Benefit Cost Analysis
Brandywine Christina Water Fund

Sep 18, 2014

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University of Delaware

Key Stakeholder Interviews

- City of Wilmington
- City of Newark
- Aqua PA
- PA American
- United Water
- Downingtown Municipal Water Authority
- Arcelor Mittal
- CTIP
- New Castle County
- DelDOT

Objective

- Prepare a subwatershed-based benefit-cost analysis to define revenue and investment needs for a future Brandywine Christina Healthy Water Fund.
- The objective of the water fund is to incentivize protection and restoration of the watershed to meet Clean Water Act fishable and swimmable and Safe Drinking Water Act potable goals by 2025.

Methods

1. Review water quality monitoring programs to measure performance of Water Fund.

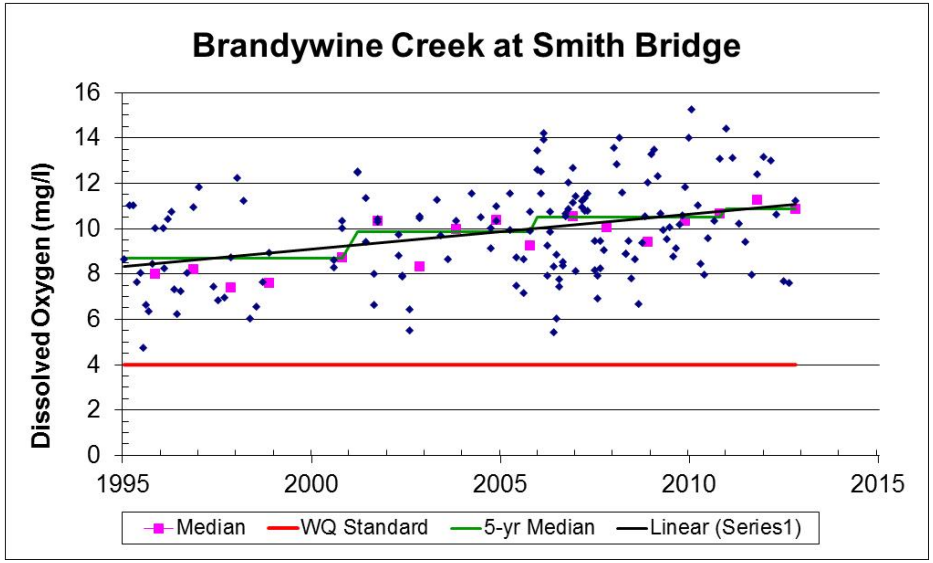
2. Utilize hydrodynamic models such as USGS SPARROW and HSPF (TMDL) to estimate N and TSS loads.

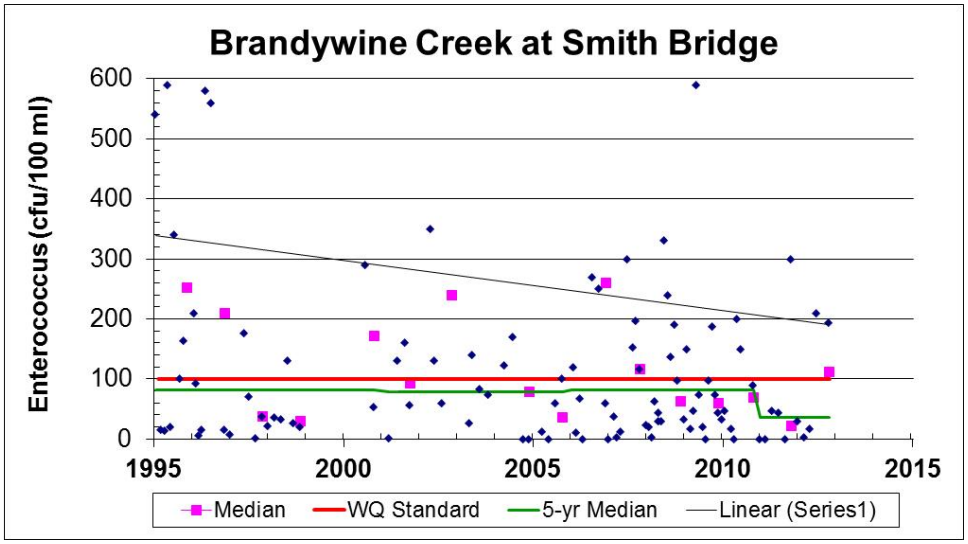
3. Tabulate TMDL reductions by subwatershed for N and TSS.

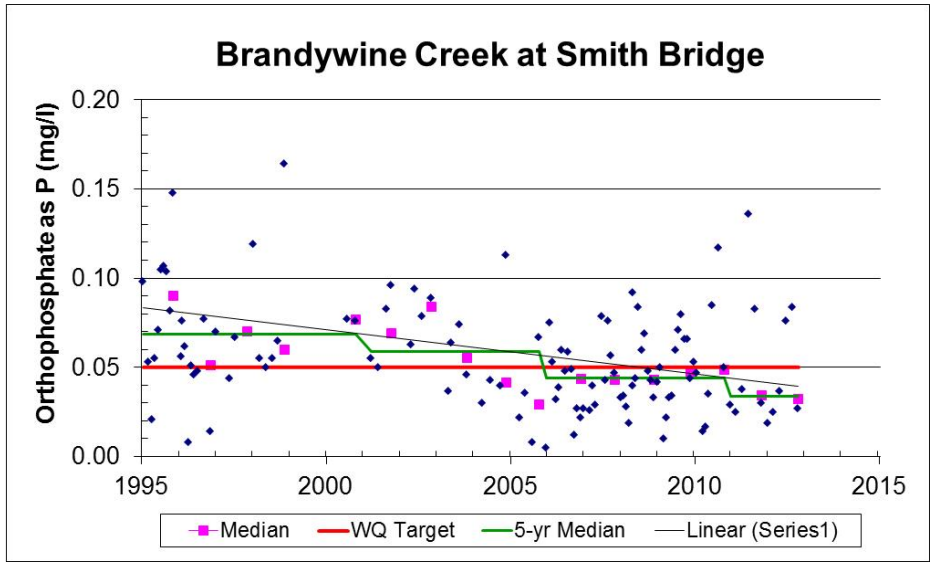
4. Estimate annual costs to reduce TMDL loads (N and TSS) by 2025.

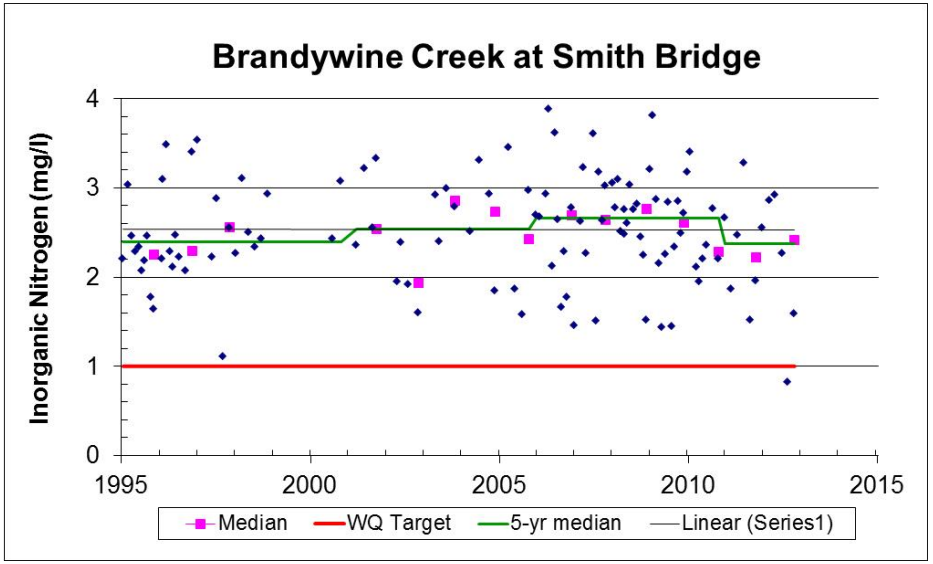
5. Calculate annual costs based on two scenarios:
    a. Load reduction costs spread evenly across all sources.
    b. Invest in least cost practices based on MAC principles.

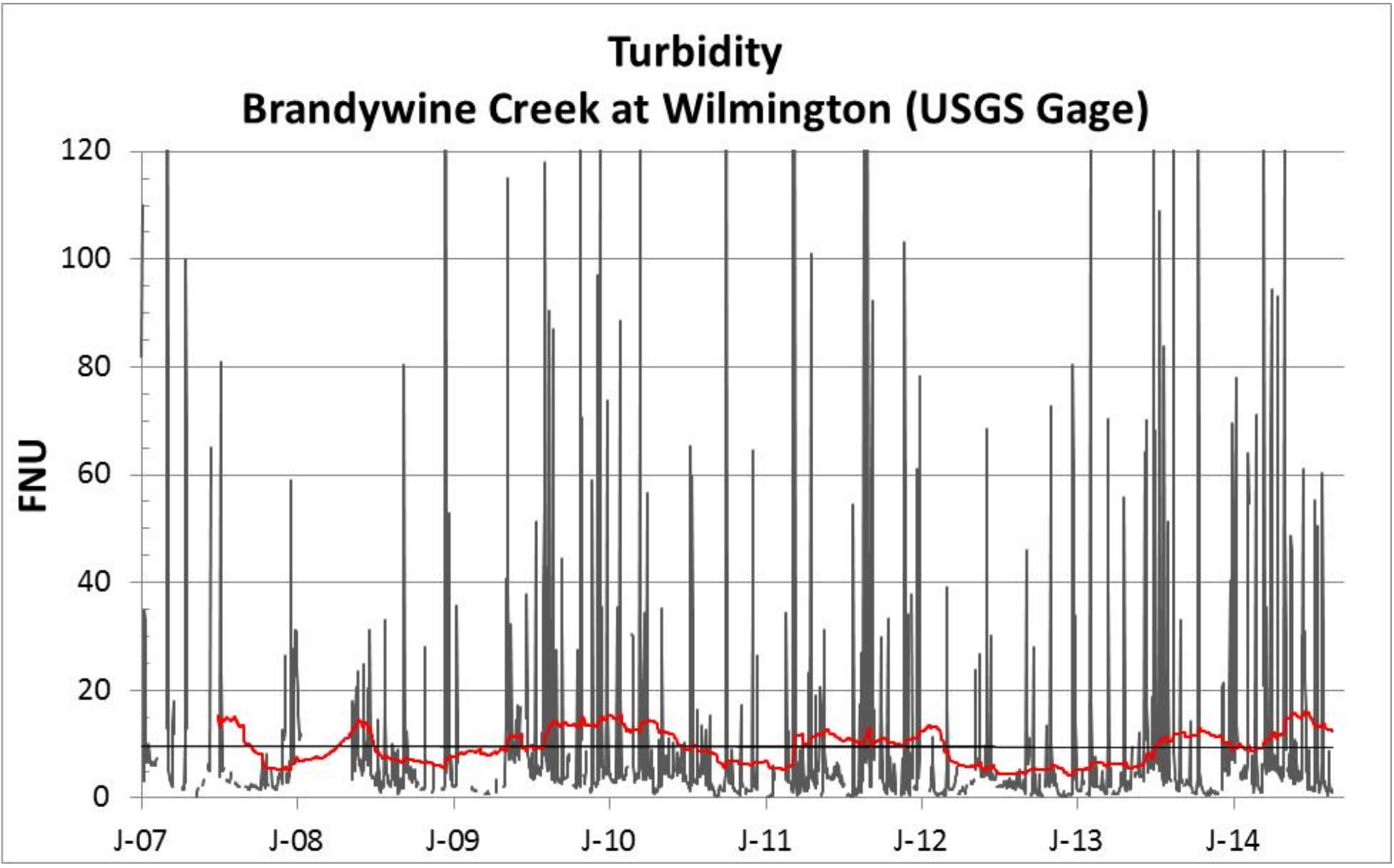
Christina Basin
DNREC STORET
Water Quality
Monitoring Stations


