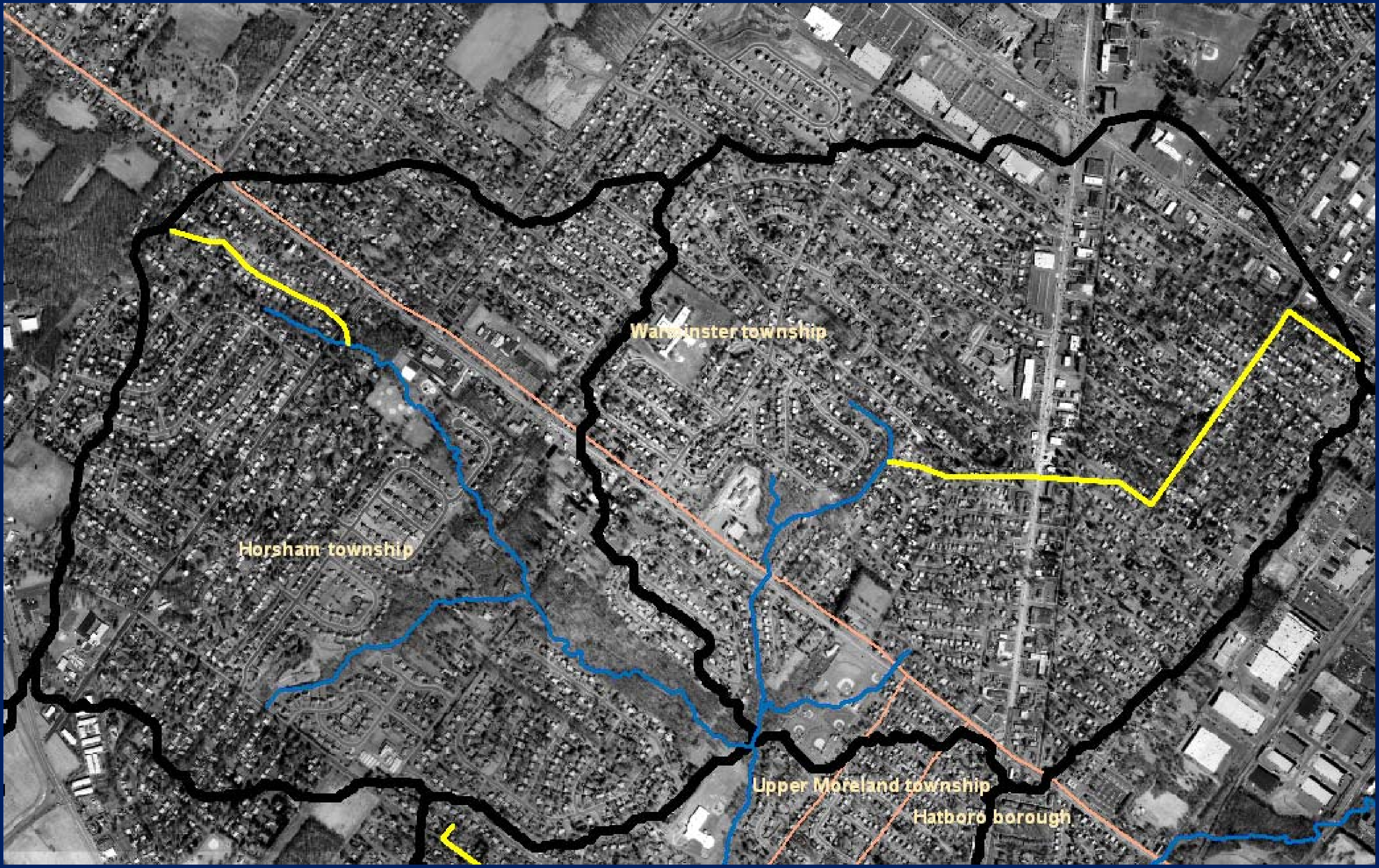
Greater than 50%

Existing detention storage was summed for each subbasin and added to the potential storage. The pervious CN value was then adjusted.

The PWD and CSC inventories were used to determine total detention.



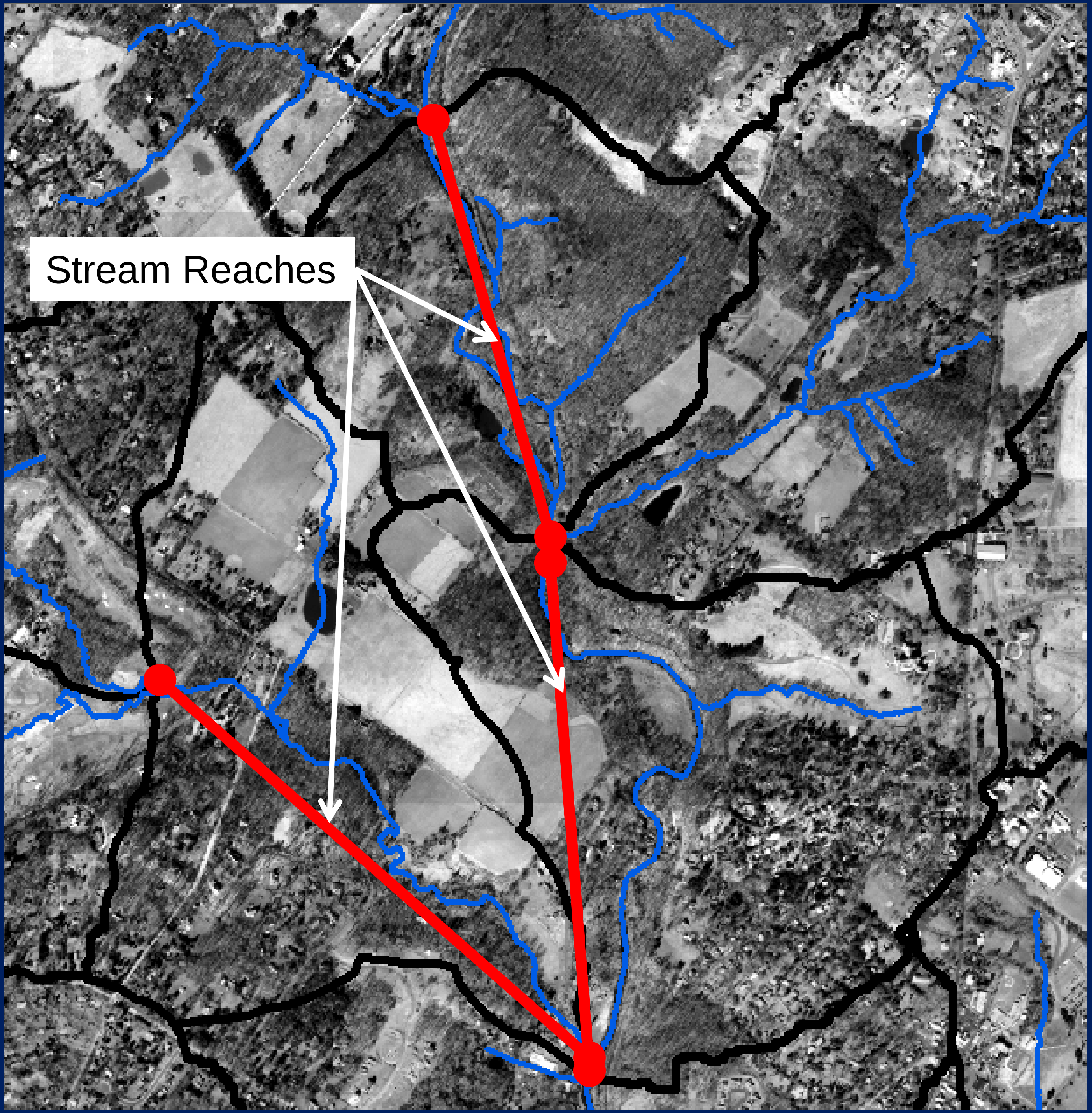
Time of concentration was calculated as the sum of sheet flow, shallow concentrated flow, and channel flow travel times. The best model result was obtained when time of concentration was used as the subasin lag.



