SURFACE WATER

Surface water is all the visible water on the Earth's surface. In all its forms, including oceans, lakes, rivers, streams, and wetlands, surface water covers more than 70% of the Earth. Surface water is critical to all life cycles; it houses resources, nutrients, minerals, and energy, and provides a three-dimensional medium for flora and fauna.

Delaware has diverse surface-water resources, from faster-moving Piedmont streams to slow-moving Coastal Plain streams, the Delaware Bay and Inland Bays estuaries, and many tidal rivers containing fresh or brackish waters. Delaware surface waters support uniquely diverse fish and wildlife populations, provide multiple recreational opportunities, and provide approximately 70% of the drinking water supply for New Castle County.

The progress of humankind has taken its toll on surface water quality. Recent improvements have helped, but pollution is still a major concern. As recently as 1975, Delaware routinely experienced serious water pollution and public health problems as a result of the discharge of untreated sewage and wastes. Since then, as a result of voluntary efforts, regulatory actions, and significant private and public investments in wastewater treatment facilities, localized improvements in water quality have been achieved.

The need for additional cleanup and pollution prevention continues. The focus of water-quality management has shifted from point source discharges (end-of-pipe) to decreased stream flows and nonpoint source problems, such as urban and agricultural runoff, erosion, and sedimentation. Unaddressed, these problems lead to poor habitat conditions for fish and other aquatic life, decreased enjoyment of our surface waters for recreation, and unhealthy conditions for those surface waters upon which we rely for drinking water and other domestic uses.

As a result of water-quality protection programs that are in place in Delaware, surface-water quality generally has remained fairly stable in spite of increasing development and population growth. Impacts to waters are generally the result of past practices or contamination events, activities that are not regulated nor otherwise managed, or changes that are occurring on a larger regional scale. For example, air pollutants from sources outside of Delaware contaminate Delaware's surface waters via rainfall.

Improvements in water quality have been documented in localized areas where a discharge was eliminated or better treatment was installed. Basin-wide water-quality improvements in waters being impacted by historical contamination and yet unquantified pollution sources are very difficult to detect over a short period of time. Targeted monitoring over long periods (years) is necessary in order to detect changes.

Although Delaware's surface-water quality may not have changed significantly over the last several years, there have been many improvements in watershed assessment approaches and methodologies. Additionally, many water-quality criteria are stricter as a result of amendments to the state's Water Quality Standards. Therefore, we have become more proficient at identifying water-quality problems and, at the same time, are calling for higher-quality waters.

The stability of Delaware's surface-water quality is likely the result of increased efforts to control both point and nonpoint sources of pollution. In addition to the significant investments in wastewater treatment technologies previously mentioned, many private business interests are investing in practical and cost-effective nonpoint source pollution control practices (Best Management Practices) on farms, residential developments, and commercial and industrial sites. Likewise, public agencies such as the Delaware Department of Transportation are investing revenues in improved stormwater management practices and wetlands creation to mitigate the impacts of maintenance and new highway construction activities.

Stream Characteristics

The White Clay Creek, Red Clay Creek, Brandywine Creek, and Christina River are part of a common hydrologic unit in southeastern Pennsylvania, northern Delaware, and northeastern Maryland known as the Christina Sub-basin. The sub-basin contains waters of high recreational use and ecological significance and also is used as a public drinking water supply in both Pennsylvania and Delaware. In addition, lands within the sub-basin have high historical and cultural value.

The White Clay Creek, Red Clay Creek, and Brandywine Creek are tributaries of the Christina River and flow southward out of the Piedmont geologic province in Pennsylvania and into Delaware near Newark, Yorklyn, and Wilmington, respectively. The headwaters of the Christina River lie within the state of Maryland and enter Delaware west of Newark. Collectively, the White Clay, Red Clay, Brandywine and upper Christina are used to supply drinking water to more than 50% of New Castle County's population. Except for their very lower reaches, which are tidal, the White Clay, Red Clay, and Brandywine creeks are free-flowing streams. The Christina River is tidal from just south of the town of Christiana to its confluence with the Delaware River at Wilmington. The Red and White Clay creeks converge in the vicinity of Stanton, Delaware, and the combined flow empties into the tidal Christina near Churchmans Marsh. Extensive tidal freshwater wetlands, including Churchmans Marsh, exist along the lower Christina. The Brandywine Creek flows through Wilmington and enters the Christina River just before the Christina flows into the Delaware River.

A host of water resource issues have arisen within the Christina Sub-basin over the past several years. These include interstate and intrastate coordination of monitoring, modeling, and pollution controls; balancing increased demands for potable water with minimum pass-by requirements for aquatic life; protection of high-quality, yet vulnerable areas; timely evaluation and cleanup of hazardous waste sites; and restoration of wetlands and other critical habitats. This survey plan is primarily intended to address the first issue: inter- and intrastate coordination of monitoring, modeling, and pollution controls. Interstate coordination is needed to ensure adequate spatial coverage of the basin and to ensure consistency between Pennsylvania and Delaware on basic issues such as monitoring objectives, sample frequency and sample timing, parameter coverage, and analytical methods. Consistency on these basic issues will make subsequent modeling work easier and more defensible.

Hydrodynamics of the Christina River

Lower portions of the Christina River, and the White Clay, Red Clay, and Brandywine creeks are under tidal influence. Accurate information about physical characteristics of the Christina River and its main tributaries are needed in order to develop and calibrate a hydrodynamic and water-quality model of the river. The following is a brief review of the available information.

Tidal Elevations

Currently, the U.S. Geological Survey (USGS), through a cooperative agreement with DNREC, is maintaining two tide gauges in the Christina River. They are located at the Marine Terminal, Wilmington, and at the Rte. 141 Bridge, Newport, and have been in operation since 1993. In addition, the Water Resources Agency for New Castle County is operating and maintaining a tide gauge at White Clay Creek just above the Amtrak railroad bridge (see Map 7). Tidal elevations at these sites are monitored every 15 minutes (see Figure 2). Information collected at these gauging stations will be used to develop and calibrate the hydrodynamic model of the Christina River.

Tidal Currents

The tidal currents of the Christina River were surveyed during the summer of 1994 by USGS through a cooperative agreement with DNREC. During these surveys, mid-channel tidal velocity was measured at the Wilmington and Newport gauge sites every 15 minutes for a full tidal cycle. Figure 3 summarize the results of these surveys.

Information collected during these surveys will be used to develop and calibrate the hydrodynamic and water-quality model of the Christina River.

Bathymetry

The latest bathymetric surveys of the Christina River and its main tributaries were conducted during summer 1994.

Figure 2
TIDAL ELEVATIONS AT MARINE TERMINAL, WILMINGTON, AND AT RTE. 141 BRIDGE, NEWPORT (AUGUST 3 – 6, 1995)

