The Role of Land Use and Land Cover in the Delivery of Nutrients to Delaware's Inland Bays: DWRC Progress Report

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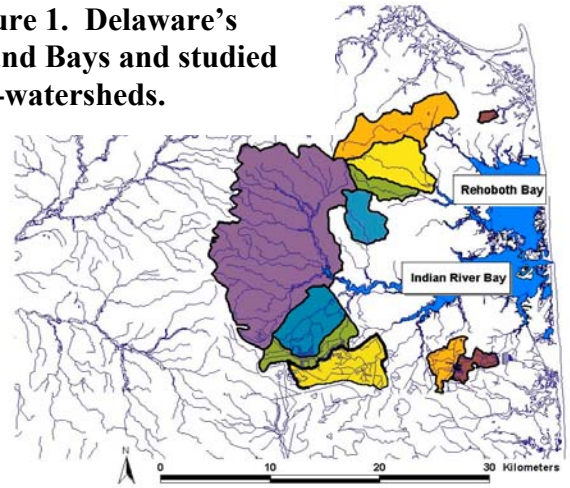
Introduction

Many coastal plain estuaries within the mid-Atlantic region of the United States suffer from eutrophication. This nutrient over-enrichment is caused by elevated nutrient loadings from domestic, municipal, industrial, and agricultural practices in the surrounding watersheds. Surface and ground water discharges from uplands, atmospheric deposition, and in some cases inputs from the coastal ocean, are responsible for the delivery of nutrients to estuaries. In the estuary, nitrogen and phosphorus fertilize vegetation leading to high levels of plant production, changes in phytoplankton species, and potentially noxious and toxic algal blooms. Eutrophication can have several other adverse effects on the ecosystem. These include increases in turbidity, decreases in dissolved oxygen concentrations, reduced biodiversity, habitat loss, and fish and shellfish kills (DNREC, 1995).

Figure 1. Delaware's Inland Bays and studied sub-watersheds.



Although fairly extensive research has been done in the identification of nutrient sources, there is little definitive proof concerning the role of the watershed, if any, in the attenuation and delivery of nutrient loads from upland land uses to the estuary. In 1998, Horsley and Witten, Inc. used estimated nitrogen loading rates for various land uses and atmospheric deposition, as well as loadings from point sources in the watershed, to compile total loading values to Delaware's coastal bays (See Figure 1). These reported

values however, were not verified by comparison to actual measured loadings to the estuary.

Objectives

The proposed research seeks to test the Horsley and Witten results at one sub-watershed of Delaware's Inland Bays, Bundicks Branch. This will require the determination of annual baseflow and storm nutrient loads through the analysis of several types of water samples. In addition, the seasonal variability in the baseflow and storm loads, as well as the role of the land use/land cover in the attenuation and delivery of nutrients from the watershed to the estuary, will be examined. Results of the study of this one sub-watershed will be applied to other sub-watersheds in the Inland Bays Basin. It is hoped that this research will lead to a better understanding of nutrient cycles and trends in the Inland Bays and other similar coastal plain watersheds. Results of this work will be used by environmental managers to develop and improve land use practices in the watershed so that the delivery of nutrients to the estuary, as well as the severity and occurrence of eutrophic events, will be reduced.

