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ABSTRACT

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Changes in land use and cover influence surface water quality and thus are a potential threat to water systems and coastal ecosystem health. The objectives of this study were to evaluate the influence of historical land use–land cover (LULC) changes and point-source sewage discharge on surface water quality of some lower Eastern Shore watersheds of Maryland. LANDSAT data for 1986–2006 was acquired and classified using Anderson level-1 classification system in ENVI 4.5, whereas LULC changes were detected in Arc-GIS 9.2 environment. Historical water monitoring and climatic data were obtained from Maryland Department of Environment–Chesapeake Bay Program, and National Oceanic and Atmospheric Administration, respectively. Nutrient loading data from wastewater treatment plants were obtained from Maryland Department of Environment and data analyzed using regression analysis and principal component analysis (PCA). The result shows that total phosphorous levels in the surface waters decreased significantly ($p < 0.05$) during the 20-year study period. However, using PCA, we determined that the declining P trend was attributable to the decreasing agricultural land use rather than the sewage discharge from wastewater treatment plants. The increase in urban land use and the resultant runoff to the water bodies may explain the declining trends in dissolved oxygen levels observed during the period, with serious implications for eutrophication. An empirical model developed for P in surface waters ($r^2 = 0.90$) showed that the combination of point and nonpoint sources and land use/cover change factors are good predictors. The incorporation of quantitative LULC data component as well as point-source nutrient loading into existing models is highly recommended for a more holistic assessment of land-use influence on water systems in general.

ADDITIONAL INDEX WORDS: *Point-source, nonpoint source, water pollution, sewage loading, remote sensing, models, nutrient loading, phosphorus, nitrogen.*

INTRODUCTION

Point- and nonpoint-source pollution from anthropogenic sources is a major threat to U.S. surface water systems. For example, a 2004 survey of some U.S. surface waters (U.S. EPA, 2004) showed that about 44% of the assessed stream miles, 64% of assessed lake acres, and 30% of the assessed bay and estuarine square miles were not clean enough to support uses such as fishing and swimming. The leading causes of impairment are pathogens, mercury, nutrients, and organic enrichment/low dissolved oxygen (DO)from sources such as hydrologic modifications, atmospheric deposition, agriculture, and several unknown sources. Although the Clean Water Act was intended to restore and maintain the chemical, physical, and biological integrity of the nation's surface waters (U.S. EPA, 2002), this goal has proven difficult to achieve because of the ubiquitous sources of the water contaminants. Equally difficult and challenging is the detection of human impacts on these water systems because of the diverse biological, chemical, hydrological, and geophysical components that must be assessed (Gergel *et al.*, 2002). Fortunately, improvements in geospatial technology and their applications in environmental and other fields hold a great promise for addressing some of these problems.

Significant relationships between land use–land cover (LULC) and water quality have been well documented over the years (*e.g.,* Basnyat *et al.,* 1999; Harding *et al.,* 1998; Karr and Schlosser, 1978; Omernik, Abernathy, and Male, 1981; Osborne and Wiley, 1988; Palmer *et al.,* 2002; Roth, Allan, and Ericson, 1996; U.S. EPA, 2008). Agriculture, urban activity, and industrialization are major sources of nonpoint pollution that contribute significant amounts of phosphorus and nitrogen to surface waters in the United States (Carpenter *et al.,* 1998). Urbanization has also been identified as a major threat to Maryland streams (Boward *et al.,* 1999). This report classified 46% of all streams in Maryland in poor biological health conditions. It has been predicted that nonpoint source pollution will increase in the future if current LULC practices continue (Carpenter *et al.,* 1998). Osborne and Wiley (1988)

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reported that the extent of urban land and its proximity to streams was the most important factor in predicting N and P concentrations in stream water. Also, lakes with highly forested catchments had lower levels of lead and chlorine and were less prone to eutrophication than lakes in nonforested catchments (Detenbbeck *et al.,* 2004). Urbanization and population growth usually lead to an increased volume of wastewater, requiring treatment before discharge into surface waters; this invariably results in higher volumes of sewage effluents (usually containing high P and N) and thus increased point-source pollution. The most deleterious effect of sewage discharge into the coastal environment is eutrophication (Parnell, 2002), which can have a major impact on aquatic biota (Adam *et al.,* 2008) and can lead to changes in abundance, biomass, and diversity of the organisms. Several studies have previously related point- and nonpoint-source pollution to deteriorating surface water quality. However, only relatively few addressed long-term geospatial trends. Such long-term geospatial studies could provide better and more holistic insight into factors influencing surface water quality; this could potentially provide more precise and useful information for decisions on land use and water system management at the watershed and landscape levels.

The main objective of this study was to evaluate the influence of historical LULC changes and sewage loading on surface water quality of some lower Eastern Shore watersheds of Maryland in the United States.

STUDY AREA

This study was conducted in the lower Eastern Shore watershed and coastal bays of Maryland. The area lies between longitudes 74°59′15.2″ W and 76°17′5.6″ W and latitudes 37°54′12.4″ N and 38°53′10.7″ N, and is located between the Atlantic Ocean and the Chesapeake Bay, the largest estuary in the United States. The lower Eastern Shore watershed and coastal bays drain approximately 5597 km^2 in Wicomico, Somerset, and Worcester counties, and some portions of Caroline and Dorchester counties of Maryland (Figure. 1). Major land use and cover in the area have been documented for the same period (Nosakhare *et al.,* 2012) and includes agricultural land or cropland, forest land, rangeland, urban or built-up land, water, wetland, and barren land. The main economic activities in the area include intensive poultry production, crop production (mainly corn, soybeans, and barley), fishing, and tourism.