Stream Reaches

33 reaches were modeled using Modified Puls routing, with channel parameters from the recent FIS HEC-RAS model.

17 reaches were modeled using Muskingum-Cunge routing, with average channel x-sections and Manninigs N values estimated from contours and ortho images.



Design Storm Rainfall

Design rainfall was based on the upper limit of the 90% confidence interval from NOAA Atlas 14 for the 24 hour Type II storm.

Storm Frequency	Total Precipitation (in)
1-Yr	2.98
2-Yr	3.60
5-Yr	4.55
10-Yr	5.35
25-Yr	6.50
50-Yr	7.50
100-Yr	8.60
500-Yr	11.61

These totals are the averages for three locations in the lower, middle and upper portions of the Pennypack watershed.

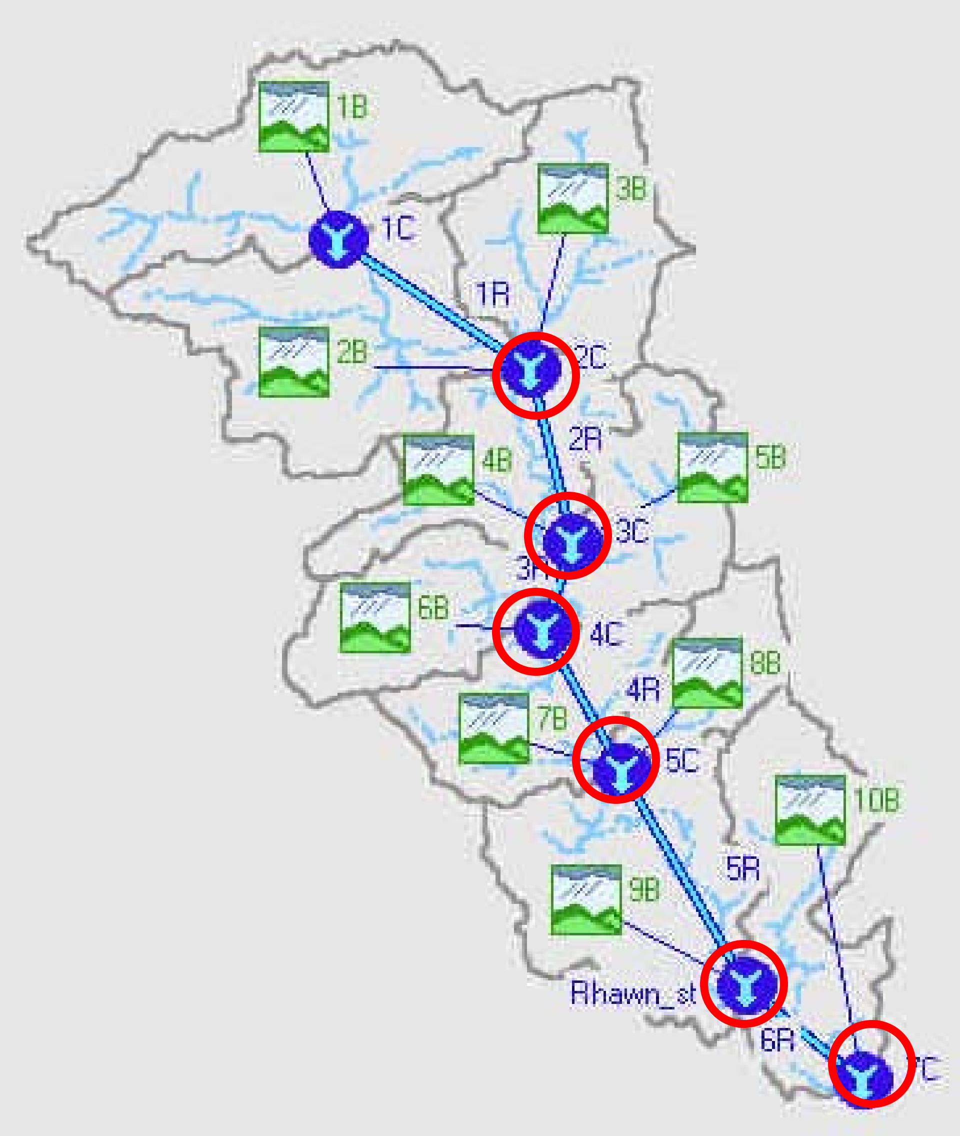
Lower Pennypack:	Lat:	40.041	Lon:	-75.053
Middle Pennypack:	Lat:	40.115	Lon:	-75.096
Upper Pennypack:	Lat:	40.147	Lon:	-75.128