Background on the Horsley and Witten (1998) Approach

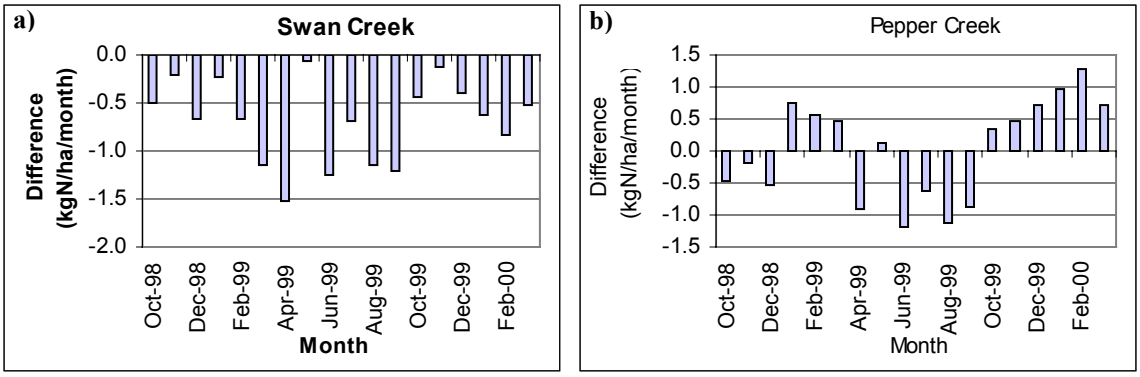
In the Horsley and Witten (1998) report, total nitrogen loads to Delaware's Inland Bays were calculated by assigning loading factors to the point and non-point sources found throughout the sub-basins, i.e. either Rehoboth Bay or Indian River Bay sub-basin, which were then summed for each embayment. Loading rates for the point sources, mainly sewage treatment plants, were based on each plant's flow rate and average effluent concentration, which was analyzed during a sampling period. To determine the loads delivered through surface runoff and groundwater discharges, more detailed calculations were utilized. It was assumed that the loads delivered through both of these non-point sources reflect the influence of the surrounding land uses. In order to take into account these effects in the Inland Bays Watershed, Horsley and Witten (1998) used nitrogen concentrations and loading rates previously determined for land uses in similar coastal areas. The only land use loading rates based on actual measured data from the watershed were for agricultural lands. Thus, this analysis does not take into account regional differences in land use practices and the majority of the loads calculated by land use acreage are only estimates based on literature values and not on actual measured data from the study area.

The Horsley and Witten report also included atmospheric deposition as a non-point source of nitrogen, but their analysis of this source was not complete and the role of atmospheric deposition in the N-budget of Delaware's Inland Bays was inaccurately represented. The deposition rate used was based on local nitrate and ammonium wet deposition data and also included estimates of the organic and dry deposition fractions. While the estimate of the organic load (15% of the inorganic) is sound, the dry deposition flux has likely been overestimated by assuming it is half of the *total* flux. Scudlark and Church (1999) estimated the dry deposition rates over both land and water by analyzing withdraw flux ratios from study sites adjacent to the Inland Bays Watershed. Over land,

the dry deposition rate is about 75% of the *wet* rate, while this value is only 25% over water due to the aerodynamic resistance encountered over smooth surfaces. Horsley and Witten's inaccurate estimate of the dry flux is further compounded by the fact that this deposition rate was only applied to the surface area of the bays themselves, which neglects the indirect deposition to the watershed all together.

Indirect atmospheric deposition may significantly affect the total nitrogen load delivered to an estuary since the precipitation falling over land contains the same concentration of nitrogen as the precipitation falling over water. In addition, indirect deposition creates runoff that delivers nutrient containing water to ground and surface waters which discharge to the bays. Another aspect of the N-budget that Horsley and Witten fail to fully consider is the attenuation of N within the watershed. Preliminary work suggests that some sub-watersheds year-round (See Figure 2a), and others on a seasonal basis (See Figure 2b), are capable of attenuating a significant amount of the atmospheric deposition. Presumably, the watershed attenuates nutrients from other sources as well. The differences in the ability of various sub-watersheds to attenuate nutrients is likely due to the differences in the land use and cover present in each sub-watershed. In order to develop accurate loading rates, the factor of within sub-watershed attenuation should be addressed.

Figure 2. Monthly differences between baseflow TDN loadings and wet atmospheric nitrogen deposition.



A final flaw in the Horsley and Witten approach is that the produced loads represent annual averages without any discussion of the seasonal or inter-annual variability of nutrient fluxes. The seasonality of these fluxes has a direct impact on the health of the ecosystem with the critical periods being spring and summer. Baseflow loadings typically reach a maximum during early spring due to increases in precipitation and fresh water discharge. This provides an abundance of nutrients, which are then used during summer months when uptake by algae and vascular plants is at a maximum and could potentially lead to harmful algal blooms. Thus, having an understanding of the seasonal variability of the nutrient fluxes from the various non-point sources would be beneficial in combating the eutrophic problems in Delaware's Inland Bays.