DATA AND METHODS

Water Quality and Satellite Image Acquisition and Processing

Historical (1986–2006) water quality data of the lower Eastern Shore watersheds monitored by Maryland's Department of Natural Resources (MD-DNR) was acquired from the U.S. Environmental Protection Agency–Chesapeake Bay Program (U.S. EPA–CBP, 2007). The scope was limited to physical and chemical water-quality parameters such as total phosphorus (TP), total nitrogen (TN), total suspended solids (TSS), chlorophyll *a* (CHLA), Secchi disc depth (SECCI), DO, pH, specific conductivity, salinity, and water temperature. Water-quality data were preprocessed by taking the means for each month. Representative months for each season were taken to avoid bias from missing data. In this regard, the month of January was taken to represent winter, April to represent spring, and July and November to represent summer and fall respectively. Only sites with continuous water-quality-monitoring data were included in the analyses. To validate the water-quality data, water samples were randomly collected from global positioning system-guided sampling sites in July 2006, and analyzed both *in situ* and in the laboratory using the same standard procedures for the historic data. Because no significant differences existed, they were excluded from the final analysis. Similarly, the historical water-quality data for the coastal bays were rather sporadic and thus were excluded from the final analysis.

LANDSAT-5 TM satellite data for Maryland for 1986 and 2006 were acquired from the U.S. Geological Survey–Center for Earth Resources Observation and Science. These images were devoid of cloud cover and had been georeferenced and atmospherically corrected. Land use–land cover classification for the study area was done in Environment for Visualizing Images (ENVI 4.5) (ITT Visual Information Solutions, 2008). To accomplish this, bands 7, 4, and 2 were selected for supervised classification using Mahalonobis distance method after several trials. The area of interest selected was corroborated with aerial photos, Google Earth, and ground truthing, as well as general knowledge of the area. The LULC classification system of Anderson *et al.* (1976) was used to classify the images in ENVI software, which classifies LULC into nine categories. However, tundra and permanent snow/ice land cover classes were removed from the classification scheme because of the absence of these categories in Maryland. Once classified, the data were exported to Arc-GIS 9.2 (ESRI, 2010) for further analysis and cartographic display.

The multivariate data set was also explored using principal component analysis (PCA) (Joliffe, 2002) to create a few key variables (each of which is a composite of many of the original variables) that characterize the multivariate data set (Gotelli and Ellison, 2004). All data sets were collated and analyzed using stepwise regression and multiple regression procedures in SPSSx.

Total N and TP load derived from the average sewage discharge during the 20-year period from wastewater treatment plants (WWTP) in the study area were obtained from Maryland Department of Environment. The geographic coordinates of the WWTP stations in Maryland were projected and displayed with the water bodies into which the sewage effluents are discharged (see Figure 2). Climatic data (temperature and precipitation) were also obtained for the study location and period from the National Oceanic and Atmospheric Administration database.

RESULTS AND DISCUSSION

The results of the land use dynamics for the Eastern Shore and coastal bays of Maryland from 1986 to 2006 has been published elsewhere (Nosakhare *et al.,* 2012). The study showed increases in urban land use (by 121.8%), forest land cover (by 8.5%), and the extent of surface water cover (by 10%) in the subwatersheds during the 20-year study period. However, agricultural or cropland and wetland areas de-

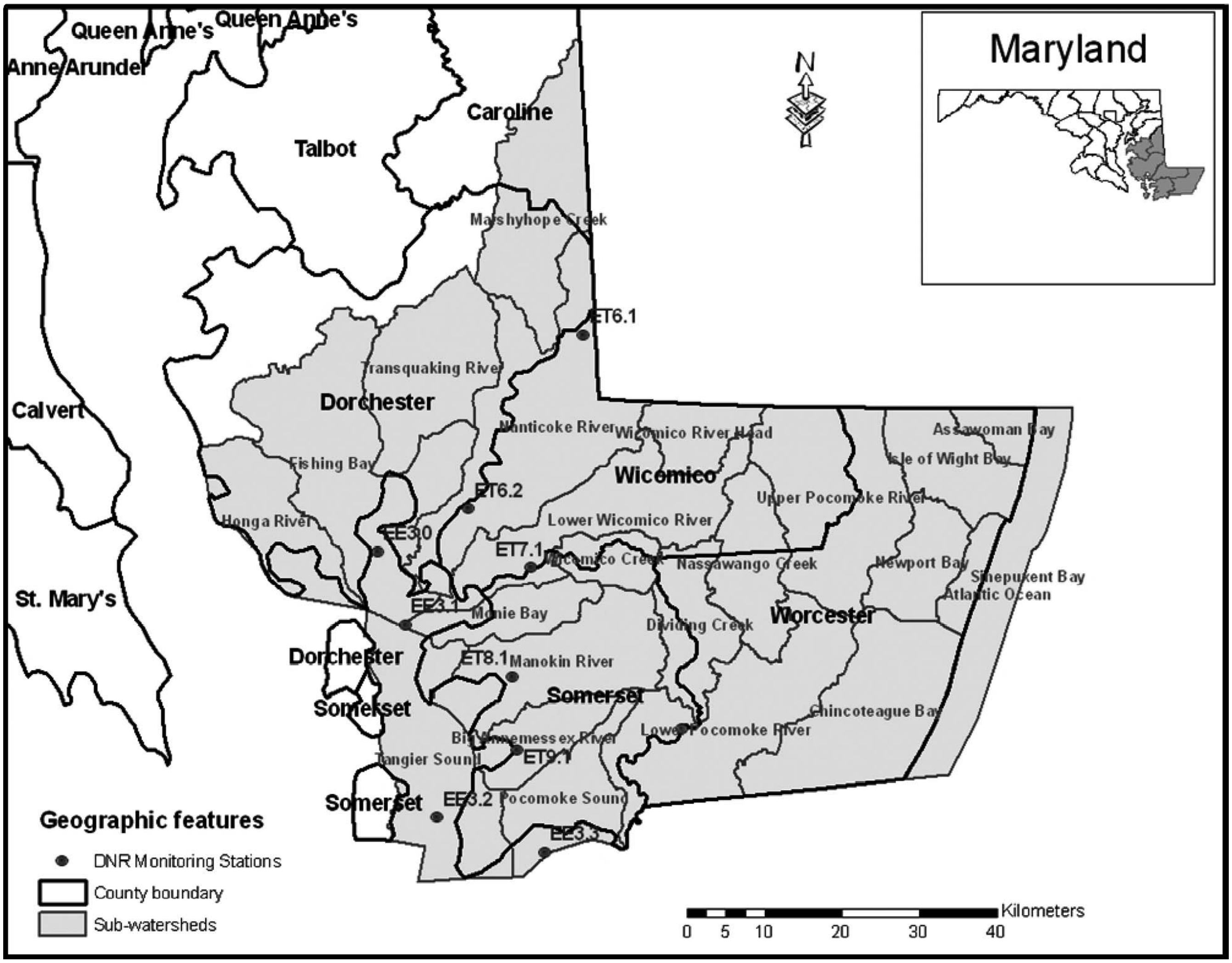

Figure 1. Lower Eastern Shore watersheds showing study site and monitoring stations.

