Christina Basin Trends, 1995-2010

July 21, 2010

For consideration by:

Christina Basin Clean Water Partnership

Prepared by:

Gerald Kauffman, Andrew Homsey, Martha Narvaez
Sarah Chatterson, Erin McVey, Stacey Mack
University of Delaware
Institute for Public Administration - Water Resources Agency
DGS Annex Academy St.
Newark, DE 19716
302-831-4929 www.wra.udel.edu

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Table of Contents

List of Tables

List of Figures

1. The Christina Basin

This report summarizes trends in the Christina Basin from 1995-2010 for (1) population, (2) land use, (3) water quality, (4) population/water quality vs. land use, (5) water temperature, and (6) streamflow. Over the last 15 years, the Christina Basin Clean Water Partnership has achieved measurable progress since it was formed in the early 90s (Fig. 1). On October 3, 2003 the Philadelphia Inquirer headlined: "Brandywine: A Creek at Risk as Pa. and Del. Debate What to Do, the Pollution Flows on" (Fig. 2). On February 5, 2009, the EPA Environmental News announced that the CBCWP in Delaware and Pennsylvania had made significant progress in reducing pollution from stormwater runoff to the Christina River Basin (Fig. 3).

The Christina River Basin, the 2nd largest tributary to the Delaware Estuary, lies in Chester County, Pennsylvania and New Castle County, Delaware with a small sliver in Cecil County, Maryland. The Christina Basin has unique interstate coordination challenges as it is the only watershed in the entire Delaware Basin that cross the borders of more than one state (Fig. 4). Since 1994 the two states, EPA, and Delaware River Basin Commission have been working together to restore the Brandywine, Red Clay, White Clay, and Christina Creeks (Fig. 5) to fishable, swimmable, and potable status as per the Federal Clean Water Act and state surface water quality standards through a phased watershed restoration approach.

Phase	Tasks	Milestones
I	DRBC/USEPA Mediation/Problem Assessment	1994 - 1996
II	GIS Watershed Characterization	1997 - 1998
III	Water Quality Monitoring/Implementation	1999 - 2000
IV/V	TMDL Modeling/Implementation	2001 - 2005
VI	Targeted Watershed Grant Implementation	2004 - 2007
VII	Implementation of Pollution Control Strategy	2008 – 2020

In 2006, the EPA and two states issued Christina Basin low flow and high flow total maximum daily loads (TMDLS) that prescribe reductions in point source pollutants from wastewater treatment plants and nonpoint source pollutants from stormwater. In 2007, Delaware completed a Christina Basin Pollution Control Strategy and has been implementing best management practices to meet the TMDLs and restore the waters to fishable and swimmable Clean Water Act standards. The cities of Wilmington and Newark and New Castle County and the Delaware Department of Transportation have begun complying with the terms of NPDES Municipal Separate Stormwater (MS4) Permits designing to reduce pollutants loads from urban and suburban stormwater. The Pennsylvania DEP and local townships, cities, and boroughs in Chester County have begun drawing up MS4 permits designed to meet the terms of the TMDL's for the upper Christina Basin where headwaters rise in the Commonwealth.

Figure 1. Organization of the Christina Basin Clean Water Partnership (UDWRA)

BRANDYWINE: A CREEK AT RISK AS PA. AND DEL. DEBATE WHAT TO DO, THE POLLUTION FLOWS ON.

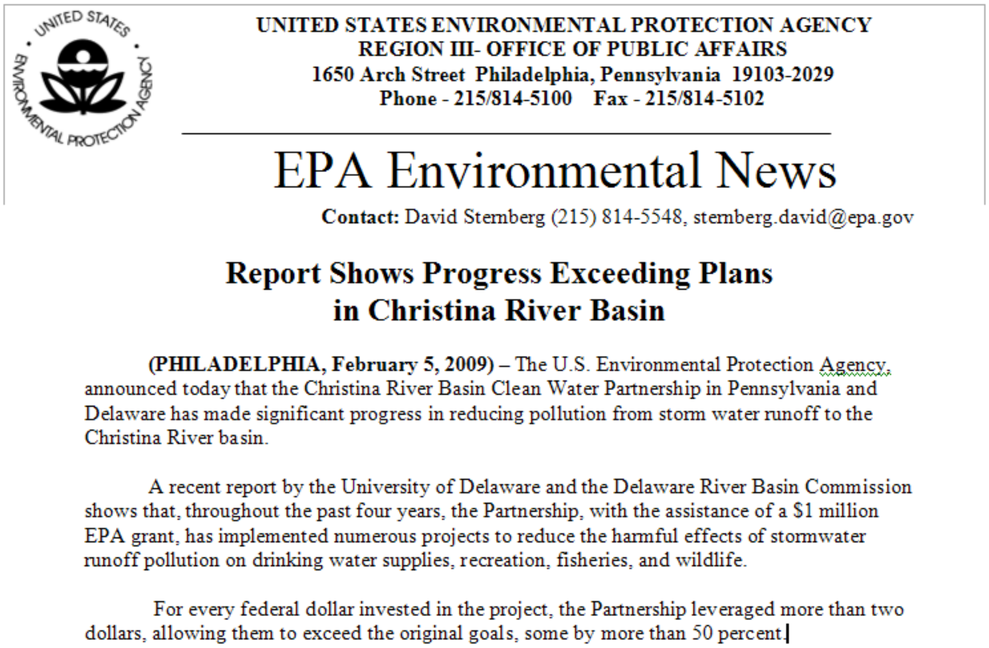
Source: Rich Henson, INQUIRER STAFF WRITER

In a corner of Chester County, on either side of a tree-lined ridge that stretches out from the Welsh Hills, the East and West Branches of the Brandywine Creek gurgle from the ground as cold, pristine springs.

For the next 20 miles, the two branches meander south through one of the most picturesque and fastest-developing areas in the Philadelphia region - past forests, meadows, farmland, industrial sites, housing developments and small towns, finally converging just north of Chadds

Published on 1993-10-03, Page A01, Philadelphia Inquirer, The (PA)

Figure. 2. Water pollution headline on Brandywine Creek pollution, October 10, 1993 (Philadelphia Inquirer)



UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION III- OFFICE OF PUBLIC AFFAIRS
1650 Arch Street Philadelphia, Pennsylvania 19103-2029
Phone - 215/814-5100 Fax - 215/814-5102

EPA Environmental News

Contact: David Sternberg (215) 814-5548, sternberg.david@epa.gov

Report Shows Progress Exceeding Plans in Christina River Basin

(PHILADELPHIA, February 5, 2009) – The U.S. Environmental Protection Agency, announced today that the Christina River Basin Clean Water Partnership in Pennsylvania and Delaware has made significant progress in reducing pollution from storm water runoff to the Christina River basin.

A recent report by the University of Delaware and the Delaware River Basin Commission shows that, throughout the past four years, the Partnership, with the assistance of a $1 million EPA grant, has implemented numerous projects to reduce the harmful effects of stormwater runoff pollution on drinking water supplies, recreation, fisheries, and wildlife.

For every federal dollar invested in the project, the Partnership leveraged more than two dollars, allowing them to exceed the original goals, some by more than 50 percent.

Figure. 3. EPA press release announcing progress in the Christina Basin, February 5, 2009

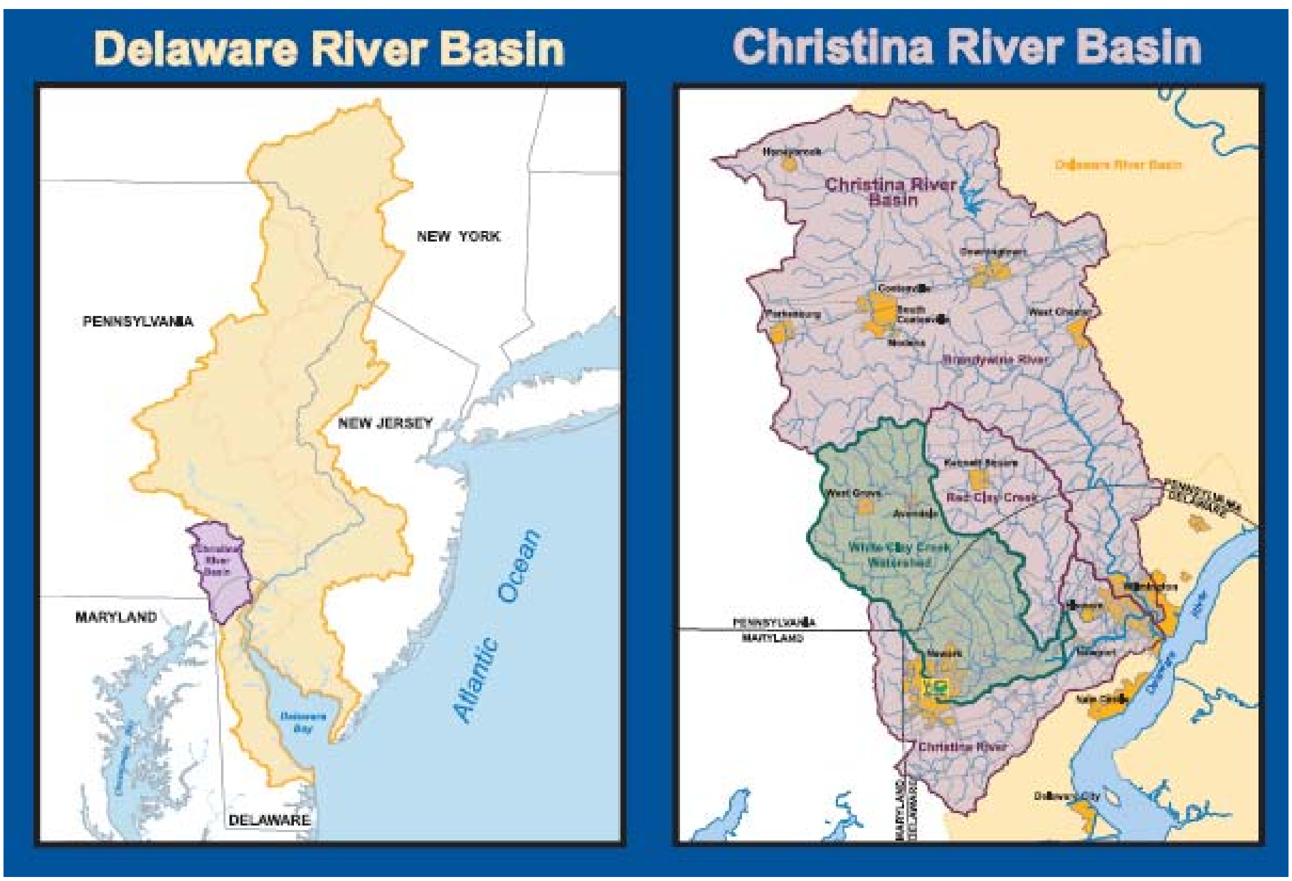


Figure 4. The Christina Basin as the only interstate watershed in the Delaware Basin (UDWRA)

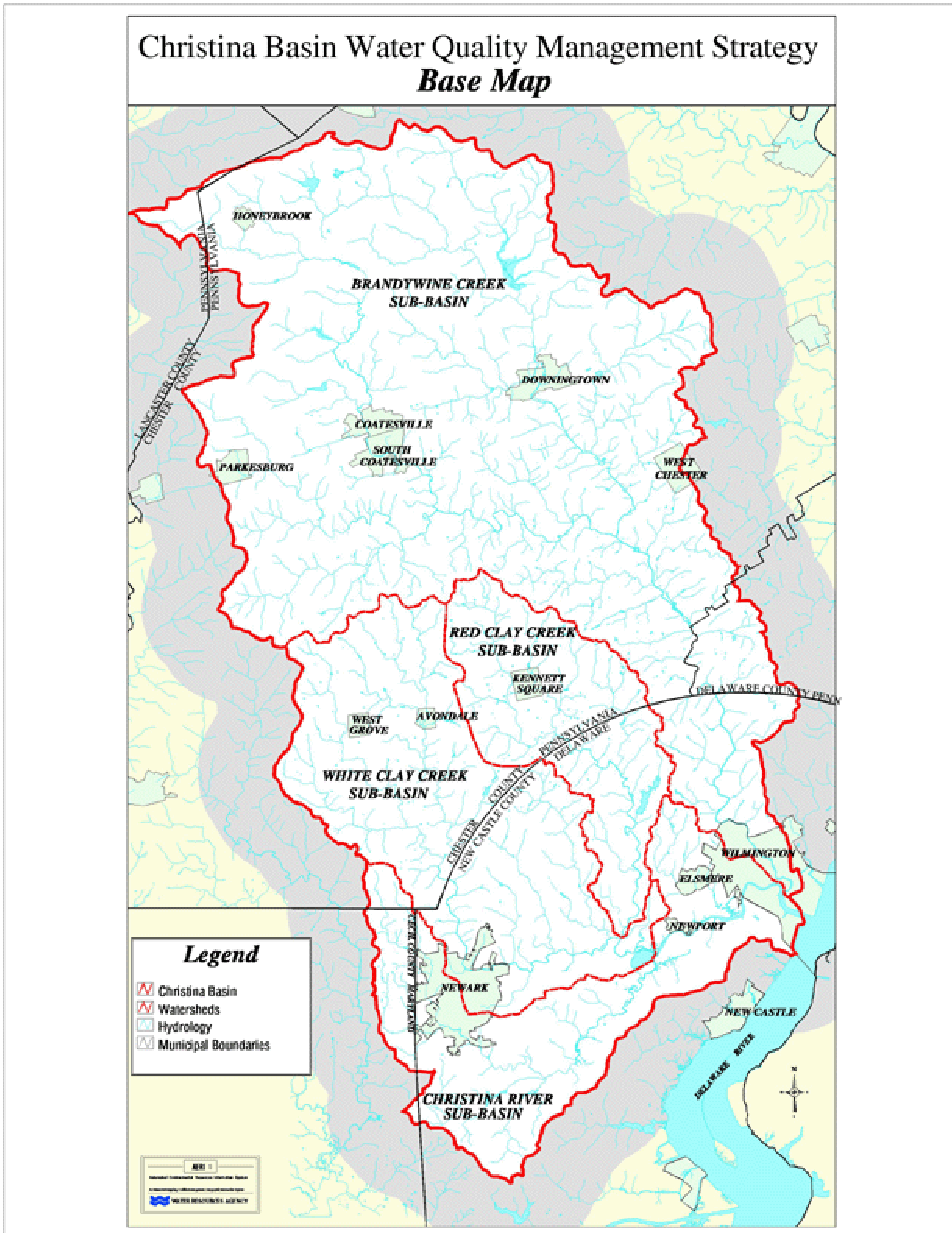


Figure 5. The interstate Christina Basin in Delaware and Pennsylvania (UDWRA)

1. Population

Between 2000 and 2010, the population of the Christina Basin grew from 549,000 to 591,000 people (Table 1 and Fig. 6), an increase of 42,000 or greater than the combined populations of Newark, Del. and West Chester, Pa. Every year, 4,200 people (12 people per day) move to the pastoral basin to live near job centers in Philadelphia, Baltimore, Wilmington, Newark, and the Exton corridor near the Pennsylvania Turnpike. Over the last 10 years, nearly 11,000 people have moved to the Delaware part of the basin, 31,000 have moved to Pennsylvania, and 430 have moved to Maryland (Fig. 7).

The Brandywine is the most populous watershed with 247,000 people or 42% of the basin population followed by the Christina River (174,000), White Clay (124,000) and Red Clay (47,000) creeks with 29%, 21%, and 8% of the population, respectively (Fig. 8). Over 335,000 people (57%) live in the Delaware portion of the Christina Basin and 254,000 people (43%) live in Pennsylvania and 2,500 residents live in Maryland (Fig. 9). The Christina Basin is home to over 40% of Delaware's population and the basin's streams and wells supply drinking water to over 70% of the First State's population.

Fig. 10 illustrates centers of high population density in the Christina Basin. In Delaware, high population densities are concentrated in the I-95 transportation corridor between Wilmington and Newark at the downstream points of the four watersheds. These highly populated areas in Delaware account for higher water demands, wastewater loads, urban/suburban pollution loads, and incidences of floodplain damage. In Pennsylvania, high population densities occur along the Route 1, Route 202, and Route 30 corridors connecting the towns and boroughs of West Grove, Avondale, Kennett Square, West Chester, Downingtown, Exton, and Coatesville. Outside of these town centers, population densities in the outlying rural areas are low. Fig. 11 and 12 show population change by state and by subwatershed,

By 2010, the population density of the basin edged over 1,000 people per square mile, a threshold that the US Census Bureau defines as an "urban area". The urbanized Christina River watershed lies in the Wilmington-Newark I-95 corridor and by far has the highest 2010 population density (2,230 p/mi^2) followed by the White Clay (1,150 p/ mi^2), and Red Clay (870 p/ mi^2) and Brandywine creeks (760 p/mi^2). At a per capita rate of 100 gpcd, the increased population results in an added water demand and wastewater flow of 4.2 million gallons per day since 1995.

Table 1. Christina Basin population change, 2000-2010 (U. S. Census)

Watershed	Area (mi^2)	2000 pop.	2010 pop.	Change	2000 (p/mi^2)	2010 (p/mi^2)
Brandywine Creek	326	221,413	246,702	25,289	679	757
Christina River	78	166,435	174,196	7,761	2,134	2,233
Red Clay Creek	54	42,630	46,893	4,263	789	868
White Clay Creek	107	118,579	123,506	4,927	1,109	1,155
Christina Basin	564	549,057	591,297	42,240	972	1,047

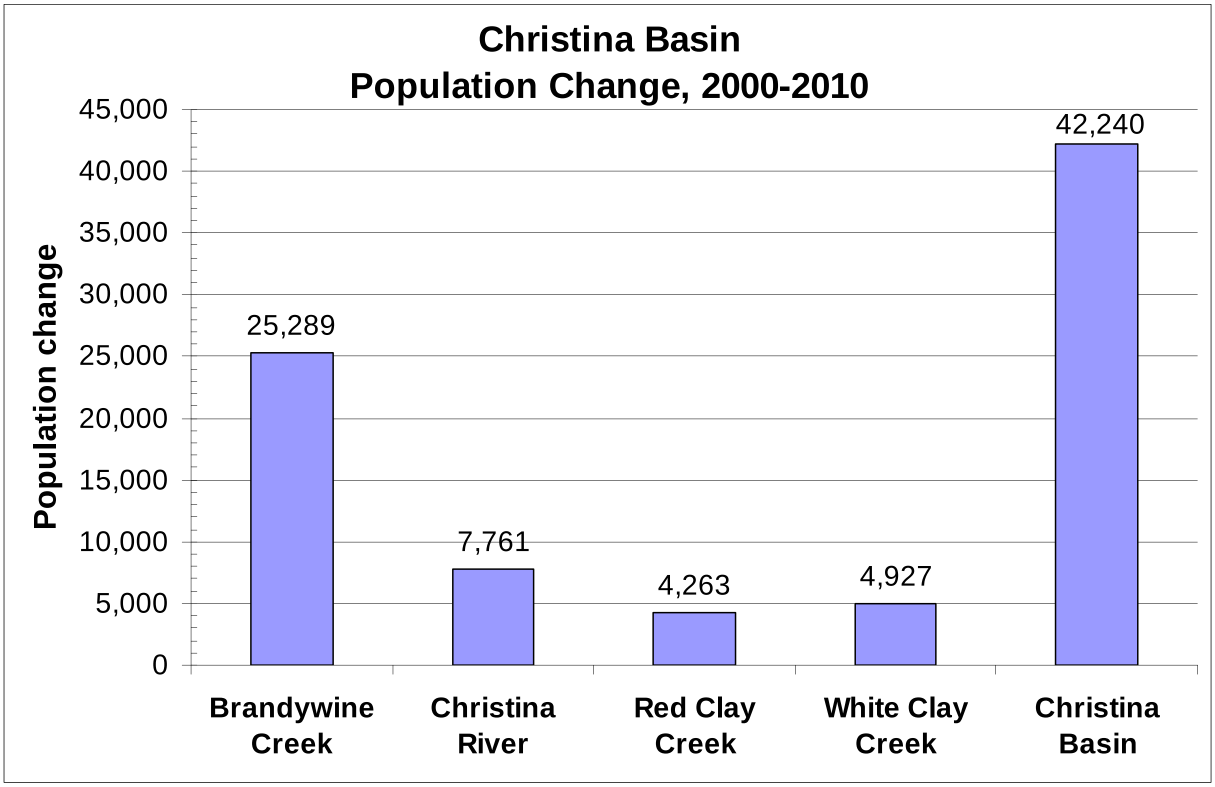


Figure 6. Christina Basin population change by watershed, 2000-2010 (U. S. Census)

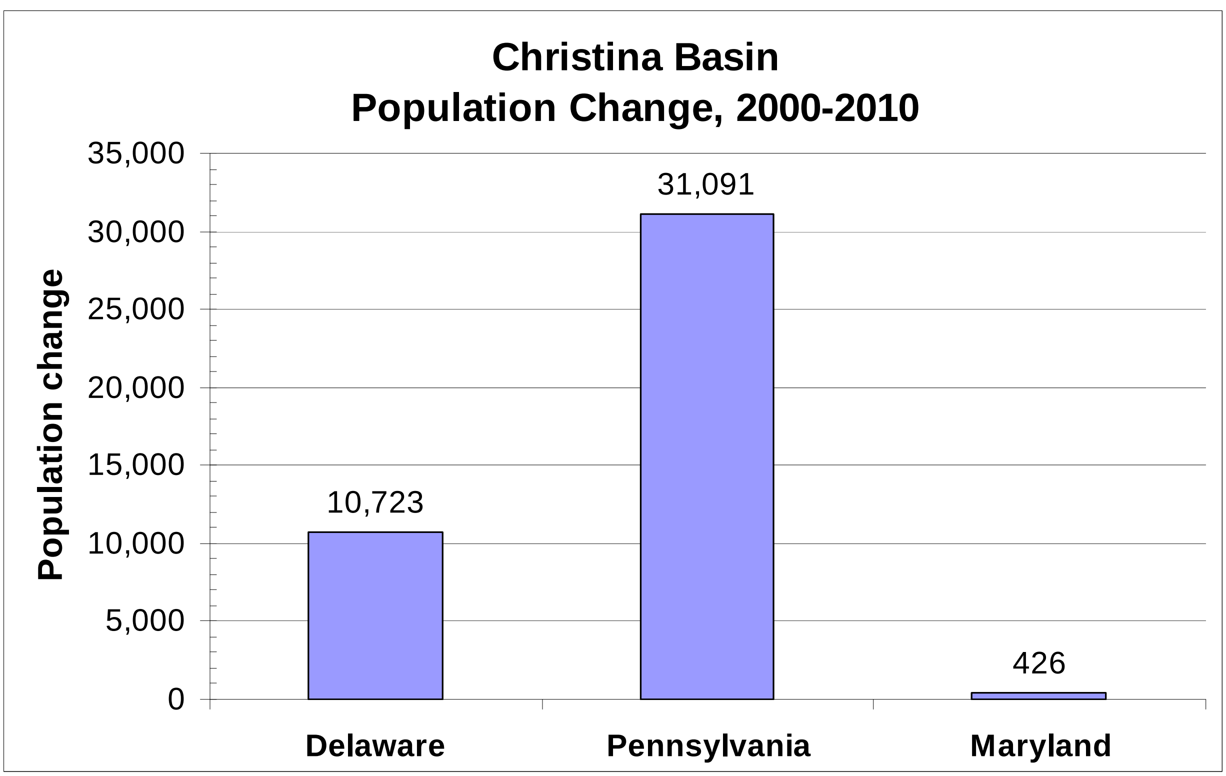


Figure 7. Christina Basin population change by state, 2000-2010 (U. S. Census)

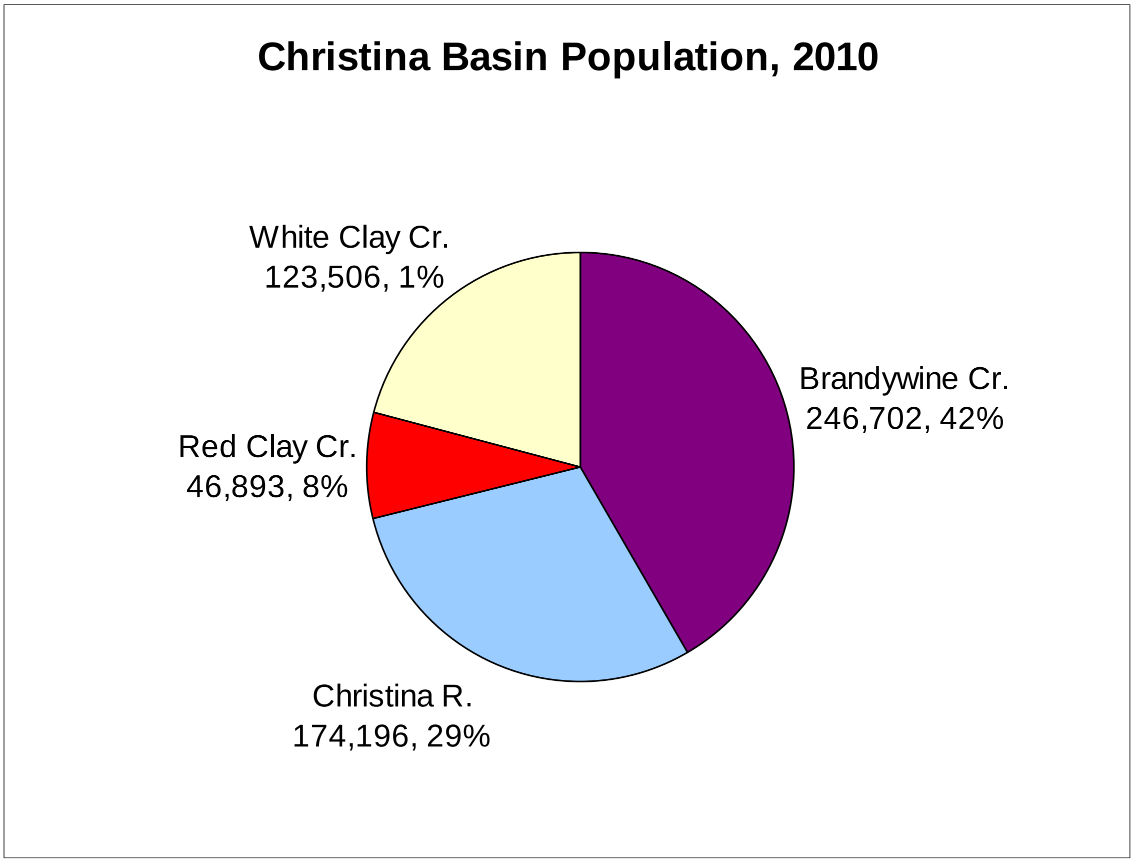


Figure 8. Christina Basin population by watershed, 2000-2010 (U. S. Census)