Brandywine Creek at Smith Bridge
Dissolved Oxygen (mg/l)
16
14
12
10
8
6
4
2
0
1995
2000
2005
2010
2015
Median
WQ Standard
5-yr Median
Linear (Series1)


Brandywine Creek at Smith Bridge
Enterococcus (cfu/100 ml)
600
500
400
300
200
100
0
1995
2000
2005
2010
2015
Median
WQ Standard
5-yr Median
Linear (Series1)


Brandywine Creek at Smith Bridge
Orthophosphate as P (mg/l)
0.20
0.15
0.10
0.05
0.00
1995
2000
2005
2010
2015
Median
WQ Target
5-yr Median
Linear (Series1)


Brandywine Creek at Smith Bridge
Inorganic Nitrogen (mg/l)
4
3
2
1
0
1995
2000
2005
2010
2015
Median
WQ Target
5-yr median
Linear (Series1)


Turbidity
Brandywine Creek at Wilmington (USGS Gage)
FNU
120
100
80
60
40
20
0
J-07
J-08
J-09
J-10
J-11
J-12
J-13
J-14

The Brandywine-Christina watershed has some of the highest nitrogen loads in the East.

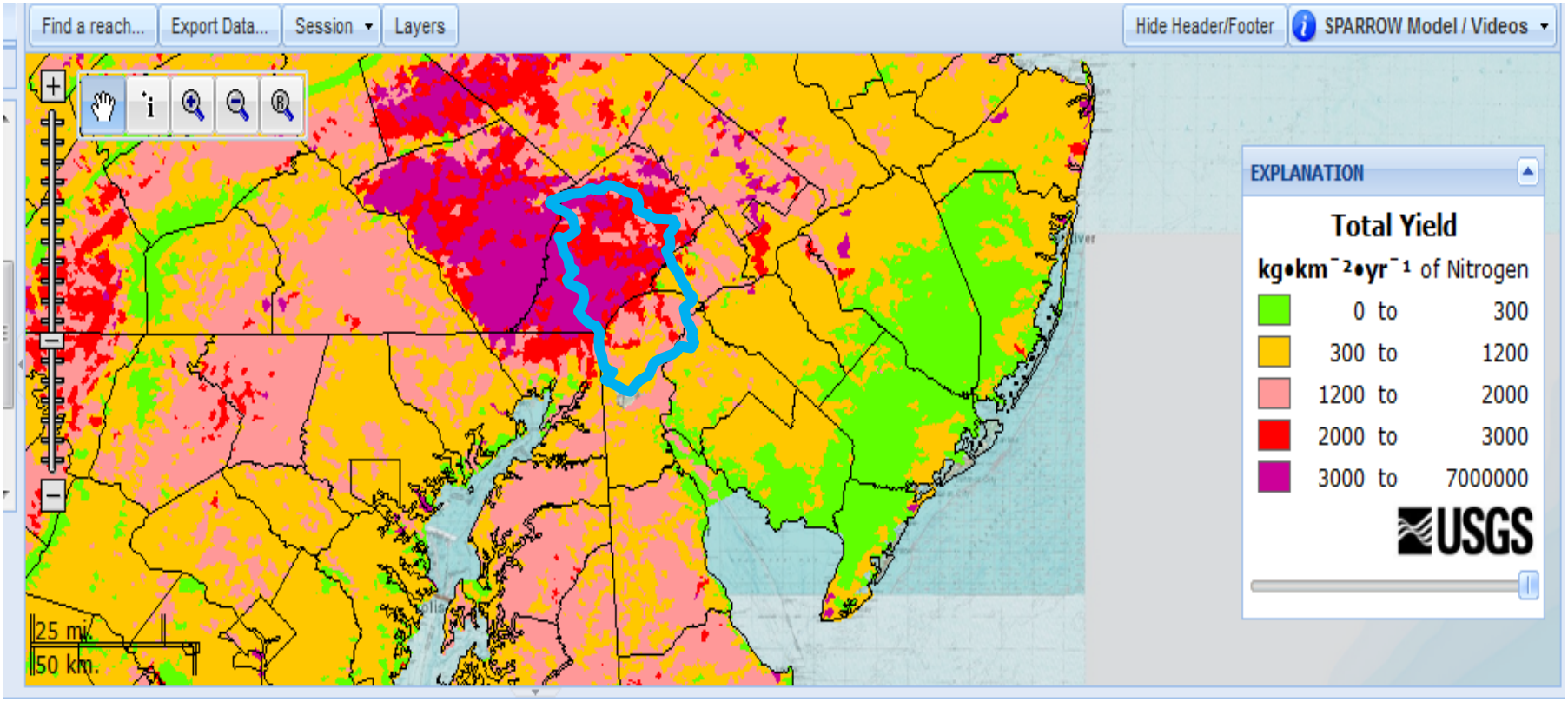


Table 1. High flow nonpoint source TMDL reductions in the Christina Basin

Watershed	% Reduction			
at PA-DE line:	**E. Bacteria**	**Sediment**	**Total N**	**Total P**
Brandywine Creek	93%	16 – 60%	46%	41%
Red Clay Creek	58%	45 – 52%	31%	40%
White Clay Creek	70%	26 – 70%	28%	73%
Christina River (at MD-DE line)	58%		73%	48%
in DE:				
Brandywine Creek	88 - 94%		16%	36%
Red Clay Creek	29 – 89%		49%	54%
White Clay Creek	66 – 89%			
Christina River	61 – 91%		6%	9%
CSO Discharges, Wilmington DE:				
Brandywine Creek	63%		64%	63%
Christina River	72%		72%	72%

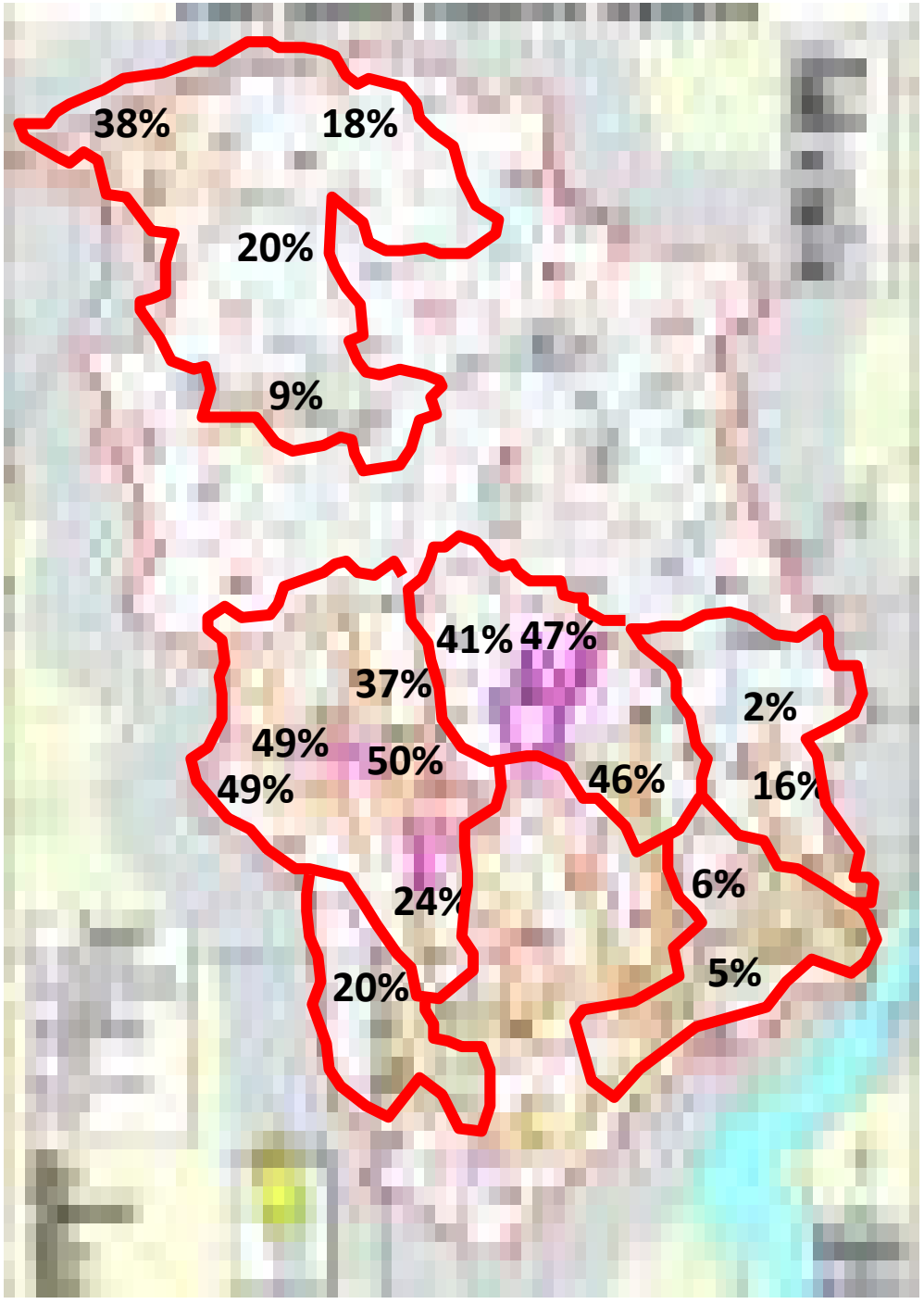
TMDL summary for Brandywine Creek Watershed