creased by 19.6% and 21.3% respectively during the same period. Urban lands increased at the expense of agricultural lands and barren lands due in part to the rapid growth in human population during the period. Increasing urban land development increases the extent of impervious surfaces from buildings, roads, and runoff that are known to accelerate nutrients, sediments, and chemical loadings into the aquatic systems (Mallin *et al.,* 2001; Van Buren *et al.*, 2000). However, an analysis of the water-quality monitoring data from several stations in the stream networks did not adequately support this trend as the TP decreased generally during the same period (Figure 3). On the other hand, the decrease in agricultural lands and phosphorus input through point sources (Figure 4) during the same period may have influenced the general trends observed, perhaps due to better compliance to the National Pollutant Discharge Elimination System (NPDES) rules in the last two decades, or more efficient use of fertilizers and soil conditioners. Total P concentration for sampled sites ranged from 0.093 mg/L in 1986 to 0.044 mg/L in 2006. However, some location variations were observed, *e.g.,* the Lower Pocomoke River and the Nanticoke River recorded the highest mean TP of 0.121 ± 0.100 mg/L and 0.083 ± 0.05 mg/L respectively. These surface waters are located within watersheds where 24.5–27% of the land is used for crop production. Consequently, the crop fields may have been contributing substantially to the phosphorus loading of the water systems from inorganic fertilizers or poultry manure applied to crops. Furthermore, these surface water systems receive sewage discharge from Sharptown and Snowhill WWTPs. Lower levels of TP at Tangier Sound and Monie Bay sites also correlated with small areas of agricultural lands. Similar trends observed for some individual sites are shown in Figures 5a–d.

Total N levels varied within a narrow range during the 20-year study period (1.00–1.71 mg/L). In general, no discernible trend was observed for N levels in the surface waters as can be seen in Figure 6. On the other hand, point-source discharge of N from the waste treatment plant increased significantly during the period (see Figure 7). The increase is due to the

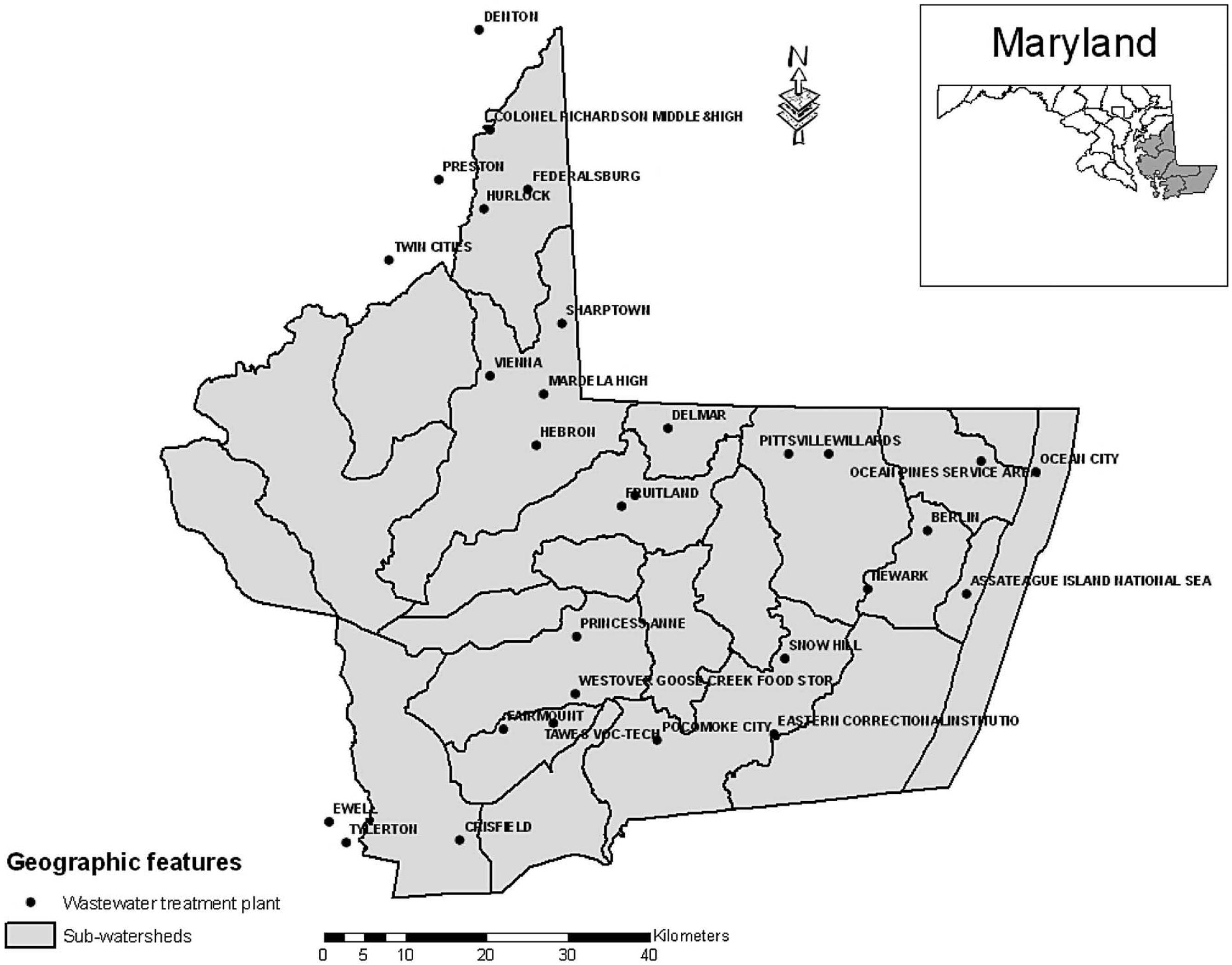

Figure 2. Lower Eastern Shore watersheds showing wastewater treatment plants.