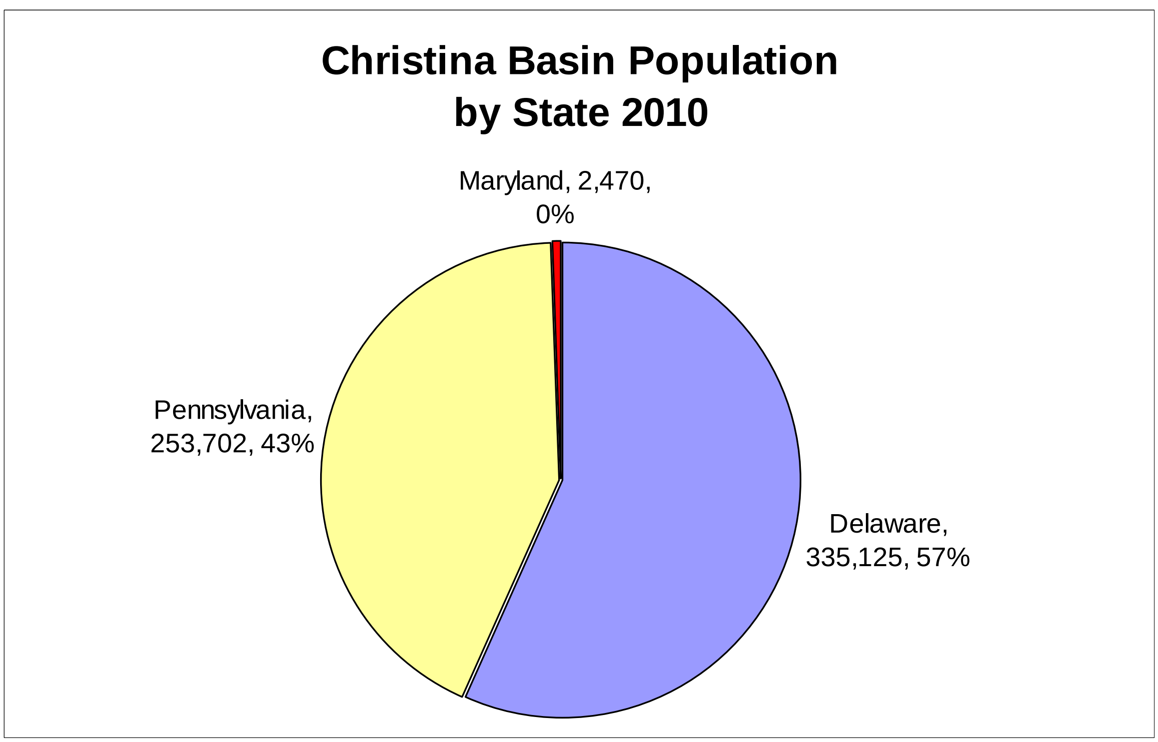


Figure 9. Christina Basin population by watershed, 2000-2010 (U. S. Census)

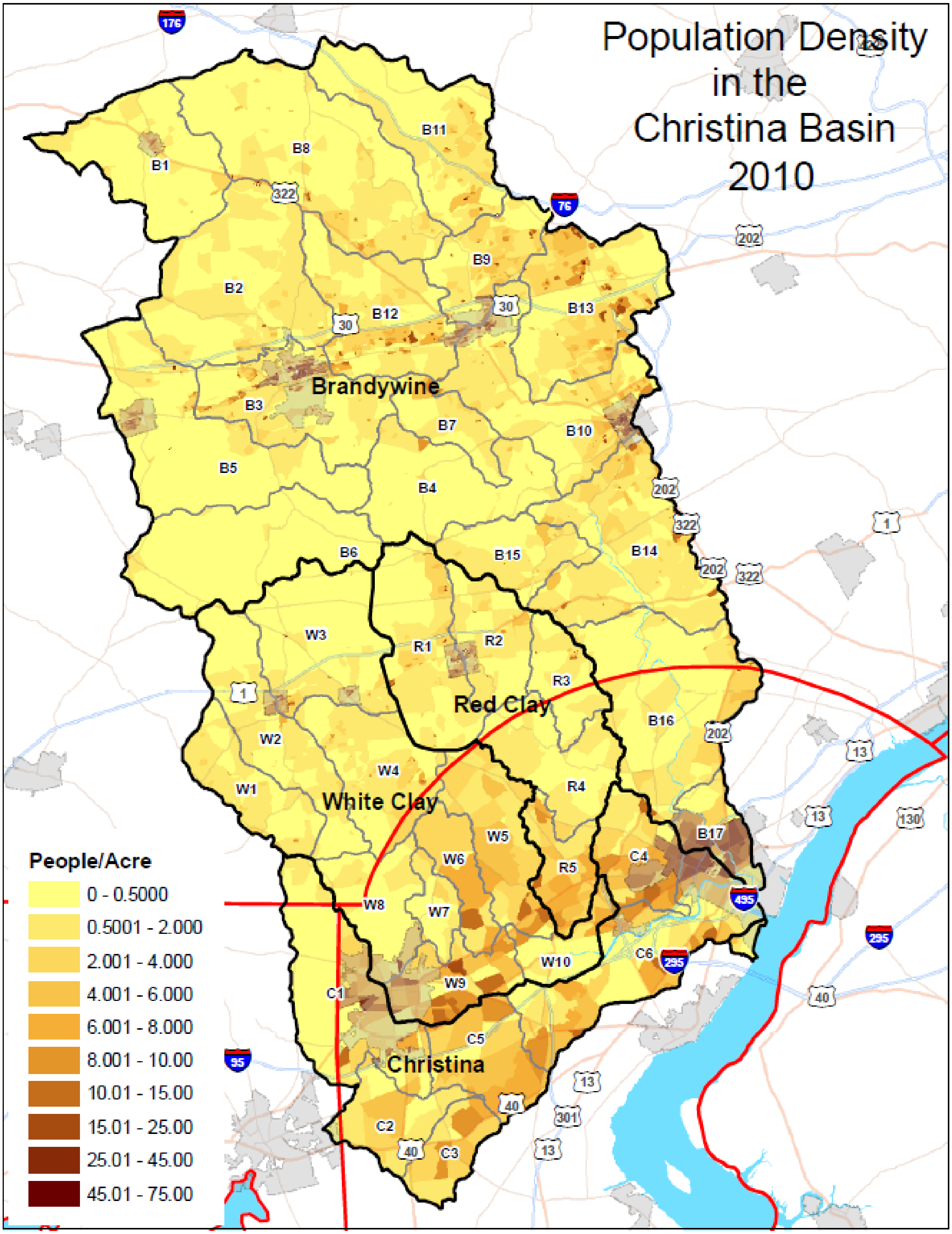


Figure 10. Christina Basin population density, 2010 (U. S. Census)

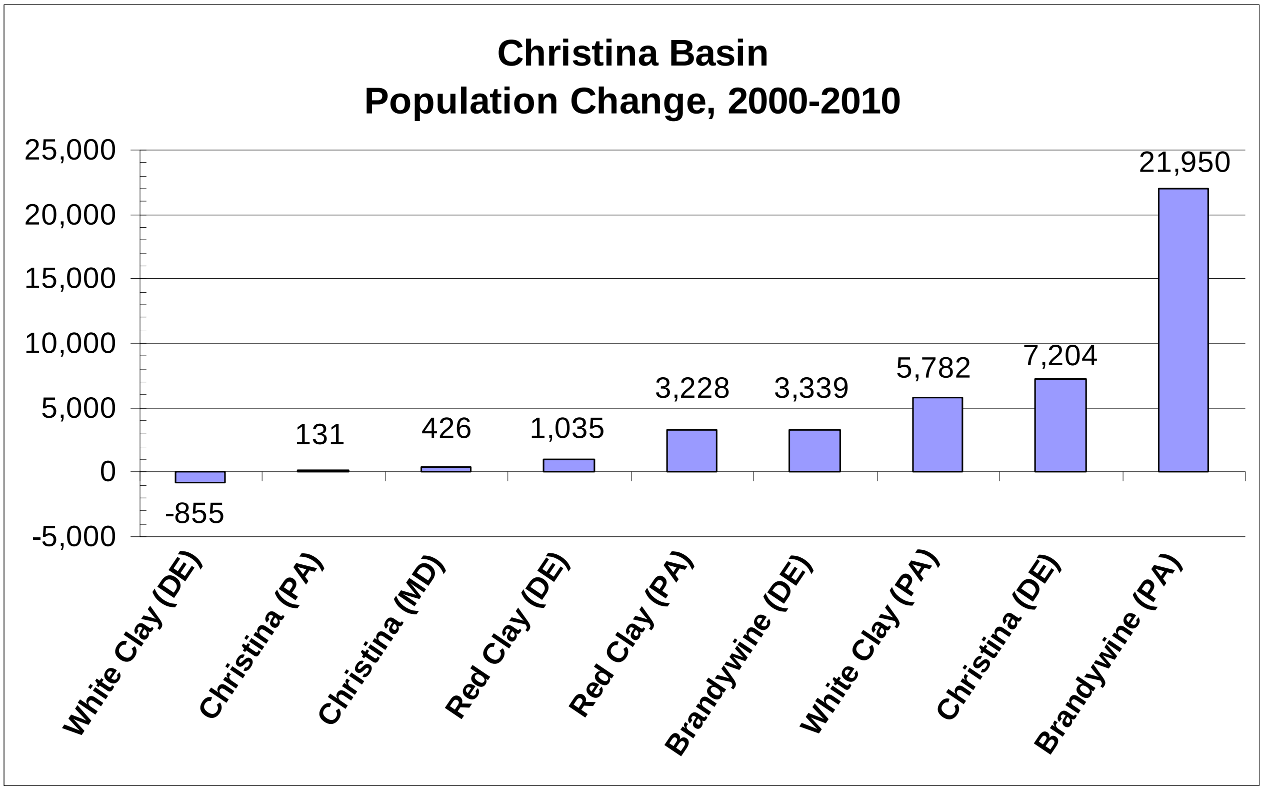


Figure 11. Christina Basin population change by watershed and state, 2000-2010 (U. S. Census)

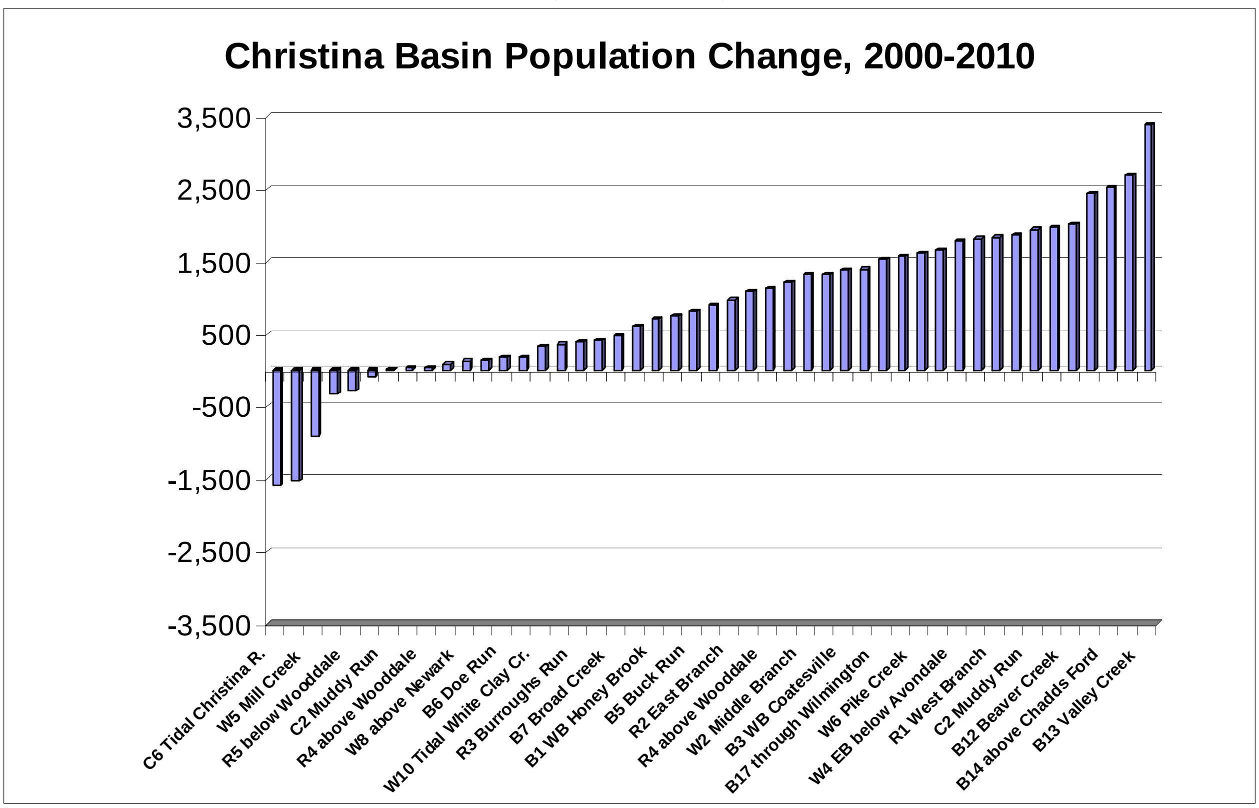


Figure 12. Christina Basin population change by subwatershed, 2000-2010 (U. S. Census)

3. Land Use

Land use data for the Christina Basin (1995 and 2005) was supplied in ArcMap GIS format by the National Oceanographic and Atmospheric Administration (NOAA) Coastal Services Center (CSC). Christina Basin land use in 2005 is split between 28% urban/suburban, 39% agriculture, and 34% forest/wetland/water (Table 2). The most urbanized portion of the Christina Basin is situated in Delaware between Wilmington and Newark and then up along the Route 202 corridor in Pennsylvania to West Chester, Downingtown, and Coatesville (Fig. 13). Upstream from Wilmington and Newark, the heavily forested Brandywine Creek and White Clay Creek State Parks are preserved just south of the arc boundary between Delaware and Pennsylvania. Moving north most of the farms in the basin are in Pennsylvania as the landscape becomes more rural. There is a growing community of Amish and Mennonite families practicing horse and plow agriculture in the upper Brandywine watershed above Honey Brook, Pa.

Table 2. Christina Basin land use, 2005 (NOAA CSC)

Watershed	Urban/ Suburb. (mi^2)	Agric. (mi^2)	Forest/ Wetland (mi^2)	Water (mi^2)	Total	Urban/ Suburb. (%)	Agric. (%)	Forest/ Wetland (%)	Water (%)
Brandywine	60.1	147.7	115.9	1.6	325.4	18%	45%	36%	0%
Christina	45.2	11.2	19.9	0.8	77.1	59%	15%	26%	1%
Red Clay	14.7	20.9	18.1	0.3	54.1	27%	39%	33%	1%
White Clay	36.8	38.1	32.0	0.3	107.3	34%	36%	30%	0%
--	0.6	0.0	0.1	0.0	0.7	92%	0%	8%	0%
Total	156.8	218.0	185.9	3.1	563.8	28%	39%	33%	1%

The Brandywine Creek watershed has the highest proportion of rural area with 36% forest/wetland and 46% agriculture land followed by the Red Clay with 33% forest/wetland and 39% agriculture and White Clay with 30% forest/wetland and 36% agriculture (Fig. 14-16).

The Christina River is the most urbanized watershed in the basin with 58% urban/suburban followed by the White Clay with 34% and Red Clay with 27%. The Brandywine Creek watershed in Delaware and Pennsylvania is just 18% urban, however, the most urbanized neighborhoods in the watershed are in Wilmington and Downingtown and Coatesville (Fig. 17).

Between 1996 and 2005, the Christina Basin gained 9.6 mi^2 of urban/suburban land and lost 6.7 mi^2 of agriculture and lost 3.1 $mi^2$of forest/wetland land (Table 3 and Fig. 18). Approximately 1 mi^2 per year (about 2 acres per day or the size of a football field) were converted to urban/suburban. Loss of agriculture over the 10-year period amounts to 0.7 mi^2 per year or about 1 ¼ acres per day. Forest/wetland losses add up to about 0.3 mi^2 per year or about a ½ acre per day. All 4 watersheds gained urban/suburban land and lost agriculture and forests in similar proportions (Fig. 19).

Greatest increases in urban/suburban land occurred in the following subwatersheds (Fig. 20-21): East Branch Brandywine Creek near Downingtown, West Branch Brandywine Creek near

Coatesville, East Branch and West Branch Red Clay Creek near Kennett Square, East Branch White Clay Creek below Avondale, Mill Creek in the White Clay watershed, Upper Christina River in Cecil County, Md., Muddy Run in the Christina watershed near Glasgow, and tidal Christina River watershed near Wilmington. All subwatersheds lost agricultural and forested land except for the East Branch White Clay Creek below Avondale and the Christina River below Newark which actually *gained* forested land between 1996 and 2005.

Table 3. Christina Basin land use change from 1996-2005 (source: NOAA CSC)

Watershed	Urban/ Suburban (mi^2)	Agriculture (mi^2)	Forest/ Wetland (mi^2)
Brandywine Cr.	+4.68	(-2.59)	(-2.09)
Christina R.	+1.93	(-1.62)	(-0.35)
Red Clay Cr.	+1.01	(-0.85)	(-0.21)
White Clay Cr.	+1.98	(-1.66)	(-0.42)
Christina Basin	**+9.61**	**(-6.72)**	**(-3.08)**

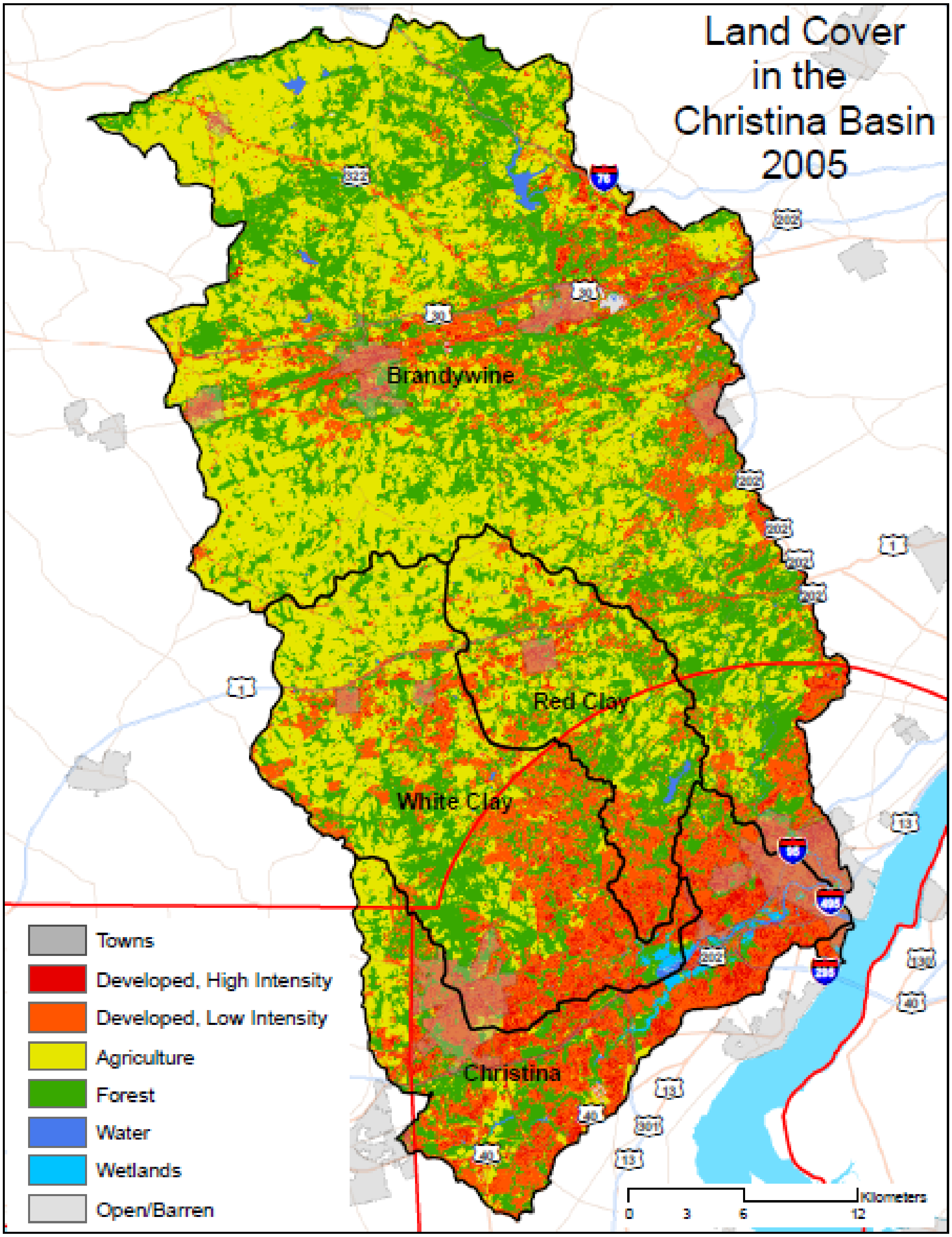


Figure 13. Christina Basin land use, 2005 (NOAA CSC)

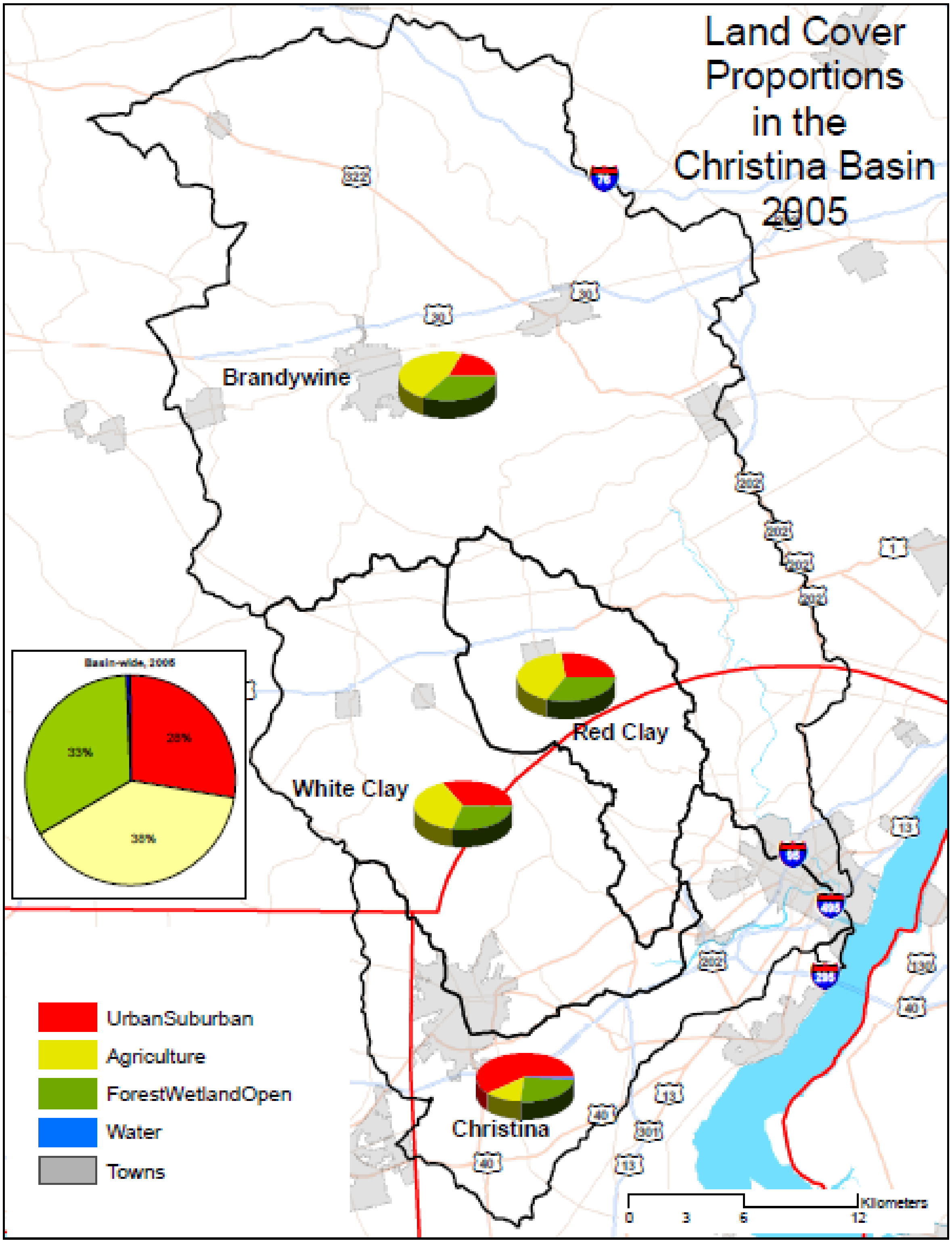


Figure 14. Christina Basin land use by watershed, 2005 (NOAA CSC)