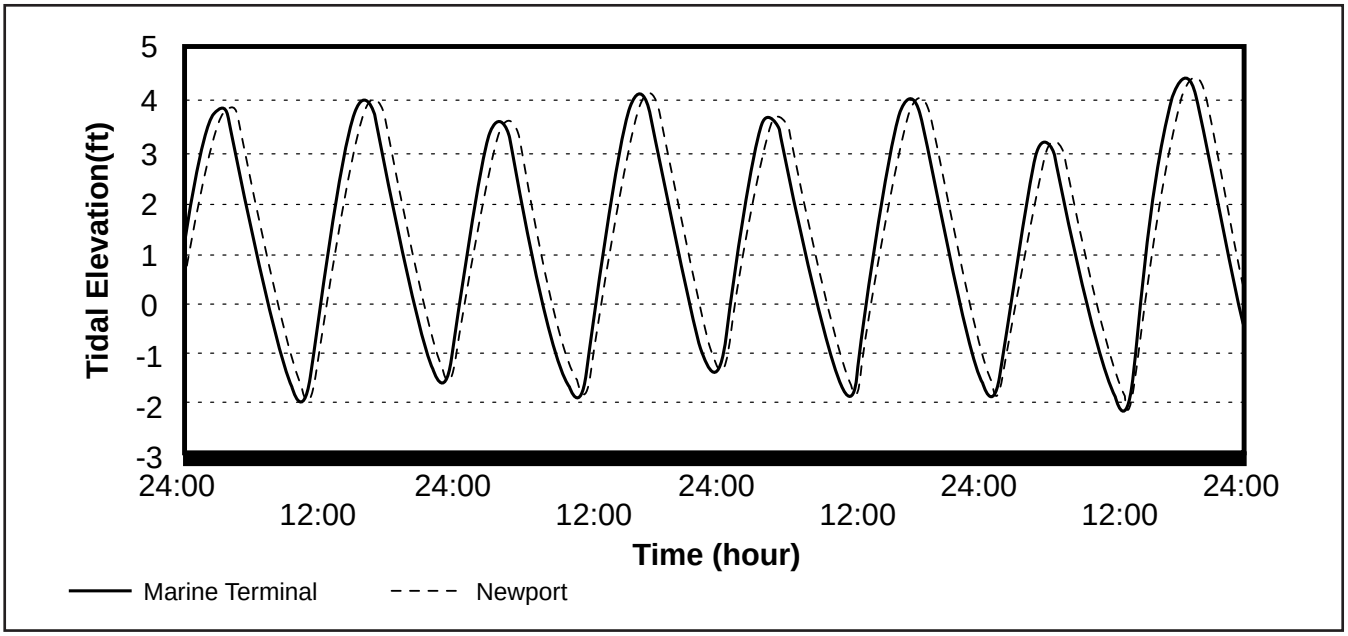


Figure 3
TIDAL VELOCITY AT MARINE TERMINAL, WILMINGTON,
AND RTE. 141 BRIDGE, NEWPORT (MAY 17 AND 19, 1994)

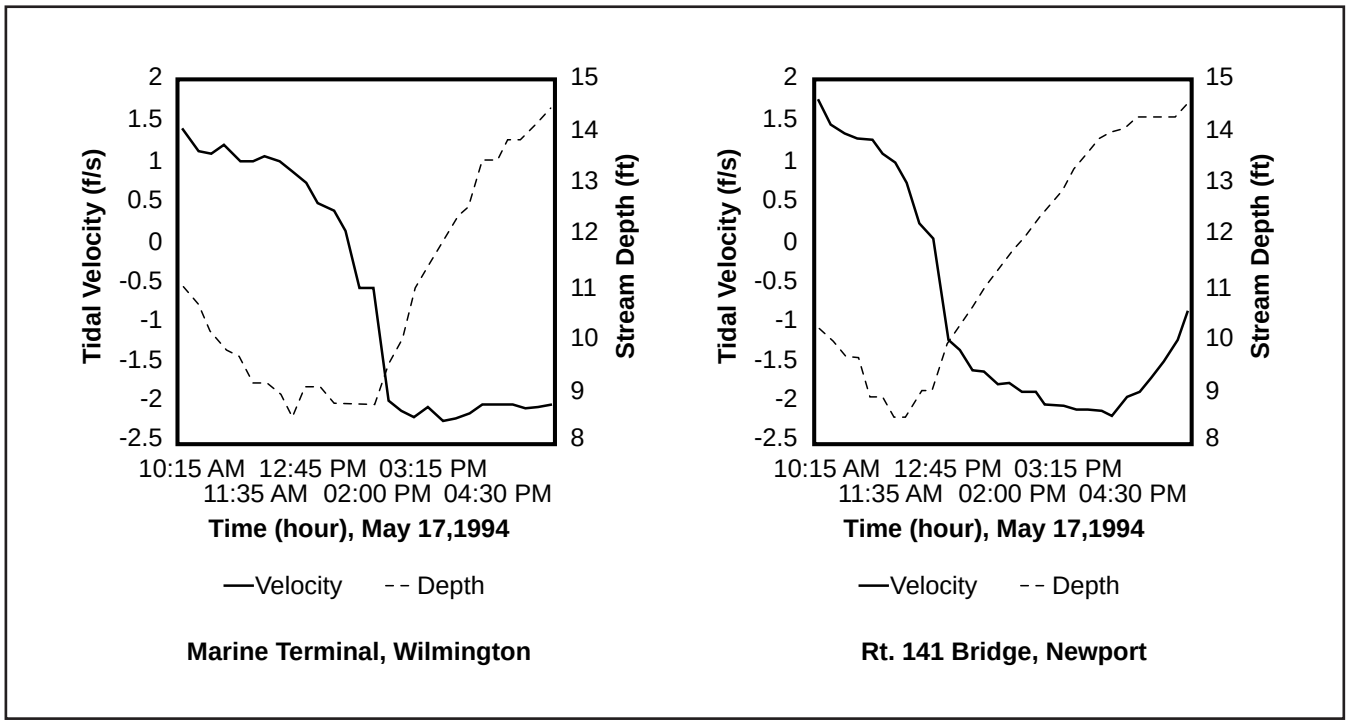
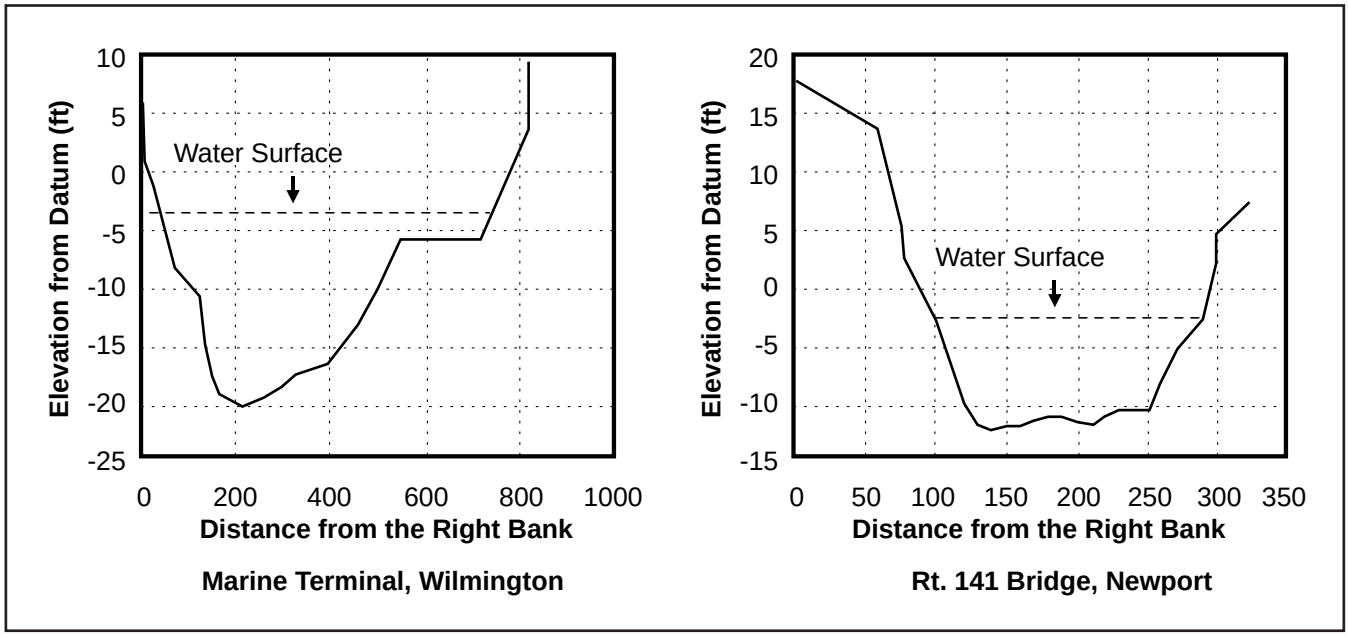


Figure 4
CHRISTINA RIVER BATHYMETRY AT MARINE TERMINAL,
WILMINGTON, AND AT RTE. 141 BRIDGE, NEWPORT (SUMMER 1994)



During these surveys, cross-sectional profiles at 10 locations along the Christina River, White Clay Creek, Red Clay Creek, and Brandywine Creek were surveyed. The location of these sites is shown on Map 7; bathymetric profiles of two sites are shown in Figure 4.

Information obtained during these surveys, along with previous bathymetric studies performed by other agencies including the Federal Emergency Management Agency, will be used to develop and calibrate a hydrodynamic and water-quality model of the Christina River.

Stream Flows And Gauging Stations

Currently, there are seven USGS stream-flow gauging stations in the Delaware portion of the Christina River Sub-basin (Map 8). General information about these stations, such as locations, the size of the catchment areas, and annual and seven-day ten-year low flows (7Q10) are shown in Table 8.