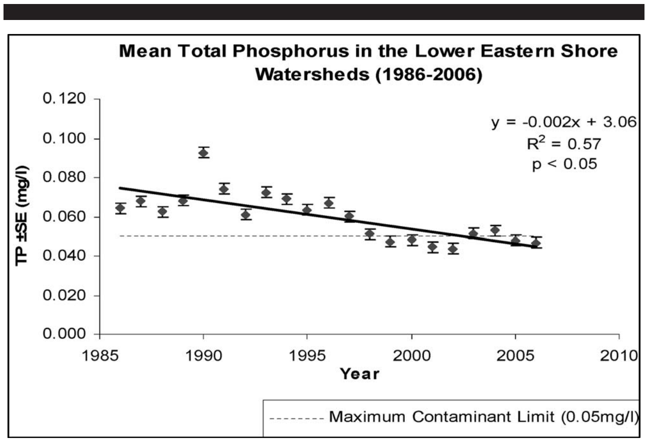

Figure 3. Mean total phosphorus in the Lower Eastern Shore surface waters (1986–2006).

steady growth in population and thus more waste being produced and processed by the various treatment plants in the area. For specific sampling sites, however, some differences were observed. For example, the Nanticoke River and the Lower Pocomoke River subwatersheds had the highest TN compared with the other subwatersheds, with mean TN of 3.218 ± 1.2 mg/L and 1.912 ± 0.7 mg/L respectively. Whereas TN increased significantly ($p < 0.05$) at the Nanticoke River, the Lower Pocomoke River experienced a decrease. This result may be due to local effects resulting from differences in the rate of sewage discharge (point sources) into these rivers rather than changes in the land use patterns. Although agricultural land area decreased in both subwatersheds during the same period and thus had relatively less contribution of N from fertilizers through runoff, their watershed profiles shows that the Nanticoke River has twice the population density of the Lower Pocomoke (MD-DNR, 2012), which may explain the local effects resulting from relatively more sewage processed and discharged.

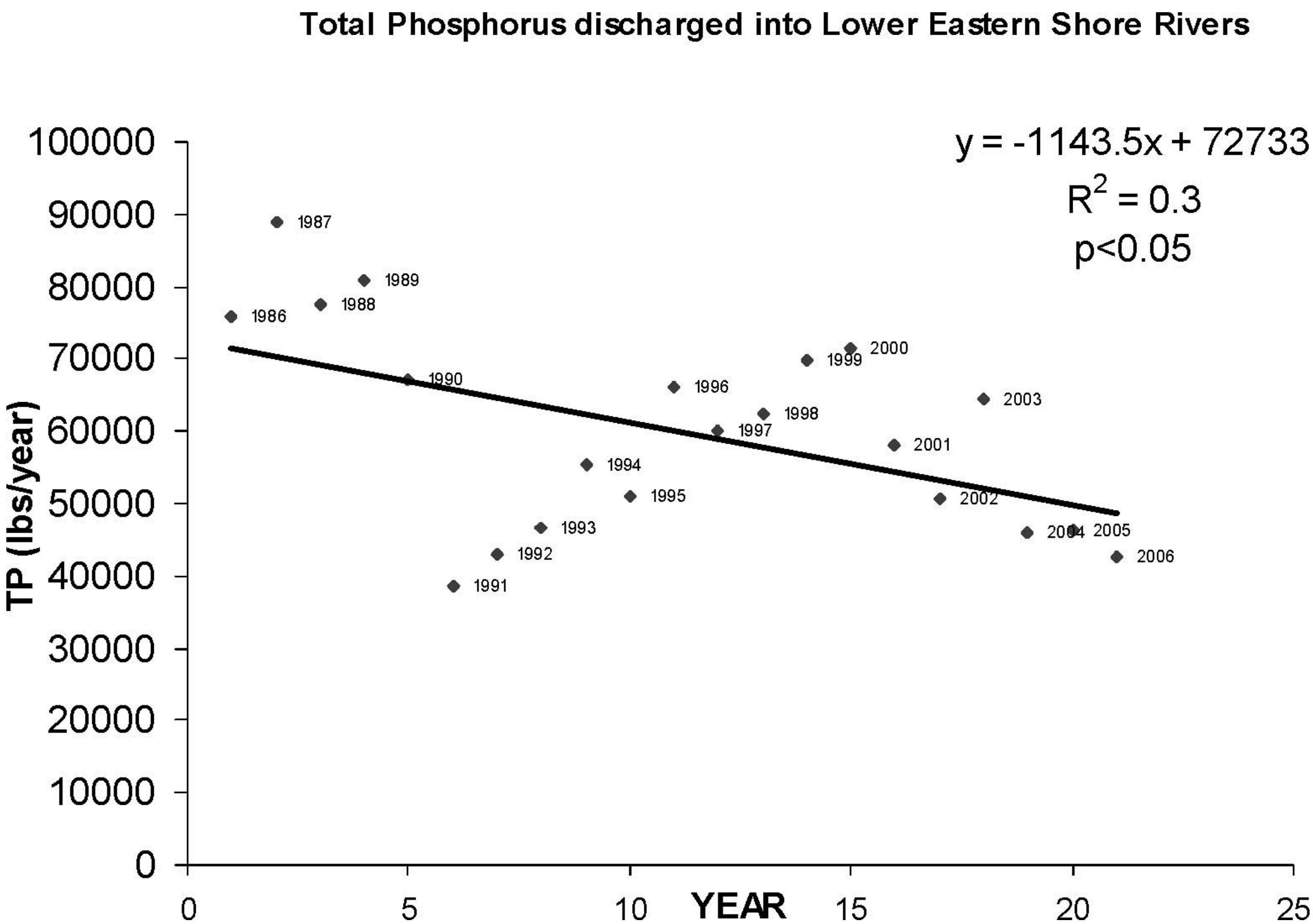

Figure 4. Total phophorus discharged into surface water from waste treatment plants.

Increased nutrient loading (particularly N and P) to surface water systems often leads to eutrophication and increase in CHLA levels in coastal waters as a result of increase in phytoplankton biomass. Chlorophyll *a* level is a useful indicator of the amount of nutrients incorporated into phytoplankton biomass. In general, no clear trend was observed except for a few of the stations. For example, the Nanticoke River sampling station and the Lower Wicomico River showed a decreasing trend. In the former, CHLA was highest, with a mean of 19.99 ± 21.4 mg/L. The declining croplands in the Nanticoke River subwatershed (but still heavily cultivated with 27% agricultural land in 2006) and decreasing sewage discharge rates are possible explanations for this specific site.