Project Descriptions and Preliminary Results

Testing the Horsley and Witten approach.

As previously discussed, the estimated nitrogen loads delivered to Delaware's Inland Bays reported by Horsley and Witten (1998) were never verified with actual measured data from the study area. To determine the accuracy of the land use and land cover loading factors used in this prior study, a comparative analysis can be done with the use of water samples that have since been collected from a tributary, Bundicks Branch, that discharges into the Rehoboth Bay. Geographic information systems (GISs) will be used to determine the areas of the various land use and land cover types within the studied sub-watershed. These areas will then be multiplied by the corresponding loading factor, as estimated by Horsley and Witten, to calculate the theoretical N-load due to the land use and land cover from Bundicks Branch.

Horsley and Witten identified the point sources within the entire Inland Bays Watershed by sub-basin. It has been determined though, that none of these point sources discharge into Bundicks Branch and will therefore not be included as an input term. In following the Horsley and Witten approach, indirect atmospheric deposition will also not be included in the total load delivered to the estuary from the sub-watershed and the effects of within sub-watershed attenuation will not be considered for this sub-project. The values computed will be compared to the loads derived from the sampled data. Several sets of water samples have been collected from Bundicks Branch and will be used to determine the tributary's annual total nutrient loads. In order to determine annual loads based on measured baseflow and storm concentrations and discharges however, a number of assumptions must be made and these must be tested. The ensuing comparison will be used to validate Horsley and Witten's approach in determining nutrient loads to an estuary.

Assignment of uncertainties to baseflow loadings.

Baseflow water samples were collected bimonthly at 12 tributary sites between October 1998 and March 2000. Samples were collected on days well away from recent precipitation so that the water chemistry reflected the ground water component and in-stream processes alone, without the added effects of precipitation and surface runoff. Samples were analyzed for dissolved and particulate fractions of nitrogen, phosphorus, and organic carbon and other parameters such as pH, conductivity, dissolved oxygen, and chlorophyll a (Ullman et al., 2001).

Daily baseflow loadings of the particulate and dissolved constituents are desired for the entire sampling period at Bundicks Branch so that monthly, quarterly, and annual loadings can be estimated. The annual loads will later be used to test the Horsley and Witten approach. In order to compute these values, nutrient concentration data must be generated by linear interpolation between baseflow sampling dates. Loadings can then be computed by multiplying these concentrations by mean daily discharges. In doing this though, it is assumed that the mean daily discharge will accurately represent the discharge, and hence the loadings, over an entire day, and that a linear interpolation will correctly represent the fluxes in concentration and loading between samplings. These

assumptions must be validated however and realistic uncertainties must be assigned to calculated baseflow loadings. To achieve this, daily and monthly variations in nutrient concentrations will be investigated.

