WATER QUALITY TRENDS ALONG DELAWARE STREAMS FROM 1970 TO 2005

Gerald J. Kauffman, Andrew C. Belden, and Christina L. Callahan[1]

ABSTRACT: Water quality trends from 1970 through 2005 were detected using the Seasonal Kendall test along 30 streams in the State of Delaware. Twenty-four streams flow east to the Delaware Bay and 6 streams flow west towards the Chesapeake Bay. Water quality improved or was constant at 69% of stations since 1990 and at 80% of stations since 1970-1980. Dissolved oxygen improved or was constant at 22 of 30 streams since 1990 and 8 of 25 streams since 1970-1980. Total suspended sediment improved or was constant at 21 of 28 streams since 1990 and 11 of 11 streams since 1970-1980. Enterococcus bacteria improved or was constant at 24 of 30 streams since 1990 and 25 of 27 streams since 1970-1980. Total Kjeldahl nitrogen improved or was constant at 14 of 29 streams since 1990 and 24 of 24 streams since 1970-1980. Total phosphorus improved or was constant at 19 of 29 streams since 1990 and 23 of 27 streams since 1970-1980. Median 2001–2005 levels were fair to good at 100% of DO stations, 75% for TSS, 48% for bacteria, 60% for TKN, and 43% for phosphorus. Water quality improves with increased forest area in Delaware watersheds. Since the Federal Clean Water Act Amendments of the 1970s, improving water quality stations (50) outnumbered degrading stations (23) along Delaware streams by a 2:1 margin. Since 1990, degrading water quality stations (46) exceeded improving water quality stations (38) indicating a slight reversal from the early gains achieved since the implementation of the 1970s Clean Water Act amendments.

KEY TERMS: surface water quality, watershed, water management

(1) Respectively, Director, Graduate Research Assistant, and GIS Scientist. University of Delaware - Water Resources Agency, DGS Annex Building, Academy Street, Newark, DE 19716. 302-831-4929, E-Mail/Kauffman: jerryk@udel.edu.

INTRODUCTION

The year 1970 was a watershed in the environmental movement as Americans observed the first Earth Day and Richard M. Nixon signed a bill creating the U. S. Environmental Protection Agency to protect the nation's water, air, and land resources (Cech 2003). The President and Congress later passed the Federal Water Pollution Control Act Amendments of 1972 and 1977, known as the Clean Water Act. The CWA set limits on pollutant discharges, funded sewage treatment plants, and set goals for fishable and swimmable waters by 1985. In the 1987 Water Quality Act, the CWA was amended to control nonpoint source pollutants from urban runoff. In the early 1990s, the USEPA began working with the states to adopt a watershed approach to control pollutants. By 2000, the USEPA issued regulations requiring states to list impaired waters and implement watershed - based Total Maximum Daily Loads (TMDL) to restrict pollutant loads entering streams (USEPA 2007).

Concurrent with Federal actions, states in the USA such as Delaware created environmental agencies such as the Department of Natural Resources and Environmental Control (DNREC) in 1970. Delaware adopted water pollution control regulations in 1974. The State passed surface water quality standards in 1999 and amended them in 2004 (DNREC 2006)

Water quality trends can detect if deterioration is occurring, evaluate the effectiveness of corrective actions, and determine if watershed programs have been successful in meeting standards set by state and federal governments (Berryman *et al.* 1988). Long-term trends since 1970 - 1980 can measure progress in restoring streams to meet fishable and swimmable goals set by the 1972 Federal Clean Water Act and amendments in 1977. Short-term trends since 1990 can measure progress toward meeting Total Maximum Daily Loads (TMDLs) in accordance with Section 303(d) of the 1987 Water Quality Act

The University of Delaware evaluated surface water quality trends along Delaware streams to determine if watershed management programs have been successful in removing and/or halting water pollution. This article examines stream monitoring data to determine whether water quality trends have improved, remained constant, or degraded in the State of Delaware between 1970 and 2005. Water quality trends were detected using the nonparametric Seasonal Kendall test for statistical significance supplemented by visual examination of time series scatterplots and boxplots illustrating the 25^{th}, 50^{th} (median), and 75^{th} percentiles of the sample.

The State of Delaware lies midway between New York City and Washington, D. C. along the Atlantic Seaboard of the USA. Approximately 60% of Delaware's watersheds flow east in the Delaware River Basin and 40% of the State's watersheds flow west in the Chesapeake Bay Basin. About 3% of the State is in the hilly Piedmont Plateau province in northern Delaware and 97% of the State is in flat, sandy Coastal Plain province.

LITERATURE REVIEW

The following studies report on changing water quality trends throughout the United States since 1970/1980. Table 1 summarizes water quality trends and statistical trend methods. Many water quality trend studies utilized the nonparametric Seasonal Kendall test for statistical significance if probability (p) ≤ 0.05 or 0.10.

The United States Geological Survey and Johns Hopkins University evaluated water quality trends at over 300 waterways in the USA from 1974 to 1981 using the nonparametric Seasonal Kendall test which defined the median slope change and statistical significance if probability $p \leq 0.1$ (Smith, Alexander, and Wolman 1987). Nitrate nitrogen levels increased at 30% and decreased at 7% of the stations. Total phosphorus levels increased at 11% and decreased at 13% of the stations. Total suspended sediment increased at 15% and decreased at 14% of the stations. Dissolved oxygen improved at 17% and degraded at 11% of the stations.

Turner and Rablais (1991) found that mean annual concentrations of nitrate nitrogen doubled in the lower Mississippi River between 1965 and 1990. Long term water quality trends from 1970 to 1991 in the Pamlico River Estuary in North Carolina indicate that nitrate nitrogen decreased in the upper/middle estuary by 3 – 6% per year and ammonia decreased at a rate of 5.5-7.7% per year (Stanley 1993). The nonparametric Seasonal Kendall test was used to detect monotonic trends as it is suitable for water quality data that are skewed, serially correlated, and impacted by seasonality. However, since it defines a linear slope direction, the Seasonal Kendall test cannot detect reversals of direction over the time period.

Hainly and Loper (1997) assessed water quality change in the Lower Susquehanna River Basin in Pennsylvania and Maryland from 1975 to 1990. Water quality trends were evaluated using graphical techniques such as boxplots, and scatterplot smoothing (LOWESS) curves and the Kruskal-Wallis test. Nitrate concentrations in streams increased slightly from 1980 to 1985 and decreased slightly from 1985 to 1989. Concentrations of nutrients and suspended sediment were elevated in agricultural drainage areas.

Stream water quality trends were evaluated using the Seasonal Kendall tau rank correlation test at 191 monitoring stations in Virginia from the 1960s to 1997 (Zipper *et al.* 1998). Total phosphorus improvements outnumbered deterioration by a ratio exceeding 3:1. For nitrate nitrogen and TKN, deteriorating water quality trends outnumbered improving trends.

Boyer, Fourqurean, and Jones (1999) summarized water quality trends in the Florida Bay between 1989 and 1997 using 4 methods: (1) monthly box and whisker plots, (2) the nonparametric Kruskal-Wallis test grouped by month, (3) a centered 12 month moving average, and (4) the Seasonal Kendall analysis for monotonic trend where statistical significance of trend was set to $p \leq 0.1$. According to the Seasonal Kendall test, total phosphorus decreased in the Eastern, Central, and Western Bays; and nitrogen increased in the Central Bay.

A USGS analysis of fecal coliform along the Brandywine Creek in Pennsylvania indicated annual median bacteria levels declined from 1973 to 1999 (Town 2001). Bacteria increased with increased streamflow. The Kruskal-Wallis test at 95% confidence level showed no statistically significant differences between fecal coliform concentrations in agricultural, forested, and residential subbasins. Bacteria concentrations in the Brandywine Creek were lower in the spring and fall than during the summer.

Heidelberg College scientists conducted a study of water quality trends from 1975 to 1995 using the LOWESS smoothing technique statistically significant to $p \leq 0.05$ along four northwest Ohio rivers tributary to Lake Erie (Richards and Baker 2002). All four rivers recorded decreased phosphorus and Kjehdahl nitrogen levels. Three of the 4 rivers had decreased total suspended solids concentrations.

The USGS used the Mann-Kendall test to assess nitrate nitrogen and phosphorus trends along streams in Chester County, Pennsylvania from 1981 to 1997 (Reif 2002). Nitrate levels increased at 16 of 43 sites, decreased at 3 sites, and no significant trends were observed at 24 sites. Phosphorus levels decreased at 13 of 43 sites, increased at 1 site, and had no significant trend at 29 sites.

Water quality sampling at 33 sites in the nontidal Chesapeake Bay Basin from 1985 to 2003 indicate nitrogen, phosphorus, and sediment decreased at 55%, 75%, and 48% of the sites, respectively (Langland, Phillips, Raffensberger, and Moyer 2004).

The Maryland Department of Natural Resources (2004) reported on water quality trends along the upper Eastern Shore of the Chesapeake Bay from 1985 to 2003. Long term trends were determined as significant provided the probability (p) ≤ 0.1 according to the Seasonal Kendall procedure using the monthly median. Total nitrogen concentrations improved at 1 station, and remained unchanged at 7 stations. Total phosphorus concentrations improved at 2 stations and remained unchanged at 6 stations. Total suspended solids improved at 3 stations and remained unchanged at 5 stations.

The New Jersey Department of Environmental Protection (2004) conducted a trend analysis along 36 New Jersey streams from 1985 to 2004 using the Seasonal Kendall Test with $p \leq 0.05$. Dissolved oxygen levels improved at 18% and remained stable at 80% of the stations. Total nitrogen improved at 63%, remained stable at 32%, and declined at 5% of the sites. Total phosphorus improved at 45% and remained stable at 55 % of the stations.

The Pennsylvania Department of Environmental Protection (2005) evaluated surface water quality trends in the Commonwealth between 1995 and 2005 using the nonparametric Seasonal Kendall test for trend ($p \leq 0.05$) where each month was treated as a separate season. Along Pennsylvania streams in the Delaware River Basin, 5 nitrogen stations had improving trends, 27 had no change, and 4 stations had degrading trends. For total phosphorus, 12 stations had improving trends, 24 stations had no change, and no stations had degrading trends.

In the St. Johns River Water Management District in Florida, samples from 192 stream monitoring stations between 1990 and 2004 found 19% had improving water quality trends, 72% were stable, and 8% were degrading (Winkler and Ceric 2006). Statistically significant trends were identified as improving or degrading if $p \leq 0.10$ using the nonparametric Mann-Kendall and Seasonal Kendall tests. Total nitrogen decreased at 29, increased at 16, and were stable at 109 sites. Total phosphorus decreased at 35, increased at 27, and were stable at 91 sites.

METHODS

Water quality trends were evaluated along Delaware streams according to the following methods:

- Map land use and impervious cover in Delaware watersheds.
- Select water quality monitoring stations with dissolved oxygen (DO), total suspended solids (TSS), enterococcus bacteria (EB), total Kjeldahl nitrogen (TKN), and total phosphorus (TP) data back to 1970.
- Prepare scatterplots of the time series water quality data and boxplots of the data at 5-year intervals.
- Conduct Seasonal Kendall tests of the water quality data and identify statistically significant water quality trends as improved, constant, or degraded according to direction of slope and if probability $(p) \leq 0.10$.
- Examine scatterplots and box plots to detect water quality trends to supplement Seasonal Kendall tests.
- Compare median concentrations (2001-2005) to criteria and quantify water quality as good, fair, or poor.
- Discuss water quality trends based on land use, drainage basin, seasonality, and pollution loads.

The State of Delaware 2002 GIS orthophoto quarter quadrangle coverage (updated to 2007) provided land use in each watershed. Land use was grouped into four categories: developed (urban/suburban), cultivated (farms/agriculture), forests, and water/wetlands. The type of land use in a watershed can impact water quality. For instance, highly developed and highly cultivated watersheds tend to exhibit lesser water quality than mostly forested watersheds. Watershed impervious cover was estimated using GIS and by multiplying the area of each land use by an impervious cover factor, summing the products, and dividing by total area of the watershed

Thirty Delaware stream monitoring stations were identified with water quality data collected by the Delaware DNREC Watershed Assessment Branch (Figure 1). Favorable monitoring stations include data that span the period of analysis, with no more than 2 years of missing data at the beginning and end of the time period, and at least ½ of the data must be present in the first and last thirds of the record (Lanfear and Alexander 1990). Stream monitoring stations were selected to minimize tidal backwater influences yet be far enough downstream to characterize water quality from most of the watershed. Twenty four (24) streams flow east to the Delaware River and Bay while 6 streams flow west to the Chesapeake Bay. Stream monitoring stations are distributed in each of Delaware's four drainage basins: Piedmont (6 stations), Delaware Estuary (14), Inland Bays (4), and Chesapeake Bay (6). Six stations drain watersheds in the hilly, rocky Piedmont physiographic province in the north and 24 are in the flat, sandy Coastal Plain province to the south.

Candidate water quality monitoring stations had at least 4 sampling points per year from 1970 – 2005 for dissolved oxygen (DO), total suspended sediment (TSS), enterococcus bacteria (EB), total Kjeldahl nitrogen (TKN), and total phosphorus (TP). The USEPA and DNREC have identified these priority parameters to establish TMDLs in Delaware streams. Sufficient DO is necessary to sustain aquatic life and is the basis for fishable water quality standards. High TSS concentrations smother fish habitat, block sunlight causing water plants to die, decrease DO levels, and increase water temperature. High bacteria levels are caused by sewage or animal waste and cause health problems if ingested during swimming or contact with polluted waters. Elevated nitrogen levels cause eutrophication and algae blooms in streams resulting in depleted oxygen levels and high turbidity. TP is needed for plant metabolism, however, in high amounts it is a limiting factor in algae blooms, eutrophication, and fish kills.

TABLE 1. Water quality trend analyses in watersheds throughout the USA.

Period	Author(s)	Watershed	Method	Summary of Trends
1974 - 1981	Smith, Alexander, and Wolman 1987.	USA	Seasonal Kendall	N: increased at 30%, decreased at 7% of stations. P: increased at 11%, decreased at 13% of stations, DO: improved at 17%, degraded at 11% of stations.
1965-1990	Turner and Rablais 1991.	Lower Mississippi R.	Mean annual concentration	Nitrate nitrogen doubled in the lower Mississippi River.
1970-1991	Stanley 1993.	Pamlico Estuary, NC	Seasonal Kendall	Nitrate N decreased in the upper/middle estuary 3 – 6% per year. Ammonia decreased at 5.5-7.7% per year
1975-1990	Hainly and Loper 1997.	Susquehanna, PA and MD	LOWESS, Kruskal-Wallis	Nitrate N increased 1980 to 1985 and decreased from 1985 to 1989.
1960s - 1997	Zipper *et al.* 1998	Virginia	Seasonal Kendall	Phosphorus improvements outnumbered deterioration by 3:1 ratio. Nitrate N and TKN, deteriorating trends outnumbered improving trends.
1989 - 1997	Boyer, Fourqurean, Jones 1999	Florida Bay	Seasonall Kendall	Total P decreased in the Eastern, Central, and Western Bays; and nitrogen increased in the Central Bay.
1973-1999	Town 2001	Brandywine Creek, PA	Kruskal-Wallis	No statistically significant differences between fecal coliform concentrations in agricultural, forested, and residential subbasins.
1975-1995	Richards and Baker 2002	NW Ohio Rivers	LOWESS smoothing	Four rivers had decreased phosphorus and Kjehdahl nitrogen levels. Three of the 4 rivers had decreased total suspended solids concentrations
1981-1997	Reif 2002	Chester County PA	Mann-Kendall	Nitrate increased at 16 of 43 sites, decreased at 3 sites, no trends at 24 sites. P decreased at 13 of 43 sites, increased 1 site, no trend at 29 sites.
1985 - 2003	Langland et. al 2004	Chesapeake Bay, MD		Sampling at 33 sites indicate total nitrogen, total phosphorus and sediment decreased at 55%, 75%, and 48% of the sites, respectively
1985 - 2003	MDDNR 2004	Eastern Shore Chesapeake Bay	Seasonal Kendall	N improved at 1 and unchanged at 7 station(s). P improved at 2 and unchanged at 6 stations. TSS improved at 3 and unchanged at 5 stations.
1985 - 2004	NJDEP 2004	NJ watersheds	Seasonal Kendall	DO improved at 18% and stable at 80% of stations. Total N improved at 63%, stable at 32%, declined at 5% of the stations. Total P improved at 45% and remained stable at 55 % of the stations.
1995 - 2005	PADEP 2005	Delaware River Basin in PA	Seasonal Kendall	For total N, 5 stations had improving trends, 27 had no change, and 4 had degrading trends. For total P, 12 stations had improving trends, 24 stations had no change, and no stations had degrading trends.
1990 - 2004	Winkler and Ceric 2006	St. Johns Water Management District, FL.	Mann-Kendall, Seasonal Kendall	Total N decreased at 29, increased at 16, and were stable at 109 sites. Total P decreased at 35, increased at 27, and were stable at 91 sites. TSS decreased at 33, increased at 18, and were stable at 100 sites.

Water quality data were depicted on time series scatterplots with concentration on the vertical axis and time on the horizontal axis. Scatterplots illustrate basic statistical parameters such as the sample, maximum/minimum, range, and variance. Two dimensional scatterplots of the sample illustrate the relationship between water quality concentration and time period and show the original characteristics of the data (Helsel and Hirsch 2002). Because the human eye has difficulty in judging the center of the scatterplot pattern, boxplots illustrate the median (50^{th} percentile) as a measure of central tendency and the 25^{th} and 75^{th} percentile to illustrate the range and skewness of the water quality data. The median, instead of the mean, is preferable when water quality concentrations are analyzed because the median is resistant to and minimally affected by outliers.

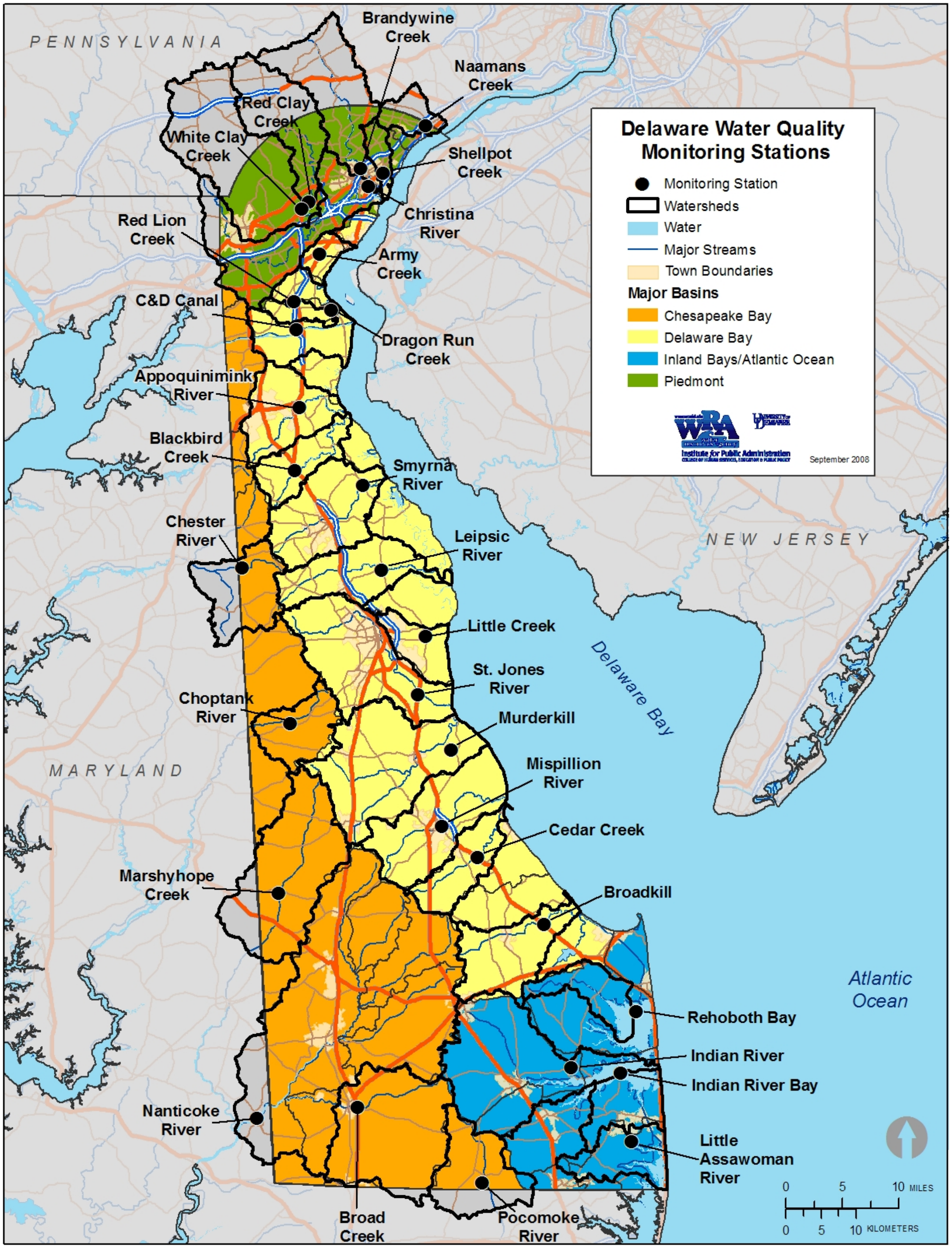


FIGURE 1. Stream water quality monitoring stations in Delaware.