Dissolved oxygen is a water-quality parameter that affects the survival of aquatic life (Adam *et al.,* 2008). Dissolved oxygen in water systems is affected by the level of nutrients such as N and P as well as the flow rate of the water body. In this study, DO levels showed a significant decrease from 1986 to 2006 in general (Figure 8). This trend is exemplified by the Lower Wicomico River, which receives sewage from three waste treatment plants (Salisbury, Fruitland, and Delmar). The DO level in this river was low during the period (See Figures 9a and b for TP and TN loading rates). On the other hand, the Annemessex River, Fishing Bay, and Monie Bay had relatively higher DO due to less wastewater discharge into their surface water systems. The mean annual TP discharged into surface water was highest (44,379.4 kg/y) at the Salisbury WWTP; however, there was a decrease in the rate of TP discharged into the Wicomico River (475 kg/y) from Salisbury WWTP during the study period. Total P decreased from an average of 19,727 kg/y in 1986 to 8835 kg/y in 1992 and remained stable from 1993 to 2006. Other WWTP with significant ($p < 0.05$, $n = 20$) decreasing TP load rates are Crisfield, Delmar, Princess Anne, and Federalsburg. Total P loading rates have, however, been increasing significantly ($p < 0.05$) at Hurlock (197 kg/y).

A stepwise regression analysis of the variables and the resulting correlation matrix is shown in Table 1. Significant positive correlations were observed between forest land cover and agricultural land use ($r^2 = 0.95$), urban land use and forest land cover ($r^2 = 0.72$), and TN and TP levels ($r^2 = 0.68$). However, significantly negative correlation was observed between SECCHI and TP. Similarly, there was a negative correlation between TP and TSS. No significant correlations were observed between the other combinations of variables

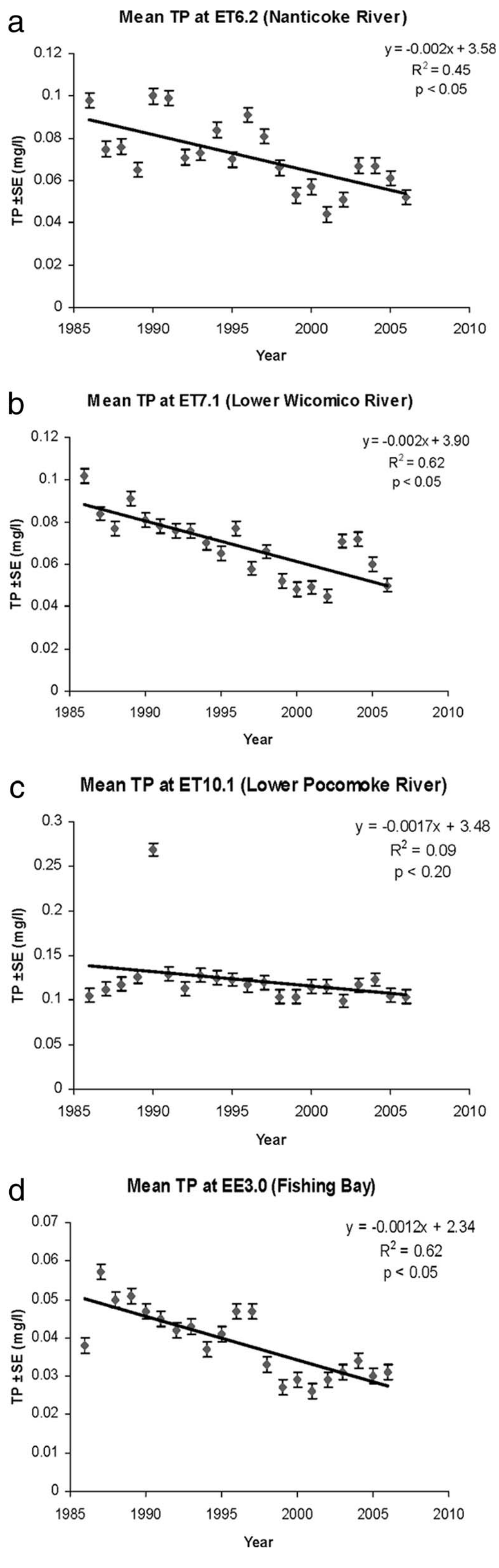

Figure 5. Total phosphorus levels at (a) the Nanticoke River site, (b) the Wicomico River site, (c) the Lower Pocomoke River site, and (d) the Fishing Bay site.

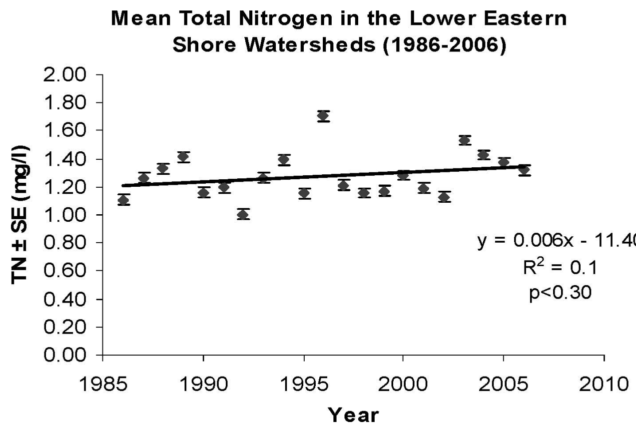

Figure 6. Mean total nitrogen in the Lower Eastern Shore watersheds (1986–2006).

evaluated. Furthermore, we attempted to develop multiple regression models for predicting TP and TN in surface waters using quantitative data from land use/land cover from the geographic information system (GIS) analysis, sewage plant loads into surface waters from sewage treatment plants, and water-quality parameters, including local temperature and rainfall averages for the period. However, it was not possible to fit the data to a viable multiple regression model for predicting TN in surface waters. For TP, however, a multiple regression model was developed. This model includes TN as one of the independent variables as shown below:

$$\begin{aligned} TP = {} & 0.149 + 0.00067wl - 0.000189ag - 0.0000403wa \\ & - 0.00000081sc + 0.000523ac + 0.000000485wp \\ & + 0.00033ts + 0.016tn + 0.00064ca - 0.002wt - 0.0105do \end{aligned}$$

$$r^2 = 0.90, n = 75$$

where TP = total P (mg/L); wl = wetland area (km^2); ag = area of agricultural land (km^2); wa = area of land covered by water (km^2); sc = specific conductivity (µS/cm); ac = change in agricultural land (km^2); wp = WWTP TP load (lbs/mo); ts = tSS (mg/L); tn = total N (mg/L); ca = CHLA (mg/L); wt = water temperature (°C); do = DO (mg/L).