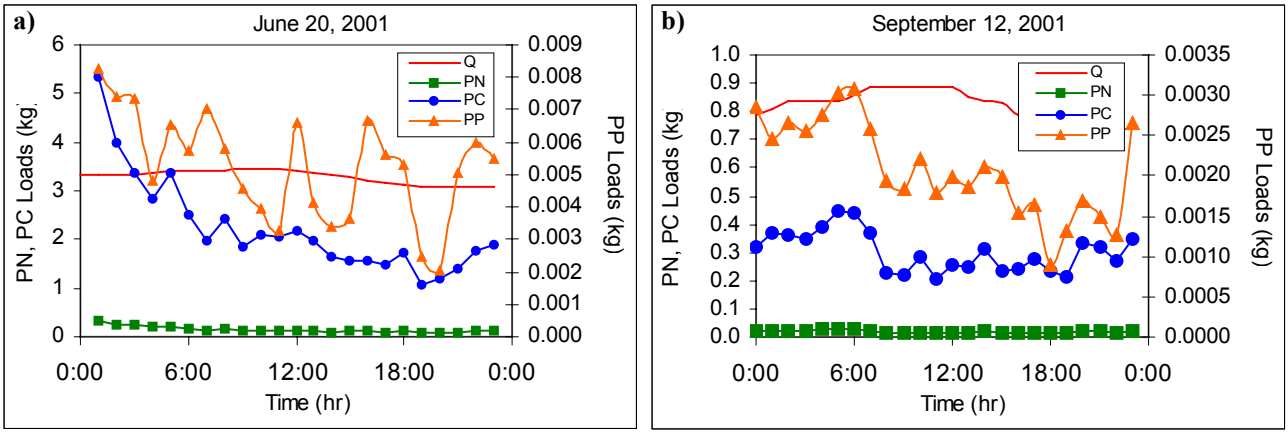
To test the first assumption, that the mean daily discharge represents the discharge over an entire day, the diurnal fluctuations in water discharge, nutrient concentrations, and loadings will be examined. In this analysis, a sample was collected every hour for an entire day by an ISCO automated sampler, which also recorded stage height every 15 minutes so that discharge could be acquired later. The experiment was conducted twice, first on June 20, 2001 and then on September 12, 2001, which were both days when the flow was dominated by baseflow, to stay consistent with the previously collected samples. The effects of photosynthesis (one of the possible attenuation processes) on nutrient concentration and discharge are also desired, so these sampling dates were sunny days as well. Samples were handled and loadings were calculated in the same manner already discussed (See Table 1). Total daily discharges and loadings can be computed (See Figure 3a and 3b) and uncertainties assigned to the results. This data set will later be compared to both the individual grab samples taken during the three-year baseflow sampling interval and the interpolated values.

Table 1. Inventory of parameters analyzed as of March 15, 2002 for both sets of hourly samples.

ID	Date	Chl a[a]	Nutrients[b]	TDN/P[c]	PP[d]	PC/N[e]	DOC[f]
JHS1	June 20, 2001	X	X	X	X	X	X
JHS2	Sept. 12, 2001	X			X	X	X

[a] Chlorophyll a
[b] Nitrate and Nitrite, ortho-phosphate, and ammonium
[c] Total dissolved nitrogen/phosphorus
[d] Particulate phosphate
[e] Particulate carbon/nitrogen
[f] Dissolved organic carbon

Figure 3. Diurnal fluctuations in particulate parameters for both hourly data sets.



To check the nutrient fluxes between the regular baseflow sampling intervals of two weeks, a water sample was collected every day for a one-month period at Bundicks

Branch. This experiment tests the second assumption, that a linear interpolation correctly represents the nutrient fluxes between the bimonthly sampling dates. Samples were collected at the same time each day and regardless of whether or not the stream was at baseflow. The stage height was recorded at the time of collection. Since nutrient loadings in baseflow have a seasonal component with maximums in winter and spring, this sampling was conducted from February 26-March 25, 2001 in order to capture this maximum period. Using the Bundicks Branch rating curve, total discharge for each day was calculated from stage height and loadings were then computed using the discharge value (See Appendix A). These total flow and loading values will further be separated into the baseflow and storm components (See Figure 4). The monthly baseflow loadings will be calculated (See Table 2) and realistic uncertainties will be assigned to the baseflow results for this tributary and by analogy, to the other tributaries in the Inland Bays. This data set can then be compared to the loadings estimated using the interpolation method. Once the validity of the baseflow results has been determined, they can be used in the testing of Horsley and Witten's approach.

Figure 4. Baseflow and storm flow separation.