Water quality trends along Delaware streams were detected using the nonparametric Seasonal Kendall test for statistical significance if the probability (p) ≤ 0.1 as outlined in Hirsch, Slack, and Smith (1982) and Helsel and Hirsch (2002). Water quality trends determine if values increase or decrease (get better or worse) over time. This non-parametric test was chosen as data collection was semi-uniform for each sampling site over the period of record. The Kendall.exe computer program developed by the USGS was used to perform the Seasonal Kendall test for quality trend (Helsel, Mueller, and Slack 2005). The program lists the correlation coefficient Kendall's tau, the slope and intercept of the Kendall's trend line, and the p-value for significance of trend. Data for each station were divided into 4 seasonal periods of 3 months each. Monotonic trends were calculated for each parameter at each site over the long term from 1970 – 1980 through 2005 and short term from 1990through 2005. Trends with p values of 0.10 or less were considered statistically significant. The direction of trend was detected by the slope of the Seasonal Kendall test line. A positive (+) slope indicated an improving trend for DO and a degrading trend for the other parameters. A negative (-) slope indicates a degrading trend for DO and improving trends for the other parameters. Appendix A summarizes the results of the Seasonal Kendall test for water quality trend. Appendix B illustrates water quality scatterplots and boxplots for each monitoring station along Delaware streams. The Seasonal Kendall test for water quality trend was selected for the following reasons:

This monotonic test for trend is appropriate as water quality data is usually skewed and not normally distributed, adjusts for seasonality, and can analyze missing data sets (Cude 2001). The Seaonal Kendall test divides data into quarterly seasons and determines the direction and statistical significance (p) of trends by using a slope estimator defined by the median of paired observations in the seasons.

Most concentrations in surface waters show strong seasonal patterns. The Seasonal Kendall test reduces the effect that seasonal differences in concentration may have on water quality trends (Hirsch, Slack, and Smith 1982).

Water quality data for suspended sediment, nutrients, and bacteria are asymmetrically distributed, therefore, nonparametric tests for trend such as the Seasonal Kendall test are preferred (Schertz, Alexander, and Ohe 1991).

Water quality trend analysis presents many challenges such as highly skewed distributions, outliers, seasonal differences, non detectable values due to laboratory limitations (Lettenmaier 1988). These problems can be addressed by using a nonparametric Seasonal Kendal test which works well for small sample sizes. However, over a time period, trends in different directions may cancel out giving the appearance of no statistical trend.

Berryman, Bobee, Cluis, and Haemmerli (1988) concluded that the Kendall test is among the best choices for nonparametric tests to detect water quality trends.

Hirsch, Slack, and Smith (1982) presented the nonparametric Seasonal Kendall test as suitable to define monotonic water quality trends. They wrote this technique is not a substitute for visual examination of the time series plots. However, if seasonality and skewness is present, visual examination of data may be different from trends derived by a statistical procedure such as the Seasonal Kendall test.

Since the monotonic Seasonal Kendall analysis is limited in detecting reversals in trends over the time period, the trend analysis was supplemented with visual examination of time series scatterplots and boxplots depicting the 25^{th} percentile (bottom of the box) 50^{th} percentile median (line though the middle of the box), and 75^{th} percentile (top of the box) at 5 year periods. Visual analyses using scatterplots and boxplots can detecting trends where water quality change is not monotonic, that is, where water quality may degrade over the first few years of record, reverses, and then improves over the latter years of record (the banana curve). We also evaluated for seasonality by plotting boxplots of the data by month. Figures 2 through 6 depict scatterplots and boxplots that illustrate improved water quality trends for Rehoboth Bay (DO), Christina River (TSS), St. Jones River (TKN), and Brandywine Creek (TP).

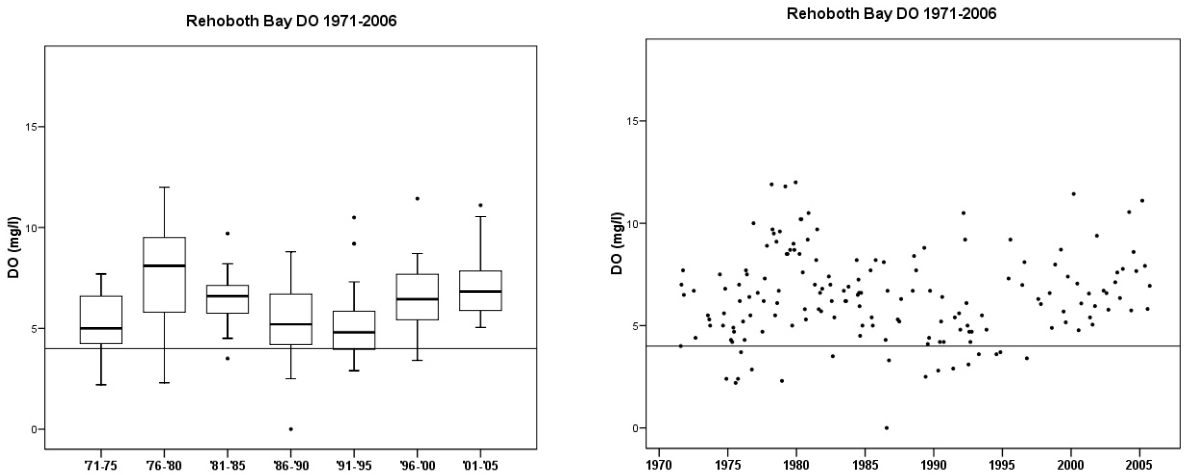


FIGURE 2. Dissolved oxygen boxplot and scatterplot in the Rehoboth Bay.

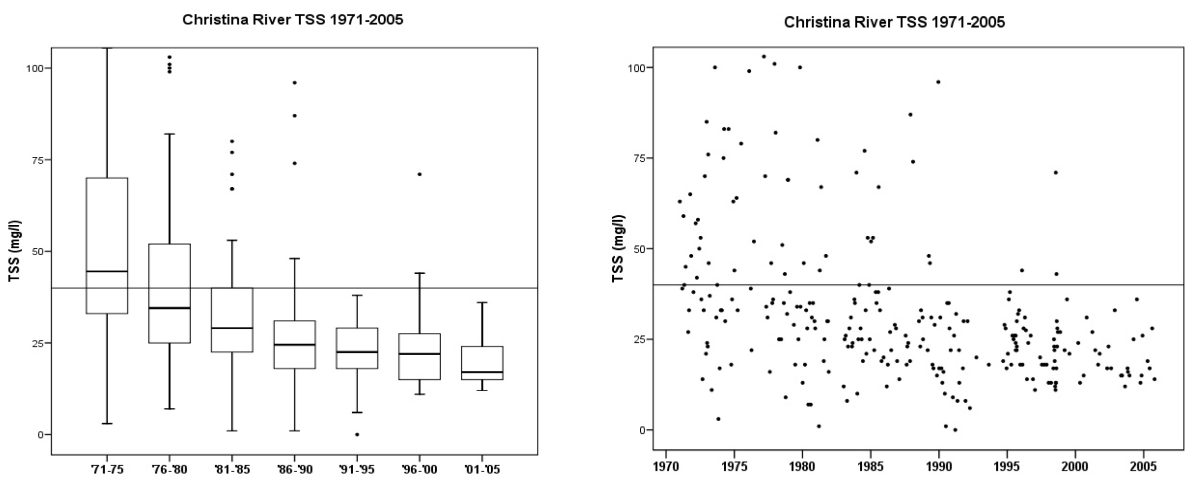


FIGURE 3. Total suspended sediment boxplot and scatterplot in the Christina River.

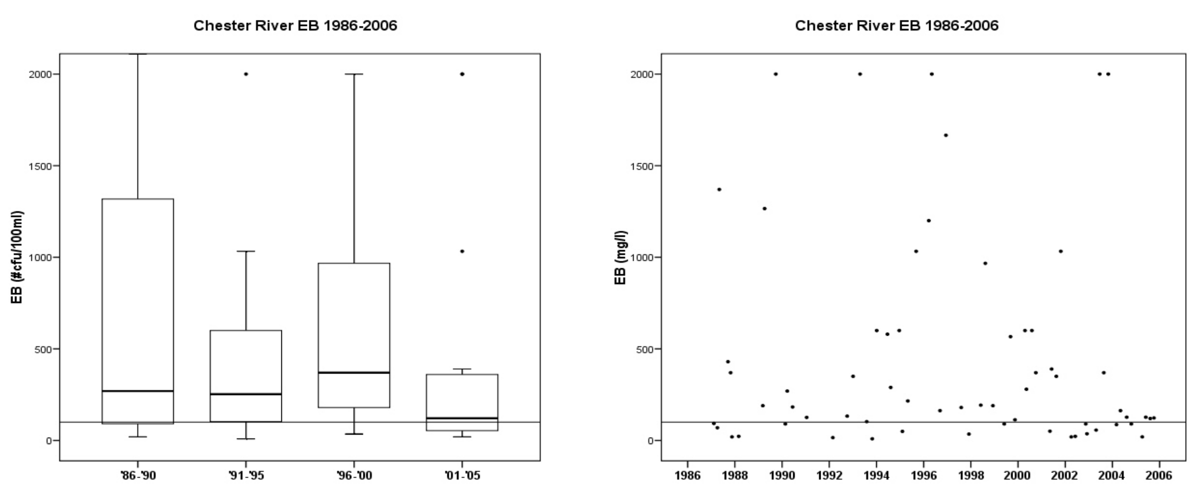


FIGURE 4. Enteroccocus bacteria boxplot and scatterplot in the Chester River.

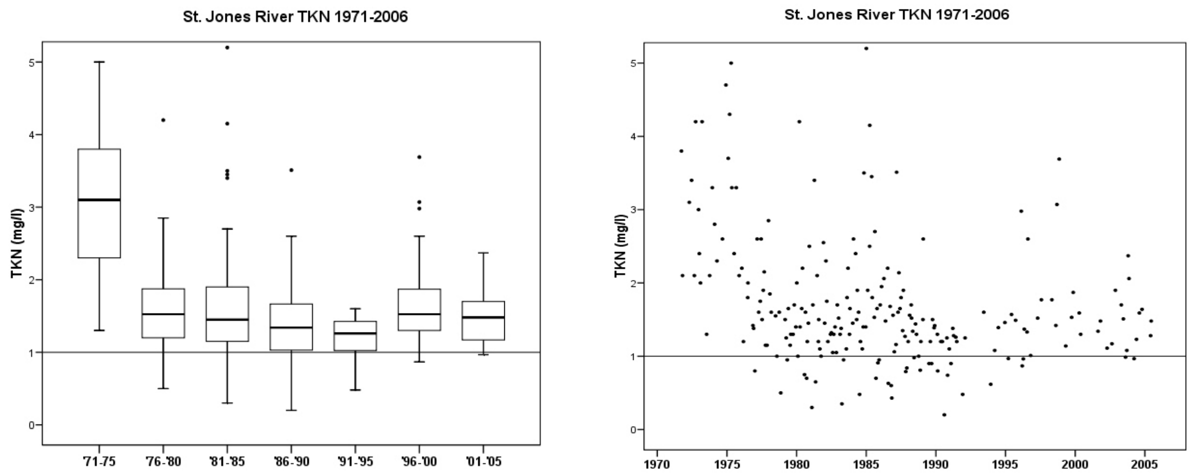


FIGURE 5. Total Kjehdahl nitrogen boxplot and scatterplot in the St.Jones River.

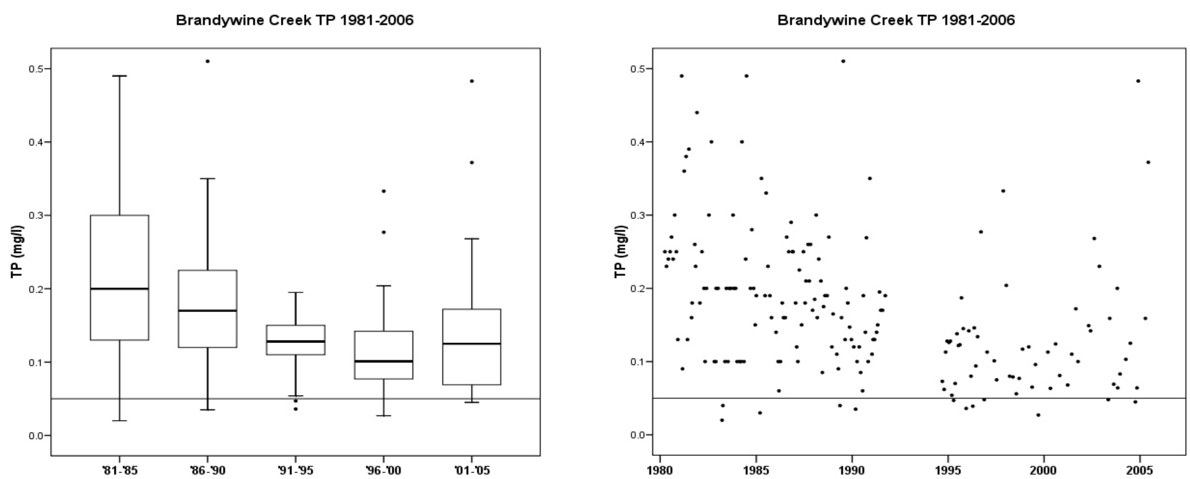


FIGURE 6. Total phosphorus boxplot and scatterplot along the Brandywine Creek .

Median water quality data was compared to Delaware surface water criteria to assess stream health. The Delaware DO standard is 4 mg/l for warm water streams and 5 mg/l for cold water put and take trout streams (Table 2). Delaware does not have a TSS standard. Therefore, neighboring New Jersey TSS standards of 25 mg/l for cold water and 40 mg/l for warm water streams are included for comparison (NJDEP 2006). The Delaware enterococcus bacteria standard is 100 colonies per ml or a geometric mean of 80 colonies per 100 ml. Delaware does not have a TKN standard, therefore, the total nitrogen target of 1.0 mg/l was included for comparison recognizing that TKN levels in streams are usually about half of total N levels. DNREC defines TP concentrations below 0.05 mg/l as low and this target level was included for comparison (DNREC 2004, 2007)

TABLE 2. Surface water quality criteria in Delaware.

Parameter	Criteria (mg/l)
Dissolved Oxygen	4.0 warm water 5.0 cold water
Total Suspended Sediment (NJ default)	25 non-trout 40 trout
Enterococcus Bacteria	100 #/ml
Total Nitrogen	< 1.0 low 1.0–3.0 med > 3.0 high
Total Phosphorus	< 0.05 low 0.05–0.10 med > 0.1 high

Water quality along Delaware streams was defined as good, fair, or poor by comparing the 2001 – 2005 median to criteria summarized in Table 3. Good water quality indicates the 5-year median for 2001-2005 exceeds water quality criteria by 50% or more. Fair water quality indicates the median is just above the criteria. Poor water quality indicates the 2001–2005 median is below criteria and does not meet the water quality standards.

TABLE 3. Water quality ladder for Delaware streams.

Water Quality	Description	DO (mg/l)	TSS (mg/l)	E. Bacteria (#/100 ml)	TKN (mg/l)	TP (mg/l)
Good	Comfortably exceeds water quality standards	> 6.0	< 25	< 50	< 0.5	< 0.05
Fair	Just above water quality standards	4.0–6.0	25-40	50-100	0.5–1.0	0.05–0.10
Poor	Below stream water quality standards	< 4.0	> 40	> 100	> 1.0	> 0.10

RESULTS

Land use varies from more than 50% developed (urban/suburban) in four watersheds in the urbanized Piedmont basin near Wilmington, Delaware to less than 20% developed along the rural coastal streams in the Delaware Bay, Inland Bays, and Chesapeake Bay basins (Figure 7). Delaware watersheds are impacted by human activity as developed plus cultivated land exceeds 50% in all but a few watersheds (Table 4 and Figure 8). Watersheds such as the Chester, Pocomoke, Leipsic, Blackbird, Rehoboth Bay, and Indian River Bay retain nearly 50% natural coverage (forest plus wetland/water). Impervious cover ranges from 14% to 40% in the Piedmont basin watersheds in urban northern Delaware and less than 10% in lightly developed Delaware Bay, Chesapeake Bay, and Inland Bay watersheds such as the Broadkill, Pocomoke, Marshyhope, and Nanticoke in rural southern Delaware.

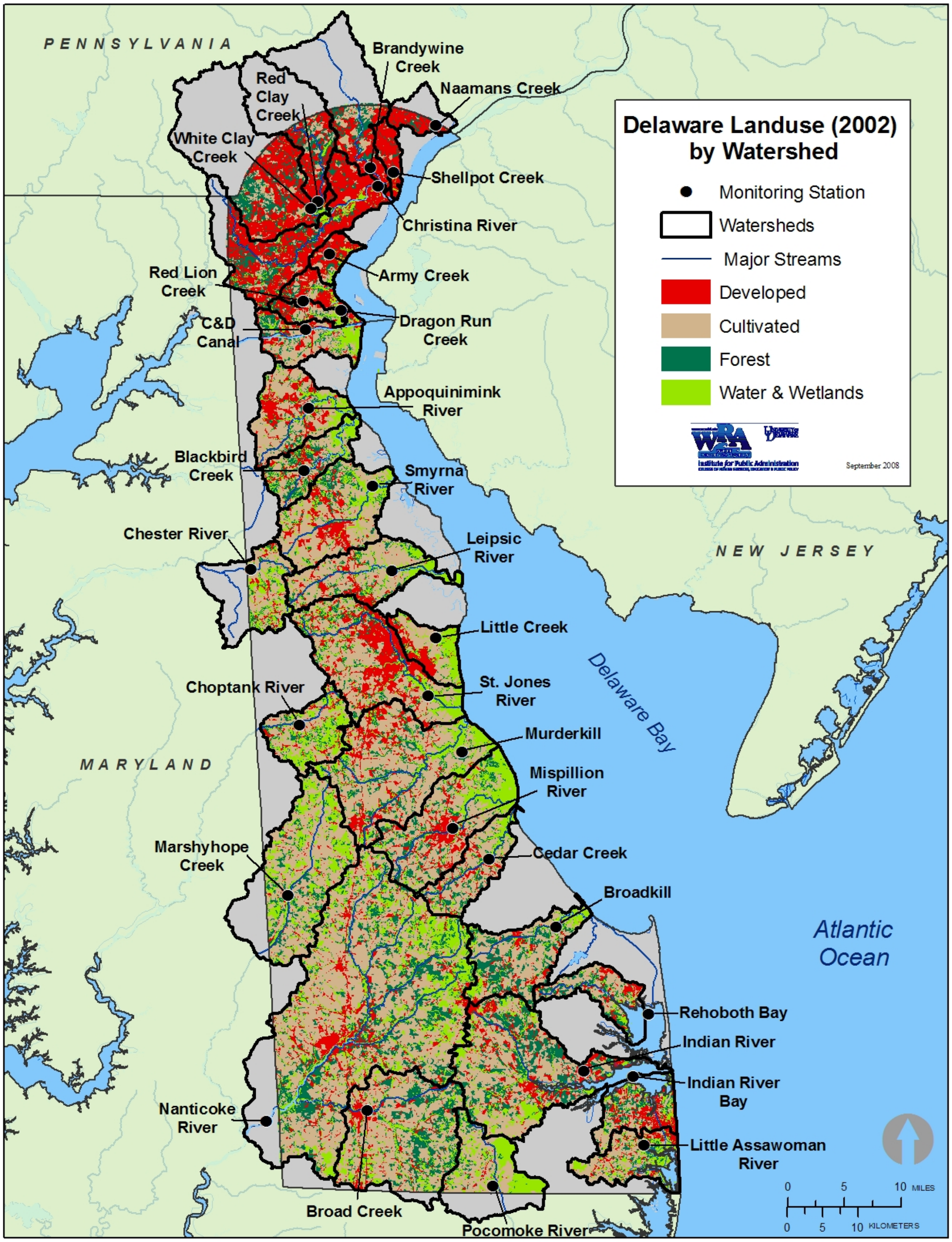


FIGURE 7. Land use in Delaware watersheds.

