EVALUATION OF CHANGES IN TOTAL NITROGEN LOADINGS TO TAMPA BAY DUE TO EXPECTED NITROGEN AIR EMISSIONS REDUCTIONS

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FOREWORD

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1 INTRODUCTION

Nitrogen loading estimates derived for the recent time periods of 1985-1994 and 1995-1998 indicate that atmospherically derived loads represent a sizeable fraction of the total nitrogen load to the bay. Estimated atmospheric deposition directly to the bay's surface accounted for approximately 30% of the total nitrogen loading to the bay from 1985 through 1994. For these periods, wet deposition was estimated utilizing precipitation and nutrient concentration data collected by the National Weather Service (NWS) and the National Atmospheric Deposition Program (NADP). Dry deposition was estimated using a regionally derived ratio of wet:dry deposition (Environmental Science & Engineering, Inc., 1987).

Given the relative importance of atmospheric deposition, more insight was needed into the contribution of atmospheric deposition to the eutrophication of the bay. The Tampa Bay National Estuary Program (TBNEP) proposed that Tampa Bay be included in the EPA Great Waters Program. The Tampa Bay Atmospheric Deposition Study (TBADS) was initiated in 1995, with funding from the Great Waters Program, with in-kind services and support provided by the Environmental Protection Commission of Hillsborough County (EPCHC) and the Pinellas County Department of Environmental Management (PCDEM).

The data collected by the TBADS program allowed estimation of both wet and dry deposition for the recent period of 1995-1998. The data available from the TBADS monitoring program for both wet and dry deposition estimates (Pribble and Janicki, 1999) were more site-specific than those used for previous estimates (Zarbock et al., 1994; 1996). Wet deposition was estimated as the product of rainfall and nitrogen concentration in the precipitation. To estimate dry deposition, concentrations of various nitrogen species in the atmosphere were measured, and deposition velocities for the nitrogen species were estimated utilizing a model developed by NOAA (Valigura, 1995). Atmospheric deposition directly to the surface of the bay accounted for approximately 21% of the total nitrogen loading to the bay during 1995-1998 (Pribble et al., 2001).

1.1 Objectives

The purpose of this TBEP project was to estimate the potential changes in total nitrogen loading from atmospheric deposition between previous estimates and that expected by 2010.

The specific objectives of the analyses reported here were to provide the following:

- Estimates of potential changes in atmospheric deposition of nitrogen directly to each bay segment from 1995 to 2000 and 2010;

- Estimates of potential changes in watershed loading to each bay segment as a result of changes in atmospheric deposition between 1995, 2000, and 2010;

- An estimate of the 2010 proportion of total nitrogen loading to the bay attributable to direct atmospheric deposition of nitrogen to the surface of the bay; and

- Comparisons of the 2010 proportion of total loads due to atmospheric deposition to those for 1992-1994 and 1998.

The bay segments of Tampa Bay are shown in Figure 1, with the watershed of the bay shown in Figure 2.

1.2 Factors Affecting Atmospheric Deposition

Atmospheric deposition of nitrogen is a function of a number of factors (Figure 3). Nitrogen is deposited from the atmosphere to the bay and its watershed via wet and dry deposition. The quantity and quality of the nitrogen deposited depends upon:

- the source of the emissions, including its location, type, and magnitude;
- the transport and transformation of the nitrogen and the resultant concentrations in the atmosphere;
- the prevailing meteorology, including rainfall and wind speed and direction; and
- the characteristics of the land and water surfaces upon which the nitrogen is deposited.

Nitrogen emissions sources include:

- stationary point sources (e.g., power generation facilities);
- stationary area sources (e.g., feedlots);
- on-road mobile sources (e.g., automobiles);
- non-road mobile sources (e.g., ships); and
- natural biogenic sources.