Subbasin	Baseline Loads (kg/day)			Allocations (kg/day)					Percent Reduction
	PS	NPS	Total	WLA	MS4 WLA	LA	MOS	TMDL	
Total Nitrogen									
B01	31.559	362.174	393.733	31.559	170.416	36.023	10.865	248.863	36.8%
B02	0.000	114.369	114.369	0.000	65.191	0.000	3.431	68.622	40.0%
B03	2.167	89.226	91.393	2.167	67.779	8.510	4.015	82.471	9.8%
B04	0.000	5.369	5.369	0.000	5.101	0.000	0.268	5.369	0.0%
B05	558.690	77.512	636.202	558.690	34.049	10.133	2.325	605.197	4.9%
B06	0.156	123.362	123.518	0.156	80.940	1.095	4.318	86.509	30.0%
B09	0.078	252.455	252.533	0.078	97.148	99.515	10.351	207.092	18.0%
B10	3.721	252.455	256.176	3.721	179.343	17.320	10.351	210.735	17.7%
B17	1.013	83.890	84.903	1.013	43.626	30.491	3.901	79.031	6.9%
B18	0.000	103.795	103.795	0.000	98.605	0.000	5.190	103.795	0.0%
B19	0.946	64.711	65.657	0.946	61.475	0.000	3.236	65.657	0.0%
B32	0.000	29.001	29.001	0.000	24.796	0.000	1.305	26.101	10.0%
B33	1.799	95.092	96.891	1.799	80.541	0.763	4.279	87.382	9.8%
B34	11.443	33.958	45.401	4.107	32.260	0.000	1.698	38.065	16.2%

Table 1. TMDL load reductions for nitrogen set by EPA in 2006

Subwatershed	Area (sq mi)	N Load (kg/day)	N Allocation (kg/day)	% N Reduction
Brandywine Creek				
B01	18.4	394	245	38%
B02	27.7	336	269	20%
B03	16.9	759	692	9%
B08	33.0	508	417	18%
B16	26.5	255	249	2%
B17	6.1	45	38	16%
Red Clay Creek				
R01	17.5	285	169	41%
R02	7.4	127	67	47%
R04	12.5	80	43	46%
White Clay Creek				
W01	10.2	158	80	49%
W02	15.8	236	120	49%
W03	18.8	266	168	37%
W04	14.3	211	106	50%
W08	10.1	72	55	24%
Christina River				
C01	20.9	208	166	20%
C04	9.2	32	30	6%
C06	21.9	78	74	5%

Nitrogen TMDL Reductions



Brandywine Creek (ID: 2796946)

Reach/Catchment Info | Model Source Inputs | **Predicted Values** | Graphs

Current Mapped Value: 2272980.97 kg·year^{-1} of Nitrogen (Total Load)

Predicted Values (Data Series)

Source	Predicted (Nitrogen kg·year^{-1})	% of Load
Total Load		
Municipal Point Source Total Load	144,815	6.4
Fertilizer Corn Soy Total Load	1,492,312	65.7
Atmospheric TIN Total Load	148,566	6.5
Manure Total Load	125,853	5.5
Developed Land Total Load	168,610	7.4
Fertilizer Other Total Load	192,826	8.5
Total Load	2,272,981	100.0

West Branch Brandywine Creek (ID: 2796458)

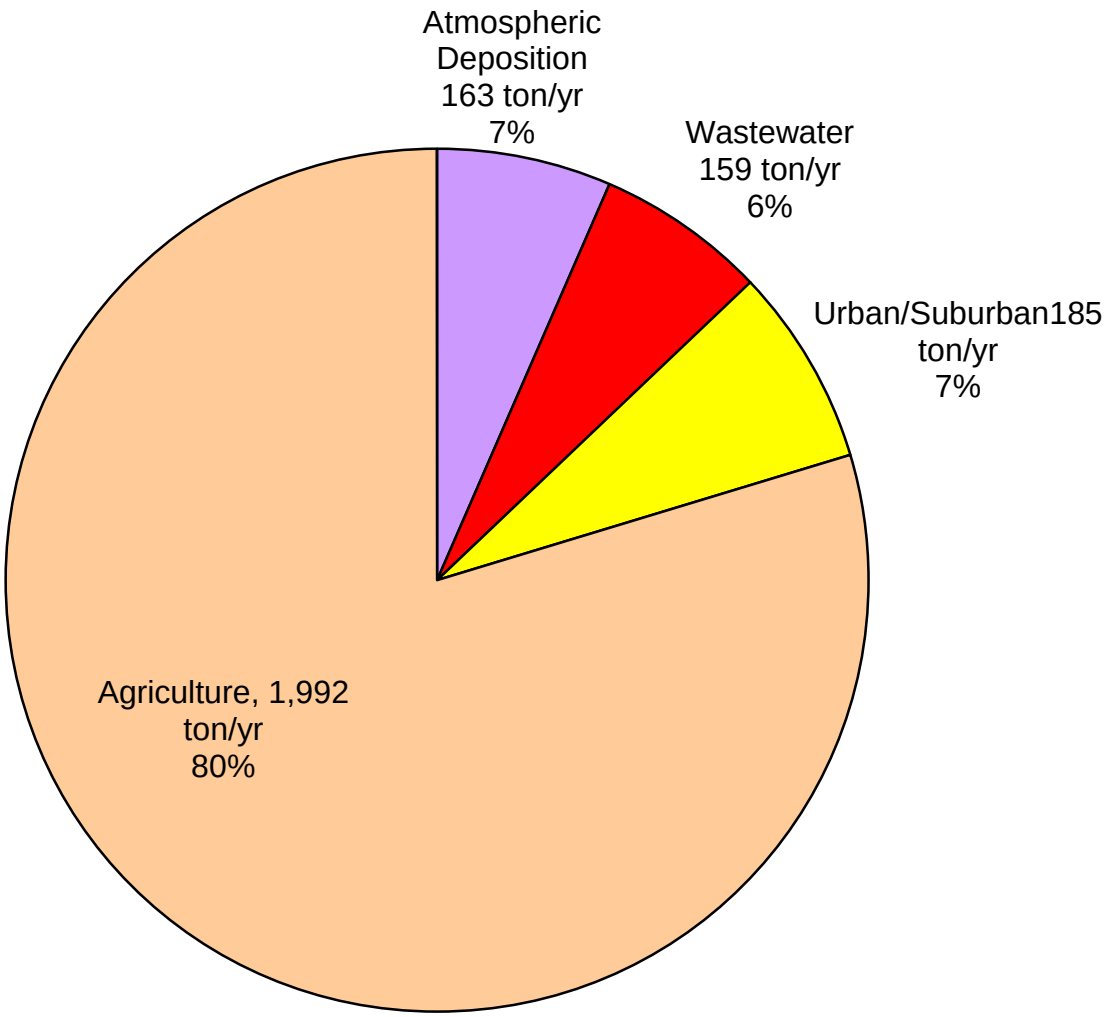
Reach/Catchment Info | Model Source Inputs | **Predicted Values** | Graphs

Current Mapped Value: 5976.2 kg·year^{-1} of Nitrogen (Incremental Load)

Predicted Values (Data Series)

Source	Predicted (Nitrogen kg·year^{-1})	% of Load
Total Load		
Municipal Point Source Total Load	35,377	3.4
Fertilizer Corn Soy Total Load	758,247	71.9
Atmospheric TIN Total Load	59,874	5.7
Manure Total Load	67,884	6.4
Developed Land Total Load	35,191	3.3
Fertilizer Other Total Load	98,597	9.3
Total Load	1,055,171	100.0