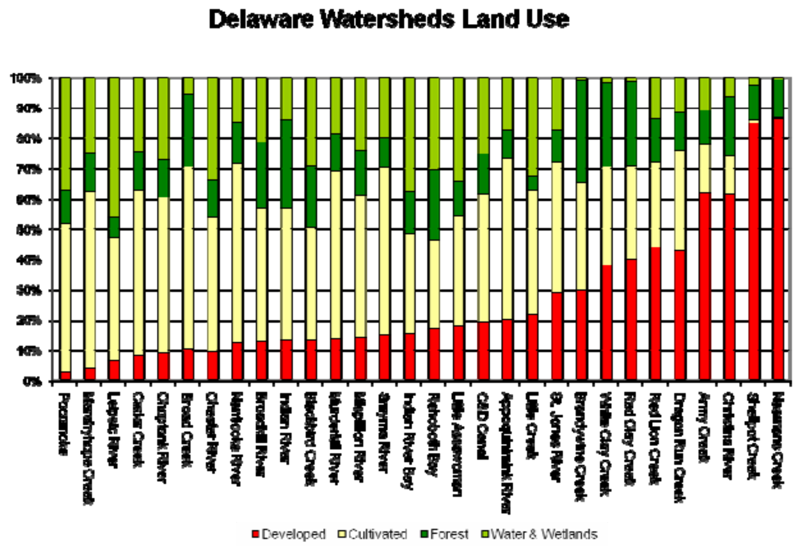


FIGURE 8. Land use area in Delaware watersheds.

TABLE 4. Land use and impervious cover in Delaware watersheds.

Watershed (DNREC Station No.)	D.A. (km^2)	Impervious (%)	Developed (%)	Cultivated (%)	Forest (%)	Wetland (%)
Piedmont Basin						
Naamans Creek at Naamans Rd (101021)	26	39	86	1	12	1
Shellpot Creek at Rte 13 (102011)	36	44	85	1	11	3
Brandywine Creek at Footbridge (104011)	835	14	30	35	33	1
White Clay Creek at Stanton (105011)	274	18	38	32	28	2
Red Clay Creek at Stanton (103011)	138	17	40	31	28	1
Christina River at Rte 13 (106011)	200	40	61	13	19	6
Delaware Estuary Basin						
Army Creek at Rte 13 (114021)	26	38	57	15	10	10
Red Lion Creek at Rte 7 (107011)	28	24	42	27	13	13
Dragon Run Creek at Rte 9 (111011)	26	23	42	32	13	11
C & D Canal at St Georges Br. (108021)	113	11	19	42	13	25
Appoquinimink River at Odessa (109051)	118	12	20	52	9	17
Blackbird Creek at Rte 13 (110021)	79	7	13	37	20	29
Smyrna River at Rte 9 (201041)	164	10	15	55	10	20
Leipsic River at Rte 9 (202031)	269	5	6	41	7	46
Little Creek at Rte 9 (204031)	59	18	22	41	4	33
St. Jones River at Barkers Ldg. (205041)	230	16	28	42	10	17
Murderkill River 3 mi from mouth 206141	274	8	13	55	12	18
Mispillion River at Rte 1 (208021)	195	9	14	47	15	24
Broadkill River at Rd 246 (303011)	274	8	13	44	22	21
Inland Bays Basin						
Rehoboth Bay at Buoy 3 (306071)	184	9	17	29	23	30
Indian River Inlet (306321)	220	9	13	43	29	14
Indian River Bay Buoy 20 (306121)	220	9	15	33	14	37
Little Assawoman at Rd 363 (310101)	95	10	18	36	11	34
Chesapeake Bay Basin						
Chester River at Sewell Br. Rd (112021)	102	5	9	44	12	34
Choptank River at Rd 208 (207021)	248	6	9	51	12	27
Marshyhope Creek (302011)	246	4	4	58	13	25
Broad Creek at Records Pond (307011)	307	6	9	54	22	5
Nanticoke River at MD Rte 313 (304011)	369	8	12	59	13	15
Pocomoke at Rd 419 (313011)	90	3	3	49	11	37

Water quality along Delaware streams improved or was constant at 69% of the stations over the short term since 1990 and 80% of the stations over the long term since 1970 – 1980 (Table 5). Since 1990, water quality improved at 38 of 146 or 26% of the stations, remained constant at 62 of 146 or 43% of the stations, and degraded at 46 of 146 or 31% of the stations. Since 1970 – 1980, water quality improved at 50 of 114 or 44% of the stations, remained constant at 41 of 114 or 36% of the stations, and degraded at 23 of 114 or 20% of the stations. (Table 6).

Since 1990; dissolved oxygen improved at 16 of 30 streams, was constant at 6, and degraded at 8 streams. Total suspended sediment improved at 9 of 28 stations, was constant at 12, and degraded at 7 streams. Enterococcus bacteria improved at 3 of 30 streams, was constant at 21, and degraded at 6 streams. Total Kjeldahl nitrogen improved at 2 of 29, was constant at 12, and degraded at 13 streams. Total phosphorus improved at 8 of 29, was constant at 11, and degraded at 10 of 29 streams.

In the northern Delaware Piedmont Basin near Wilmington, water quality improved or remained constant at 21 of 30 stations over the last 15 years with 9 of 30 stations recording degrading trends (Figure 9). Five stations recorded deteriorating trends for sediment and 3 stations has degrading TKN trends.

In the Coastal Plain watersheds draining to the the Delaware Estuary, 47 of 69 stations recorded improving or constant trends. Most of the degrading trends were recorded for TKN. Streams recording two or more parameters with worsening trends include urban watersheds with more than 40% developed land such as Army Creek (DO, bacteria, TKN, and TP) and Dragon Run Creek (DO, TKN, and TP) and rural, yet suburbanizing watersheds with over 30% cultivated land such as Leipsic River (TSS, TKN, and TP), and Mispillion (TSS and TKN).

In the Inland Bays, water quality improved or remained constant at 16 of 20 or 80% of the stations. Degrading levels of TKN and TP were observed in the Rehoboth Bay. Little Assowoman Bay had degrading trends for DO, and TKN.

In the Chesapeake Bay Basin, 16 of 27 of the stations recorded improving or constant trends and 11 of the stations recorded degrading trends. Most of the degrading trends were observed for TKN and TP.

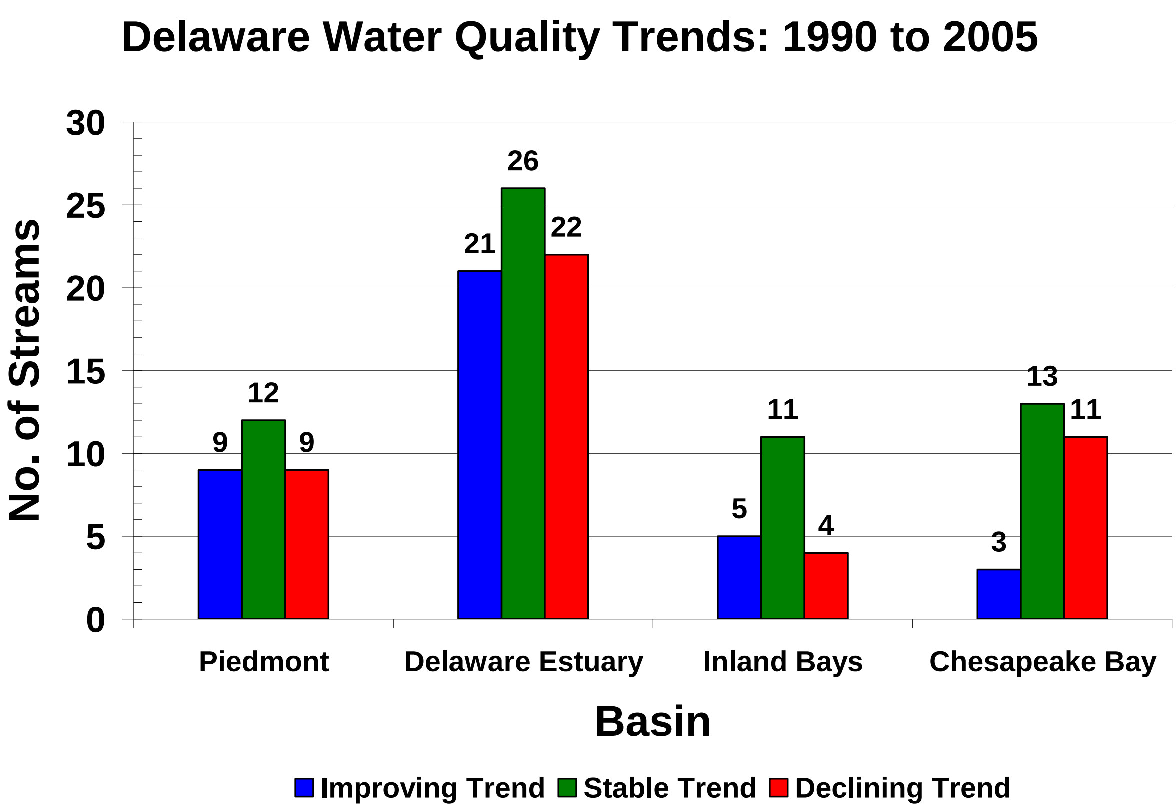


FIGURE 9. Short term water quality trends along Delaware streams from 1990 to 2005.

Since 1970 to 1980; DO improved at 4 of 25 streams, was constant at 4, and degraded at 17 of 25 streams. TSS improved at 11 of 11 monitored streams. Bacteria improved at 5 of 27 streams, was constant at 20, and degraded at 2 streams. TKN improved at 21 of 24 and was constant at 3 streams. Total P improved at 9 of 27, was constant at 14, and degraded at 4 streams.

In the Piedmont Basin since 1970 -1980, 24 of 29 or 80% of the streams recorded improving or constant trends in water quality (Figure 10). Five of the streams recorded degrading water quality trends for DO.

In the Delaware Bay Basin, 42 of 66 7 or 67% of the stations recorded improving or constant water quality trends. Nine stations recorded degrading trends for DO since 1970- 1980 particularly in the urban watersheds of Red Lion Creek and Dragon Run and in the agricultural coastal plain watersheds from the Appoquinimink in southern New Castle County down to the St. Jones River in Kent County.

In the Inland Bays, all stations recorded improved or constant water quality since 1970 – 1980.

In the Chesapeake Bay basin since 1970 – 1980, only 4 of 19 stations (18%) recorded degrading water quality. The Choptank (DO), Marshyhope, (DO), Nanticoke (DO), and Pocomoke (bacteria) showed degrading trends.

Figure 11 and Figure 12 illustrate short term (1990 – 2005) and long term (1970/1980 – 2005) water quality trends along Delaware streams.

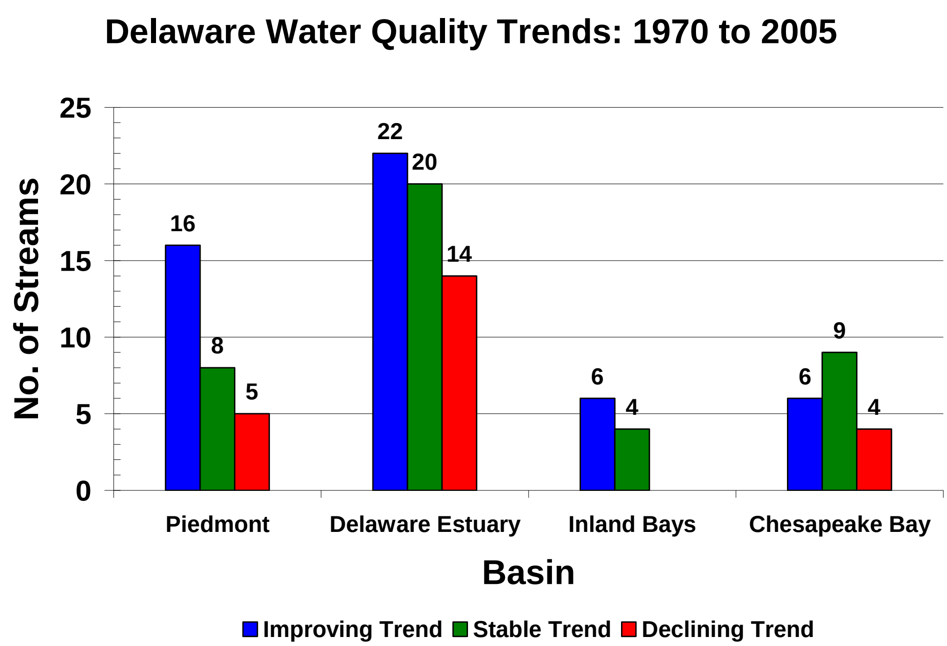


FIGURE 10. Long term water quality trends along Delaware streams from 1970/1980 to 2005.

TABLE 5. Number of streams recording improved, constant, or degraded water quality trends in Delaware.

Water Quality Trend	DO	TSS	E. Bacteria	TKN	TP	Total
Short Term since 1990						
Improved	16	9	3	2	8	38 (26%)
Constant	6	12	21	12	11	62 (42%)
Degraded	8	7	6	15	10	46 (31%)
	30	28	30	29	29	146
Long Term since 1970-1980						
Improved	4	11	5	21	9	50 (44%)
Constant	4	0	20	3	14	41 (36%)
Degraded	17	0	2	0	4	23 (20%
	25	11	27	24	27	114

TABLE 6. Short term and long term water quality trends along Delaware streams.

Stream	Long term water quality trends since 1970/1980										Short term water quality trends since 1990									
	DO (mg/L)		TSS (mg/L)		Bacteria (#/100ml)		TKN (mg/L)		Total P (mg/L)		DO (mg/L)		TSS (mg/L)		Bacteria (#/100ml)		TKN (mg/L)		Total P (mg/L)	
Naamans Cr	8.7	▼*	5	–	380	●	0.44	▲*	0.54	●	8.7	●	5	●	380	▼*	0.44	●	0.54	●
Shellpot Creek	7.5	▼	6	▲	245	▲	0.70	▲*	0.06	●	7.5	●	6	▼*	245	●	0.70	▼	0.06	▼*
Brandywine Cr	10.5	▼*	6	▲*	143	●	0.64	▲*	0.13	▲*	10.5	▲*	6	▼	143	●	0.64	▼	0.13	▲
White Clay Cr	9.9	▼*	6	▲*	232	●	0.69	▲*	0.12	●	9.9	▲	6	▼	232	●	0.69	▼	0.12	●
Red Clay Cr	10.1	▼*	6	▲*	195	●	0.62	▲*	0.16	▲*	10.1	▲	6	▼*	195	●	0.62	●	0.16	▲
Christina River	8.5	▲*	17	▲*	100	●	0.69	▲*	0.12	▲*	8.5	▲*	17	▲	100	●	0.69	▲	0.12	▲*
Army Creek	7.1	–	8	–	172	▲	0.88	–	0.13	●	7.1	▼	8	●	172	▼*	0.88	▼	0.13	▼
Red Lion Creek	8.4	▼*	6	▲	370	▲*	0.58	▲*	0.06	●	8.4	▲	6	●	370	●	0.58	▼*	0.06	●
Dragon Run Cr	4.9	▼	8	–	33	–	0.91	●	0.11	●	4.9	▼	8	▲	33	●	0.91	▼*	0.11	▼
C&D Canal	8.4	●	49	–	12	●	0.81	▲*	0.15	●	8.4	▲	49	●	12	▼*	0.81	▼*	0.15	▼*
Appoquinimink	6.3	▼*	49	▲	180	●	1.10	▲*	0.18	▼*	6.3	▼	49	▲*	180	●	1.10	●	0.18	●
Blackbird Creek	8.2	▼	5	–	117	▲	0.75	▲*	0.09	▲*	8.2	▲*	5	▲	117	●	0.75	●	0.09	●
Smyrna River	6.4	▼	86	–	290	▼*	1.24	▲*	0.21	▼*	6.4	▼	86	●	290	▲*	1.24	●	0.21	●
Leipsic River	4.1	▼	66	–	80	●	1.43	●	0.32	▼*	4.1	▲*	66	▼	80	●	1.43	▼*	0.32	▼*
Little Creek	5.2	▼*	78	–	860	▼	2.19	▲*	0.31	●	5.2	●	78	▲	860	▼	2.19	●	0.31	●
St. Jones River	5	▼	67	▲*	92	●	1.48	▲*	0.23	●	5.0	▼	67	▲*	92	●	1.48	●	0.23	▲*
Murderkill River	4.2	▲*	48	–	90	●	1.13	▲*	0.32	▲*	4.2	▲*	48	–	90	▲*	1.13	●	0.32	▲
Mispillion River	8.6	▼	24	–	155	●	1.15	▲*	0.09	▲	8.6	●	24	▼*	155	●	1.15	▼*	0.09	▲
Cedar Creek	7.5	●	–	–	87	●	1.06	●	0.07	●	7.5	▲*	–	●	87	▲	1.06	▼*	0.07	▲
Broadkill River	7.6	▲	48	–	160	●	0.47	▲*	0.16	▲	7.6	▲*	48	●	160	▼	0.47	▲	0.16	▲
Rehoboth Bay	6.8	▲	27	–	0	●	0.84	▲*	0.10	▲*	6.8	▲*	27	●	0	●	0.84	▼	0.10	▼
Indian River	7.1	–	25	–	0	●	0.59	–	0.06	–	7.1	▲*	25	▲	0	●	0.59	●	0.06	●
Indian R. Bay	7.3	●	26	▲	0	●	0.64	▲*	0.07	▲*	7.3	▲*	26	▲	0	●	0.64	●	0.07	●
L. Assawoman	5.7	–	8	–	100	–	1.45	–	0.09	–	5.7	▼	8	●	100	●	1.45	▼*	0.09	●
Chester River	6.2	–	6	–	122	●	0.88	–	0.24	●	6.2	●	6	●	122	●	0.88	▼	0.24	▼
Choptank River	6.8	▼*	4	▲	65	●	0.67	▲*	0.09	●	6.8	▼	4	●	65	●	0.67	▼*	0.09	▼*
Marshyhope Cr	8.7	▼	–	–	53	–	–	–	–	–	8.7	▲	–	–	53	●	–	–	–	–
Broad Creek	9.1	●	4	–	33	●	0.81	▲	0.06	●	9.1	▲	4	▼*	33	●	0.81	▼*	0.06	▼*
Nanticoke R.	6.6	▼	18	▲	29	●	0.78	▲*	0.09	●	6.6	▼	18	▲	29	●	0.78	●	0.09	●
Pocomoke	6.7	–	9	–	147	▲	0.80	–	0.12	▼*	6.7	●	9	●	147	▼	0.80	●	0.12	▼*
▲ Improving	4 of 25		11 of 11		5 of 27		21 of 25		9 of 27		16 of 30		9 of 28		3 of 30		2 of 29		8 of 29	
● Constant	4 of 25		0 of 11		20 of 27		3 of 25		14 of 27		6 of 30		12 of 28		21 of 30		12 of 29		11 of 29	
▼ Degrading	17 of 25		0 of 11		2 of 27		0 of 25		4 of 27		8 of 30		7 of 28		6 of 30		15 of 29		10 of 29	

Note: (*) denotes a statistically significant Seasonal Kendall trend at the p< 0.10 level. 2001 – 2005 median water quality: 8.1 green = good blue = fair red = poor

Short Term Water Quality Trends in Delaware (1990 to 2005)

