CMAQ-UCD Atmospheric Deposition Estimates to Tampa Bay Watershed Sub-basins and Tampa Bay Waters

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Model-derived estimates of wet and dry atmospheric deposition of nitrogen (N) to the Tampa bay and its watershed sub-basins from the CMAQ-UCD model are provided here for use in the Tampa Bay TMDL implementation planning process.

The deposition estimates are from the CMAQ-UCD model run at a 2km resolution over the Tampa and nearby regions to be able to adequately resolve the bay waters and watershed sub-basins. The 2km domain is nested within an 8km domain that covers all of Florida and most of South Carolina, Georgia and Alabama. A 32km outer domain covers the continental United States.

The CMAQ-UCD hourly results are combined into a constructed annual average from 10 months of simulations that meet a criterion that each simulation month's rainfall is close to the 15-year average rainfall across the watershed. The 10 months are April, May, July, August, September, October and November of 2002 and January, February and March of 2003.

Units of the results are typically kg-N/ha or kg-N. However, totals for the bay and watershed are also presented in lbs-N.

To facilitate the Tampa Bay Estuary Program (TBEP) TMDL planning process, CMAQ-UCD has been run in several modes to provide answers to TBEP questions aimed at developing an improved understanding of atmospheric deposition of N to Tampa bay and its watershed. Results are provided in several attachments, each attachment addressing a major question posed by the TBEP:

Attachment A: Base 2002 estimates of atmospheric wet and dry deposition of oxidized- and reduced-nitrogen to bay segments and watershed sub-basins

Attachment B: Estimates of the relative contribution from local source emissions to oxidized-N deposition to bay segments and watershed sub-basins, including the breakdown of these local source contributions into mobile, power plant and other sources

Attachment C: Estimates of the reductions in N deposition to bay segments and watershed sub-basins associated with power plant upgrades (to reduce emissions) to the Gannon and Big Bend power plants

Attachment D: Estimates of the reductions in N deposition to bay segments and watershed sub-basins associated with the 2010 Clean Air Interstate Rule (CAIR) air emission reductions

The emissions basically represent 2002 conditions. The mobile source and power plant emissions, representing approximately 75% of the emissions in the watershed are for 2002. The other sector emissions, representing 25% are for 2001, but with the slow economic growth during this period it appears reasonable to assume these 2001 emissions will be nearly equal to those for 2002.

Deposition estimates are provided in terms of oxidized nitrogen (ox-N) and reduced nitrogen (red-N). Ox-N dry deposition is comprised of total-nitrate deposition (TNO3) (TNO3 = nitric acid (HNO_3) + coarse and fine particulate nitrate) plus deposition of NO_X (NO_X = NO + NO_2) and other oxides of nitrogen. The dry deposition rates take into account the fact that NO_X and many of the other oxides of nitrogen are less water soluble than nitric acid. Red-N dry and wet deposition is comprised of ammonia gas and particulate ammonium deposition.

Attachment A
Base 2002 CMAQ-UCD Estimates of Annual Atmospheric Wet and Dry Deposition of Oxidized- and Reduced-Nitrogen to Bay Segments and Watershed Sub-basins

Table A-1a gives the CMAQ-UCD nominal base case estimates of annual nitrogen deposition to the watershed sub-basins and the bay segments in units of kg-N. A companion table, A-1b, gives the totals in units of lbs-N. These estimates stem from using the standard EPA national emissions inventory for the southeast and Florida. The watershed sub-basins and bay segments as defined by the Tampa Bay Estuary Program and used in all of the following tables are shown in Figure A-1.

A comparison against long-term wet deposition data for Florida was conducted. This comparison showed that while the agreement was rather good for the summer period, cold season ammonia predictions of wet deposition across Florida were consistently low by a factor of 2-3. Upon reflection, one would expect the national inventory to be incorrect for Florida. This is because the EPA inventory assumes a seasonal profile for ammonia emissions based on the colder regions of the mid-west with snow in the winter. This is not applicable to Florida. One would expect a more uniform seasonal profile for Florida. A rough inverse suggests that Florida ammonia emissions should be doubled or tripled over the national inventory numbers during the cold months. Overall, this would result in a 70-80 percent increase in annual ammonia emissions in Florida. The CMAQ-UCD was rerun with these new, estimated ammonia emissions to create an Adjusted Base Case. The result is that the wet deposition of ammonia to the watershed is approximately 30% larger, on average. The wet deposition to the bay surfaces is approximately 26% larger, on average.

A second factor affecting ammonia is that the dry deposition velocity for ammonia depositing to land surfaces in CMAQ is thought to be too high. This comes from investigations of the ammonia (NH_3) deposition velocity to terrestrial surfaces compared to sulfur dioxide (SO_2) and nitric acid (HNO_3). This investigation shows that for land surfaces the NH_3 deposition velocity is much closer to that of HNO_3, but we believe it should be closer to SO_2. Hence, consistent with sensitivity studies conducted for Chesapeake Bay, the recommendation is to reduce the total ammonia dry deposition by 30%. This was also done for the construction of the Adjusted Base Case. The result is that in the Adjusted Base the total ammonia dry deposition to the watershed land surfaces is approximately 43% larger, on average than the Nominal Base. Because of the greater availability of ammonia, more particulate nitrate if formed from the total nitrate. A larger particulate nitrate fraction of total nitrate reduces the ox-N deposition to the watershed by approximately 2.5%, on average. There is no consideration needed for deposition to water surfaces. Both ammonia and nitric acid are very water soluble.

We consider the Adjusted Base Case (Tables A-2 and A-3), which includes the changes to ammonia emissions and deposition, to represent our best estimate of the annual N deposition to Tampa. The total spatially-accumulated annual N deposition values for the watershed sub-basins and bay segments are given in Table A-2. The average annual per unit area N deposition values are given in

Table A-3. Figure A-2 shows the total nitrogen deposition (wet + dry), in kg-N/ha, for the Adjusted Base Case for the full 2-km CMAQ-UCD domain. Orlando is shown as well as Tampa. Tampa has noticeably more deposition than Orlando. Figure A-3 shows the total nitrogen deposition (wet + dry) for the Adjusted Base Case, in kg-N/ha, zoomed to a domain around Tampa that is larger than the Tampa watershed.

A few points of interpretation for the Adjusted Base Case may be of interest. First, the dry deposition of NO and NO_2 is very important, especially over the urban areas. The NO + NO_2 dry deposition is comparable to or greater than the dry deposition of total-nitrate (HNO_3 + particulate nitrate). For the urban areas it is greater and the rural areas it is smaller. The total-nitrate dry deposition increases on the order of 50-100% across the urban areas compared to the rural areas. However, the NO + NO_2 dry deposition more than doubles across the urban areas compared to the suburban/rural areas. Thus, there is a noticeable increase in dry oxidized-N deposition from rural to urban areas and that increase is enhanced by the local deposition of NO + NO_2.

Second, dry oxidized-N deposition is greater than dry reduced-N deposition, a factor of 1.8 larger, mostly because of the influence of the local deposition of NO + NO_2. Thus, 64% of dry N-deposition is from dry oxidized-N and 36% is from dry reduced-N.

Third, dry deposition of N is greater than wet deposition of N for the watershed. For oxidized-N dry is roughly 4 (3.7) times wet. For reduced-N dry is roughly 2 (2.1) times wet. Thus, the old rule of thumb that dry is approximately equal to wet deposition is not true for urban areas like Tampa. It may be approximately correct for some rural areas if only total-nitrate and total-ammonia deposition is considered. It is not true, even there, when deposition from other forms of oxidized nitrogen are included, which they should be.

Fourth, dry deposition to the watershed is greater than dry deposition to the bay waters. This is because there is less turbulence over the water, slowing down the ability of gases and particles to get close to the water's surface and get incorporated into it. Wet deposition is approximately the same over water and land surfaces.

Finally, in terms of the two forms of nitrogen, oxidized-N deposition is greater than reduced-N deposition by a moderate amount. Total deposition of oxidized-N is approximately 56% higher than reduced-N deposition on average for the watershed. Total deposition of oxidized-N is approximately 39% higher than reduced-N deposition on average for the bay waters. Most of the difference is the result of differences in dry deposition. These percentages vary among the different sub-basins.

Uncertainty 1: A bias in a CMAQ dry deposition computation was uncovered at the end of this study. CMAQ developers discovered the NO and NO_2 dry deposition parameterizations were missing a component, making the CMAQ estimate of NO and NO_2 dry deposition to vegetative surfaces up to a factor of two too high. The PAN deposition was updated at the same time, increasing its rate of deposition. Also, the deposition exchange with water surfaces was updated, reducing the rate of NO and NO_2 dry deposition to water. There is no error for dry deposition to impervious surfaces. The NO and NO_2 dry deposition formulation errors introduce a bias in the tabulated results for the oxidized-N deposition estimates. A subset of 4 months was used to develop a "best" estimate of the bias in the annual deposition numbers. As a result, the oxidized-N dry deposition in Tables A-1, A-2 and A-3 is approximately 17% and 24% too high for land and water, respectively. The Total-N in Table A-1 is approximately 9.8% and 11.4% too high for land and water total accumulated deposition, respectively. The Total-N in Tables A-2 and A-3 is approximately 8.1% and 7.5% too high for land and water total deposition, respectively. The bias in Total-N in Tables A-2 and A-3 is largest for the watershed sub-basins with dense urban emissions. The Total-N numbers for Coastal Old Tampa Bay, Coastal Hillsborough Bay, Coastal Middle Tampa Bay, and Boca Ciega Bay are 14.8%, 12.9%, 12.2%, and 13.0% too high, respectively.