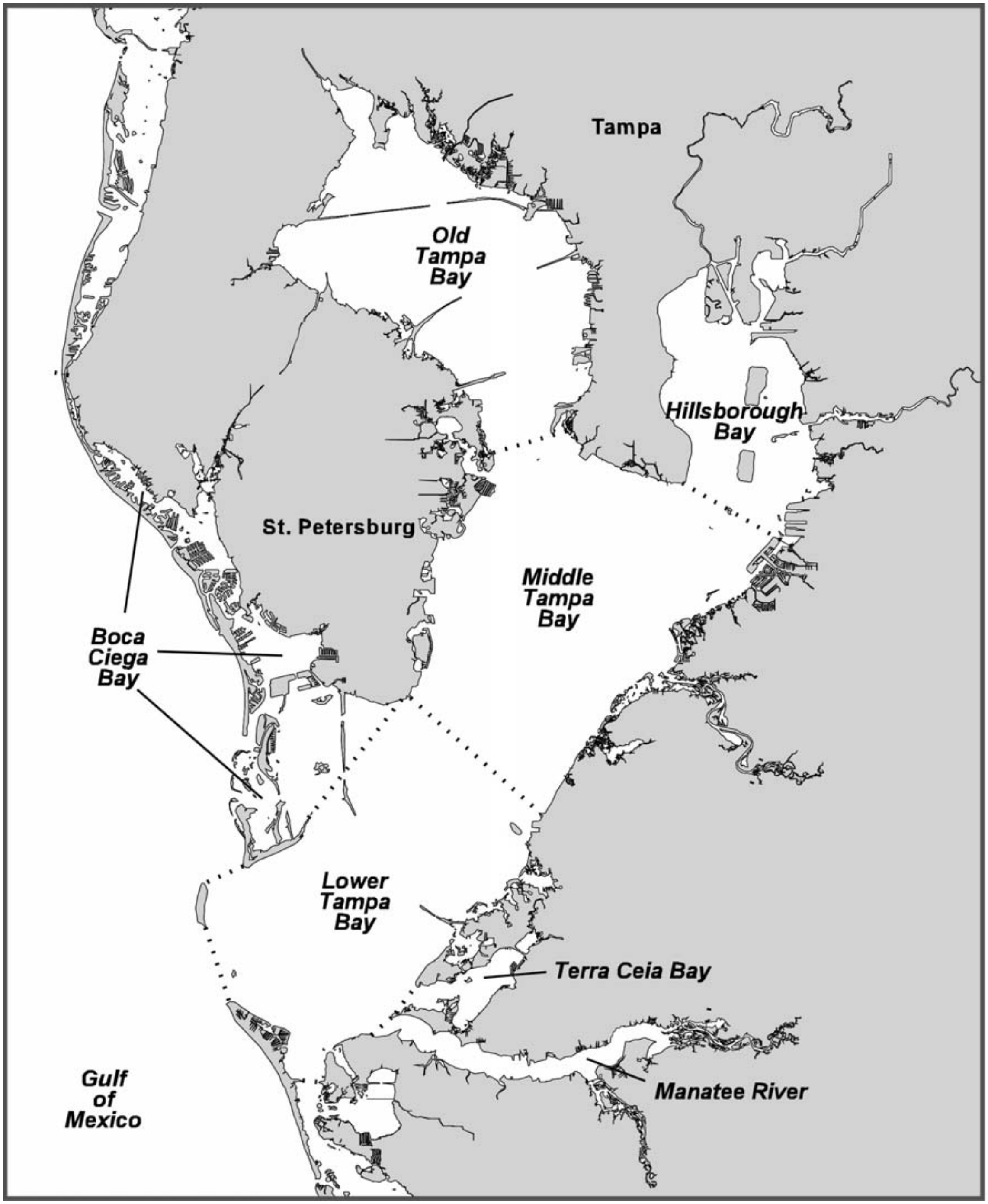

Figure 1. Bay segments of Tampa Bay.

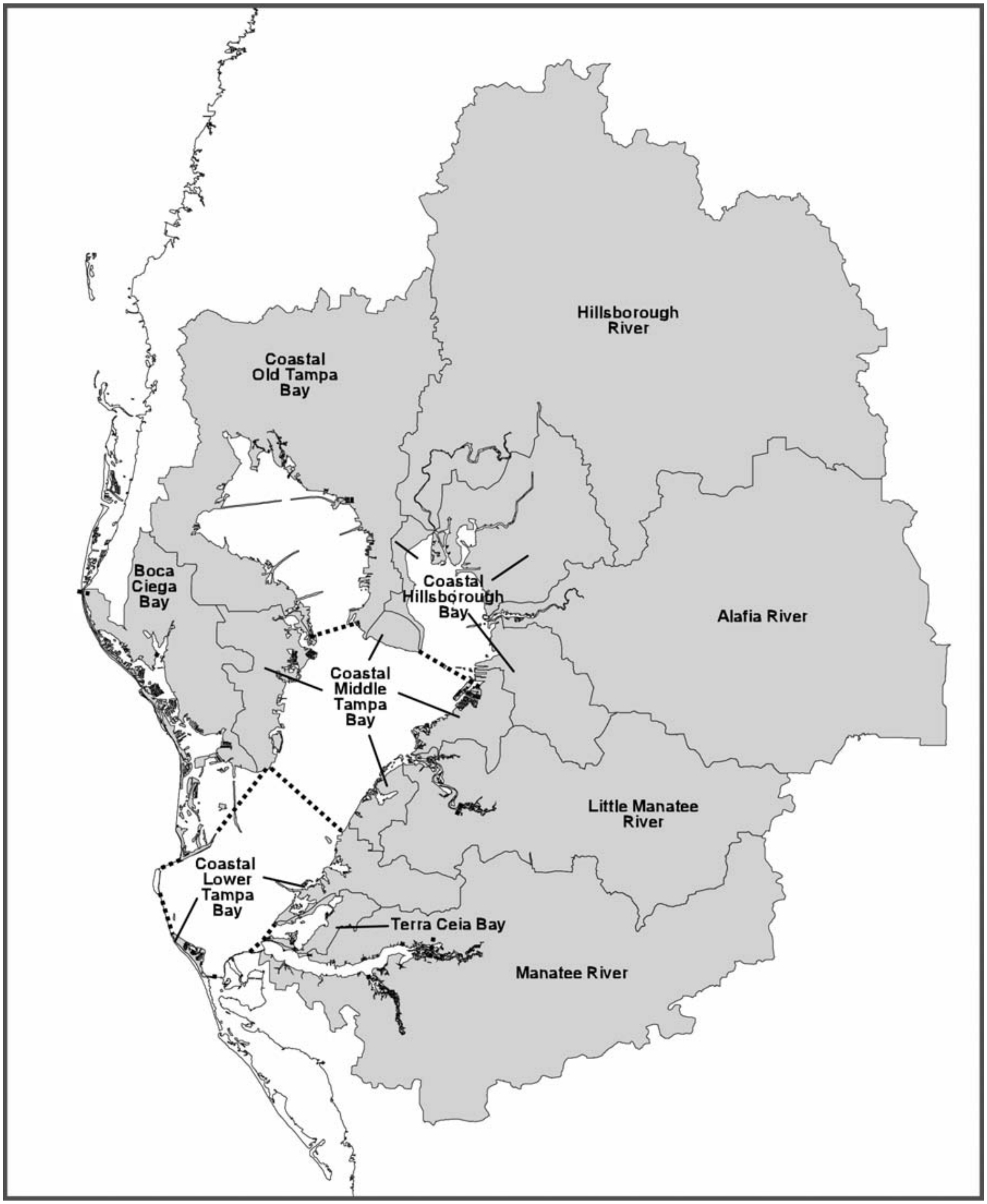

Figure 2. The Tampa Bay Watershed and its major basins.