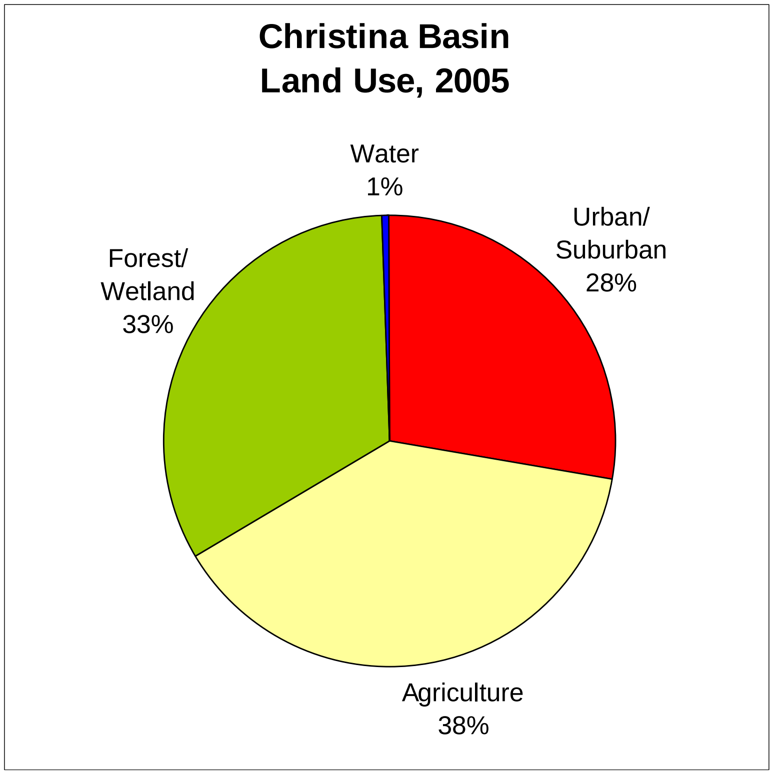


Figure 15. Christina Basin land use, 2005 (NOAA CSC)

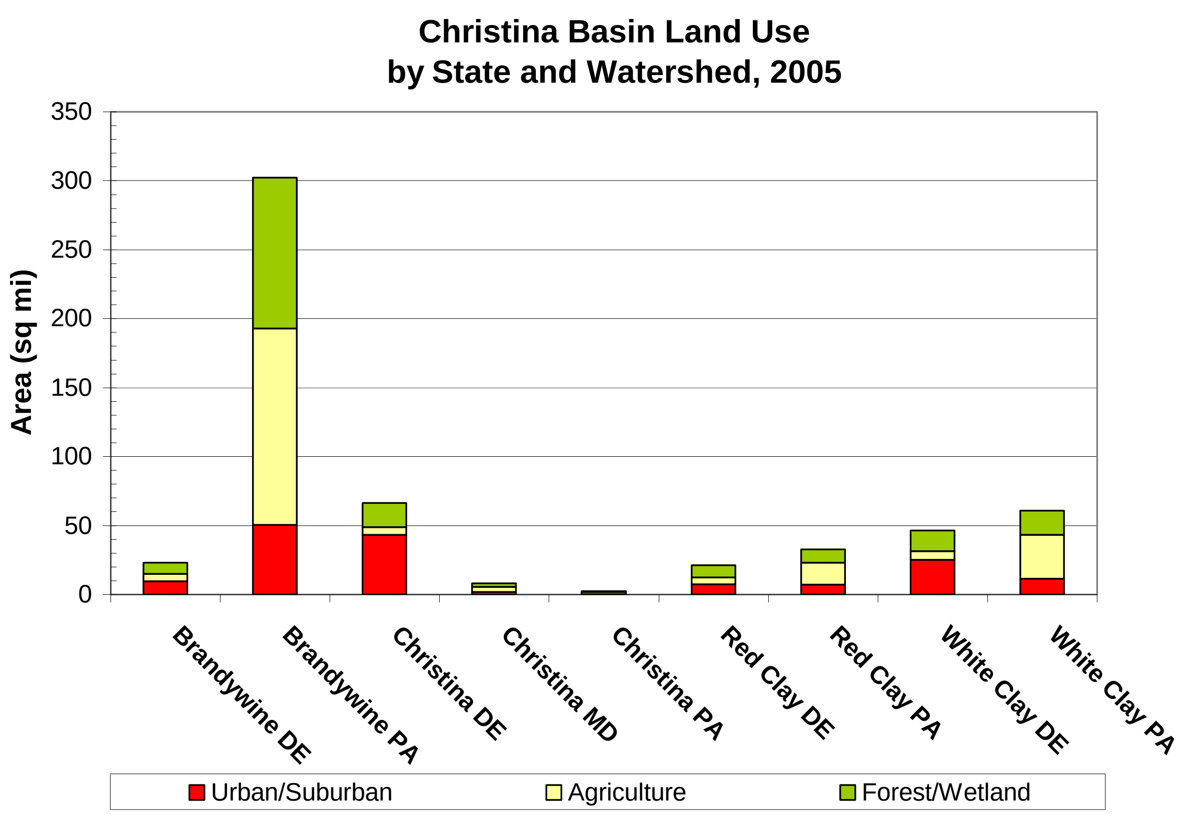


Figure 16. Christina Basin land use by state and watershed, 2005 (NOAA CSC)

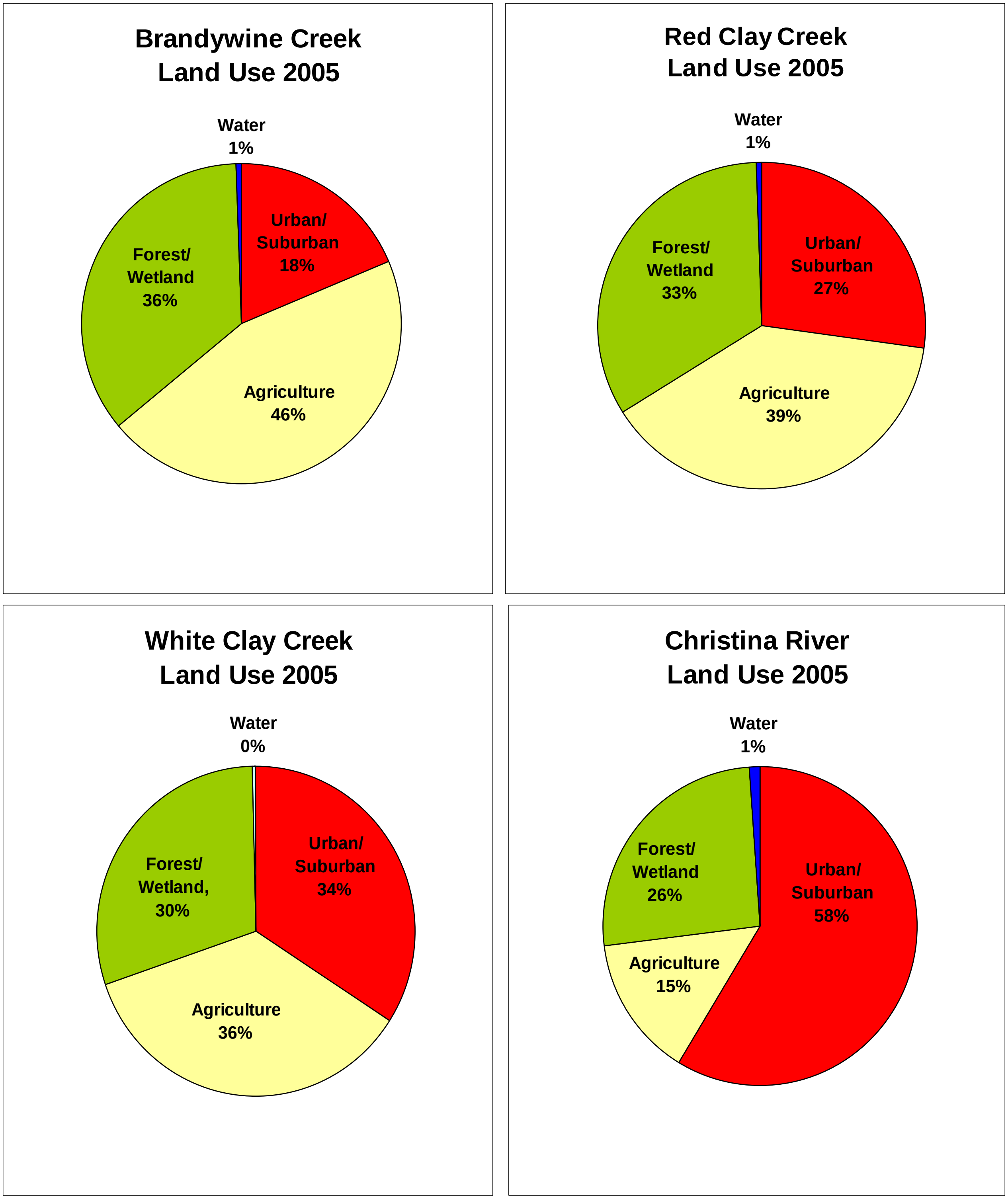


Figure 17. Christina Basin land use by watershed, 2005 (NOAA CSC)

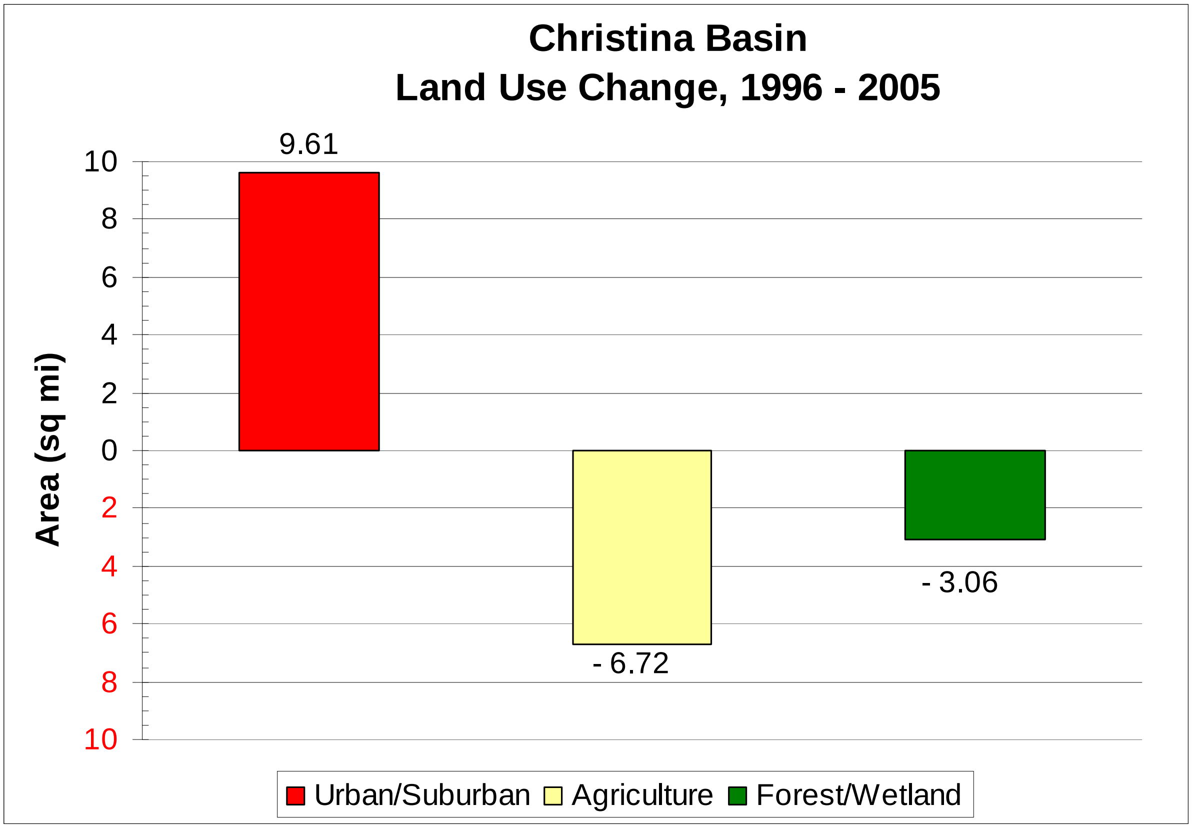


Figure 18. Christina Basin land use change, 1996-2005 (NOAA CSC)

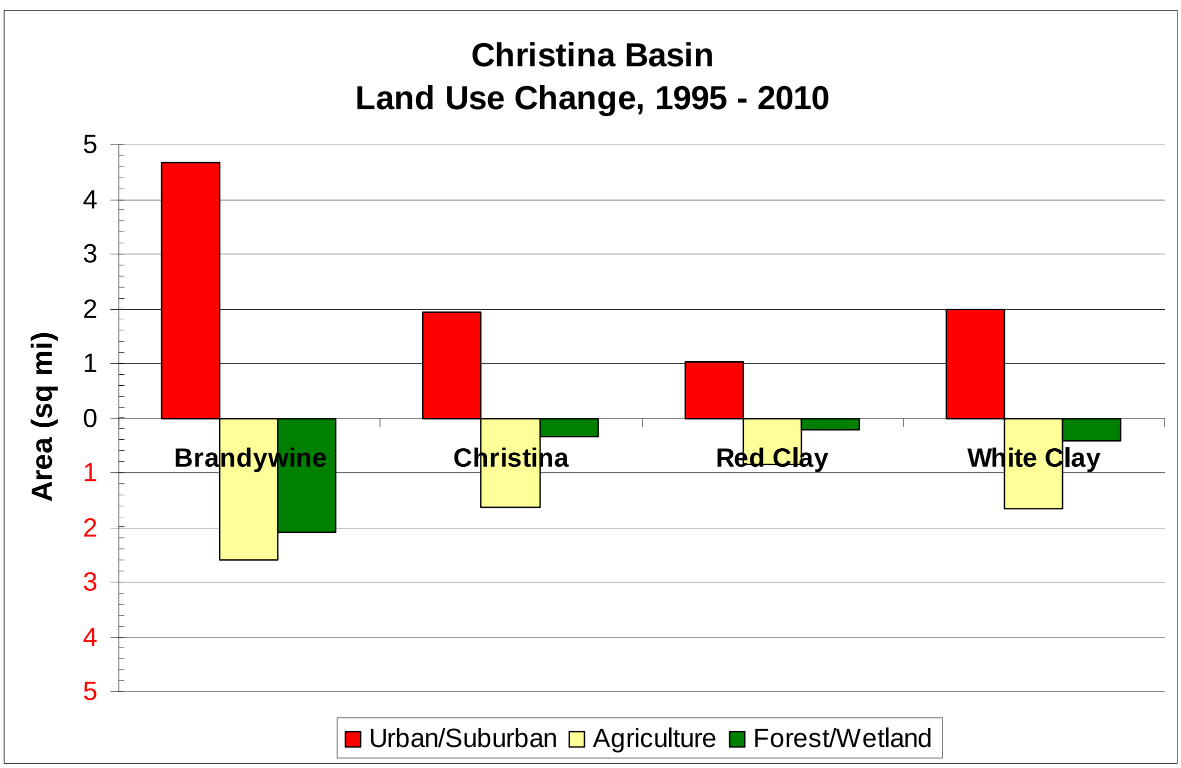


Figure 19. Christina Basin land use change by watershed, 1995-2005 (NOAA CSC)

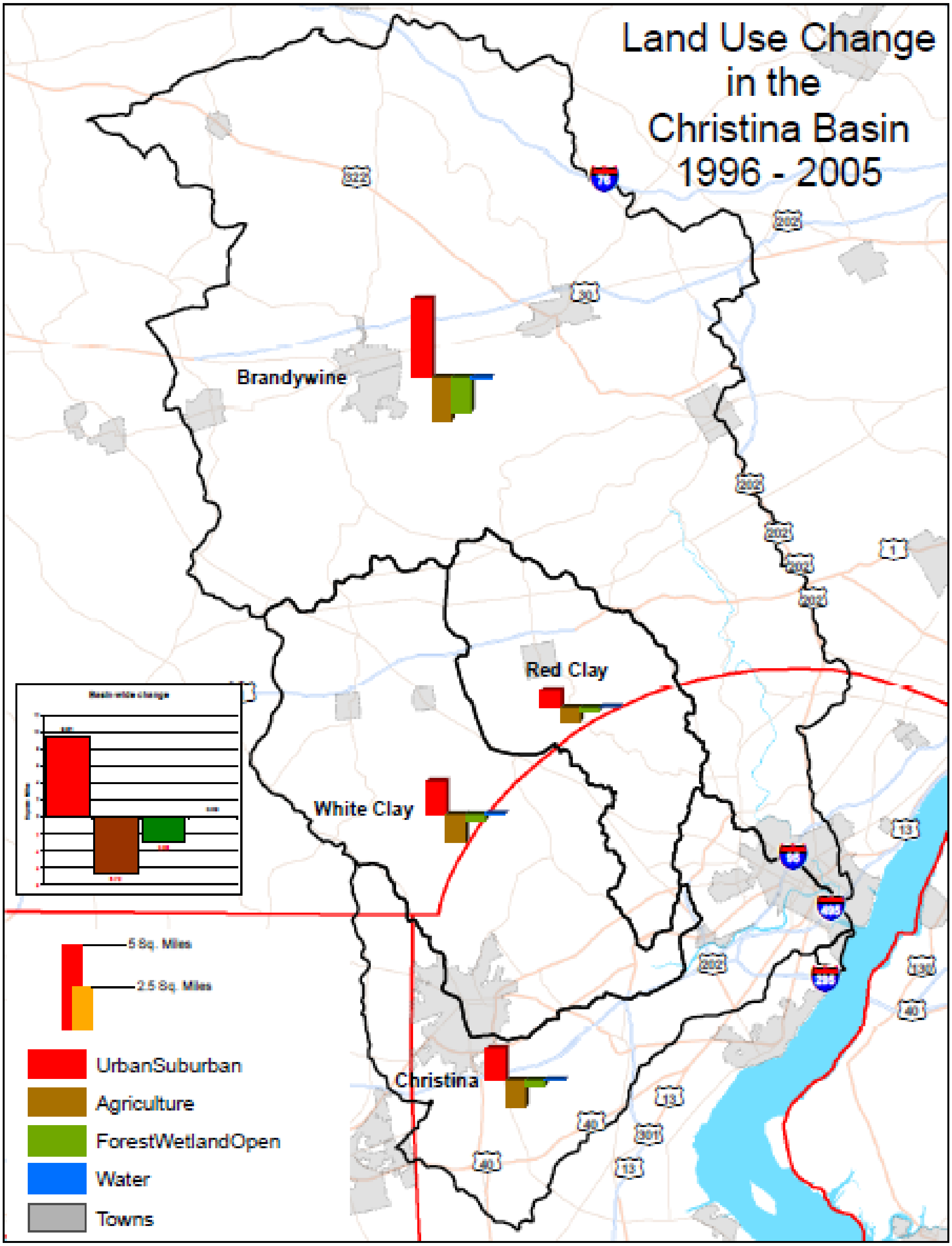


Figure 20. Land use change in the Christina Basin by watershed, 1996-2005 (NOAA CSC)

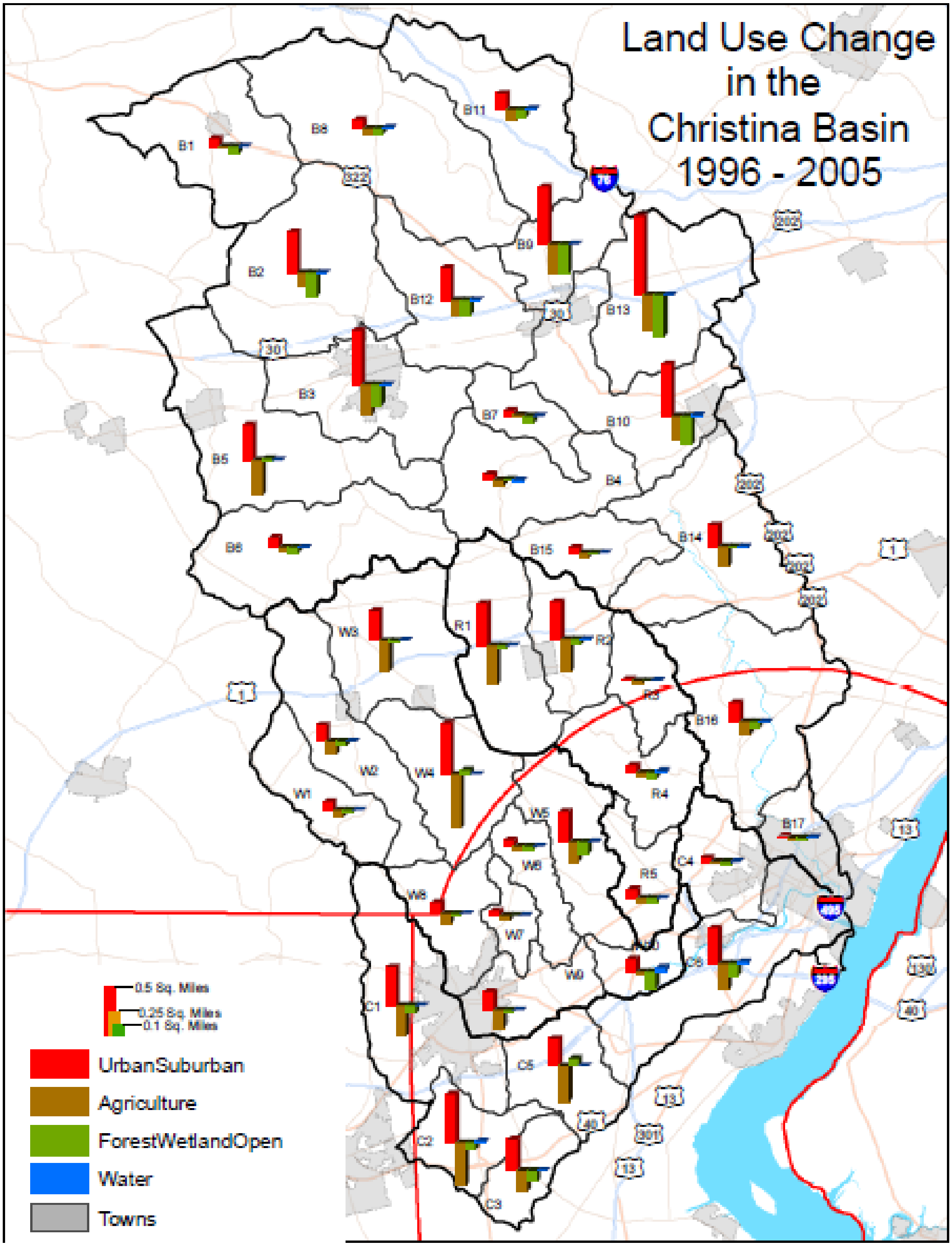


Figure 21. Land use change in the Christina Basin by subwatershed, 1996-2005 (NOAA CSC)

4. Water Quality

Water quality trends were derived for 1995-2010 at Christina Basin stations in Delaware for the following parameters: dissolved oxygen (DO), total suspended sediment (TSS), Enterococcus bacteria, nitrogen, and phosphorus. Water quality data were collected and provided by the Delaware DNREC Watershed Assessment Section at STORET monitoring stations along the Brandywine, Red Clay, and White Clay creeks and Christina River (Fig. 22).

For each monitoring station, water quality data were plotted on scatterplots to provide visual examination of the results and boxplots at five -year intervals that depict the 25th percentile (bottom of the box), 50th percentile or median (middle of the box), and 75th percentile (top of the box) to examine for trends. Water quality trends were determined to be statistically significant if probability (p) ≤ 0.10 using the USGS Seasonal Kendall test (Table 4). Visual examination of scatterplot and boxplot data were used to detect for trend in cases where the nonparametric Seasonal Kendall test is not appropriate such as when water quality improves over the first few years, levels off, and then degrades at the end of the period (the banana curve effect).

Between 1995 and 2010, water quality has improved at 13 of 20 (65%), remained constant at 4 of 20 (20%), and degraded at 3 of 20 (15%) of the monitoring stations in the Christina Basin (Table 5 and Fig. 23). Water quality has mostly improved for DO, TSS, bacteria, and P, however, nitrogen levels have begun to degrade lately.

DO levels have improved along all four streams since 1995 (Fig. 24 and 25). All DO samples collected during the 15-year period meet the minimum Delaware warm water quality standard (4 mg/l). Median DO levels for 2005-2010 are good and exceed the 4 mg/l standard by at least 2x.

TSS levels have improved along 3 of 4 streams (Fig. 26 and 27). TSS levels have remained constant along the Brandywine Creek. While Delaware and Pennsylvania do not have numeric sediment standards, over 95% of TSS samples are below the 40 mg/l standard specified by the State of New Jersey. Median TSS levels for 2005-2010 are good and are comfortably below 40 mg/l.

Enterococcus bacteria levels have improved along all four streams since 1995 (Fig. 28 and 29). Over half the bacteria samples collected during the 15-year period continue to violate the Delaware WQ standard (100 #/100 ml).

Inorganic nitrogen levels have degraded along the Brandywine and Red Clay creeks and Christina River and remained constant only along the White Clay Creek (Fig. 30 and 31). Inorganic N levels remain poor and continue to exceed the Delaware DNREC TMDL low target level of 0.5 mg/l at over 75% of the samples collected from 1995-2010. Increased N levels may be from land based sources such as manure, fertilizer, and leaking septic systems, air emissions from power plants and motor vehicles, and/or oxidation from increased DO related to chemical stochiometry.