Unlike several models relating P to water quality, the multiple regression model developed here contains some variables seldom included in most models because of the lack of readily available data They include (1) the areal extent of wetlands (wl) known to affect waste filtration of nutrients and other chemicals bound for surface waters; (2) agricultural land area (ag), which determines the rate of P fertilizer input for agricultural production; (3) change in agricultural land area (ac), which is a dynamic factor; (4) the extent of surface water cover, which affects input of P from runoff; and (5) P input from WWTP (wp). These variables thus make this model potentially more robust than many others. Tong and Chen (2003) applied such a GIS-based model to examine the hydrologic effects of land use at both regional and local scales in Ohio; their study showed that agricultural and impervious urban land produced a much higher level of N and P in surface waters than other surfaces.

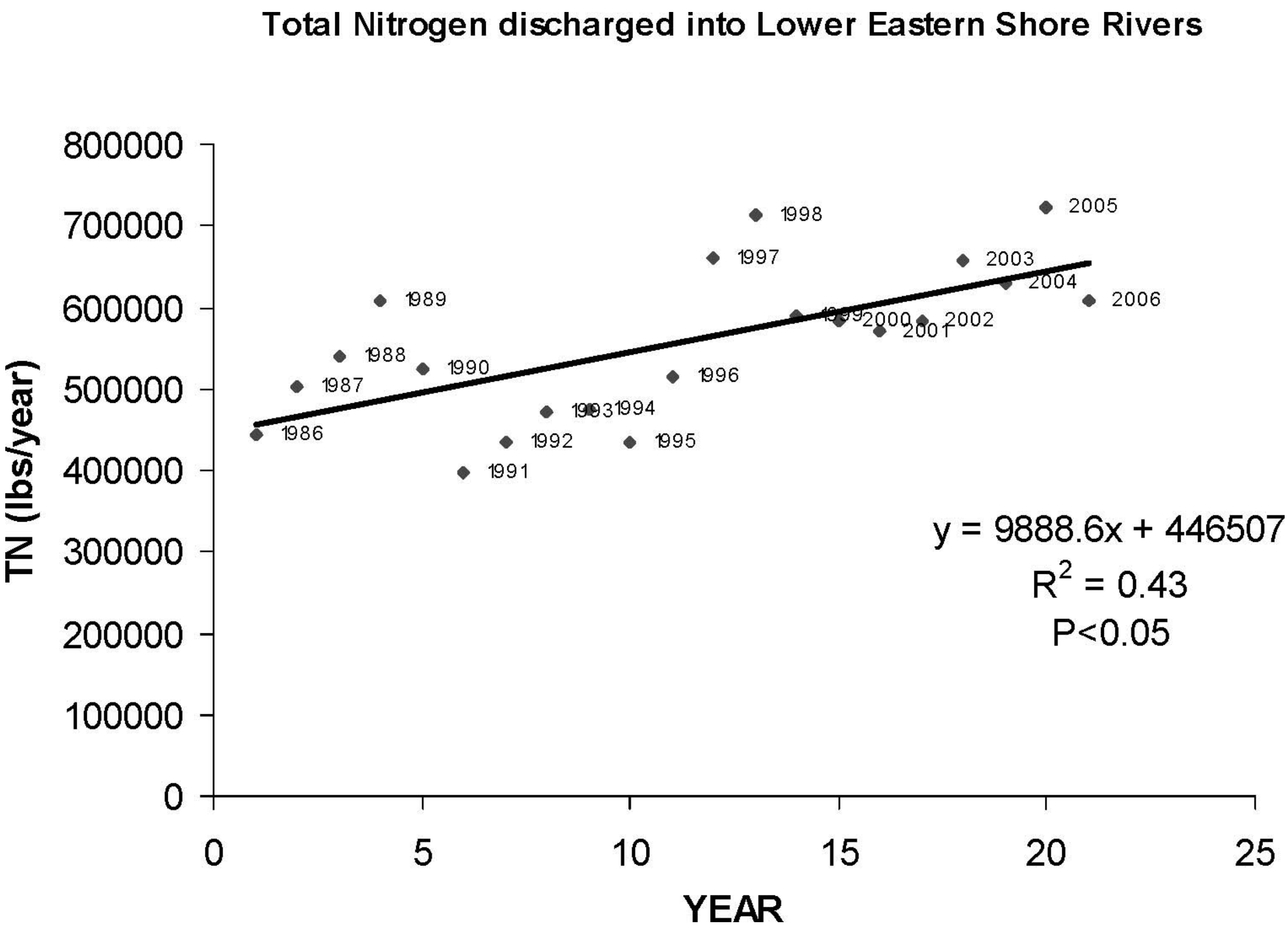

Figure 7. Total nitrogen discharged into Lower Eastern Shore rivers.

However, their model did not assess some of the geospatial parameters contained in the model developed in this study.