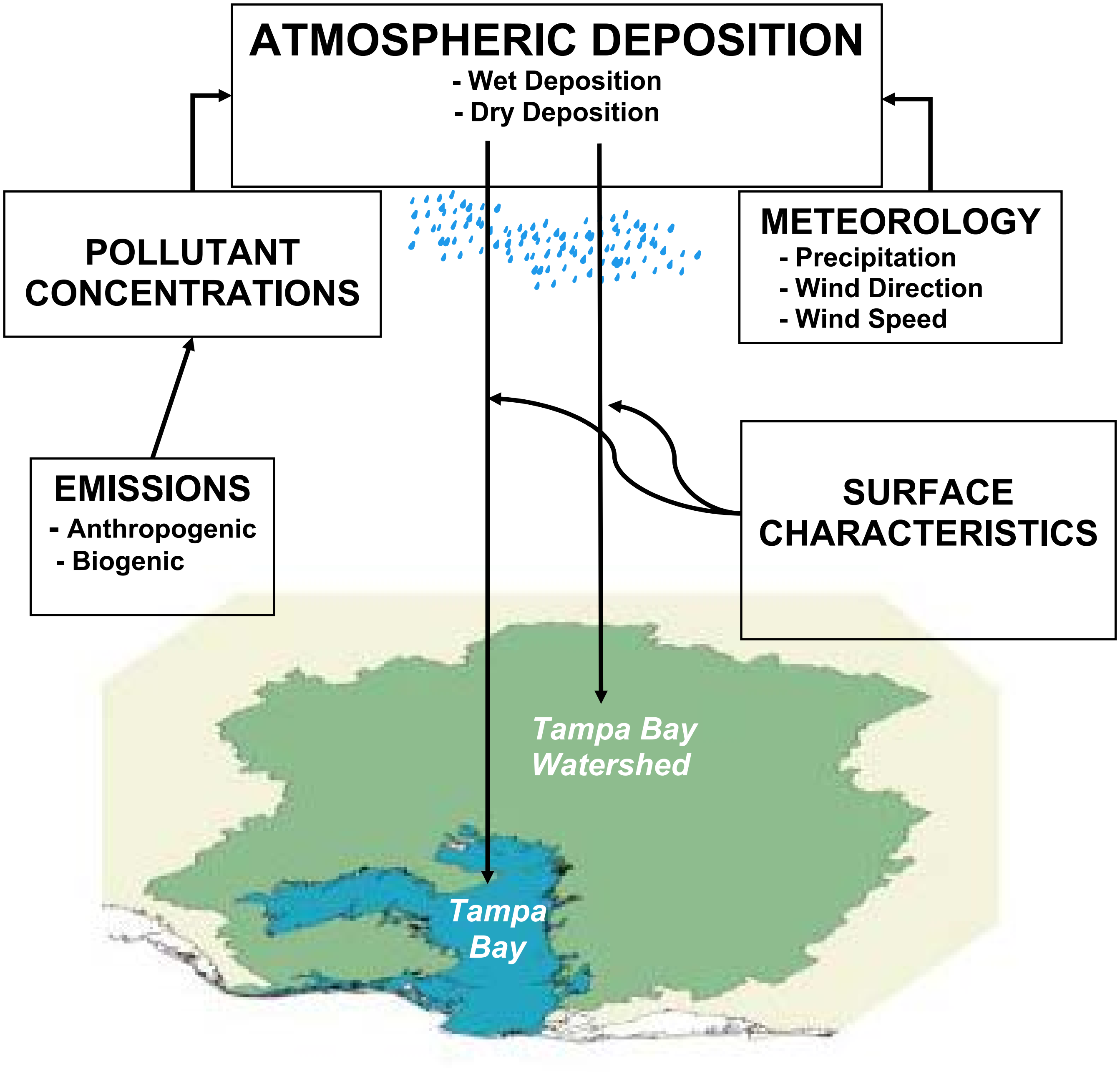

Figure 3. Factors that influence the atmospheric deposition of nitrogen to Tampa Bay and its watershed.

1.3 Nitrogen Sources in the Tampa Bay Airshed

Two of the largest stationary point sources in Florida are in the Tampa Bay area, the Tampa Electric Company's (TECO) Big Bend and F.J. Gannon facilities. In 1997, these two facilities contributed 76,800 tons of NO_x to the atmosphere (FDEP, 2000a), accounting for more than 50% of the atmospheric nitrogen emissions from Hillsborough and Pinellas counties.

Major changes in NO_x emissions in the Tampa Bay region will result as part of a landmark agreement between the EPA and TECO. In November 1999, the EPA filed seven lawsuits against electric utility companies in the Midwest and South, including TECO, charging that the companies' power plants illegally released large quantities of air pollutants. The suits charged that the companies violated the 1990 Clean Air Act Amendments by making major modifications to many of their plants without installing the equipment required to control smog, acid rain, and soot. The EPA then issued Notices of Violation to the companies, which triggered a 30-day window in which state environmental regulators were to step in to negotiate the needed emissions reductions with the companies.

In December 1999, TECO and the FDEP reached an agreement that required that TECO add NO_x controls, or shut down or re-power the coal-fired units at their Gannon Station and Big Bend plants by May 2010. This agreement also called for the shut down of three of the Gannon Station units, while the other three units were to be switched to natural gas.

In February 2000, TECO and the EPA settled the November 1999 federal litigation, providing significant additional details for the implementation of requirements of the agreement. The agreement featured the conversion of the TECO Gannon Station facility from coal to natural gas, with Gannon Station Units 1, 2, and 6 shutting down in 2004 and Units 3, 4, and 5 converting to natural gas. The repowered Gannon Station will be renamed the Bayside Power Station. The agreement also called for major reductions in NO_x emissions by 2010 from the TECO Big Bend Station, to be achieved by installing NO_x controls.

In 1997, stationary point sources and on-road mobile sources accounted for approximately 87% (130,000 tons) of the total NO_x emissions from Hillsborough and Pinellas counties (149,000 tons). Stationary point sources accounted for about 62% (93,100 tons/yr) of the total annual NO_x emissions from the two counties, while on-road mobile sources accounted for an additional 25% (37,600 tons/yr) of NO_x emissions (FDEP, 2000). During the same year, the TECO Big Bend and F.J. Gannon facilities accounted for approximately 80% of the stationary point source nitrogen emissions from Hillsborough and Pinellas counties (FDEP, 2000b; TECO, 2000).