Nitrogen Loads by Source
Brandywine Creek Watershed



Per-Pound Costs of Reducing Nitrogen Pollution in the Chesapeake Bay Region

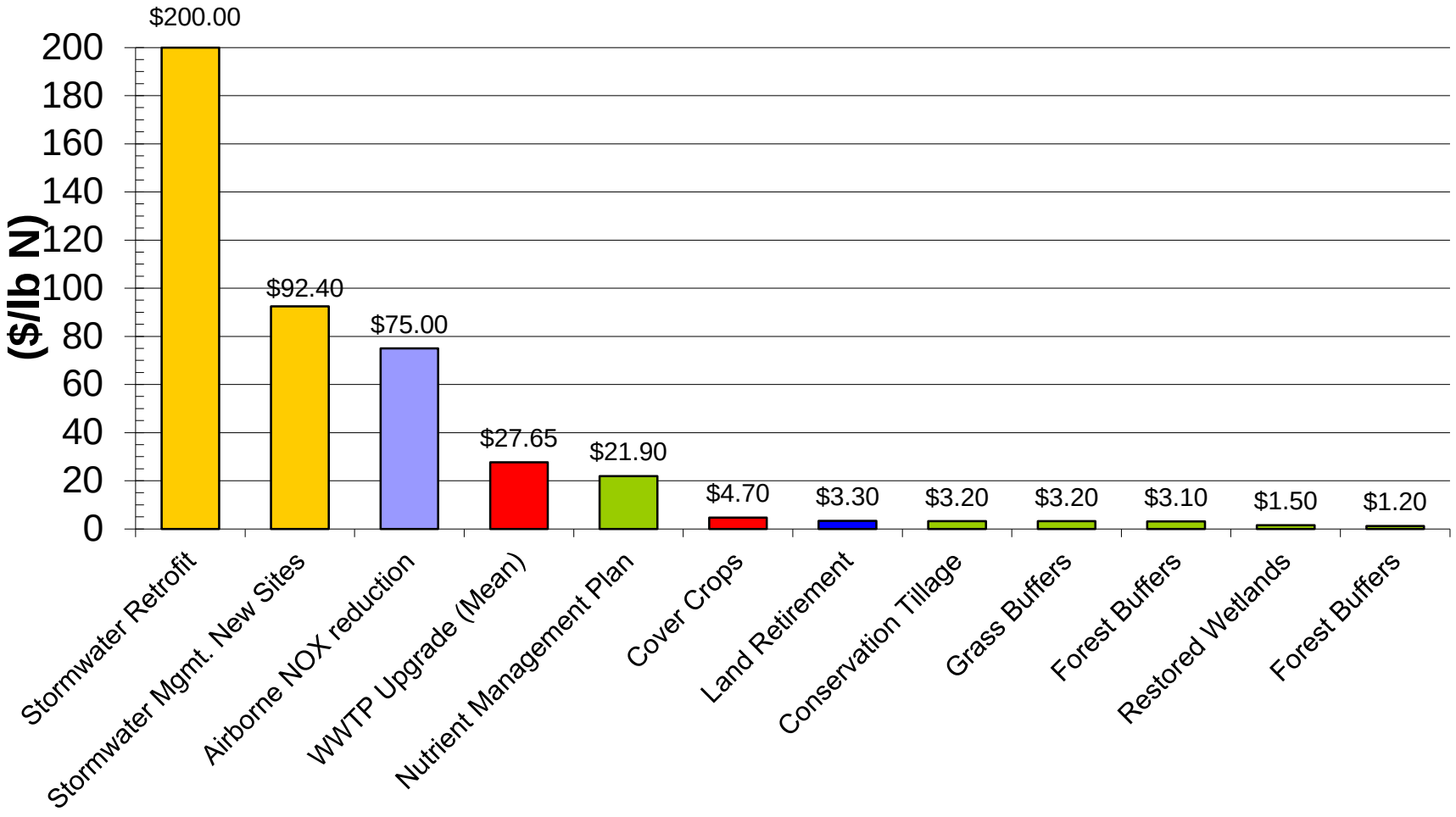
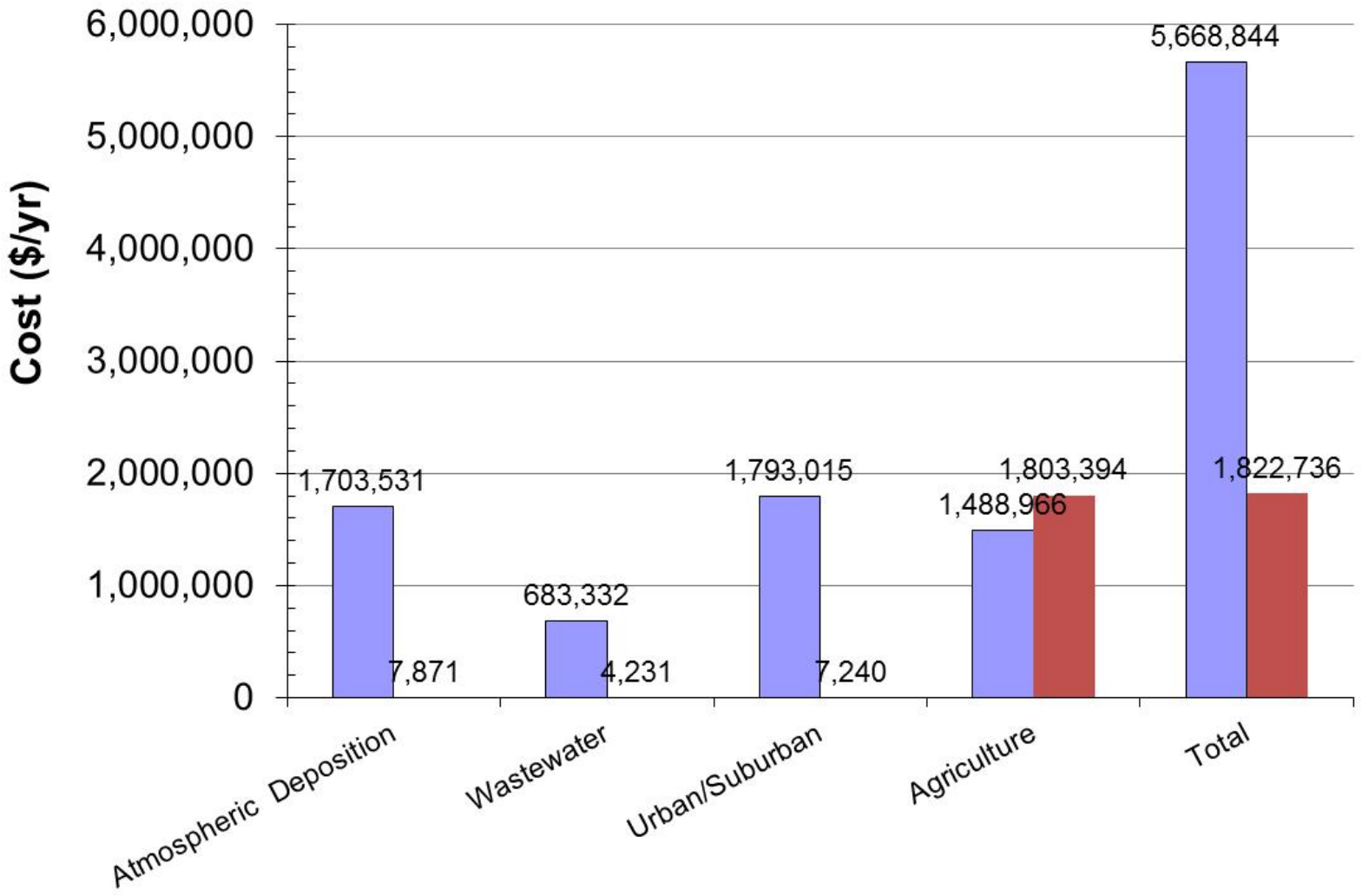


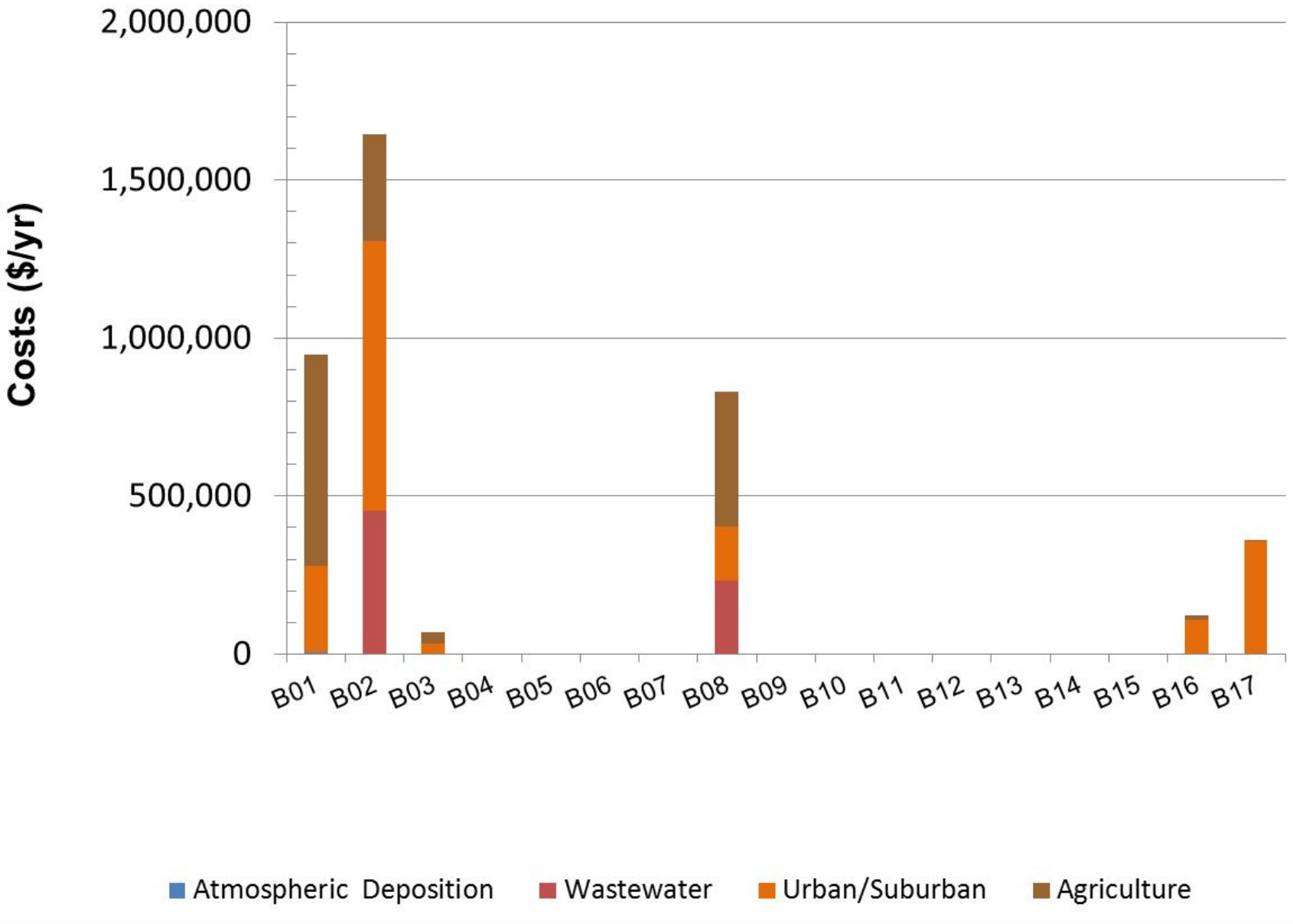
Table 2. Annual cost of nitrogen load reductions in Brandywine-Christina watershed

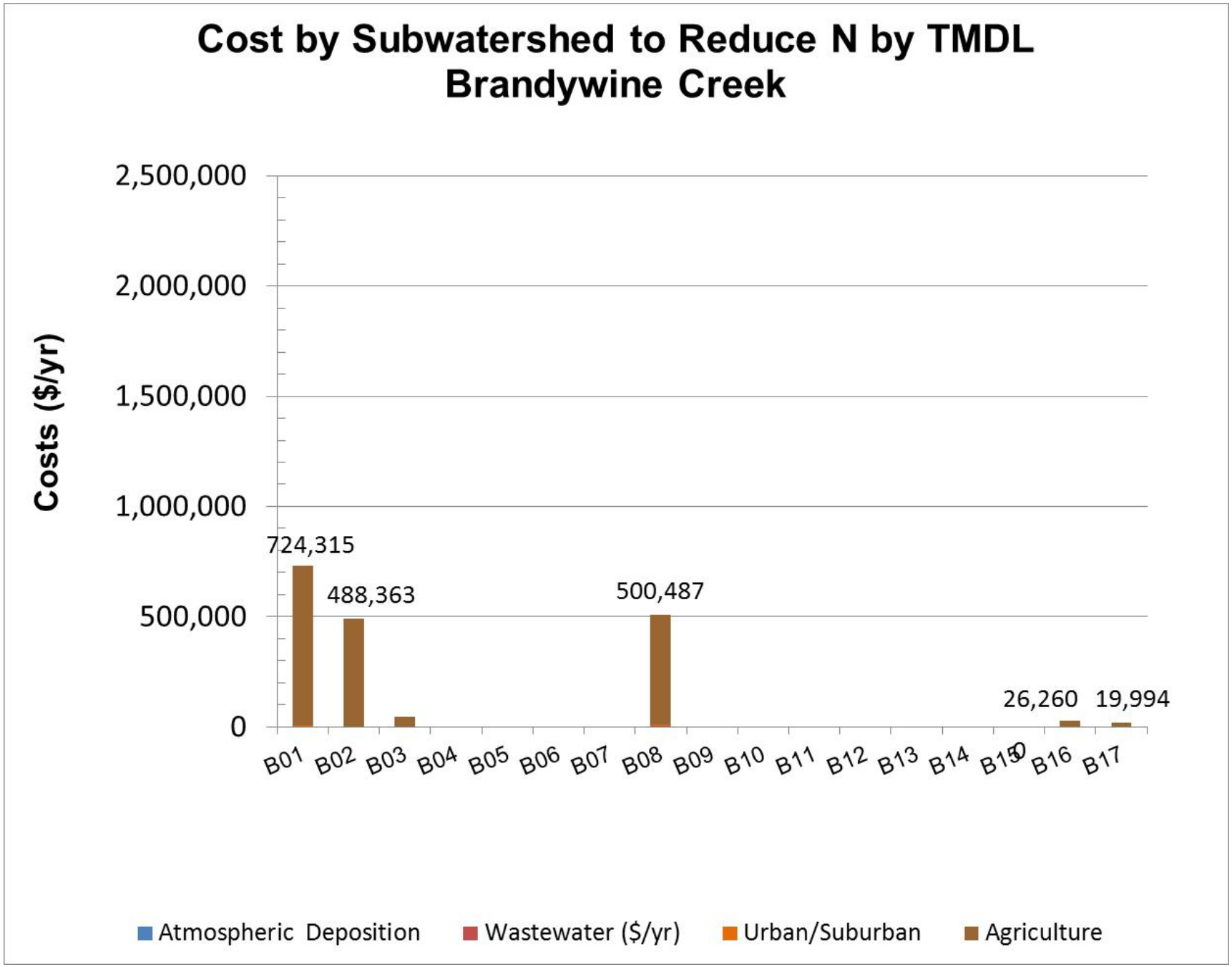
Water shed	Load	Atmos	WWTP	Urban	Ag	TMDL		Atmos ($/yr)	WWTP ($/yr)	Urban ($/yr)	Ag ($/yr)	Cost ($/yr)
	ton/yr	ton/yr	ton/yr	ton/yr	ton/yr	%		$75/lb N	$28/lb N	$100/lb N	$5/lb N	
BRC	A											
B01	72	4	0	1	67	38%		627,105	0	273,971	668,088	1,569,164
B02	49	3	8	4	34	20%		461,744	450,258	855,797	335,800	2,103,599
B03	4	0	0	0	4	9%		41,919	0	31,170	38,819	111,907
B08	51	3	4	1	43	18%		470,105	233,074	167,963	426,925	1,298,067
B16	3	0	0	1	2	2%		54,893	0	106,697	15,447	177,037
B17	2	0	0	2	0	16%		47,766	0	357,417	3,888	409,070
								1,703,532	**683,332**	**1,793,015**	**1,488,967**	**5,668,844**
	B											
B01	72.4	0	0	0	72	41%		3,772	0	2,805	724,315	730,892
B02	49.0	0	0	0	49	29%		1,855	0	227	488,363	490,445
B03	4.2	0	0	0	4	10%		724	0	546	43,976	45,245
B08	50.8	0	1	0	50	21%		1,288	4,146	3,294	500,487	509,215
B16	3	0	0	0	3	4%		232	85	368	26,260	26,945
B17	2	0	0	0	2	80%		0	0	0	19,994	19,994
						Max Ag		**7,871**	**4,231**	**7,240**	**1,803,394**	**1,822,736**