Model Testing

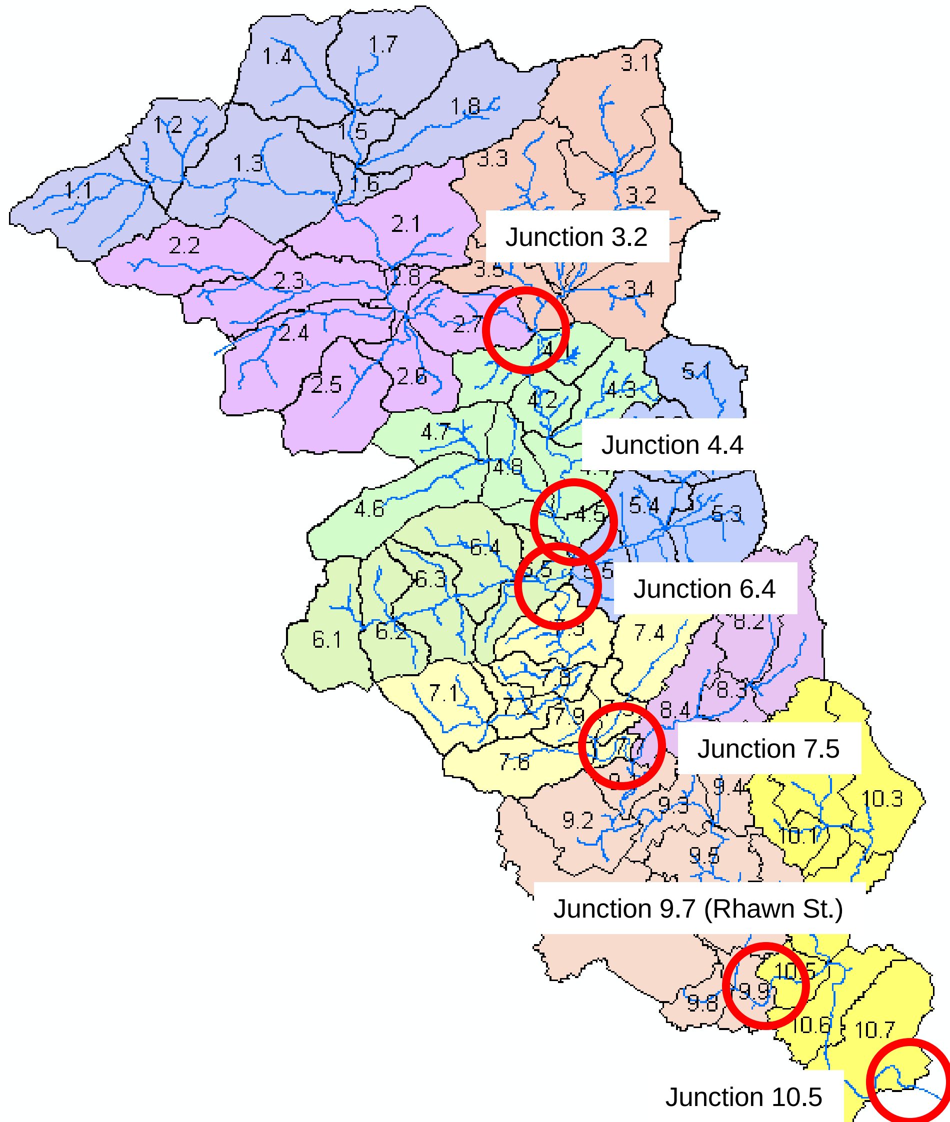
Comparison of Model Results for Design Storms – Pennypack Creek Watershed

*Peak flows and volumes for 1 year thru 100 year events were compared at junctions and for large subasin outlets