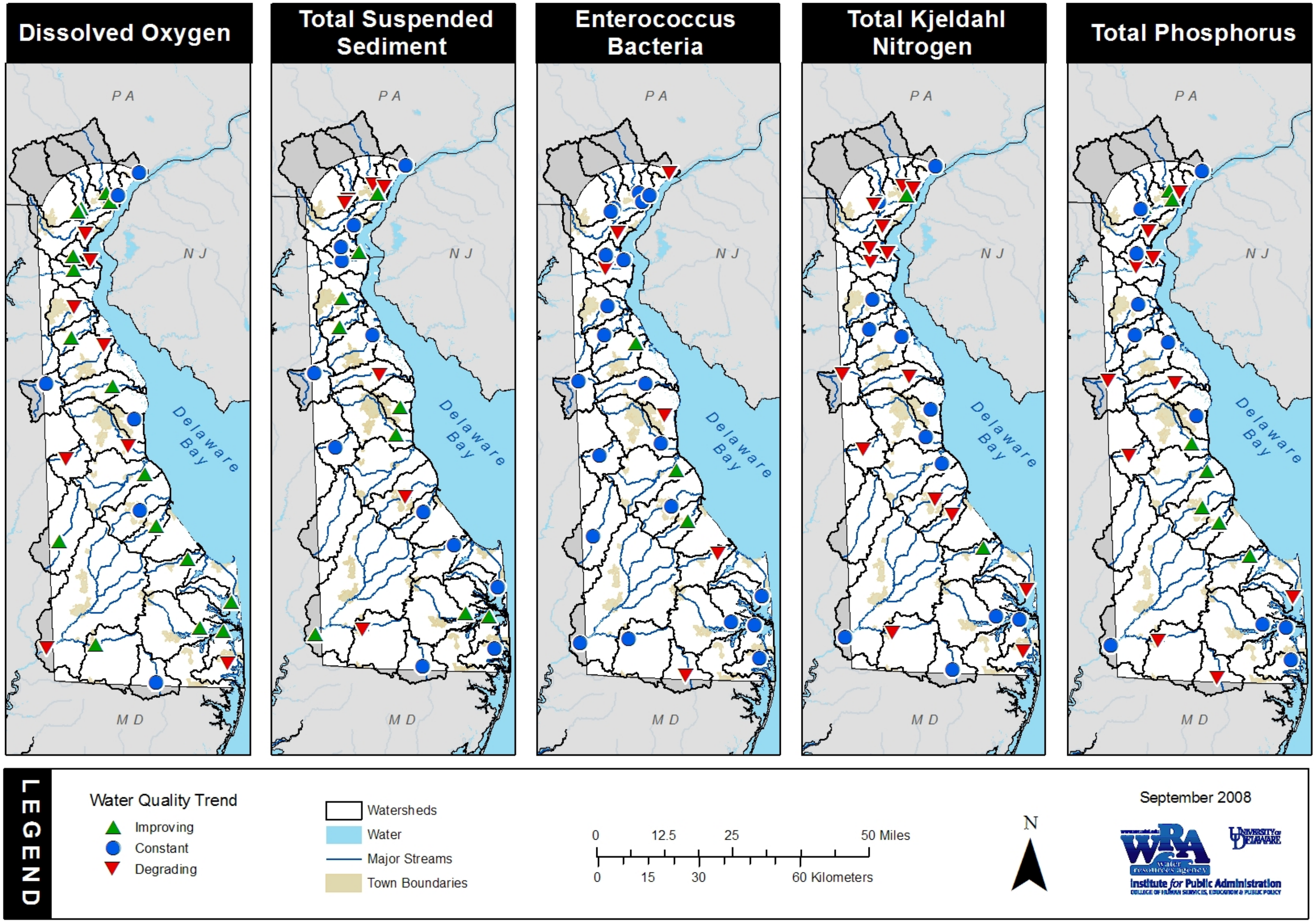


FIGURE 11. Short term water quality trends along Delaware streams from 1990 to 2005.

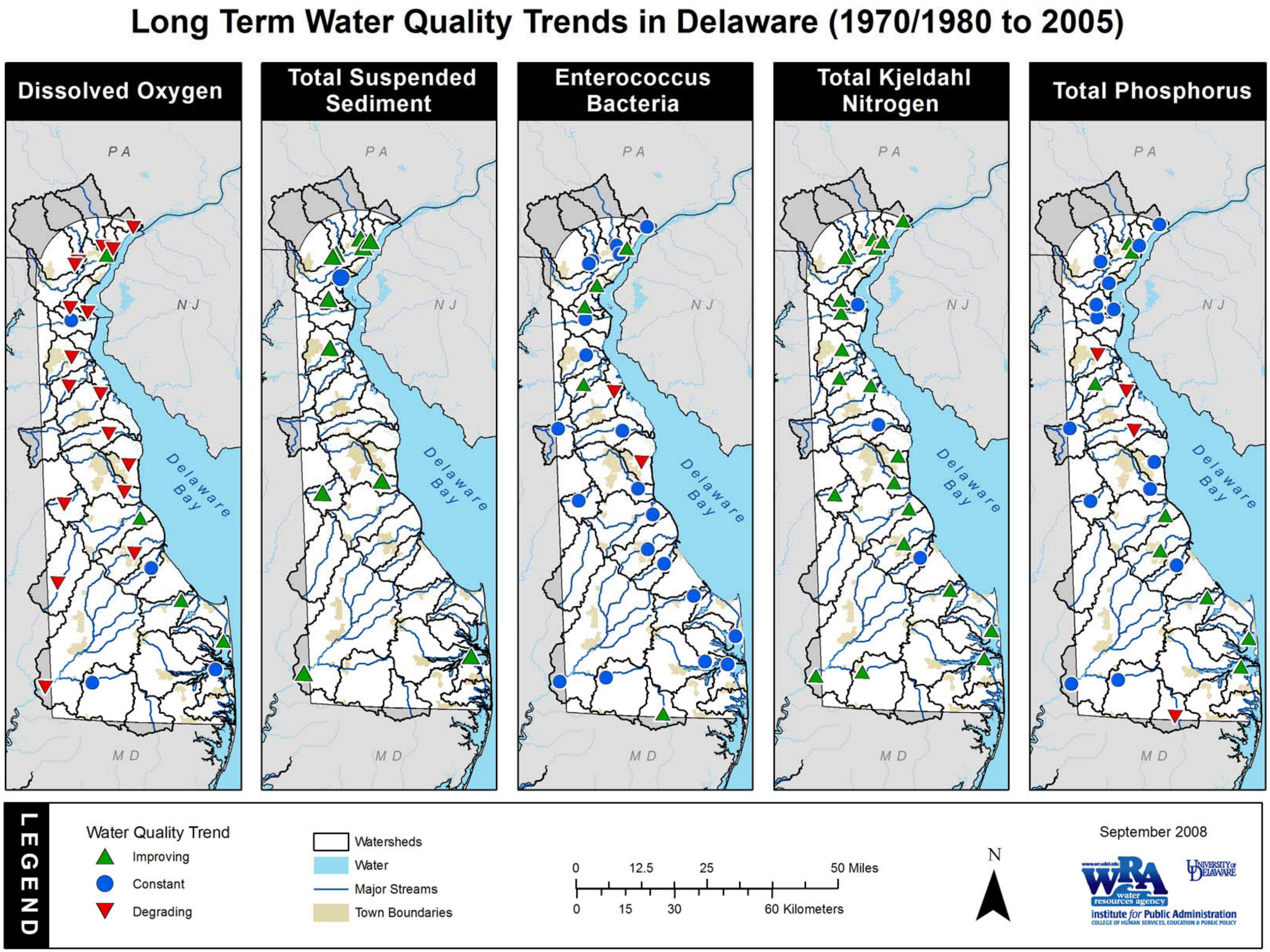


FIGURE 12. Long term water quality trends along Delaware streams from 1970-1980 to 2005.

During 2001–2005, median levels were good or fair at 100% of the stations for DO, 75% for TSS, 48% for bacteria, 50% for TKN, and 43% of the stations for total P.

Median dissolved oxygen levels from 2001-2005 are good with a few fair readings (Figure 13). DO levels as recorded by the 5-year median from 2001–2005 are good and exceed 6 mg/l in 24 of 30 (80%) of the streams and levels are fair and exceed the Delaware fresh water standard of 4 mg/l in 20% of the streams. None of the streams recorded poor median DO levels below the 4 mg/l standard. A hand full of streams have recorded individual DO samples below the 4 mg/l standard between 2001–2005 notably along the Dragon Run, Appoquinimink, Leipsic River, Little Creek, St. Jones, Murderkill, and Mispillion.

Median total suspended sediment levels from 2001-2005 are good in all streams (< 25 mg/l) except along the coastal plain streams in the Delaware Bay Basin where levels are poor and exceed 40 mg/l (Figure 14). Seven streams from the C&D Canal south to the Murderkill have cultivated land exceeding 40% of the watershed with median sediment concentrations between 45 and 90 mg/l, appreciably higher than levels in other Delaware basins.

Median bacteria levels from 2001–2005 are poor and exceed the Delaware standard of 100 colonies per 100 ml in 17 of 30 streams. Bacteria levels are good in the Inland Bays and along several Chesapeake Bay tributaries such as the Broad Creek and Nanticoke where bacteria levels are less than 35 colonies per 100 ml (Figure 15). Median bacteria levels are particularly poor ranging from 140 to 380 colonies per 100 ml in 5 of 6 Piedmont streams in urbanized northern Delaware.

Median total Kjehdahl nitrogen levels are good or fair and are less than 1.0 mg/l in 60% of the Delaware streams and poor in 40% of the streams (Figure 16). All agricultural Delaware Bay coastal plain watersheds from the Appoquinimink River south to the Broadkill except for the forested and wetland covered Blackbird Creek watershed have poor TKN median levels exceeding 1 mg/l.

Total phosphorus medians are poor exceeding 0.1 mg/l in half of the watersheds in Delaware (Figure 17). Total P exceeds 0.1 mg/l in the Piedmont and Delaware Bay Basins and is mostly fair ranging from 0.05 to 0.1 mg/l in the Inland Bays and Chesapeake Basins. None of the streams have good median TP levels less than 0.5 mg/l.

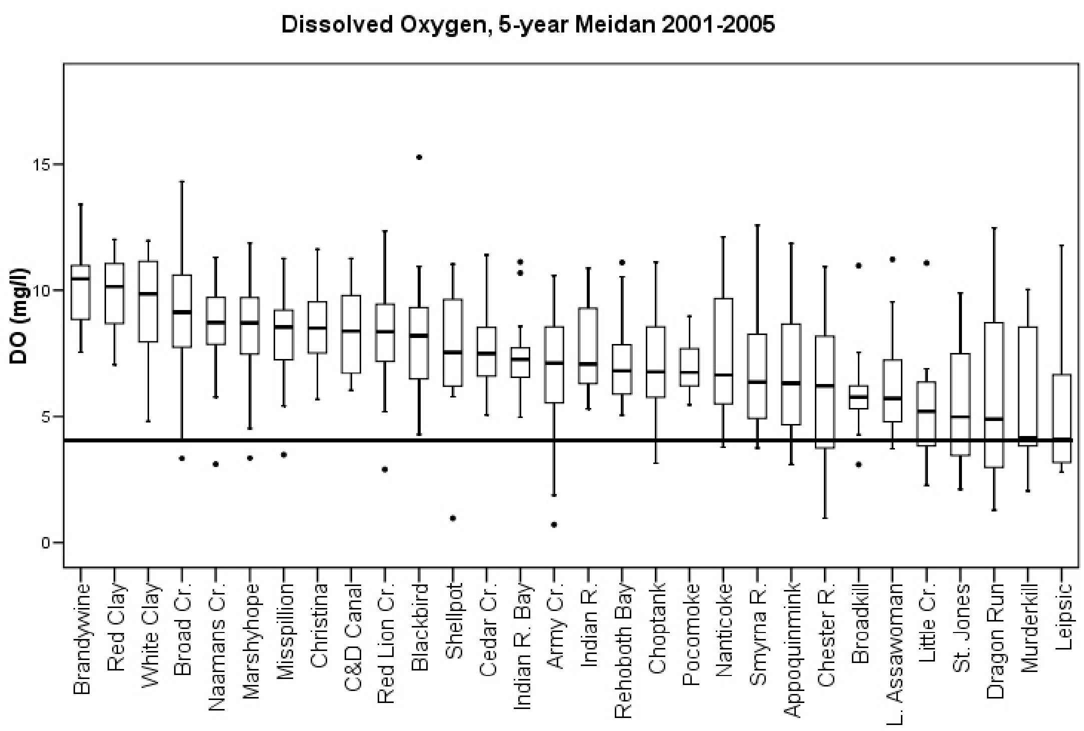


FIGURE 13. Median dissolved oxygen levels along Delaware streams (2001-2005).

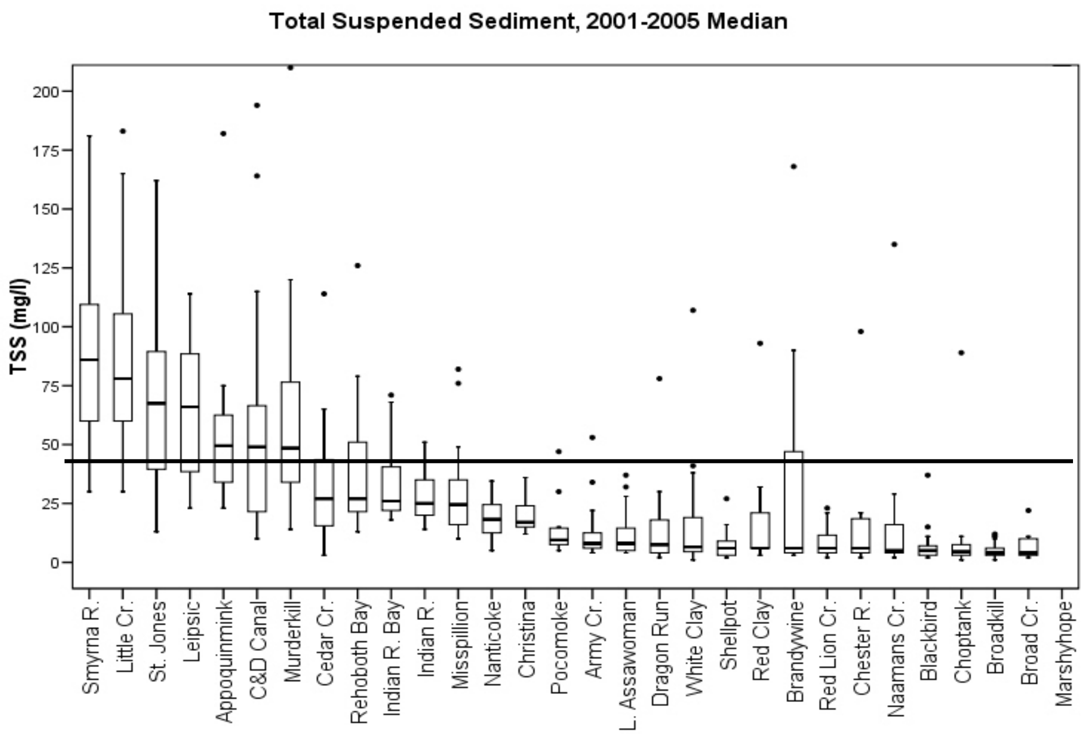


FIGURE 14. Median total suspended sediment along Delaware streams (2001-2005).

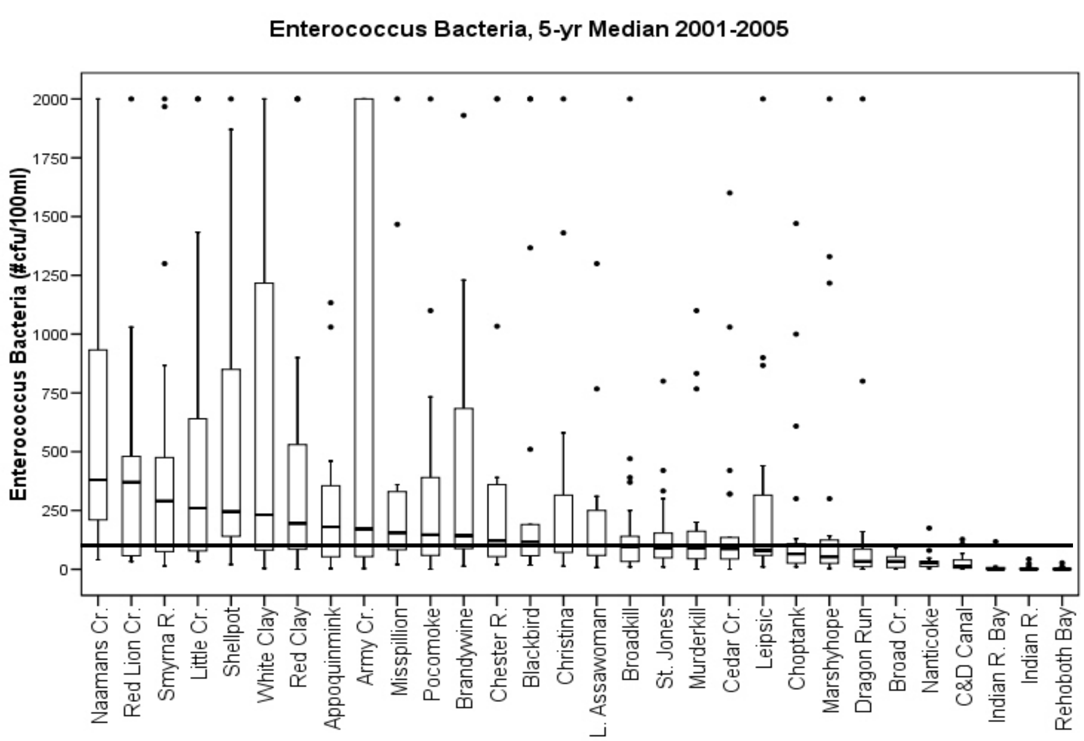


FIGURE 15. Median enterococci bacteria levels along Delaware streams (2001-2005).

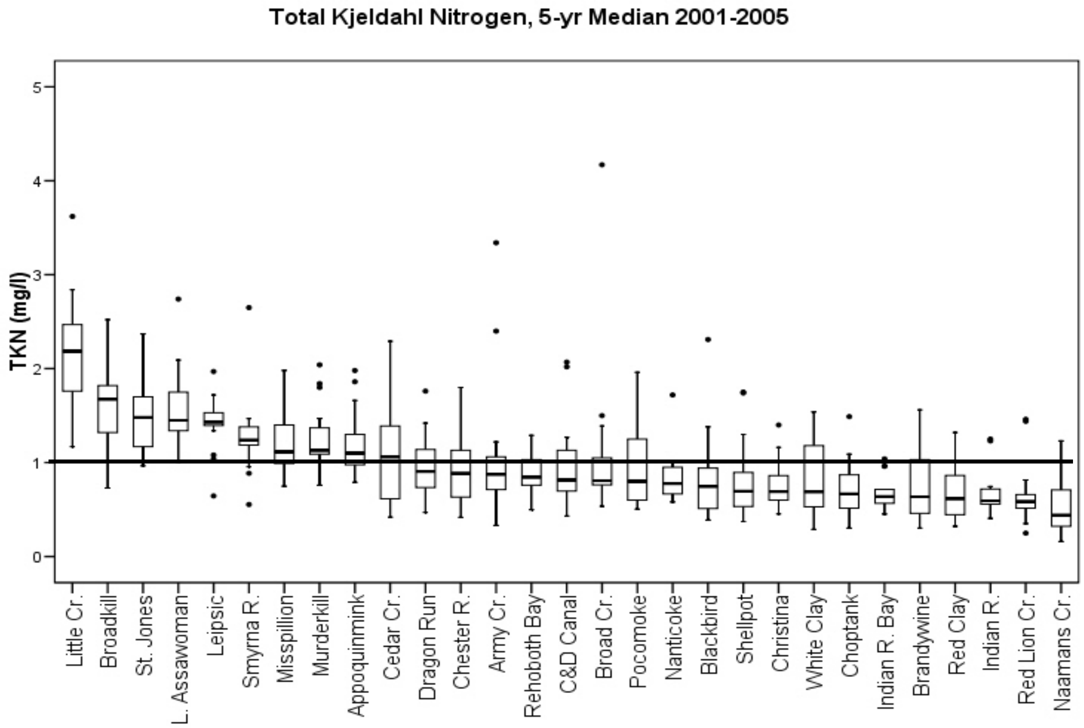


FIGURE 16. Median total kjelhdahl nitrogen levels along Delaware streams (2001-2005).