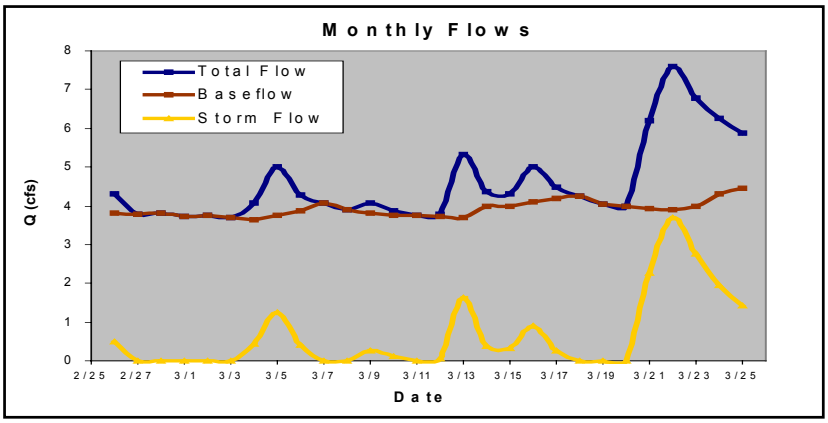


Table 2. Summed baseflow loads of interpolated and measured data for the one-month period of February 26-March 25.

Parameter	1999 Interpolated loadings	2000 Interpolated loadings	2001[a] Measured loadings
TSS[b]	96.77	312.22	565.04
TDN	565.86	819.76	861.97
PN	0.78	6.61	15.57
TDP	1.12	2.35	3.80
PP	0.35	0.53	0.66
DOC	400.83	1058.31	834.09
PC	29.94	55.05	94.29
Discharge (cfs)	51.12	80.60	85.30
Precipitation (in)[c]	4.45	5.79	1.92

[a] Does not include values for February 26 or March 21-25, 2001 (values still pending)
[b] Total suspended solids
[c] Data from **http://www.rec.udel.edu/TopLevel/Weather.htm**

Determination and inclusion of annual storm loads.

The Horsley and Witten loading factors are designed to yield total annual loads including the surface runoff in response to storm events. This latter component must be added to the baseflow measurements in order to conduct the direct comparison proposed above. With the use of storm water samples collected at six Inland Bay tributary stations on as many as eight occasions between 21 May 1999 and 10 April 2000, as well as additional to-be-collected storm samples from Bundicks Branch, this objective and several sub-objectives can be accomplished.

Several methods of projecting annual storm loads with the use of only a limited storm data set are being evaluated. The first of these methods seeks correlations between nutrient concentration and water discharge, but correlations thus far have not produced consistently useful results (See Appendix B). For example, Bundicks Branch yielded a good correlation (0.86) between flow and TDN concentration for an October storm, but a poor correlation (0.26) during a March storm. This could be due to seasonal effects or variations in the storm size and intensity. However, when looking at two different sites during the same storm, which removes these variables, correlations are still not consistent, and suggest that the differences are due to the different hydrological characteristics of each site.

Mr. A. Scott Andres (Delaware Geological Survey) devised a method to estimate the annual storm loads based on the monitored storm data. With data from a rain site in Georgetown, DE, a ratio of the amount of precipitation occurring during the monitored storms to the total amount of precipitation in the one-year sampling period was calculated. Total nutrient loads due to storm events were then projected by applying this ratio to the summed loads of the monitored storms. This method assumes that water discharge and hence, nutrient loadings, are proportional to the amount of precipitation, but it neglects the possible influences of season and variable storm size and intensity on annual nutrient loads.

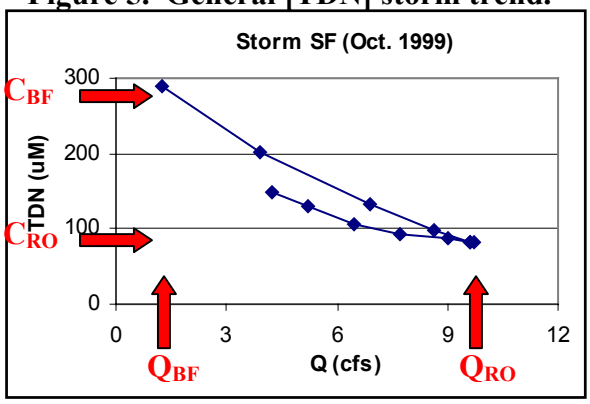
The third method under evaluation is designed to take into account the seasonal influences on nutrient loads. It is based on the simple relationship that the total load is the sum of the baseflow and runoff (storm) loads (Eq. 1).

