New Cost-Benefit Model for Storm Water Management Facilities

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Credits

- Paul Horna (Springfield Twp.)
- Frank Dowman (CRC Watersheds Assoc.)
- Colton Bangs ’07 (storm event monitoring)
- Scott Fortman-Roe ’08 (GUI programming)
- Micajah McGarity (Georgia Tech – GUI programming)
- Samuel McGarity (U. Penn/Wharton - GIS)

Acknowledgements

- U.S. EPA Office of Wetlands, Oceans, and Watersheds
- Pennsylvania Coastal Management Program
- National Oceanic and Atmospheric Administration
- Swarthmore College
- Springfield Township, Pennsylvania

StormWISE

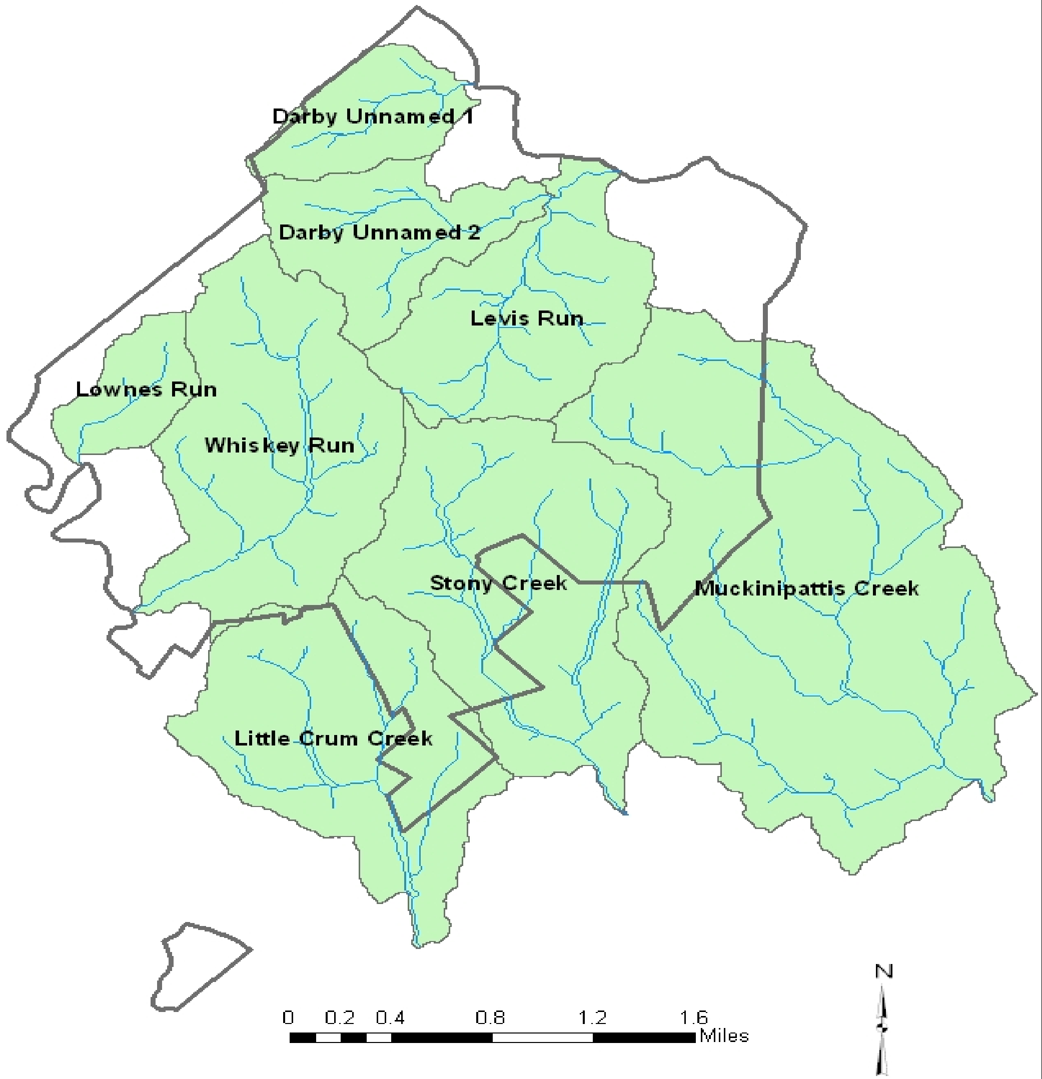
- **Storm W**ater **I**nvestment **S**trategy **E**valuator
- Screening Model: high level, early stages
- Extends nonpoint pollutant load models to include BMP cost and optimization
- Prioritizes BMP project sites by drainage area and land use category
- Potential front end for site specific simulation/optimization model