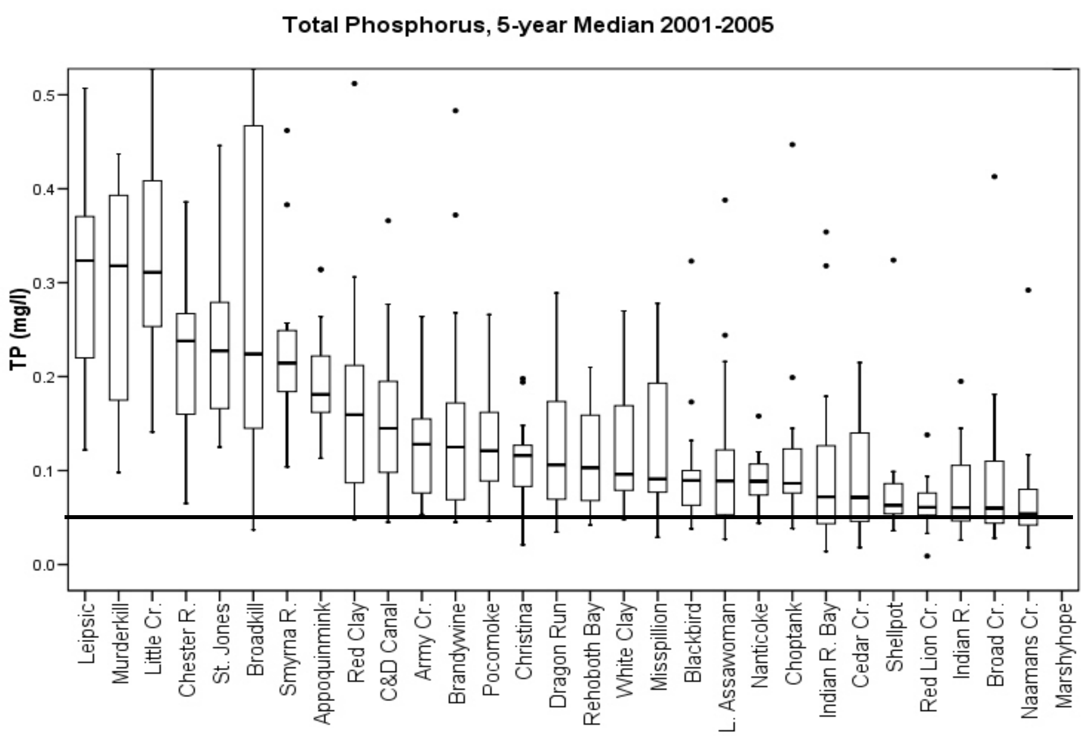
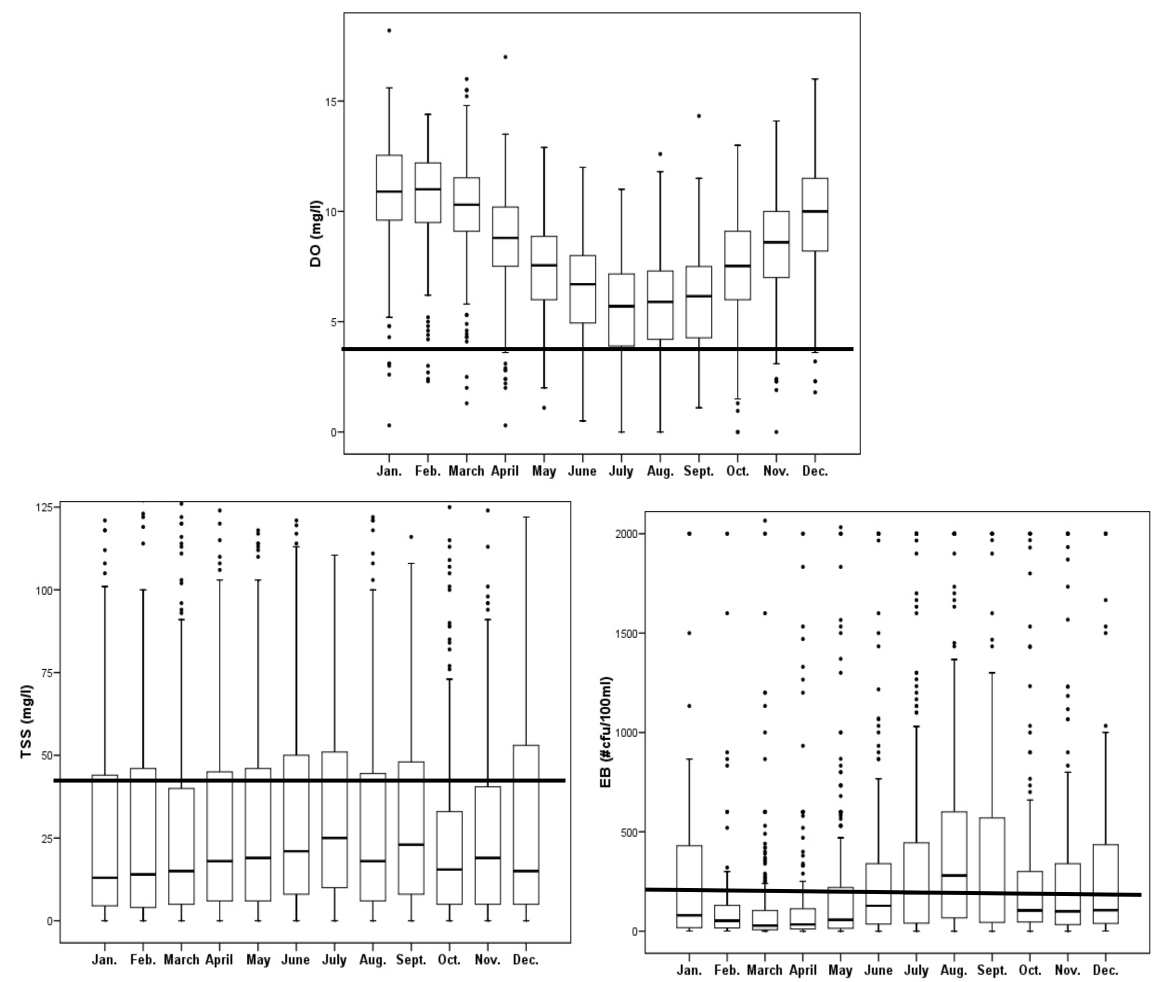


FIGURE 17. Median total phosphorus levels along Delaware streams (2001-2005).

DISCUSSION

Water quality as measured by DO, TSS, bacteria, TKN, and TP along Delaware streams improved or remained constant at nearly ¾ of the monitoring stations over the short term between 1990 and 2005 and at over ¾ of the stations over the long term from 1970 – 1980 to 2005. Water quality can be influenced by stream flow, seasonality, drainage basin, land use, and pollutant loads. Just 5 of 30 monitored streams have stream gaging stations with long term records, therefore, stream flow was not analyzed as an influencing factor on water quality change.

Many surface water quality parameters show strong seasonal patterns. The Seasonal Kendall test accounts for seasonality by grouping data into the 4 seasons of the year. Seasonal water quality change was also evaluated by comparing month by month box plots (Figure 18). Visual examination of the box plots indicates dissolved oxygen varies with the seasons ranging from highest levels during the colder months of November through March to the lowest levels during the warm summer months of June through September. The 25th percentile of DO readings in Delaware streams exceed the 4 mg/l water quality standard in every month of the year. TSS levels began rising in April, peak from July through August, and start declining by October in synchronicity with the construction season and agricultural plowing cycle. Bacteria levels peak in the warm months of July through September. TKN and Total P levels did not vary over the course of the year. Nutrients usually rise during spring and early summer due to fertilization on farms and lawns. Nitrogen levels along Delaware streams did not rise during spring and summer but phosphorus levels did rise from June though September.



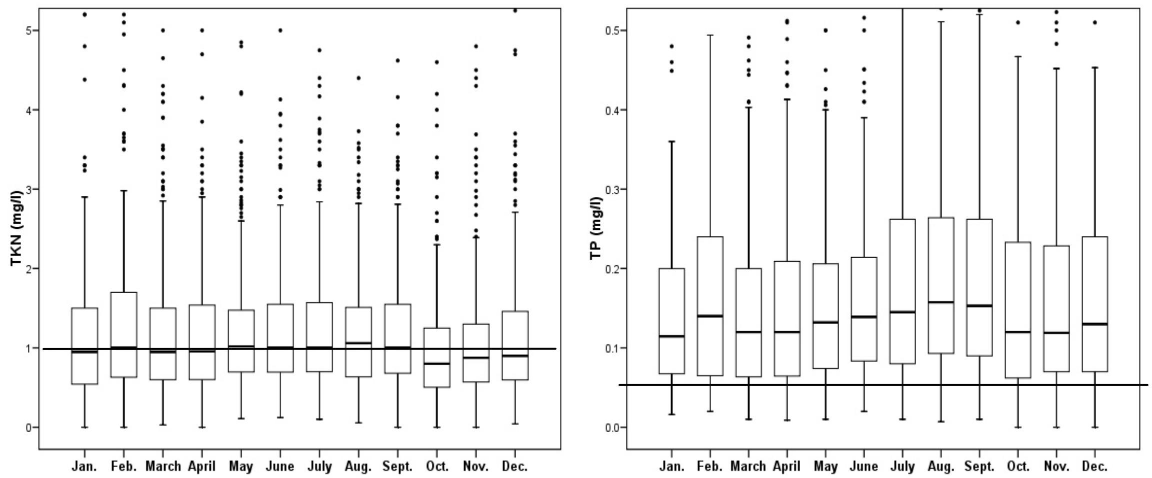
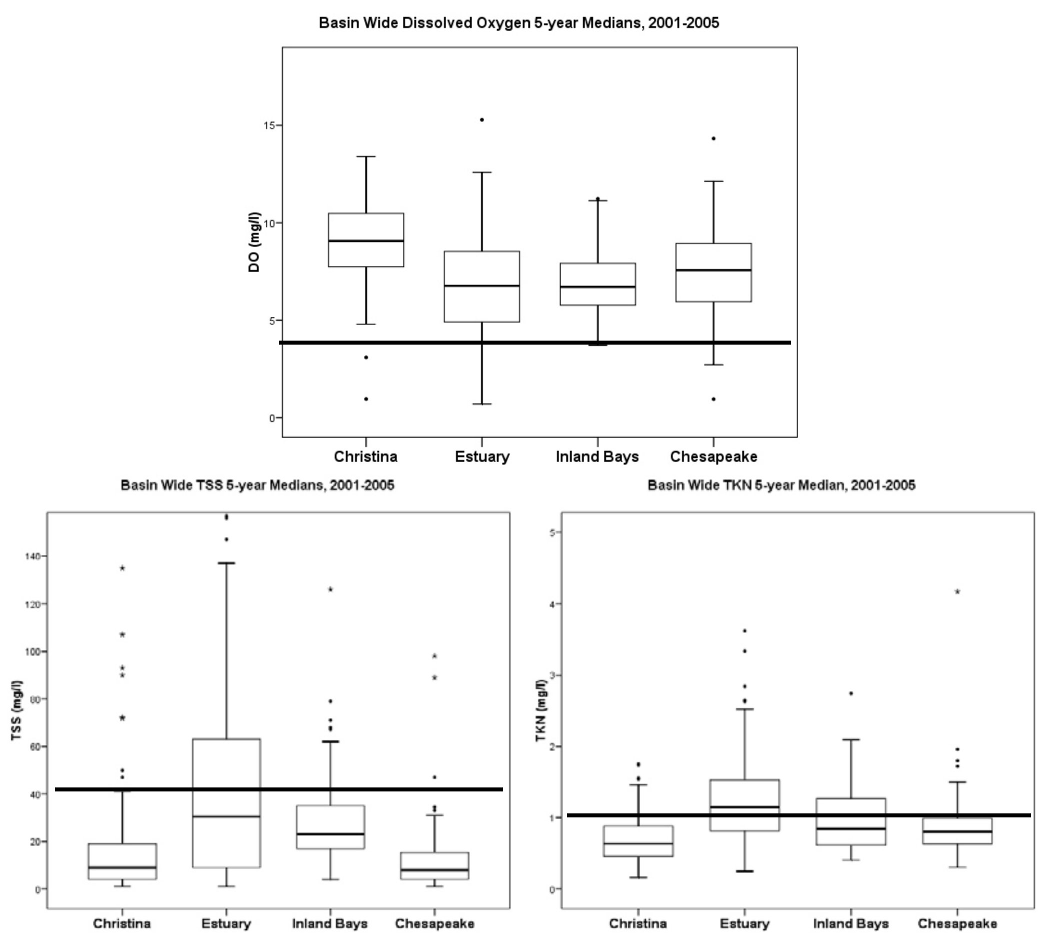


FIGURE 18. Seasonal comparison of water quality boxplots in Delaware (2001-2005).

Stream water quality in Delaware varies depending on the drainage basin (Figure 19). Median dissolved oxygen levels are highest in the urbanized hilly, rocky, Piedmont Basin compared to lower DO levels in the rural, flat sandy coastal plain basins draining to the Delaware Estuary, Inland Bays, and Chesapeake Bay. The Delaware Estuary Basin recorded the highest median levels of TSS, TKN, and TP probably due to high amounts of agricultural land in the watersheds. Piedmont Basin streams had the highest bacteria levels most likely due to leaking septic systems and runoff from horse and cattle farms upstream from Delaware in the Pennsylvania portion of the basin..



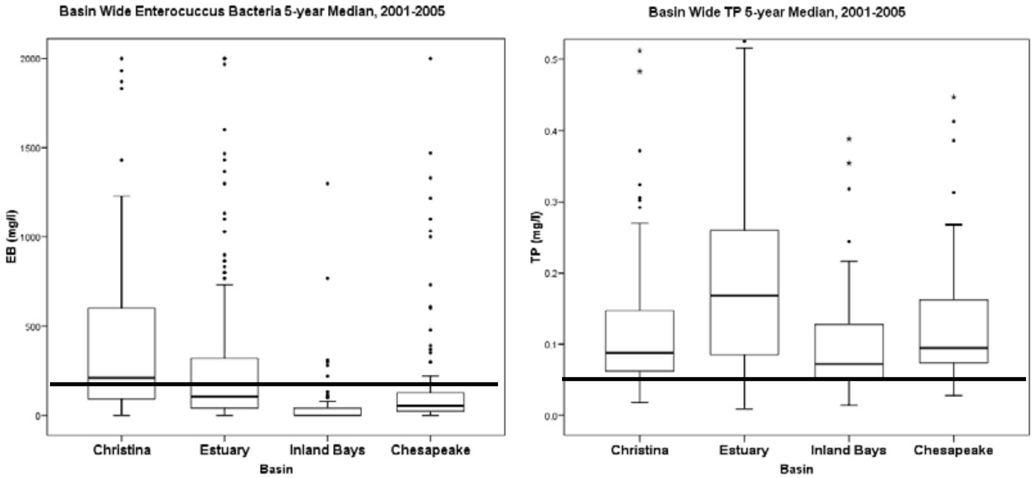
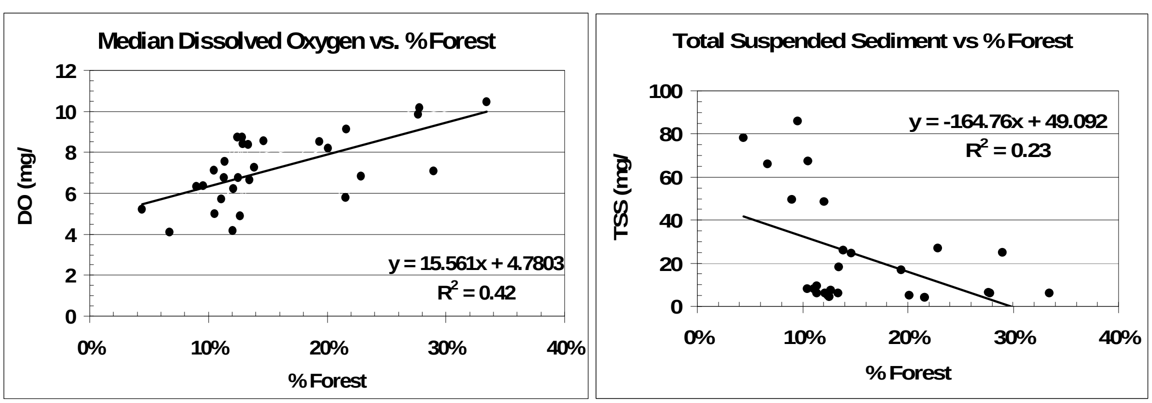


FIGURE 19. Comparison of water quality by drainage basin in Delaware.

Stream water quality varies depending on watershed land use. Streams recording degrading water quality since 1990 for at least 3 of 5 parameters include urbanizing watersheds such as the Shellpot Creek, Army Creek, and Dragon Run with developed land exceeding 60% of the watershed and rural yet suburbanizing C&D Canal, Liepsic, Choptank, and Broad Creek watersheds where agricultural land covers over 30% of the watershed.

Streams with the best water quality tend to have the highest watershed forest cover. The Brandywine Creek has the highest median DO level of 10.5 mg/l and a watershed covered with 33% forest. Streams such as the Broad Creek and Broadkill have the lowest sediment levels at 4 mg/l and watersheds with 22% forested land. The Rehoboth Bay and Indian River Bay have the lowest median bacteria counts close to zero and with watershed forest land at 23% and 29%, respectively.

A linear regression analysis indicates median water quality (2001-2005) correlates to the area of forest in a watershed (Figure 20). Dissolved oxygen increases with the amount forest cover as the coefficient of determination (r^2)= 0.42. An r^2 value of 1.0 would indicate a perfect line of fit for a plot of DO and forest land. An r^2 > 0.4 is considered to be a fair correlation. Visual examination of box plots ranked in order of increasing forest cover also indicates that dissolved oxygen increases with more forest cover (Figure 21). TSS, TKN, and TP levels decline (improve) with increasing forest cover in Delaware watersheds although the r^2 values are less significant ranging from 0.12 to 0.23.



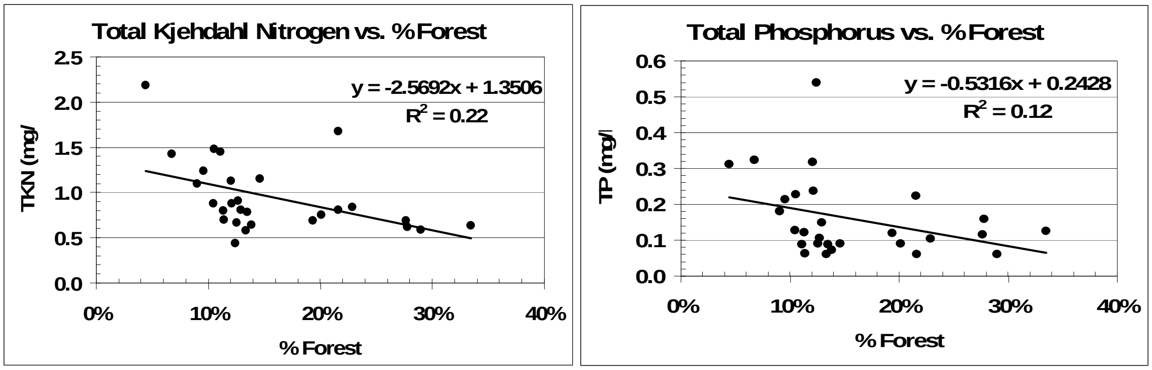


FIGURE 20. Water quality correlation with forest cover in Delaware watersheds.