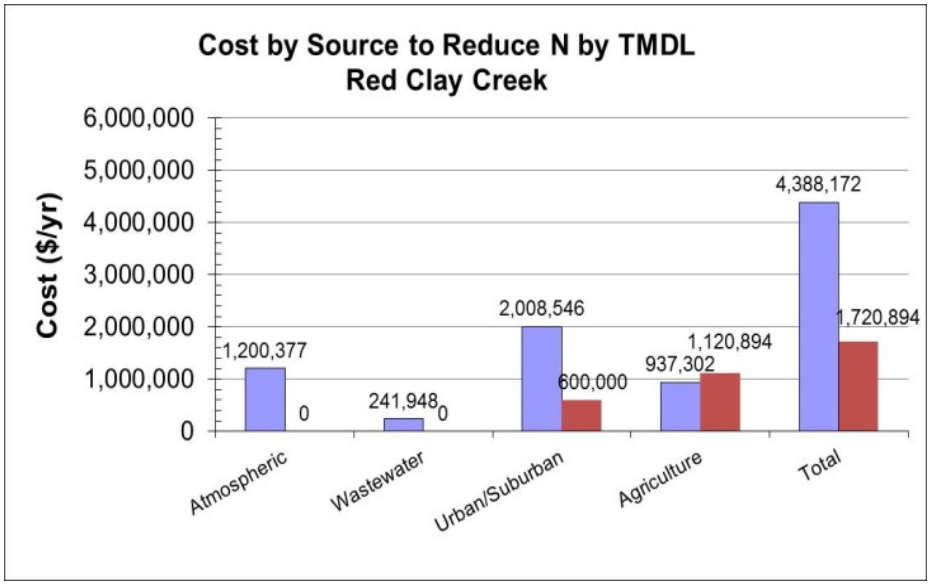
Cost by Source to Reduce N by TMDL
Brandywine Creek

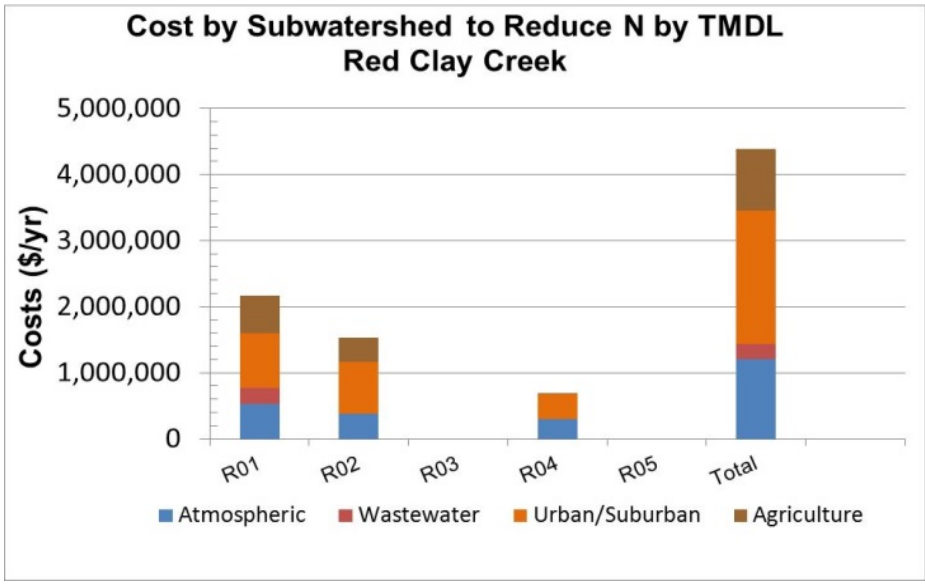


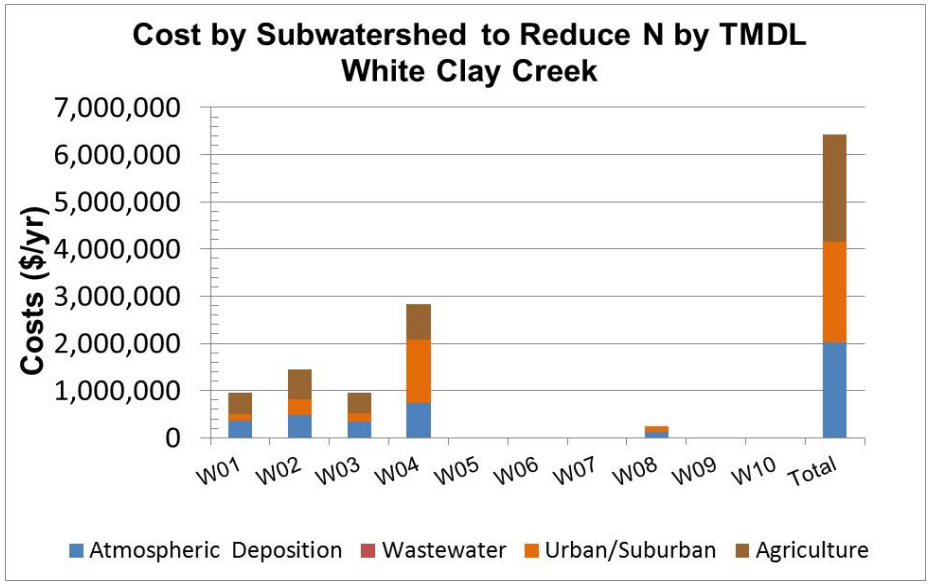
Cost by Subwatershed to Reduce N by TMDL
Brandywine Creek

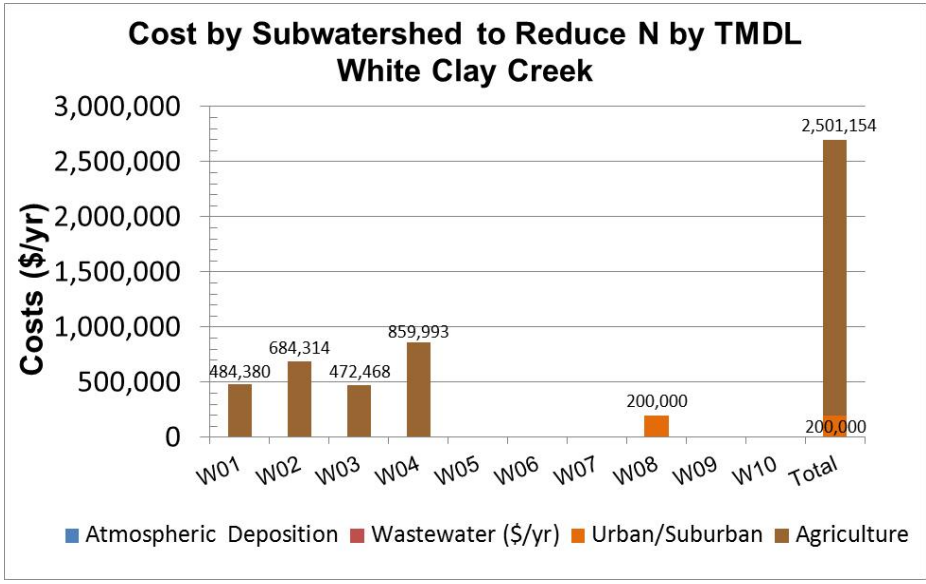



Cost by Subwatershed to Reduce N by TMDL
Brandywine Creek
Costs ($/yr)
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
724,315
488,363
500,487
26,260
19,994
B01
B02
B03
B04
B05
B06
B07
B08
B09
B10
B11
B12
B13
B14
B15
B16
B17
Atmospheric Deposition
Wastewater ($/yr)
Urban/Suburban
Agriculture


Cost by Source to Reduce N by TMDL
Red Clay Creek
Cost ($/yr)
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
0
1,200,377
0
241,948
0
2,008,546
600,000
937,302
1,120,894
4,388,172
1,720,894
Atmospheric
Wastewater
Urban/Suburban
Agriculture
Total


Cost by Subwatershed to Reduce N by TMDL
Red Clay Creek
Costs ($/yr)
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
0
R01
R02
R03
R04
R05
Total
Atmospheric
Wastewater
Urban/Suburban
Agriculture


Cost by Subwatershed to Reduce N by TMDL
White Clay Creek
Costs ($/yr)
7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
0
W01
W02
W03
W04
W05
W06
W07
W08
W09
W10
Total
Atmospheric Deposition
Wastewater
Urban/Suburban
Agriculture


Cost by Subwatershed to Reduce N by TMDL
White Clay Creek
Costs ($/yr)
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
484,380
684,314
472,468
859,993
200,000
2,501,154
200,000
W01
W02
W03
W04
W05
W06
W07
W08
W09
W10
Total
Atmospheric Deposition
Wastewater ($/yr)
Urban/Suburban
Agriculture