Urban Stormwater Management Example

Springfield Township, Pennsylvania

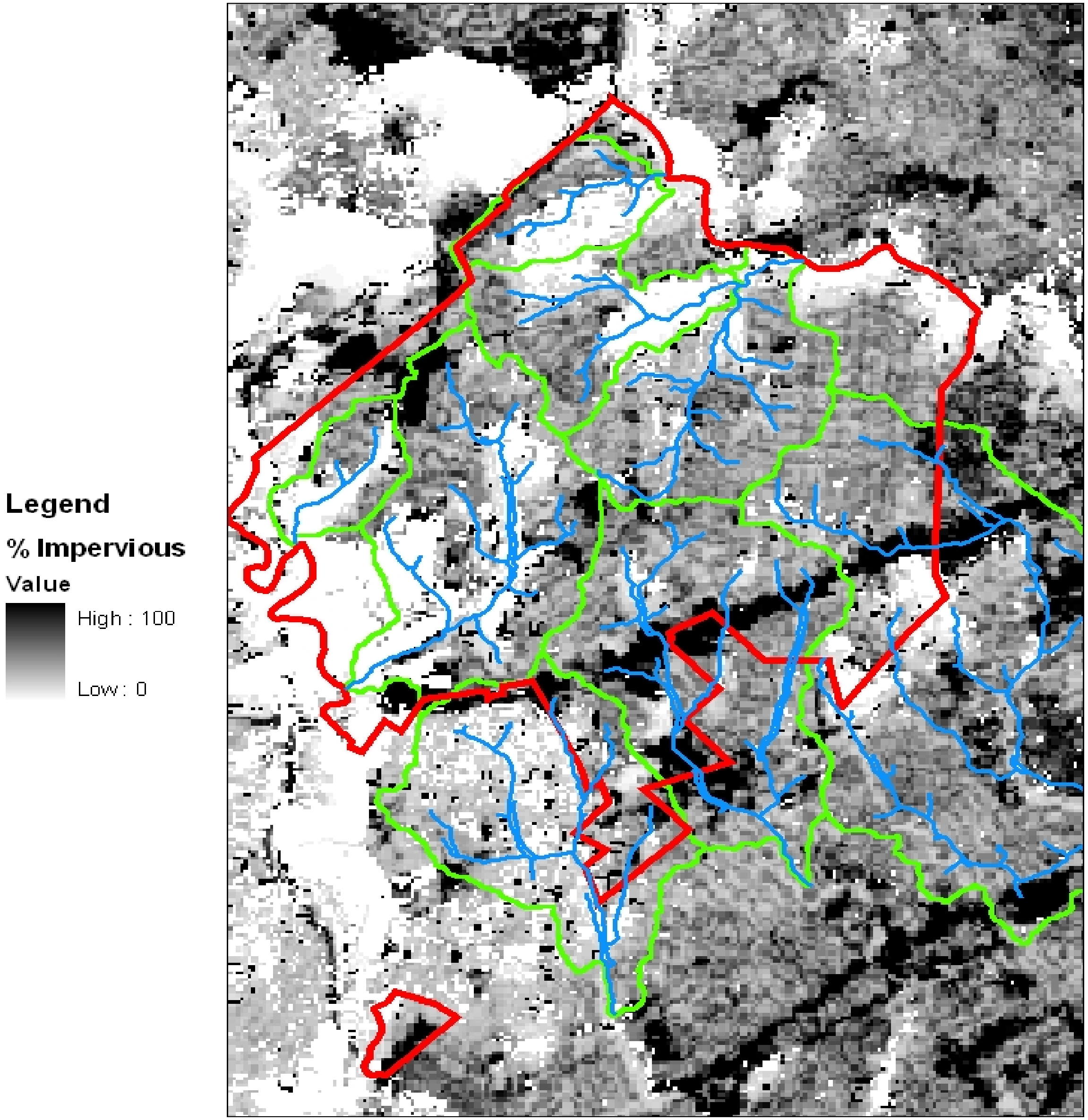
Suburban Philadelphia

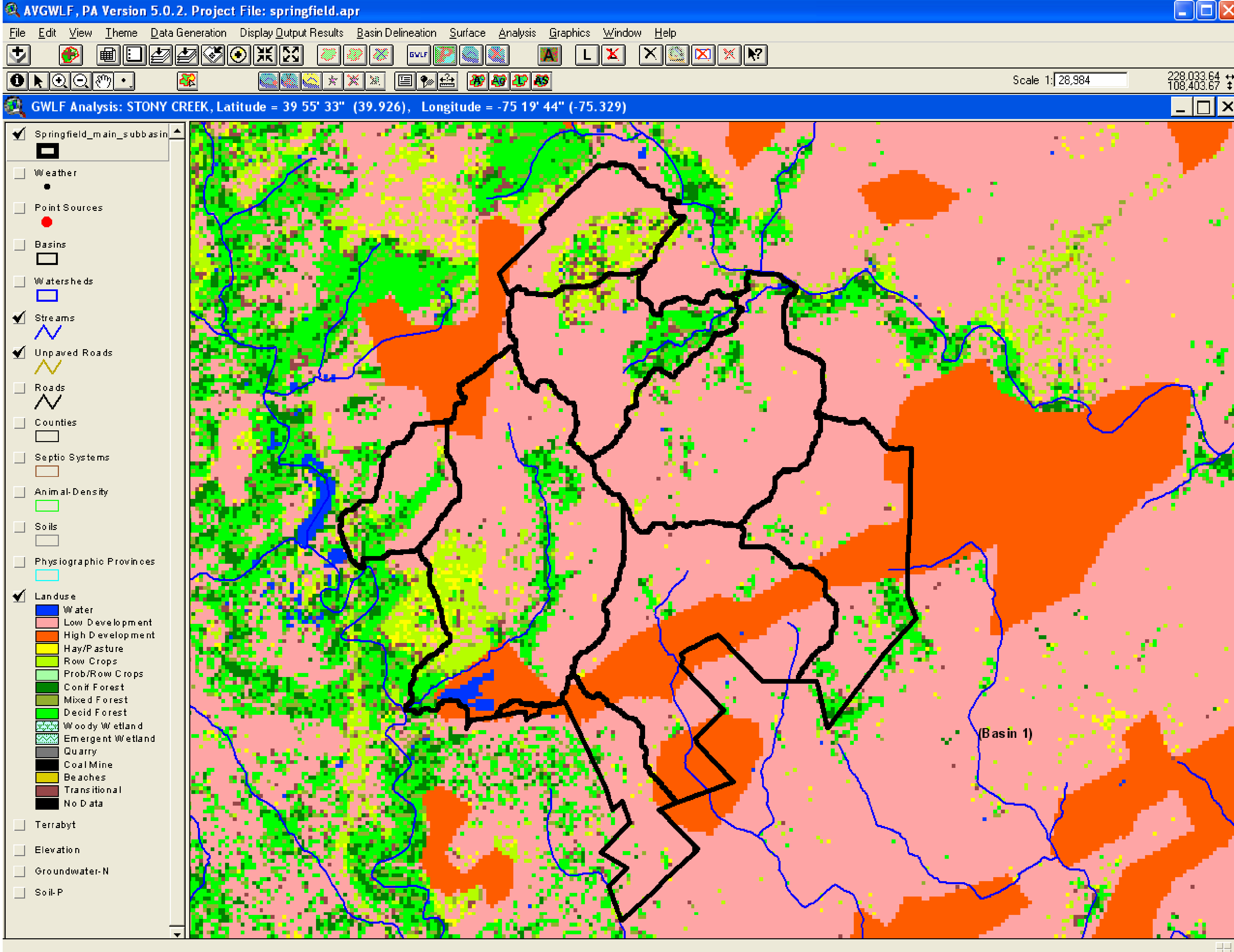
Springfield, PA with Main Subwatersheds



Subwatersheds with Aerial Photograph

Percent Impervious




AVGWLF, PA Version 5.0.2. Project File: springfield.apr
File Edit View Theme Data Generation Display Output Results Basin Delineation Surface Analysis Graphics Window Help
Scale 1: 28,984
228,033.64
108,403.67
GWLF Analysis: STONY CREEK, Latitude = 39 55' 33" (39.926), Longitude = -75 19' 44" (-75.329)
Springfield_main_subbasin
Weather
Point Sources
Basins
Watersheds
Streams
Unpaved Roads
Roads
Counties
Septic Systems
Animal-Density
Soils
Physiographic Provinces
Landuse
Water
Low Development
High Development
Hay/Pasture
Row Crops
Prob/Row Crops
Conif Forest
Mixed Forest
Decid Forest
Woody Wetland
Emergent Wetland
Quarry
Coal Mine
Beaches
Transitional
No Data
Terrabyt
Elevation
Groundwater-N
Soil-P
(Basin 1)

Overall By Landuse Categories

Name	Area (Acres)	Percent Impervious	Impervious (Acres)	Commercial (Acres)	Residential (Acres)	Barren (Acres)	Recreational (Acres)	Forest (Acres)
Darby Unnamed Tributary #1	205.1	20.8%	42.66	4.9	123.6	9.9	49.40	17.3
Darby Unnamed Tributary #2	331.1	22.4%	74.17	0	232.3	7.4	17.30	74.1
Levis Run	523.9	29.1%	152.45	0	479.4	0	9.80	34.7
Little Crum Creek	182.9	39.4%	72.06	22.2	143.3	0	9.80	7.6
Lownes Run	145.8	22.9%	33.39	0	93.9	7.4	14.80	29.7
Muckinipattis Creek	420.1	33.8%	141.99	89.0	281.7	2.5	7.40	39.5
Stony Creek	578.2	43.5%	251.52	222.4	343.5	0	2.50	9.8
Whiskey Run	783.3	28.7%	224.81	93.9	469.5	9.9	96.40	113.6
Total	**3170.4**	**31.3%**	**993.05**	**432.4**	**2167.2**	**37.10**	**207.40**	**326.3**

Springfield Township, Pennsylvania

Annual Sediment Loads: AVGWLF Model Output

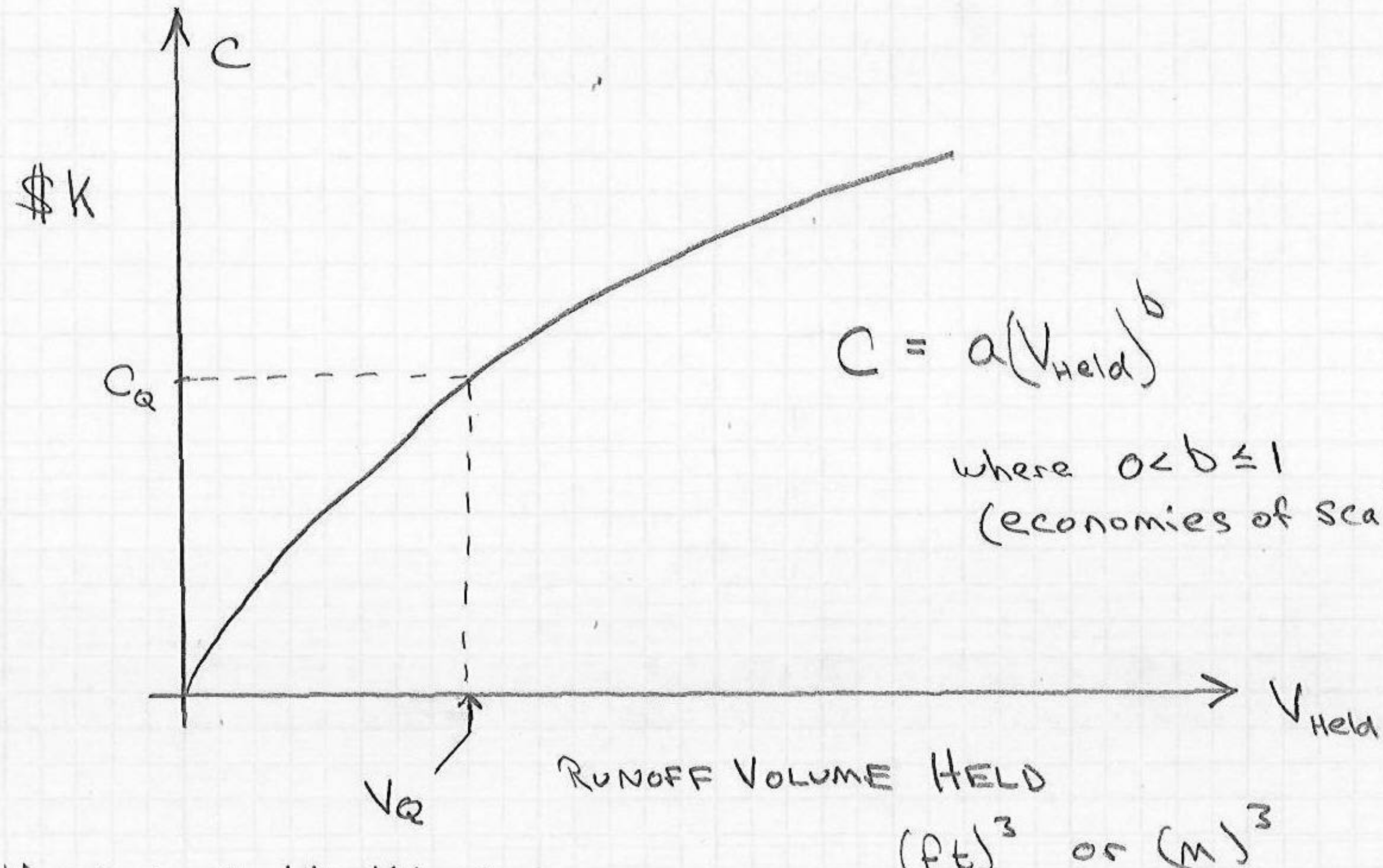
Subwatershed Name	Land Soil Erosion (Tons)	Land Soil Erosion Transported to Runoff Sediment (Tons)	Stream Bank Erosion Sediment (Tons)	Total Sediment in Stream: Runoff Sediment Plus Stream Bank Sediment (Tons)
Darby Unnamed Tributary #1	123.87	24.44	19.58	44
Darby Unnamed Tributary #2	157	30.82	44.08	74.9
Levis Run	40.5	7.89	115.30	123.2
Little Crum Creek	17.4	3.43	18.68	22.1
Lownes Run	248.1	48.87	9.85	58.7
Muckinipattis Creek	41.4	8.13	60.17	68.3
Stony Creek	57.9	11.32	198.99	210.3
Whiskey Run	202.4	39.28	187.27	226.4
Total	**888.57**	**174.18**	**653.92**	**827.9**

Annual Nutrient Loads:

Subwatershed Name	Dissolved Nitrogen in Stream (Pounds)	Total Nitrogen from Groundwater (Pounds)	Total Nitrogen from Stream Bank Erosion (Pounds)	Total Nitrogen from Runoff (Pounds)	Total Nitrogen in Stream (Pounds)
Darby Unnamed Tributary #1	796.72	737.89	1.96	174.98	914.83
Darby Unnamed Tributary #2	1512.4	1315.67	4.41	314.93	1635.01
Levis Run	909.31	776.16	11.53	146.70	934.39
Little Crum Creek	196.92	154.02	1.87	45.48	201.37
Lownes Run	223.09	139.27	0.98	337.57	477.82
Muckinipattis Creek	3395.53	3308.82	6.02	105.23	3420.07
Stony Creek	1479.6	1351.60	19.90	183.99	1555.49
Whiskey Run	2105.66	1691.52	18.73	544.58	2254.81
Total	**10619.23**	**9474.95**	**65.40**	**1853.46**	**11393.79**

BMP Economics 101

<u>Site</u> Scale BMP Cost Function

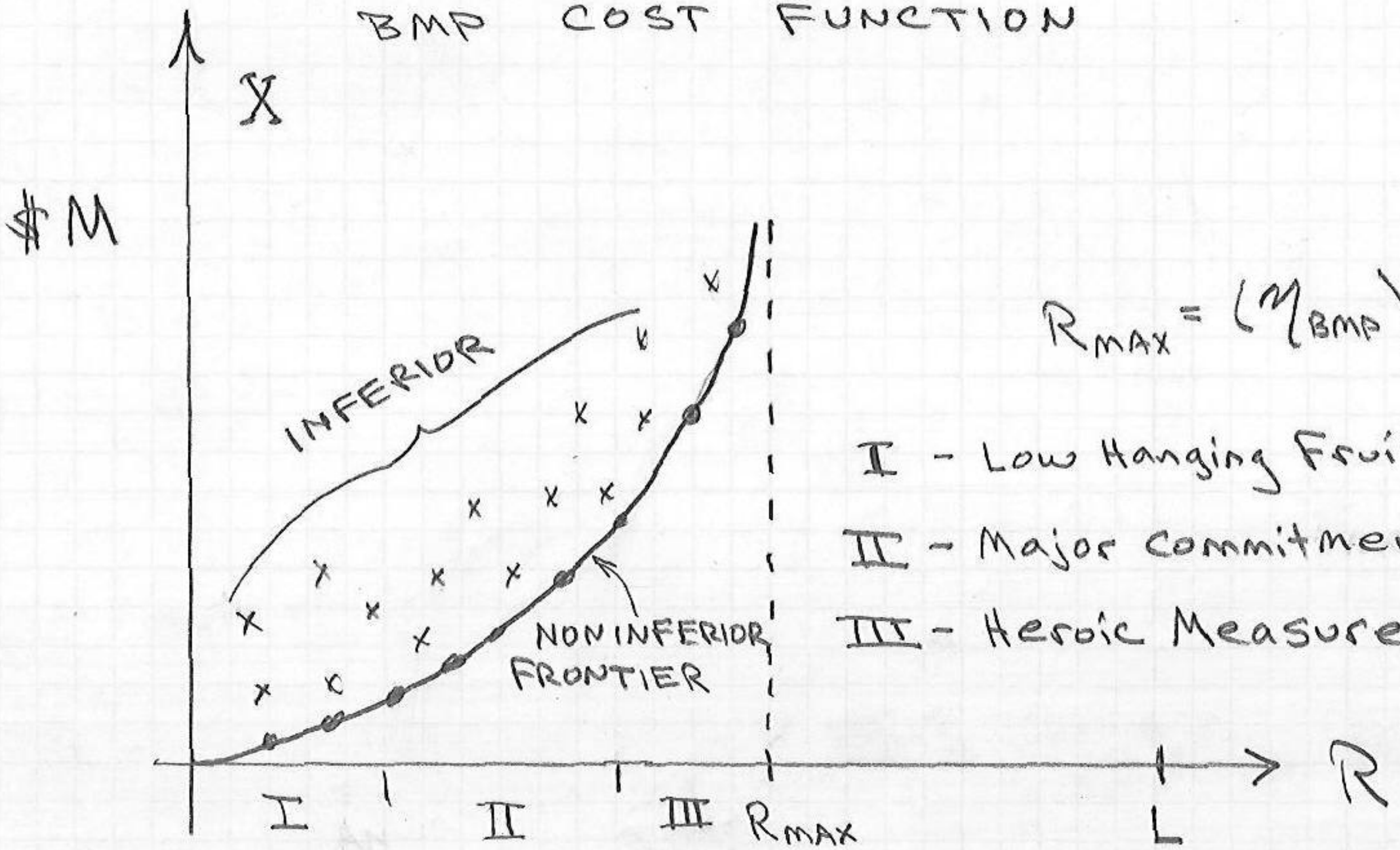


V_Q = Water Quality Volume

Captures 90% of all storms

SUBWATERSHED SCALE

BMP COST FUNCTION



$R_{MAX} = (\eta_{BMP}) L$

I - Low Hanging Fruit

II - Major Commitment

III - Heroic Measures

↑ ANNUAL LOAD BEFORE BMP's

ANNUAL POLLUTANT LOAD REDUCTION

(Tons of Sediment or Pounds of Nutrients)

- Site BMP COSTS BASED ON LAND AREA TREATED

$$V_Q = P_D R_v A_{SITE}$$

P_D = Design Rainfall (1" in E. PA)

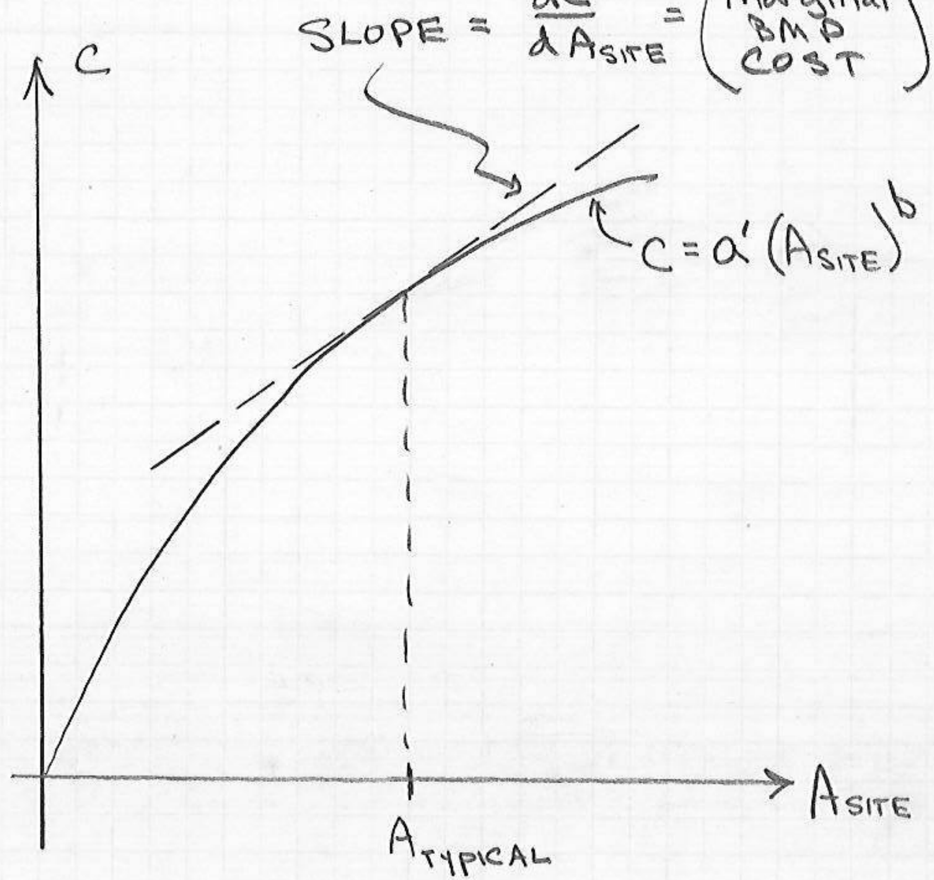
$R_v = \dfrac{\text{inches Runoff}}{\text{inches Precip.}}$ (depends on imperv. %)

Cost Function:

$$C = a(P_D R_v A_{SITE})^b$$

$$= \underbrace{a(P_D R_v)^b}_{a'} (A_{SITE})^b$$

$$C = a'(A_{SITE})^b$$



SITE SPECIFIC BMP COSTS

Subwatershed BMP costs based on land area treated

- Annual volume

$$Q_{TREAT} = f_R P_{ann} R_v A_{TREAT}$$

f_R = fraction of annual precip. that produces runoff

P_{ann} = annual precipitation

A_{TREAT} = Subwatershed land area treated (acres)