One of the results of the activities called for in the previously discussed federal agreement for the TECO facilities is the reduction in NO_x emissions from the two facilities by approximately 90% between 1997 and 2010 (TECO, 2000). These reductions alone constitute a 46% reduction in NO_x emissions from Hillsborough and Pinellas counties compared to 1997 levels.

NO_x emissions from mobile on-road sources are not expected to change significantly by 2010 (FDEP, 2000a). Projected increases in the numbers of automobiles are expected to be offset by implementation of EPA emissions standards taking effect in 2004, yielding no net change in NO_x emissions from mobile on-road sources.

1.4 Response in Atmospheric Deposition to NO_x Emissions Reductions

The response in atmospheric deposition of nitrogen due to the expected reductions in anthropogenic emissions must also be examined in order to understand how emissions reductions may affect water quality in Tampa Bay. Previous attempts to predict the change in deposition in response to a change in emissions have pointed to the relatively high degree of uncertainty in deriving the relationship between atmospheric emissions and deposition.

Various methods may be used to relate changes in emissions to changes in deposition. As discussed above, the reduction in emissions resulting from the scheduled modifications to the TECO facilities, and the projected no net change in on-road mobile sources emissions, corresponded to a reduction in atmospheric emissions of 46% by 2010. Following is a description of the method utilized for this work effort to relate emissions reductions to reductions in deposition.

The simplest approach to relating emission reductions to deposition reductions would be to assume that there is a directly proportional relationship between emissions and deposition. Thus, a 10% reduction in emissions would translate to a 10% reduction in deposition. This method of relating changes in atmospheric nitrogen emissions to changes in deposition has been used to estimate the potential 2010 deposition (Janicki et al., 2001). For that analysis, it was assumed that atmospheric emissions remained unchanged in 2010 from the emissions for 1997 from sources other than stationary point sources.

A more accurate approach to relating emission reductions to deposition reductions is to assume that reductions in deposition may only occur above a certain background deposition level. In areas relatively unimpacted by anthropogenic activities, deposition may be considered to be representative of background conditions for the purposes of this study. The NADP sites at Quincy (in the Florida Panhandle), Bradford Forest (North Florida), and Chassahowitzka National Wildlife Refuge (west coast of Florida north of Tampa Bay) averaged 2.8 kg N/ha wet deposition annually during the 1996-1999 period (NADP website), and may be considered representative of background conditions. During this same period, the wet deposition from the TBADS site in Tampa Bay was estimated to be 4.1 kg N/ha/yr (Poor and Pribble, 2003). Wet deposition at the Tampa Bay site is therefore approximately 1.3 kg N/ha/yr greater than background conditions. As total deposition is approximately twice the wet deposition in Tampa Bay (Poor and Pribble, 2003), this equates to approximately 2.6 kg N/ha/yr of deposition attributable to anthropogenic activities beyond those contributing to deposition at the background sites. Using this method, a 10% reduction in emissions results in a 10% reduction in deposition over and above the 2.6 kg N/ha/yr considered as baseline deposition, or a reduction of 0.26 kg N/ha/yr.

More complex methods of estimating responses of atmospheric deposition to emissions reductions depend upon knowledge of the locations of the various point sources in an airshed, the relative quantities of the emissions from each point source, and the fate of emissions once in the atmosphere. These methods must consider the complexities of atmospheric chemistry, atmospheric dynamics, and precipitation chemistry. Atmospheric deposition models, such as the Regional Acid Deposition Model (RADM) (Chang et al., 1987), are currently in use for estimation of atmospheric deposition as a function of emissions. The RADM model is part of the model suite in use by the Chesapeake Bay Program to estimate nitrogen loadings to the estuary (Dennis, 1996).

In the Tampa Bay area, the FDEP and the TBEP have joined in the Bay Region Atmospheric Chemistry Experiment (BRACE). The overall objective of this study is to provide improved estimates of the effects on Tampa Bay of local and regional emissions of NO_x. Advanced modeling efforts are planned as part of the BRACE study, and the RADM model is initially slated to serve as one of deposition models to be used (FDEP, 1999). However, the BRACE study is currently in its initial stages, and results are not currently available for use in this analysis.

For this analysis, the second method described above is used to estimate changes in deposition resulting from changes in emissions. This method estimates changes in deposition above background levels to be directly proportional to changes in emissions.

2 METHODS

The following presents the methods employed for estimation of atmospheric nitrogen loading for the relevant time period to both the surface of the bay and to the bay via transport from the watershed.

2.1 Estimation of Atmospheric Nitrogen Loading Directly to the Bay Surface

Atmospheric deposition of nitrogen directly to the surface of Tampa Bay was defined as the sum of wet deposition (rainfall) and dry deposition (gaseous constituent interaction and dust fallout). Only wet and dry deposition delivered directly to the open water estuary was accounted for as atmospheric input for this portion of the analysis.

There were three types of data needed to estimate atmospheric deposition directly to the bay. First, an estimate of the hydrologic load to the bay via precipitation was needed. Secondly, an estimate of the nitrogen concentration in that precipitation was needed. Lastly, an estimate of dry deposition was needed, either from empirical data or model-based estimates.

The hydrologic load via direct precipitation to each segment of the bay was estimated as the product of the rainfall depth and the open water area of the segment. An inverse distance-squared surface fitting method was applied to data from 22 NWS rainfall monitoring sites in or near the Tampa Bay watershed to provide bay segment-specific monthly rainfall amounts. Prior to August 1996, the nitrogen concentration in the precipitation was derived from data collected at the NADP Verna Wellfield site (Zarbock et al., 1994; 1996). This site is located near the southern boundary of the Tampa Bay watershed in Sarasota County, and it represented the nearest site measuring precipitation concentration data at the time. Since August 1996, precipitation nitrogen concentrations were derived from data collected by TBADS (Pribble and Janicki, 1999). This program includes sampling elements for both wet and dry deposition at an intensive monitoring site located on the Gandy Bridge Causeway. Wet deposition nitrogen loadings were calculated on a monthly basis for each bay segment by multiplying the direct precipitation volume by the nitrogen concentration.