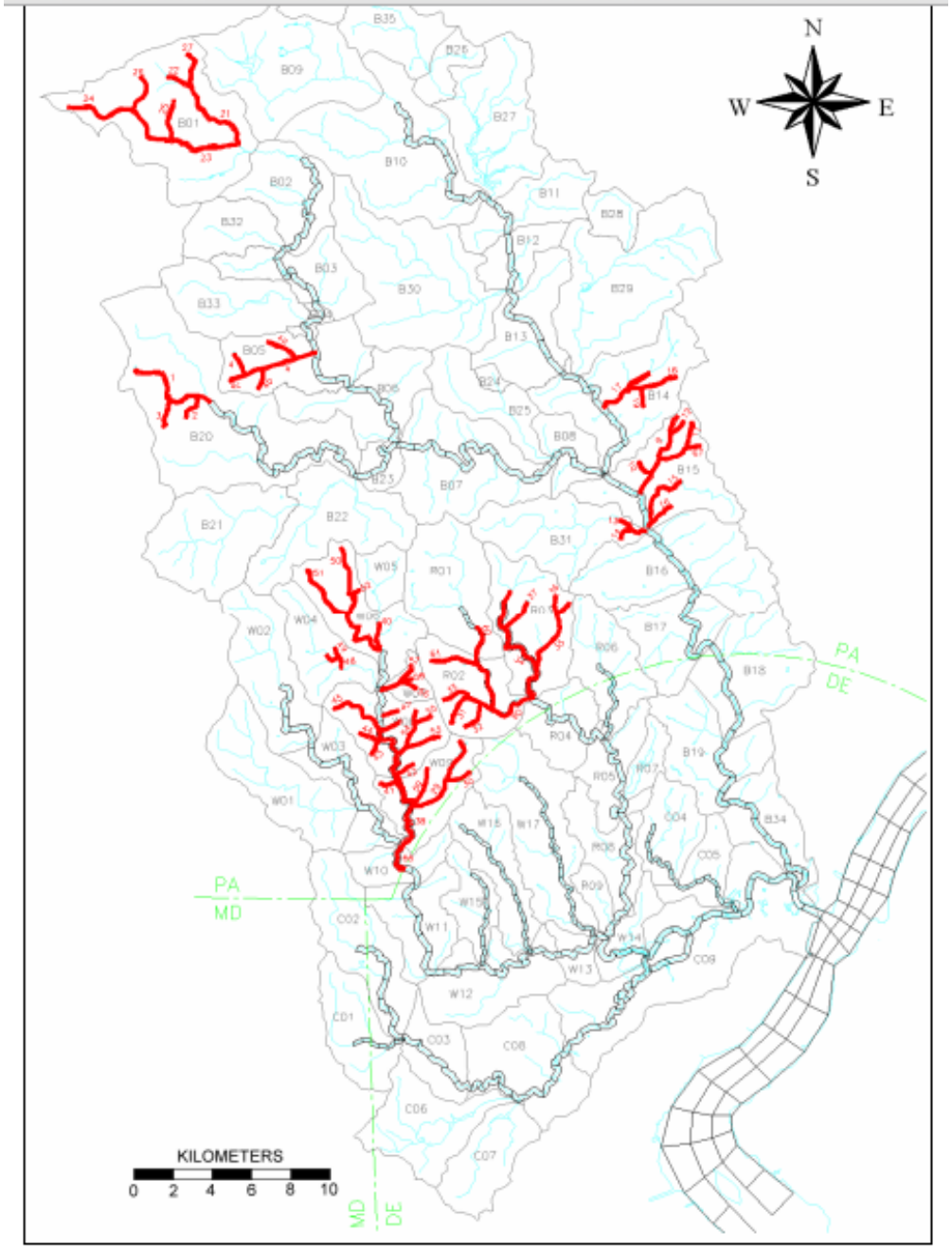


Figure 4-4. Stream segments impaired by sediment on Pennsylvania 1998 Section 303(d) list

Table 4-7. Average annual[6] allocations for Christina River Basin sediment TMDL

Subbasin	Baseline Load (ton/yr)			TMDL Allocation (ton/yr)					Percent Reduction
	PS	NPS	Total	WLA	MS4 WLA	LA	MOS	TMDL	
Brandywine Creek									
B01	29.80	776.03	805.83	29.80	414.16	84.82	27.83	556.61	30.9%
B04	0.00	42.63	42.63	0.00	21.77	-	1.15	22.92	46.2%
B05	246.02	1278.65	1524.67	246.02	421.74	-	35.15	702.91	53.9%
B06	0.08	340.20	340.28	0.08	219.34		11.55	230.97	32.1%
B09	0.04	498.86	498.89	0.04	180.75	218.75	21.03	420.57	15.7%
B14	79.81	1637.50	1717.31	79.81	631.82	-	37.45	749.08	56.4%
B15	9.19	1214.60	1223.79	9.19	509.37	-	27.29	545.85	55.4%
B20	1.68	1119.58	1121.26	1.68	645.94	49.03	36.67	733.31	34.6%
B31	0.04	1189.38	1189.42	0.04	452.25	-	23.80	476.09	60.0%
White Clay Creek									
W01	0.30	5353.56	5353.87	0.30	2940.17	-	154.76	3095.23	42.2%
W02	11.42	7999.18	8010.60	11.42	2283.47	449.21	144.43	2888.53	63.9%
W03	0.00	3168.54	3168.54	0.00	1825.04	-	96.05	1921.10	39.4%
W04	0.00	5187.94	5187.94	0.00	1722.66	58.57	94.49	1875.72	63.8%
W06	2.83	8114.08	8116.92	2.83	1795.34	667.6	129.78	2595.55	68.0%
W07	2.97	1414.61	1417.58	2.97	393.60	-	20.87	417.44	70.6%
W08	2.19	4606.80	4609.00	2.19	2146.83	-	113.11	2262.13	50.9%
W09	0.05	2808.89	2808.95	0.05	1968.74	-	103.62	2072.42	26.2%
Red Clay Creek									
R01	8.45	8424.04	8432.49	8.45	3500.39	329.31	201.96	4040.11	52.1%
R02	50.26	6252.12	6302.38	50.26	2805.45	-	150.30	3006.01	52.3%
R03	6.85	7218.12	7224.97	6.85	3761.33	-	198.33	3966.51	45.1%

Sediment TMDL Reductions

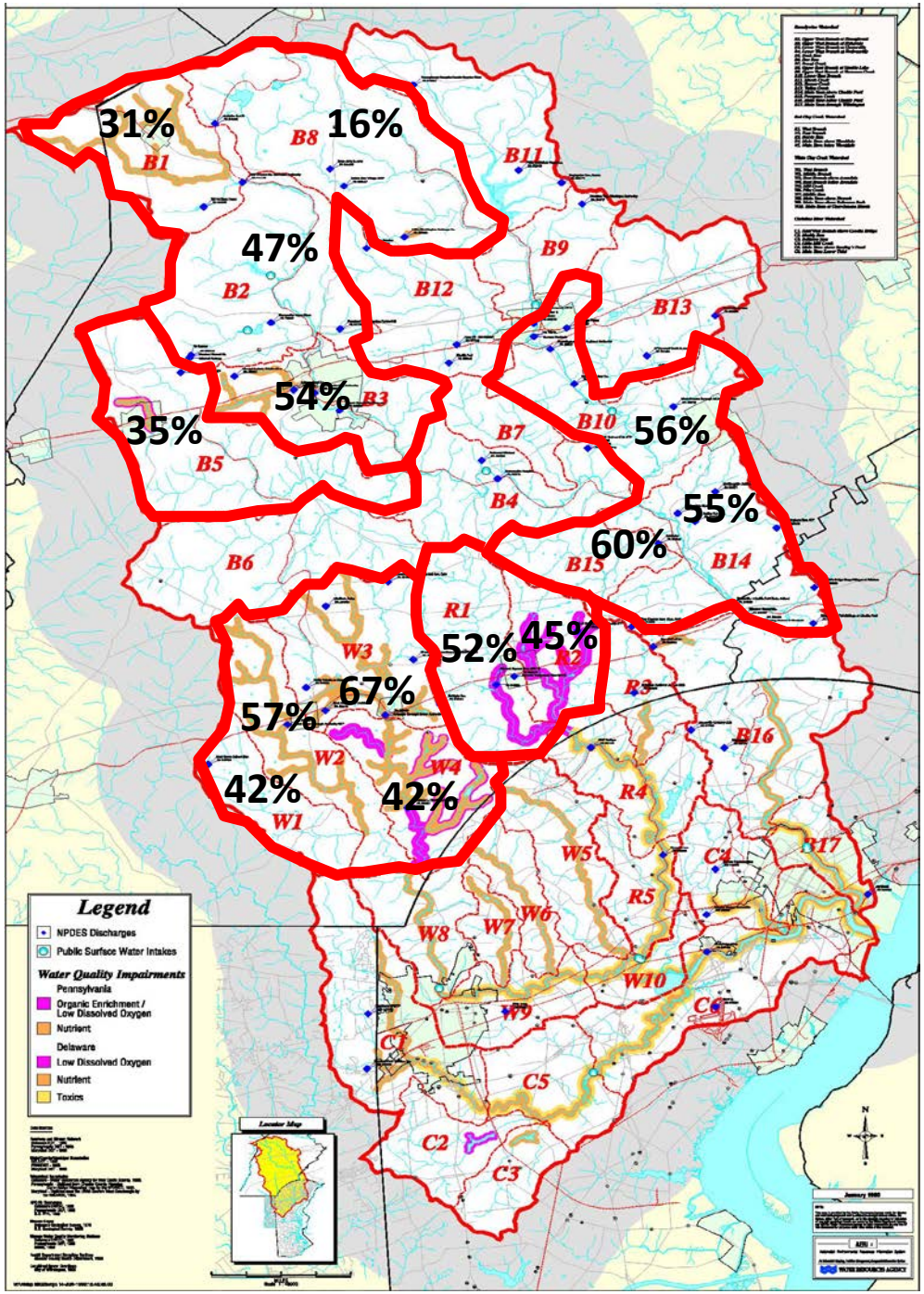
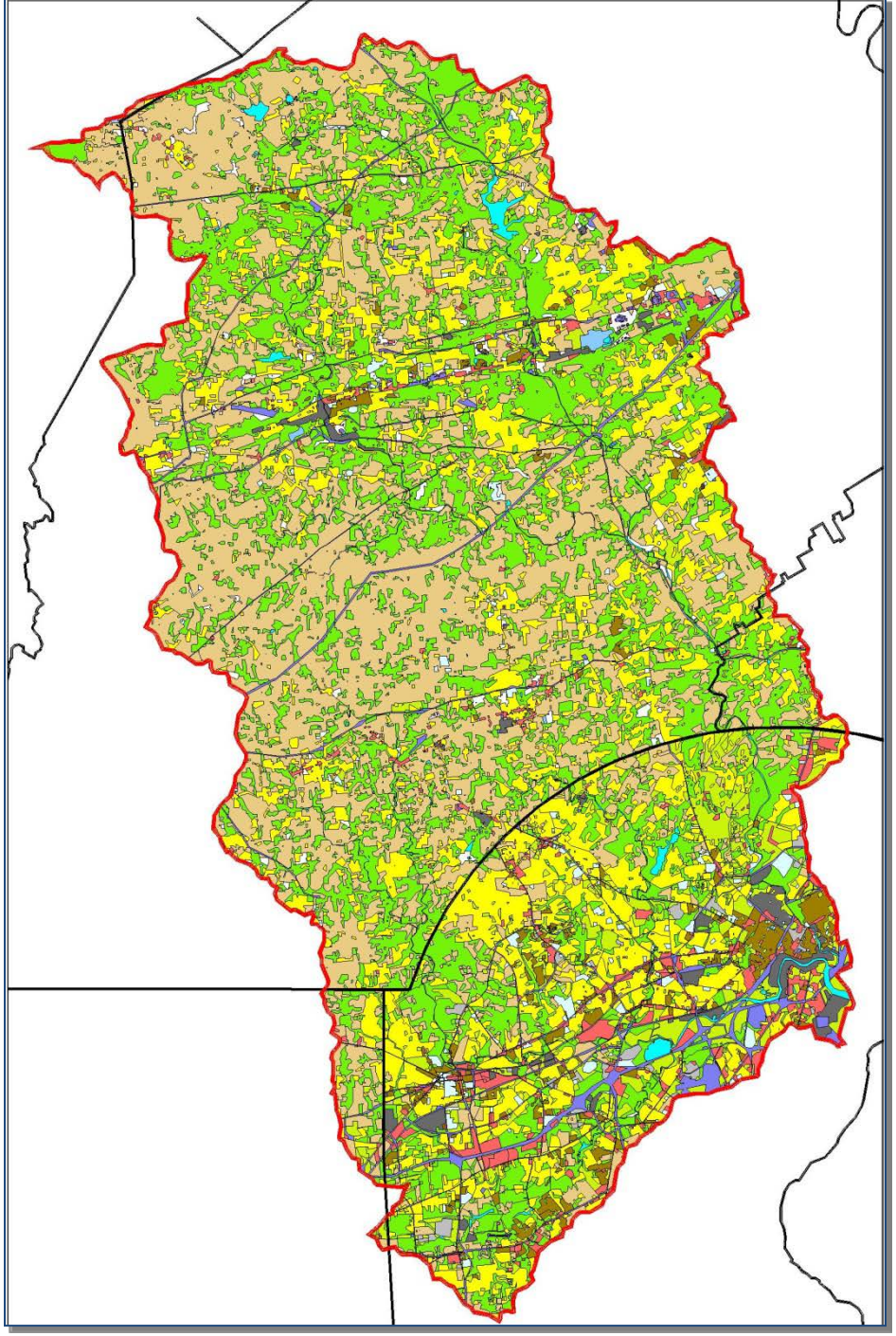