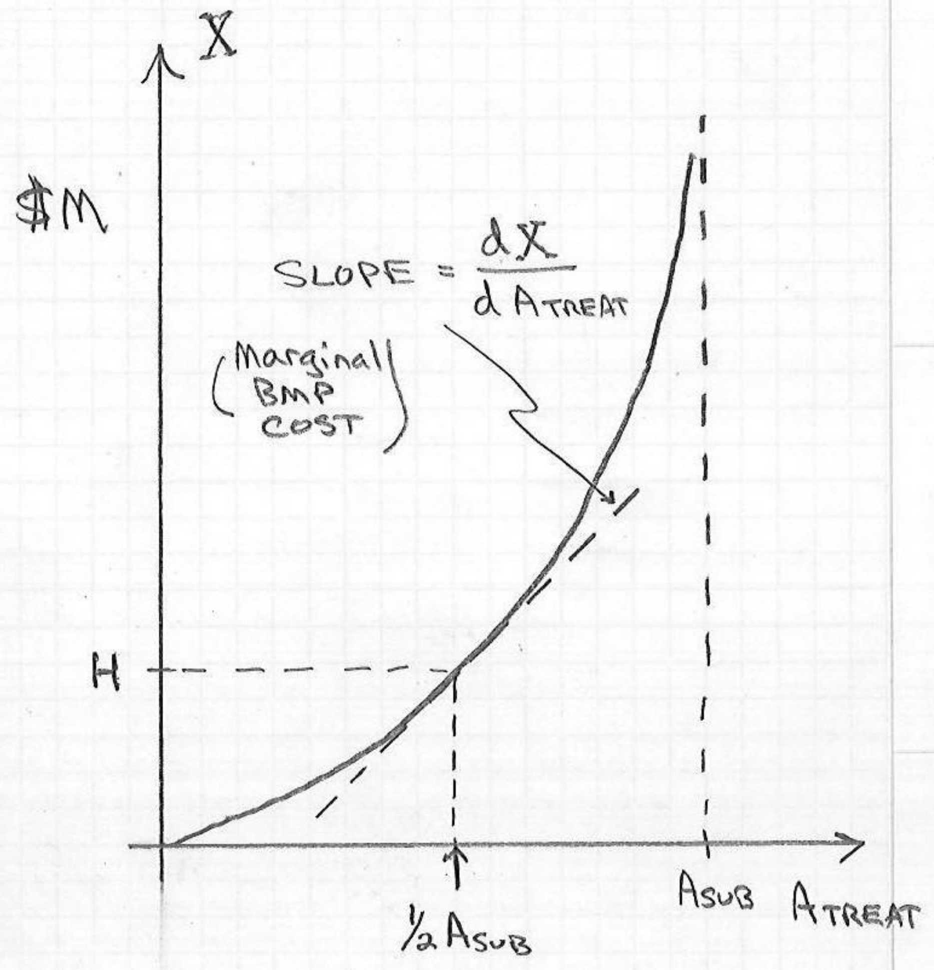
- Annual load reduction

$$R = \eta_{BMP} C_{EM} Q_{TREAT}$$

C_{EM} = pollutant event mean concentration

so

$$A_{TREAT} = \left(\frac{1}{\eta_{BMP} C_{EM} f_R P_{ann} R_v}\right) R$$



“Saturation” function

$$f = \frac{X}{(H + X)}$$

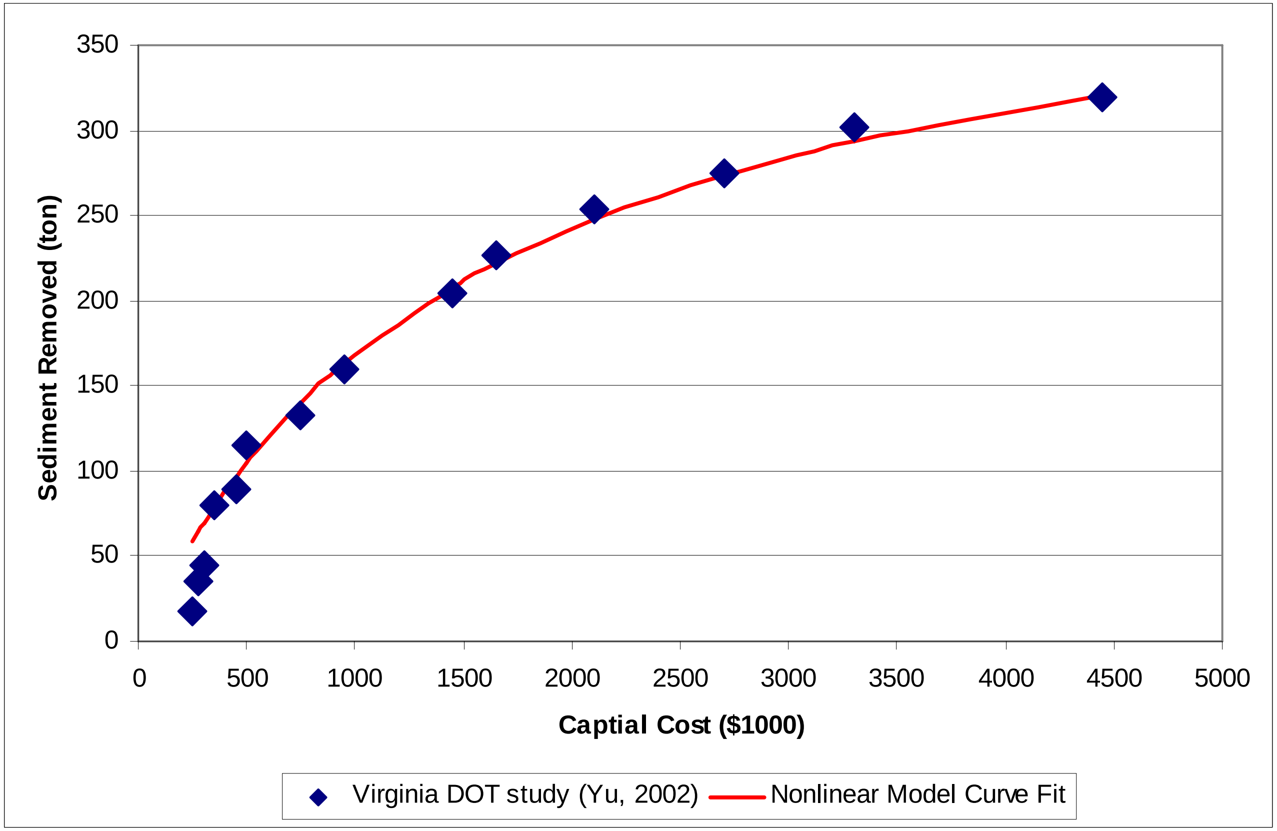
where:

f = fraction of land area treated by BMPs

X = resources devoted to BMPs ($1000)

H = “half-cost” – the resources required to treat one-half of the land area ($1000)

Watershed-scale BMP cost effectiveness curve



SINGLE POINT CALIBRATION

"Median BMP" - Watershed manager's judgement to specify

Calibrate Subwatershed Cost Function USING:

$$\left(\frac{dX}{dA_{TREAT}}\right)_{\frac{1}{2}A_{sub}} = \left(\frac{dC}{dA_{SITE}}\right)_{A_{typical\ for\ Median\ BMP}}$$

MULTIPOINT CALIBRATION

Select 3 or More BMP Technologies from groups I, II, and III

Then find best fit curve:

$$\epsilon_{I} = \left| \left(\frac{dx}{dA_{TREAT}} \right)_{I} - \left(\frac{dc}{dA_{SITE}} \right)_{I} \right|$$

$$\epsilon_{II} = \left| \left(\frac{dx}{dA_{TREAT}} \right)_{II} - \left(\frac{dc}{dA_{SITE}} \right)_{II} \right|$$

$$\epsilon_{III} = \left| \left(\frac{dx}{dA_{TREAT}} \right)_{III} - \left(\frac{dc}{dA_{SITE}} \right)_{III} \right|$$

Then Minimize $\epsilon_{I} + \epsilon_{II} + \epsilon_{III}$ to find BEST FIT CURVE