Uncertainty 2: There are several sources of uncertainty affecting the deposition estimates from the CMAQ-UCD: meteorological and emissions input uncertainties (especially NO_X and NH_3 emissions) and model process description uncertainties. The evaluation of the meteorology for Tampa suggests the meteorological model is performing in a quantified bias and error range typical of performance for the rest of the US. The evaluation of CMAQ-UCD against the May 2002 data suggests it too is functioning in a fairly typical manner, similar to evaluations performed for other areas in the eastern US. The seasonal and annual wet deposition comparisons for Florida sites suggest CMAQ-UCD is functioning in a manner typical of its performance for the rest of the eastern US. Thus, uncertainties for Tampa are expected to be of the same order as uncertainties observed for the eastern US in CMAQ evaluation studies. For annual results, wet deposition can have uncertainties at any one location of ±50% to ±100%. Ambient concentrations at any one location can have uncertainties of ±25% to ±50%. The uncertainties in the dry deposition parameterizations and representation of turbulent mixing will add to and inflate these ambient concentration uncertainty estimates. Emissions uncertainties are judged to be the order of ±40% to ±50%. The uncertainties in meteorology, emissions, and model process descriptions are by and large independent. Thus, the uncertainty of the CMAQ-UCD estimates of total deposition is expected to be ±50% and up to a factor of 2 at any one location.

Table A-1a. Nominal Base Case: Accumulated Annual Deposition of N Across Each Region's Area

	DryOx-N (kg-N)	DryRed-N (kg-N)	Dry-N (kg-N)	WetOx-N (kg-N)	WetRed-N (kg-N)	Wet-N (kg-N)	TotOx-N (kg-N)	TotRed-N (kg-N)	Total-N (kg-N)
Watershed Sub-basins									
Coastal Old Tampa Bay	518,408	119,509	637,917	104,787	64,284	169,071	623,195	183,793	806,988
Alafia River	557,161	261,505	818,666	168,052	133,097	301,149	725,212	394,602	1,119,815
Hillsborough River	1,070,093	339,766	1,409,860	275,783	180,851	456,634	1,345,877	520,616	1,866,494
Coastal Hillsborough Bay	293,905	135,390	429,295	58,405	49,037	107,442	352,310	184,427	536,737
Little Manatee River	270,510	189,341	459,851	88,358	91,702	180,060	358,868	281,042	639,911
Coastal Middle Tampa Bay	110,613	37,266	147,879	23,118	15,907	39,024	133,731	53,173	186,903
Coastal Lower Tampa Bay	37,676	11,959	49,635	10,447	8,401	18,848	48,122	20,360	68,482
Terra Ceia Watershed	7,218	1,693	8,912	1,776	1,271	3,047	8,994	2,964	11,959
Manatee River Watershed	373,931	142,827	516,758	131,706	105,816	237,522	505,637	248,643	754,280
Boca Ciega Bay	154,313	43,048	197,361	31,078	18,787	49,865	185,391	61,835	247,226
Total Watershed	3,393,829	1,282,304	4,676,133	893,510	669,152	1,562,661	4,287,338	1,951,456	6,238,974
Tampa Bay Segments									
Old Tampa Bay	47,123	12,045	59,168	35,621	20,973	56,593	82,744	33,018	115,762
Hillsborough Bay	26,768	8,806	35,574	13,652	10,601	24,253	40,420	19,407	59,827
Middle Tampa Bay	38,276	15,960	54,237	49,152	32,755	81,907	87,429	48,715	136,144
Lower Tampa Bay	31,163	7,627	38,790	38,207	20,012	58,219	69,371	27,639	97,010
Boca Ciega Bay	14,725	4,205	18,929	9,031	4,686	13,717	23,756	8,890	32,646
Terra Ceia Bay	2,109	431	2,540	711	438	1,149	2,820	869	3,689
Manatee River	13,236	3,334	16,570	3,663	2,459	6,122	16,898	5,793	22,692
Total Bay	173,400	52,408	225,808	150,037	91,924	241,961	323,437	144,332	467,769

Table A-1b. Nominal Base Case: Accumulated Deposition Totals in Pounds Nitrogen

	DryOx-N (lbs-N)	DryRed-N (lbs-N)	Dry-N (lbs-N)	WetOx-N (lbs-N)	WetRed-N (lbs-N)	Wet-N (lbs-N)	TotOx-N (lbs-N)	TotRed-N (lbs-N)	Total-N (lbs-N)
Total Watershed	7,466,423	2,821,069	10,287,492	1,965,721	1,472,134	3,437,855	9,432,144	4,293,203	13,725,347
Total Bay	381,480	115,298	496,778	330,082	202,232	532,314	711,562	317,530	1,029,092

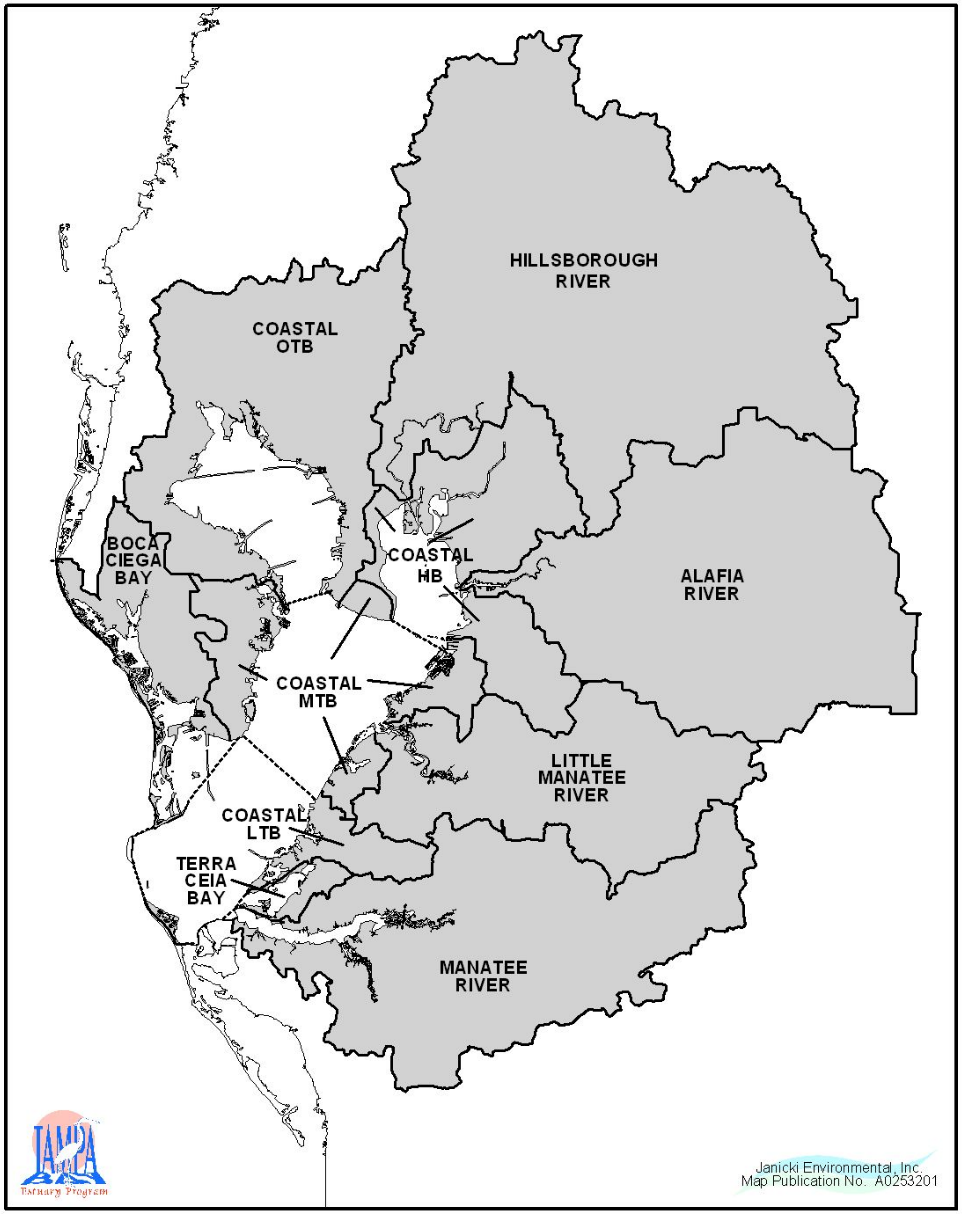

Figure A-1. Tampa Bay Watershed Sub-basins and Bay Segments

Table A-2a. Adjusted Base Case: Accumulated Annual Deposition of N Across Each Region's Area

	DryOx-N (kg-N)	DryRed-N (kg-N)	Dry-N (kg-N)	WetOx-N (kg-N)	WetRed-N (kg-N)	Wet-N (kg-N)	TotOx-N (kg-N)	TotRed-N (kg-N)	Total-N (kg-N)
Watershed Sub-basins									
Coastal Old Tampa Bay	509,566	173,930	683,496	104,885	83,501	188,386	614,451	257,431	871,882
Alafia River	541,968	371,419	913,387	168,126	176,234	344,360	710,094	547,653	1,257,747
Hillsborough River	1,048,172	486,852	1,535,023	276,022	245,462	521,484	1,324,193	732,314	2,056,507
Coastal Hillsborough Bay	287,339	187,262	474,601	58,428	64,579	123,007	345,767	251,841	597,608
Little Manatee River	259,960	263,433	523,393	88,397	115,997	204,394	348,357	379,429	727,787
Coastal Middle Tampa Bay	107,601	53,931	161,532	23,124	20,303	43,427	130,725	74,234	204,959
Coastal Lower Tampa Bay	36,644	17,596	54,240	10,447	10,287	20,735	47,091	27,883	74,974
Terra Ceia Watershed	7,039	2,562	9,602	1,776	1,560	3,336	8,815	4,122	12,938
Manatee River Watershed	361,563	210,425	571,988	131,751	129,770	261,521	493,314	340,195	833,509
Boca Ciega Bay	150,333	64,293	214,626	31,091	23,835	54,926	181,424	88,128	269,552
Total Watershed	3,310,185	1,831,703	5,141,888	894,046	871,528	1,765,574	4,204,231	2,703,231	6,907,462
Tampa Bay Segments									
Old Tampa Bay	46,093	26,422	72,515	35,632	26,646	62,279	81,725	53,068	134,793
Hillsborough Bay	26,119	19,230	45,349	13,656	14,056	27,712	39,775	33,286	73,060
Middle Tampa Bay	37,128	32,934	70,062	49,164	41,124	90,287	86,292	74,057	160,349
Lower Tampa Bay	30,389	17,331	47,720	38,219	24,772	62,991	68,608	42,103	110,711
Boca Ciega Bay	14,322	9,303	23,625	9,035	5,858	14,893	23,356	15,162	38,518
Terra Ceia Bay	2,045	948	2,992	711	545	1,256	2,755	1,493	4,248
Manatee River	12,864	7,052	19,916	3,663	3,053	6,715	16,527	10,104	26,631
Total Bay	168,959	113,219	282,179	150,079	116,054	266,132	319,038	229,273	548,311