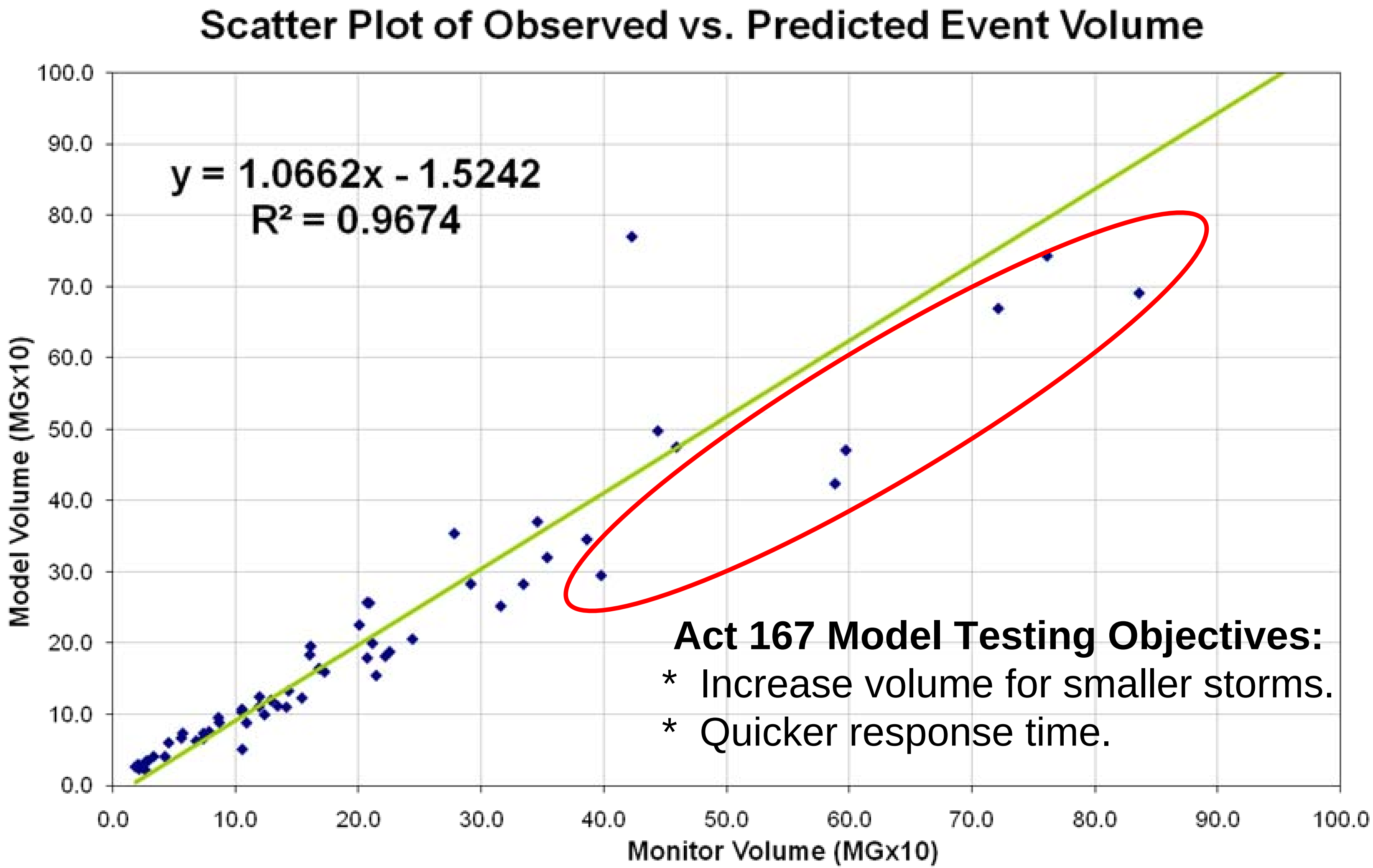
Original 10 Subasin Model



Detailed Model – 68 Subasins



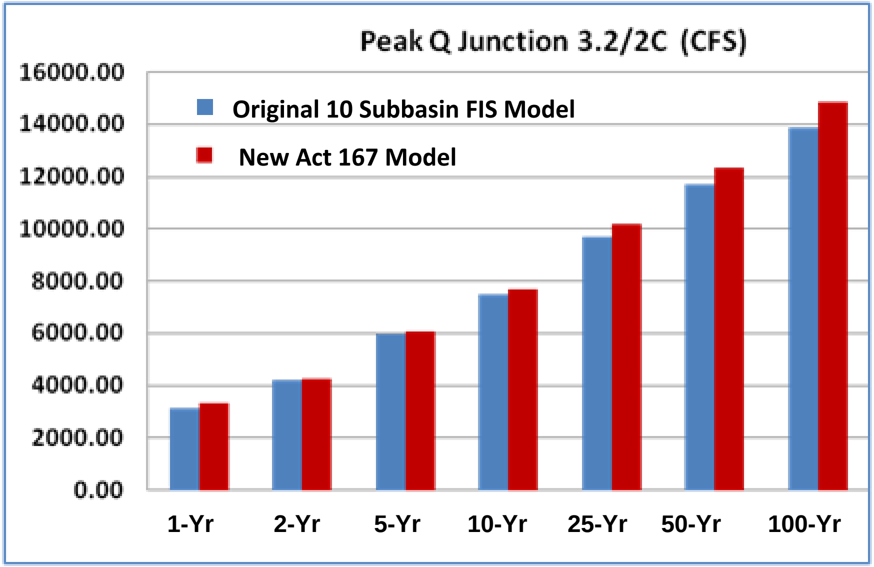
The new Act 167 model was matched against the original 10 subasin model, but improvement was sought based on test results of the original model vs. observed rainfall and flow at Rhawn Street.

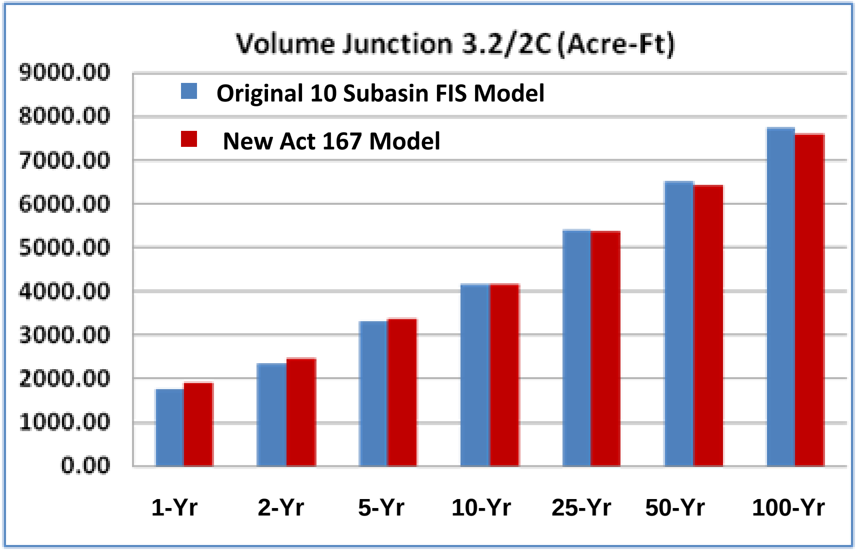


Observed volume at USGS Stream Gage at Rhawn Street

Analysis of results was performed by the Philadelphia Water Department

Comparison at Junction 3.2

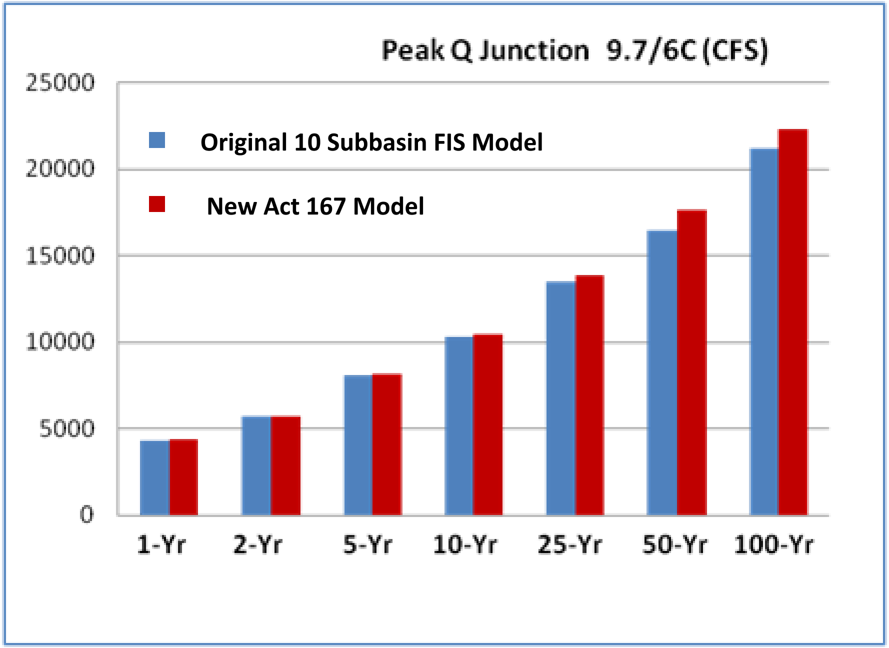


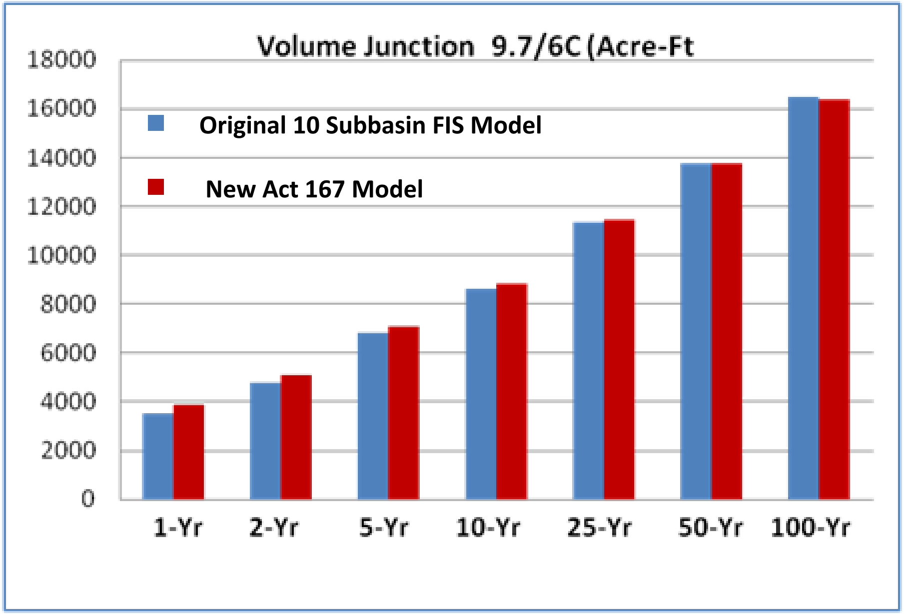


	Junction 3.2/2c	Peak discharge (cfs)	
Storm	Original Model	New Model	% Difference
1-Yr	3107.10	3335.70	7.36
2--Yr	4207.00	4271.00	1.52
5-Yr	5961.80	6078.80	1.96
10-Yr	7481.20	7700.40	2.93
25-Yr	9716.10	10166.30	4.63
50-Yr	11689.40	12323.50	5.42
100-Yr	13883.20	14839.00	6.88