Dry fluxes of nitrogen to the surface of the bay were estimated using the best available data describing the relationship between wet and dry deposition. Since 1996, monitoring at the TBADS site provided atmospheric nitrogen concentration data. Utilizing these data, meteorological data, and a deposition model, estimates of dry deposition at the TBADS monitoring site were obtained (Pribble and Janicki, 1999). Seasonal-specific ratios of wet:dry deposition at the TBADS site were estimated, and this ratio was applied to the wet deposition estimate to each bay segment to derive the dry deposition for 1995. The sum of the monthly wet and dry deposition of nitrogen to each segment represents the total atmospheric deposition directly to the segment.

1995 Estimate

Atmospheric deposition loads from rainfall were derived from the 1995 NWS rainfall records and precipitation concentration data from the NADP Verna Wellfield site. Atmospheric deposition loads from dryfall were derived using the seasonal ratios of wet:dry deposition derived from the TBADS monitoring data, as reported previously in Pribble et al. (2001).

2000 Estimate

Atmospheric deposition nitrogen loads from rainfall were derived from the 2000 NWS rainfall records and precipitation concentration data from the TBADS monitoring site. Utilizing these data, meteorological data, and a deposition model (Valigura, 1995), estimates of dry deposition at the TBADS monitoring site were obtained. Seasonal-specific ratios of wet:dry deposition at the TBADS site were estimated for 2000, and these ratios were applied to the monthly wet deposition estimates to each bay segment to derive the dry deposition. The sum of the monthly wet and dry deposition of nitrogen to each segment represents the total atmospheric deposition directly to the segment.

The meteorological data used in the estimate of dry deposition for 2000 were not from the TBADS meteorological monitoring site. The dry deposition model required inputs of wind speed, air temperature, water temperature, and relative humidity. Meteorological data were obtained from Dr. Noreen Poor that incorporated air and water temperature data from the Clearwater monitoring site and relative humidity data from the Tampa International Airport monitoring site. Wind speed data from several sites were examined for similarity to those observed at the TBADS site for the August 1996-July 1999 period, but were not significantly correlated at either daily or weekly time scales.

To provide an estimated wind speed dataset for input to the dry deposition model, the wind speed at the St. Petersburg Albert Whitted Airport was used. For the period August 1996 through July 1999, mean monthly wind speed data from the St. Petersburg site and the TBADS site were compared. A monthly-specific ratio relating the mean monthly wind speed at the TBADS site to that at the St. Petersburg site was derived for this period. These monthly-specific ratios were then applied to the 2000 wind speed data from the St. Petersburg site to provide an estimate of wind speeds at the TBADS site for 2000.

2010 Estimate

The estimate of 2010 rainfall was derived from that of the 1992-1994 period, considered representative of long-term average meteorological conditions. These data were used to develop average monthly rainfall for 2010.

Two estimates of the 2010 atmospheric nitrogen deposition were derived. The first estimate of the 2010 atmospheric nitrogen deposition was based on no changes in atmospheric emissions from those based on TBADS data from the 1996-1998 period. This estimate provides an upper bound on 2010 atmospheric deposition, considering no reductions occurring in deposition as a result of expected emissions reductions. This atmospheric deposition estimate utilized the following data, with no concentration reductions: TBADS nitrogen concentration data from the 1996-1998 period, the 1992-1994 segment-specific rainfall, and the wet:dry deposition ratio derived from the TBADS monitoring data.

The second estimate of the 2010 atmospheric nitrogen deposition utilized projections of a decline in atmospheric nitrogen emissions to adjust the atmospheric nitrogen concentrations derived from the TBADS data of 1996-1998. The projected 46% reduction in atmospheric emissions by 2010, previously discussed, was applied to concentrations above those concentrations derived from the NADP sites defined above as representative of baseline deposition, namely the Quincy site, the Bradford Forest site, and the Chassahowitzka site. For this estimate, the projected 46% reduction in atmospheric emissions by 2010 corresponded to a 46% reduction in atmospheric nitrogen concentrations for that fraction of the TBADS concentration above the baseline concentration. Thus, the 1996-1998 monthly precipitation nitrogen concentrations measured at the TBADS site were compared to mean monthly concentrations from the three baseline sites, and that concentration over and above the baseline concentrations was reduced by 46% to create the monthly 2010 concentration data. These data were used with the 1992-1994 segment-specific rainfall data to derive the 2010 wet atmospheric deposition estimate. The wet:dry deposition ratio derived from the 1996-1998 TBADS data was used to estimate dry deposition to each segment.

2.2 Estimation of Watershed Loading of Atmospheric Nitrogen to the Bay

Loading of atmospheric nitrogen to the bay also occurs via deposition to the watershed and subsequent transfer of nitrogen from the watershed to the bay. Nitrogen loading to the watershed occurs through both wet and dry deposition. However, prior to being transported to the bay, these watershed nitrogen loads are attenuated on both land and in waterways. On land, attenuation occurs via uptake by vegetation, infiltration to groundwater, and storage in surface waters. In surface waters, attenuation results from uptake by algae and sedimentation.

Additional attenuation of atmospherically derived nitrogen occurs through denitrification and ammonia volatilization, both on land and in the water.

As with deposition directly to the surface of the bay, nitrogen deposition to the watershed is the sum of wet and dry deposition. This deposition was estimated in the same manner as that to the surface of the bay. The monthly hydrologic load via precipitation to each basin of the watershed was estimated, using a rainfall surface derived from 22 NWS sites. Within each basin, the nitrogen loads from precipitation to each of four land use types in the Tampa Bay watershed were estimated as the product of the rainfall volume and nitrogen concentration in the rainfall. The four land use types were urban, agricultural, wetland, and forested. The monthly total deposition to each land use category and basin was then estimated using the wet:dry ratio obtained from the TBADS monitoring. Because of the lack of data for watershed dry deposition, the wet:dry deposition ratio estimated for the surface of the bay was used for the watershed as well.