Meteorological Data

Three long-term meteorological stations are currently in operation in the Delaware portion of the Christina River Sub-basin. Information about these stations is provided in Table 8, and their locations are shown on Map 8. At these stations, daily meteorological data such as temperature, precipitation, and wind speed are recorded and maintained by the Northeast Regional Office of the National Weather Service.

Detailed meteorological data collected at these stations will be used to develop and calibrate the watershed model for the Christina River Sub-basin.

Table 8

WEATHER STATIONS IN THE CHRISTINA RIVER SUB-BASIN

STATION	STATION NO.	LATITUDE	LONGITUDE	DATA SINCE	OPERATED BY
Newark University Farm	076410	39° 40′	75° 44′	8/1/48	University of Delaware, Agriculture Farm
Wilmington WSO Airport	079595	39° 40′	75° 36′	8/1/48	National Weather Service
Wilmington Porter Reservoir	079605	39° 46′	75° 32′	8/1/48	City of Wilmington

Trends

Surface Water Quality Assessment

This section reports the findings of the preliminary assessment of water-quality data for the Piedmont Basin. For this assessment, data from over 34 sampling locations were analyzed. Sampling locations were distributed along the Christina River, Brandywine Creek, Red Clay Creek, White Clay Creek, Naamans Creek, and Shellpot Creek in Delaware. For each sampling location, up to 22 water-quality parameters were analyzed, including chemical and physical parameters, bacteria, nutrients, and metals.

Water-quality data assessed in the study were retrieved from the EPA's Water Quality Information System and were manipulated or treated before applying statistical methods because of missing values, censored values, outliers, multiple observations within a month, and small sample sizes.

This preliminary study characterized the water and identifies existing and potential water-quality problems in streams through trend and status analysis. It applied all three types of statistical analysis methods — graphical method, estimation method, and test of hypotheses —on each parameter for each sampling location. The study also identified and discussed data gaps that affected the statistical analysis.

The assessment revealed many existing and potential water-quality problems. In some cases, water-quality criteria were frequently violated or trends indicated potential future problems, or both.

- Enterococcus bacteria concentrations frequently exceeded criteria throughout the Piedmont Basin.
- Zinc exceedances of criteria occurred frequently along Red Clay Creek.
- Iron violations of criteria occurred along the lower reach of the Christina River.
- Total phosphorus excessive concentrations (average above 0.1 mg/l) support the concern for nutrient over-enrichment in the Christina River, Brandywine Creek, Red Clay Creek, and White Clay Creek watersheds; however, concentrations are on the decline.
- Dissolved-oxygen concentrations decreased steadily within the last 26 years in the entire Piedmont Basin, although criteria were not violated frequently. Therefore, trends indicate that future violations will occur frequently.
- Nitrate-nitrogen increasing trends in the Christina River, Brandywine Creek, Red Clay Creek, and White Clay Creek during 1970 to 1990 suggest that water quality had declined and will continue to decline in these regions.

Data Selection and Description

Water-quality data for this analysis were retrieved from the EPA's Water Quality Information System called STORET (STOrage and RETrieval). Stream-flow data were collected from USGS flow records. The Piedmont Basin has been monitored for over 26 years. During this time, DNREC's stream water-quality monitoring protocol changed due mainly to resource constraints. This caused difficulty for the statistical analysis of the data. In briefly examining available data stored in the STORET system, we noticed problems such as (1) short records for some stations and parameters; (2) changes in frequency, location, and method of measurement; (3) significant variations in monitoring period among stations; (4) many missing data points; and (5) lack of monitoring protocols to support important correlative data analyses, such as stream flow and conductivity along with other water-quality data. These shortcomings restricted this assessment to statistical analysis in carefully selected stations and water-quality parameters.

Thirty-four stream water-quality monitoring stations were determined suitable and thus were selected for this study. Such selection considered the following factors: (1) each station's strategic location in the watershed, (2) each station's representativeness of an area and of a pollutant of concern, and (3) each station's data availability in terms of data record length and value to support statistical analysis. These 34 stations are listed in Table 9 and marked on Map 9.

Initially, data for 50 water-quality parameters were retrieved for each of the chosen stations. However, for the analysis, many parameters were questionable. After careful review, the data were narrowed down to 22 parameters (see Table 10) with data quality suitable for the study.

As with any water-quality data, these data are also characterized by censored values, missing values, outliers, and field replicates (multiple observations within a time interval), as well as seasonal patterns and serial correlations. These kinds of data have to be treated before using them for statistical analysis. Treatments for censored values, missing values, seasonal patterns, and serial correlation are associated with specific analytical methods.

The treatments for outliers and multiple observations used for all analyses are as follows. Multiple observations within a month interval were averaged to obtain a single value for the month. Outliers were identified by examining data graphically and analytically. Suspected values were verified by the laboratory before removal from the records.

Preliminary Assessment Approaches

To reach the objectives, the assessment team employed statistical methods to analyze the water-quality data. The two general categories of the analysis were status analysis and trend analysis. Status analysis evaluated average condition and extreme condition (excursion) of water quality. Trend analysis detected both sudden and gradual changes of water quality over time. Based on the analysis results, the existing and potential water-quality problems were easily identified. Data gaps were also becoming clear during the process of preparing data for each statistical analysis with each parameter. This section provides an explanation about how these analyses were performed and what data sets were used.

Average-Condition Analysis

Average-condition analysis provides a general overview of how good or poor the water is by describing the general situation of a given water body. It consists of calculating mean, median, standard deviation, skew coefficient, and quartiles for each individual water-quality parameter at each station and displaying the data graphically.

To differentiate most-current condition from historical background condition, this analysis examined most current data separately from historical data. A *current data set* includes the data collected between September 1991 and May 1996, whereas a *historical data set* contains all data collected before May 1996.

For current data, only the mean, median, and standard deviation were calculated. For historical data, a time series plot, a seasonal box plot, an annual box plot, and interquartile ranges were generated besides the calculation of the mean, median, standard deviation, and skewness. For the parameters of concern, multiple Box-and-Whisker plots were also generated.

Extreme-Condition Analysis

Extreme-condition (excursion) analysis provides information on how observed water quality compares with Delaware's water-quality standards. Analyzed were those parameters that have applicable water-quality criteria. Table 11 lists these criteria and their origins. Under those parameters, the current data sets (September 1991 to May 1996), as defined in the *Average-Condition Analysis*, were used. In the extreme-condition analysis, each value of a data set was compared against the criteria. Exceedances of a specific criterion were accounted and reported in a percentage over the total reviewed data points.

Gradual Trend Analysis

Trend analysis, in this case, refers to the detection of a gradual increase or decrease of a pollutant concentration over time. It is used in determining if water quality has changed (become *better* or *worse)* at particular locations over specific periods.

Table 9

SELECTED MONITORING STATIONS

STATION NUMBER	LOCATION	RIVER MILE
Christina River		
106011	US Rte. 13 at 3rd St. Bridge	70.8/2.1
106021	DE Rte. 141 at drawbridge, Newport	70.8/6.9
106031	Smalleys Dam spillway	70.8/13.6
106111	Road 346 Bridge	70.8/15.4
106121	Becks Pond at Salem Church Road	70.8/17.0/0.1/0.5
106131	Sunset Lake at Sunset Lake Road	70.8/17.0/1.7
106141	Road 26 at Old Baltimore Pike	70.8/20.4
106161	West Branch at DE Rte 2	70.8/20.9/1.0
106171	Sandy Brae Road at Persimmon Run	70.8/20.9/0.6/0.3
106181	DE Rte. 2 at Elkton Road	70.8/23.5
106191	DE Rte. 273 above Newark	70.8/25.5
Brandywine Creek		
104011	Foot Bridge in Brandywine Pike	70.8/1.5/3.0
104021	Road 279 Bridge, DuPont Experimental Station	70.8/1.5/4.6
104051	Smith Bridge	70.8/1.5/9.6
Red Clay Creek		
103011	DE Rte. 4 at Stanton Bridge	70.8/10.0/1.5/0.8
103021	Road 332 in Marshallton	70.8/10.0/1.5/1.72
103031	DE Rte. 48 at Woodale, USGS 01480000	70.8/10.0/1.5/4.35
103041	Road 258A in Ashland	70.8/10.0/1.5/8.73
103051	Road 252 in Yorklyn	70.8/10.0/1.5/10.3
103061	Confluence of Burroughs Run with Red Clay Creek, Rte. 241 at bridge	70.8/10.0/1.5/8.4
White Clay Creek		
105011	DE Rte. 7 Bridge, Stanton	70.8/10.0/2.9
105021	DE Rte. 2 Bridge near Newark	70.8/10.0/8.0
105031	Road 329 near Thompson's Bridge	70.8/10.0/13.1
105041	East side of DE Rte. 72 at bridge	70.8/10.0/9.8
105071	Just above the confluence with Mill Creek	
105101	Pike Creek at Road 322	
105151	35-ft. downstream from a road owned by DE Racing Association	
Naamans Creek		
101011	Behind Phoenix Steel	
101021	Naamans Rd	
101031	South Branch behind housing	
Shellpot Creek		
102011	US Rte. 13 Bridge (Gov. Printz Blvd.)	
102021	Rd. 214 at Shipley Road	
102031	Matson Run, off US Rte. 13	
102041	Cherry Island, Road 501 Bridge	