To identify the relative contributions of nonpoint-source nutrient loading *vs.* point source from WWTPs to the surface water-quality parameters, PCA was used. Principal component analysis is used to reduce the dimensionality of a data set consisting of a large number of interrelated variables, while retaining as much as possible of the variation present in the data set. This is achieved by transforming to a new set of variables the principal components (PCs), which are uncorrelated, and which are ordered so that the first few retain most of the variation present in all of the original variables. This technique was used in this study in conjunction with regression analysis to summarize the multivariate data set into fewer dimensions so as to determine the highest, the second highest, and successively smaller amounts of variation using principal axes, which makes interpretation of clouds of observations on a scatter plot easier (Sokal and Rohlf, 1996). The result showed that only the first two axes (F1 and F2) were most meaningful/principal axes with respect to LULC, water quality, and sewage discharge (Figure 10). F1, which represents the first axis (eigenvalue = 4.3), accounted for 33.34% of the variance, whereas F2 which represents the second axis (eigenvalue = 2.98), accounted for 22.89% of the variance observed in the PCA analysis. These first two

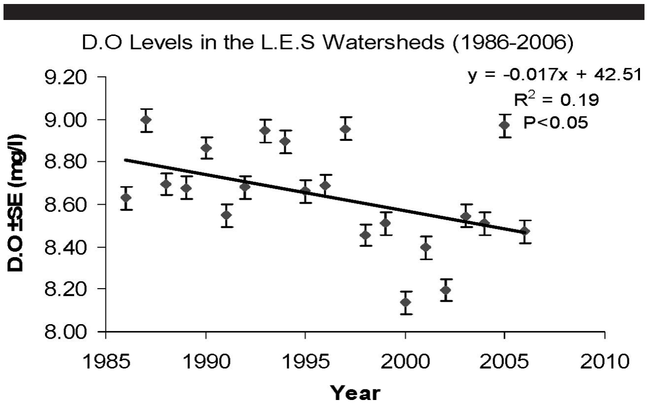

Figure 8. Dissolved oxygen in the Lower Eastern Shore watersheds (1986–2006).

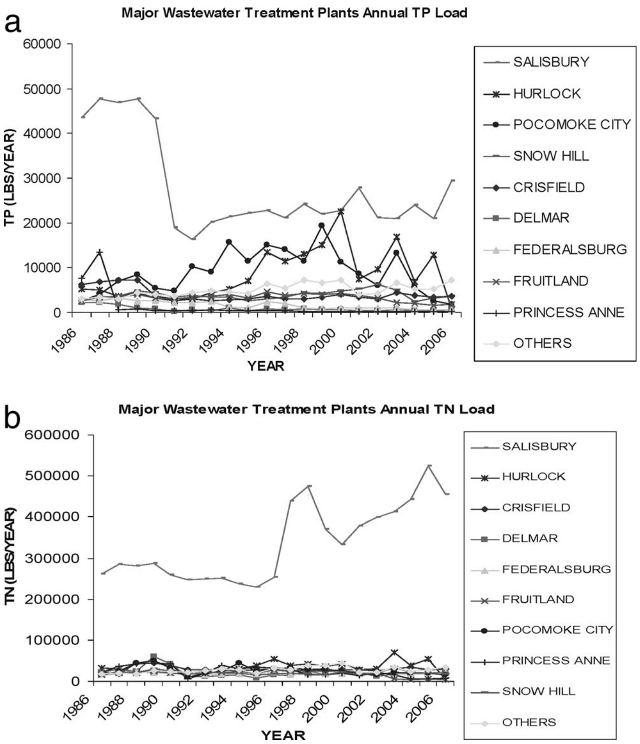

Figure 9. (a) Major wastewater treatment plant (WWTP) total phosphorus annual load; (b) major WWTP total nitrogen annual load.

axes alone accounted for 56.22% of the total variance in the data.

Axis 1 (F1) was mainly positively correlated with agricultural land use (0.935), forest land (0.930), urban land (0.635), TN (0.766), and TP (0.750) (Table 2). All of these variables were directly correlated with each other on axis one, indicating that increases in agricultural, urban, and forest lands are the PCs influencing the levels of TN and TP in the study

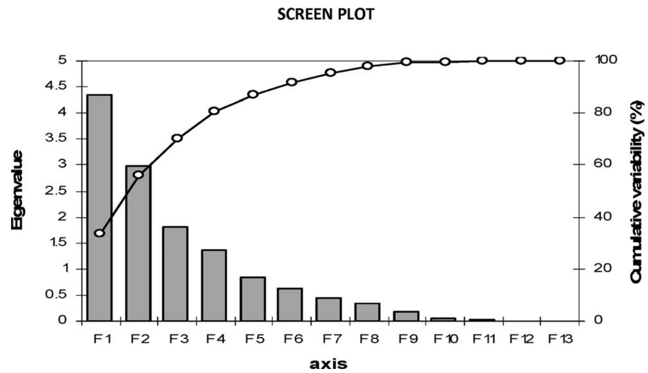

Figure 10. Screen plot from principal component analysis.

area. This axis was thus labeled as LULC. Axis 2 (F2) is mainly correlated with WWTP TN discharged (0.792), WWTP TP discharged (0.755), wetland (−0.741), DO (−0.671), and urban (0.529) (Figure 11). This indicates that increased levels of TN and TP discharged from waste treatment plants correlated with declining DO levels. Loss of wetlands also correlated with decreased DO levels; this axis was labeled WWTP discharge. Site ET7.1 (located in Lower Wicomico River subwatershed) clustered around the vectors of WWTP TN and TP, indicating urbanization in the region. High levels of discharge of TN and TP from Salisbury, Fruitland, and Delmar waste treatment plants discharging into the Wicomico River where site ET7.1 is located both correlated ($r^2 = -0.53$, $p < 0.05$) with decreased levels of DO and increasing urbanization in the Lower Wicomico River subwatershed, suggesting that point sources best explain the low DO levels at this site. The Lower Pocomoke River subwatershed clustered around the increased urban land, which experienced the third largest net increase in urban land of 11.67 km^2 in two decades, but most of that increase (8.64 km^2) occurred between 1996

Table 1. *Pearson correlation of log-transformed data (*$p < 0.05$, $n = 113$*).*

	URBAN	AGRIC	FOREST	WATER	BARREN	TN	TP	TSS
URBAN*								
AGRIC	0.69							
FOREST	0.72	0.95						
WATER		−0.41						
WETLAND		0.37	0.45	0.54				
BARREN	0.6	0.8	0.68					
TN								
TP	−0.22	−0.22			−0.21	0.68		
TSS						0.51	0.64	
CHLA						0.41	0.41	0.37
SALINITY						−0.68	−0.48	−0.48
SECCHI					0.26	−0.52	−0.71	−0.74
WWTPTN	0.54	0.28					0.24	−0.28
WWTPTP	0.55	0.29					−0.22	−0.26
TIME	0.4				−0.29			
PRECI								

* CHLA = chlorophyll *a* (mg/L), TN = total N (mg/L), TP = total P (mg/L), DO = dissolved oxygen (mg/L), PRECI = precipitation (in/mo), URBAN = area of urban land (km^2), AGRIC = area of agricultural land (km^2), FOREST = area of forest land (km^2), WATER = area of land covered by water (km^2), WETLAND = wetland area (km^2), BARREN = area of barren land (km^2), WWTP TN = wastewater treatment plant TN load (lbs/y), WWTP TP = wastewater treatment plant TP load (lbs/y).