Table 3. Annual cost of sediment load reductions in Brandywine-Christina watershed

Subwatershed	Area (sq mi)	Load (lb/yr)	Allocation (lb/yr)	Reduction (lb/yr)	% Reduction	Cost ($0.20/lb/yr)
Brandywine Cr.						
B01 (WB Honeybrook)	18.4	1,612,000	447,271	1,164,729	72%	$232,946
B02 (WB Hibernia)	27.7	34,529	18,469	16,060	47%	$3,212
B03 (WB Coatesville)	16.9	1,224,575	564,509	660,066	54%	$132,013
B05 (Buck Run)	25.5	900,163	588,599	311,564	35%	$62,313
B08 (EB Struble Lake)	33.0	400,697	338,063	62,634	16%	$12,527
B10 (EB West Chester)	20.8	1,378,751	601,447	777,304	56%	$155,461
B14 (Chadds Ford)	24.5	982,872	438,438	544,434	55%	$108,887
B15 (Pocopson Creek)	9.2	954,767	382,228	572,539	60%	$114,508
						821,866
Red Clay Creek						
R01 (West Branch)	17.5	29,468,000	14,092,000	15,376,000	52%	$3,075,200
R02 (East Branch)	9.9	14,448,000	7,932,000	6,516,000	45%	$1,303,200
						$4,378,400
White Clay Creek						
W01 (West Branch)	18.4	10,708,000	6,190,000	4,518,000	42%	$903,600
W02 (Middle Branch)	27.7	22,360,000	9,618,000	12,742,000	57%	$2,548,400
W03 (EB abv. Avondale)	16.9	29,446,000	9,776,000	19,670,000	67%	$3,934,000
W04 (EB below Avondale)	17.1	14,834,000	8,668,000	6,166,000	42%	$1,233,200
						$8,619,200



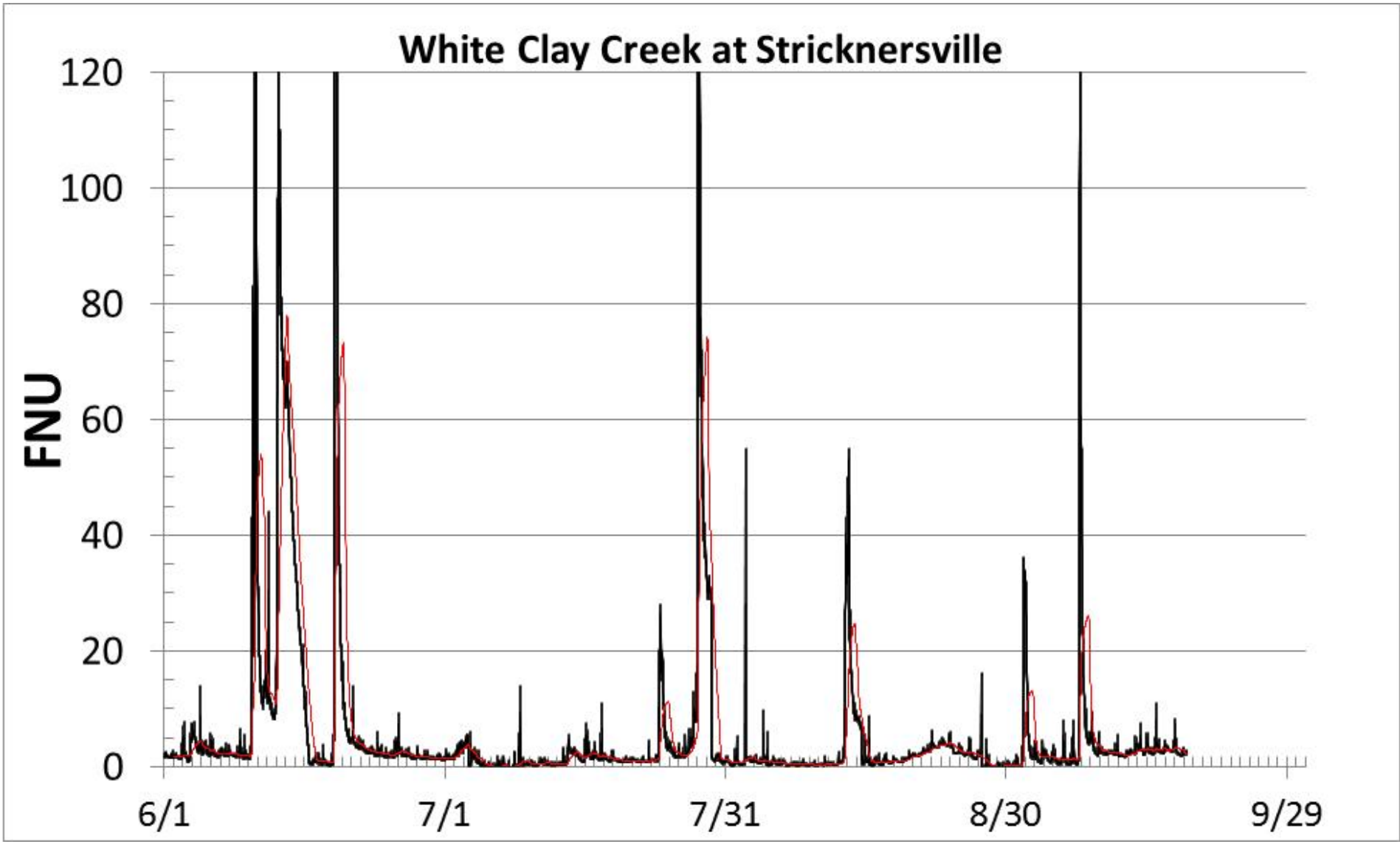
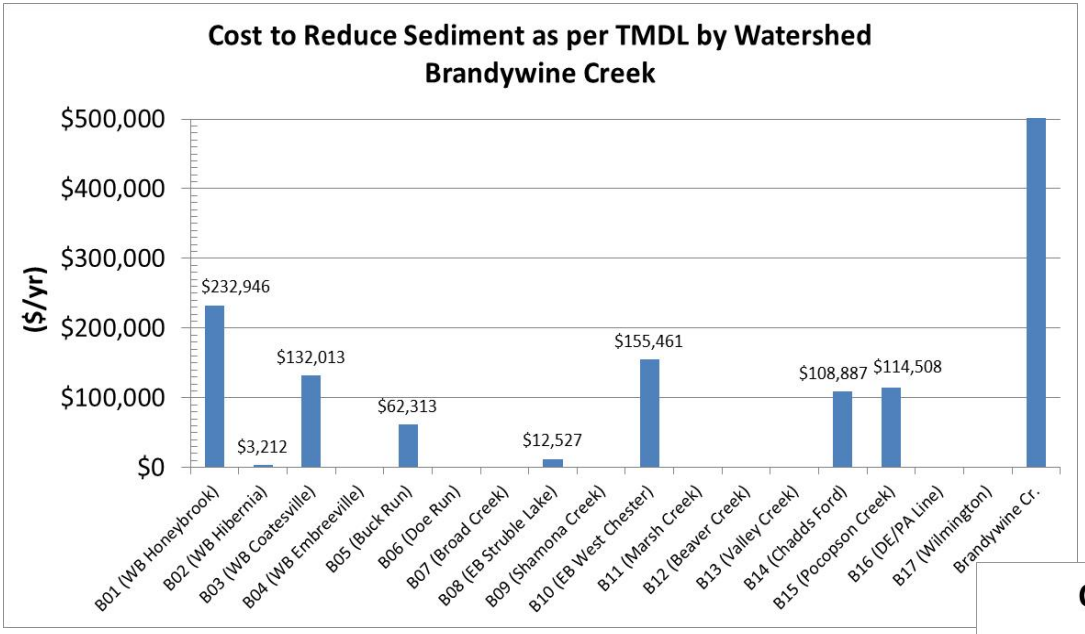
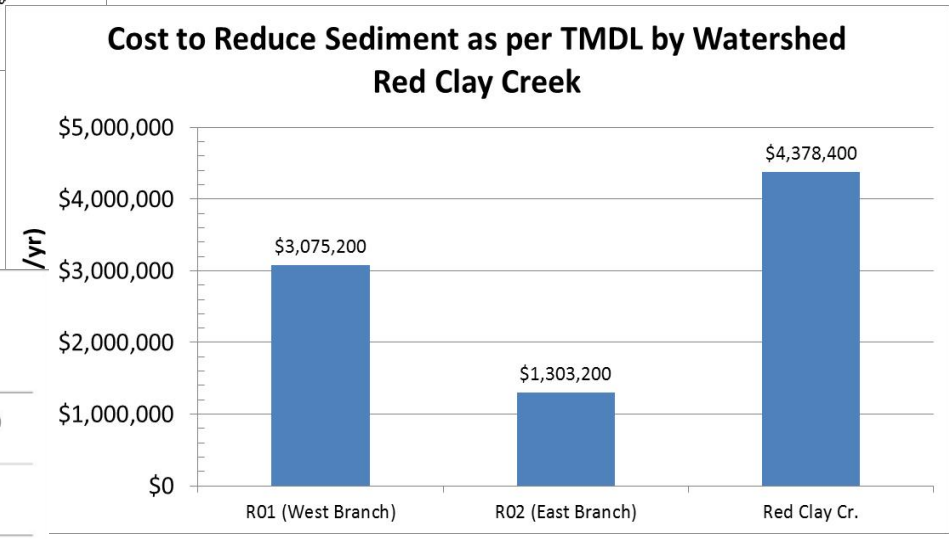
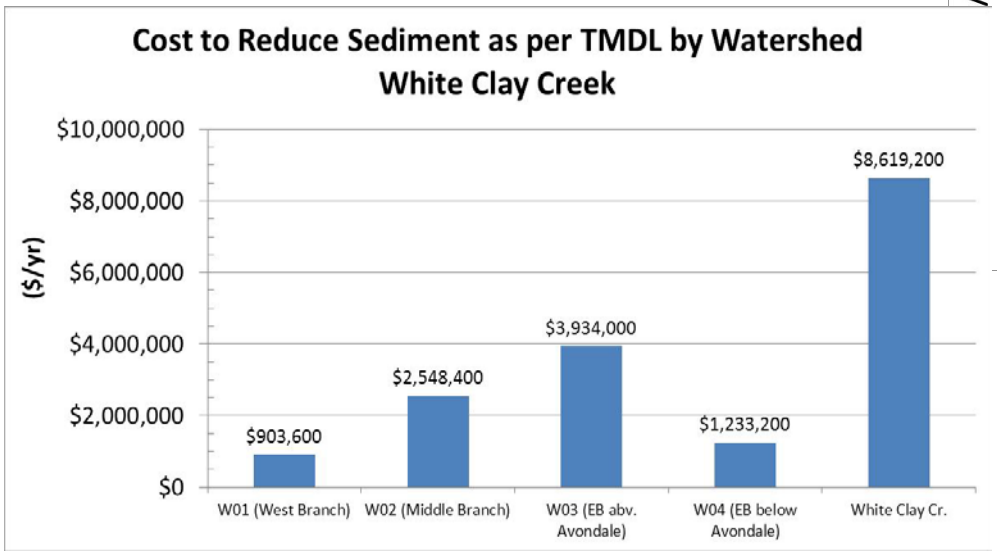