Table A-2b. Adjusted Base Case: Accumulated Deposition Totals in Pounds Nitrogen

	DryOx-N (lbs-N)	DryRed-N (lbs-N)	Dry-N (lbs-N)	WetOx-N (lbs-N)	WetRed-N (lbs-N)	Wet-N (lbs-N)	TotOx-N (lbs-N)	TotRed-N (lbs-N)	Total-N (lbs-N)
Total Watershed	7,282,408	4,029,747	11,312,155	1,966,901	1,917,361	3,884,262	9,249,309	5,947,108	15,196,417
Total Bay	371,711	249,082	620,793	330,174	255,318	585,491	701,884	504,400	1,206,285

Table A-3. Adjusted Base Case: Average Unit Area Annual Deposition of N for Each Region

	DryOx-N (kg-N/ha)	DryRed-N (kg-N/ha)	Dry-N (kg-N/ha)	WetOx-N (kg-N/ha)	WetRed-N (kg-N/ha)	Wet-N (kg-N/ha)	TotOx-N (kg-N/ha)	TotRed-N (kg-N/ha)	Total-N (kg-N/ha)
Watershed Sub-basins									
Coastal Old Tampa Bay	9.06	3.09	12.15	1.86	1.48	3.35	10.92	4.58	15.50
Alafia River	4.93	3.38	8.31	1.53	1.60	3.13	6.46	4.98	11.44
Hillsborough River	6.06	2.81	8.88	1.60	1.42	3.02	7.66	4.23	11.89
Coastal Hillsborough Bay	8.47	5.52	14.00	1.72	1.90	3.63	10.20	7.43	17.62
Little Manatee River	4.87	4.93	9.80	1.66	2.17	3.83	6.52	7.11	13.63
Coastal Middle Tampa Bay	9.06	4.54	13.60	1.95	1.71	3.66	11.00	6.25	17.25
Coastal Lower Tampa Bay	5.82	2.80	8.62	1.66	1.63	3.29	7.48	4.43	11.91
Terra Ceia Watershed	6.39	2.32	8.71	1.61	1.42	3.03	8.00	3.74	11.74
Manatee River Watershed	4.35	2.53	6.88	1.58	1.56	3.14	5.93	4.09	10.02
Boca Ciega Bay	9.58	4.10	13.68	1.98	1.52	3.50	11.56	5.62	17.18
Total Watershed	6.08	3.36	9.44	1.64	1.60	3.24	7.72	4.96	12.68
Tampa Bay Segments									
Old Tampa Bay	2.58	1.48	4.06	1.99	1.49	3.48	4.57	2.97	7.54
Hillsborough Bay	3.33	2.45	5.78	1.74	1.79	3.53	5.07	4.24	9.30
Middle Tampa Bay	1.47	1.30	2.77	1.94	1.63	3.57	3.41	2.93	6.34
Lower Tampa Bay	1.33	0.76	2.08	1.67	1.08	2.75	2.99	1.84	4.83
Boca Ciega Bay	2.91	1.89	4.80	1.84	1.19	3.03	4.75	3.08	7.83
Terra Ceia Bay	4.56	2.11	6.67	1.58	1.22	2.80	6.14	3.33	9.47
Manatee River	5.38	2.95	8.33	1.53	1.28	2.81	6.92	4.23	11.14
Total Bay	2.07	1.39	3.45	1.84	1.42	3.26	3.90	2.81	6.71

Note: 1 kg/ha = 0.89 lbs/ac

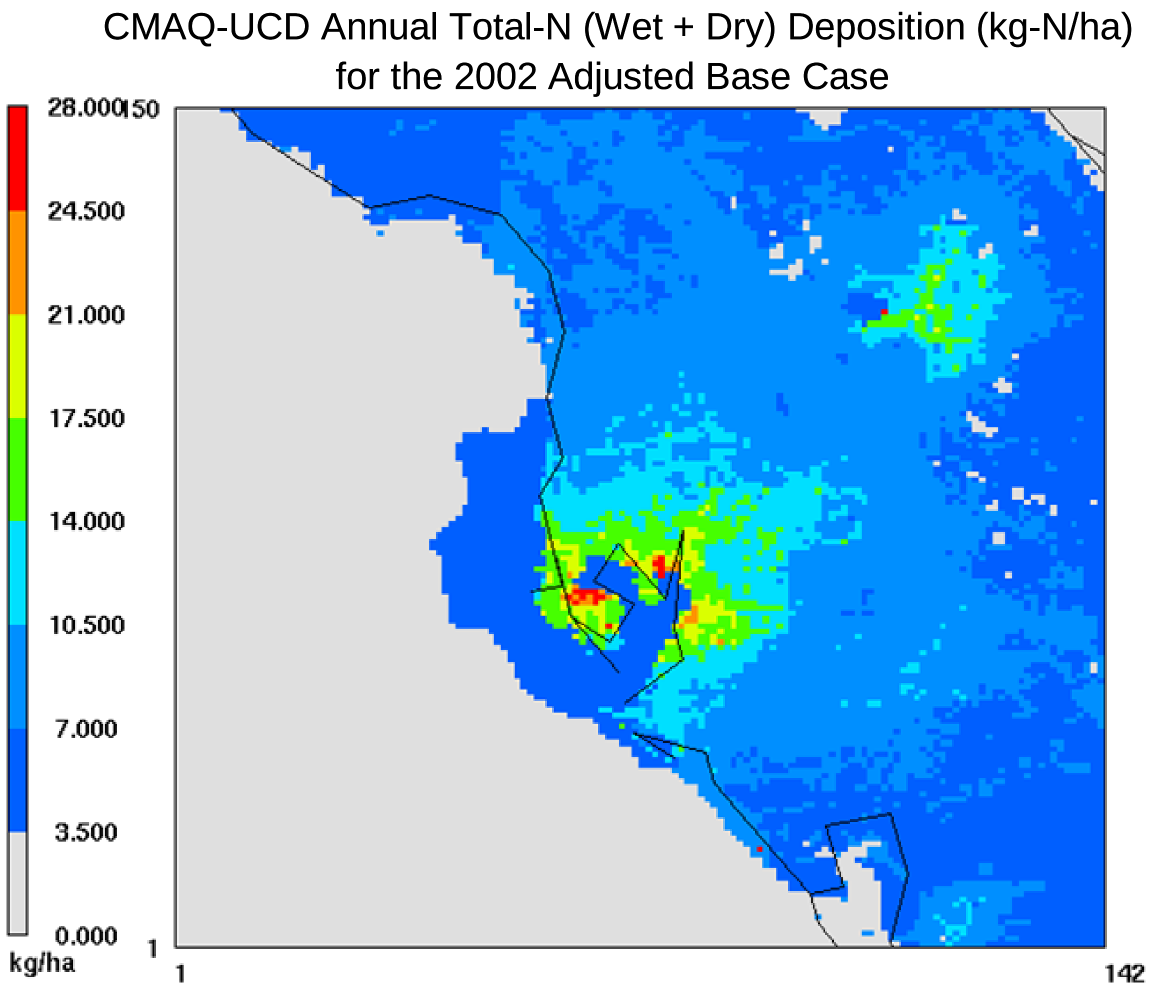

Figure A-2. Total nitrogen deposition (wet + dry), in kg-N/ha, estimated by CMAQ-UCD for the Adjusted Base Case for the full 2-km CMAQ-UCD domain. Orlando is shown as well as Tampa. The nitrogen deposition is nominally for 2002 emission rates.