	Junction 3.2/2c	Volume (Acre-Ft)	
Storm	Original Model	New Model	% Difference
1-Yr	1766.80	1915.90	8.44
2-Yr	2358.50	2473.00	4.85
5-Yr	3317.20	3378.60	1.85
10-Yr	4157.20	4176.80	0.47
25-Yr	5401.00	5364.00	-0.69
50-Yr	6504.60	6423.70	-1.24
100-Yr	7736.70	7611.80	-1.61

Comparison at Junction 9.7 – Rhawn Street Gage

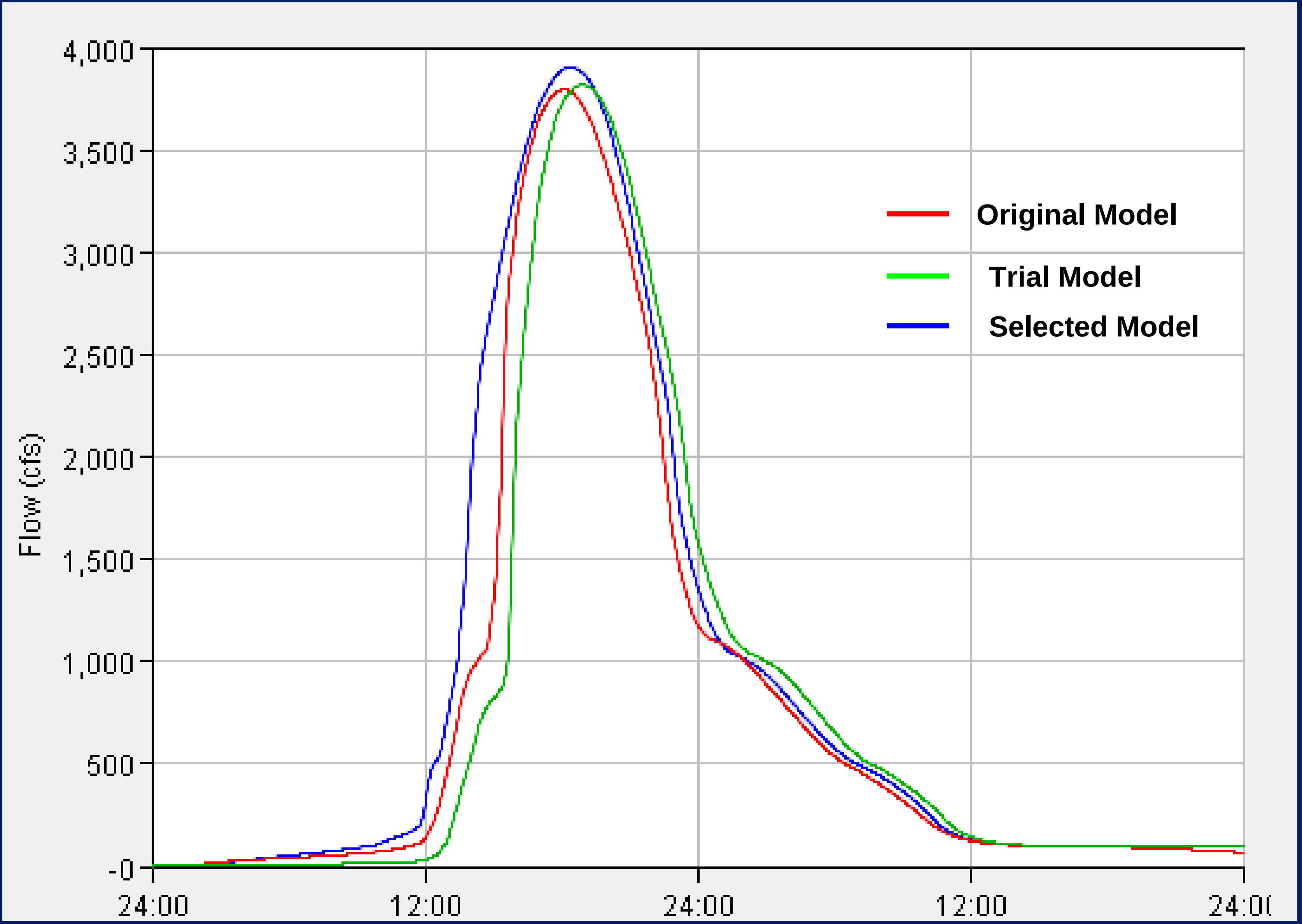




	Junction 9.7/6C	Peak Discharge (CFS)	
Storm	Original Model	New Model	% Difference
1-Yr	4320.1	4346.5	0.61
2-Yr	5720.2	5702.3	-0.31
5-Yr	8073	8150.4	0.96
10-Yr	10331.80	10437	1.02
25-Yr	13478.5	13895.9	3.10
50-Yr	16478.40	17668.9	7.22
100-Yr	21164.30	22273.3	5.24

	Junction 9.7/6C	Volume (Acre-FT)	
Storm	Original Model	New Model	% Difference
1-Yr	3508.6	3907.9	11.38
2-Yr	4762.8	5108.7	7.26
5-Yr	6820.2	7072.7	3.70
10-Yr	8639.20	8819.3	2.08
25-Yr	11354.7	11425.8	0.63
50-Yr	13775.20	13768.4	-0.05
100-Yr	16489.70	16403.1	-0.53