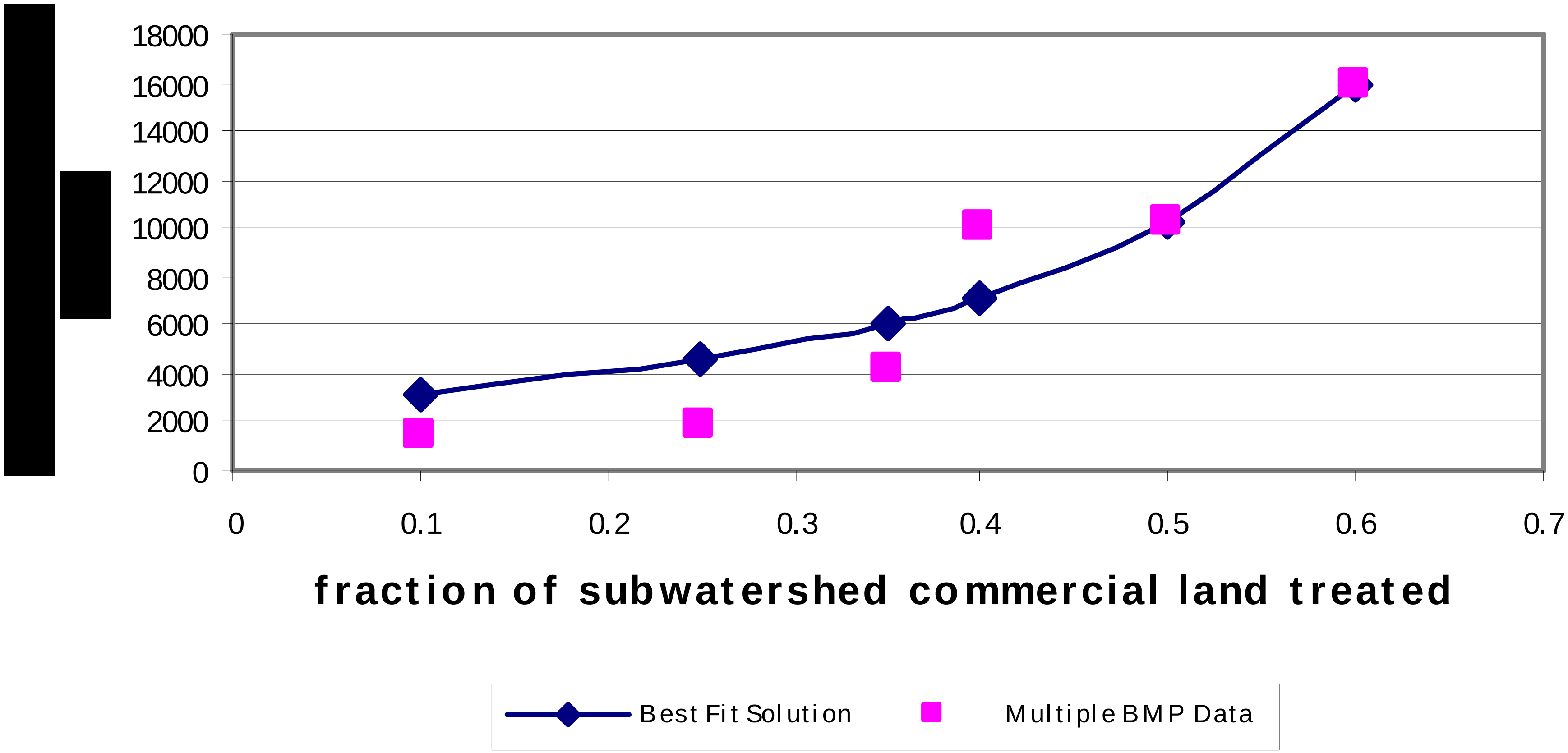
StormWISE Modules

BMPFIT & NPSOPT

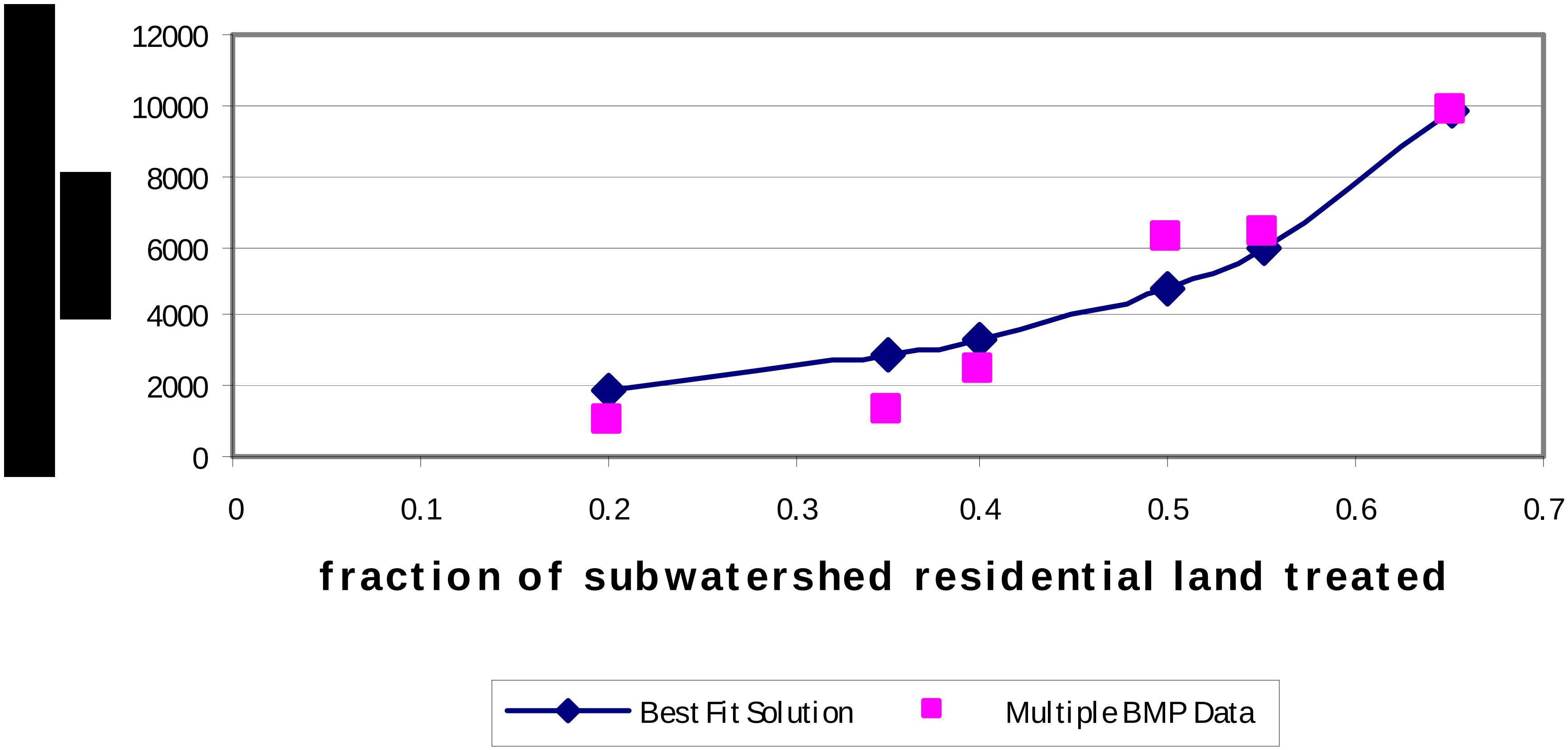
BMPFIT modules

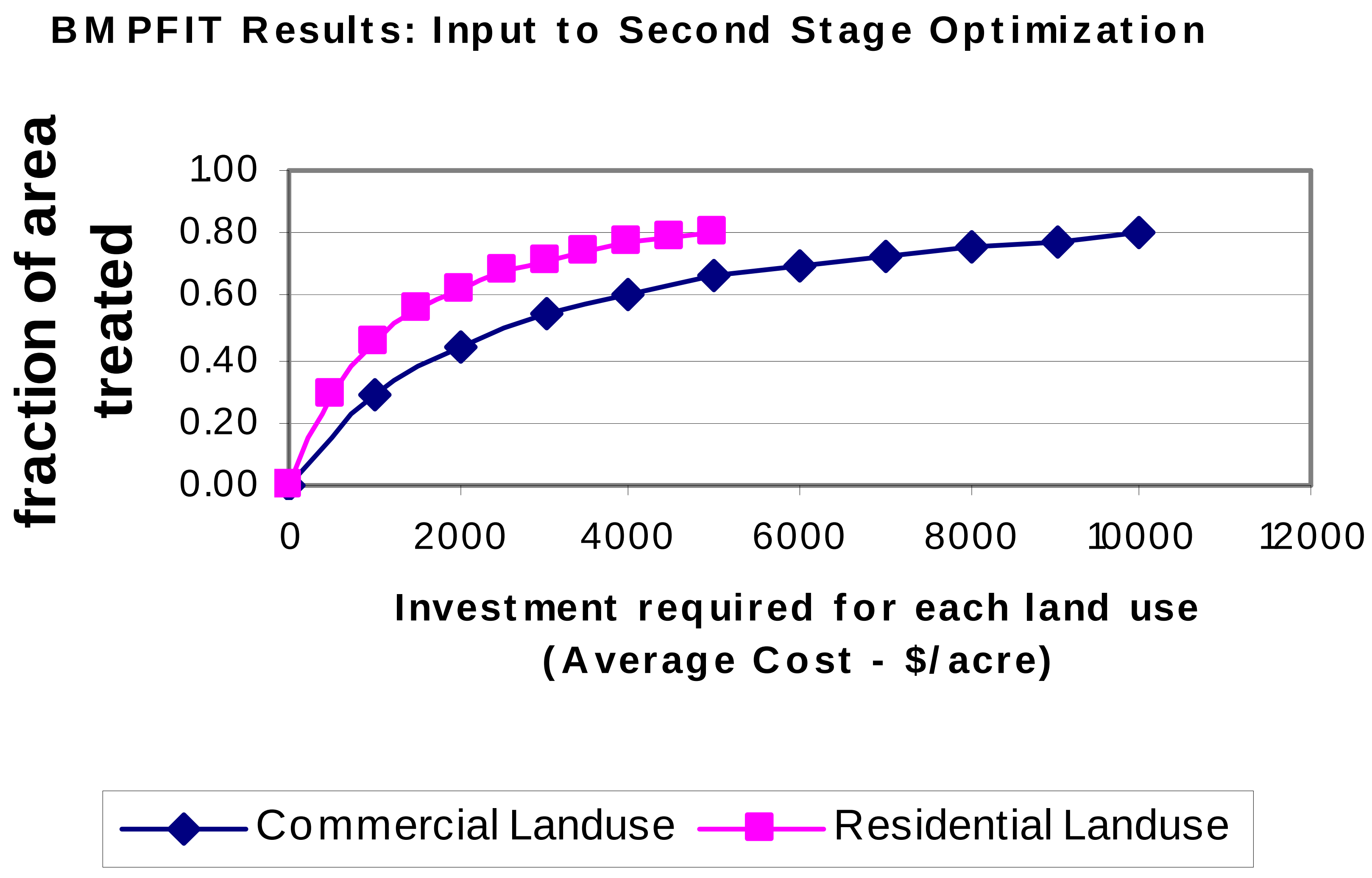
- Minimize sum of absolute deviations of data points from fitted curve
- Subject to:
- Site-specific BMP cost data
- BMP's ranked by marginal costs
- BMP's assigned ranges of application by fraction of drainage area treated