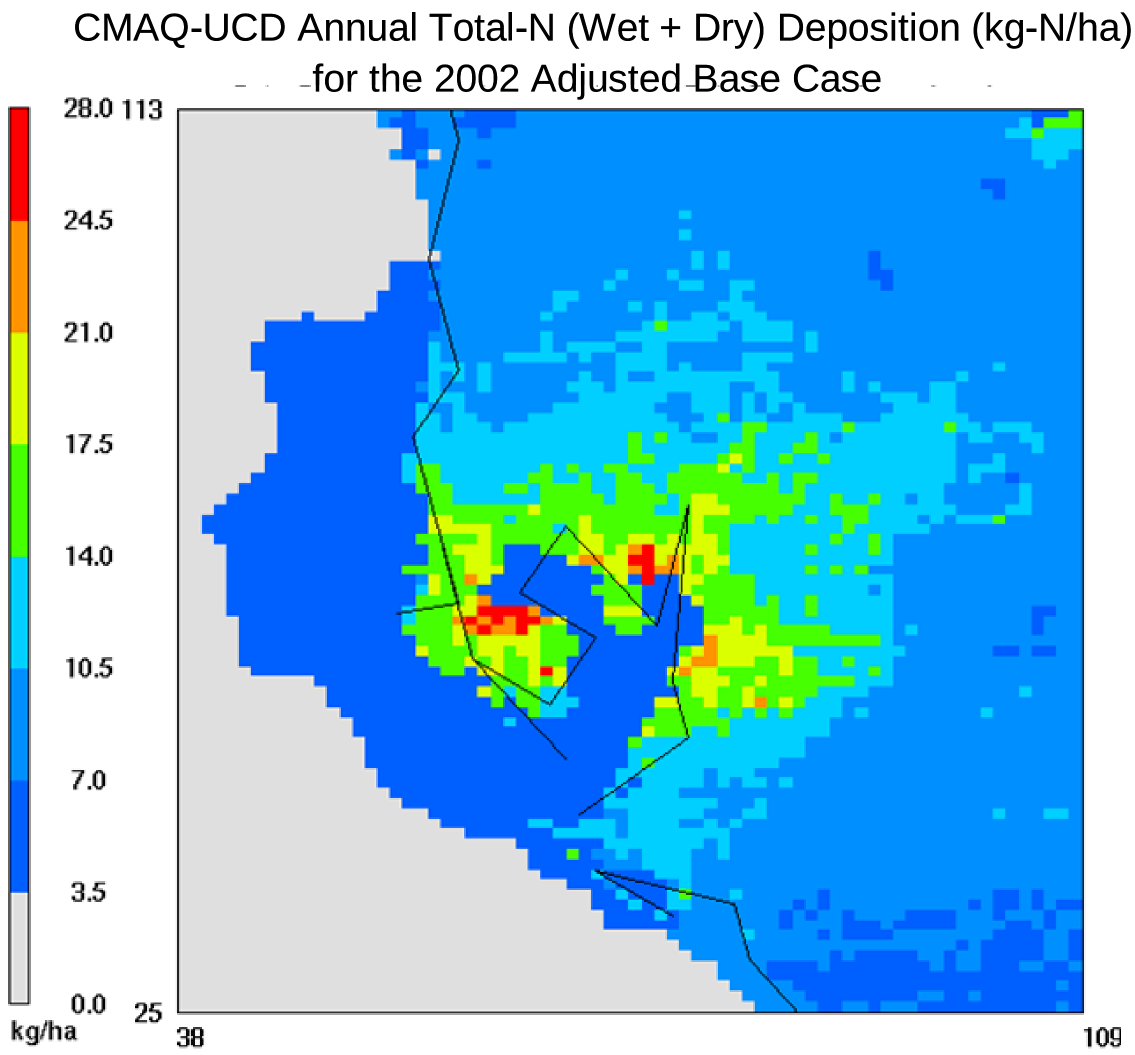

Figure A-3. Total nitrogen deposition (wet + dry), in kg-N/ha, estimated by CMAQ-UCD for the Adjusted Base Case for the 2-km CMAQ-UCD domain surrounding Tampa. The nitrogen deposition is nominally for 2002 emission rates.

Attachment B
CMAQ-UCD Estimates of the Relative Contribution
from Local Watershed Sources of NO_X Emissions to Annual Oxidized-N (Ox-N) Deposition Across the Watershed

Table B-1. Relative Responsibility of all NO_X Emissions within the Watershed for Annual Ox-N Deposition across the Watershed

All Watershed NO_X Emissions			
	DryOx-N (%)	WetOx-N (%)	TotalOx-N (%)
Watershed Sub-basins			
Coastal Old Tampa Bay	63.9	44.6	60.7
Alafia River	44.3	33.7	41.9
Hillsborough River	48.2	36.3	45.8
Coastal Hillsborough Bay	69.5	37.8	64.3
Little Manatee River	50.1	33.4	46.0
Coastal Middle Tampa Bay	66.2	41.0	61.9
Coastal Lower Tampa Bay	57.9	35.3	53.0
Terra Ceia Watershed	58.1	36.0	53.7
Manatee River Watershed	44.1	32.7	41.1
Boca Ciega Bay	64.5	44.0	61.0
Total Watershed	53.0	36.4	49.5
Tampa Bay Segments			
Old Tampa Bay	47.1	45.0	46.2
Hillsborough Bay	63.3	36.3	54.1
Middle Tampa Bay	32.0	40.2	36.6
Lower Tampa Bay	23.8	41.1	33.3
Boca Ciega Bay	47.4	43.6	46.0
Terra Ceia Bay	41.4	38.0	40.6
Manatee River	48.7	36.2	46.0
Total Bay	42.2	41.3	41.8

Table B-1 gives the estimates of the relative contribution of all of the NO_X emissions from within the watershed boundaries to dry, wet and total oxidized-nitrogen deposition to the watershed sub-basins and bay segments. Figure B-1 shows the relative contribution of watershed NO_X emissions to total oxidized-nitrogen deposition across the Tampa region by 2-km grid cell. Figure B-2 shows the relative contribution of watershed NO_X emissions to dry oxidized-nitrogen deposition across the Tampa region by 2-km grid cell.

As shown in Table B-1, local, watershed NO_X emissions are responsible for half of the oxidized-nitrogen deposition to the watershed (approximately 50%). The degree of responsibility varies across space, being more like 42% in the rural areas and 61-64% in the urbanized areas (see for example Coastal Hillsborough Bay's 64%). The strong degree of spatial variation is illustrated in Figures B-1 and B-2. As shown in the figures, the impact of the Tampa watershed NO_X emissions is highly localized to the Tampa region. Also, in the urban core the degree of responsibility of local NO_X emissions to oxidized-nitrogen deposition reaches more than 80%. The range of percent responsibility would be even larger for a finer grid size. The CMAQ-UCD estimates may represent fairly well the average impact of local emissions and the spatial variability of that impact across the Tampa watershed.

The contribution of local, watershed NO_X emissions to oxidized-nitrogen deposition is significantly higher for dry deposition than for wet deposition. This is evident in the difference between Figures B-1 and B-2. Wet deposition has more of a regional character. For urban areas dry deposition percent responsibility is a bit less than double that for wet deposition (for example, 70% versus 38% for Coastal Hillsborough Bay). For rural areas (like the Manatee River Watershed) dry deposition percent responsibility is a bit more than one-third-again as high as wet deposition. On average over the watershed the local, watershed NO_X emission-related dry deposition responsibility (53%) is about 26% higher than the responsibility for wet deposition (42%).

As shown in Table B-1, local, watershed NO_X emissions are responsible for about two-fifths of the total oxidized-nitrogen deposition to the bay waters (approximately 42%).

Table B-1 indicates that spatial variation in the relative percent contribution of local emissions to deposition to the watershed and bay waters is driven by dry deposition (see Figure B-2). For the watershed the percent contribution of dry deposition varies from 44-70%, with an average of 53%. For the bay segments the percent contribution of dry deposition varies from 24-63%, with an average of 42%. On the other hand, the relative % contribution of local watershed NO_X emissions to wet deposition is not very variable. For the watershed it varies from 33-44%. For the bay segments it varies between 36% and 45%.

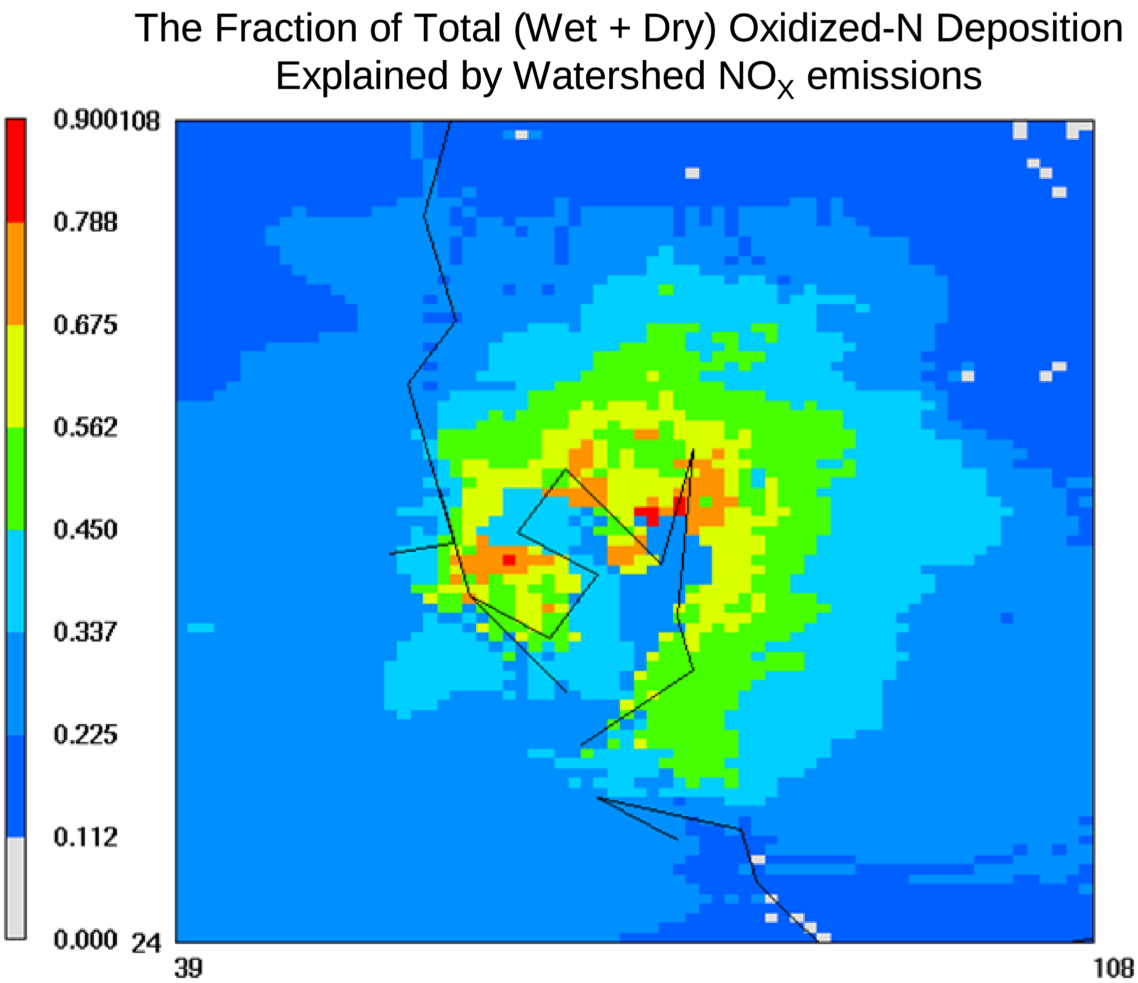

Figure B-1. Fraction of the Annual Total, Wet plus Dry, Oxidized-Nitrogen Deposition that CMAQ-UCD Predicts is Explained by the Watershed NO_X Emissions.