White Clay Creek at Stricknersville
FNU
120
100
80
60
40
20
0
6/1
7/1
7/31
8/30
9/29

Table 1. Cost Effectiveness of Agricultural Management Measures

Practice	Soil Loss Reduction %	Soil Loss Annual Cost ($/lb)
No Till Conservation	60-90	0-11.00
Contouring	40-80	0.4-4.8
Terraces	50-90	4.0-44.0
Grassed Waterways	60-80	0.3-2.6
Sediment Basins	60-95	2.8-29.0


Cost to Reduce Sediment as per TMDL by Watershed
Brandywine Creek
($/yr)
$500,000
$400,000
$300,000
$200,000
$100,000
$0
$232,946
$3,212
$132,013
$62,313
$12,527
$155,461
$108,887
$114,508
B01 (WB Honeybrook)
B02 (WB Hibernia)
B03 (WB Coatesville)
B04 (WB Embreeville)
B05 (Buck Run)
B06 (Doe Run)
B07 (Broad Creek)
B08 (EB Struble Lake)
B09 (Shamona Creek)
B10 (EB West Chester)
B11 (Marsh Creek)
B12 (Beaver Creek)
B13 (Valley Creek)
B14 (Chadds Ford)
B15 (Pocopson Creek)
B16 (DE/PA Line)
B17 (Wilmington)
Brandywine Cr.


Cost to Reduce Sediment as per TMDL by Watershed
Red Clay Creek
/yr)
$5,000,000
$4,000,000
$3,000,000
$2,000,000
$1,000,000
$0
$3,075,200
$1,303,200
$4,378,400
R01 (West Branch)
R02 (East Branch)
Red Clay Cr.


Cost to Reduce Sediment as per TMDL by Watershed
White Clay Creek
($/yr)
$10,000,000
$8,000,000
$6,000,000
$4,000,000
$2,000,000
$0
$903,600
$2,548,400
$3,934,000
$1,233,200
$8,619,200
W01 (West Branch)
W02 (Middle Branch)
W03 (EB abv. Avondale)
W04 (EB below Avondale)
White Clay Cr.

Annual Costs of Restoration

Watershed	Nitrogen	Sediment
Brandywine	$1,800,000	$800,000
Red Clay	$1,700,000	$4,400,000
White Clay	$2,700,000	$8,600,000
Christina	$500,000	No TMDL in Del.
Brandywine/Christina	**$6,700,000**	**$13,800,000**

Brandywine Headwaters Preservation

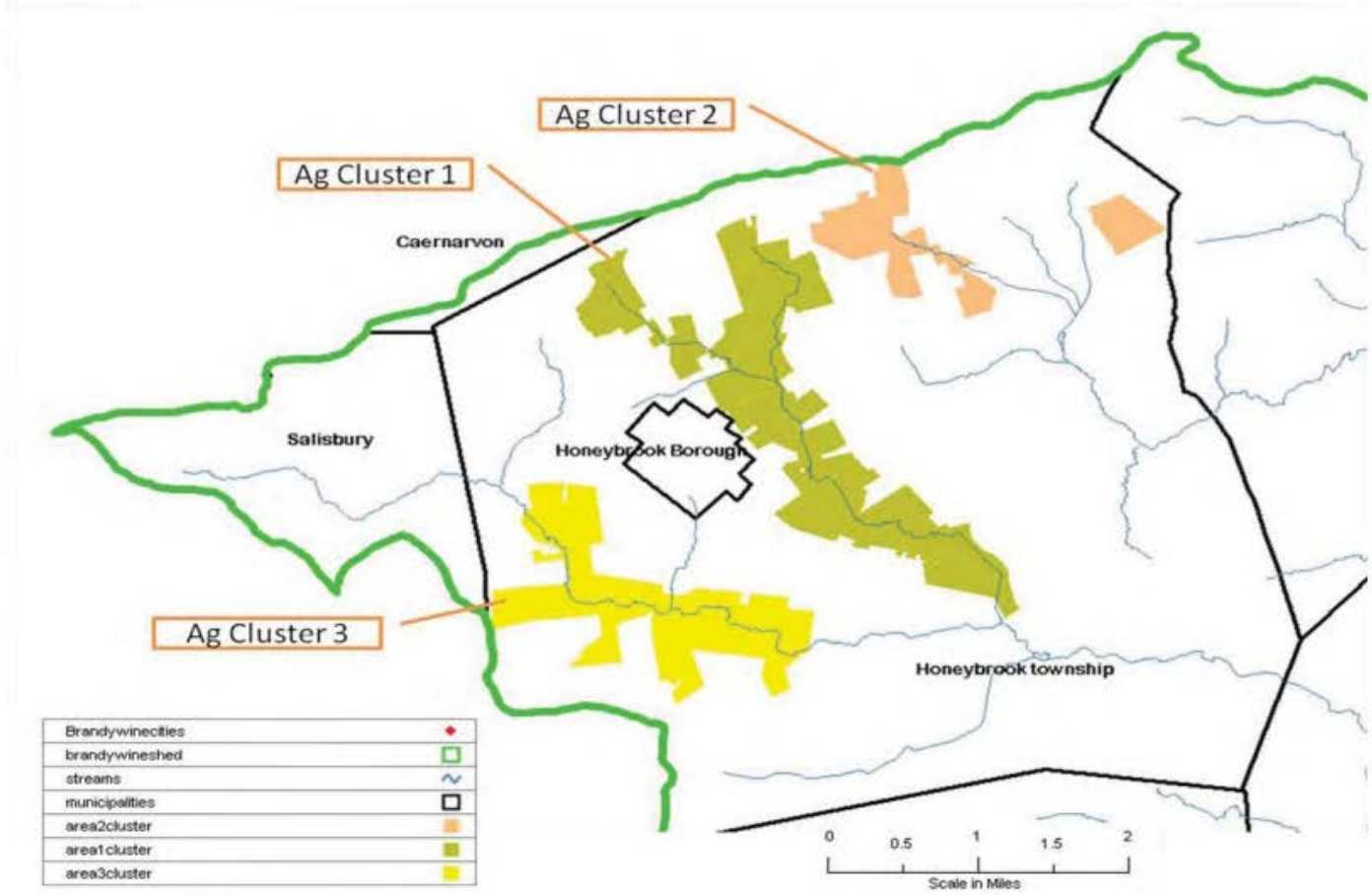


Figure 7-2 – Priority Agricultural Preservation Areas on West Branch Brandywine Creek in Honey Brook

Chester County Open Space Preservation

2013 Conservancy Grants

Conservancy Grants Awarded in 2013

Conservancy	Municipality	Project	Acres	County Funds Awarded
French & Pickering Creeks Conservation Trust	E. Nantmeal	Why Not Farm	91	$158,500
Natural Lands Trust	W. Pikeland	Carmichael Easement	21	$42,000
French & Pickering Creeks Conservation Trust	W. Pikeland	Thayer Farm	28	$92,084
Natural Lands Trust	E. Nantmeal	ConaMoore Farm	44	$68,053
Natural Lands Trust	E. Brandywine	Dilworth Farm	82	$268,000
Willistown Conservation Trust	Willistown	Rushton Woods Preserve	5	$266,500
Natural Lands Trust	W. Pikeland	Woodland Easement	20	$39,800
Brandywine Conservancy	Honey Brook Twp.	Fisher Easement	68	$76,500
		Total:	**359**	**$1,011,437**
		Total Leveraged Funds:		**$3,523,932**

Revenue Streams

- USDA Farm Bill (80%)
- Source Water Fund (20%)
  - 100 mgd x ($0.10/1,000 gal) = $3.6 million/yr
  - $6.00/yr/customer @ 60,000 gal/yr consumption