Table 10

SELECTED WATER-QUALITY PARAMETERS

PARAMETER CODE	DESCRIPTION	UNIT
General Chemical and Physical		
00300	Dissolved oxygen	mg/l
00530	Total suspended solids	mg/l
00900	Total hardness as $CaCO_3$	mg/l
00400	pH	std unit
00010	Water temperature	°C
*****	Flow rate	cfs
04101	Alkalinity	mg/l
00940	Chloride	mg/l
00076	Turbidity	FTU
Bacteria		
31639	Enterococcus bacteria	#/100 ml
Nutrient		
00665	Total phosphorus	mg/l
00671	Dissolved phosphorus	mg/l
*****	Total nitrogen (TKN + NO_3 + NO_2 as N)	mg/l
00625	Total Kjeldahl nitrogen (TKN)	mg/l
00620	Nitrate nitrogen (NO_3 - N)	mg/l
00615	Nitrite nitrogen (NO_2 - N)	mg/l
00630	Combination of NO_3 - N & NO_2 - N	mg/l
00610	Ammonia nitrogen (NH_3 + NH_4^+ -N)	mg/l
Metal		
01045	Total iron	µg/l
01051	Total lead	µg/l
01055	Total manganese	µg/l
01092	Total zinc	µg/l

Methods. Trend analysis is performed by testing for the statistical significance of an apparent change (increase or decrease) in concentration over time. The Mann-Kendall Test and Seasonal Kendall Test were used since they are nonparametric and robust methods that can accommodate missing values and non-detects without gross effect on the results (Helsel and Hirsch, 1992; Gilbert, 1987). Generally, a Seasonal Kendall Test was used for data records of more than five years, and the Mann-Kendall test for data records of shorter length — less than five years (*WQStat User's Manual*, 1988). A trend was reported for a parameter over a specified period if the change was statistically significant (90% confidence level). If no trend was reported, it may be a result of one or more of the following: (1) no data, (2) short data record, (3) too many missing values in a defined period, and (4) no trends indeed. A step-by-step trend testing procedure is shown in Figures 5 and 6.

Besides knowing whether a trend exists, we need to estimate its magnitude. This magnitude is expressed as a slope (value per year). Closely related to the Seasonal Kendall and Mann-Kendall tests, the Seasonal Kendall Slope Estimator and Sen Slope Estimator were calculated to show the changes in magnitude.

Data Selections. Data used in this trend analysis include two subsets from available data for each parameter at each location. One subset is a *long-term data set*, which includes all data collected between 1970 and 1996. Usually, it has the same length as the *historical data set*. Another subset is a *short-term data set*, which consists of data collected between January 1984 and May 1996. A dilemma arose in deciding how long a record should be used for this trend analysis. A trend that is now in existence may have existed for only a few years or for a very long time, or may even be