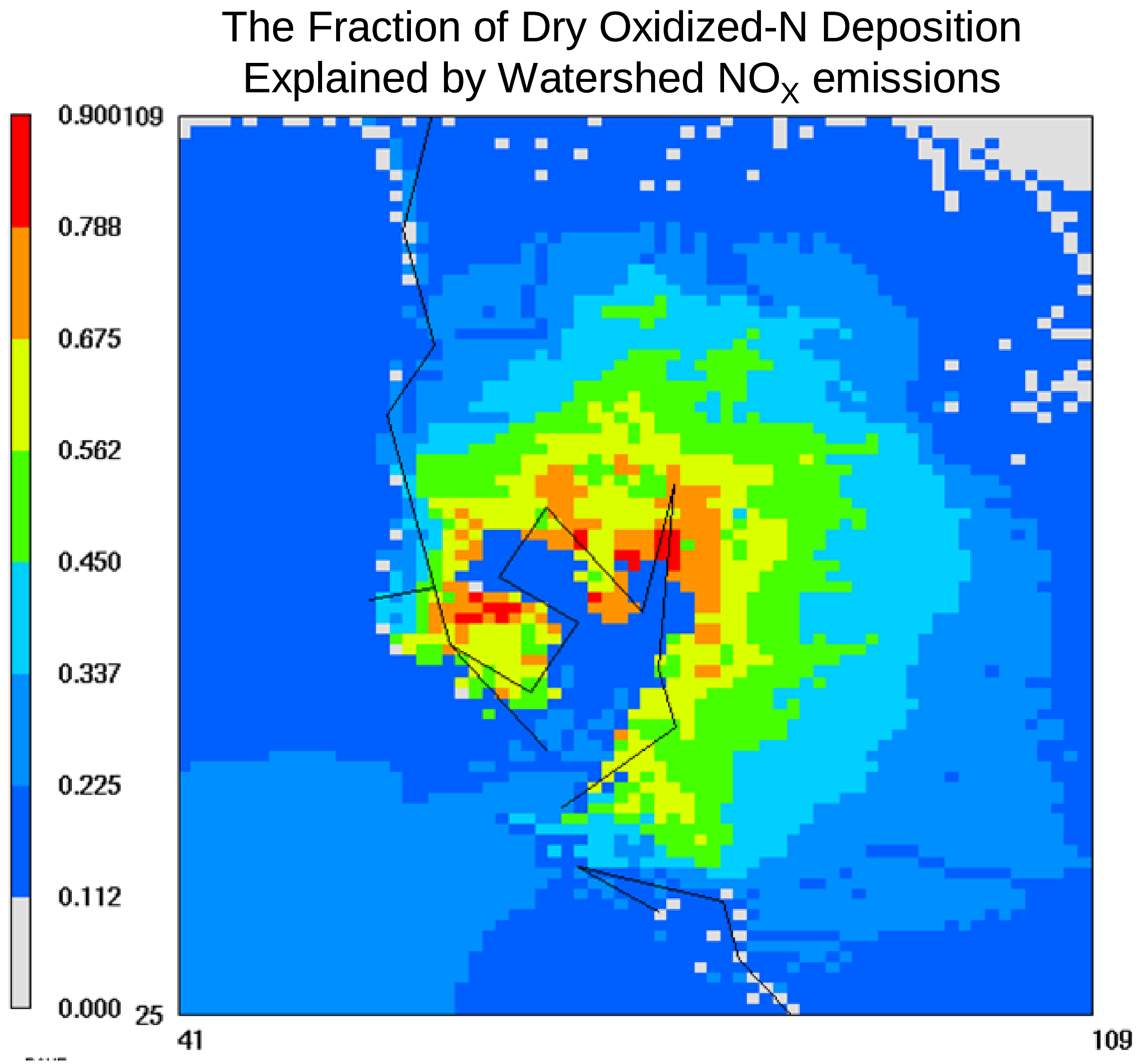

Figure B-2. Fraction of the Annual Dry Oxidized-Nitrogen Deposition that CMAQ-UCD Predicts is Explained by the Watershed NO_X Emissions.

Table B-2 gives the absolute and relative contribution to the total NO_X emissions of the NO_X emissions from the three "sectors" chosen for study. The NO_X emissions from Hillsborough, Manatee and Pinellas Counties are used to approximate the emissions from the watershed. Approximately half of the emissions are associated with electric generating units. Mobile source and Other NO_X emissions equally divide responsibility for the other half of the emissions.

Table B-2

2002 NO_X Emissions for Hillsborough, Manatee and Pinellas Counties To Approximate Emissions from Watershed				
	Mobile Source NO_X (tons/yr)	Power Plant NO_X (tons/yr)	Other NO_X (tons/yr)	Total NO_X (tons/yr)
3-County Total	35,569	72,105	35,158	144,098
Percent of Total	24.7%	50.0%	25.1%	

Table B-3 gives the relative contribution of the NO_X emissions from the three sectors to the oxidized-N deposition. The four sets of numbers are independent calculations. The sum of Mobile, Power Plants and Other compared to Total is a measure of the internal consistency of the model predictions. All but three sets are within 1%. Two are within 2% and one within 3%. This is excellent.

Table B-3. Relative Responsibility of a Three-Sector Subdivision of NO_X Emissions within the Watershed to Annual Ox-N Deposition

Percent Contribution of Watershed NO_X Emissions to Ox-N Deposition by Source Category				
	Mobile (%)	PowerPlants (%)	Other (%)	TotalOx-N (%)
Watershed Sub-basins				Table B-1
Coastal Old Tampa Bay	30.2	12.1	17.9	60.7
Alafia River	16.9	13.9	10.5	41.9
Hillsborough River	24.3	11.0	9.9	45.8
Coastal Hillsborough Bay	29.0	18.7	16.1	64.3
Little Manatee River	18.5	17.7	9.3	46.0
Coastal Middle Tampa Bay	26.6	16.1	18.9	61.9
Coastal Lower Tampa Bay	24.2	16.7	11.7	53.0
Terra Ceia Watershed	27.0	14.1	12.2	53.7
Manatee River Watershed	17.0	14.3	9.4	41.1
Boca Ciega Bay	30.4	11.5	18.8	61.0
Total Watershed	23.3	13.5	12.3	49.5
Tampa Bay Segments				
Old Tampa Bay	17.5	13.9	13.9	46.2
Hillsborough Bay	16.9	15.6	21.0	54.1
Middle Tampa Bay	11.1	13.7	10.8	36.6
Lower Tampa Bay	9.6	13.6	9.1	33.3
Boca Ciega Bay	19.0	13.3	12.9	46.0
Terra Ceia Bay	17.6	11.7	10.8	40.6
Manatee River	21.0	11.4	13.1	46.0
Total Bay	14.3	13.8	12.8	41.8

It is immediately apparent that the NO_X emission fractions are not a predictor of the oxidized-N deposition fractions.

As shown in Table B-2 the power plants contribute 50% of the watershed NO_X emissions, double the mobile source contribution of 25%. However, as shown in Table B-3, for deposition to the watershed the roles of power plants and mobile sources are nearly reversed in terms of oxidized-nitrogen deposition. Mobile sources are responsible for almost twice as much deposition (23%) as power plants (13.5%). This is because power plants, with their stacks, are putting the emissions higher up in the atmosphere where they can transport and mix and dilute; thus, contributing more to long range transport and regional deposition and less to local deposition. The mobile source emissions are close to the ground, allowing them to locally deposit more effectively. The Other sector NO_X emissions are responsible for about the same fraction of deposition as power plants. The Other sector NO_X emissions do not contribute the same amount of oxidized-nitrogen deposition per unit of emissions as mobile sources, but they contribute more oxidized-nitrogen deposition per unit of emissions than do power plants. The Other sector emissions effectiveness is in the middle between mobile sources and power plants. This may be related to their being less spatially concentrated and to their proximity to sources of ammonia around the watershed. The CMAQ-UCD results are that the mobile sources have by far the largest responsibility for oxidized-nitrogen deposition per unit of NO_X emissions. We have confirmed that the CMAQ-UCD results are internally consistent.

For deposition to the bay segments (water surface), the three source categories contribute about equally to the oxidized-nitrogen deposition. Here the deposition effectiveness of the Other source emissions catches up with the mobile source emissions. To the water surface, both are twice as effective at depositing oxidized nitrogen per unit of NO_X emissions as are emissions of power plants.

The relative responsibilities of the mobile source NO_X emissions, the power plant emissions and the other sector emissions to the wet and dry components of the oxidized-N deposition to the watershed sub-basins and bay segments are given in Tables B-4, B-5, and B-6, respectively.

As shown in Table B-4, the dry oxidized-nitrogen deposition contribution from mobile sources to the watershed deposition is several times larger than the wet oxidized-nitrogen deposition. On average, dry is more than 3 times higher than wet (3.5 times). This is because the NO_X deposition is a very important component of mobile source dry deposition and wet deposition only involves total nitrate (= nitric acid + particulate nitrate). Half of the responsibility of oxidized-nitrogen dry deposition from local sources is attributable to mobile source NO_X emissions. But mobile sources are responsible for less than a quarter of the oxidized nitrogen wet deposition associated with local, watershed sources. The same pattern holds for oxidized-nitrogen deposition to the bay segments.

As shown in Table B-5, the wet oxidized-nitrogen deposition contribution to the watershed deposition from power plants is larger than the dry oxidized-nitrogen deposition, on average 34% larger. This is because the power plant emissions are emitted above the surface and have to be mixed downward (with dilution) to dry deposit. The power plants are responsible for a bit under a quarter of the locally associated dry deposition to the watershed, but almost half of the locally associated wet deposition.