The total nitrogen load to the watershed is not only a function of atmospheric deposition. Previous studies of nitrogen loading to the Chesapeake Bay watershed also considered inputs from fertilizer and manure application to agricultural lands (Linker et al., 2000). In the Tampa Bay watershed, nitrogen loading to agricultural lands from fertilizer application has been estimated at approximately 120 kg/ha/yr (Patwardhan and Donigian, 1995). The total nitrogen load to agricultural lands was the sum of the atmospheric deposition and the fertilizer load. Typical fertilizer application rates in urban areas in Florida are on the order of 20 kg N/ha/yr (Florida Yards & Neighborhoods website), so that the total nitrogen load to urban lands was estimated as the sum of the atmospheric deposition and this fertilizer load. The total nitrogen load to all other land uses was made up entirely of the atmospheric deposition load.

1995 Estimate

The method used for estimation of the 1995 watershed loading of atmospherically deposited TN load transported to the bay was as follows. First, the total nitrogen loading to each of the four general land use categories in each basin was estimated, using 1995 land use, 1995 rainfall, and nitrogen concentration data in the rainfall from the NADP site at Verna Wellfield. Atmospheric deposition loads from dryfall were estimated using the seasonal ratios of wet:dry deposition derived from the TBADS monitoring data, as reported previously in Pribble et al. (2001). Next, the estimated TN load reaching the bay from each land use category in each basin (Pribble et al., 2001) was divided by the total TN load to each land use type in each basin, the loads being from atmospheric deposition and fertilization. This resulted in a ratio of estimated TN load to the bay from each land use category in each basin to the estimated TN load to each land use category in each basin. Finally, the ratio derived for each land use category in each basin was used to multiply the TN loads to the watershed from atmospheric deposition, in order to derive an estimate of the TN load from atmospheric deposition to the watershed reaching the bay. These estimates were summed by bay segment to provide an estimate of segment-specific TN loads from atmospheric deposition to the watershed for 1995.

2000 Estimate

The method used for estimation of the 2000 watershed loading of atmospherically deposited TN load transported to the bay was similar to that used for the 1995 estimate. The total atmospheric nitrogen loading to each of the four general land use categories in each basin was estimated, using 1995 land use and the 2000 rainfall surface previously described. The nitrogen concentration in the rainfall, as obtained from the 2000 TBADS data, was multiplied by the rainfall to each basin to provide the total wet deposition to the basin. As discussed above, the dry deposition for 2000 was estimated using derived meteorological data from sites other than the TBADS site, and atmospheric nitrogen concentration data from the TBADS site. The monthly-specific wet:dry ratio was used to estimate total atmospheric deposition to each of the four land use categories in each basin. Finally, the basin-specific and land use category-specific ratios of TN load to the watershed to TN load to the bay, as derived for the 1995 estimate, were used to estimate the TN loads to the watershed from atmospheric deposition, resulting in an estimate of the TN load from atmospheric deposition to the watershed reaching the bay. These estimates were summed by bay segment to provide an estimate of segment-specific TN loads from atmospheric deposition to the watershed for 2000.

2010 Estimate

To estimate the 2010 atmospherically deposited TN load to the watershed reaching the bay, previously estimated nonpoint source loads for 2010 (Janicki et al., 2001) were used. The 2010 rainfall was derived from that of the 1992-1994 period, considered representative of long-term average meteorological conditions. The nitrogen concentration in rainfall was obtained from the TBADS data for August 1996-December 1998, as was the ratio of wet:dry deposition. The 2010 land use data used are the most recently developed future land use projections (Janicki et al., 2001).

Two estimates of the 2010 atmospheric nitrogen deposition were derived. The first estimate of the 2010 atmospheric nitrogen deposition was based on no changes in atmospheric emissions from those of the 1996-1998 period. This estimate provides an upper bound on 2010 atmospheric deposition, considering no reductions occurring in deposition as a result of expected emissions reductions. The second estimate utilized projections of a decline in atmospheric nitrogen emissions to adjust the atmospheric nitrogen concentrations derived from the TBADS data of 1996-1998. For this estimate, the previously discussed 46% reduction in atmospheric emissions by 2010 corresponded to a 46% reduction in atmospheric nitrogen concentrations above background levels from those observed during the 1996-1998 period. Thus, the 1996-1998 monthly precipitation nitrogen concentrations above background levels, as discussed above, were reduced by 46% to create the monthly 2010 concentration data.

For the no-change scenario, the first step was estimation of the atmospheric deposition to each of the four land use categories in each basin. This was accomplished using the 1992-1994 rainfall to each basin, the 1996-1998 nitrogen concentration in rainfall from the TBADS data, and the wet:dry ratio derived from the 1996-1998 TBADS data. The next step for the no-change scenario, as for the 1995 estimate, was to estimate the total nitrogen load to each land use category in each basin as the sum of atmospheric deposition and fertilizer application. Thirdly, the total nitrogen load to each land use category in each basin was divided by the estimated nonpoint source TN load for 2010 developed previously (Janicki et al., 2001), yielding a ratio of the TN load reaching the bay to the TN load deposited on the watershed. This ratio was then used to multiply the atmospheric TN load deposited to the watershed, resulting in the TN load from atmospheric deposition on the watershed reaching the bay for the no-change scenario. These estimates were summed by bay segment to provide an estimate of segment-specific TN loads from atmospheric deposition to the watershed for 2010.

For the second scenario, in which the concentration of atmospheric nitrogen above background levels was reduced by 46% commensurate with the expected reductions in atmospheric emissions of nitrogen, the atmospheric deposition to the watershed was estimated in a similar manner. The ratio of the TN load reaching the bay to the TN load deposited on the watershed derived for the no-change scenario was then used to multiply the atmospheric load to the watershed to derive the TN load reaching the bay in the concentration reduction scenario. As in the no-change scenario, the estimates were summed by bay segment to provide an estimate of segment-specific TN loads from atmospheric deposition to the watershed for 2010.