Figure 5

TREND ANALYSIS WITH DATA RECORD LENGTH >5 YEARS

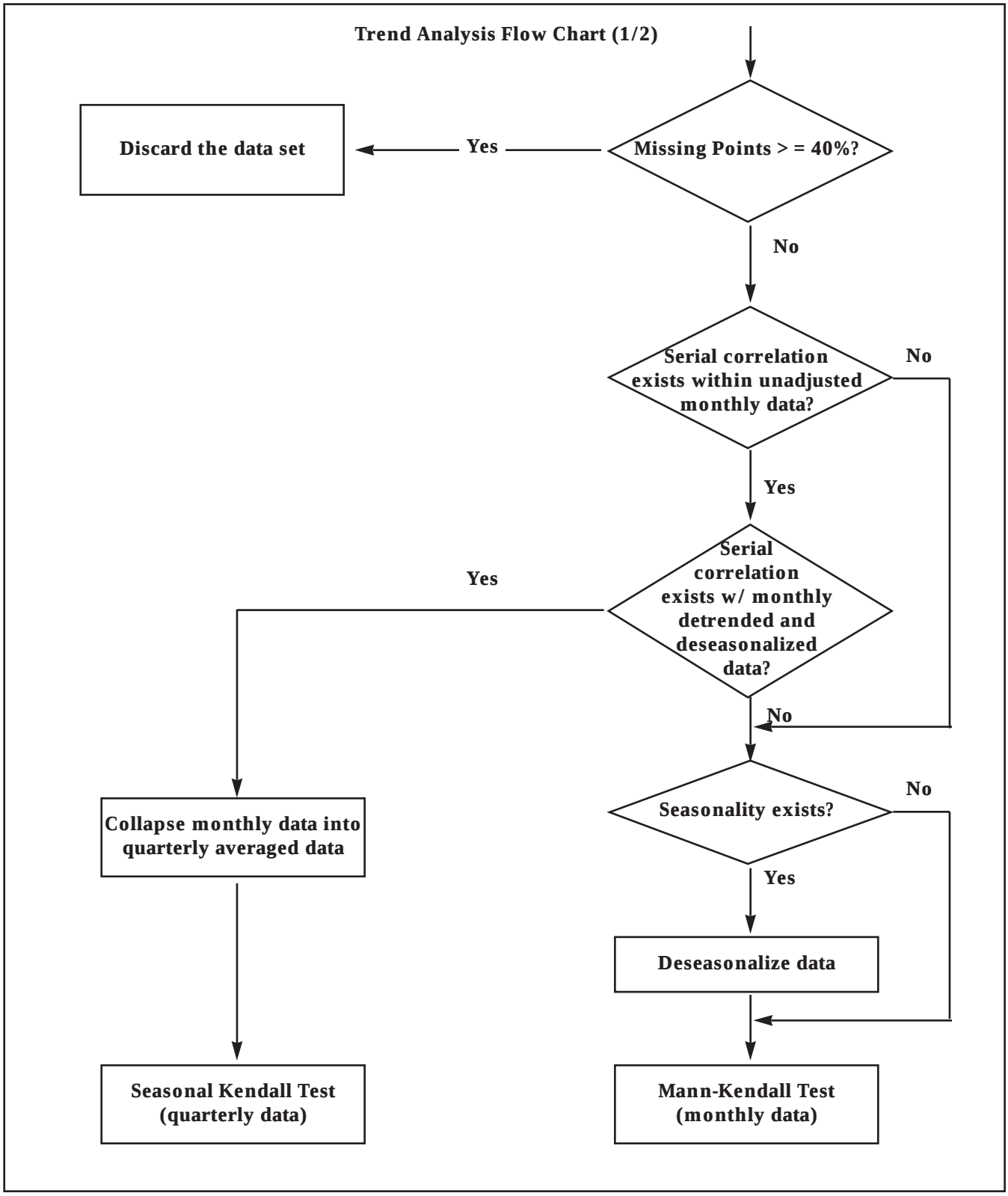


Figure 6
TREND ANALYSIS WITH DATA RECORD LENGTH ≤ 5 YEARS

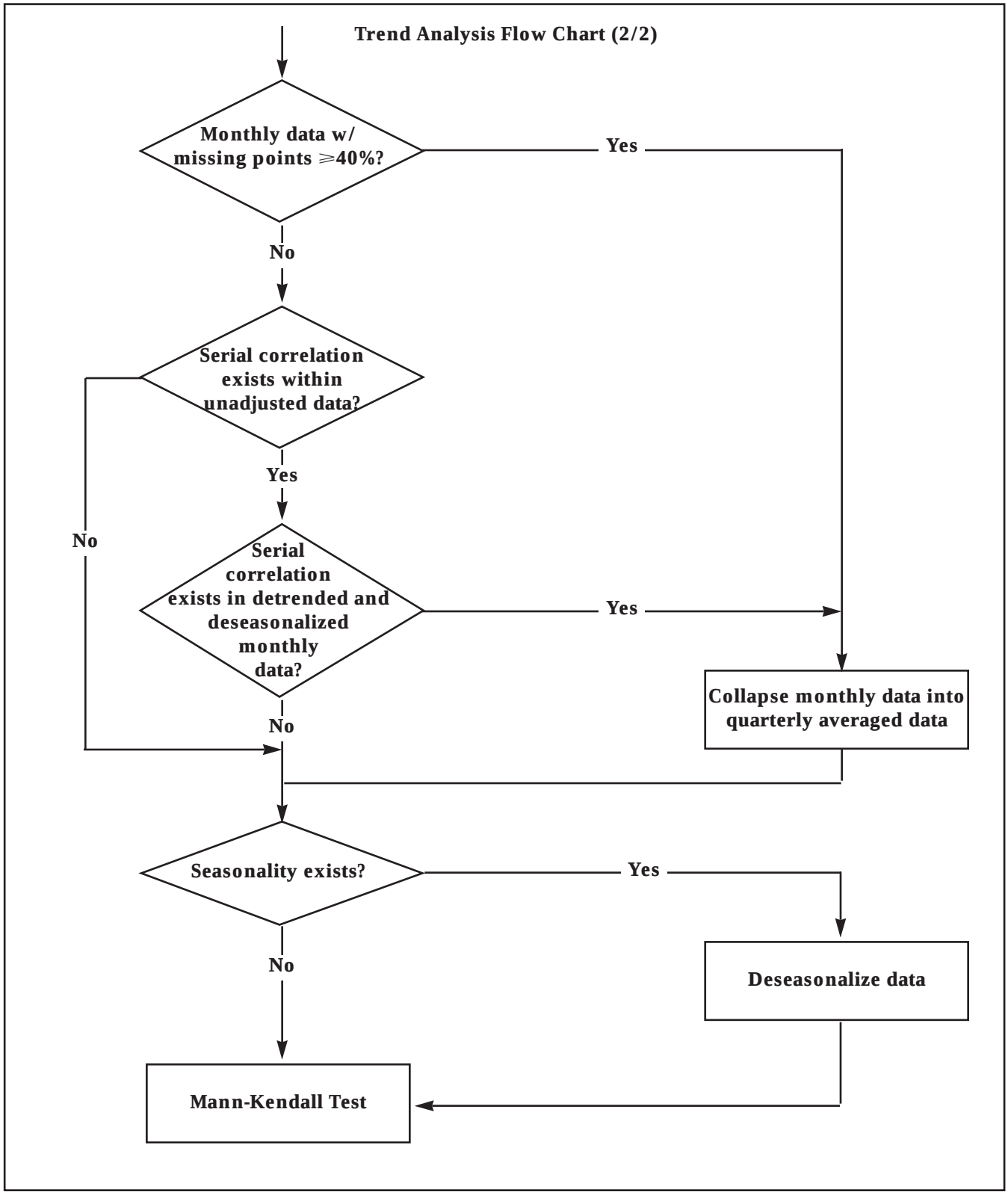


Table 11

WATER-QUALITY CRITERIA

PARAMETER	CRITERIA	ORIGIN*
Bacteria	Concentration $\leqslant 100^{\#}/100$ ml	A
DO	Daily average $\geqslant$ 5.5 mg/l for the June – Sept. period The minimum = 4.0 mg/l	A
pH	Within 6.5 – 8.5 su	A
Alkalinity	Conc. $\geqslant$ 20 mg/l as $CaCO_3$	A
Phosphorus	Conc. < 0.025 mg/l within a lake < 0.05 mg/l right before a stream entering a lake < 0.1 mg/l in streams not flowing directly into lakes	B
Iron	Conc. < 1000 μg/l chronically	A
Zinc	Conc. < $e^{(1.273[\ln(\text{hardness})]-1.460)}$ acutely < $e^{(1.273[\ln(\text{hardness})]-4.705)}$ chronically	A

*A — *State of Delaware Surface Water-Quality Standards [2].* B — *EPA Quality Criteria for Water [3].*

a reversal of a previous trend. If a very short record is used, it may not contain enough data to identify a trend or to distinguish it from the natural variability in the data. On the other hand, a long record may include opposite trends, or later data points in the record may offset the trend which appeared among the earlier data points. In spite of the dilemma, the two subsets as defined above were considered a reasonable, although arbitrary, choice of record length for this stage of study.

Data Treatment. As mentioned earlier, water-quality data have the characteristics of multiple observations, missing values, censored values, seasonal patterns, and serial correlation. These characteristics affect trend testing in various degrees. To reduce this effect, before trend testing, the data were treated for different situations as noted below:

- Any multiple observations within a month, such as from laboratory repeats or field replicates, were averaged to obtain a single value.
- In a record, if less than 40% of the data points were recorded as either non-detected or greater than values, the data set was considered valid for trend testing. Then, one-half of the detection limit was used to replace those non-detected points, and the detection limit was used to replace those greater than points (Helsel and Hirsch, 1992).
- If more than 40% of the data points were recorded as the censored values in a record, the record was considered not suitable for trend testing and thus was not used in the trend analysis (Helsel and Hirsch, 1992).
- For data showing seasonal patterns, the seasonal Kendall Test was used. Otherwise, the Mann-Kendall Test was used for trend testing (*WQStat User's Manual*, 1988).
- Quarterly averages, calculated by collapsing monthly averages, were used for data having serial correlations (Helsel and Hirsch, 1992; Gilbert, 1987).
- Possible influence of stream-flow variations on trend testing for an individual parameter was evaluated by testing the correlation between the parameter and stream flow. If the correlation was strong, flow-adjusted concentrations for this parameter were used in the trend test. Otherwise, non-adjusted data were used.

It is recognized that there are many confounding factors in stream water-quality analysis and that it is difficult, if impossible, to identify and account for all of them. However, by using the nonparametric methods and by collapsing data into quarterly values, the trend test gives us more confidence with its results (Helsel and Hirsch, 1992).

Computer Software. WQStat II, a water-quality statistics computer software developed by Colorado State University, was employed for trend analysis and trend-plot generation.

Notes about Trend Analysis. Although trend analysis can be very informative, there are a number of difficulties or

precautions that must be considered before drawing conclusions. To make trend analysis meaningful, at least five years' data are needed to be able to detect a trend reliably (*WQStat User's Manual*, 1988). For a record less than five years, it was reported as insufficient data. Furthermore, data must be collected using a consistent methodology over the length of a record, i.e., all sampling procedures and analytical methods should be the same over the period of a record. Any change made to sampling or analytical procedures may produce observed changes that are not related to environmental conditions. At this stage of analysis, identification of changes in data collection (including sampling and analytical procedures) was not conducted. Besides, even if statistically significant trends are detected, the absolute magnitude of the change may be very small and not be necessarily significant in terms of the overall water-quality perspective. So it is not always easy to explain the results of a trend analysis.

Step-Change Analysis

A step change is an abrupt change in water-quality concentration that may be caused by addition or elimination of a pollution source or by a change in data collection procedures. As with gradual trend analysis, step-change analysis does not examine the causes, but the change itself.

The change was evaluated by comparing the median values of the two data sets before and after the change was observed in a record. The first step was to visually examine the time-series plot to spot abrupt changes. When a change was identified, both median values before and after the abrupt changes were calculated. Then, the Mann-Whitney method was employed to test if the two median values were significantly different (at 95% confidence level). If it was, a step change was reported. Otherwise, no change was detected. The WQStat statistical software was used for this analysis, too.