$$Q_T C_T = Q_{BF} C_{BF} + Q_{RO} C_{RO} \qquad \textbf{Eq. 1}$$

Figure 5 shows the general trend that TDN concentrations follow in response to the changing flow throughout the duration of a storm. Storm flow varies with the intensity of the rainfall and the season while the concentration of the runoff is a function of the rainfall concentration as well as the land use/land cover and season. Values for the flow variables in Eq. 1 are available for each of the storm-sampling periods. The storm data set will be consulted to retrieve a runoff concentration (C_{RO}) for a storm in a particular season, while the baseflow concentration (C_{BF}) on any day of the year will be estimated by fitting the three-year baseflow data set to a trend with a one-year period (this trend has not yet been determined). Thus the total concentration (C_T) for any unmonitored storms can be determined by plugging these values into Eq. 1. All three methods will undergo

further scrutiny to determine if one, or a combination of the three, produce the best estimate of annual storm loads.

Figure 5. General [TDN] storm trend.



Since precipitation varies both annually and seasonally, and the seasonal distribution of rainfall likely affects nutrient discharges, additional storm data can be used to determine the seasonal and inter-annual variability in storm nutrient loads. Storm water samples will be collected in a similar manner as described above at the Bundicks Branch site with the goal of collecting one storm event per month for a one-year period beginning in the spring of 2001. These samples will be analyzed in the exact manner already described (See Table 3). This sampling regime will provide adequate data to study the variability and trends in storm loads as a result of changing seasons. In addition, the effects of land use/land cover and soil types on the seasonal loads will be examined. This information will lead to a better understanding of the nutrient loads produced by storm events and may be used by land managers to further develop discharge targets and management practices. Typically, Total Maximum Daily Loads (TMDLs) use annual averages of discharges and loadings integrated over an entire watershed, which tends to neglect the effects of particularly wet or dry seasons or years and ignores the differences in watershed land use and other characteristics like soil type or the presence of riparian zones. Differences in storm loadings that are related to these characteristics may suggest that it is advantageous to use more localized TMDL targets.

Table 3. Inventory of parameters analyzed as of March 15, 2002 for collected storm events.

ID	Date	Chl a	Nutrients	TDN/P	PP	PC/N	DOC
JSA	May 19-20, 2001	X			X	X	
JSB	May 21-22, 2001	X	X	X	X	X	X
JSC	June 1-3, 2001	X	X	X	X	X	
JSD	July 18-19, 2001	X			X	X	
JSE	August 10-12, 2001	X			X	X	
JSF	September 24-26, 2001	X			X	X	
JSG	November 20, 2001	X			X	X	X
JSH	December 8-10, 2001	X			X		

Annual storm loads will be projected for the sampling period between May 2001 and April 2002 using the chosen method or a combination of methods previously discussed. Examination of precipitation amounts from the last several years will allow for the classification of the one-year sampling periods as average, wet, or dry. This storm data set, when compared to the pre-existing storm data set, will allow for the assignment of realistic upper and lower boundaries of annual storm loads as a result of the variability of precipitation. Once this has been completed, the annual storm loads at Bundicks

Branch can be added to the annual baseflow loads and used to test Horsley and Witten's method at this particular site. This model of calculating annual total storm loads will be tested for its applicability at less documented sub-watersheds adjacent to Bundicks Branch.

Determination of indirect atmospheric deposition and within sub-watershed attenuation factors.

The proposed comparison to test the Horsley and Witten method of determining nutrient loads to an estuary may find that this approach produces accurate estimates, but perhaps a more inclusive approach would include indirect atmospheric deposition and within sub-watershed attenuation factors as well. The final objective of the proposed research project is to develop estimates of the nutrient deposition and attenuation rates within the Inland Bays sub-watersheds.