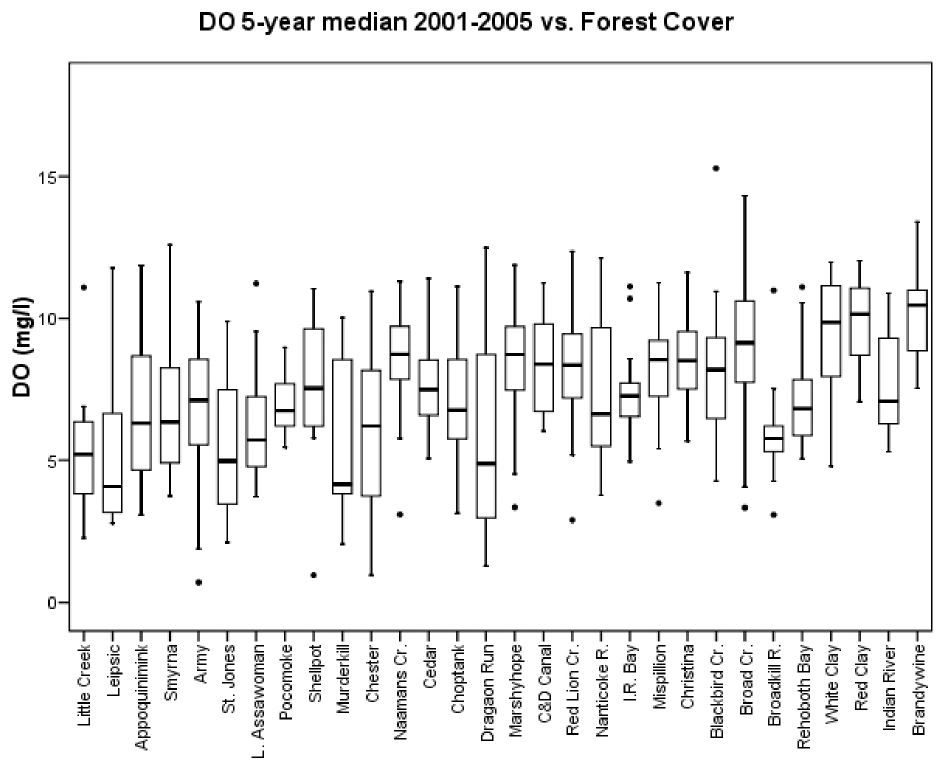


FIGURE 21. Median (2001-2005) DO levels along Delaware streams ranked from left to right in order of increased forest cover.

Improved or constant water quality trends along Delaware streams coincided with programs implemented by USEPA, Delaware DNREC, and the Clean Water Act since the early 1970s. Delaware established water pollution regulations in 1974 and passed stream water quality standards in 1991. DNREC commenced state-wide water quality monitoring in 1970 along streams and bays. Since 1990, DNREC issued NPDES discharge permits to 65 dischargers including 21 sewage treatment plants (Table 7). The Murderkill and Nanticoke Rivers benefited from improvements to sewage treatment plants owned by Kent County and the City of Seaford, Delaware. In 1998, Delaware began implementing Total Maximum Daily Loads (TMDLs) per Section 303(d) of the Clean Water Act and by the end of 2006 set standards for 32 watersheds (Table 8). Pollution control strategies are designed to implement TMDLs and include agricultural nutrient and sediment management, reforestation, septic system relief, and soil erosion and sediment control programs. The ban on phosphate detergent during the 1980s has resulted in significant phosphorus reductions in Delaware streams. These Federal and State watershed programs were congruent with improved or constant water quality along Delaware streams

TABLE 7. Permitted NPDES sewage treatment plants in Delaware watersheds.

Watershed	Sewage Treatment Plant
Brandywine Creek	Greenville Country Club Winterthur
C & D Canal	Lums Pond State Park
Appoquinimink Cr.	Middletown-Odessa
Smyrna River	Hanover Foods
Murderkill River	Harrington STP Kent County STP Southwood Acres MHP Canterbury Crossing
Broadkill River	Milton STP
Rehoboth Bay	Lewes STP Colonial Estates MHP
Indian River Bay	Bayshore MHP Georgetown STP Millsboro STP
Little Assowoman	Selbyville STP South Coastal Reg'l STP
Broad Creek	Laurel STP
Nanticoke River	Mobile Gardens Trailer Park Bridgeville STP Seaford STP

TABLE 8. Completed Total Maximum Daily Loads (TMDLS) in Delaware watersheds.

Watershed	Completed TMDL
Broad Creek, Nanticoke River	1998
Christina Basin	2001
Appoquinimink River	2003
Buntings Branch	2004
Delaware Estuary, Naamans Creek, Shellpot Creek	2005
Little Assawoman Bay	2005
Indian River, Indian River Bay, and Rehoboth Bay	2005
Pocomoke, Marshyhope, Chester, Choptank	2005
Army Creek, Dragon Run Creek, Red Lion Creek	2006
Blackbird Creek, Smyrna River, Leipsic River	2006
Cedar Creek, St Jones River	2006
Nanticoke, Gum Branch, Broad Creek	2006
Gravelly Branch, Deep Creek	2006
Mispillion River, Murderkill, Broadkill	2006

SUMMARY

Water quality improved or was constant along 30 Delaware streams at 69% of the stations since 1990 and 79% of the stations since 1970-1980. Twenty-four streams flow east to the Delaware Bay and 6 streams flow west towards the Chesapeake Bay. Dissolved oxygen improved or was constant at 73% of the streams since 1990 and 32% of the streams since 1970-1980. Total suspended sediment improved or was constant at 75% of the streams since 1990 and 100% of the streams since 1970-1980. Enterococcus bacteria improved or was constant at 80% of the streams since 1990 and 93% of the streams since 1970-1980. Total Kjeldahl nitrogen improved or was constant at 48% of the streams since 1990 and 100% of the streams since 1970-1980. Total phosphorus improved or was constant at 66% of the streams since 1990 and 85% of the streams since 1970-1980 During 2001–2005, median water quality levels were good or fair at 100% of the stations for dissolved oxygen, 75% for total suspended sediment, 48% for bacteria, 60% for totsl Kjehdahl nitrogen, and 43% of the stations for total phosphorus. Dissolved oxygen, nitrogen, sediment, and phosphorus levels improve with increased forest cover in Delaware watersheds.

Approximately ¾ of monitored streams in Delaware recorded improved or constant water quality over the last 35 years during an era when Federal and State governments implemented watershed management programs. Since the 1970s when governments passed laws creating the USEPA, Delaware DNREC, and the Federal Clean Water Act; improving water quality stations (50) outnumbered the degrading stations (23) along Delaware streams by a 2 : 1 margin. Since 1990, the number of stations with degrading water quality (46) exceeded the stations with improving quality (38) indicating a slight reversal from the early gains achieved since the implementation of the 1970s Clean Water Act amendments.
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APPENDIX A – 1. Short term (1990 to 2005) Seasonal Kendall test results for water quality monitoring stations in Delaware.

No.	Stream	DO				TSS				Entero. Bacteria				TKN				TP			
		p	slope	year	n	p	slope	year	n	p	slope	year	n	p	slope	year	n	p	slope	year	n
1	Naamans Cr	0.963	-0.028	1991	51	0.956	0.000	1991	44	**0.089**	25.2	1991	51	0.683	0.014	1991	48	0.332	0.001	1991	47
2	Shellpot Creek	0.404	-0.073	1991	49	**0.005**	0.329	1991	46	0.710	4.7	1991	51	0.121	0.027	1991	46	**0.015**	0.003	1991	46
3	Brandywine Cr	**0.093**	0.086	1991	91	0.108	0.275	1991	89	0.347	8.3	1991	90	0.225	0.018	1991	75	0.858	-0.001	1991	75
4	White Clay Cr	0.321	0.035	1994	67	0.142	0.800	1994	65	0.928	2.1	1994	65	0.114	0.034	1994	62	0.382	0.004	1994	59
5	Red Clay Cr	0.142	0.112	1991	80	**0.052**	0.400	1991	75	0.690	8.4	1991	78	0.530	0.010	1991	75	0.147	-0.005	1991	76
6	Christina River	**0.025**	0.146	1991	99	0.893	0.000	1991	98	0.225	3.8	1991	100	0.775	-0.008	1991	83	**0.098**	-0.002	1991	83
7	Army Creek	0.491	-0.088	1991	42	0.571	-0.400	1991	48	**0.061**	37.0	1991	42	0.319	0.026	1991	39	0.148	0.007	1991	39
8	Red Lion Creek	0.368	0.081	1991	42	0.318	0.500	1996	126	1.000	-0.5	1991	40	**0.054**	0.008	1991	38	0.276	0.003	1991	38
9	Dragon Run Cr	0.452	-0.126	1992	48	0.632	-0.167	1994	71	0.607	0.8	1992	48	**0.034**	0.031	1992	44	0.145	0.004	1992	44
10	C&D Canal	0.375	0.049	1991	50	0.405	1.250	1991	93	**0.073**	1.6	1991	50	**0.004**	0.032	1991	47	**0.052**	0.005	1991	47
11	Appoquinimink	0.685	-0.031	1991	69	**0.105**	-1.500	1991	93	0.651	2.5	1991	69	0.168	0.019	1991	66	1.000	0.000	1991	67
12	Blackbird Creek	**0.032**	0.171	1991	48	0.219	-0.188	1991	49	0.568	5.2	1991	48	0.902	0.001	1991	44	0.514	0.001	1991	44
13	Smyrna River	0.343	-0.035	1991	57	0.973	-0.031	1991	62	0.324	10.5	1991	58	0.243	0.017	1991	53	0.969	-0.001	1991	52
14	Leipsic River	**0.010**	0.102	1991	55	1.000	-0.004	1991	61	0.581	4.0	1991	56	**0.092**	0.023	1991	52	**0.010**	0.010	1991	52
15	Little Creek	0.809	-0.021	1991	55	0.618	-0.938	1991	66	0.790	5.0	1991	56	0.738	0.021	1991	52	0.738	-0.002	1991	52
16	St. Jones River	0.641	-0.041	1991	52	**0.085**	-2.583	1991	54	0.851	-0.4	1991	53	0.457	0.015	1991	51	**0.007**	-0.010	1991	52
17	Murderkill River	**0.014**	0.215	1994	41	n/a	n/a	n/a	n/a	**0.046**	-23.5	1994	41	0.412	-0.069	1994	38	0.145	-0.018	1994	38
18	Mispillion River	0.974	-0.001	1991	55	**0.027**	1.183	1991	67	0.441	4.4	1991	54	**0.020**	0.045	1991	52	0.819	-0.001	1991	51
19	Cedar Creek	**0.007**	0.225	1991	76	0.604	0.450	1999	30	0.268	-6.6	1991	53	**0.047**	0.048	1991	48	0.428	-0.002	1991	48
20	Broadkill River	**0.001**	0.291	1991	58	0.388	0.111	1991	90	0.365	1.3	1991	57	0.491	-0.048	1991	54	0.916	-0.002	1991	55
21	Rehoboth Bay	**0.007**	0.187	1991	55	0.450	0.611	1991	82	0.390	0.0	1991	58	0.348	0.018	1991	55	**0.104**	0.003	1991	53
22	Indian River	**0.044**	0.143	1991	45	0.500	-0.631	1991	66	0.531	0.0	1991	47	0.464	0.011	1991	45	0.828	0.001	1991	44
23	Indian R. Bay	**0.002**	0.208	1991	56	0.724	0.278	1991	59	0.607	0.0	1991	58	0.258	0.011	1991	56	0.818	0.001	1991	54
24	L. Assawoman	0.658	0.025	1992	48	0.425	-0.375	1994	49	0.967	-0.6	1992	49	**0.095**	0.061	1992	45	0.687	-0.001	1992	45
25	Chester River	0.957	0.002	1991	51	0.535	0.293	1991	54	0.821	-2.4	1991	51	0.190	0.027	1991	49	0.234	0.006	1991	49
26	Choptank River	0.637	-0.025	1991	50	0.141	0.250	1991	64	0.465	2.6	1991	51	**0.078**	0.030	1991	48	**0.054**	0.004	1991	48
27	Marshyhope Cr	0.367	0.075	1991	49	-	-	-	-	0.540	-1.9	1991	49	-	-	-	-	-	-	-	-
28	Broad Creek	0.309	0.050	1991	83	**0.006**	0.268	1991	90	0.720	-0.8	1991	81	**0.061**	0.031	1991	82	**0.080**	0.002	1991	79
29	Nanticoke R.	0.734	-0.030	1991	65	0.350	-0.438	1991	111	0.781	0.3	1991	66	0.733	0.003	1991	64	1.000	0.000	1991	62
30	Pocomoke	0.847	-0.015	1991	52	0.696	0.058	1991	58	0.106	9.5	1991	54	0.352	0.023	1991	51	**0.008**	0.006	1991	51

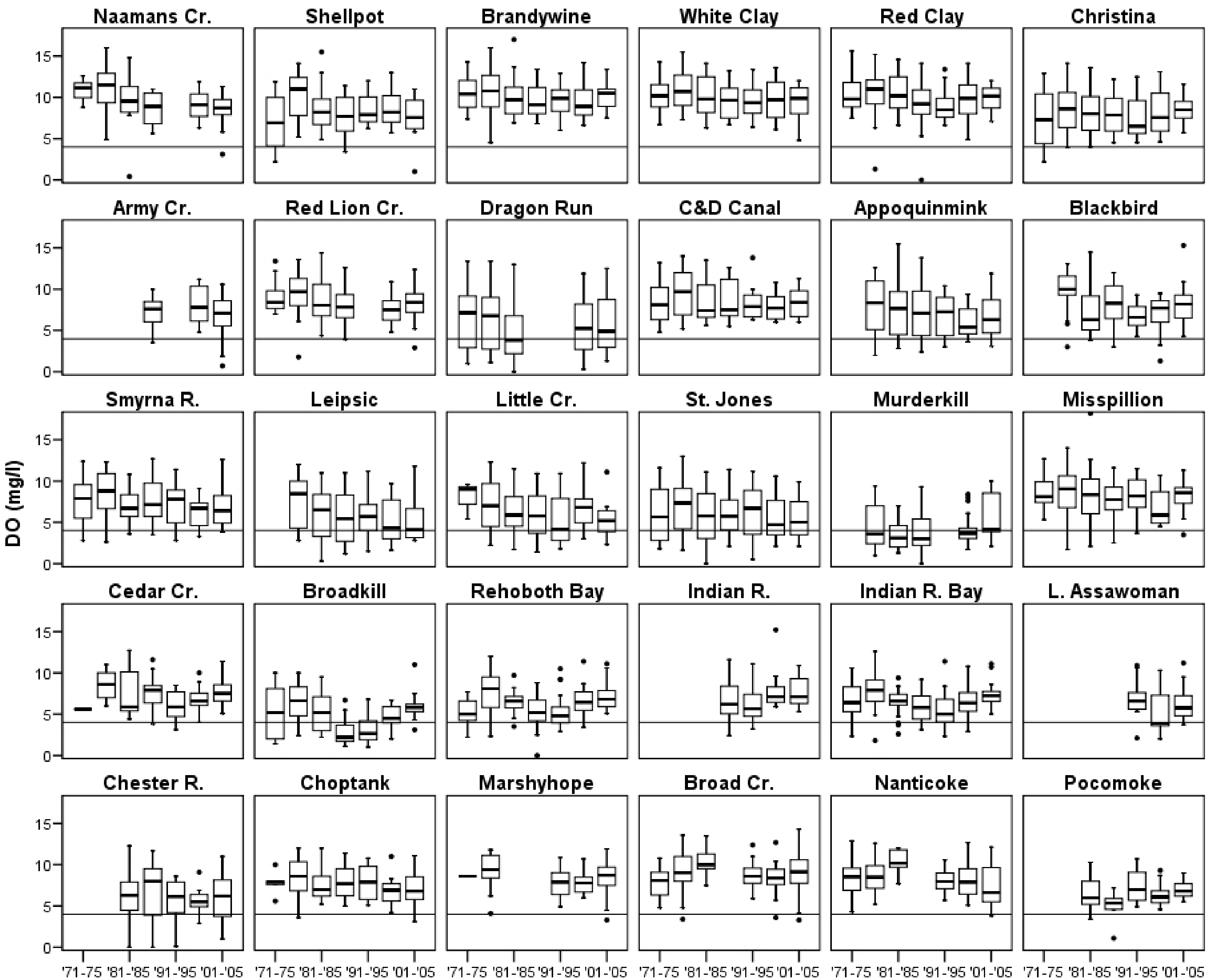
p = probability ≤ 0.1 = statistically significant. slope of Seasonal Kendal trend line in (mg/l)/year or (#cfu/100ml)/year. year = first year record. n = number of samples.

APPENDIX A – 2. Long term (1970-1980 to 2005) Seasonal Kendall test results for water quality monitoring stations in Delaware.

No.	Stream	DO				TSS				Entero. Bacteria				TKN				TP			
		p	slope	year	n	p	slope	year	n	p	slope	year	n	p	slope	year	n	p	slope	year	n
1	Naamans Cr	**0.000**	-0.082	1971	135					0.576	5.56	1986	64	**0.012**	-0.011	1971	131	0.945	0.000	1980	91
2	Shellpot Creek	0.112	-0.044	1971	135	0.281	-0.100	1970	109	0.948	0.45	1986	63	**0.003**	-0.012	1971	130	0.925	0.000	1980	89
3	Brandywine Cr	**0.091**	-0.024	1971	325	**0.000**	-0.370	1970	302	0.189	6.50	1986	146	**0.001**	-0.015	1971	304	**0.001**	-0.006	1980	198
4	White Clay Cr	**0.057**	-0.027	1971	269	**0.006**	-0.360	1971	210	0.260	14.68	1986	91	**0.002**	-0.015	1971	253	0.110	0.002	1980	153
5	Red Clay Cr	**0.021**	-0.025	1971	361	**0.014**	-0.216	1971	283	0.463	5.00	1986	127	**0.000**	-0.013	1971	341	**0.007**	-0.005	1980	200
6	Christina River	**0.087**	0.030	1971	312	**0.000**	-0.724	1971	292	1.000	0.13	1986	148	**0.000**	-0.035	1971	293	**0.001**	-0.002	1980	193
7	Army Creek	-	-	-	-	-	-	-	-	0.532	-19.12	1986	55	-	-	-	-	0.812	0.001	1983	60
8	Red Lion Creek	**0.063**	-0.045	1971	181	-	-	-	-	**0.048**	-20.14	1986	65	**0.001**	-0.010	1971	171	0.632	0.000	1980	110
9	Dragon Run Cr	0.488	-0.021	1972	155	-	-	-	-	-	-	-	-	0.499	-0.002	1972	147	0.112	0.002	1979	81
10	C&D Canal	0.463	-0.009	1971	189	-	-	-	-	0.152	0.44	1986	61	**0.000**	-0.030	1971	185	0.219	0.002	1980	91
11	Appoquinimink	**0.089**	-0.033	1971	159	-	-	-	-	0.482	2.08	1986	82	**0.000**	-0.020	1971	144	**0.016**	0.003	1980	126
12	Blackbird Creek	0.145	-0.044	1971	101	-	-	-	-	0.396	-12.90	1986	60	**0.079**	-0.012	1971	97	**0.004**	-0.003	1980	72
13	Smyrna River	**0.057**	-0.039	1971	141	-	-	-	-	**0.024**	14.81	1986	73	**0.073**	-0.010	1971	130	**0.026**	0.003	1980	98
14	Leipsic River	0.417	0.014	1971	126	-	-	-	-	0.868	0.63	1986	78	0.464	0.005	1971	117	**0.009**	0.005	1979	99
15	Little Creek	**0.016**	-0.055	1971	179	-	-	-	-	0.462	4.04	1986	82	**0.051**	-0.022	1971	172	0.205	0.003	1979	141
16	St. Jones River	0.327	-0.020	1971	236	**0.030**	-1.366	1979	172	0.262	0.08	1989	100	**0.000**	-0.026	1971	230	0.244	0.002	1980	171
17	Murderkill River	**0.044**	0.046	1976	115	-	-	-	-	0.709	-2.14	1986	54	**0.001**	-0.023	1976	111	**0.067**	-0.005	1980	83
18	Mispillion River	0.324	-0.024	1971	181	-	-	-	-	0.357	4.42	1986	83	**0.028**	-0.019	1971	173	0.124	-0.002	1979	133
19	Cedar Creek	0.743	0.012	1975	118	-	-	-	-	0.942	-0.50	1987	66	0.849	0.001	1975	84	0.976	0.000	1980	81
20	Broadkill River	0.285	0.035	1971	109	-	-	-	-	0.260	1.54	1988	76	**0.001**	-0.119	1971	103	0.137	-0.011	1980	86
21	Rehoboth Bay	0.797	0.004	1971	170	-	-	-	-	0.896	0.00	1986	76	**0.001**	-0.025	1971	168	**0.035**	-0.002	1979	119
22	Indian River	-	-	-	-	-	-	-	-	0.262	0.08	1989	66	-	-	-	-	-	-	-	-
23	Indian R. Bay	0.724	0.009	1971	200	-	-	-	-	0.534	0.00	1986	77	**0.001**	-0.025	1971	203	**0.005**	-0.003	1979	122
24	L. Assawoman	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
25	Chester River	-	-	-	-	-	-	-	-	0.545	-4.77	1986	66	-	-	-	-	0.275	0.003	1983	90
26	Choptank River	**0.007**	-0.046	1971	135	-	-	-	-	0.718	0.93	1986	66	**0.050**	-0.010	1971	123	0.732	0.000	1980	105
27	Marshyhope Cr	0.159	-0.046	1971	71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
28	Broad Creek	0.764	0.002	1971	172	-	-	-	-	0.787	0.47	1987	88	0.105	-0.006	1971	162	0.345	0.001	1980	105
29	Nanticoke R.	0.109	-0.031	1971	149	-	-	-	-	0.393	0.50	1987	68	-	-	-	-	0.715	0.000	1981	74
30	Pocomoke	-	-	-	-	-	-	-	-	0.817	1.19	1986	64	-	-	-	-	**0.010**	0.002	1983	74

p = probability ≤ 0.1 = statistically significant. slope of Seasonal Kendal trend line in (mg/l)/year or (#cfu/100ml)/year. year = first year record. n = number of samples.