Hydrograph Comparison
1-Yr Storm



Summary of Model Assumptions

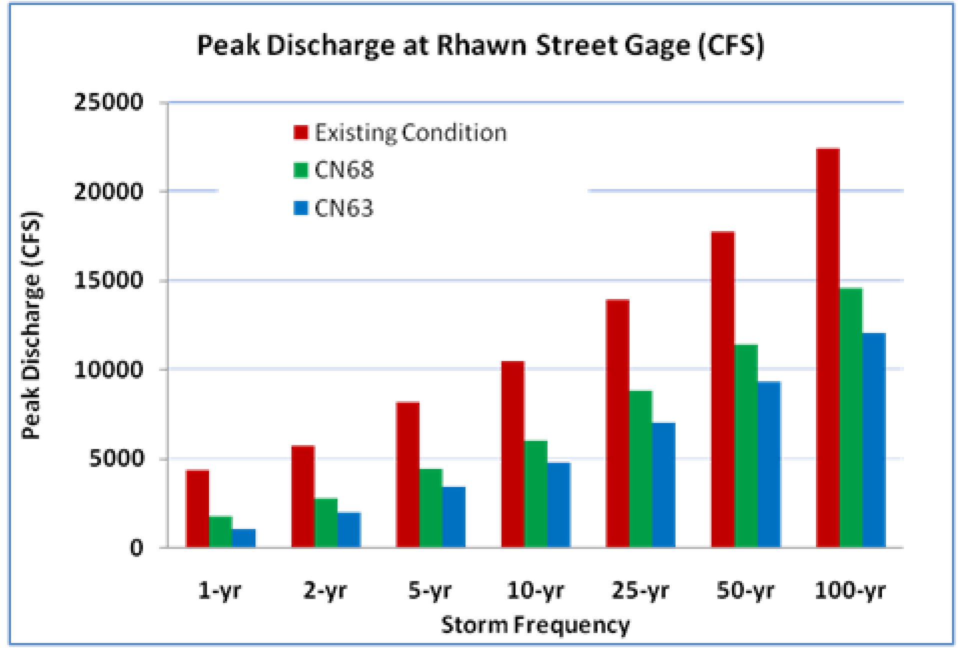
- **Subbasin properties are averages for the subbasin area.**
- **Rainfall is applied uniformly over the entire basin.**
- **The maximum sheet flow length was assumed to be 100 ft. (Based on Merkel, NRCS, 2001)**
- **All impervious area was assumed connected to the stream via runoff over other impervious areas or inlets to storm sewers. (Affect: Raises volume for smaller storms)**
- **Subbasin lag time was set equal to the sum of sheet flow, shallow concentrated flow and channel flow. Multiplying this value by 0.6 (standard method) yielded high peak flows. (Affect: Lowers peak flows)**
- **Existing detention storage was considered additional potential storage and the Curve Number was adjusted for the pervious portion of each subasin.**

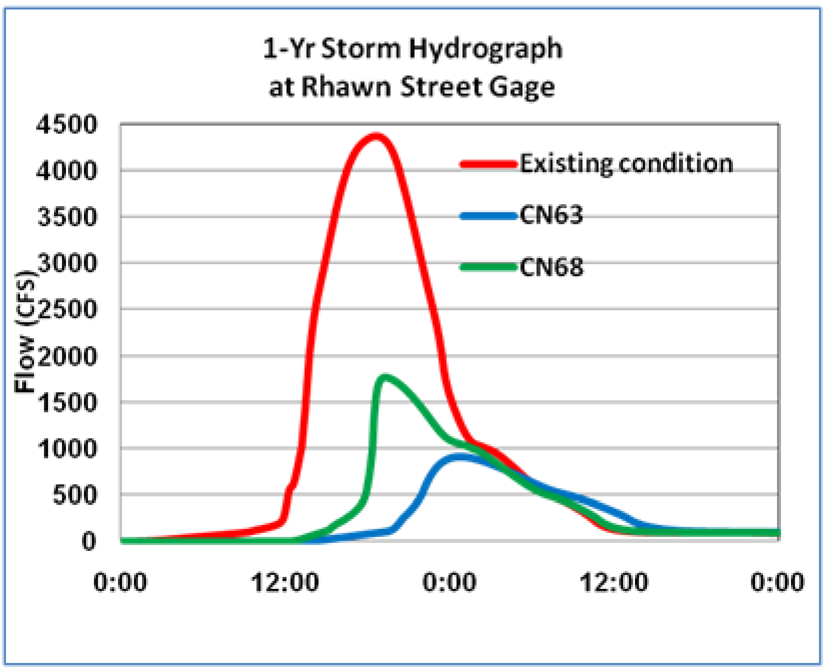
Model Applications

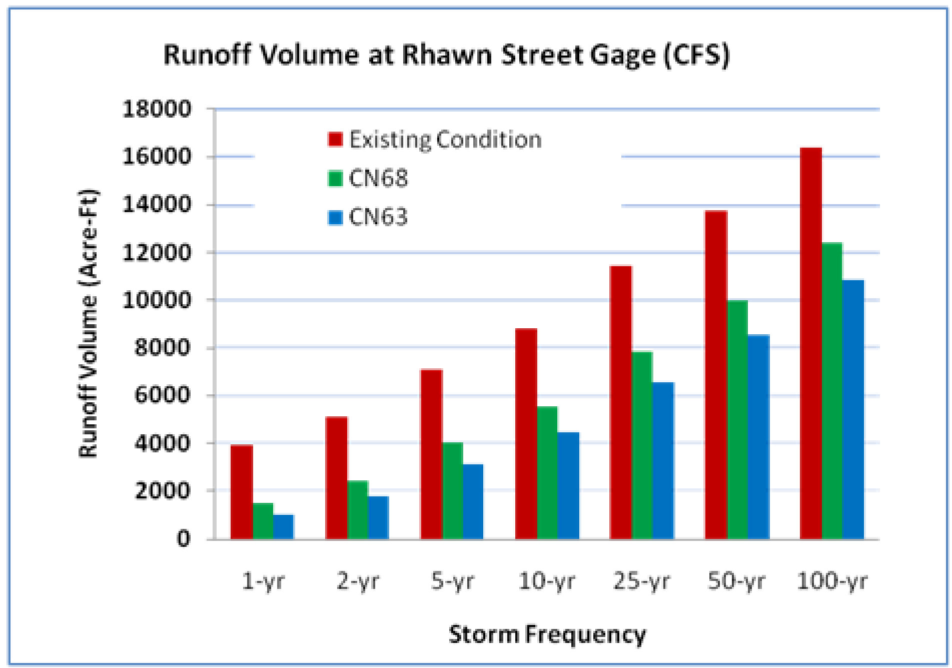
- “Natural” Conditions
- Capture of additional inch of storage
- Land Use Change Scenarios
- Potential Improvements
- Peak Rate Control

Existing vs. "Natural Conditions"

- Location: Pennypack Creek at Rhawn Street
- Total Precipitation for 1-Yr Storm = 2.98 inches
- Comparison is to NRCS Curve Numbers of 63 and 68.
- A curve number of 63 represents forest cover in good condition averaged for hydrologic soil groups B and C.