Orthophosphorus levels have improved along the Brandywine and White Clay creeks and remained constant along the Red Clay Creek and Christina River from 1995-2010 (Fig. 32 and 33). Ortho P levels remain poor and continue to exceed the Delaware DNREC TMDL low target level of 0.05 mg/l at over 60% of the samples collected over 15 years.

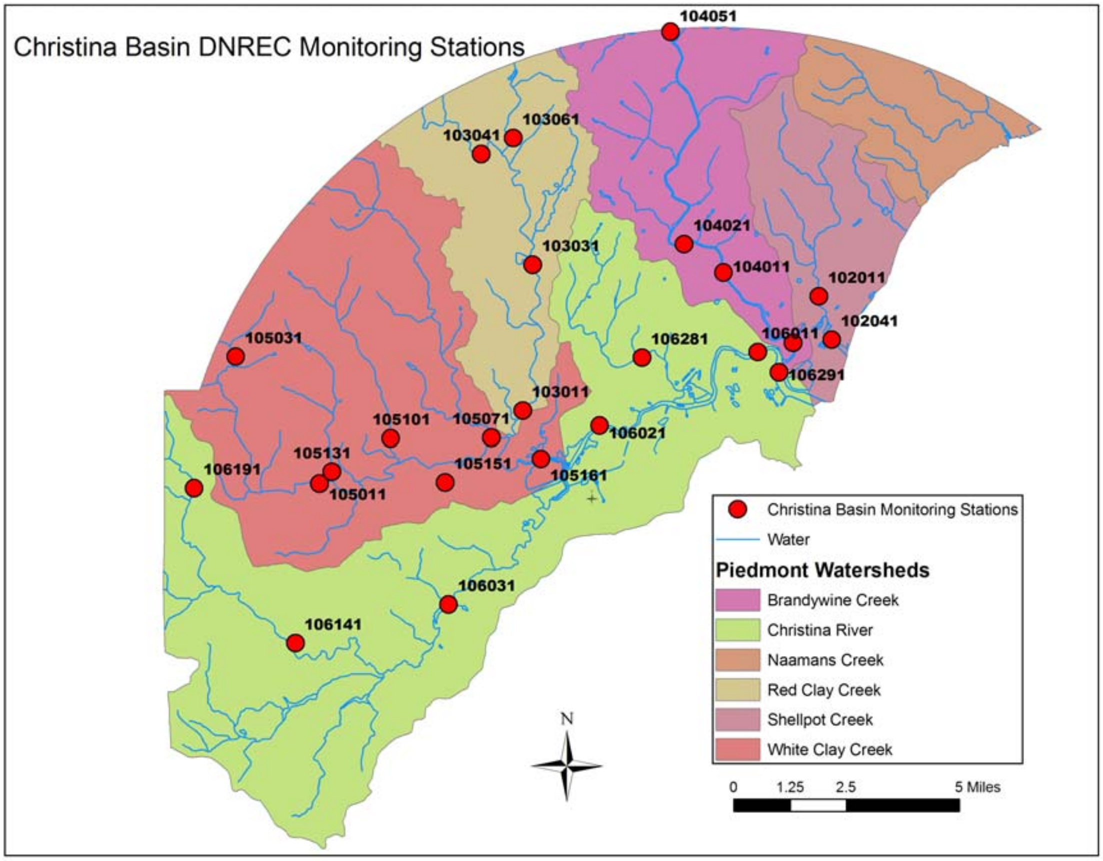


Figure 22. DNREC STORET stream monitoring stations in the Christina Basin. Water quality trends were examined at monitoring stations Brandywine Creek at Footbridge (104011), Red Clay Creek at Stanton (103011), White Clay Creek. at Old Route 7 Bridge (105071), and Christina River at Wilmington (106291).

Table 4. Seasonal Kendall Test for Dissolved Oxygen, 1995-2010

Watershed	Median Value	Variance	Z	P	P (adjusted)	Median Annual Sen slope	5% Confidence Limit	95% Confidence Limit
Red Clay Cr.	10.082	1128.00	5.9847	0.0000	0.0000	0.3491	-99.9900	0.0000
Brandywine Cr.	10.100	1244.00	4.2812	0.0000	0.0017	0.1861	-99.9900	0.0000
White Clay Cr.	9.750	718.33	3.4699	0.0005	0.0044	0.0177	-99.9900	0.0000
Christina R.	8.167	1147.66	4.0735	0.0000	0.0001	0.0983	-99.9900	0.0000

Table 5. Christina Basin water quality trends, 1995-2010

Watershed	DO (mg/L)		TSS (mg/L)		Bacteria (#/100ml)		Inorg. N (mg/L)		Ortho P (mg/L)	
Brandywine Cr.	10.4	▲*	5	●	97	▲	2.90	▼	0.06	▲
Red Clay Cr.	10.5	▲*	4	▲*	85	▲*	3.10	▼	0.07	●*
White Clay Cr.	10.0	▲*	5	▲*	93	▲*	2.82	●	0.04	▲
Christina R.	8.9	▲*	17	▲*	90	▲	1.91	▼	0.04	●*
▲ Improving	4/4 (100%)		3/4 (75%)		4/4 (100%)		0/4 (0%)		2/4 (50%)	
● Constant	0/4 (0%)		1/4 (25%)		0/4 (0%)		1/4 (25%)		2/4 (50%)	
▼ Degrading	0/4 (0%)		0/4 (0%)		0/4 (0%)		3/4 (75%)		0/4 (0%)	

* Statistically significant using Seasonal Kendall test at $p \leq 0.10$

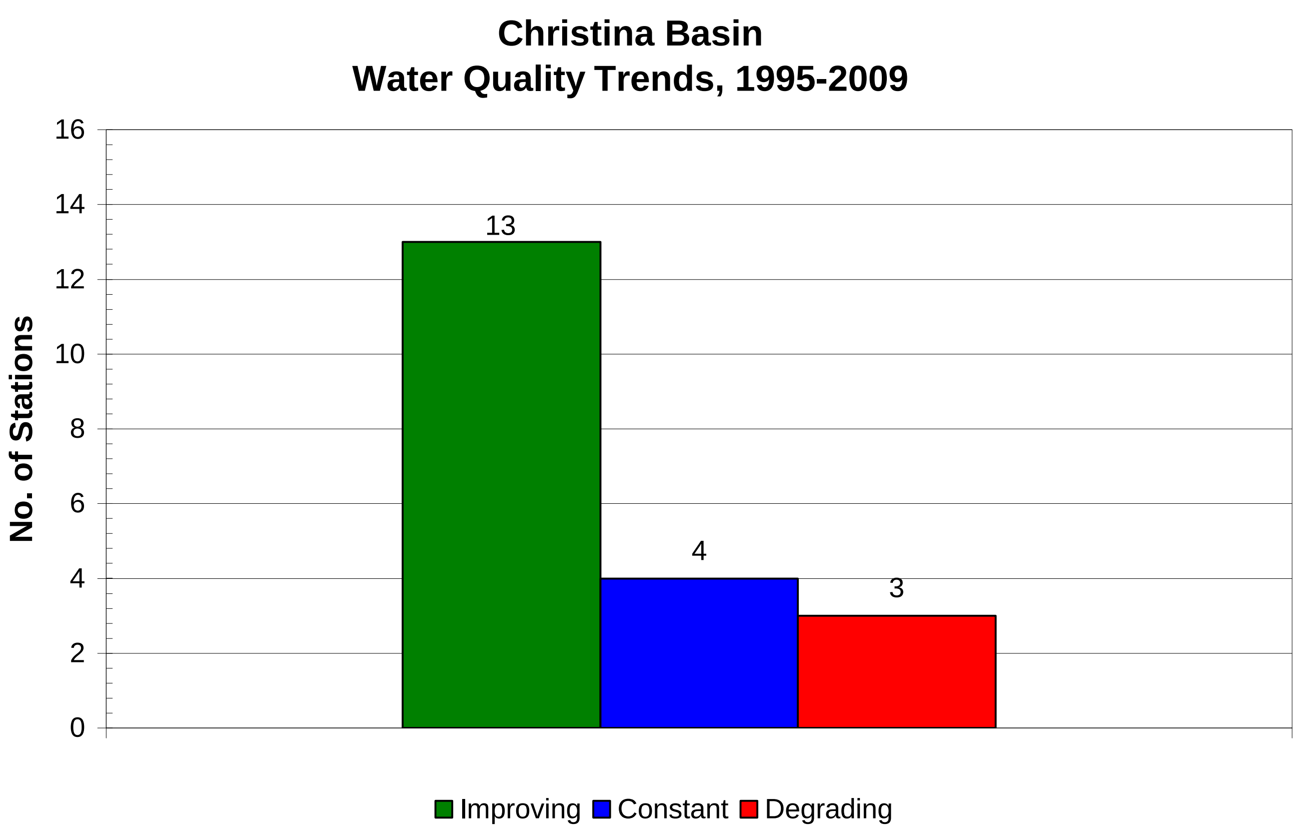
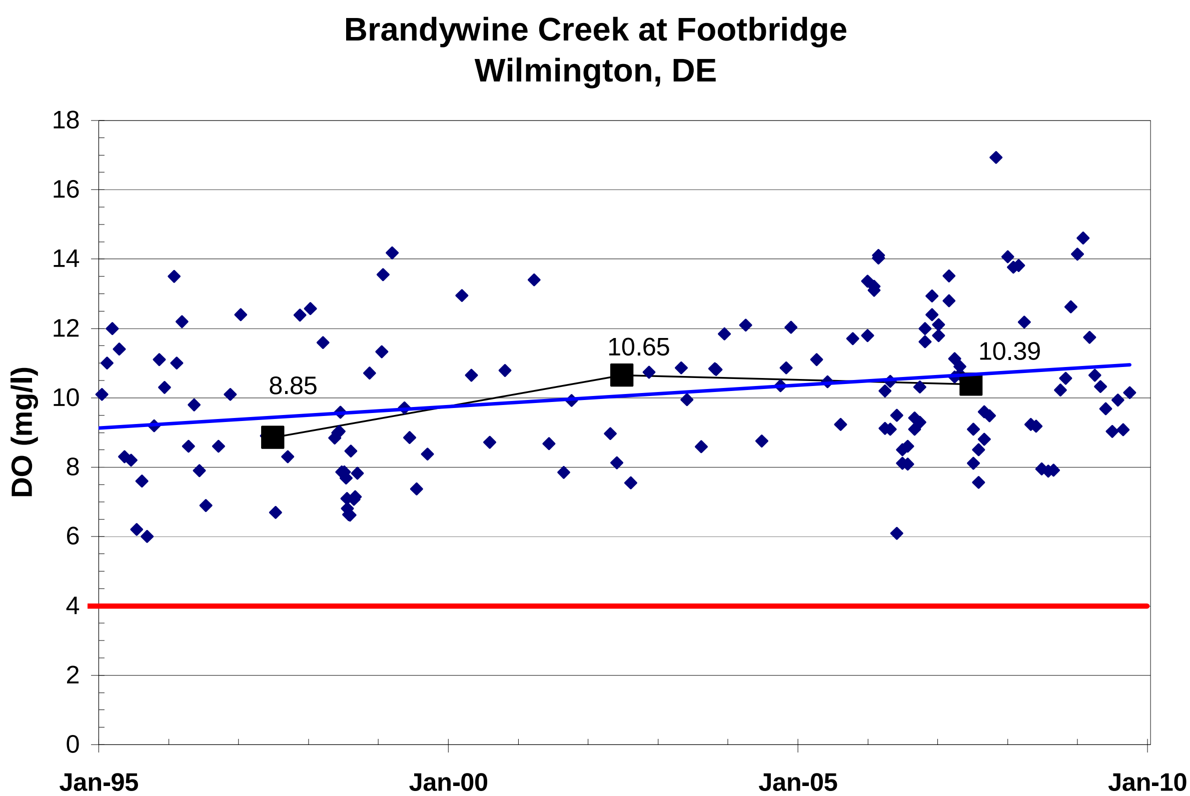


Figure 23. Christina Basin water quality trends, 1995-2010



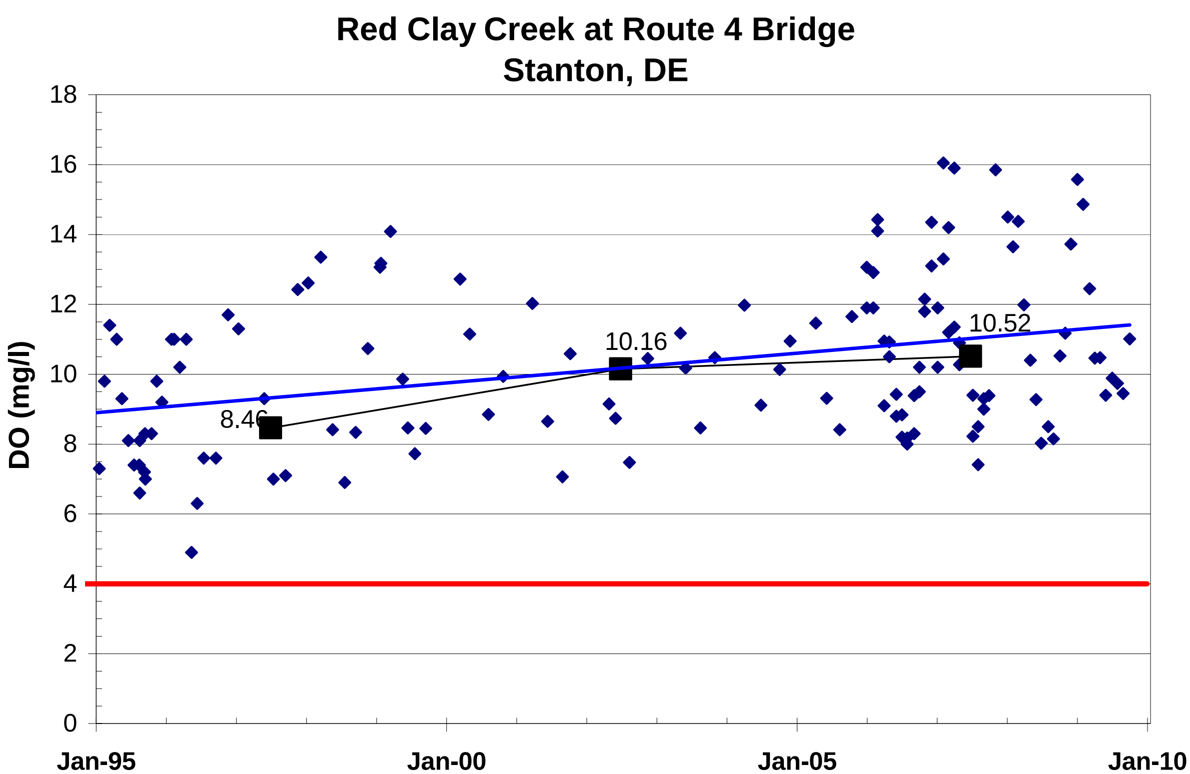
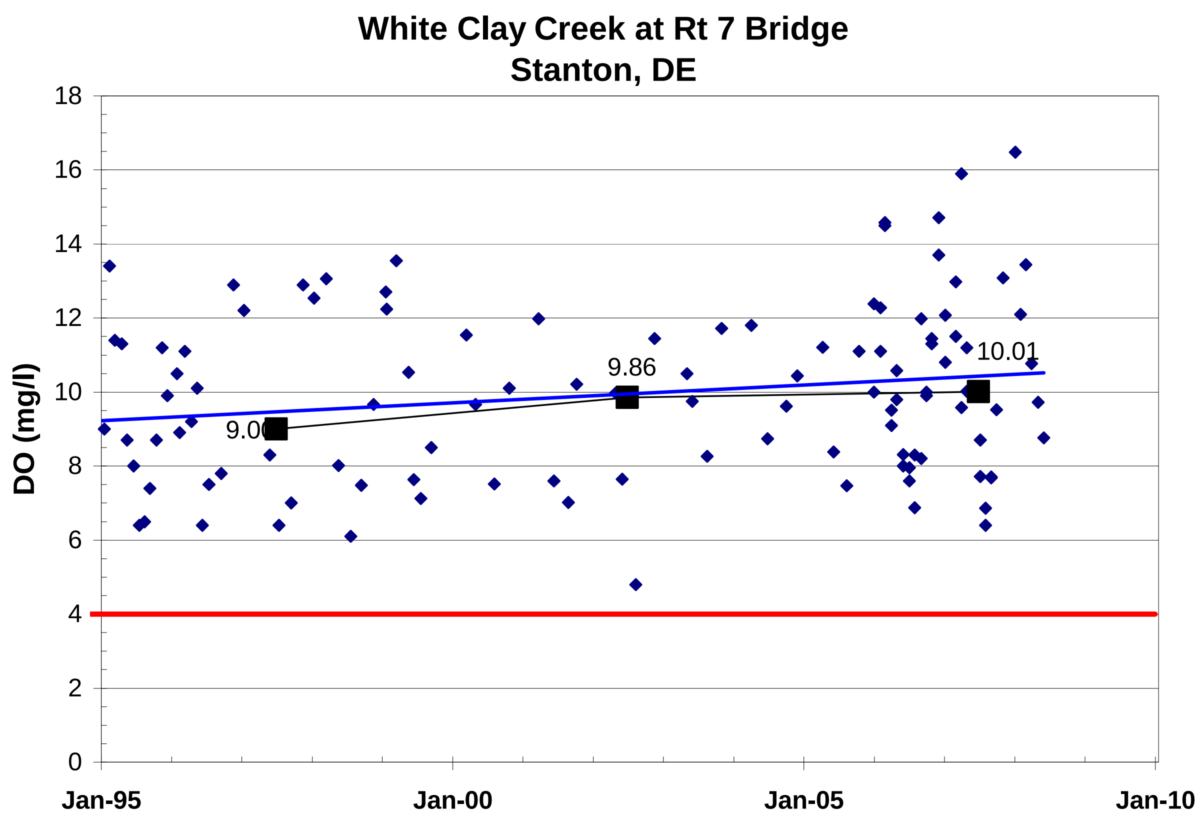


Figure 24. Dissolved oxygen along the Brandywine Creek and Red Clay Creek. Delaware DO water quality standard of 4 mg/l depicted by red line.



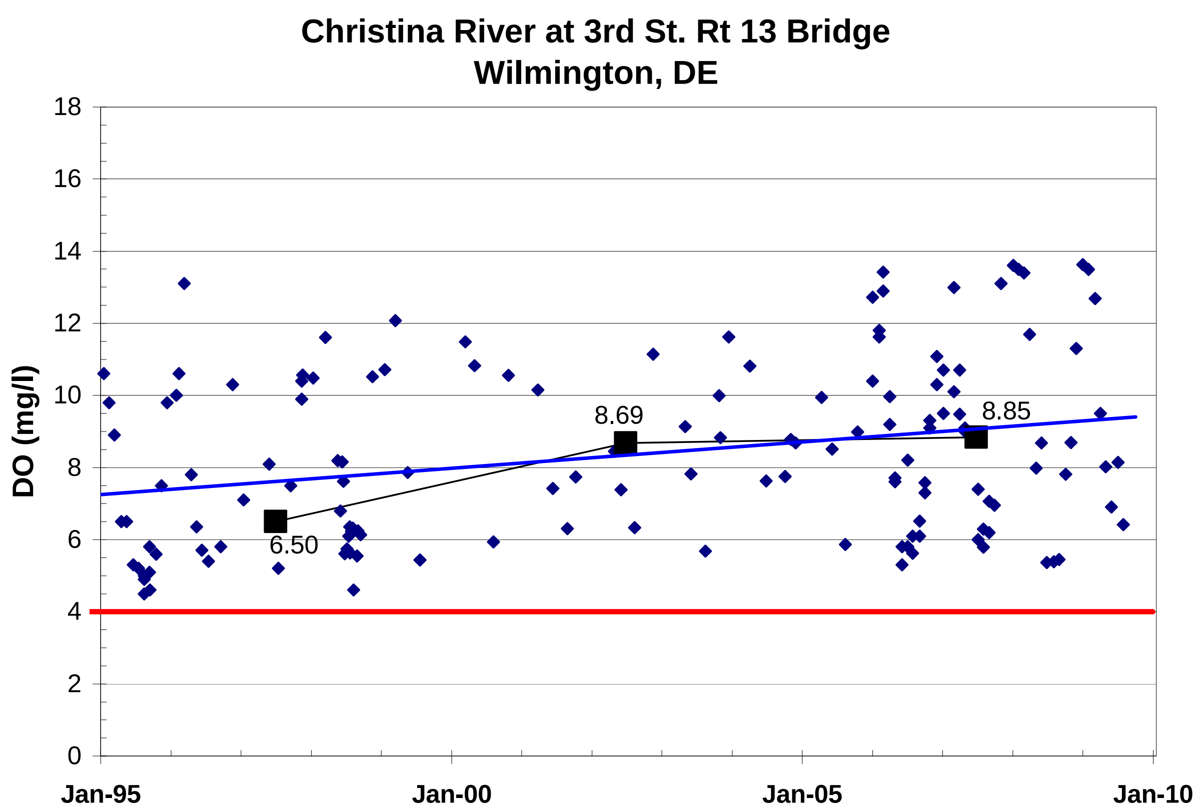


Figure 25. Dissolved oxygen along the White Clay Creek and Christina River. Delaware DO water quality standard of 4 mg/l depicted by red line.

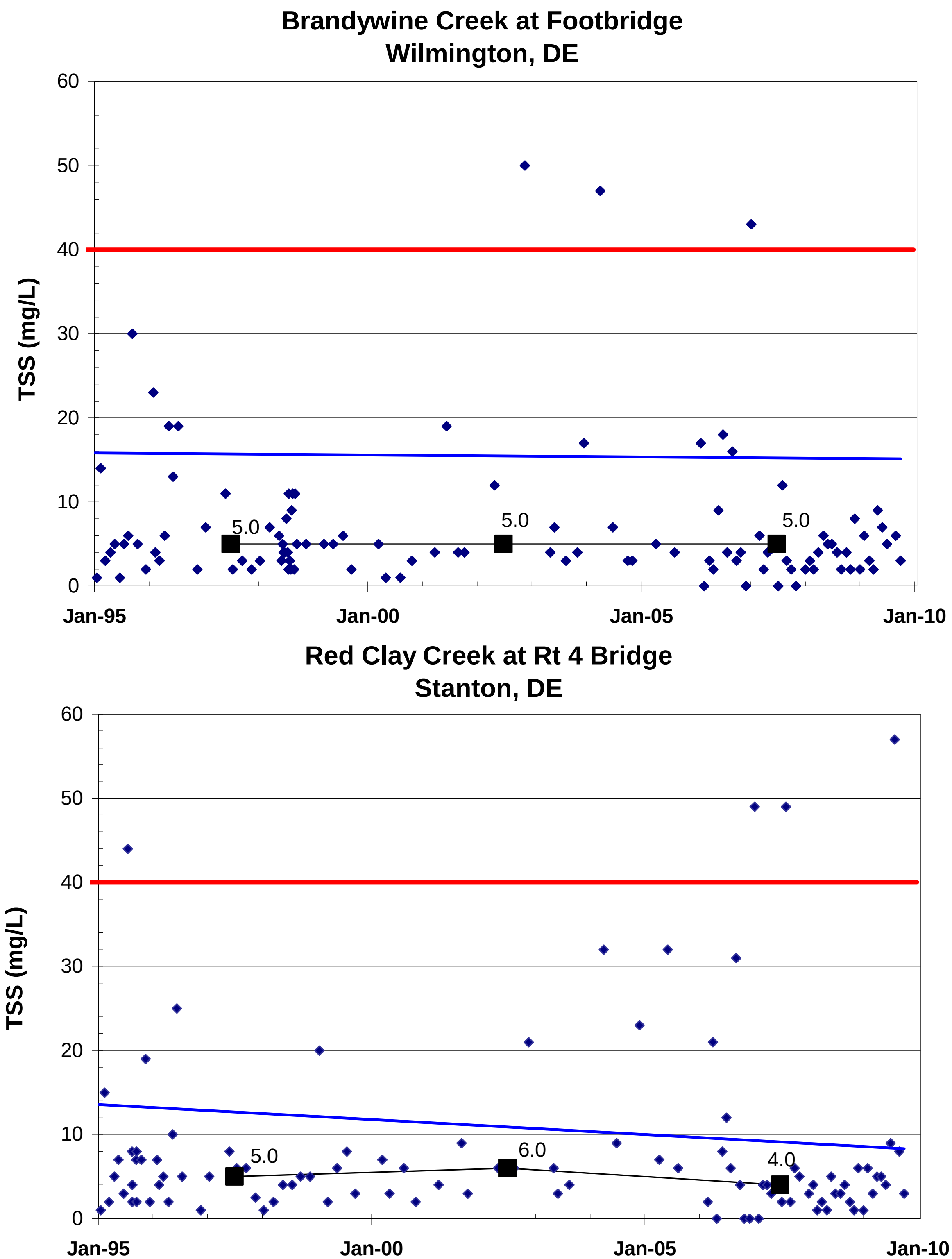


Figure 26. Total suspended sediment along the Brandywine Creek and Red Clay Creek. New Jersey TSS water quality standard of 40 mg/l depicted by red line for comparison purposes.