Table 2. *Factor loadings.*

Variable	F1	F2
CHLA	−0.037	−0.461
TN	0.766	−0.161
TP	0.750	−0.024
DO	−0.259	−0.671
PRECI.	−0.058	0.199
URBAN	0.635	0.529
AGRIC	0.935	−0.244
FOREST	0.930	−0.201
WATER	−0.655	−0.274
WETLAND	0.397	−0.741
BARREN	0.565	−0.211
WWTP TN	0.153	0.792
WWTP TP	0.204	0.755

* CHLA = Chlorophyll *a* (mg/L), TN = total N (mg/L), TP = total P (mg/L), DO = dissolved oxygen (mg/L), PRECI = precipitation (in/mo), URBAN = area of urban land (km^2), AGRIC = area of agricultural land (km^2), FOREST = area of forest land (km^2), WATER = area of land covered by water (km^2), WETLAND = wetland area (km^2), BARREN = area of barren land (km^2), WWTP TN = wastewater treatment plant TN load (lbs/y), WWTP TP = wastewater treatment plant TP load (lbs/y).

and 2006. Declining DO levels at this site may be related to increased urbanization and an agricultural land area of 110 km^2 in 2006 (representing 27%). Total P and TN and agricultural land use both correlated strongly on axis one, whereas WWTP TP and TN discharge correlated to a different axis. This indicates that the observed trends in TP and TN are more strongly influenced and explained by agricultural land use rather than WWTP TP and TN discharge. Agricultural activities have been identified as the major source of surface water pollution and contributor to environmental stress (Cooper, 1993) as N and P are macronutrient fertilizers usually supplied to cultivated plants in large amounts for optimum growth and development.

CONCLUSIONS

Excessive concentrations of P are the most common cause of eutrophication in freshwater lakes, reservoirs, streams, and in headwaters of estuarine systems (Corelli, 1998). However, traditional approaches for assessing impact of land use change on P and other water-quality parameters have been developed on the basis of physically based models that predict changes in water quality in real time and work well in small catchments, or where they were developed; they are often limited by the high data requirements and difficulty in calibration for use in larger catchments or watersheds. Furthermore, many do not combine point and nonpoint sources of pollutants or quantitative historical land-use parameters. The multiple regression model developed in this study attempted to overcome some of these limitations as it includes quantitative land-use and cover variables, including physical and chemical water parameters that make it potentially more robust. The growing geospatial infrastructure in the United States is definitely an asset in generating and applying LULC data used in this study for fine-tuning existing watershed models. Phosphorus levels for the study location showed a decreasing trend that was mostly attributable to the declining agricultural land use, rather than the decrease in P loading from WWTPs. Obviously, the increase in urban land use and the resultant increase in impervious surface area and runoff may have contributed other pollutants rather than P. Although there were no discernible trends in TN in general, the Lower Wicomico River, which receives a very heavy N load annually (from three WWTPs [Delmar, Fruitland and Salisbury]), showed a generally increasing trend, albeit local. This result is supported by a Hawaiian coastal waters study (Parnell, 2002) where the discharge of effluent from two WWTPs did not significantly affect water-quality parameters outside the zone of initial dilution. The Lower Wicomico River also received mean TP load of 14,514 kg/y and had the highest P levels, though with a declining trend like others, probably reflecting more compliance to NPDES rules over the years. This site is apparently being affected by both urban land use and waste treatment plant discharge resulting from the growing human population (particularly Salisbury) in the watershed. There was also a general decrease in the DO levels in the surface waters during the period. Although this could be due to complex interaction of several natural and man-made factors, this general trend is supported by Karlsen *et al.* (2000), whose investigation on the historic trends in the Chesapeake Bay DO showed that the unprecedented anoxia in the area since the early 1970s is attributable mainly to high freshwater flow and to an increase in nutrient concentrations from the watershed. Although the increase in urbanization and the resultant increase in TN loading from sewage plants were only detectable locally, the general decline in the DO levels attests to the possible deleterious impact of the excess N on the oxygen level and thus surface water quality. High N and P levels in water are known to cause eutrophication, leading to anoxic conditions. This can lead to fish kill and loss of biodiversity in the surface water system. Unlike P in freshwaters, N is the most limiting nutrient in estuaries and coastal waters (Pepper, Gerba, and Brusseau, 2006) such as this study site. Consequently, the increasing supply of N from the waste treatment plants into these fragile estuarine/coastal waters of the Maryland Eastern Shore

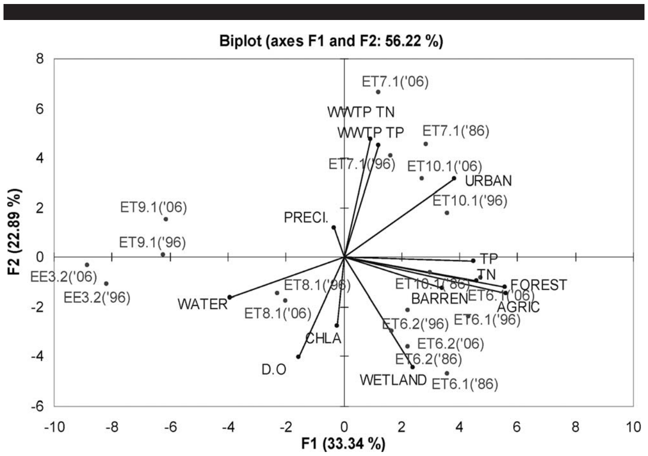

Figure 11. Principal component plot showing score sites.

deserves further studies as it could lead to more serious impacts for the fishing industry and recreation in the future.

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