Findings and Discussions

With the methods described above, each water-quality parameter at each station was analyzed for trend and status. In the results of the study, the characteristics of the water became clear, and major concerns surfaced, through parameters reflecting the existing and potential water-quality problems. This section briefly discusses these characteristics and concerns through the related parameters for each watershed.

Christina River

Enterococcus Bacteria. Evaluation of historical and current data sets demonstrated that enterococcus bacteria concentrations frequently violated the state water-quality standard. Excursion analysis showed that most stations had 25% of the data exceeding the criteria of 100 colonies/100 ml, suggesting that the river's use for swimming is not supported according to EPA guidelines (*305[b] Report*, 1993).

Dissolved Oxygen. Concentrations decreased steadily over the last 15 to 26 years (1970 to 1996, or 1977 to 1996) in large parts of the watershed. Although the dissolved oxygen concentration showed compliance with the state water-quality standard, the long-term decreasing trends signal deterioration of water quality with respect to dissolved oxygen. The areal distribution of trends is shown in Map 10.

Total Suspended Solids. For the last 26 years, total suspended solids had a decrease in large parts of the watershed. This indicates that water quality has improved during this long period in regard to solids.

Phosphorus. The total phosphorus concentration (average above 0.1 mg/l) supports the concern about nutrient enrichment in large parts of the watershed, as indicated in Map 11. Excursion analysis showed that the lower part of the river (Stations 106011 to 106031) exceeded the EPA-recommended criterion of 0.1 mg/l more than 68% of the time.

Nitrogen-to-phosphorous ratios were calculated at each station for possible limiting nutrient in the eutrophication process (Davis, 1993). The ratios of total nitrogen to total phosphorus at all stations were well above 10, which suggests that phosphorus may be the limiting nutrient in the watershed.

Decreasing trends of total phosphorus were detected in large parts of the watershed during 1980 to 1996, although the magnitudes of the decrease were very small. Map 12 shows the areal distribution of the detected trend in the watershed.

Nitrate-Nitrogen. An increasing trend of nitrate-nitrogen in large parts of the watershed during 1970 to 1990 suggests that water quality had declined in these regions. The areal distribution of trends is shown in Map 13.

Iron. Iron concentrations violated the state water-quality standard along the lower reaches of the Christina River (from Station 106011 to Station 106031). Historical and current data showed that average concentrations of total iron were above the criterion of 1000 µg/l, and more than 55% of current data exceeded the criterion.

Brandywine Creek

Enterococcus Bacteria. Evaluation of historical and current data sets demonstrated that enterococcus bacteria concentrations frequently violated the state water-quality standard. Excursion analysis showed that more than 48% of the data exceeded the criteria of 100 colonies/100 ml throughout the watershed, suggesting that the use for

swimming is not supported according to EPA guidelines (*305[b] Report*, 1993).

Dissolved Oxygen. Concentrations have decreased steadily over the last 26 years, from 1970 to 1996, throughout the watershed. Although dissolved oxygen concentration showed compliance with the state water-quality standard, the long-term decreasing trends signal deterioration of water quality with respect to dissolved oxygen. The areal distribution of the trends is shown in Map 10.

Total Suspended Solids. For the last 26 years, total suspended solids decreased throughout the watershed. This indicates that water quality has improved during this period in regard to solids.

Phosphorus. Total phosphorus concentrations (average above 0.1 mg/l) support the concern about nutrient enrichment throughout the watershed, as indicated in Map 11. Excursion analysis showed that total phosphorus at all stations exceeded the EPA-recommended criterion of 0.1 mg/l more than 55% of the time.

Nitrogen-to-phosphorus ratios were calculated at each station for possible limiting nutrient in the eutrophication process (Thomann, 1987). The ratios of total nitrogen to total phosphorus at all stations were above 10, which suggests that phosphorus may be the limiting nutrient in the watershed.

Decreasing trends of total phosphorus were detected throughout the watershed during 1980 to 1996, although the magnitudes of the decreases were very small. Map 12 shows the areal distribution of the detected trend in the watershed.

Nitrate-Nitrogen. A widespread increasing trend of nitrate-nitrogen during 1970 to 1990 suggests that water quality has declined in the watershed. The trend distribution is shown in Map 13.

Red Clay Creek

Enterococcus Bacteria. Evaluation of historical and current data sets demonstrated that enterococcus bacteria concentrations frequently violated the state water-quality standard. Excursion analysis showed that more than 50% of the data exceeded the criteria of 100 colonies/100 ml throughout the watershed, suggesting that the use for swimming is not supported according to EPA guidelines (*305[b] Report*, 1993).

Dissolved Oxygen. Concentrations decreased steadily over the last 15 to 26 years in large parts of the watershed. Although the dissolved-oxygen concentration showed compliance with the state water-quality standard, the long-term decreasing trends signal deterioration of water quality with respect to dissolved oxygen. The areal distribution of the trends is shown in Map 10.

Total Suspended Solids. For the last 26 years, total suspended solids had a decrease in large parts of the watershed. This indicates that water quality has improved during this long period in regard to solids.

Phosphorus. Total phosphorus concentrations (average above 0.1 mg/l) support the concern about nutrient enrichment throughout the watershed, as indicated in Map 11. Excursion analysis showed that the main stem of the Red Clay Creek (Stations 103011 to 103051) exceeded the EPA-recommended criteria 0.1 mg/l more than 90% of the time.

Nitrogen-to-phosphorus ratios were calculated at each station for possible limiting nutrient in the eutrophication process (Thomann, 1987). The ratios of total nitrogen to total phosphorus at all stations were above 10, which suggests that phosphorus may be the limiting nutrient in the watershed.

Decreasing trends of total phosphorus were detected in large parts of the watershed during 1980 to 1996, although the magnitudes of the decrease were very small. Map 12 shows the areal distribution of the detected trend in the watershed.

Nitrate-Nitrogen. A widespread increasing trend of nitrate-nitrogen in the main stream during 1970 to 1990 suggests that water quality had declined in the watershed. The trend distribution is shown in Map 13.

Zinc. Zinc criteria exceedances occurred frequently along the main stream of the Red Clay Creek (from Station 103011 to Station 103041). Although the decreasing trend of total zinc concentration was observed along this reach, current data still frequently exceed the acute and chronic criteria of the state water-quality standard (for more than 85% of observed data points).

White Clay Creek

Enterococcus Bacteria. Evaluation of historical and current data sets demonstrated that enterococcus bacteria concentrations frequently violated the state water-quality standard. Excursion analysis showed that more than 50% of the data exceeded the criterion of 100 colonies/100 ml throughout the watershed, suggesting that the use for swimming is not supported according to EPA guidelines (*305[b] Report*, 1993).

Dissolved Oxygen. Concentrations decreased steadily over the last 15 to 26 years in large parts of the watershed. Although dissolved-oxygen concentrations showed compliance with the state water-quality standard, the long-term decreasing trends signal deterioration of water quality with respect to dissolved oxygen. The areal distribution of the trends is shown in Map 10.

Total Suspended Solids. For the last 26 years, total suspended solids had a decrease in large parts of the watershed. This indicates that water quality has improved during this period in regard to solids.

Phosphorus. Total phosphorus concentrations (average above 0.1 mg/l) support the concern about nutrient

enrichment in the main stem of the stream, as indicated in Map 11. Excursion analysis showed that total phosphorus along the main stream exceeded the EPA-recommended criterion of 0.1 mg/l more than 40% of the time.

Nitrogen-to-phosphorus ratios were calculated at each station for possible limiting nutrient in the eutrophication process (Thomann, 1987). The ratios of total nitrogen to total phosphorus at all stations were above 10, which suggests that phosphorus may be the limiting nutrient in the watershed.

Nitrate-Nitrogen. An increasing trend of nitrate-nitrogen in large parts of the watershed during 1970 to 1990 suggests that water quality had declined. Trend distribution is shown in Map 13.

Naamans Creek

Enterococcus Bacteria. Evaluation of historical and current data sets demonstrated that enterococcus bacteria concentrations frequently violated the state water-quality standard. Excursion analysis showed that more than 50% percent of the data exceeded the criterion of 100 colonies/ 100 ml throughout the watershed, suggesting that the use for swimming is not supported according to EPA guidelines (*305[b] Report*, 1993).