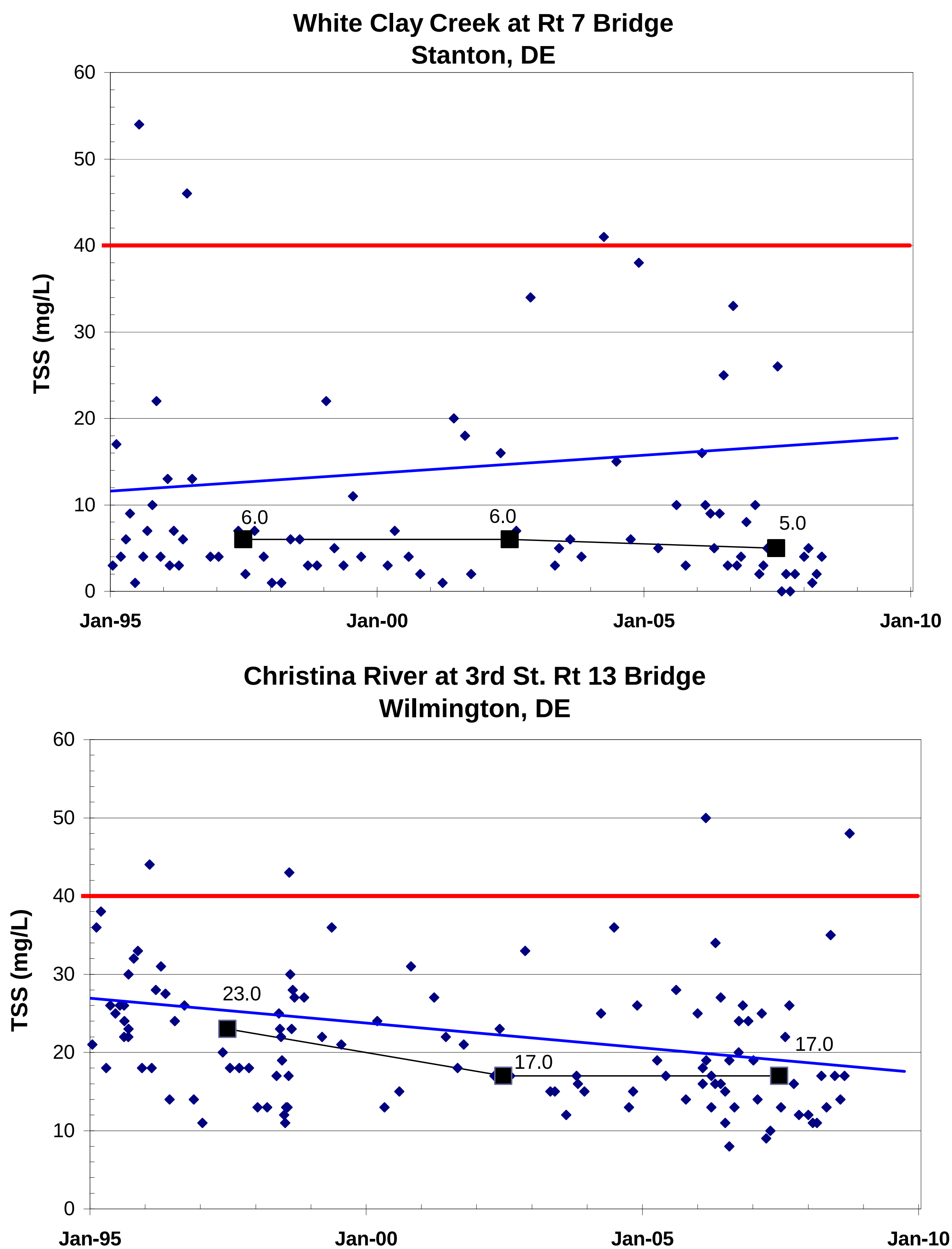
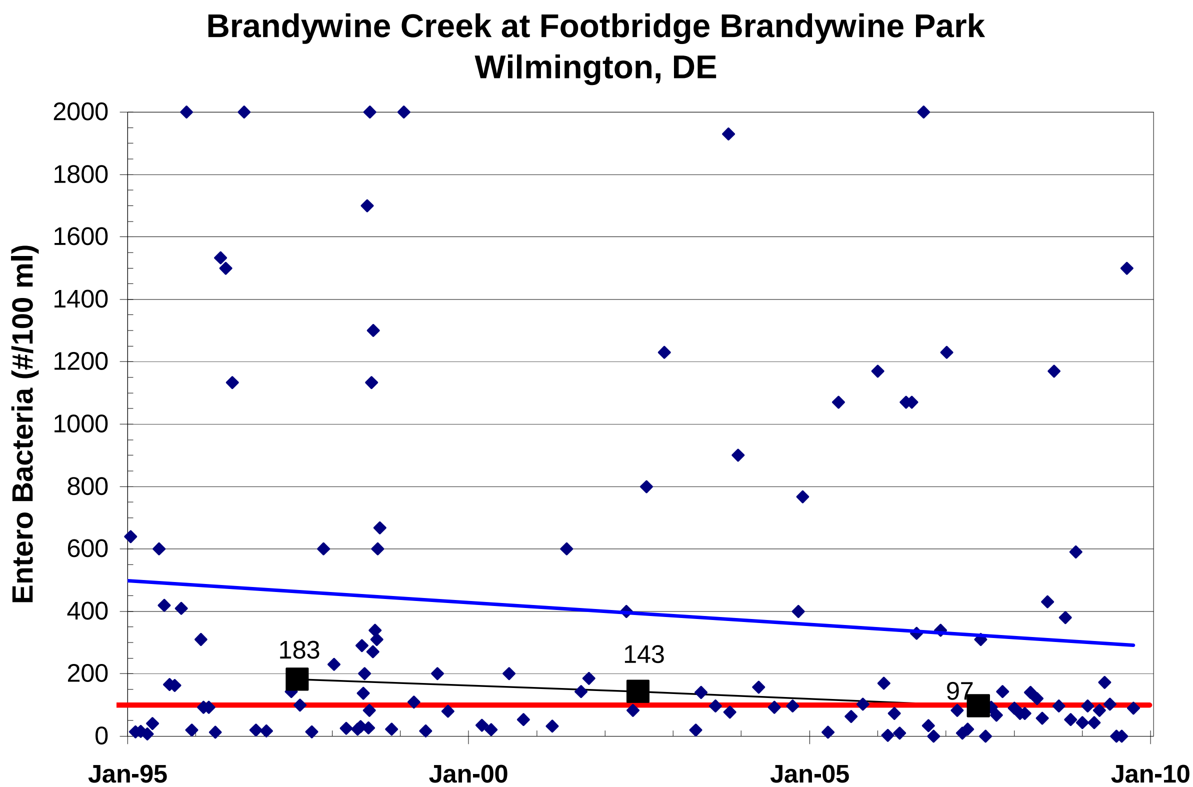


Figure 27. Total suspended sediment along the White Clay Creek and Christina River. New Jersey TSS water quality standard of 40 mg/l depicted by red line for comparison purposes.



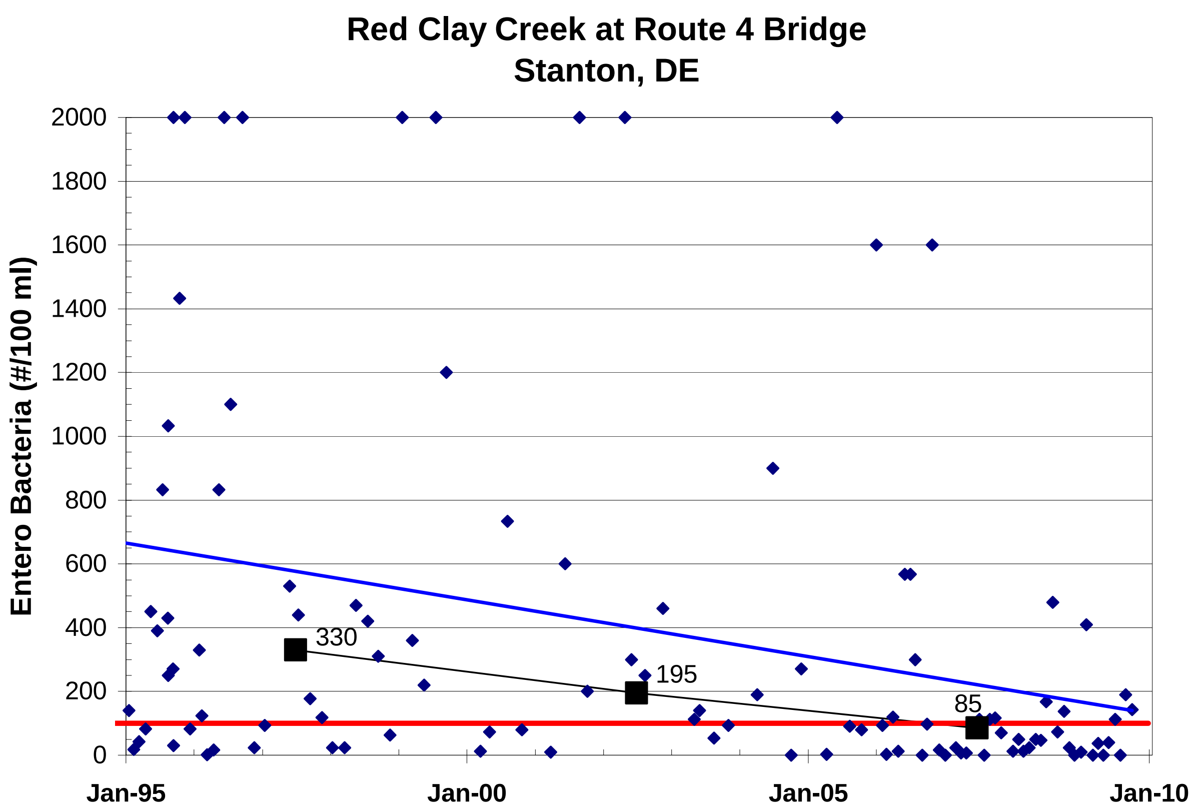


Figure 28. Enterococcus bacteria along the Brandywine Creek and Red Clay Creek. Delaware water quality standard of 100#/100 ml depicted by red line.

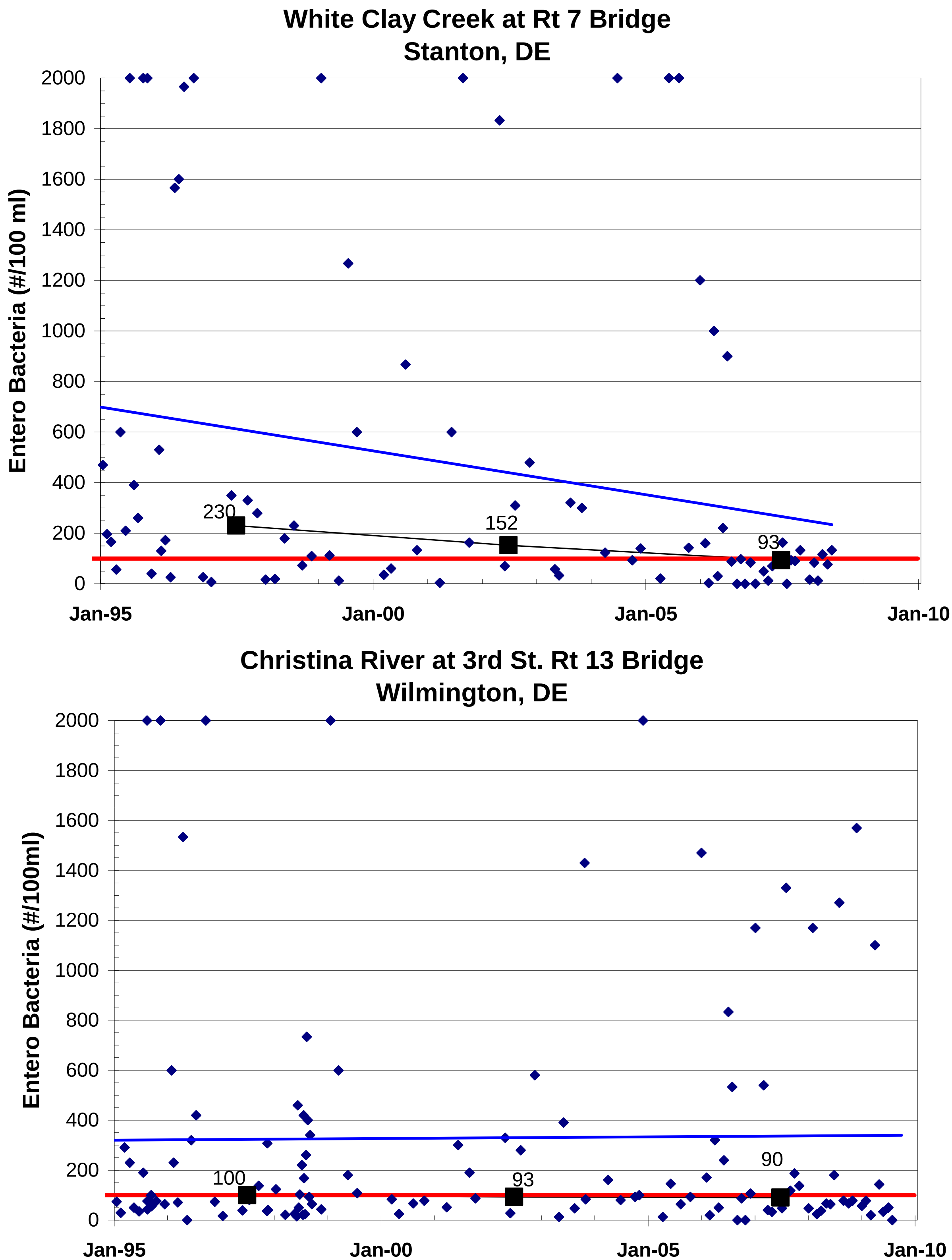
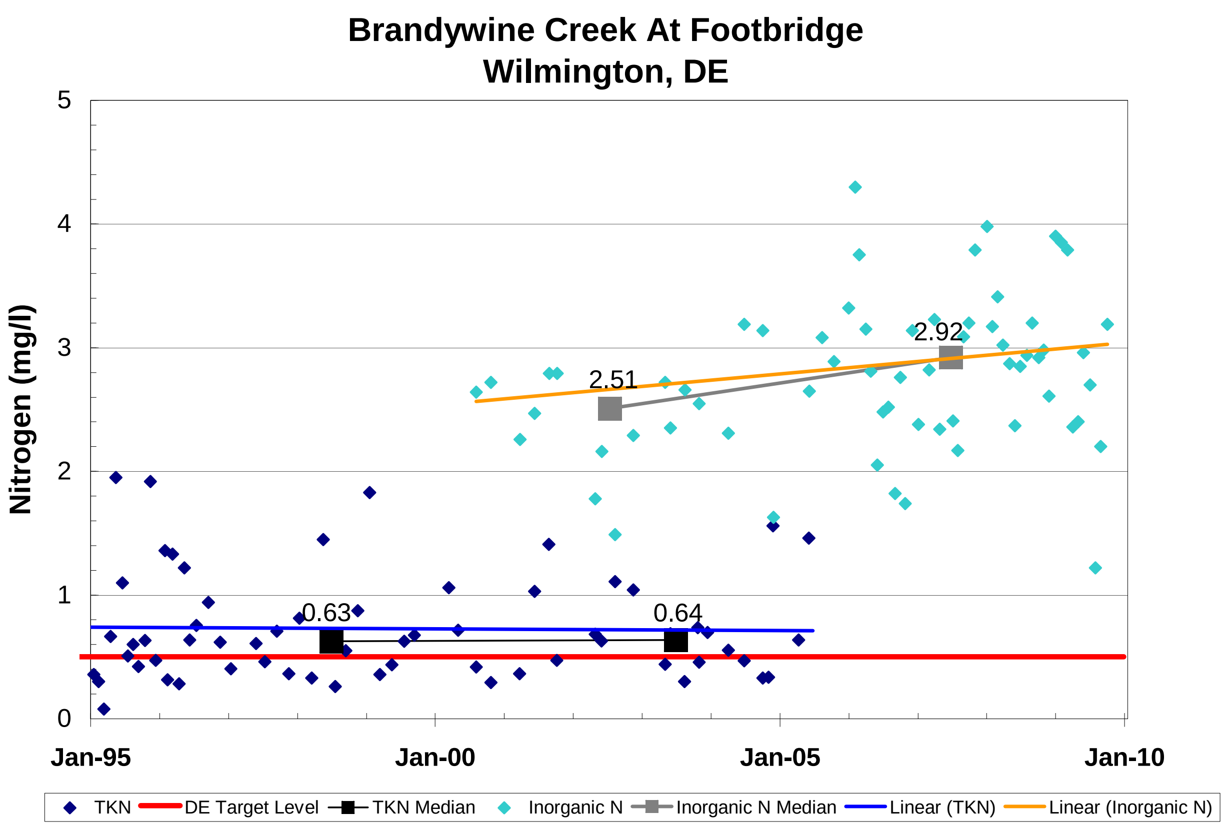


Figure 29. Enterococcus bacteria along the White Clay Creek and Christina River. Delaware water quality standard of 100#/100 ml depicted by red line.



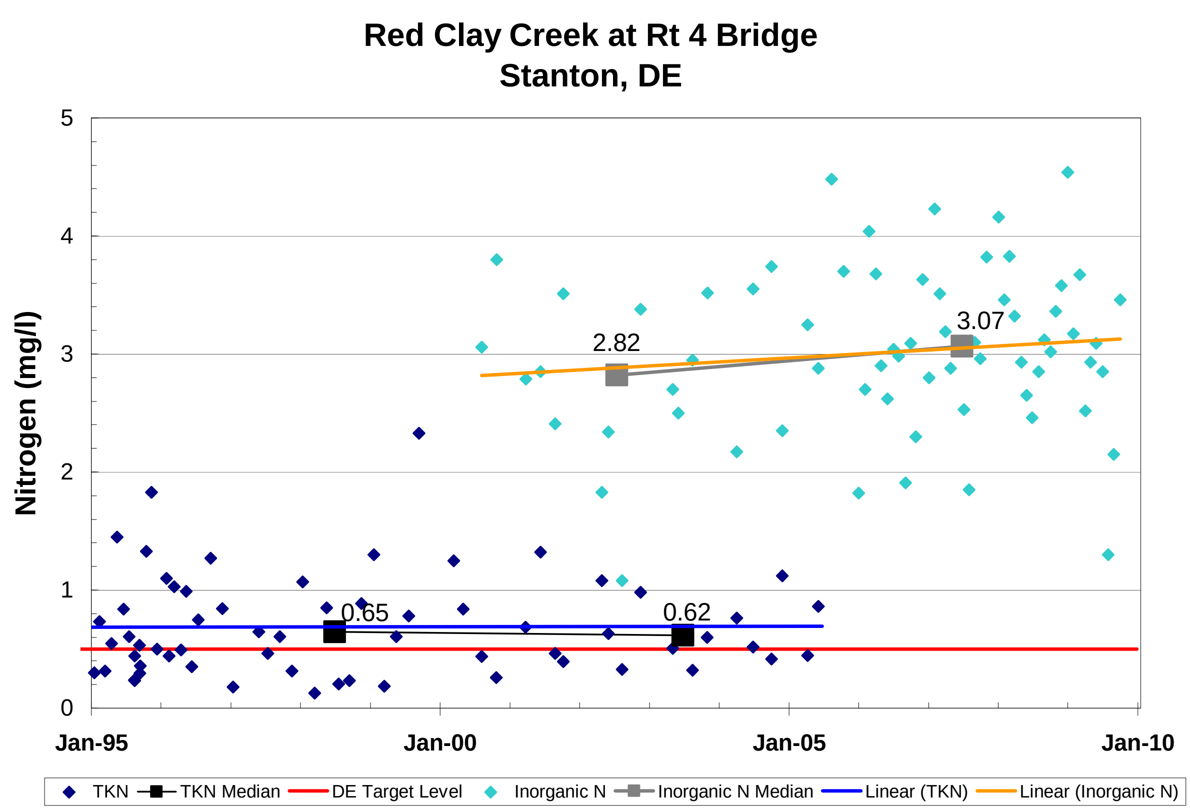
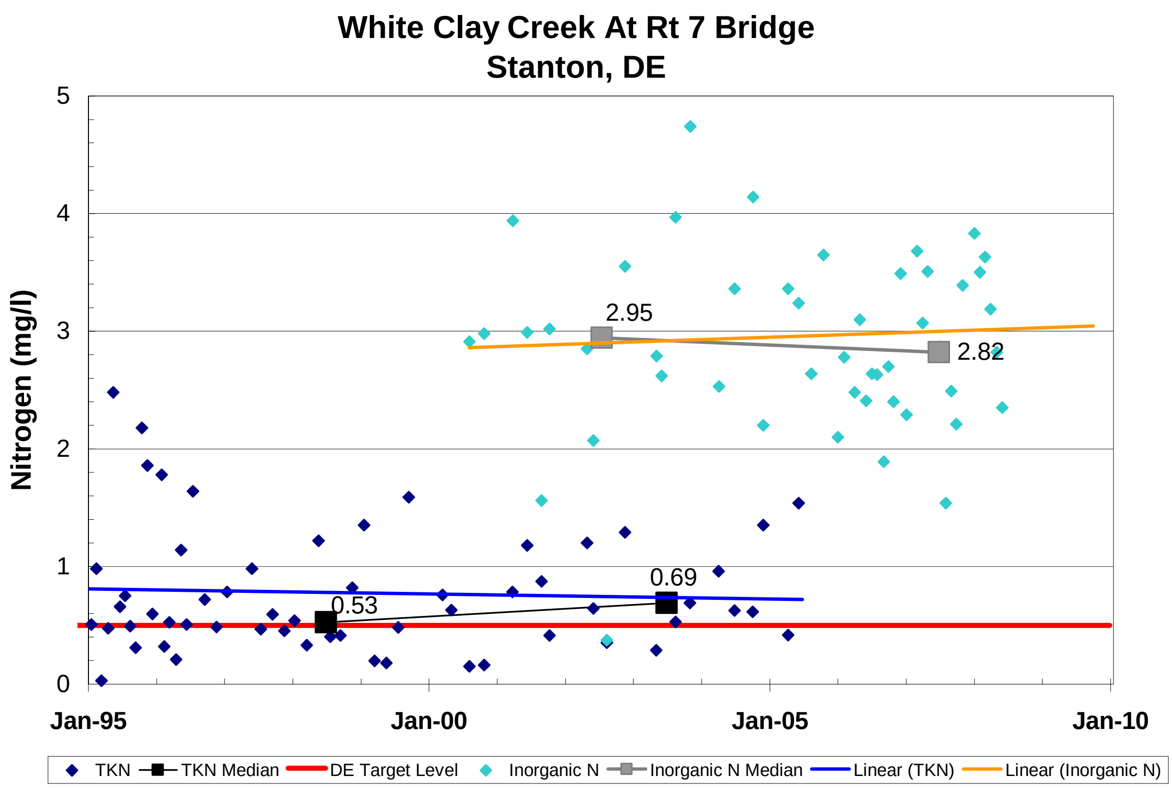


Figure 30. Nitrogen levels along the Brandywine Creek and Red Clay Creek. Delaware TMDL low target level of 0.5 mg/l depicted by red line for comparison purposes.