BMPFIT: Best Fit - Commercial



BMPFIT: Best Fit - Residential



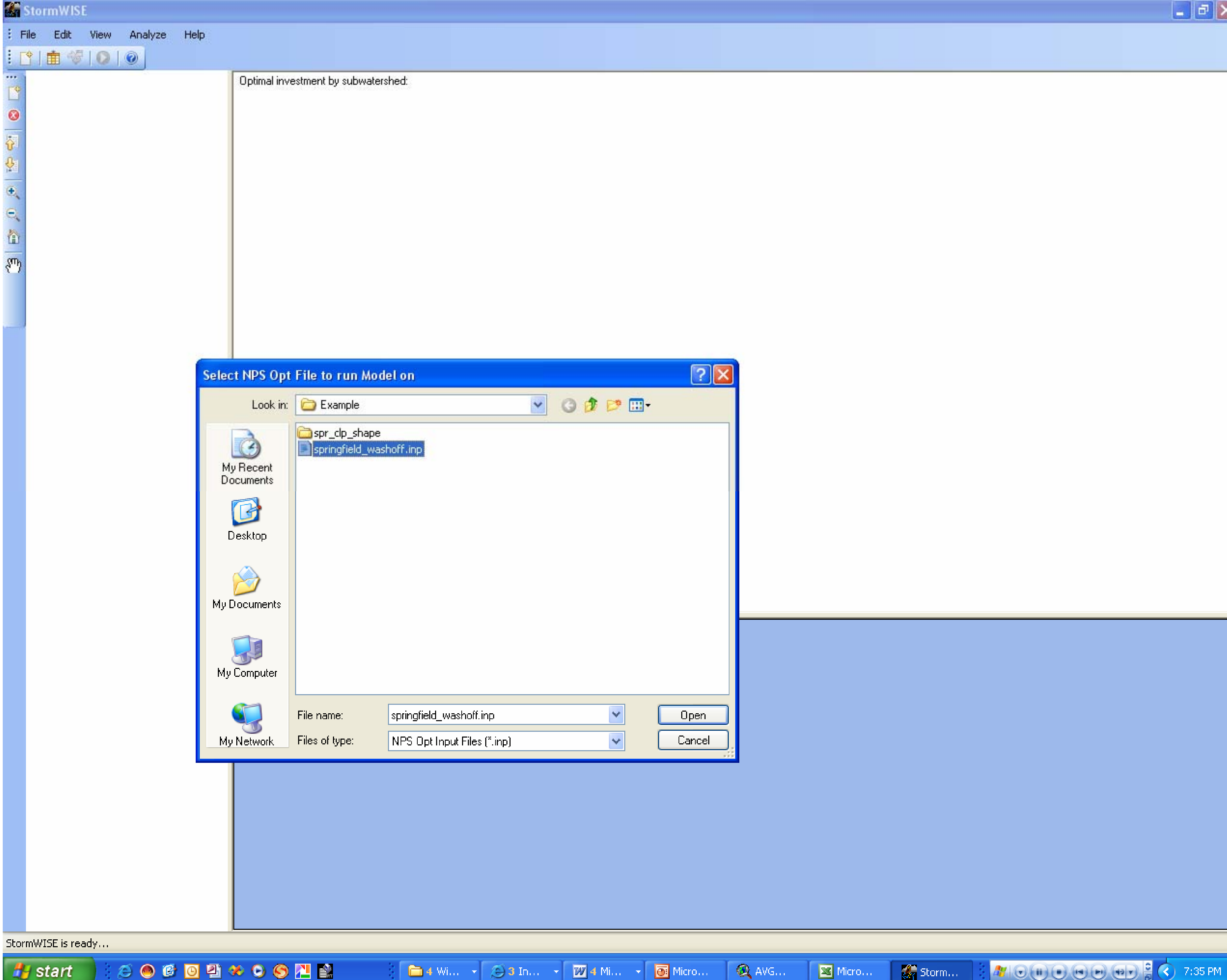

BMPFIT Results: Input to Second Stage Optimization
fraction of area treated
1.00
0.80
0.60
0.40
0.20
0.00
0
2000
4000
6000
8000
10000
12000
Investment required for each land use (Average Cost - $/acre)
Commercial Landuse
Residential Landuse