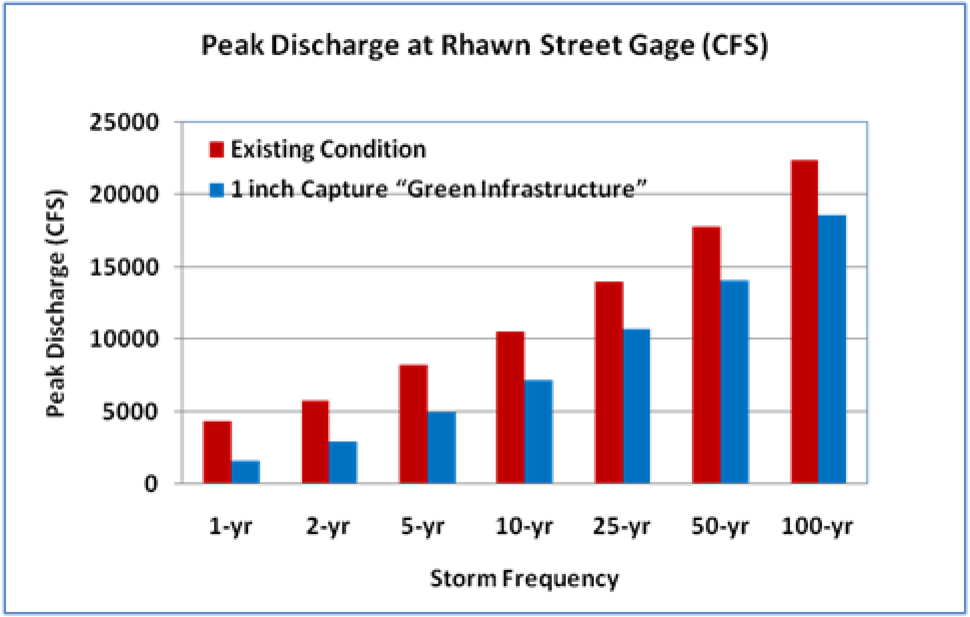


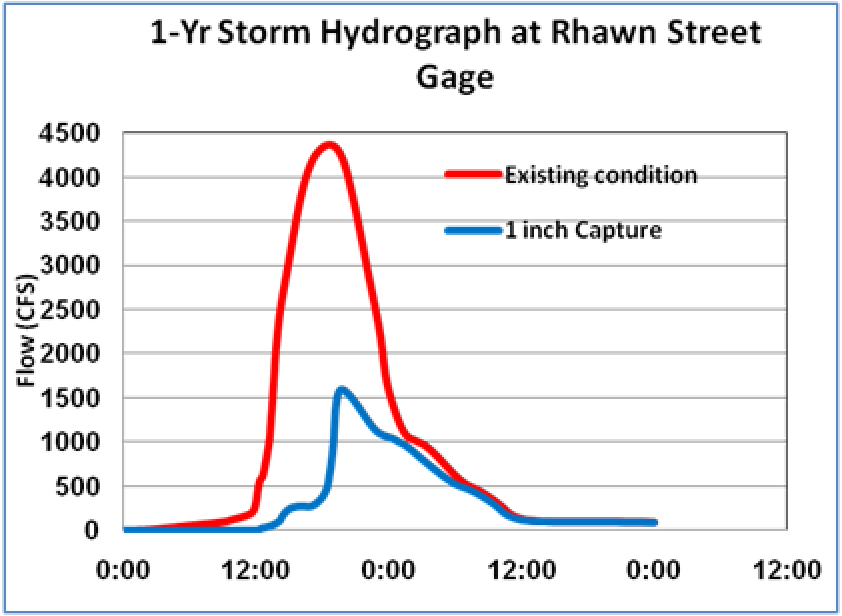


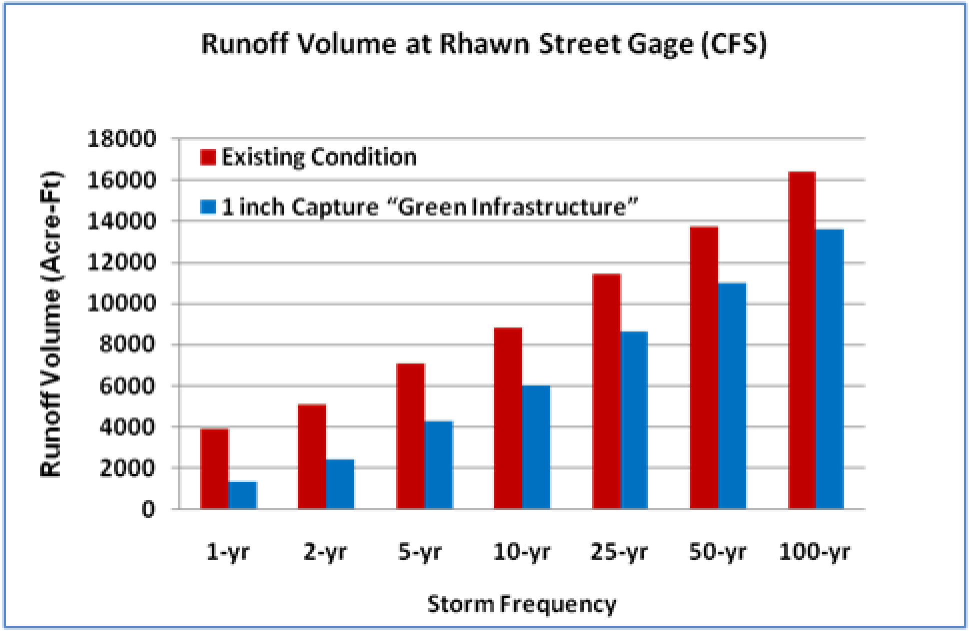


Existing vs. Capture of Additional 1 inch of Runoff

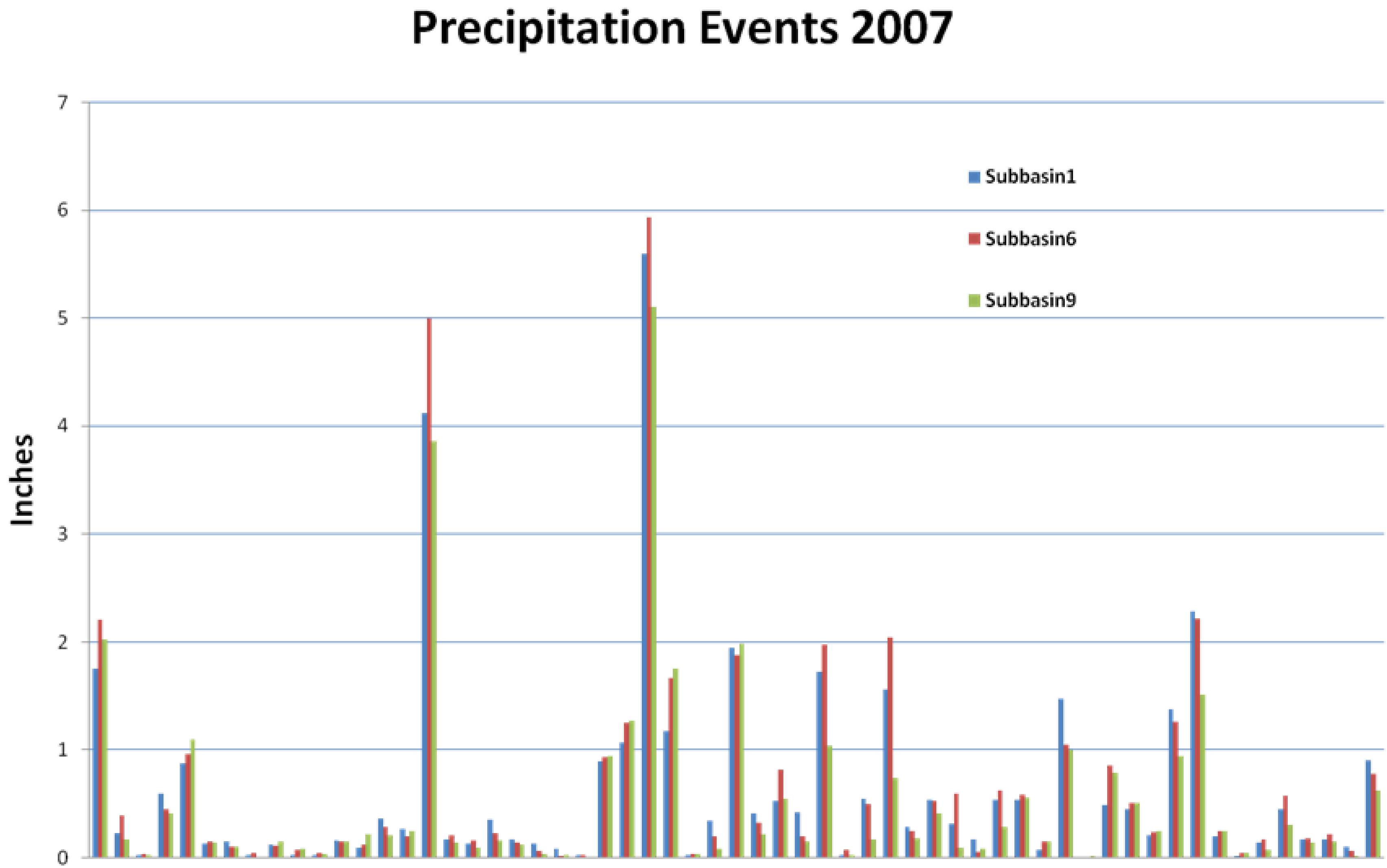
- Location: Pennypack Creek at Rhawn Street
- Total Precipitation for 1-Yr Storm = 2.98 inches
- Initial abstraction is increased by one additional inch over and above existing.
- Impervious cover is disconnected via localized retention, infiltration, and storage.







Most storm events produce less than one inch of runoff



Precipitation Data Provided by the City of Philadelphia Water Department

Land Use Change Scenarios

Housing Unit Calculation Explanations

- Used DVRPC 2035 population projections for each municipality
- Calculated percentage of residential area of municipality inside watershed, multiplied by total projected population increase to find population increase in watershed
- Divided by current housing unit occupancy rate (plus vacancy factor) to find number of new housing units needed in watershed

Housing Unit Projection Calculations

Municipality	Absolute change in population 2008-2035	Percent change 2008-2035	Municipal Area in Pennypack (Sq. mi.)	Municipal total area (Sq. mi.)	% of residential area of municipality in watershed	Increase in 2035 population within watershed (# of people)	Occupancy Rate (persons per household plus vacancy factor)	New Housing Units Needed
Abington Township	2,236	4%	7.81	15.50	50.45%	1,128	2.59	**436.15**
Bryn Athyn Borough	106	8%	1.92	1.92	100.00%	106	3.59	**29.55**
Hatboro Borough	518	7%	1.42	1.42	100.00%	518	2.43	**213.06**
Horsham Township	5,430	22%	5.75	17.32	42.70%	2,319	2.68	**866.50**
Jenkintown Borough	162	4%	0.07	0.58	9.57%	16	2.20	**7.03**
Lower Moreland Township	31	0%	6.25	7.26	80.93%	25	2.74	**9.15**