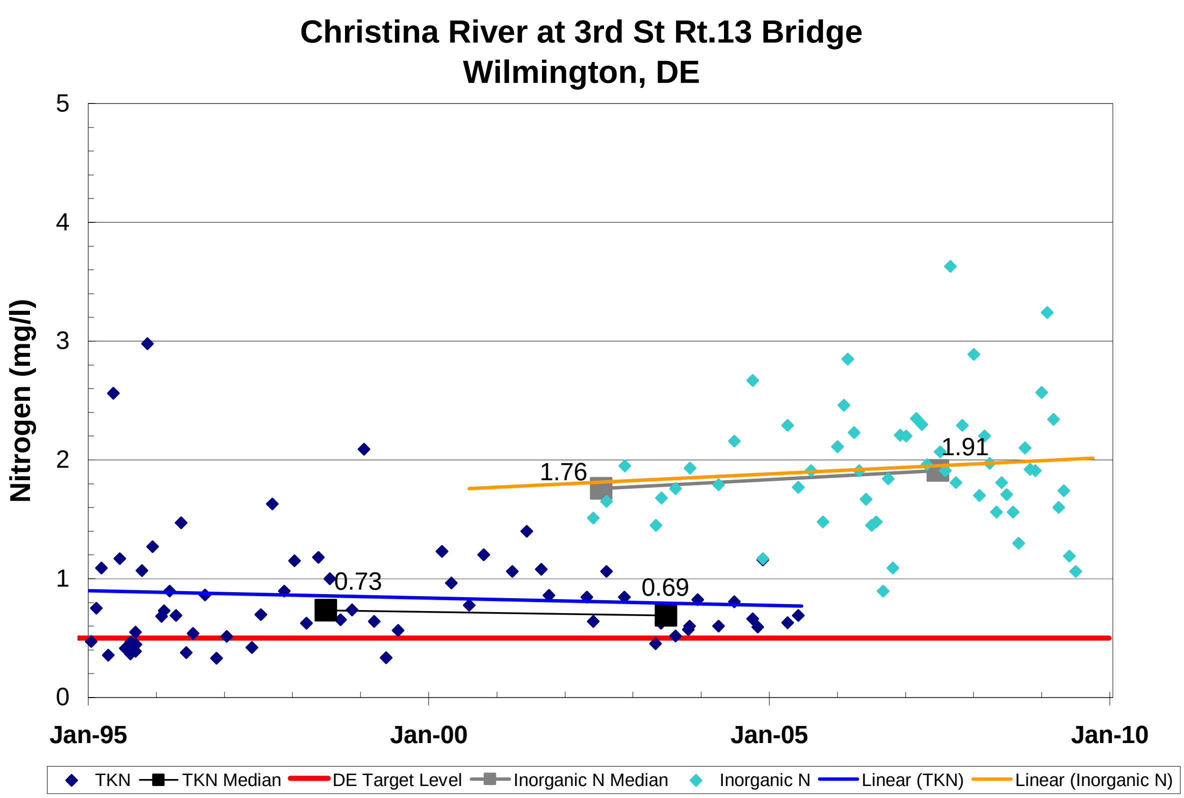
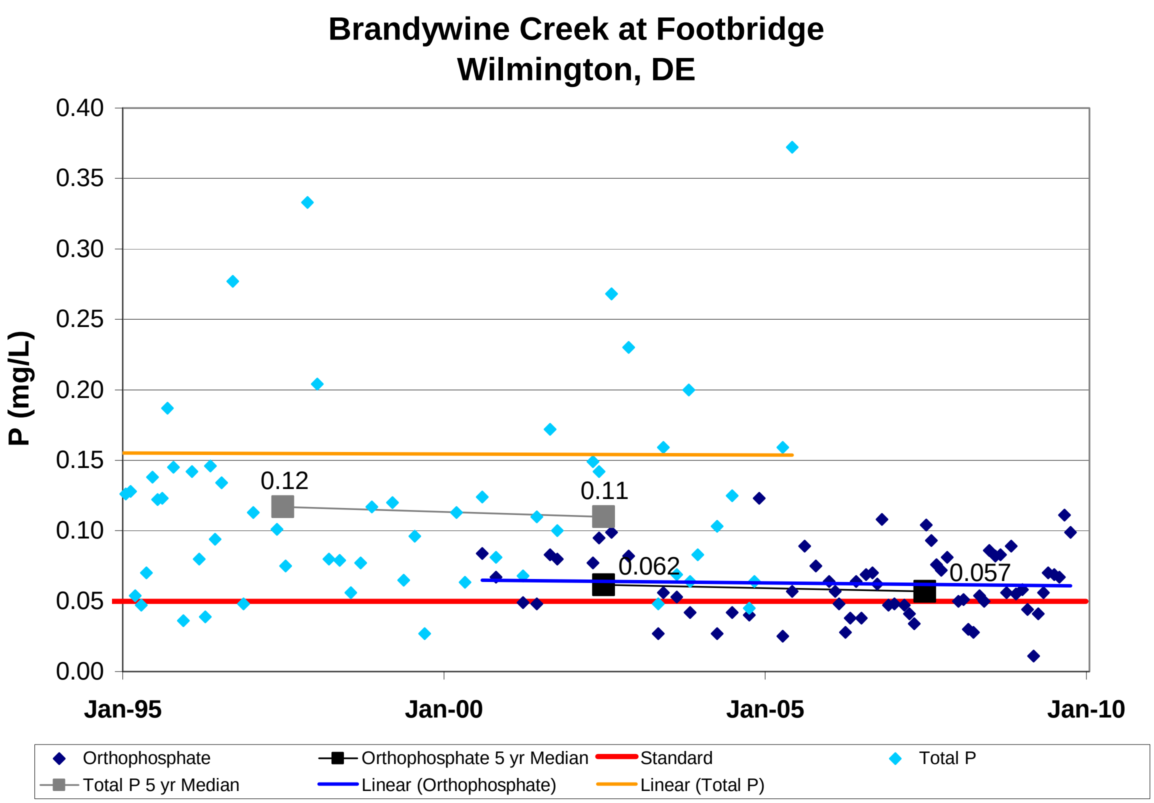


Figure 31. Nitrogen levels along the White Clay Creek and Christina River. Delaware TMDL low target level of 0.5 mg/l depicted by red line for comparison purposes.



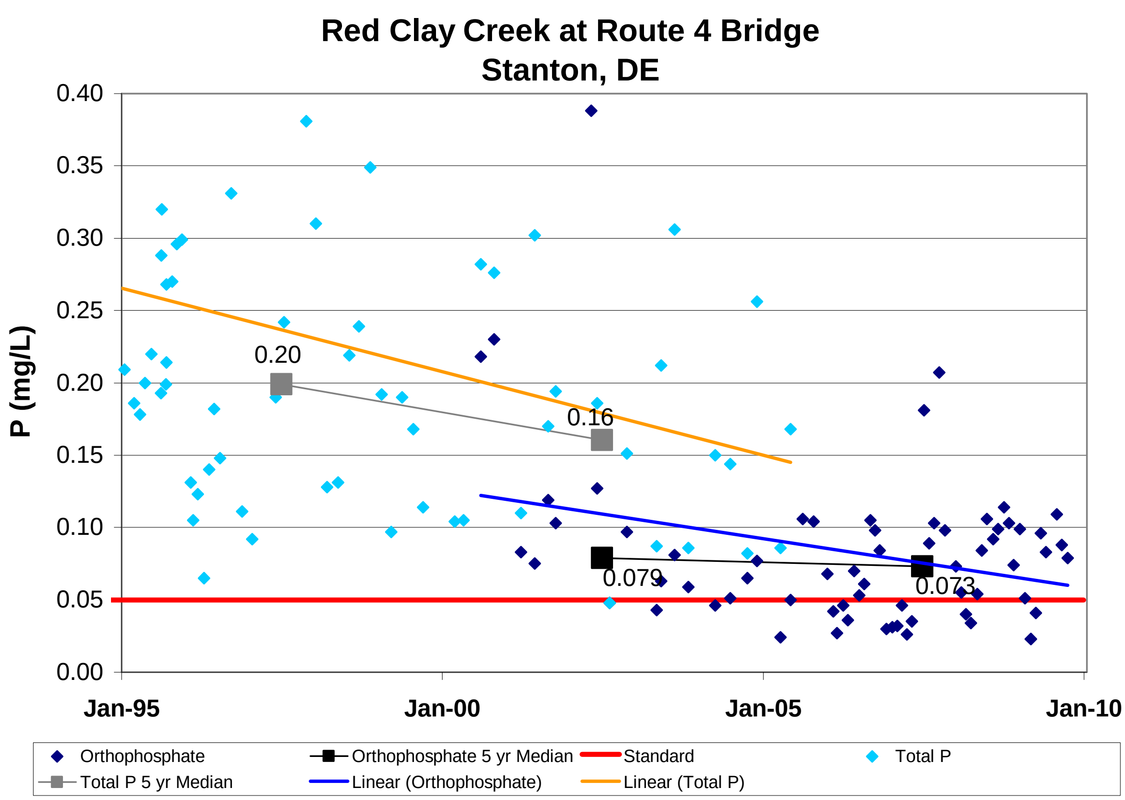
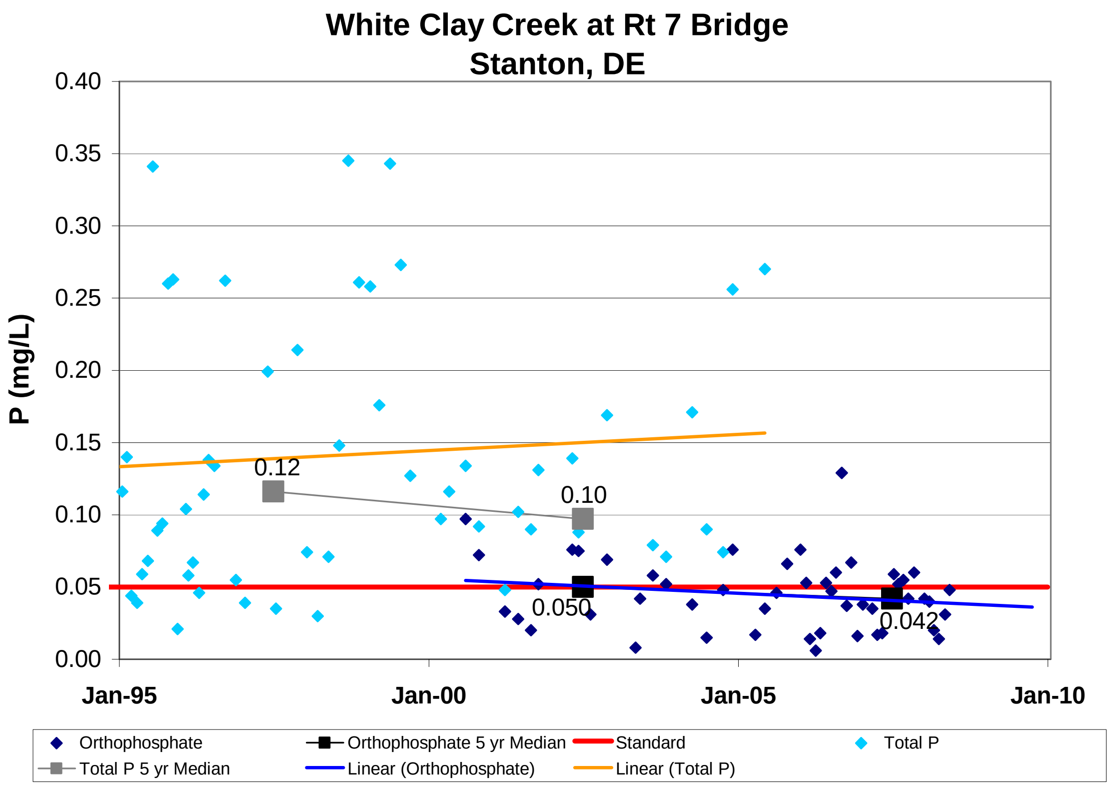


Figure 32. Phosphorus levels along the Brandywine Creek and Red Clay Creek. Delaware TMDL low target level of 0.05 mg/l depicted by red line for comparison purposes.



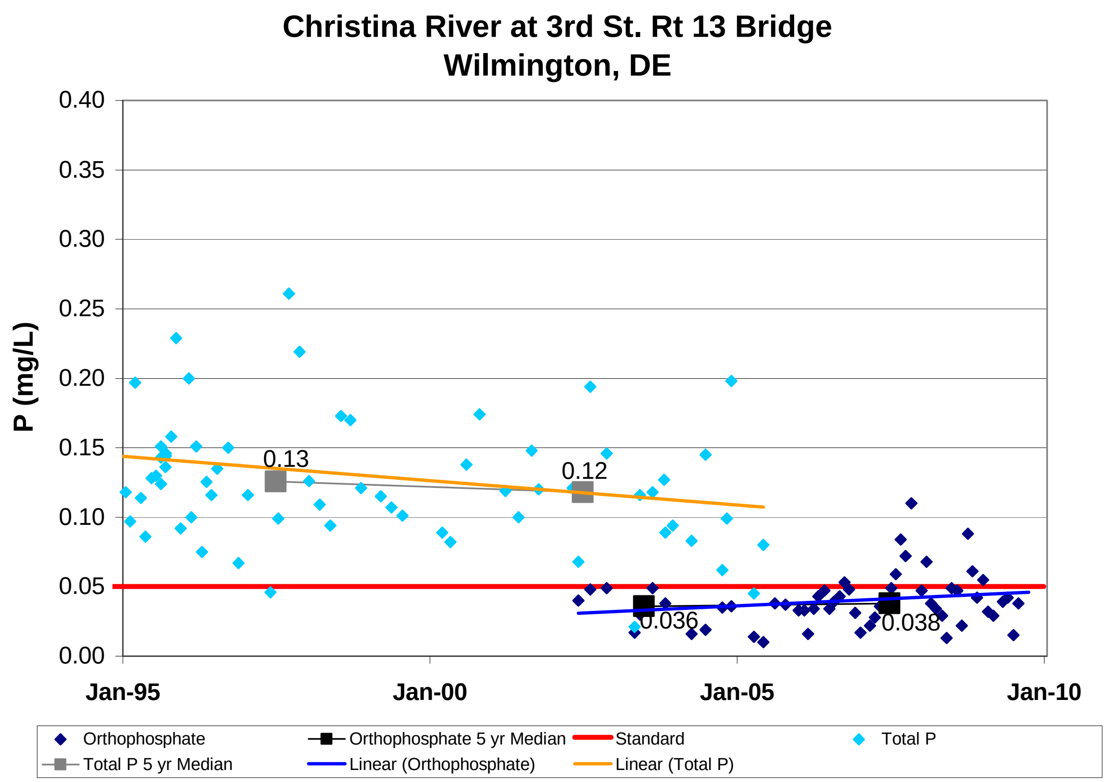


Figure 33. Phosphorus levels along the White Clay Creek and Christina River. Delaware TMDL low target level of 0.05 mg/l depicted by red line for comparison purposes.

5. Water Quality vs. Population and Land Use

Using linear regression, water quality (median 2005-2010) was correlated with watershed population density and land use (Fig. 34-39). Coefficients of determination (r^2) between 0.3 and 0.5 are considered a moderate correlation. An r^2 greater than 0.5 is considered a good correlation. An $r^2 = 1.0$ is a line with the best fit and would be considered a perfect correlation. Table 6 summarizes the coefficients of determination where r^2 greater than 0.3 (at least moderately correlated) for correlations between water quality and population density and land use.

- Increased population density correlates with decreased dissolved oxygen ($r^2 = 0.36$) and increased total suspended sediment ($r^2 = 0.88$) levels.

- Increased urban/suburban land correlates with decreased dissolved oxygen ($r^2 = 0.40$) and bacteria ($r^2 = 0.33$) and increased sediment ($r^2 = 0.83$) and nitrogen ($r^2 = 0.53$) levels.

- Increased agricultural land correlates with increased dissolved oxygen ($r^2 = 0.41$) and bacteria ($r^2 = 0.34$) and decreased sediment ($r^2 = 0.86$) and nitrogen ($r^2 = 0.58$) levels.

- Increased forest/wetland areas correlate with increased dissolved oxygen ($r^2 = 0.33$) and decreased sediment ($r^2 = 0.68$) levels

Table 6. Coefficients of determination (r^2) for correlations between population density and land use and water quality in the Christina Basin.

Watershed Parameter	DO (r^2)	TSS (r^2)	Bacteria (r^2)	N (r^2)	P (r^2)
Population Density	0.36	0.88			
Urban/Suburban	0.40	0.83	0.33	0.53	
Agriculture	0.41	0.86	0.34	0.58	
Forest/Wetlands	0.33	0.68			

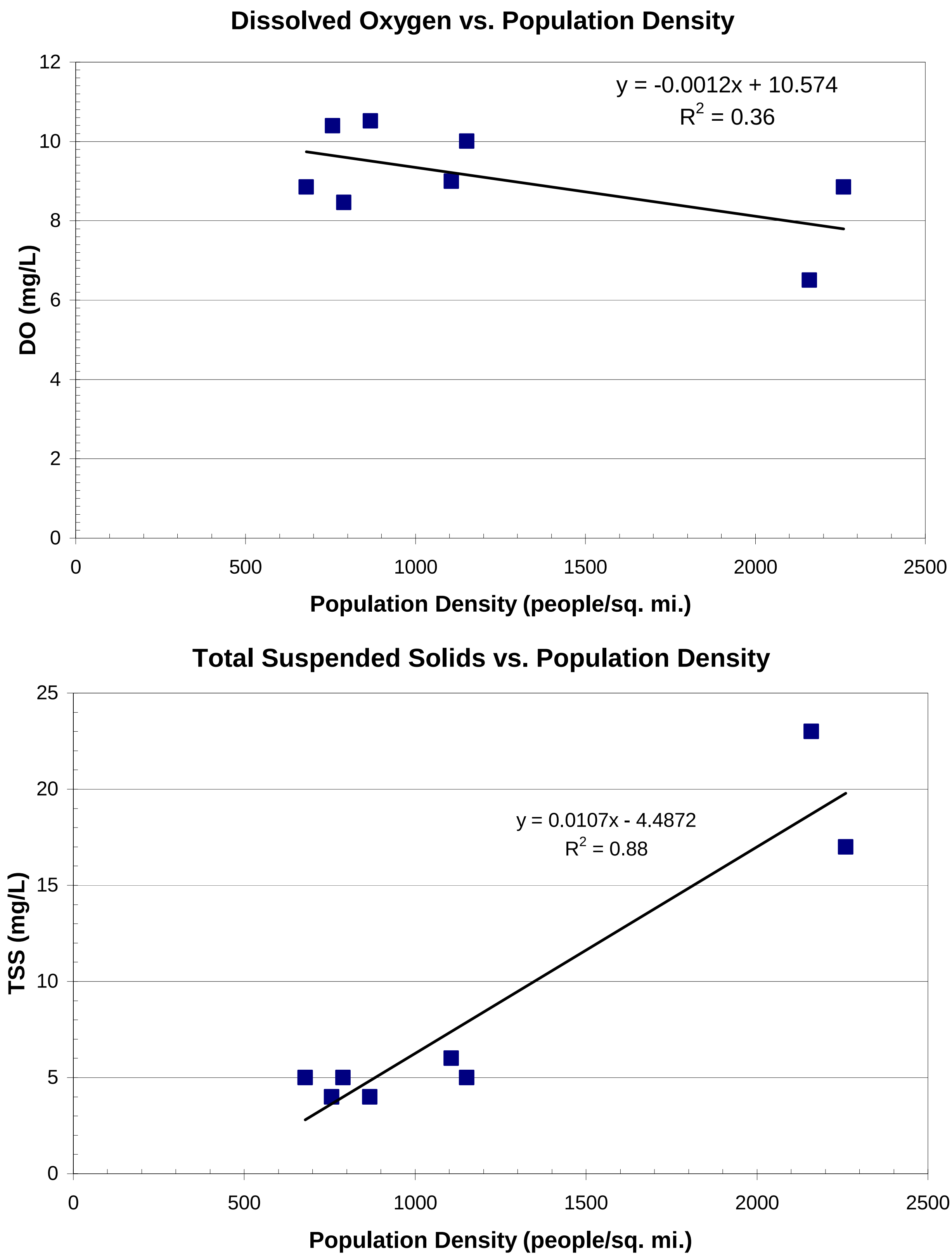
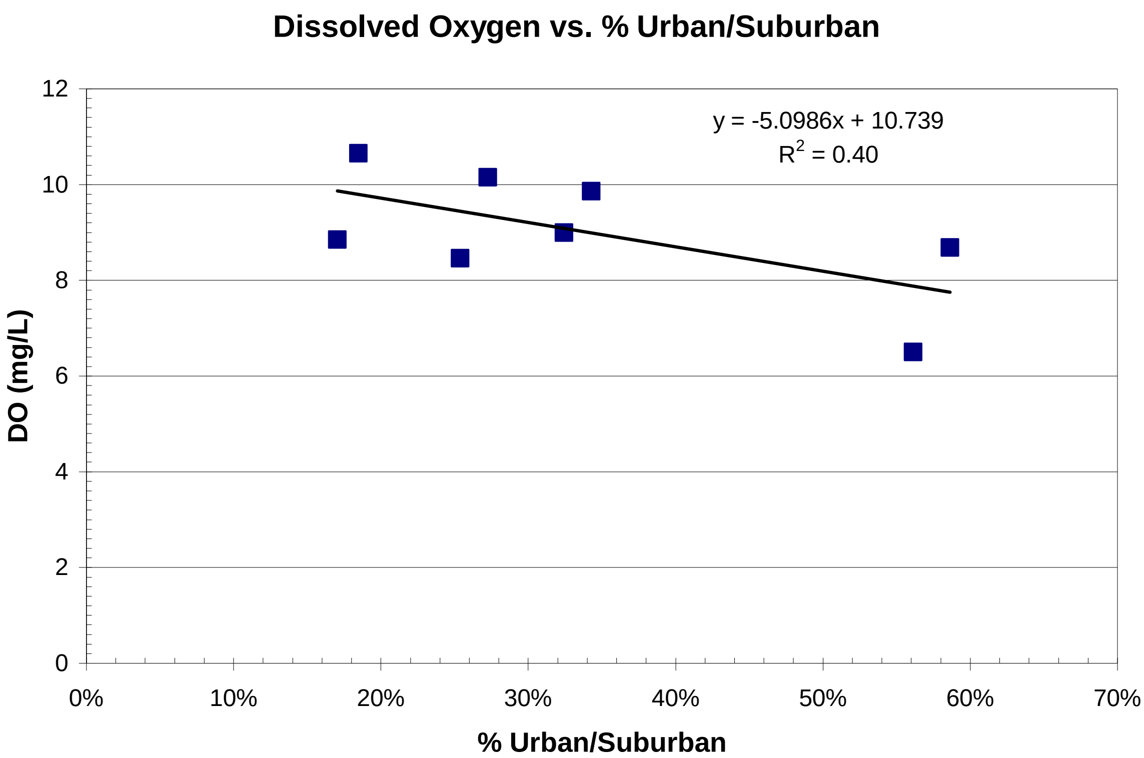


Figure 34. Correlation of water quality with population density along Christina Basin streams.



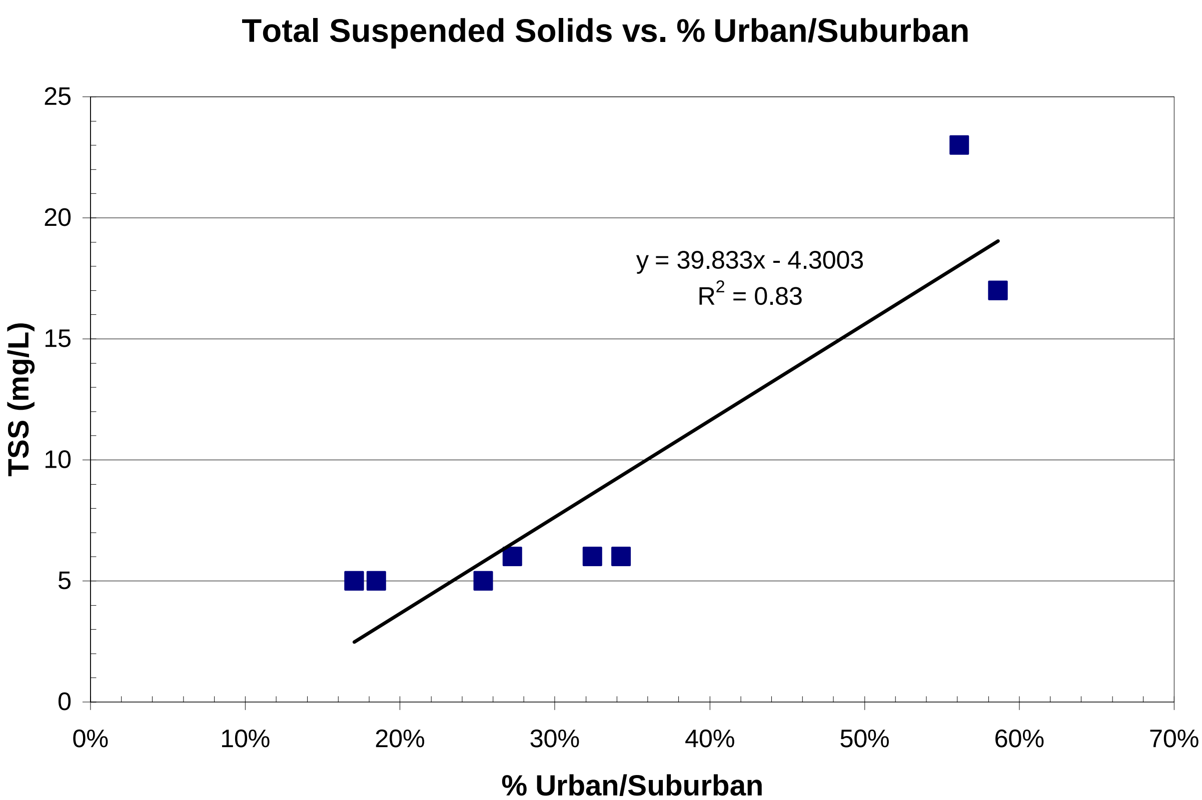


Figure 35. Correlation of water quality with urban/suburban land along Christina Basin streams.