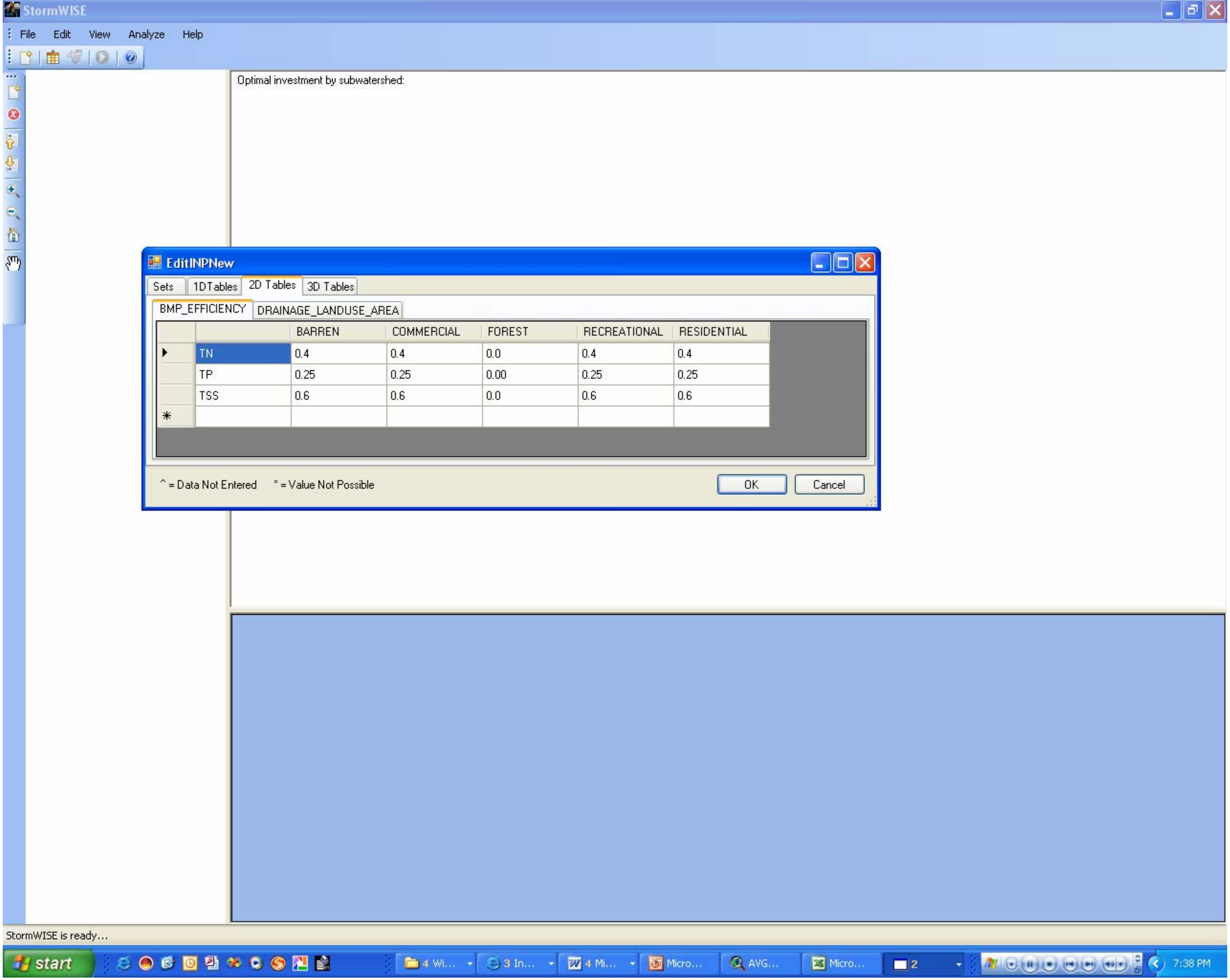
StormWISE Software

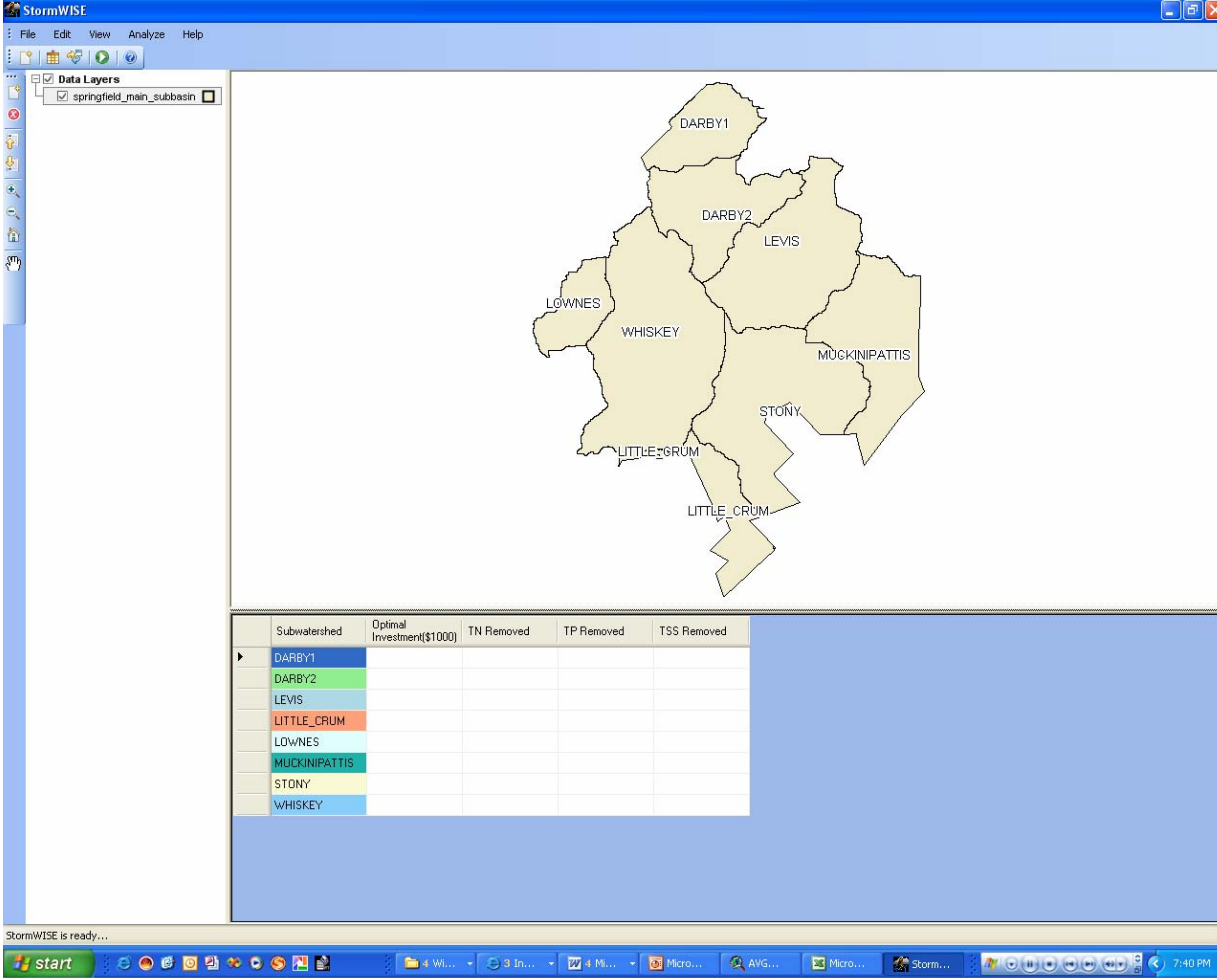
Demonstration

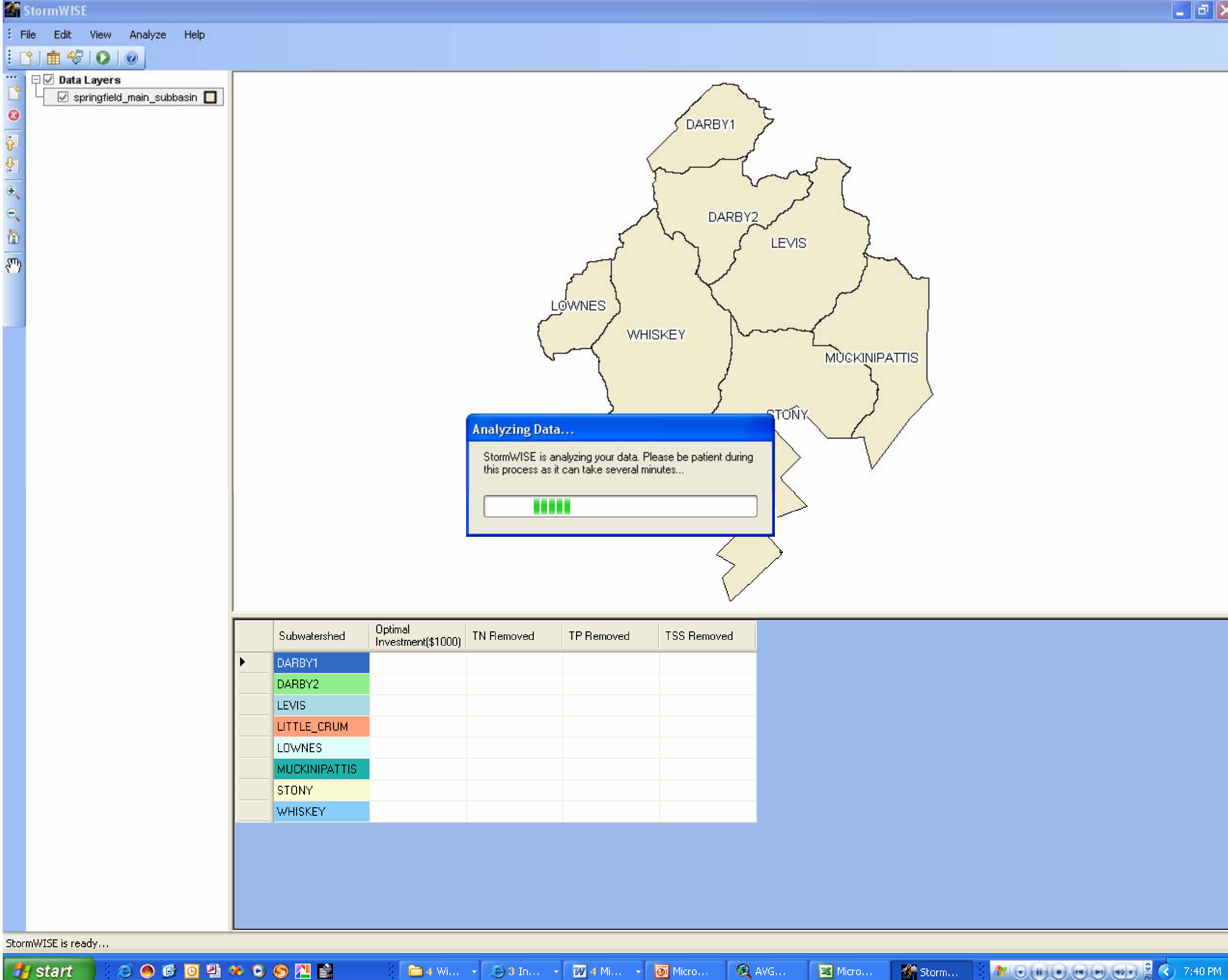
NPSOPT Modules

- Minimize total cost of BMP’s over entire watershed
- Subject to:
- Watershed-scale BMP cost-effectiveness curves for each landuse category within each subwatershed drainage area calibrated by BMPFIT
- User specified pollutant reduction levels for sediment and nutrients
- Solved using AMPL optimization software


StormWISE
File
Edit
View
Analyze
Help
Optimal investment by subwatershed:
Select NPS Opt File to run Model on
Look in:
Example
My Recent Documents
Desktop
My Documents
My Computer
My Network
spr_clp_shape
springfield_washoff.inp
File name:
springfield_washoff.inp
Files of type:
NPS Opt Input Files (*.inp)
Open
Cancel
StormWISE is ready...
start
7:35 PM


StormWISE
File
Edit
View
Analyze
Help
Optimal investment by subwatershed:
EditINPNew
Sets
1DTables
2D Tables
3D Tables
BMP_EFFICIENCY
DRAINAGE_LANDUSE_AREA
BARREN
COMMERCIAL
FOREST
RECREATIONAL
RESIDENTIAL
TN 0.4 0.4 0.0 0.4 0.4
TP 0.25 0.25 0.00 0.25 0.25
TSS 0.6 0.6 0.0 0.6 0.6
^ = Data Not Entered
* = Value Not Possible
OK
Cancel
StormWISE is ready...
start
7:38 PM


StormWISE
File
Edit
View
Analyze
Help
Data Layers
springfield_main_subbasin
DARBY1
DARBY2
LEVIS
LOWNES
WHISKEY
MUCKINIPATTIS
STONY
LITTLE_CRUM
LITTLE_CRUM
Subwatershed
Optimal Investment($1000)
TN Removed
TP Removed
TSS Removed
DARBY1
DARBY2
LEVIS
LITTLE_CRUM
LOWNES
MUCKINIPATTIS
STONY
WHISKEY
StormWISE is ready...
start
7:40 PM


StormWISE
File
Edit
View
Analyze
Help
Data Layers
springfield_main_subbasin
DARBY1
DARBY2
LEVIS
LOWNES
WHISKEY
MUCKINIPATTIS
STONY
Analyzing Data...
StormWISE is analyzing your data. Please be patient during this process as it can take several minutes...
Subwatershed
Optimal Investment($1000)
TN Removed
TP Removed
TSS Removed
DARBY1
DARBY2
LEVIS
LITTLE_CRUM
LOWNES
MUCKINIPATTIS
STONY
WHISKEY
StormWISE is ready...
start
7:40 PM

StormWISE

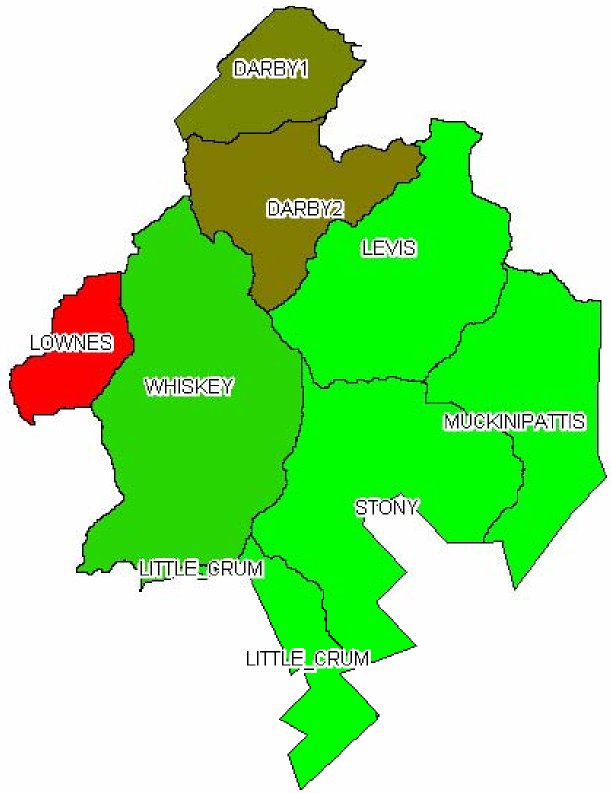
File Edit View Analyze Help

Data Layers

springfield_main_subbasin

- 0.00 - 1.17
- 1.17 - 2.34
- 2.34 - 3.52
- 3.52 - 4.69
- 4.69 - 5.86
- 5.86 - 7.03
- 7.03 - 8.21
- 8.21 - 9.38

Investment ($1000)



Reduce Sediment Load by 25 Tons

Subwatershed	Optimal Investment($1000)	TN Removed	TP Removed	TSS Removed
DARBY1	4.47	20.60	0.89	3.95
DARBY2	4.80	24.62	1.07	5.07
LEVIS	0.00	0.00	0.00	0.00
LITTLE_CRUM	0.00	0.00	0.00	0.00
LOWNES	9.38	65.63	2.87	15.08
MUCKINIPATTIS	0.00	0.00	0.00	0.00
STONY	0.00	0.00	0.00	0.00
WHISKEY	1.47	5.87	0.25	0.90
Total	20.12	116.71	5.09	25.00

StormWISE is ready...