Rockledge Borough	113	5%	0.19	0.34	64.31%	73	2.43	**29.88**
Upper Dublin Township	2,356	9%	0.51	13.22	6.08%	143	2.83	**50.74**
Upper Moreland Township	1,332	6%	7.84	7.99	99.45%	1,325	2.47	**535.73**
Upper Southampton Township	1,578	10%	1.82	6.63	24.46%	386	2.61	**147.66**
Warminster Township	4,134	12%	4.60	10.16	48.31%	1,997	2.77	**722.22**
TOTAL (excluding Philadelphia)						8,035	2.67	***3,047.68***

Specific Scenario Calculations

- Trend scenario:
  - Determined current density of residential units per acre in watershed
  - Divided into housing units needed to find residential acreage need
  - Assumed 2000 square feet per person for non-residential use
- “Green” scenario:
  - Assumed constant density of 6 units/acre for new development
  - Divided into housing units needed to find residential acreage need
  - Assumed 1500 square feet per person for non-residential use

Trend Scenario Calculations

Jurisdiction	Housing Units in Pennypack, 2000	Area of Residential Land in Pennypack (acres)	Density of Housing Units per acre, 2000	Residential Acreage Need	Non-Residential Acreage Need (2000 sq ft/person)	Total Acreage Need for Development
Abington Township	11,284	3,098.92	3.64	119.78	51.79	171.57
Bryn Athyn Borough	381	232.00	1.64	18.00	4.87	22.86
Hatboro Borough	3121	579.87	5.38	39.59	23.78	63.37
Horsham Township	3958	1,643.66	2.41	359.84	106.46	466.30
Jenkintown Borough	200	24.58	8.12	0.87	0.71	1.58
Lower Moreland Township	3622	2,099.52	1.62	5.64	1.15	6.79
Rockledge Borough	702	99.63	7.04	4.24	3.34	7.58
Upper Dublin Township	569	289.25	1.97	25.81	6.58	32.39
Upper Moreland Township	10,346	2,668.61	3.88	138.19	60.82	199.01
Upper Southampton Township	1,498	643.44	2.33	63.44	17.72	81.16
Warminster Township	5,625	1,683.76	3.34	216.20	91.69	307.89
TOTAL				**991.58**	**368.91**	**1,360.50**