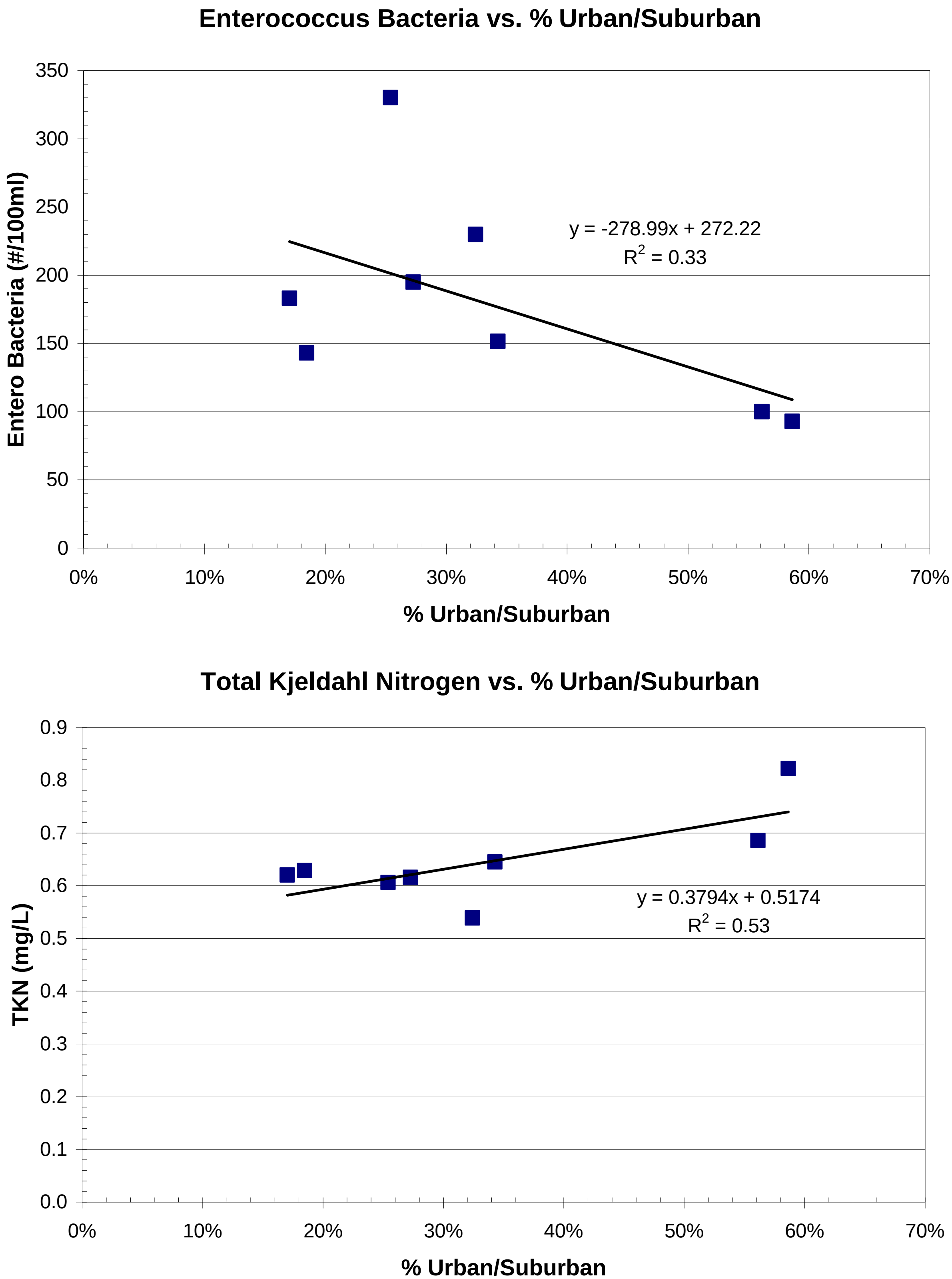
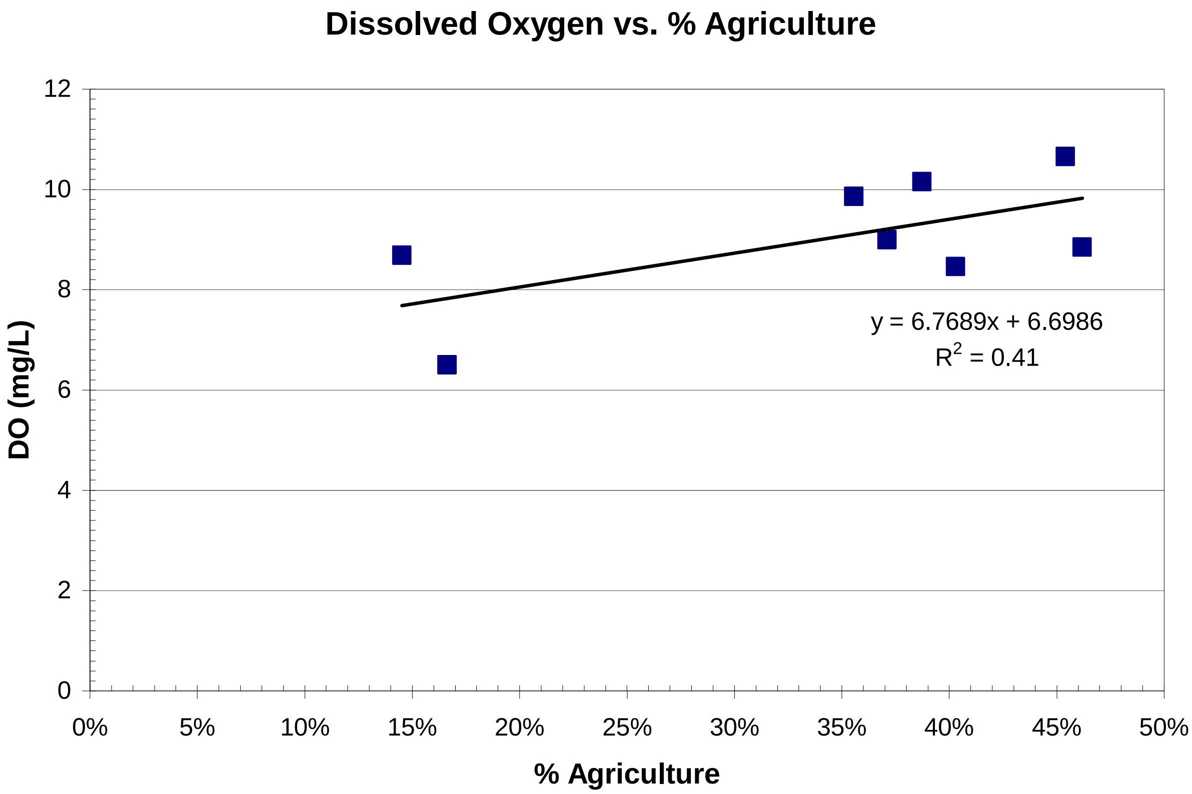


Figure 36. Correlation of water quality with urban/suburban land along Christina Basin streams



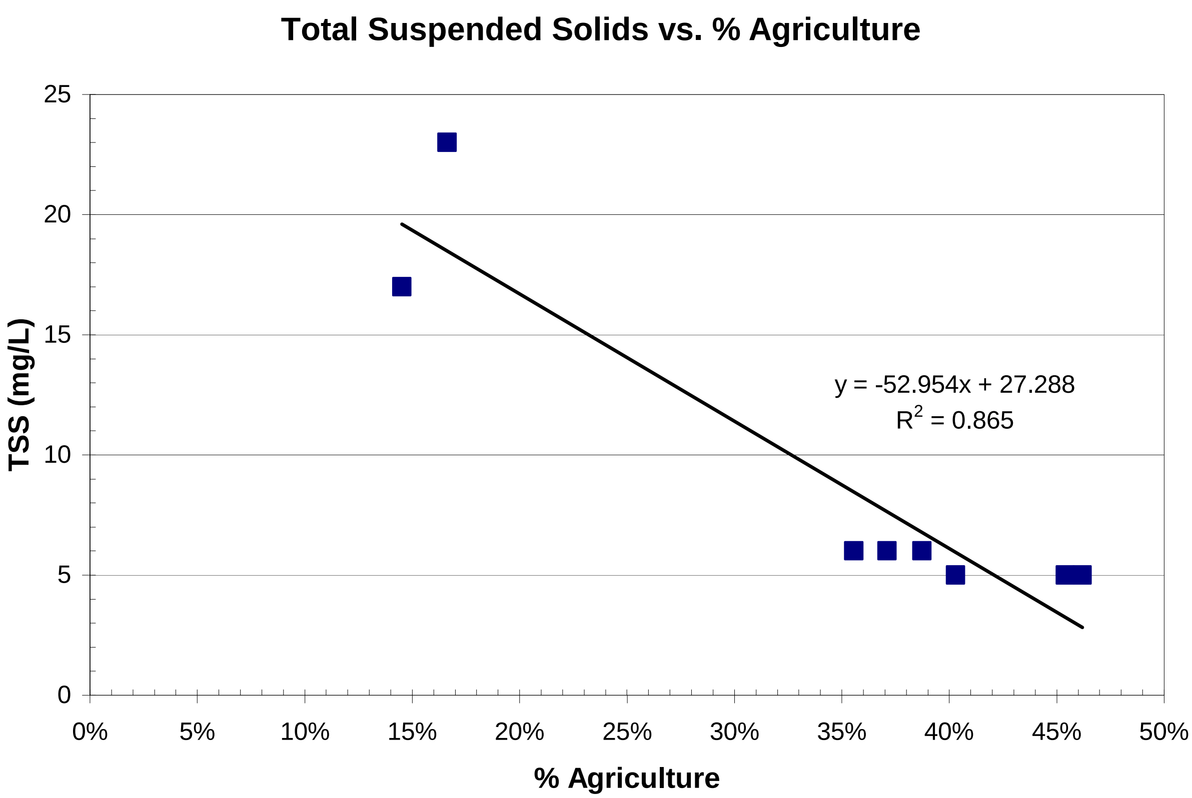
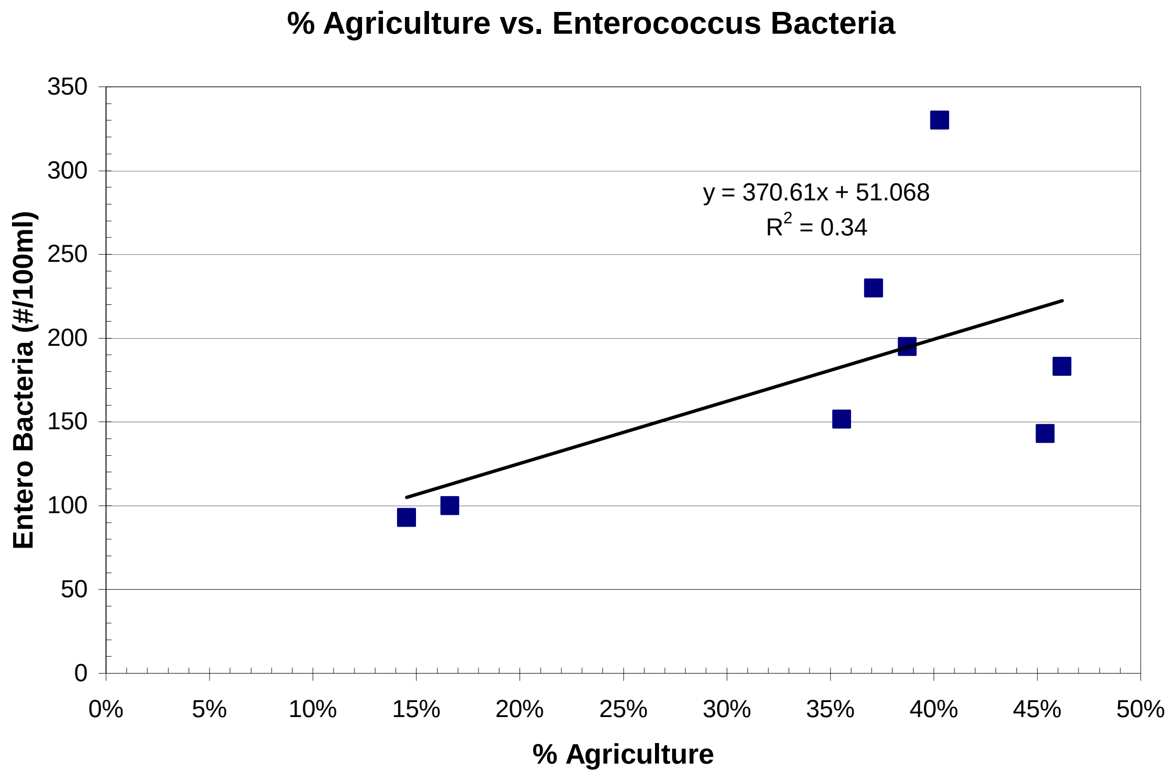


Figure 37. Correlation of water quality with agriculture along Christina Basin streams



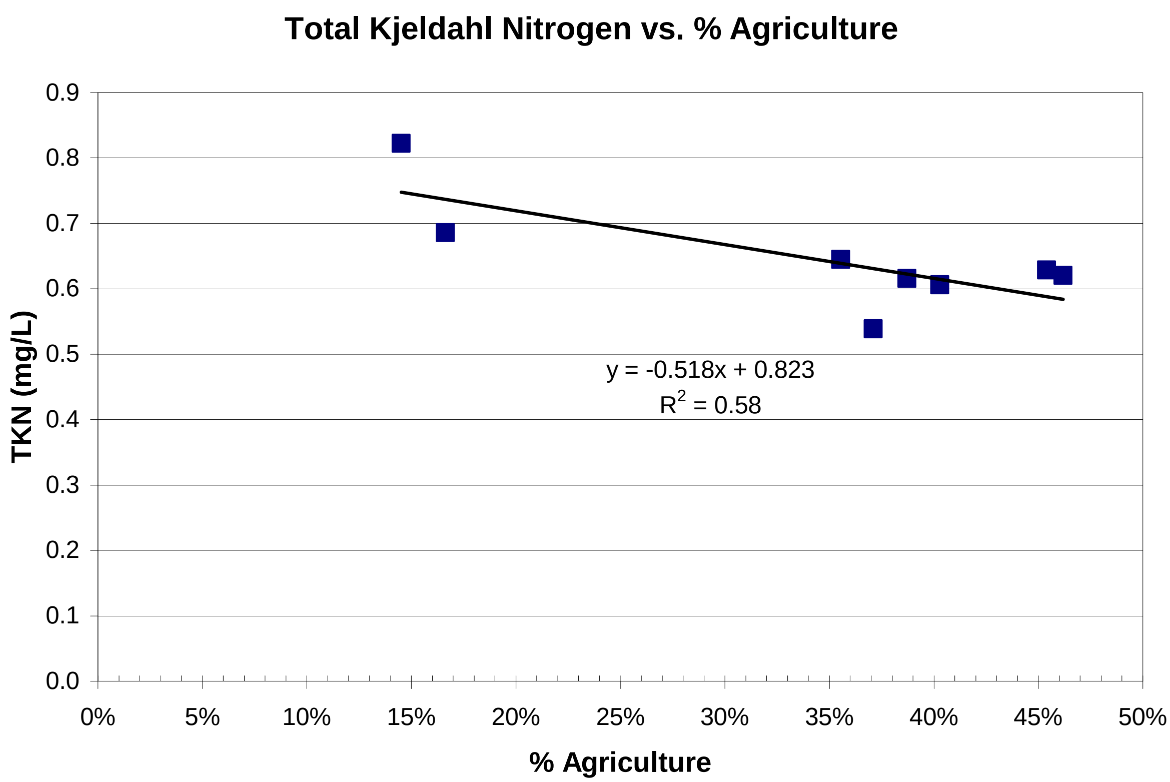
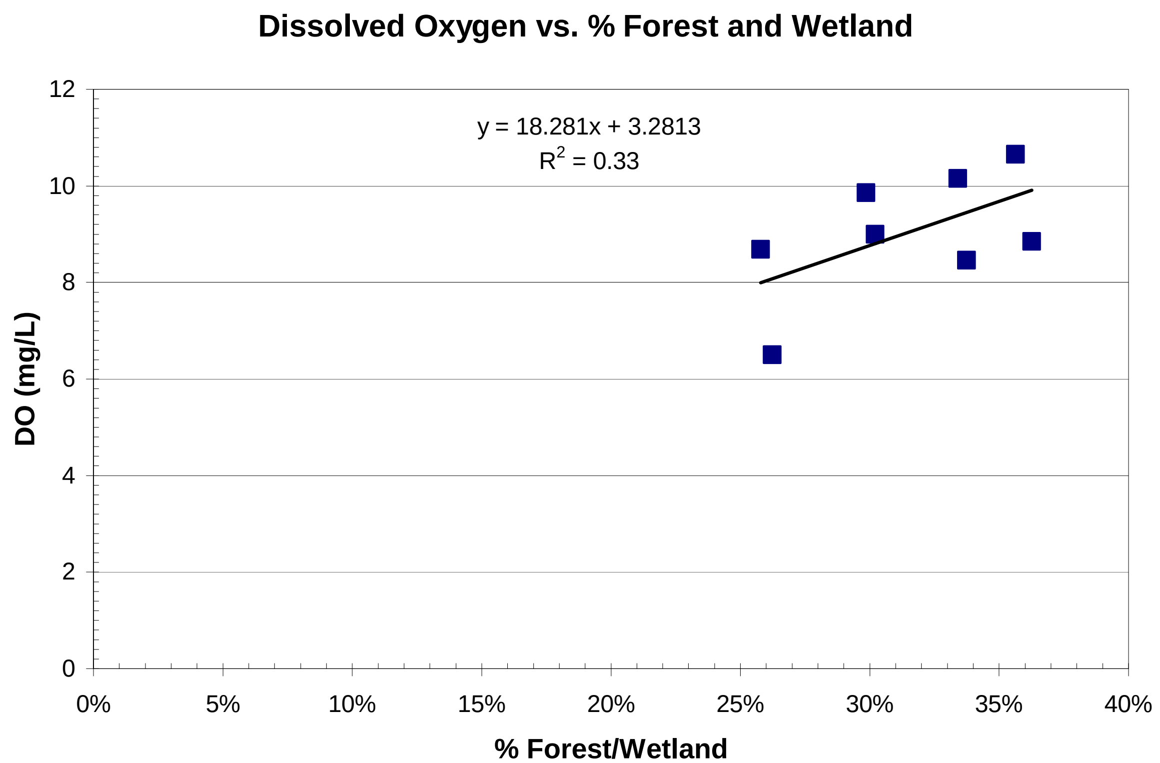


Figure 38. Correlation of water quality with agriculture along Christina Basin streams



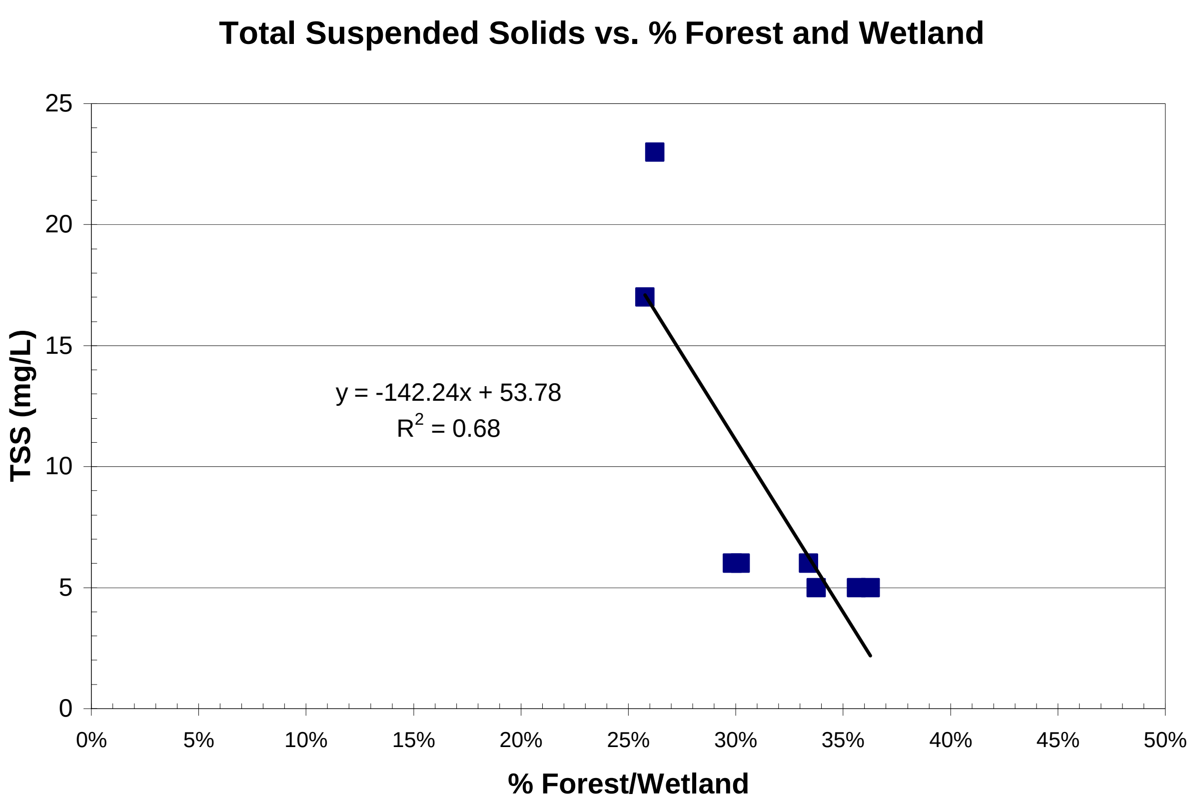


Figure 39. Correlation of water quality with forest/wetlnds along Christina Basin streams

6. Water Temperature

Mean daily, maximum annual, and mean annual water temperatures were plotted for the Brandywine Creek at Chadds Ford USGS gage from 1995-2010 (Fig. 40). Water temperatures are important criteria for fisheries (cool water species such as trout desire water temperatures less than 68 deg F) and kayaking/canoeing/wading (water temperatures above 70 deg F are desirable). Maximum annual water temperatures are constant (by linear trend line) over the last 15 years and fluctuate from near 75 deg F in cooler summers such as 1996 and 2003 to almost 90 deg F during hot summers such as the drought years of 1999 and 2002. Mean annual water temperature has remained unchanged over the last 15 years and is approximately 61 deg F.

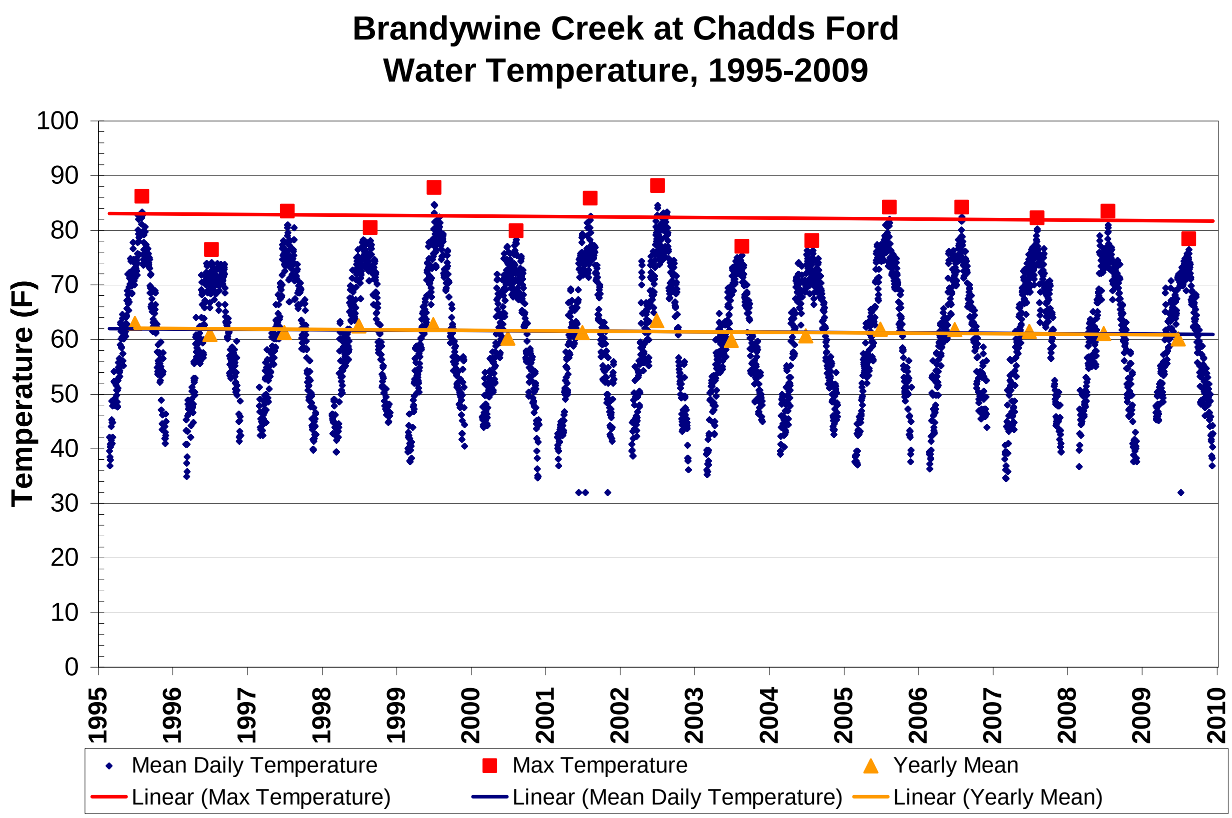


Figure 40. Water temperature at the Brandywine Creek at Chadds Ford USGS gage (source: www.usgs.gov)

7. Streamflow

Annual low flows (an indicator of drought) and annual peak flows (an indicator of flood) were plotted for 1995-2010 at the following USGS stream gages within the Christina Basin in Delaware.

- Brandywine Creek at Wilmington (USGS Gage 01481500)
- Red Clay Creek at Stanton (USGS Gage 01480015)
- White Clay Creek near Newark (USGS Gage 0147900)
- Christina River at Cooches Bridge (USGS Gage 01478000

The lowest annual low flows occurred during the drought of 2002 followed by the next lowest flows during the droughts of 1999 and 1995 (Fig 41-42). Drought emergencies were declared in Delaware and Pennsylvania for the Christina Basin during 1995, 1999, and 2002 when streamflows declined below the 7Q10 flow (Table 7). The 7Q10 flow is the low flow likely to occur for 7 days in a row once every 10 years. The 7Q10 is the 2 percentile flow meaning that flows below the 7Q10 occur 2% of the time in any given year. Since 2002, annual low flows have been comfortably above the 7Q10 flow therefore drought and impacts on drinking water have not been a concern.