StormWISE

File Edit View Analyze Help

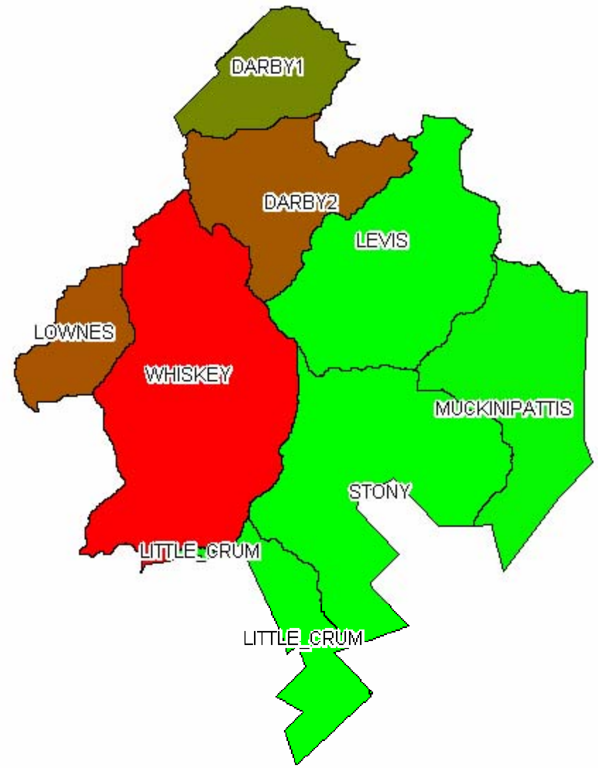
Data Layers

springfield_main_subbasin

- 0.00 - 43.13
- 43.13 - 86.26
- 86.26 - 129.38
- 129.38 - 172.51
- 172.51 - 215.64
- 215.64 - 258.77
- 258.77 - 301.89
- 301.89 - 345.02

Reduce Sediment Load by 50 Tons

Investment ($1000)



Subwatershed	Optimal Investment($1000)	TN Removed	TP Removed	TSS Removed
DARBY1	158.20	50.89	2.33	9.23
DARBY2	223.02	45.47	1.95	10.45
LEVIS	2.17	0.47	0.03	0.02
LITTLE_CRUM	0.00	0.00	0.00	0.00
LOWNES	229.54	95.22	4.23	22.67
MUCKINIPATTIS	10.98	4.67	0.21	0.50
STONY	0.00	0.00	0.00	0.00
WHISKEY	345.02	41.44	2.10	7.13
Total	968.94	238.15	10.84	50.00

StormWISE is ready...

StormWISE

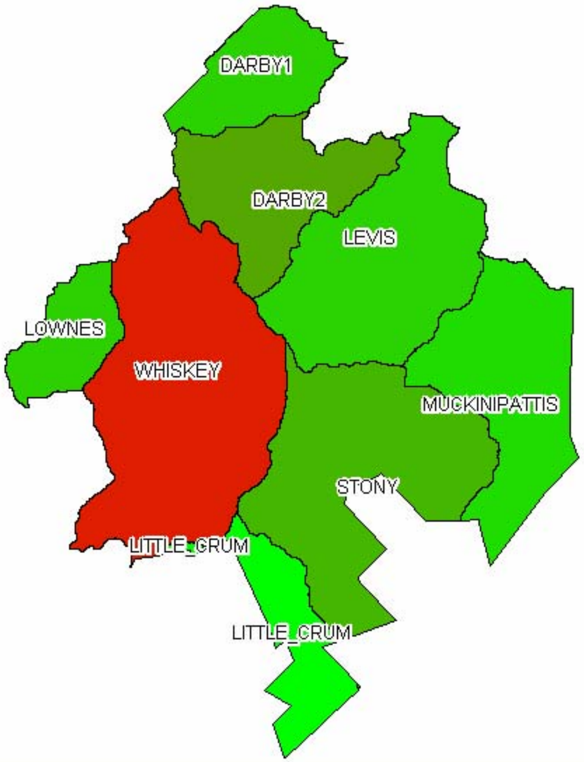
File Edit View Analyze Help

Data Layers

springfield_main_subbasin

- 402.82 - 814.12
- 814.12 - 1,225.41
- 1,225.41 - 1,636.71
- 1,636.71 - 2,048.01
- 2,048.01 - 2,459.31
- 2,459.31 - 2,870.60
- 2,870.60 - 3,281.90
- 3,281.90 - 3,693.20

Investment ($1000)

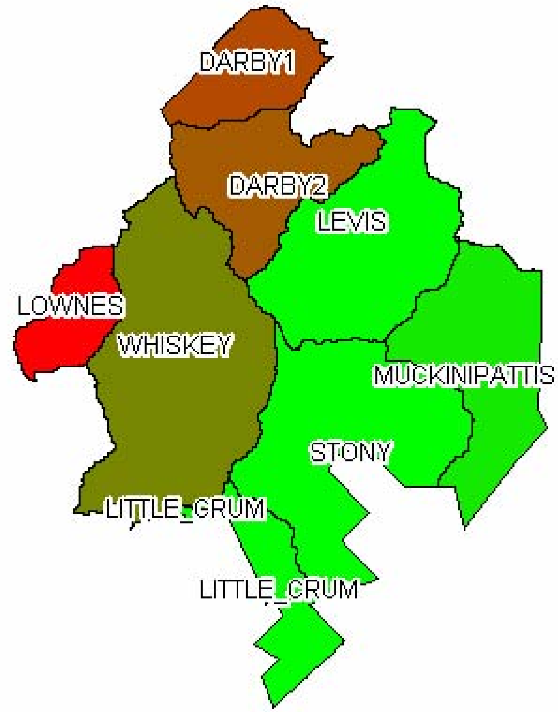


Reduce Sediment Load by 75 Tons

Subwatershed	Optimal Investment($1000)	TN Removed	TP Removed	TSS Removed
DARBY1	985.50	58.26	2.73	11.70
DARBY2	1,509.06	50.75	2.21	14.31
LEVIS	964.51	3.78	0.28	2.06
LITTLE_CRUM	402.82	5.55	0.37	0.94
LOWNES	1,001.87	99.19	4.43	24.99
MUCKINIPATTIS	852.13	7.59	0.40	2.37
STONY	1,323.02	7.90	0.57	2.85
WHISKEY	3,290.38	63.60	3.57	15.78
Total	10,329.29	296.61	14.55	75.00

StormWISE is ready...

Reduce Sediment Load by 50 Tons



Subwatershed	Optimal Investment($1000)	TN Removed	TP Removed	TSS Removed
DARBY1	69.98	50.89	2.33	9.23
DARBY2	63.61	45.47	1.95	10.45
LEVIS	0.00	0.47	0.03	0.02
LITTLE_CRUM	0.00	0.00	0.00	0.00
LOWNES	98.84	95.22	4.23	22.67
MUCKINIPATTIS	8.14	4.67	0.21	0.50
STONY	0.00	0.00	0.00	0.00
WHISKEY	46.92	41.44	2.10	7.13
Total	287.48	238.15	10.84	50.00

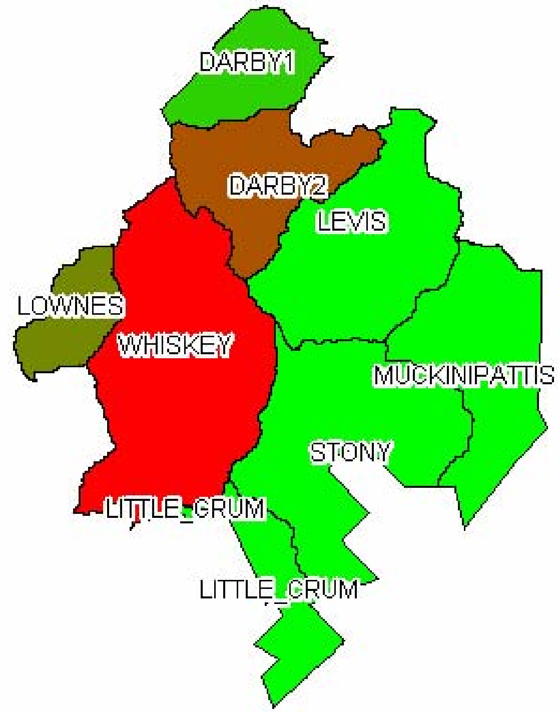
StormWISE is ready...

StormWISE

File Edit View Analyze Help

- All Land Uses
- No Land Uses
- BARREN
- COMMERCIAL
- FOREST
- RECREATIONAL
- ✓ RESIDENTIAL

Reduce Sediment Load by 50 Tons



Subwatershed	Optimal Investment($1000)	TN Removed	TP Removed	TSS Removed
DARBY1	40.11	50.89	2.33	9.23
DARBY2	147.95	45.47	1.95	10.45
LEVIS	0.00	0.47	0.03	0.02
LITTLE_CRUM	0.00	0.00	0.00	0.00
LOWNES	101.25	95.22	4.23	22.67
MUCKINIPATTIS	0.00	4.67	0.21	0.50
STONY	0.00	0.00	0.00	0.00
WHISKEY	219.89	41.44	2.10	7.13
Total	509.20	238.15	10.84	50.00

StormWISE is ready...

start Norton 1:09 AM

Stay Tuned

- StormWISE program soon available – public domain and open source
- Coastal Zone project reports
- EPA project report
- Visit Swarthmore College's Watershed Web Site:
- http://watershed.swarthmore.edu