Table B-4. Relative Responsibility of Mobile Source NO_X Emissions within the Watershed to Annual Watershed Ox-N Deposition

Watershed Mobile Source NO_X Emissions			
	DryOx-N (%)	WetOx-N (%)	TotalOx-N (%)
Watershed Sub-basins			
Coastal Old Tampa Bay	34.2	10.7	30.2
Alafia River	20.0	6.5	16.9
Hillsborough River	28.6	7.8	24.3
Coastal Hillsborough Bay	33.2	8.1	29.0
Little Manatee River	22.3	6.9	18.5
Coastal Middle Tampa Bay	30.3	8.6	26.6
Coastal Lower Tampa Bay	28.8	7.8	24.2
Terra Ceia Watershed	31.7	8.2	27.0
Manatee River Watershed	20.5	7.0	17.0
Boca Ciega Bay	34.6	9.4	30.4
Total Watershed	27.4	7.8	23.3
Tampa Bay Segments			
Old Tampa Bay	23.5	9.6	17.5
Hillsborough Bay	21.4	8.2	16.9
Middle Tampa Bay	14.4	8.6	11.1
Lower Tampa Bay	10.9	8.6	9.6
Boca Ciega Bay	25.2	8.9	19.0
Terra Ceia Bay	20.5	9.1	17.6
Manatee River	24.2	9.0	21.0
Total Bay	19.1	8.8	14.3

Table B-5. Relative Responsibility of Power Plant NO_X Emissions within the Watershed to Annual Watershed Ox-N Deposition

Watershed Power Plant NO_X Emissions			
	DryOx-N (%)	WetOx-N (%)	TotalOx-N (%)
Watershed Sub-basins			
Coastal Old Tampa Bay	10.8	18.6	12.1
Alafia River	13.2	16.4	13.9
Hillsborough River	9.4	16.9	11.0
Coastal Hillsborough Bay	19.0	17.6	18.7
Little Manatee River	18.2	16.0	17.7
Coastal Middle Tampa Bay	15.5	18.9	16.1
Coastal Lower Tampa Bay	16.8	16.4	16.7
Terra Ceia Watershed	13.6	16.2	14.1
Manatee River Watershed	13.8	15.4	14.3
Boca Ciega Bay	9.7	20.6	11.5
Total Watershed	12.6	16.9	13.5
Tampa Bay Segments			
Old Tampa Bay	9.3	20.1	13.9
Hillsborough Bay	15.4	15.9	15.6
Middle Tampa Bay	9.1	17.2	13.7
Lower Tampa Bay	6.9	19.2	13.6
Boca Ciega Bay	8.4	21.4	13.3
Terra Ceia Bay	10.2	16.1	11.7
Manatee River	10.4	15.3	11.4
Total Bay	9.8	18.5	13.8

Table B-6. Relative Responsibility of Other NO_X Emissions within the Watershed to Annual Watershed Ox-N Deposition

Watershed Other NO_X Emissions			
	DryOx-N (%)	WetOx-N (%)	TotalOx-N (%)
Watershed Sub-basins			
Coastal Old Tampa Bay	18.8	13.5	17.9
Alafia River	11.0	9.1	10.5
Hillsborough River	10.0	9.7	9.9
Coastal Hillsborough Bay	17.2	10.3	16.1
Little Manatee River	9.4	8.9	9.3
Coastal Middle Tampa Bay	20.3	11.9	18.9
Coastal Lower Tampa Bay	12.2	9.7	11.7
Terra Ceia Watershed	12.7	10.2	12.2
Manatee River Watershed	9.5	9.0	9.4
Boca Ciega Bay	20.0	12.3	18.8
Total Watershed	12.9	10.0	12.3
Tampa Bay Segments			
Old Tampa Bay	14.1	13.6	13.9
Hillsborough Bay	26.3	10.6	21.0
Middle Tampa Bay	8.3	12.8	10.8
Lower Tampa Bay	5.7	11.9	9.1
Boca Ciega Bay	13.5	11.9	12.9
Terra Ceia Bay	10.6	11.5	10.8
Manatee River	13.8	10.7	13.1
Total Bay	13.1	12.4	12.8

As shown in Table B-5, the wet oxidized-nitrogen deposition relative contribution to the bay segment (water surface) deposition from power plants is nearly twice the dry oxidized-nitrogen deposition. Not quite a quarter of the responsibility of oxidized-nitrogen dry deposition from local sources is attributable to power plant NO_X emissions. But power plant emissions are responsible for about half of the oxidized nitrogen wet deposition associated with local, watershed sources. The same pattern holds for oxidized-nitrogen deposition to the bay segments.

As shown in Table B-6, the dry oxidized-nitrogen deposition contribution to the watershed deposition from the other source category is somewhat larger (30% larger) than the wet oxidized-nitrogen deposition. For the oxidized-nitrogen deposition to the bay segments the average deposition is basically equal. For oxidized-nitrogen deposition attributable to watershed NO_X emissions, the emissions from the other source category are responsible for about a quarter of both wet and dry deposition.

Attachment C
CMAQ-UCD Estimates of the Reduction in Annual N Deposition by 2010
Due to the Repowering of Gannon and Big Bend

Table C-1 gives the change in oxidized-nitrogen deposition as a result of the repowering of the Gannon and Big Bend plants. The change is for the year 2010, when full repowering is attained at the Big Bend plant. Figure C-1 shows the absolute change in oxidized-nitrogen deposition by 2-km grid cell.

Our Base emissions numbers come from 2002 CEM (continuous emissions monitoring) data for 2002 and 2001 NEI emissions based on CEM data for January – March 2003 (to avoid effects of Gannon's early repowering in 2003). We used 28,099 tons NO_X/yr and 24,739 tons NO_X/yr for Big Bend and Gannon, respectively. We developed our emissions reductions from information Laura Crouch provided to the TBEP with necessary adjustments to reflect full repowering of Big Bend. The 2010 emissions were 5,620 tons NO_X/yr and 371 tons NO_X/yr for Big Bend and Gannon (now named Bayside), respectively. Our 2010 emissions are very close to but not identical to the emission numbers for these two plants in the EPA's 2010 CAIR emissions inventory. The total repowering NO_X reduction represents a 65% reduction in power plant emissions shown in Table B-2. Overall, the decrease in oxidized-nitrogen deposition to the watershed is 9.9% and to the bay waters is 10.5%. Factoring in the ammonia deposition, the decrease in the total-nitrogen deposition is 6.6% for the watershed and 7.2% for the bay waters.

For the watershed, the decrease in absolute kg's of dry oxidized-nitrogen deposition is more than three times the decrease in wet oxidized-nitrogen deposition. However, the percent reduction for wet deposition is modestly higher than for dry deposition, about 39% higher. As shown in Table B-5, local power plants contribute a larger fraction to the wet deposition than to the dry deposition because their NO_X is emitted aloft. Thus, it is logical to expect the wet deposition response to the repowering will be relatively larger than the dry deposition response.

It is interesting that there is a slight increase in reduced-nitrogen dry deposition, less than 1%, however. This is because the Gannon repowering reduces SO_2 emissions as well as NO_X emissions. With the decrease in sulfate, there will then be a decrease in NH_4^+ concentrations and an increase in NH_3 concentrations (for the same total ammonia). This will result in an increase in reduced-nitrogen dry deposition. In this instance, the sulfate effect is rather small and the increase is dry deposition of reduced-nitrogen happens to be very modest. There is effectively no change in wet deposition because both NH_3 and NH_4^+ are quite water soluble.

The reductions computed from the repowering CMAQ-UCD simulation are 414,399 kg for the total watershed and 33,603 kg for Tampa Bay waters. This estimate translates to a reduction in N-deposition to the watershed of 456 English tons-N or 82.1 English tons-N delivered to the bay waters, using the TBEP transfer coefficient of 0.18. Adding this to the estimated 37.0 English tons-N reduction from direct deposition to the bay waters results in an overall nitrogen load reduction to Tampa bay of 119.0 tons-N from 2002 to 2010 (8 years) or about 14.9 tons-N per year (assuming a simple linear reduction). The reduction of 119.0 tons of N by 2010 is larger than, but within the range, of a Tampa Electric Company (TECO) estimate of 95.3 tons-N provided by Holly Greening.

Uncertainty 1: A bias in a CMAQ dry deposition computation was uncovered at the end of this study. CMAQ developers discovered the NO and NO_2 dry deposition parameterizations were missing a component, making the CMAQ estimate of NO and NO_2 dry deposition to vegetative surfaces up to a factor of two too high. The PAN deposition was updated at the same time, increasing its rate of deposition. Also, the deposition exchange with water surfaces was updated, reducing the rate of NO and NO_2 dry deposition to water. There is no error for dry deposition to impervious surfaces. The NO and NO_2 dry deposition formulation errors introduce a bias in the tabulated results for the oxidized-N deposition estimates. A subset of 4 months was used to develop a "best" estimate of the bias in the annual deposition numbers. The dry deposition formulation errors reduce the oxidized-N deposition in the Base Case totaled over the watershed by roughly 17% and by 14% in the Repowering Case (24% and 23%, respectively, for the total to the water surfaces). As a result, there is a significant decrease in the deposition reduction attributable to Repowering. The analysis indicates the Total-N deposition reduction in Table C-1 is approximately 29.7% and 13.2% too high for the total land and water area, respectively. Thus, the above estimate of the total N load reduction to Tampa Bay waters is approximately 25% too high. An estimated bias-corrected reduction of N to Tampa Bay waters due to Repowering would be 89.8 tons of N from 2002 to 2010 (8 years) or about 11.2 tons-N per year (assuming a simple linear reduction). The 90 tons of N reduction estimate is very close to the 95.3 tons-N reduction estimated by TECO for 2010, as provided by Holly Greening.