2.3 Comparison of 1992-1994, 1998, and 2010 Proportions of Total Nitrogen Loading from Direct Loading to the Bay Surface

Estimates of total nitrogen loading to the bay from all sources, including atmospheric deposition of nitrogen directly to the surface of the bay, have been previously derived for 1992-1994 (Zarbock et al., 1996), 1998 (Pribble et al., 2001) and 2010 (Janicki et al., 2001). The proportion of the TN load attributable to atmospheric deposition directly to the bay during each period was derived by dividing the atmospheric TN load by the total TN load to the bay during each period.

3 RESULTS AND CONCLUSION

This section presents the results of the analyses performed to derive estimates of atmospheric deposition of nitrogen directly to the surface of the bay, estimates of atmospheric deposition of nitrogen to the watershed, and estimates of the amount of atmospheric nitrogen deposited on the watershed that eventually reaches the bay. Following these results is a discussion of the proportion of the total nitrogen load to the bay estimated from atmospheric deposition to the bay and its watershed.

3.1 Atmospheric Nitrogen Loading Directly to the Bay Surface: 1995, 2000, and 2010

Estimated loadings of atmospheric nitrogen directly to the surface of each bay segment for 1995, 2000, and 2010 are shown in Table 1. For 2010, the estimates reflect loadings with and without reductions in emissions. The 2000 loads are somewhat less than those of 1995, as expected given the relatively low rainfall of 2000 (Table 2). The 2010 loads without emissions reductions considered are slightly greater than those of 1995. The 2010 loads estimated considering reductions in emissions are approximately 84% of the 2010 loads estimated with no reductions, as a result of the 46% reduction in atmospheric nitrogen concentrations above the background levels (as represented by the background NADP sites described above).

Table 1. Atmospheric TN load to surface of the bay (tons/yr).

Bay Segment	1995	2000	2010 Without Reductions	2010 With Reductions
Old Tampa Bay	219	170	218	182
Hillsborough Bay	102	82	111	94
Middle Tampa Bay	298	252	295	248
Lower Tampa Bay	246	213	284	238
Boca Ciega Bay	94	80	89	75
Terra Ceia Bay	15	14	20	17
Manatee River	39	37	54	45
Total	1014	847	1071	899

Table 2. Estimated rainfall to bay segments (in/yr).

Bay Segment	1995	2000	2010
Old Tampa Bay	57.8	36.1	42.6
Hillsborough Bay	58.2	36.5	46.2
Middle Tampa Bay	62.9	42.3	46.4
Lower Tampa Bay	63.9	40.7	51.2
Boca Ciega Bay	63.5	43.5	45.4
Terra Ceia Bay	64.5	39.4	55.5
Manatee River	64.3	40.0	56.8

The similarity of the estimated loads for 1995 and the 2010 scenario without reductions is the result of two factors; rainfall and atmospheric nitrogen concentration. The 1992-1994 rainfall used to estimate the 2010 loads was less than that in 1995 (Pribble et al., 2001), on the order of five to ten inches in most bay segments. The atmospheric deposition during each period is related to the product of rainfall and the atmospheric nitrogen concentration. For the 1995 estimate, the atmospheric nitrogen concentrations were obtained from the NADP site at Verna Wellfield. For the 2010 estimate, data collected at the TBADS site in Tampa Bay were used. The TBADS concentrations are typically higher than those from the Verna Wellfield. The data for August 1996-December 1998 show higher concentrations of atmospheric nitrogen than those observed at the Verna site during the same period, as shown in Table 3. Thus, the product of the lower rainfall of the 1992-1994 period and the higher atmospheric nitrogen concentrations from TBADS used to estimate the 2010 deposition yielded slightly higher deposition than the 1995 rainfall and 1995 Verna Wellfield concentrations.

Table 3. Mean monthly atmospheric nitrogen concentrations at the NADP Verna Wellfield site and the TBADS site, August 1996 through December 1998 (mg/L).

Month	Verna Wellfield	TBADS
January	0.14	0.22
February	0.24	0.30
March	0.22	0.28
April	0.37	0.64
May	0.50	0.64
June	0.45	0.66
July	0.26	0.43
August	0.28	0.67
September	0.20	0.32
October	0.29	0.41
November	0.07	0.26
December	0.18	0.16

3.2 Watershed Loading of Atmospheric Nitrogen to the Bay: 1995, 2000, and 2010

To estimate the loading of atmospheric nitrogen to the bay from the watershed, it was first necessary to estimate the loading of atmospheric nitrogen directly to the watershed. These estimates are shown in Table 4 for 1995, 2000, and 2010. As for deposition directly to the surface of the bay, deposition to the watersheds of the bay segments is less in 2000 than in 1995, in keeping with the lower rainfall in 2000 (Table 5). Similarly, estimated loadings to the watershed in 2010 with no emission reductions considered were greater than in 1995, as discussed above for deposition to the bay's surface. Again, as with deposition directly to the surface of the bay, the 2010 deposition estimates with emission reductions considered are approximately 85% of the 2010 estimate with no change in emissions.

The estimated loadings of atmospherically deposited nitrogen from the watershed to the bay are shown in Table 6 for 1995, 2000, and 2010 with and without consideration of reductions in emissions. As for deposition to the surface of the bay, the estimated atmospheric TN load from the watershed to the bay was less in 2000 than in 1995, primarily because of the lower rainfall in 2000. However, the 2010 no-change scenario loading estimates to the bay from the watershed are less than those of 1995. This is in direct contrast to the atmospheric deposition to the watershed for these periods.