Dissolved Oxygen. Concentrations decreased steadily over the last 15 to 25 years in large parts of the watershed. Although the dissolved-oxygen concentration showed compliance with the state water-quality standard, the long-term decreasing trends signal deterioration of water quality with respect to dissolved oxygen. The areal distribution of trends is shown in Map 10.

Total Suspended Solids. For the last 26 years, total suspended solids showed a decrease in large parts of the watershed. Thus, water quality has improved during this period in regard to solids.

Shellpot Creek

Enterococcus Bacteria. Evaluation of historical and current data sets demonstrated that enterococcus bacteria concentrations frequently violated the state water-quality standard. Excursion analysis showed that the data exceeded the criterion of 100 colonies/100 ml in large parts of the watershed, suggesting that the use for swimming is not supported according to EPA guidelines (*305[b] Report*, 1993).

Dissolved Oxygen. Concentrations decreased steadily over the last 15 to 25 years in parts of the watershed. Although the dissolved-oxygen concentration showed compliance with the state water-quality standard, the long-term decreasing trends signal deterioration of water quality with respect to dissolved oxygen The areal distribution of trends is shown in Map 10.

Table 12

PARAMETERS FREQUENTLY EXCEEDING CRITERIA

WATERSHED	BACTERIA	ZINC	IRON	PHOSPHORUS
Christina River	Yes		Yes	Yes
Brandywine Creek	Yes			Yes
Red Clay Creek	Yes	Yes		Yes
White Clay Creek	Yes			Yes
Naamans Creek	Yes			
Shellpot Creek	Yes			

Conclusion 1: Poor water quality. Based on the analysis results, initial concerns arose with bacterial contamination, metal pollution, and nutrient overenrichment. Table 12 summarizes the pollutants that frequently exceeded water-quality criteria in the listed watersheds.

Table 13

PARAMETERS IN COMPLIANCE WITH CRITERIA

WATERSHED	DO	pH	IRON	PHOSPHORUS
Christina River	Yes	Yes		
Brandywine Creek	Yes	Yes	Yes	
Red Clay Creek	Yes	Yes	Yes	
White Clay Creek	Yes		Yes	
Naamans Creek	Yes	Yes	Yes	Yes
Shellpot Creek	Yes	Yes		

Conclusion 2: Good water quality. Table 13 shows the parameters in compliance with the water-quality standards.

Conclusions

From the previous analysis and discussion, the conclusions shown in Tables 12, 13, 14, and 15 are made based on parameters showing *poor* water quality, *good* water quality, and the direction of water quality change.

Problems. Due to missing data points and censored values, statistical analyses could not be performed for certain parameters. Missing data were particularly a problem during the period from 1991 to 1994. Non-detected values were very common in metal records, which seriously hampered analyses of metals data. Another problem encountered during this study was lack of pertinent data such as stream flow and conductivity. Typically, many water-quality data correlate with these two physical parameters.

Table 14

PARAMETERS SHOWING WATER-QUALITY DETERIORATION

WATERSHED	DO	NO_3-N	NO_3+NO_2-N
Christina River	Yes	Yes	
Brandywine Creek	Yes	Yes	
Red Clay Creek	Yes	Yes	Yes
White Clay Creek	Yes	Yes	
Naamans Creek	Yes		
Shellpot Creek	Yes		

Conclusion 3: The water is becoming worse. Table 14 lists the parameters that have shown significant trends in stream water-quality deterioration in the watersheds.

Table 15

PARAMETERS SHOWING WATER-QUALITY IMPROVEMENT

WATERSHED	TSS	TKN	PHOSPHORUS	ZINC
Christina River	Yes		Yes	
Brandywine Creek	Yes			
Red Clay Creek	Yes	Yes	Yes	Yes
White Clay Creek	Yes	Yes		
Naamans Creek	Yes			
Shellpot Creek				

Conclusion 4: The water is becoming better. Table 15 lists the parameters that have shown significant trends in stream water-quality improvement in the watersheds.

Sources of Impact

Point Source Discharges

Point source discharges in the state of Delaware are regulated through issuance of National Pollutant Discharge Elimination System (NPDES) permits. Section 402 of the Clean Water Act, as amended by the Water Quality Act of 1987, gives the EPA and states with approved NPDES programs the authority to issue discharge permits. Seventeen facilities in the Piedmont Basin have active NPDES permits to discharge into surface waters. The permit is generally issued for a five-year period and regulates the type, concentration, and load of pollutants that can be discharged from a facility. Furthermore, NPDES permits establish monitoring and reporting requirements to be conducted by the facility.

All facilities with active NPDES discharge permits in the state are required to monitor their discharges regularly and to report the results of the monitoring to DNREC quarterly using Discharge Monitoring Reports. This information is maintained by DNREC and can be accessed through the EPA's centralized Pollution Compliance System data base.

The impact of point source discharges on the water quality of the Christina River and its main tributaries will be evaluated during the water-quality modeling phase of the five-year Christina Basin Watershed Management Plan.

Nonpoint Sources

Generally defined, nonpoint source pollution of surface waters results from runoff, percolation, and groundwater discharge to surface waters and atmospheric deposition of pollutants to water. It can also be defined as any human-induced pollution that does not come from a precise location such as a waste pipe discharging to a river. Examples of nonpoint source pollution include runoff from agriculture, silviculture, construction, and land-disposal sites.

Delaware's Nonpoint Source Pollution Program seeks to address nonpoint source pollution through coordination with other agencies and by funding control and mitigation projects. Many private businesses are investing in practical and cost-effective nonpoint source pollution control practices (Best Management Practices) on farms, residential developments, and commercial and industrial sites. Likewise, public agencies such as the Delaware Department of Transportation are investing revenues in improved stormwater management practices and wetlands creation to mitigate the impacts of maintenance and new highway construction activities.

Waste Sites

Runoff and leachate from waste sites can adversely impact aquatic ecosystems and human health. The "Contaminant Sources" section of this *Preliminary Assessment Report* discusses various waste sites in the Piedmont Basin and their known or potential impact. Significant progress has been made in controlling these sites. However, uncertainties such as the link between waste sites and fish contamination, for example, need to be addressed.

Atmospheric Deposition

Pollutants emitted into the air from various sources can be deposited into aquatic ecosystems far removed from their original source. Studies have proven that atmospheric deposition can be a major contributor to the degradation of water quality, producing significant human health and ecological impacts. Much work is needed to quantify the impact of atmospheric deposition in the Piedmont Basin.

Positive Initiatives

Christina River Initiative

DNREC, in cooperation with the Pennsylvania Department of Environmental Protection, EPA, Delaware River Basin Commission, and other federal, state, and local agencies, has initiated the development of a comprehensive water-quality management plan for the Christina River watershed. The plan will cover the entire 564 square miles of the watershed in Delaware and Pennsylvania and includes Brandywine Creek, White Clay Creek, and Red Clay Creek. Specific tasks included as part of this five-year study include intensive water-quality and quantity monitoring; comprehensive assessment of water-quality conditions; development of water-quality models for the watershed and for receiving streams; establishment of total maximum daily loads for point and nonpoint sources of pollution; and public education and participation. Total maximum daily loads establish the maximum amount of a pollutant (or pollutants) that a water body can assimilate and still meet water-quality standards and support designated uses.

Currently, DNREC is actively involved in the second year of the above five-year plan. Efforts are under way to finalize the comprehensive water-quality assessment of the Christina River watershed; conduct intensive water-quality and quantity monitoring; build an inventory of Geographic Information System (GIS) data layers regarding land use/land cover, geology, soil, topography, etc., for the watershed; and develop hydrodynamic and water-quality models for the watershed and for receiving streams.

The Northern Delaware Wetlands Rehabilitation Program was established by DNREC to bring together civic and business leaders, scientists, resource managers, and property owners to develop strategies to restore nearly 10,000 acres of wetlands (31 distinct sites) along the Christina and Delaware rivers. Start-up funding was provided by NOAA to the Delaware Coastal Management Program, and this project has become a cooperative effort between that program and DNREC's Division of Fish and Wildlife. The goals of the Northern Delaware Wetlands Rehabilitation Program are to improve water quality, increase wildlife populations, control nuisance plants, control mosquitoes, control flooding, and improve recreational and educational opportunities near the two rivers.