Uncertainty 2: There are several sources of uncertainty affecting the deposition estimates from the CMAQ-UCD: meteorological and emissions input uncertainties (especially NO_X and NH_3 emissions) and model process description uncertainties. The evaluation of the meteorology for Tampa suggests the meteorological model is performing in a quantified bias and error range typical of performance for the rest of the US. The evaluation of CMAQ-UCD against the May 2002 data suggests it too is functioning in a fairly typical manner, similar to evaluations performed for other areas in the eastern US. The seasonal and annual wet deposition comparisons for Florida sites suggest CMAQ-UCD is functioning in a manner typical of its performance for the rest of the eastern US. Thus, uncertainties for Tampa are expected to be of the same order as uncertainties observed for the eastern US in CMAQ evaluation studies. For annual results, wet deposition can have uncertainties at any one location of ±50% to ±100%. Ambient concentrations at any one location can have uncertainties of ±25% to ±50%. The uncertainties in the dry deposition parameterizations and representation of turbulent mixing will add to and inflate these ambient concentration uncertainty estimates. Emissions uncertainties are judged to be the order of ±40% to ±50%. The uncertainties in meteorology, emissions, and model process descriptions are by and large independent. Thus, the uncertainty of the CMAQ-UCD estimates of total deposition is expected to be ±50% and up to a factor of 2 at any one location. For the annual relative change estimates, several types of uncertainties can cancel or be damped because the same uncertainty affects both the base and the change cases. The air quality models are always expected to perform better at estimating relative change than for estimating absolute amounts. The uncertainty for relative changes is judged to be the order of ±25% up to ±50%.

Table C-1. Change in Annual Nitrogen Deposition by 2010 Due to Repowering

	DryOx-N (kg-N)	DryRed-N (kg-N)	Dry-N (kg-N)	WetOx-N (kg-N)	WetRed-N (kg-N)	Wet-N (kg-N)	TotOx-N (kg-N)	TotRed-N (kg-N)	Total-N (kg-N)
Watershed Sub-basins									
Coastal Old Tampa Bay	-37,925	1,339	-36,586	-14,355	-1	-14,356	-52,280	1,338	-50,942
Alafia River	-56,642	1,809	-54,833	-20,920	-55	-20,975	-77,563	1,754	-75,809
Hillsborough River	-78,110	3,557	-74,553	-36,224	10	-36,215	-114,334	3,566	-110,767
Coastal Hillsborough Bay	-44,823	867	-43,956	-8,753	28	-8,725	-53,575	894	-52,681
Little Manatee River	-33,913	1,260	-32,654	-9,927	-128	-10,055	-43,840	1,131	-42,709
Coastal Middle Tampa Bay	-11,673	252	-11,421	-3,447	-8	-3,455	-15,120	244	-14,876
Coastal Lower Tampa Bay	-4,335	62	-4,272	-1,199	-10	-1,209	-5,534	52	-5,482
Terra Ceia Watershed	-689	9	-680	-204	-1	-205	-893	8	-885
Manatee River Watershed	-33,144	1,060	-32,084	-13,877	-113	-13,990	-47,021	947	-46,074
Boca Ciega Bay	-9,549	334	-9,215	-4,928	-31	-4,959	-14,477	303	-14,174
Total Watershed	-310,803	10,548	-300,254	-113,834	-310	-114,144	-424,637	10,238	-414,399
Tampa Bay Segments									
Old Tampa Bay	-3,039	138	-2,901	-5,840	1	-5,839	-8,880	140	-8,740
Hillsborough Bay	-3,446	65	-3,381	-1,993	13	-1,980	-5,439	78	-5,361
Middle Tampa Bay	-2,680	111	-2,570	-6,746	2	-6,744	-9,426	113	-9,313
Lower Tampa Bay	-1,748	39	-1,709	-4,704	-1	-4,705	-6,451	38	-6,413
Boca Ciega Bay	-857	31	-826	-1,331	-5	-1,337	-2,189	26	-2,163
Terra Ceia Bay	-157	2	-155	-81	0	-81	-238	2	-236
Manatee River	-985	17	-968	-408	0	-408	-1,393	17	-1,376
Total Bay	-12,913	404	-12,509	-21,104	10	-21,094	-34,016	414	-33,603

	DryOx-N (lbs-N)	DryRed-N (lbs-N)	Dry-N (lbs-N)	WetOx-N (lbs-N)	WetRed-N (lbs-N)	Wet-N (lbs-N)	TotOx-N (lbs-N)	TotRed-N (lbs-N)	Total-N (lbs-N)
Total Watershed	-683,766	23,206	-660,559	-250,435	-682	-251,117	-934,201	22,524	-911,677
Total Bay	-28,408	888	-27,519	-46,428	22	-46,406	-74,836	910	-73,926

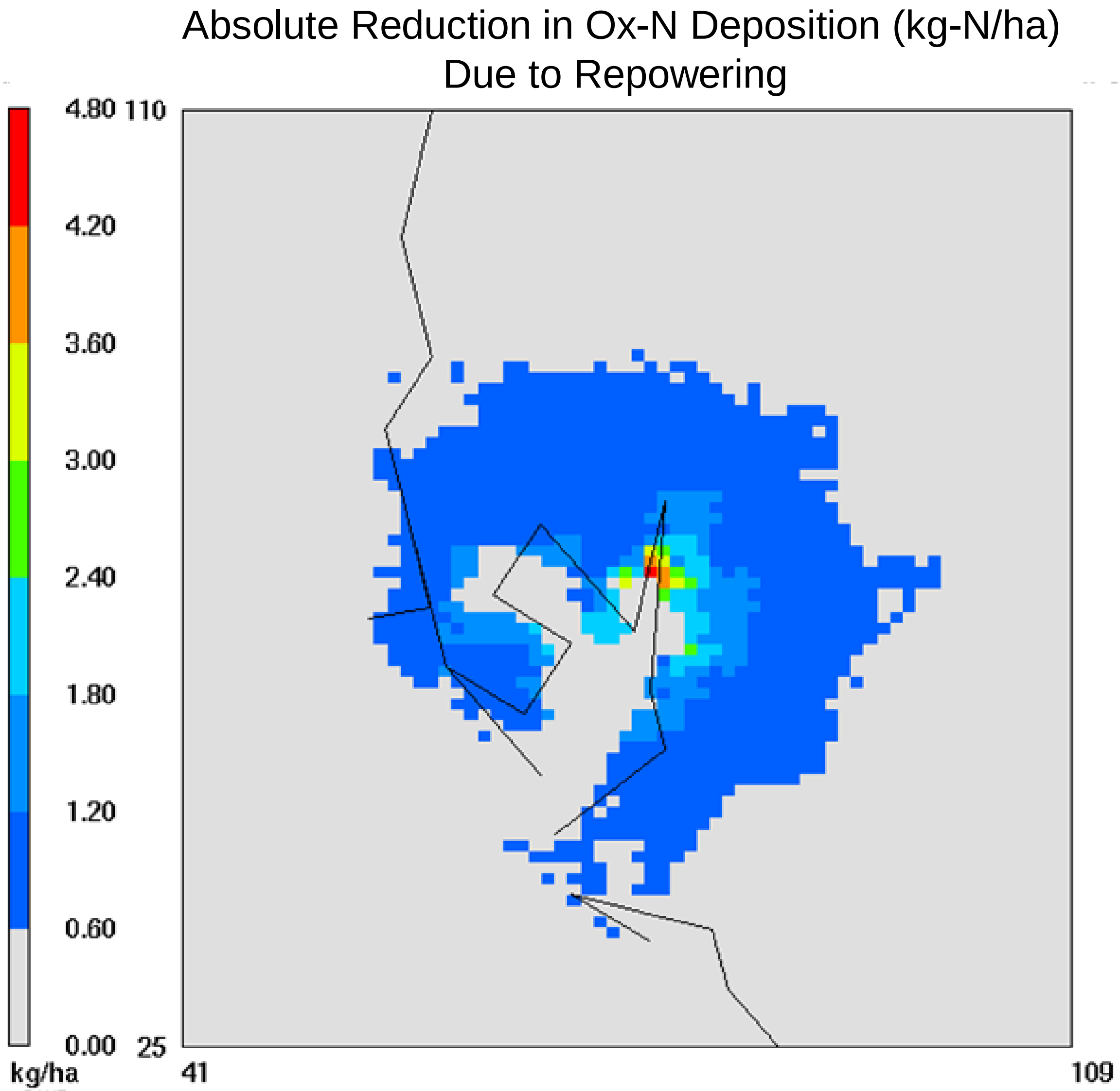

Figure C-1. Absolute Reduction in Annual Total Oxidized-Nitrogen Deposition (Wet plus Dry) (kg-N/ha) from the 2002 Base Case Predicted by CMAQ-UCD Due to the Repowering of the Gannon and Big Bend Power Plants.

Attachment D

CMAQ-UCD Estimates of the Reduction in Annual N Deposition Due to the 2010 CAIR Rule

Table D-1 gives the change in nitrogen deposition that is estimated to occur in 2010 as a result of the Clean Air Interstate Rule (CAIR). CAIR requires power plant NO_X emission reductions be in effect the entire year, not just the ozone season of May through September called for in the NO_X SIP Call. It also requires power plant SO_2 emission reductions and it includes the Tier II tail-pipe emission standards for on-road gasoline cars and trucks to reduce NO_X and VOC emissions. The 2010CAIR emissions estimates take into account the growth in population and vehicle miles traveled. The absolute change in annual oxidized-nitrogen deposition due to the 2010CAIR emissions reductions is shown in Figure D-1 for the entire 2-km domain and in Figure D-2 for the Tampa region.