APPENDIX B. Boxplots and scatterplots of water quality data along Delaware streams.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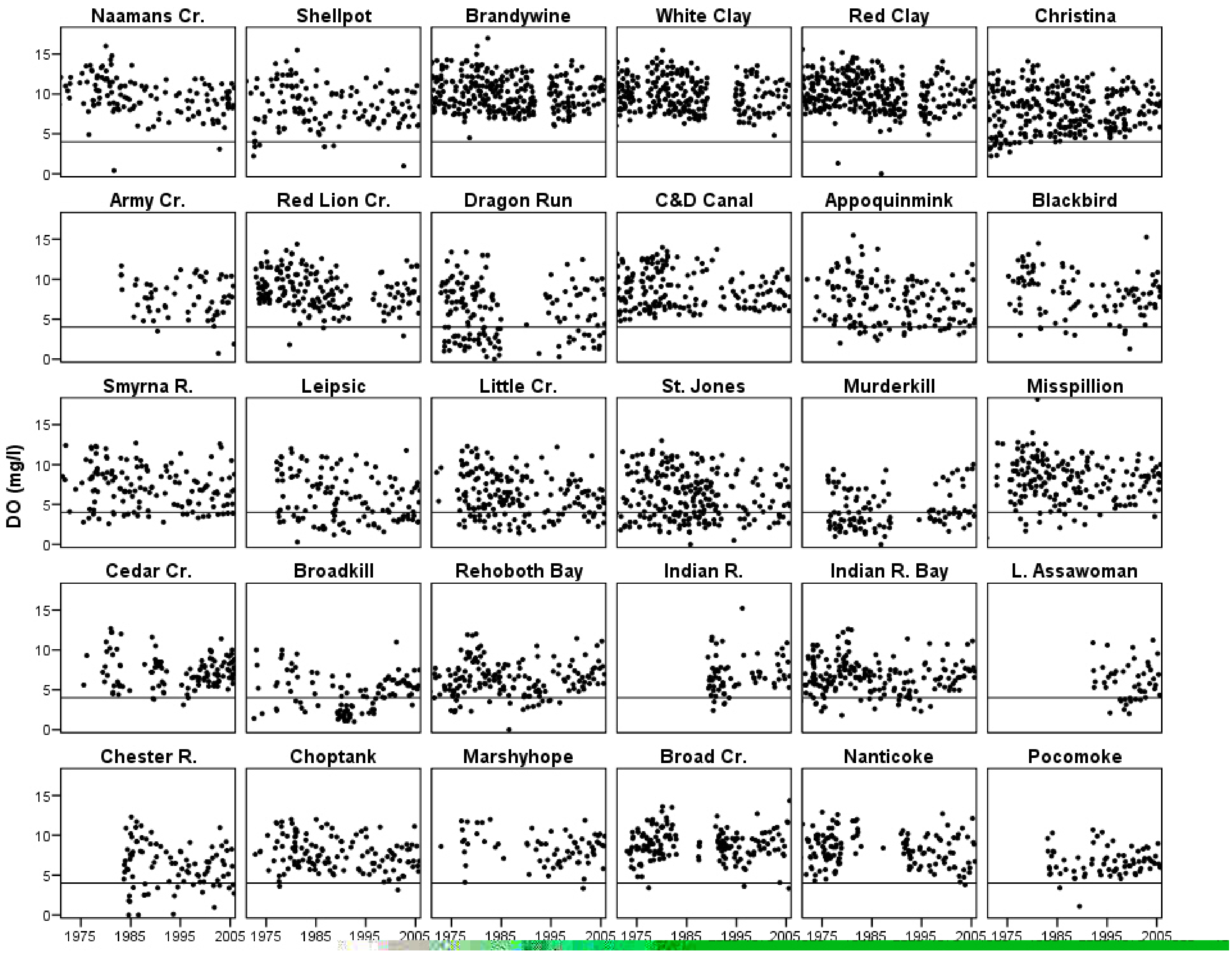
White Clay
Red Clay
Christina
Army Cr.
Red Lion Cr.
Dragon Run
C&D Canal
Appoquinmink
Blackbird
Smyrna R.
Leipsic
Little Cr.
St. Jones
Murderkill
Misspillion
Cedar Cr.
Broadkill
Rehoboth Bay
Indian R.
Indian R. Bay
L. Assawoman
Chester R.
Choptank
Marshyhope
Broad Cr.
Nanticoke
Pocomoke
DO (mg/l)
0
5
10
15
'71-'75
'81-'85
'91-'95
'01-'05



Naamans Cr.
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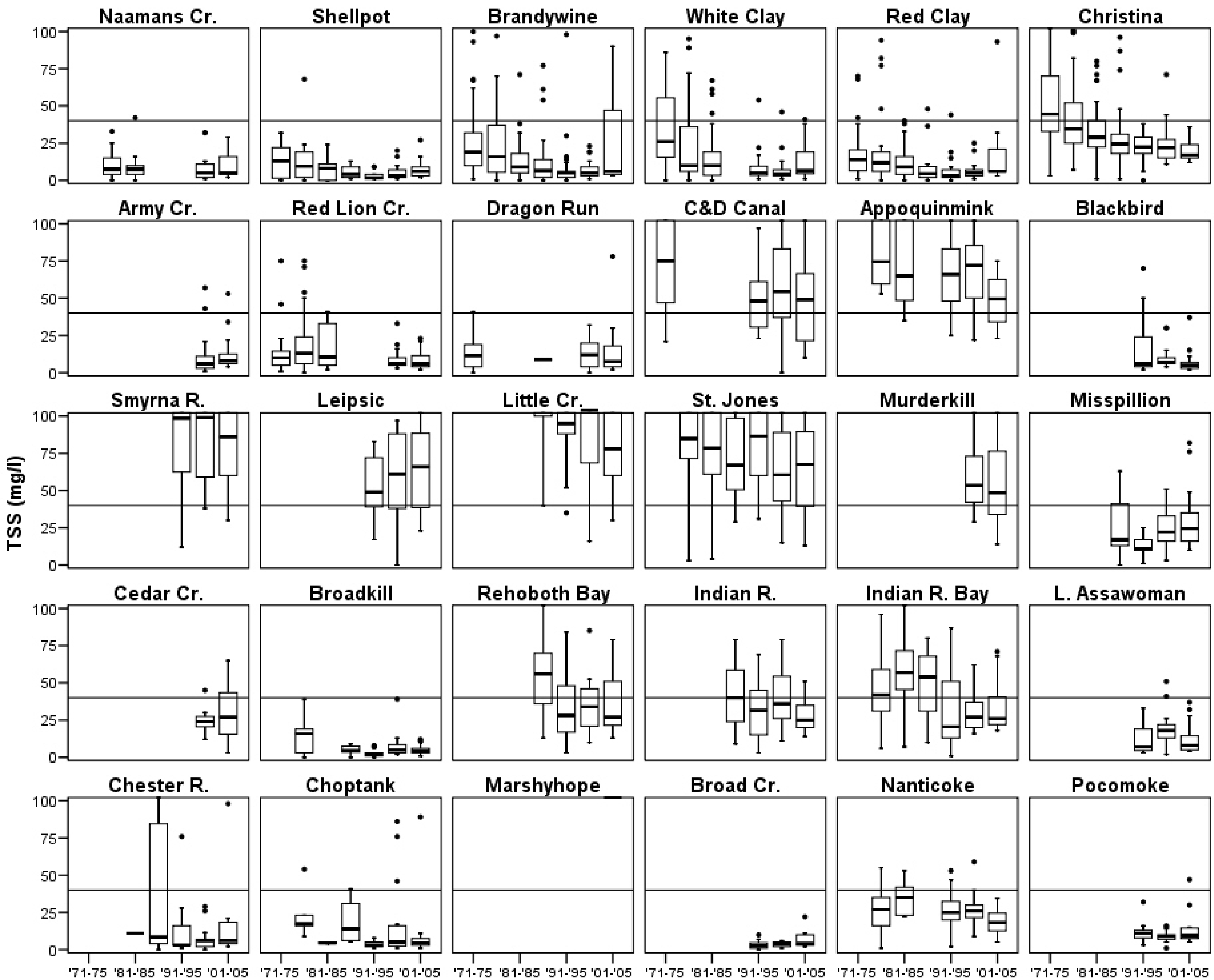
White Clay
Red Clay
Christina
Army Cr.
Red Lion Cr.
Dragon Run
C&D Canal
Appoquinmink
Blackbird
Smyrna R.
Leipsic
Little Cr.
St. Jones
Murderkill
Misspillion
Cedar Cr.
Broadkill
Rehoboth Bay
Indian R.
Indian R. Bay
L. Assawoman
Chester R.
Choptank
Marshyhope
Broad Cr.
Nanticoke
Pocomoke
DO (mg/l)
0
5
10
15
1975
1985
1995
2005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Red Lion Cr.
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C&D Canal
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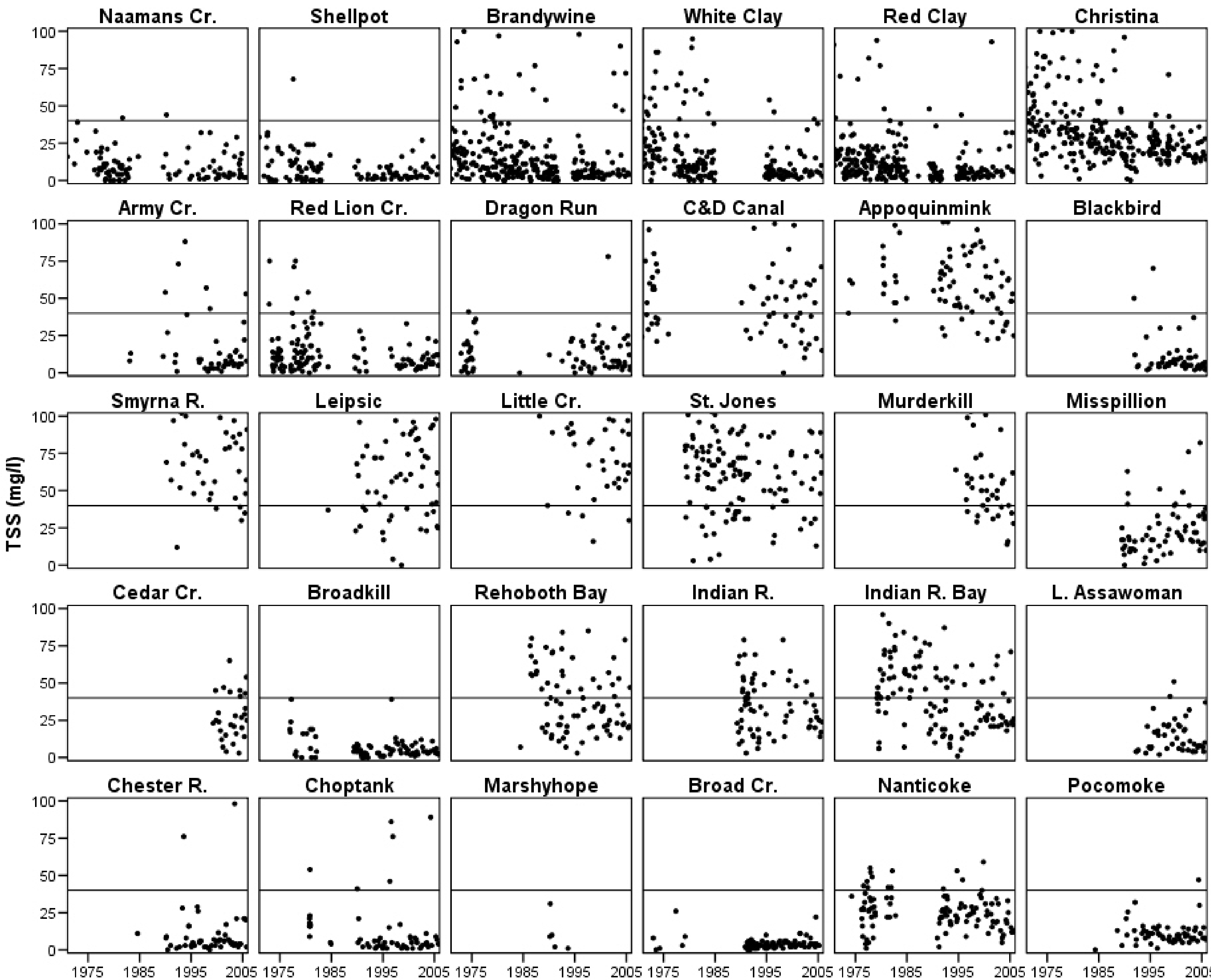
Blackbird
Smyrna R.
Leipsic
Little Cr.
St. Jones
Murderkill
Misspillion
Cedar Cr.
Broadkill
Rehoboth Bay
Indian R.
Indian R. Bay
L. Assawoman
Chester R.
Choptank
Marshyhope
Broad Cr.
Nanticoke
Pocomoke
TSS (mg/l)
0
25
50
75
100
'71-'75
'81-'85
'91-'95
'01-'05



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White Clay
Red Clay
Christina
Army Cr.
Red Lion Cr.
Dragon Run
C&D Canal
Appoquinmink
Blackbird
Smyrna R.
Leipsic
Little Cr.
St. Jones
Murderkill
Misspillion
Cedar Cr.
Broadkill
Rehoboth Bay
Indian R.
Indian R. Bay
L. Assawoman
Chester R.
Choptank
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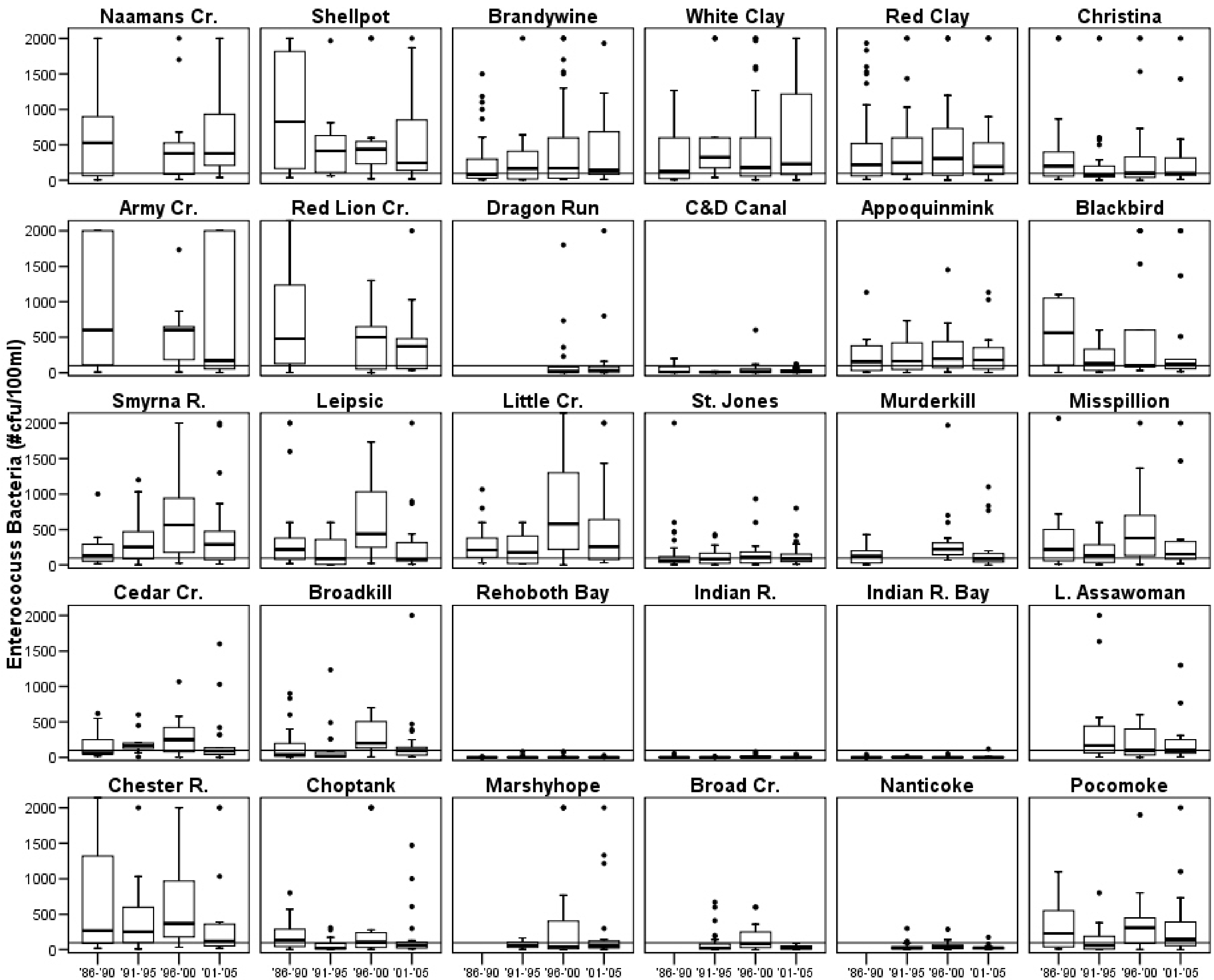
Broad Cr.
Nanticoke
Pocomoke
TSS (mg/l)
0
25
50
75
100
1975
1985
1995
2005