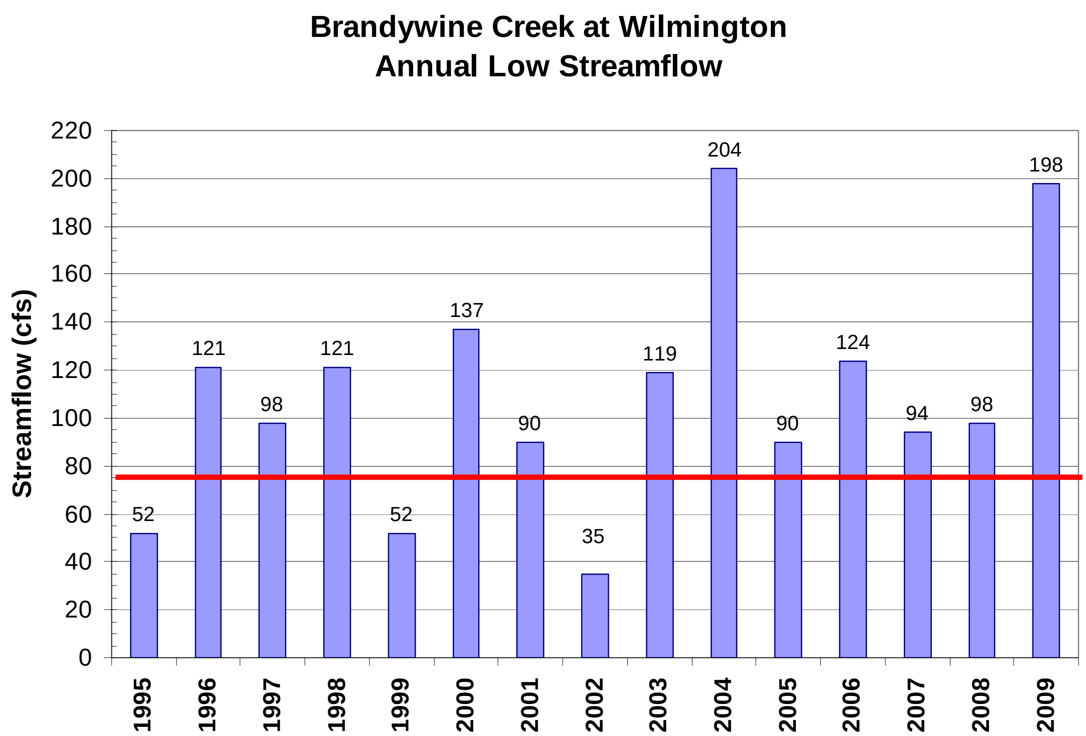
Table 7. 7Q10 low flows along Christina Basin streams

Stream Gage	7Q10 flow (cfs)	Years below 7Q10
Brandywine Cr. at Wilmington (USGS 01481500)	76	1995, 1999, 2002
Red Clay Creek at Stanton (USGS 01480015)	8.5	1995, 1999, 2002
White Clay Creek near Newark (USGS 0147900)	17.5	1995, 1999, 2002
Christina River at Cooches Bridge (USGS 01478000	1.9	1995, 1999, 2001, 2002

Significant floods have occurred along Christina Basin streams from 1995 to 2010 during Hurricane Floyd in September 1999, Tropical Storm Henri in September 2003, and Tropical Storm Jeanne in September 2004 (Table 8 and Fig. 43-44). Seven 10-yr floods and one 100-yr flood has occurred along the Brandywine Creek in 15 years. Four 10-yr floods and two 100-yr floods have occurred along the Red Clay Creek. Two 10-yr floods and two 100-yr floods have occurred along the White Clay Creek. Two 10-yr floods and two 100-yr floods have occurred along the Christina River.

Table 8. Flood flows along Christina Basin streams (FEMA FIS)

Stream Gage	10-yr flood (cfs)	Years ≥ 10-yr flood	100-yr flood (cfs)	Years ≥ 100-yr flood
Brandywine Creek at Wilmington	13,000	1996, 1997, 2000, 2001, 2003, 2004, 2006	25,600	1999
Red Clay Creek at Stanton	4,900	1996, 2003, 2004, 2006	10,200	2003, 2004
White Clay Creek near Newark	7,200	1996, 2000	14,200	1999, 2003
Christina River at Cooches Bridge	2,400	2001, 2003	5,500	1999, 2004



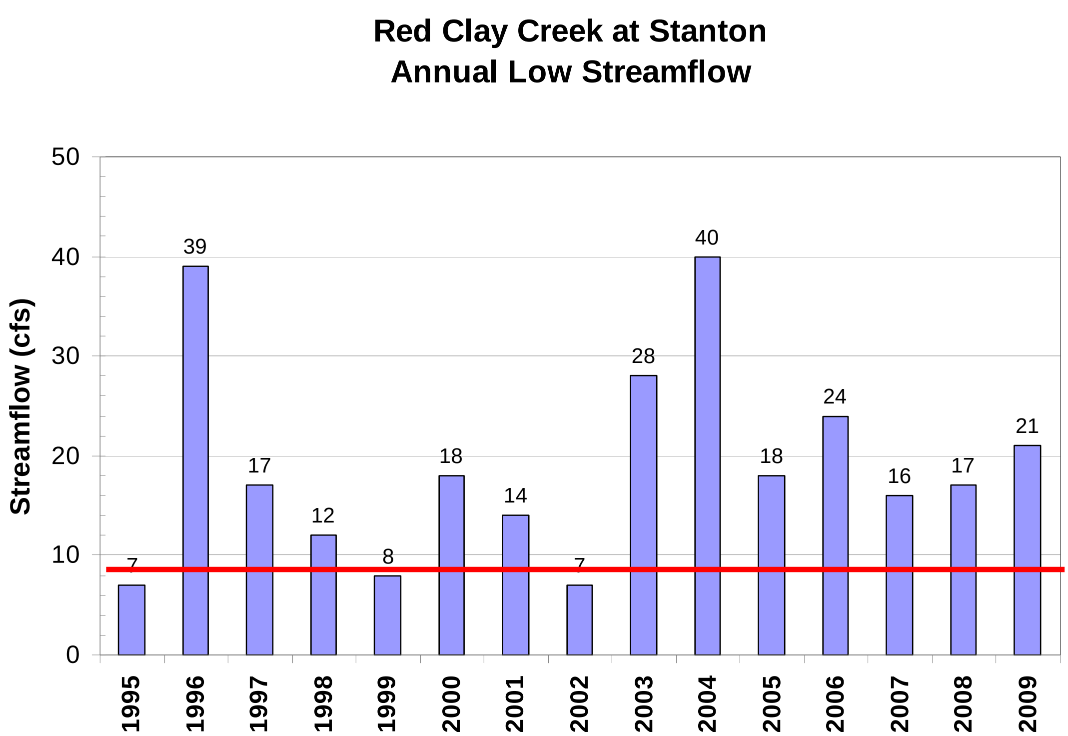
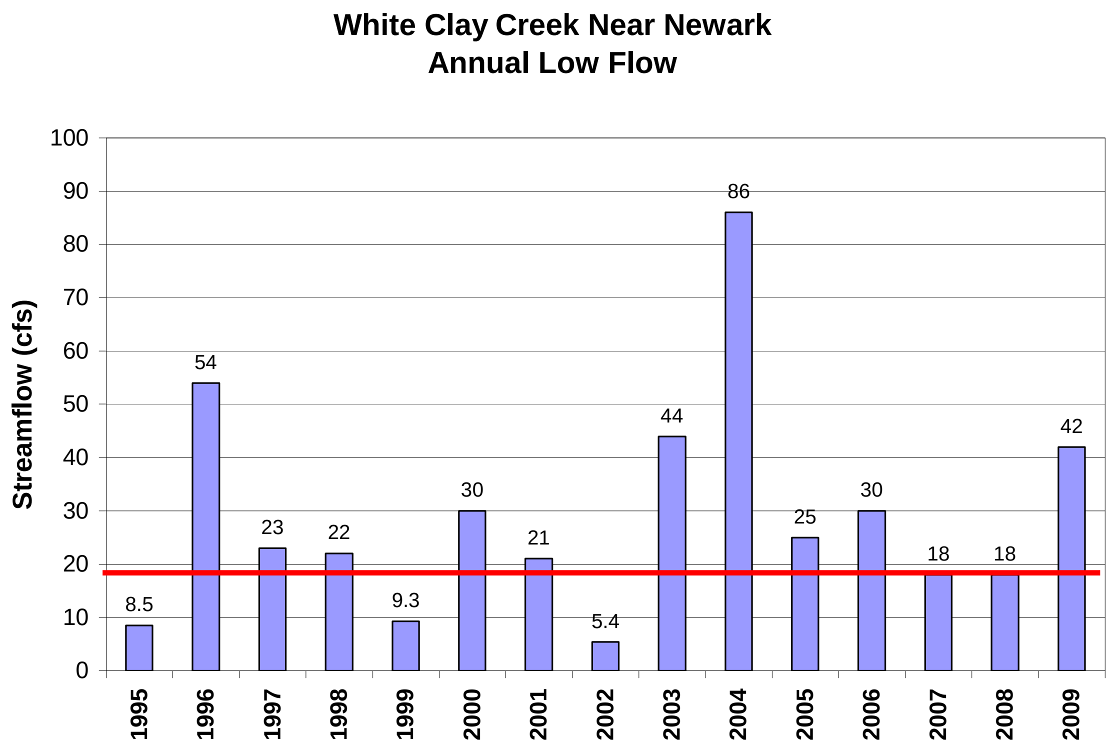


Figure 41. Annual low streamflows along the Brandywine Creek at Wilmington and Red Clay Creek at Stanton. 7Q10 low flow defined by red line. (www.usgs.gov)



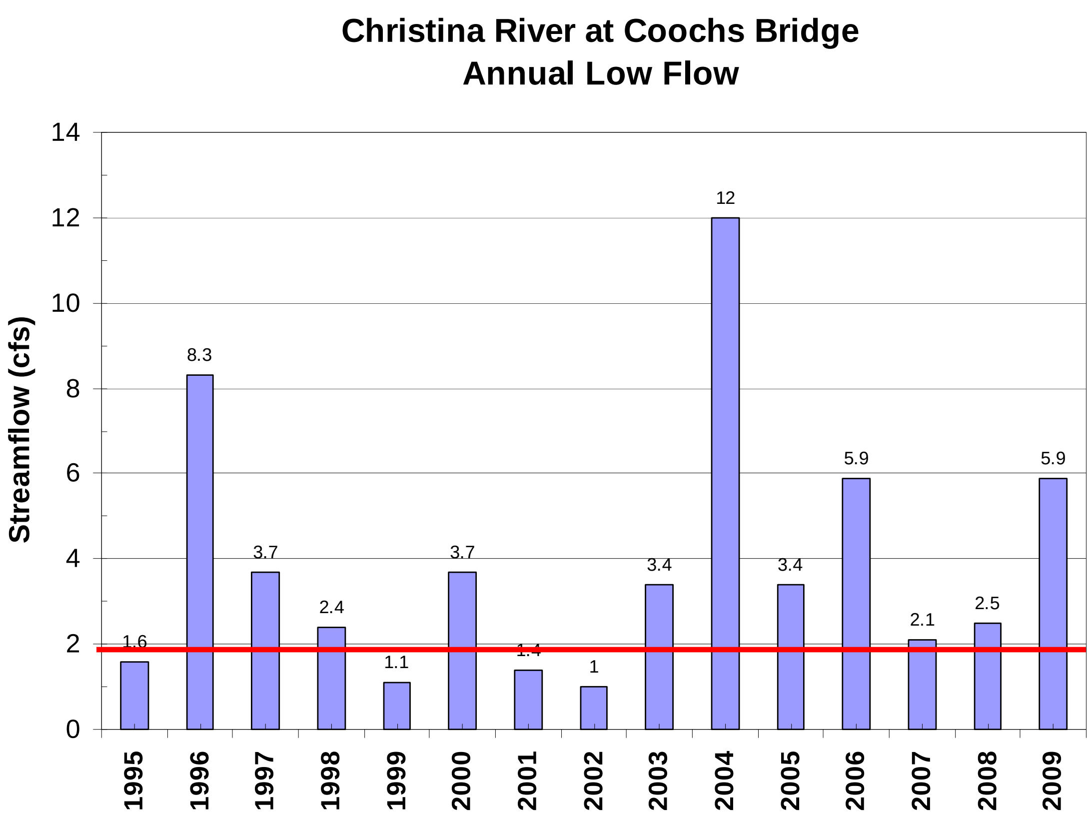


Figure 42. Annual low streamflows along the White Clay Creek near Newark and Christina River at Cooches Bridge. 7Q10 low flow defined by red line. (www.usgs.gov)

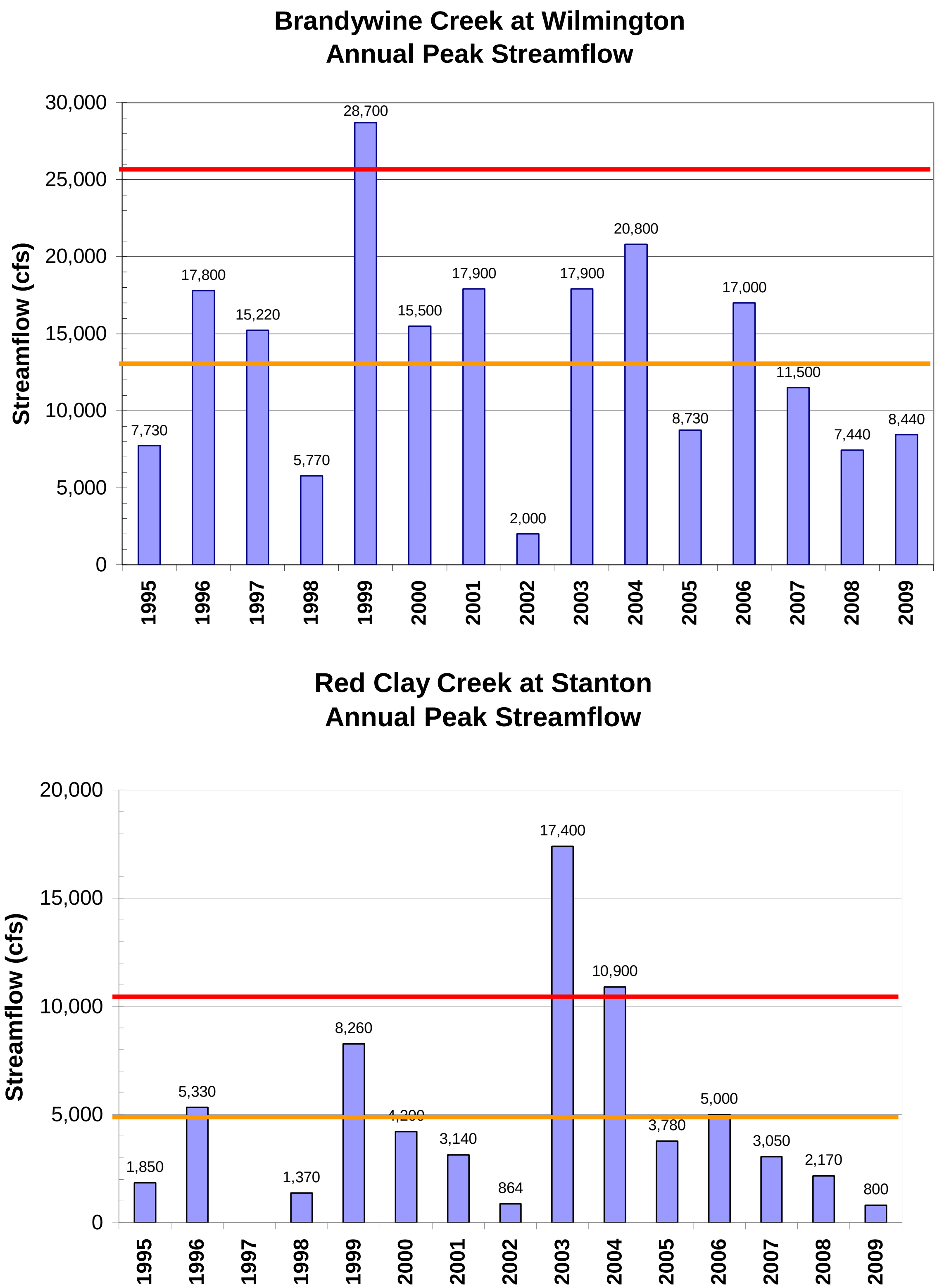
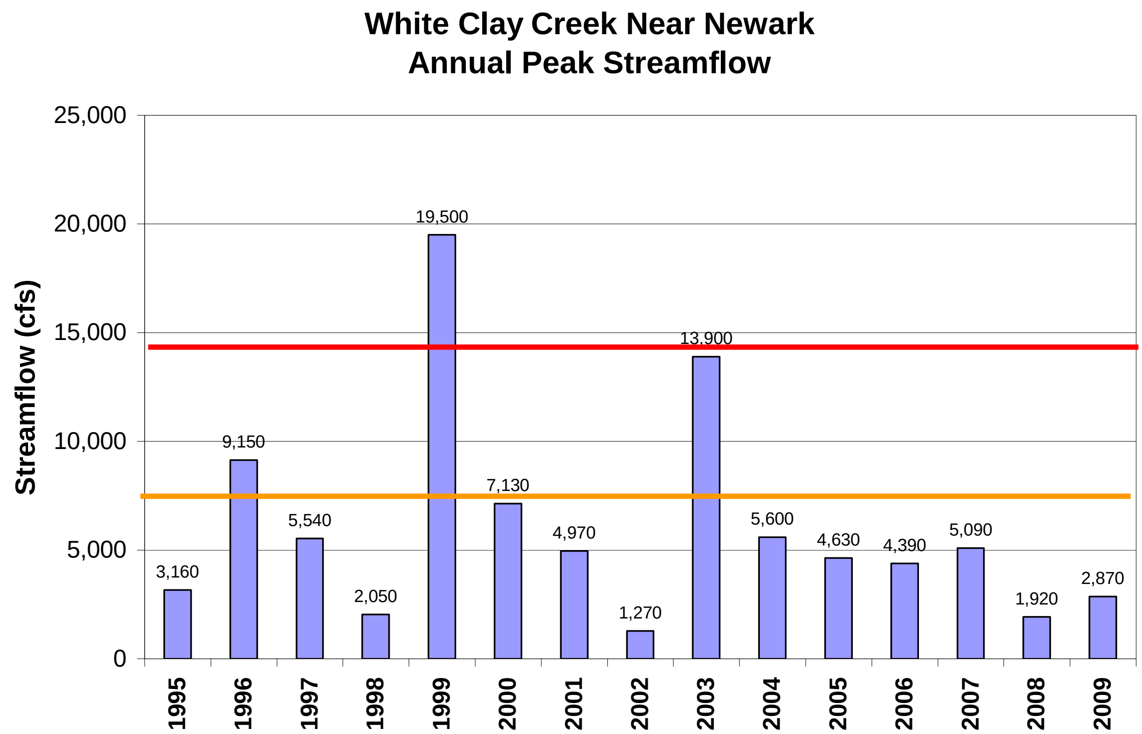


Figure 43. Annual peak flows along Brandywine Cr. at Wilmington and Red Clay Cr. at Stanton. 10-yr and 100-yr floods defined by orange and red lines, respectively. (www.usgs.gov)



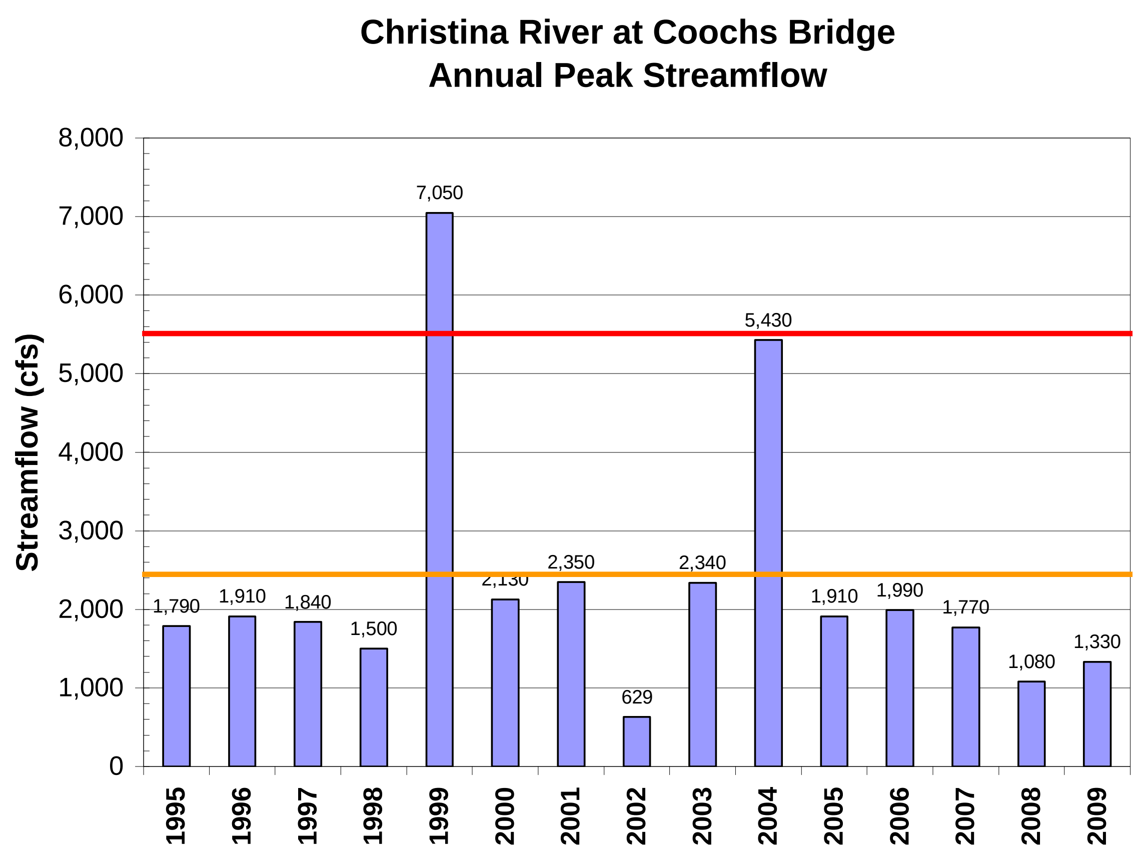


Figure 44. Annual peak flows along White Clay Cr. near Newark and Christina River at Stanton. 10-yr and 100-yr floods defined by orange and red lines, respectively. (www.usgs.gov)

8. Summary

The following trends were observed over the 15 years from 1995-2010 that the Christina Basin Clean Water Partnership has been working to restore the waters of the Brandywine, Red Clay, and White Clay creeks, and Christina River in Delaware, Maryland, and Pennsylvania.

Population

- Between 2000 and 2010, the basin population grew from 549,000 to 591,000 people, an increase of 42,000 or greater than the combined populations of Newark, Del. and West Chester, Pa.

- Over the last 10 years, nearly 11,000 people have moved to the Delaware part of the basin, 31,000 have moved to Pennsylvania, and 430 have moved to Maryland.

- By state, 335,000 people (57%) live in the Delaware portion of the Christina Basin and 254,000 people (43%) live in Pennsylvania and 2,500 residents live in Maryland.

- By 2010, the population density of the basin edged over 1,000 people per square mile, a threshold that the US Census Bureau defines as an "urban area".

- At a per capita rate of 100 gpcd, the increased population results in an added water demand and wastewater flow of 4.2 million gallons per day.

Land Use

- Christina Basin land use in 2005 is split between 28% urban/suburban, 39% agriculture, and 34% forest/wetland/water.

- The Brandywine has the most rural area with 36% forest and 46% agriculture followed by Red Clay with 33% forest and 39% agriculture and White Clay with 30% forest and 36% agriculture.

- Between 1996 and 2005, the Christina Basin gained 9.6 mi^2 of urban/suburban land and lost 6.7 mi^2 of agriculture and lost 3.1 mi^2 of forest/wetland land.

- Approximately 1 mi^2 per year (2 acres per day or the size of a football field) was converted to urban/suburban. Loss of agriculture over 10 years amounts to 0.7 mi^2 per year or 1 ¼ acres per day. Forest/wetland losses add up to 0.3 mi^2 per year or ½ acre per day.

Water Quality

- Between 1995 and 2010, water quality improved at 65%, remained constant at 20%, and degraded at 15% of the monitoring stations in the Christina Basin. Water quality has mostly improved for DO, TSS, bacteria, and P, however, nitrogen levels have degraded lately.

- Dissolved oxygen levels improved along all four streams since 1995. All DO samples collected during the 15-year period meet the Delaware stream water quality standard (4 mg/l).

- Total suspended sediment levels improved along 3 of the 4 streams with TSS levels constant along the Brandywine Creek since the 1995. Delaware has no TSS standard. Over 95% of TSS samples are below a New Jersey 40 mg/l standard that is used for comparison purposes.

- Enterococcus bacteria levels have improved along all four streams since 1995. Over half the bacteria samples during 15 years continue to violate the Delaware WQ standard (100 #/100 ml).

- Inorganic nitrogen levels degraded along the Brandywine, Red Clay, and Christina River and remained constant along the White Clay. The rise in N levels in the streams may be due to atmospheric deposition of NOX (a concern) and conversion of ammonia to forms of N with rising DO levels (a positive). Inorganic N levels exceeded the Delaware TMDL low target level (0.5 mg/l) at 75% of the samples collected from 1995-2010.

- Orthophosphate improved along the Brandywine and White Clay and remained constant along the Red Clay and Christina River from 1995-2010. Ortho P levels exceeded the Delaware TMDL low target level (0.05 mg/l) at over 60% of the samples over 15 years.

Water Quality vs. Population and Land Use

- Increased population density correlates with decreased dissolved oxygen ($r^2 = 0.36$) and increased total suspended sediment ($r^2 = 0.88$) levels.

- Increased urban/suburban land correlates with decreased dissolved oxygen ($r^2 = 0.40$) and bacteria ($r^2 = 0.33$) and increased sediment ($r^2 = 0.83$) and nitrogen ($r^2 = 0.53$) levels.

- Increased agricultural land correlates with increased dissolved oxygen ($r^2 = 0.41$) and bacteria ($r^2 = 0.34$) and decreased sediment ($r^2 = 0.86$) and nitrogen ($r^2 = 0.58$) levels.

- Increased forest/wetland areas correlate with increased dissolved oxygen ($r^2 = 0.33$) and decreased sediment ($r^2 = 0.68$) levels

Water Temperature

- Maximum water temperatures are constant over the last 15 years and fluctuate from 75 deg F in cooler summers (1996 and 2003) to almost 90 deg F during hot drought years (1999 and 2002.

- Mean annual water temperature have remained unchanged over the last 15 years at approximately 61 deg F.

Streamflow

- Lowest low flows along the Brandywine, Red Clay, White Clay, and Christina occurred during the droughts of 2002, 1999 and 1995 when streamflows declined below the 7Q10 low flow.

- Significant 100-yr floods occurred along Christina Basin streams during Hurricane Floyd in Sep 1999, Tropical Storm Henri in September 2003, and Tropical Storm Jeanne in September 2004.