One primary factor differentiates the methods of estimating the transfer of atmospheric nitrogen from the watershed to the bay for 1995/2000 and 2010. This factor is the ratio relating nitrogen load from the watershed to the bay to nitrogen deposition to the watershed. For the 1995 and 2000 periods, the fraction of atmospheric nitrogen reaching the bay from the watershed was estimated by deriving a basin- and land use-specific ratio between the estimated nonpoint source load for 1995 and nitrogen deposited to the watershed, from the atmosphere and fertilizer, in 1995. The estimated nonpoint source load was based on both measured and estimated water quality and discharge data (Pribble et al., 2001). The 2010 estimated nonpoint source load developed previously (Janicki et al., 2001) was based entirely on estimated water quality and discharge data. The estimated 2010 nonpoint source load and the estimated 2010 watershed TN load from atmospheric deposition and fertilizer application were used to derive a ratio of bay loading to watershed loading. The ratios for the 2010 period were typically less than those from the 1995 period, resulting in less transfer of atmospheric nitrogen from the watershed to the bay.

Table 4. Atmospheric TN load to the watershed (tons/yr).

Bay Segment	1995	2000	2010 Without Reductions	2010 With Reductions
Old Tampa Bay	586	485	674	566
Hillsborough Bay	3032	2659	4013	3414
Middle Tampa Bay	739	664	1035	884
Lower Tampa Bay	82	72	108	92
Boca Ciega Bay	212	182	209	176
Terra Ceia Bay	27	24	38	33
Manatee River	829	801	1303	1116
Total	5506	4888	7381	6280

Table 5. Estimated rainfall to the watershed of each bay segment (in/yr).			
Bay Segment	**1995**	**2000**	**2010**
Old Tampa Bay	57.2	37.3	44.9
Hillsborough Bay	56.0	37.5	51.6
Middle Tampa Bay	62.5	39.8	53.3
Lower Tampa Bay	64.1	37.6	55.4
Boca Ciega Bay	63.1	44.0	44.0
Terra Ceia Bay	64.3	38.4	56.4
Manatee River	63.7	40.9	58.2

Table 6. Atmospheric TN load from the watershed to the bay (tons/yr).				
Bay Segment	**1995**	**2000**	**2010 Without Reductions**	**2010 With Reductions**
Old Tampa Bay	157	131	107	89
Hillsborough Bay	886	777	309	263
Middle Tampa Bay	388	359	186	159
Lower Tampa Bay	40	35	22	19
Boca Ciega Bay	104	89	29	24
Terra Ceia Bay	9	9	6	5
Manatee River	478	477	323	311
Total	2062	1876	1021	870

3.3 Proportions of Total Nitrogen Loading from Direct Loading to the Bay Surface: 1992-1994, 1998, and 2010

An additional analysis requested by the TBEP was to compare the proportions of nitrogen loading to the bay directly from the atmosphere for three periods; 1992-1994, 1998, and 2010. The proportions of the TN load to the bay segments due to direct atmospheric deposition are shown in Table 7 for the 1992-1994 period, 1998, and 2010. The 1998 proportions are considerably less than those of the 1992-1994 period, despite the higher rainfall observed in 1998. This is primarily the result of the much greater nonpoint source load estimated for 1998 (Pribble et al., 2001) than in the 1992-1994 period (Zarbock et al., 1996), so that despite the greater deposition in 1998, atmospheric deposition directly to the surface of the bay was a smaller proportion of the total during 1998.

The estimated proportions of TN load from atmospheric deposition directly to the surface of the bay in 2010, with no emission reductions considered, are very similar to those of the 1992-1994 period. This is as expected, as the 1992-1994 rainfall was used to derive the estimates for both periods. The 1992-1994 estimates were derived using different atmospheric concentration data and a different relationship between dry and wet deposition that the estimates for 2010, however, so that the proportions for the two periods are not identical. The proportion of the 2010 TN loading due to atmospheric deposition with emission reductions considered is approximately 84% of that without reductions.

Table 7. Proportions of TN load from atmospheric deposition to the bay surface.				
Bay Segment	**1992-1994[a]**	**1998[b]**	**2010 Without Reductions**	**2010 With Reductions**
Old Tampa Bay	47%	32%	45%	40%
Hillsborough Bay	8%	4%	8%	8%
Middle Tampa Bay	38%	34%	45%	41%
Lower Tampa Bay	83%	61%	93%	92%
Boca Ciega Bay	53%	34%	47%	42%
Terra Ceia Bay	57%	44%	57%	53%
Manatee River	11%	5%	12%	10%
Tampa Bay	29%	21%	32%	27%

a- after Zarbock et al., 1996
b- after Pribble et al., 2001

3.4 Contributions of Atmospheric Deposition to Bay Loads: 1995 and 2010

Combining the information presented above with the estimated total loads to the bay for 1995 (Pribble et al., 2001) and 2010 (Janicki et al., 2001) provides estimates of the contributions of atmospherically deposited nitrogen to Tampa Bay. Table 8 shows the estimated TN load to the bay for 1995 and 2010 previously derived. Both the 2010 scenarios, with and without emission reductions considered, are shown. The total nitrogen contribution from the atmosphere to the bay, directly to the bay surface and through the watershed to the bay, is estimated to be approximately 56% of the total for 1995. The 2010 no-change scenario results in a slightly higher proportion, with the atmosphere contributing approximately 63% of the total nitrogen load to the bay. The 2010 scenario accounting for emission reductions results in approximately 54% of the total load to the bay deriving from the atmosphere.

Table 8. Atmospheric contributions to TN loadings to Tampa Bay.			
Year	**Bay and Watershed to Bay (tons/yr)**	**Total Nitrogen Load (tons/yr)**	**Load Proportion from Atmosphere**
1995	3076	5470	56%
2010 No Change	2092	3304	63%
2010 Reduction	1769	3271	54%

3.5 Conclusion

Responses in atmospheric nitrogen concentrations are expected to be observed as planned emission reductions are realized. The current analyses suggest that a reduction in emissions should result in a decline in atmospheric contributions to nitrogen loading to the bay. The magnitude of this decline is not certain. The response in atmospheric nitrogen concentrations to emission reductions used in this analysis will be refined as data are collected. To accomplish this, active atmospheric deposition monitoring programs must remain in place in Tampa Bay through 2010.

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