Citizens Monitoring Programs in Delaware

In recent years, many citizens groups have been formed nationwide in response to growing concerns about degraded water quality. Delaware was one of the first states to initiate a citizens water-quality monitoring program of streams to augment fixed monitoring by state agencies. The involvement of citizens in collecting data and making observations on their streams results in an educated public with an appreciation for their watersheds and an awareness of pollution threats to vital resources. Data and observations collected by citizens with a strong sense of environmental stewardship will contribute to the long-term success of environmental strategies. Delaware has four programs that use citizens to monitor water quality. Stream Watch was established in 1985 by the Delaware Nature Society in cooperation with DNREC. The Inland Bays Citizen Monitoring program was established by the University of Delaware Sea Grant College Program in 1990 as part of the Inland Bays Estuary Program. The Nanticoke Citizen Monitoring Program was founded in 1991 by concerned citizens of the city of Seaford in cooperation with DNREC. The most recent addition is the Adopt-a-Wetland Program initiated in May 1993 by the Division of Water Resources.

Delaware Stream Watch

Delaware Stream Watch, a grass-roots volunteer water resource protection program, is a cooperative effort of the Delaware Nature Society, DNREC, and more recently, industry. Since its inception in 1985, Stream Watch has focused on pollution detection and water-quality education. Four monitoring programs are presently being conducted: Stream Adoption, Technical Monitoring, White Clay Creek Macroinvertebrate Survey, and the Red Clay Creek Microbiological Monitoring Project. As part of the Stream Adoption program, some 159 sites in 28 of Delaware's 41 watersheds have been formally adopted. Technical Monitoring now includes more than 30 adults and college students and 16 high-school students monitoring over 25 sites monthly in the greater Christina basin. Over 400 hours of volunteer time were donated by 30 volunteers to conduct a quantified macroinvertebrate survey on three sites in the Delaware portion of the White Clay Creek. Finally, a small enterococcus monitoring project is being conducted in the Red Clay Creek basin. In addition, various educational events are conducted each year to train nearly 900 persons in monitoring techniques and to increase awareness of water issues for an additional 4,000 persons.

Stream Adoption

To reach the largest audience, the Stream Adoption Program is designed with flexibility for the volunteers. Volunteer Stream Watchers are trained in a three-hour workshop to recognize and report four major water pollution problems: toxic, organic, nutrient, and sediment problems. They are also trained to conduct three types of water-quality surveys (visual, chemical/physical, and macroinvertebrate) using simple methods and equipment.

The visual survey includes an inventory of pollution signs such as excess algae and unusual water color or odor; potential pollution sources such as water discharge pipes

or materials stockpiled next to the water; and obvious ecological factors that may affect stream health such as bank erosion due to loss of vegetation.

The chemical/physical survey includes air and surface temperature and the use of field test kits to determine the pH, levels of dissolved oxygen, and occasionally in coastal waters, salinity.

The macroinvertebrate survey consists of collecting aquatic insects from rocks, leaf packets, vegetation, sticks, logs, and/or bottom sediments, using washing and sieving techniques or constructed nets. Volunteers are then taught to recognize four types of aquatic insect larvae or nymphs that are useful indicators of pollution.

Each volunteer receives an illustrated, step-by-step *Delaware Stream Watch Guide* to reinforce and supplement the information provided during the workshop. They are encouraged to adopt a stream (or other body of water) and choose from among the survey methods according to the type of waterway and their individual interests and capabilities. They are requested to fill in data sheets and mail them to DNREC upon completion of the survey. Monitoring seasonally at least four times per year is encouraged.

Stream Watchers can adopt waterway sections as individuals or as a group. Of the 159 sites currently adopted, approximately one-quarter are monitored. Some volunteers collect and mail in detailed visual, chemical, and/or macroinvertebrate data at a minimum of three to four times per year. A few volunteers collect and mail in data on a monthly or bimonthly basis. The remaining volunteers visually monitor for evidence of pollution. These volunteers report any pollution problems to the appropriate agency, but are not required to record and mail in data sheets.

Technical Monitoring

In 1995, Stream Watch expanded the Technical Monitoring program from the original six sites in the Red Clay Creek basin to more than 25 sites in the greater Christina basin (which includes the Red Clay, White Clay, and Brandywine Creek sub-basins). The technical monitoring program's monthly sampling frequency, strategic site selection, and rigorous quality-control and assurance measures provide accurate baseline data and allow for subtle trend analysis. Volunteers range from persons with advanced engineering and science degrees to two high-school groups. Field test kits are used to monitor air and surface-water temperature, dissolved-oxygen levels, pH, nitrate-nitrogen, and alkalinity. Some visual observations are also recorded.

White Clay Creek Macroinvertebrate Survey

In partnership with the Stroud Water Research Center, the White Clay Watershed Association, and the University of Delaware, Stream Watch began an annual quantified macro-invertebrate survey on three sites in the Delaware portion of the White Clay Creek. Four survey samples are collected at each site, and specimens are preserved in the field. Later, in the laboratory, specimens are identified to family or order level and the taxa are tallied. Data are analyzed at the Stroud Center.

Red Clay Creek Microbiological Project

Seven sites are sampled monthly in the Red Clay Creek basin and tested at the University of Delaware for enterococcus bacteria. The purpose of the project is to establish baseline data.

The program's educational focus is extended through various avenues. The semiannual editions of *Stream Talk* reach a mailing list of over 1,400 concerned citizens. Water-quality monitoring and stream ecology workshops involve 100 citizens, 100 teachers, and 700 kindergarten through college students per year. Other educational activities conducted statewide include slide presentations, public exhibits, and seminars and conferences on water-quality concerns.

Contact with Stream Watch Adopters is maintained in several ways. All Stream Watchers receive the newsletter *Stream Talk*, edited by Delaware Nature Society and published twice a year. Volunteers are also encouraged to attend a refresher/enrichment training session once a year. At this session, volunteers also may be retrained in chemical test-kit procedures and macroinvertebrate identification, are able to check the validity of their individual test kits, and receive one-on-one answers to their monitoring questions. Volunteers with questions or concerns call the Stream Watch office, the DNREC liaison, or their watershed cluster leader (an experienced volunteer in their local area) for assistance. In addition, the DNREC liaison maintains personal written contact with volunteers, responding to every data report submitted and answering individual questions on monitoring techniques, malfunctioning equipment, or biological observations. The DNREC liaison also phones the volunteers when necessary to recommend an appropriate agency to solve a pollution problem.

Stream Watch pollution reports have been well received by state and county officials. Telephone calls from Stream Watchers to DNREC's toll-free 24-hour Environmental Complaint Hotline or through the DNREC liaison are welcomed by enforcement officers because they know that the individuals have been trained to recognize signs of pollution. The detailed observations and site locations provided by Stream Watchers make responses faster and more effective. Since the program's inception, Stream Watch volunteers have been the first to report fish kills, illegal trash dumping, high coliform counts, failing septic systems, sewer overflows, and erosion/sedimentation problems.

Delaware Nature Society employs one full-time coordinator and two part-time assistants to conduct the Stream Watch program. The staff at Delaware Nature Society recruit, train, support, and cultivate the volunteers; plan and administer the program; serve as information resources; and provide various educational programs. DNREC also employs a Stream Watch coordinator, who serves as a liaison to receive, acknowledge, and direct responses to the data received from the volunteers and report regulatory problems to enforcement personnel, who respond as appropriate. The DNREC coordinator also develops and conducts workshops and participates in some of the educational activities organized by the Delaware Nature Society.

Funding for Stream Watch is from DNREC, the Delaware Nature Society, and industry. Originally, DNREC funds were obtained via a grant from the EPA and later from penalty fees resulting from enforcement actions. Currently, Stream Watch receives the major portion of its funding ($65,000) through a line-item in the DNREC budget. The Delaware Nature Society provides office space, equipment, and in-kind services in addition to contributing funds directly. The society also receives grants for specific items in the Stream Watch budget. In particular, the technical monitoring program is almost entirely supported by funds and in-kind support from several local industries.

For More Information

The 1996 Delaware Watershed Assessment Report provides a statewide assessment of all surface-water and groundwater resources and highlights Delaware's initiatives in water resources management and pollution control during 1994 and 1995. This report summarizes the statewide water-quality assessment and provides an overview of major initiatives and concerns for each watershed in the state.

For further information, please contact:

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