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Army Cr.
Red Lion Cr.
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C&D Canal
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Blackbird
Smyrna R.
Leipsic
Little Cr.
St. Jones
Murderkill
Misspillion
Cedar Cr.
Broadkill
Rehoboth Bay
Indian R.
Indian R. Bay
L. Assawoman
Chester R.
Choptank
Marshyhope
Broad Cr.
Nanticoke
Pocomoke
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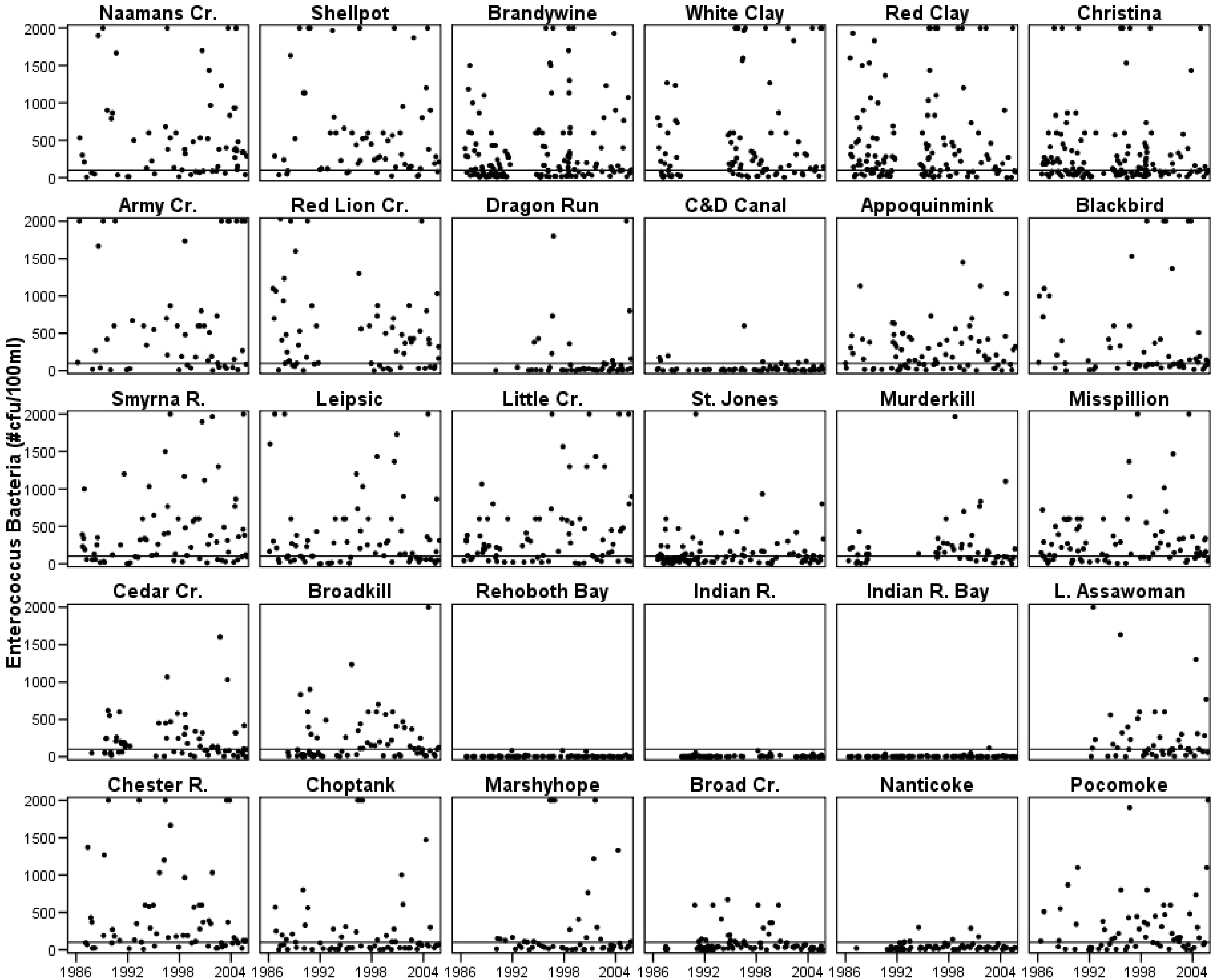
0
500
1000
1500
2000
'86-'90
'91-'95
'96-'00
'01-'05



Enterococcus Bacteria (#cfu/100ml)
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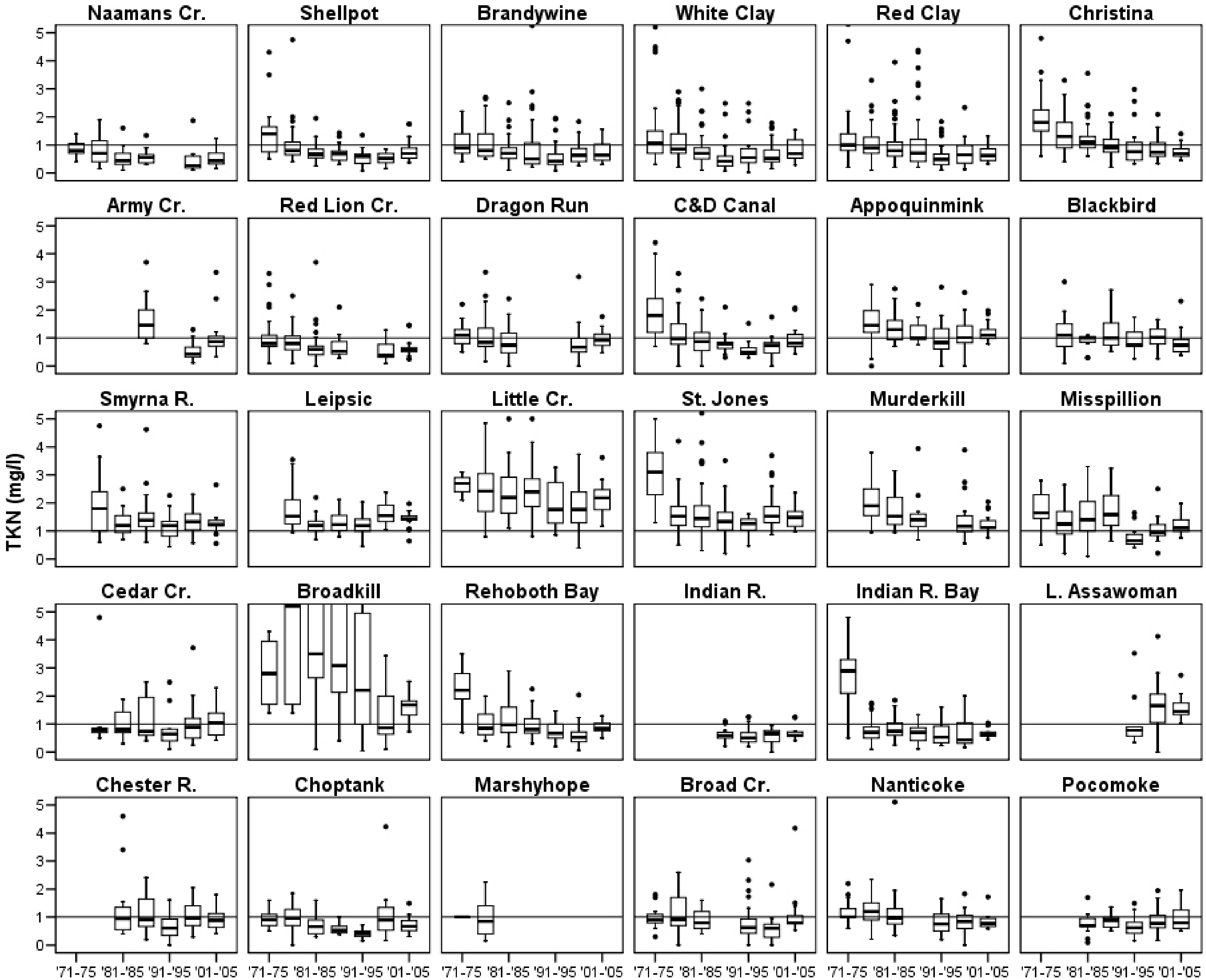
Brandywine
White Clay
Red Clay
Christina
Army Cr.
Red Lion Cr.
Dragon Run
C&D Canal
Appoquinmink
Blackbird
Smyrna R.
Leipsic
Little Cr.
St. Jones
Murderkill
Misspillion
Cedar Cr.
Broadkill
Rehoboth Bay
Indian R.
Indian R. Bay
L. Assawoman
Chester R.
Choptank
Marshyhope
Broad Cr.
Nanticoke
Pocomoke
0
500
1000
1500
2000
1986
1992
1998
2004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Red Lion Cr.
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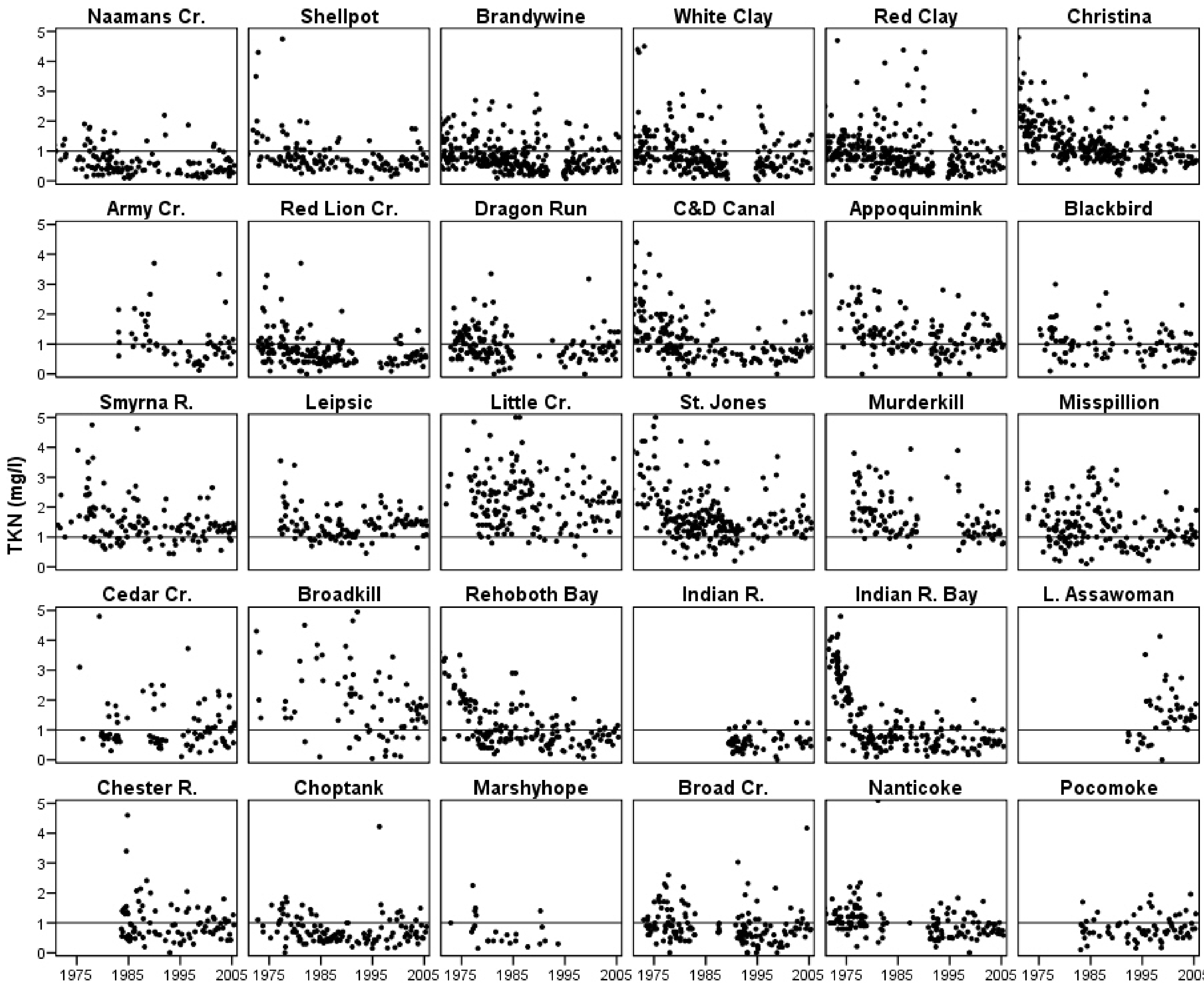
C&D Canal
Appoquinmink
Blackbird
Smyrna R.
Leipsic
Little Cr.
St. Jones
Murderkill
Misspillion
Cedar Cr.
Broadkill
Rehoboth Bay
Indian R.
Indian R. Bay
L. Assawoman
Chester R.
Choptank
Marshyhope
Broad Cr.
Nanticoke
Pocomoke
TKN (mg/l)
0
1
2
3
4
5
'71-'75
'81-'85
'91-'95
'01-'05



Naamans Cr.
Shellpot
Brandywine
White Clay
Red Clay
Christina
Army Cr.
Red Lion Cr.
Dragon Run
C&D Canal
Appoquinmink
Blackbird
Smyrna R.
Leipsic
Little Cr.
St. Jones
Murderkill
Misspillion
Cedar Cr.
Broadkill
Rehoboth Bay
Indian R.
Indian R. Bay
L. Assawoman
Chester R.
Choptank
Marshyhope
Broad Cr.
Nanticoke
Pocomoke
TKN (mg/l)
0
1
2
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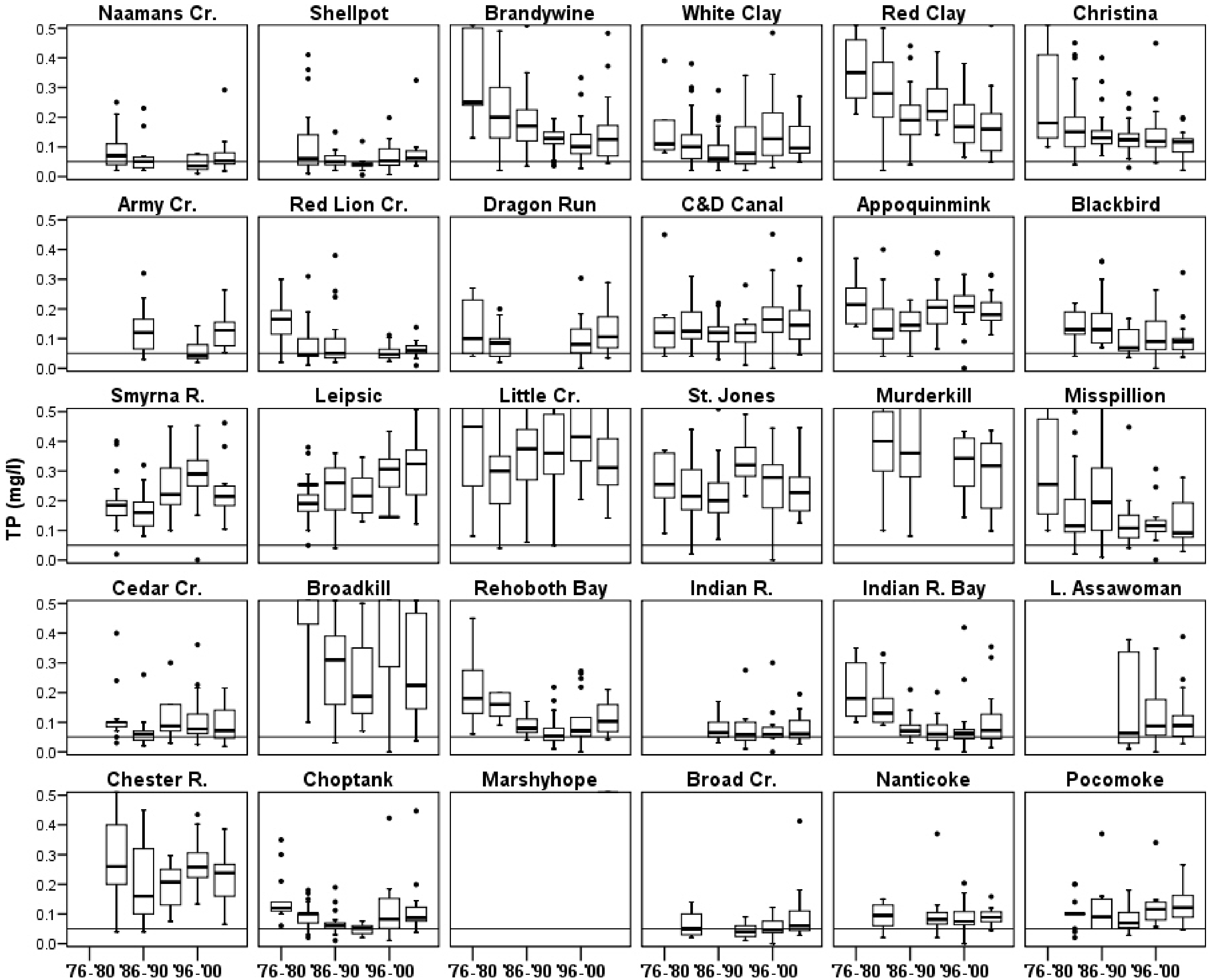
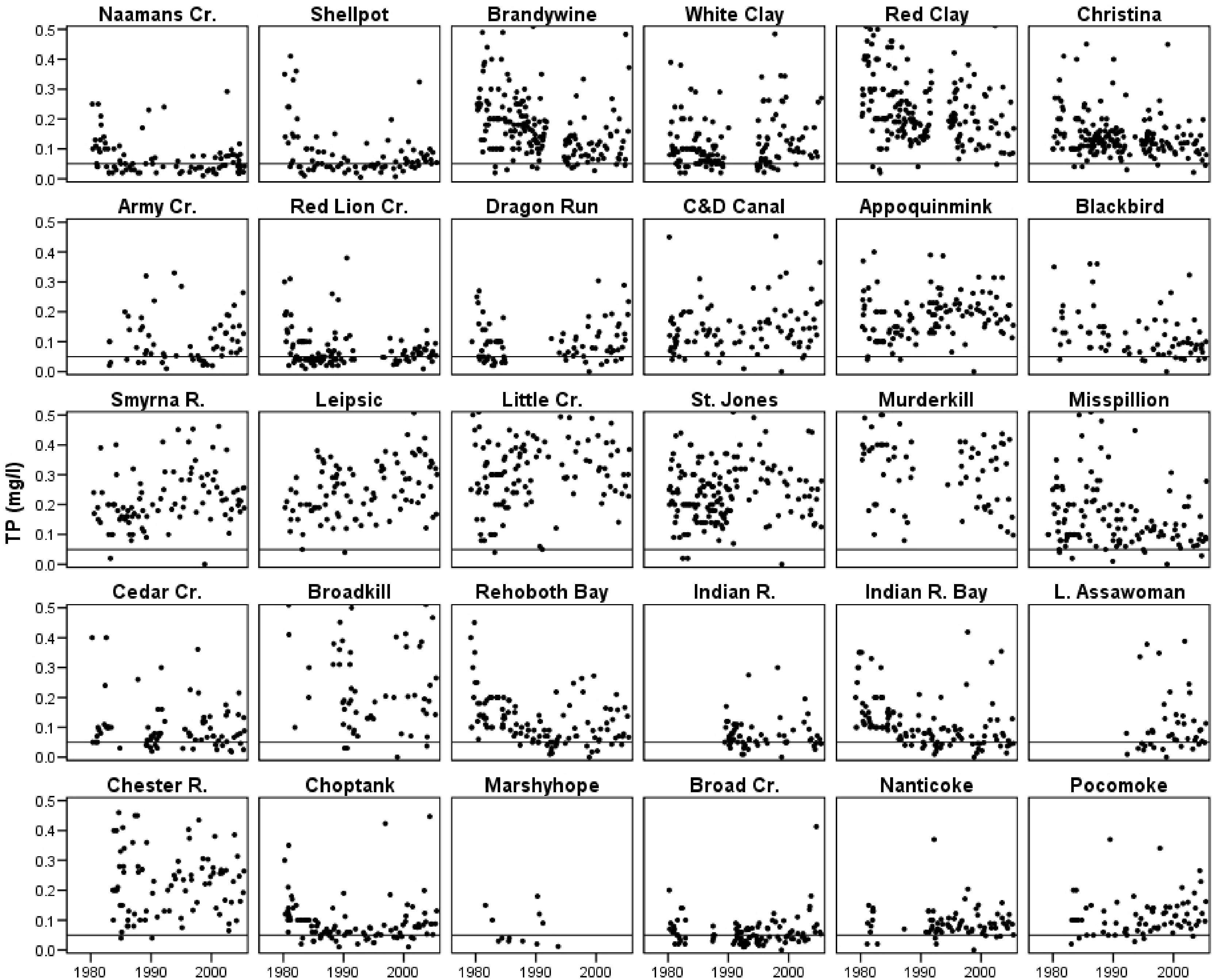
1975
1985
1995
2005


Naamans Cr.
Shellpot
Brandywine
White Clay
Red Clay
Christina
Army Cr.
Red Lion Cr.
Dragon Run
C&D Canal
Appoquinmink
Blackbird
Smyrna R.
Leipsic
Little Cr.
St. Jones
Murderkill
Misspillion
Cedar Cr.
Broadkill
Rehoboth Bay
Indian R.
Indian R. Bay
L. Assawoman
Chester R.
Choptank
Marshyhope
Broad Cr.
Nanticoke
Pocomoke
TP (mg/l)
0.0
0.1
0.2
0.3
0.4
0.5
'76-'80
'86-'90
'96-'00



Naamans Cr.
Shellpot
Brandywine
White Clay
Red Clay
Christina
Army Cr.
Red Lion Cr.
Dragon Run
C&D Canal
Appoquinmink
Blackbird
Smyrna R.
Leipsic
Little Cr.
St. Jones
Murderkill
Misspillion
Cedar Cr.
Broadkill
Rehoboth Bay
Indian R.
Indian R. Bay
L. Assawoman
Chester R.
Choptank
Marshyhope
Broad Cr.
Nanticoke
Pocomoke
TP (mg/l)
0.0
0.1
0.2
0.3
0.4
0.5
1980
1990
2000