The indirect atmospheric deposition to each sub-watershed has been estimated using wet atmospheric chemistry data provided by Mr. Joseph Scudlark. The precipitation was collected at the rain site in Cape Henlopen State Park, which is located just a few miles northeast of the study area. Monthly totals of dissolved inorganic nitrogen (NO_3 and NH_4^+) in rainfall are available for an 18-month period of time during which the baseflow sampling occurred (October 1998-March 2000). To have a total nitrogen deposition value, dry deposition and organic nitrogen values must be added. To account for the dry deposition over the watershed, the ratio of dry to wet deposition (0.76 = 5.6 kgN/ha/yr : 7.4 kgN/ha/yr; Scudlark and Church, 1999) has been applied to the atmospheric DIN numbers and included in the total inorganic nitrogen value. Atmospheric organic nitrogen is believed to comprise 20% of the total dissolved nitrogen in precipitation (Scudlark et al., 1998), so this percentage has also been computed and included to calculate the total atmospheric nitrogen deposition to the sub-watershed. The annually averaged indirect atmospheric deposition rate to Bundicks Branch is 1.56×10^4 kg N/yr.

With the addition of the indirect atmospheric deposition component to the point source and land use loading factors from the Horsley and Witten method and the use of the compiled baseflow and storm data, a within sub-watershed attenuation factor can be back-calculated. More specifically, the input terms can be subtracted from the total stream loadings, which represent the total value exported from the watershed to the estuary, to determine the magnitude of the output term. This analysis can be done to calculate annual averages, but the seasonal variation in attenuation rates can also be examined by using the monthly and seasonal baseflow and atmospheric data in lieu of the annually averaged data. Finally, the attenuation rates can be evaluated for correlations with the land use and land cover within the entire sub-watershed as well as within riparian zones. The results of this research will lead to a better understanding of nutrient cycling within a watershed and the effects, if any, of the land use and land cover on the nutrient discharges to Delaware's Inland Bays. This information may allow for the development of more effective discharge targets for the Inland Bays TMDL program and aid in identifying areas within the watershed where changes in land use management practices will likely achieve these TMDL target loadings.

Conclusions and Implications

For many years now, Delaware's Inland Bays have been experiencing extensive eutrophication and suffering from its effects. The nutrient over-enrichment is due to the domestic, municipal, industrial, and agricultural practices within the watershed. In 1998, Horsley and Witten, Inc. estimated the nitrogen loads to the estuary using a method that relied on land use loading factors from other coastal plain ecosystems and the results were never verified with actual measurements from the study area. In addition, this approach failed to consider the effects of indirect atmospheric deposition and within sub-watershed attenuation even though both may influence the magnitude of nutrient discharges. In order to effectively control the nutrient loadings by the way of TMDLs, a thorough understanding of the processes controlling their discharge is needed. Horsley and Witten's results can be tested and this understanding gained by studying measured baseflow and storm discharges and evaluating the influences of land use and season on these rates.

References

DNREC. **1995**. *A Comprehensive Conservation and Management Plan for Delaware's Inland Bays*. Delaware Department of Natural Resources and Environmental Control, Dover, DE (March 1995).

Horsley and Witten, Inc. **1998**. *Assessment of Nitrogen Loading to the Delaware Inland Bays*, a report prepared for the Center for the Inland Bays.

Scudlark, J.R., K.M. Russell, J.N. Galloway, T.M. Church, and W.C., Keene. **1998**. Organic Nitrogen in Precipitation at the Mid-Atlantic U.S. Coast: Methods Evaluation and Preliminary Measurements. *Atmospheric Environment* 32(10): 1719-1728.

Scudlark, J.R. and T.M. Church. **1999**. *A Comprehensive Reexamination of the Input of Atmospheric Nitrogen to the Rehoboth and Indian River Estuaries*, a control report prepared for the Center for the Inland Bays and Delaware Department of Natural Resources and Environmental Control.

Ullman, W.J., J.R. Scudlark, and A.S. Andres. **2001**. *Storm-water Sampling and Analysis in the Inland Bays: Final Report to the Delaware Department of Natural Resources and Environmental Control under Contract No. 939519.*