As shown in Table D-1, the absolute total nitrogen deposition reductions in 2010 to the Tampa watershed due to the CAIR rule are expected to be significant. Comparing Table D-1 and Table C-1, the reductions estimated for the CAIR in 2010 are approximately 3.8 times larger than the reductions estimated for the repowering of Gannon and Big Bend in 2010. In relative terms, the decrease in oxidized-nitrogen deposition due to 2010CAIR is 44% for deposition to the watershed and 41% for deposition to the bay waters. The decrease in total-nitrogen deposition due to 2010CAIR is 25% for deposition to the watershed and 24% for deposition to the by waters. Reductions in total N-deposition computed from the 2010CAIR CMAQ-UCD simulation are 1,561,954 kg for the total watershed and 112,471 kg for Tampa Bay waters. This estimate translates to a reduction in N-deposition to the watershed of 1,718 English tons-N or 309.3 English tons-N delivered to the bay waters, using the TBEP transfer coefficient of 0.18. Adding this to the estimated 123.7 English tons-N reduction from direct deposition to the bay waters results in an overall nitrogen load reduction to Tampa Bay waters of 433.0 tons of N from 2002 to 2010 (8 years) or about 54.1 tons-N per year (assuming a simple linear reduction, which in fact is not the case). This is approximately triple the Tampa Bay Estuary Program target of 17 tons-N per year. Clearly, the reductions mandated by the CAIR rule are important to Tampa Bay.

While the power plant NO_X and SO_2 emission reductions are expected to be good estimates, there are significant uncertainties in the estimates given in Table D-1. First, the effectiveness of mobile source controls is uncertain. It is possible they will not be as effective as estimated by the mobile source model, making the overall reduction in oxidized nitrogen deposition smaller. Second, the estimated growth in ammonia emissions is highly uncertain. The increase in reduced-N deposition offsets a major portion of the oxidized nitrogen reduction. A substantial increase in ammonia emissions of about 20% from area, mobile source and industrial sources is posited in the 2010CAIR emission inventory compared to 2001 emissions. The agricultural ammonia emissions from Hillsborough Country increase significantly, by more than 40%, in the 2010CAIR emission inventory over the 2001 base inventory. This appears to be very unrealistic because for Florida, as a whole, agricultural ammonia emissions reduce 2% from 2001 levels and the Agricultural Census for Hillsborough County indicates that agricultural production (in dollars) is declining, not growing. To be conservative, a new estimate that assumed the ammonia emissions from agriculture in Hillsborough County remained constant was simulated. This is expected to be closer to reality, but still is expected to be an over-estimate of the growth in ammonia emissions for the Tampa Bay area. It is this estimate that is included in Table D-1.

Addressing the uncertainty in the trends in oxidized- and reduced-nitrogen deposition and uncertainty in the air quality model is warranted and will be important to help understand observed changes in water quality in Tampa Bay. It will be important to empirically monitor multi-year trends in air concentrations of NO, NO_2, NO_Y, NH_3 and NH_4^+ around the Tampa and St. Petersburg area to provide a local cross-check on the growth and change estimates in the national emissions inventory. Wet deposition trends alone may not provide a relevant check on the local Tampa and St. Petersburg trends in ammonia emissions. The trends will need to be documented in terms of ambient air concentrations.

Uncertainty 1: A bias in a CMAQ dry deposition computation was uncovered at the end of this study. CMAQ developers discovered the NO and NO_2 dry deposition parameterizations were missing a component, making the CMAQ estimate of NO and NO_2 dry deposition to vegetative surfaces up to a factor of two too high. The PAN deposition was updated at the same time, increasing its rate of deposition. Also, the deposition exchange with water surfaces was updated, reducing the rate of NO and NO_2 dry deposition to water. There is no error for dry deposition to impervious surfaces. The NO and NO_2 dry deposition formulation errors introduce a bias in the tabulated results for the oxidized-N deposition estimates. A subset of 4 months was used to develop a "best" estimate of the bias in the annual deposition numbers. The dry deposition formulation errors reduce the oxidized-N deposition in the Base Case by roughly 17% and 15% in the 2010 Clean Air Interstate Rule (CAIR) Case for land (24% and 28%, respectively, for water). As a result, there is a noticeable decrease in the deposition reduction attributable to the 2010CAIR. The bias in the Total-N reductions in Table D-1 is largest for the watershed sub-basins with dense urban emissions. The Total-N reductions for Coastal Old Tampa Bay, Coastal Hillsborough Bay, Coastal Middle Tampa Bay, and Boca Ciega Bay are 26.3%, 28.5%, 26.1%, and 26.6% too high, respectively. The bias in the other sub-basins is much lower. The bias for the Tampa Bay segments ranges between 4 and 15%. The analysis indicates the Total-N deposition reduction in Table D-1 is approximately 18.4% and 8.9% too high for the land and water area total accumulated deposition, respectively. Thus, the above estimate of the total N load reduction to Tampa Bay waters is approximately 16% too high. An estimated bias-corrected reduction of Total-N to Tampa Bay waters due to 2010CAIR NO_X and SO_2 emissions reductions would be (252.4 + 112.7 =) 365.1 tons-N from 2002 to 2010 (8 years) or about 45.6 tons-N per year (assuming a simple linear reduction).

Uncertainty 2: There are several sources of uncertainty affecting the deposition estimates from the CMAQ-UCD: meteorological and emissions input uncertainties (especially NO_X and NH_3 emissions) and model process description uncertainties. The evaluation of the meteorology for Tampa suggests the meteorological model is performing in a quantified bias and error range typical of performance for the rest of the US. The evaluation of CMAQ-UCD against the May 2002 data suggests it too is functioning in a fairly typical manner, similar to evaluations performed for other areas in the eastern US. The seasonal and annual wet deposition comparisons for Florida sites suggest CMAQ-UCD is functioning in a manner typical of its performance for the rest of the eastern US. Thus, uncertainties for Tampa are expected to be of the same order as uncertainties observed for the eastern US in CMAQ evaluation studies. For annual results, wet deposition can have uncertainties at any one location of ±50% to ±100%. Ambient concentrations at any one location can have uncertainties of ±25% to ±50%. The uncertainties in the dry deposition parameterizations and representation of turbulent mixing will add to and inflate these ambient concentration uncertainty estimates. Emissions uncertainties are judged to be the order of ±40% to ±50%. The uncertainties in meteorology, emissions, and model process descriptions are by and large independent. Thus, the uncertainty of the CMAQ-UCD estimates of total deposition is expected to be ±50% and up to a factor of 2 at any one location. For the annual relative change estimates, several types of uncertainties can cancel or be damped because the same uncertainty affects both the base and the change cases. The air quality models are always expected to perform better at estimating relative change than for estimating absolute amounts. The uncertainty for relative changes is judged to be the order of ±25% up to ±50%. The NO_2 bias discussed above is an example of the uncertainty in the estimation of an absolute amount of change, rather than a relative change. In the NO_2 bias case, both the base and the control case were changed by approximately the same percentage. Therefore, the relative change, as a percent reduction, remains basically the same for the original Base-to-2010CAIR and the bias-corrected Base-to-2010CAIR with a difference of less than half of a percentage point between them.

Table D-1. Change in Annual Nitrogen Deposition by 2010 Due to Clean Air Interstate Rule (CAIR)

	DryOx-N (kg-N)	DryRed-N (kg-N)	Dry-N (kg-N)	WetOx-N (kg-N)	WetRed-N (kg-N)	Wet-N (kg-N)	TotOx-N (kg-N)	TotRed-N (kg-N)	Total-N (kg-N)
Watershed Sub-basins					*See Note*				
Coastal Old Tampa Bay	-205,988	42,641	-163,347	-52,905	1,871	-51,034	-258,894	44,512	-214,381
Alafia River	-240,633	54,168	-186,465	-81,113	-3,451	-84,564	-321,746	50,717	-271,029
Hillsborough River	-481,026	93,827	-387,199	-138,140	-1,798	-139,937	-619,166	92,029	-527,137
Coastal Hillsborough Bay	-97,853	32,288	-65,565	-27,829	2,631	-25,198	-125,682	34,919	-90,762
Little Manatee River	-124,479	32,595	-91,885	-41,627	-829	-42,457	-166,107	31,765	-134,342
Coastal Middle Tampa Bay	-44,653	10,530	-34,123	-11,372	343	-11,028	-56,024	10,873	-45,151
Coastal Lower Tampa Bay	-16,373	3,151	-13,221	-4,965	110	-4,855	-21,338	3,262	-18,077
Terra Ceia Watershed	-3,020	564	-2,456	-838	-12	-850	-3,858	552	3,306
Manatee River Watershed	-164,069	34,917	-129,151	-60,632	-3,093	-63,725	-224,701	31,824	-192,876
Boca Ciega Bay	-65,212	15,733	-49,480	-15,868	599	-15,269	-81,080	16,332	-64,749
Total Watershed	-1,443,306	320,414	-1,122,893	-435,289	-3,772	-439,061	-1,878,595	316,641	-1,561,954
Tampa Bay Segments									
Old Tampa Bay	-17,969	4,924	-13,045	-17,904	586	-17,318	-35,873	5,510	-30,363
Hillsborough Bay	-3,832	3,008	-824	-6,443	509	-5,935	-10,275	3,516	-6,758
Middle Tampa Bay	-14,565	4,284	-10,282	-23,269	816	-22,453	-37,835	5,100	-32,735
Lower Tampa Bay	-11,940	2,866	-9,074	-18,292	351	-17,941	-30,232	3,216	-27,015
Boca Ciega Bay	-5,990	1,633	-4,357	-4,551	89	-4,463	-10,541	1,722	-8,820
Terra Ceia Bay	-855	150	-705	-328	10	-317	-1,183	160	-1,022
Manatee River	-5,372	1,104	-4,268	-1,652	30	-1,622	-7,024	1,134	-5,890
Total Bay	-60,523	17,969	-42,554	-72,439	2,523	-69,916	-132,962	20,492	-112,471

	DryOx-N (lbs-N)	DryRed-N (lbs-N)	Dry-N (lbs-N)	WetOx-N (lbs-N)	WetRed-N (lbs-N)	Wet-N (lbs-N)	TotOx-N (lbs-N)	TotRed-N (lbs-N)	Total-N (lbs-N)
Total Watershed	-3,175,274	704,910	-2,470,364	-957,636	-8,299	-965,935	-4,132,909	696,611	-3,436,298
Total Bay	-133,151	39,531	-93,620	-159,366	5,550	-153,816	-292,517	45,081	-247,435

Note: The Wet Reduced-N column has an estimated adjustment to correct for the agricultural emissions inventory error in ammonia

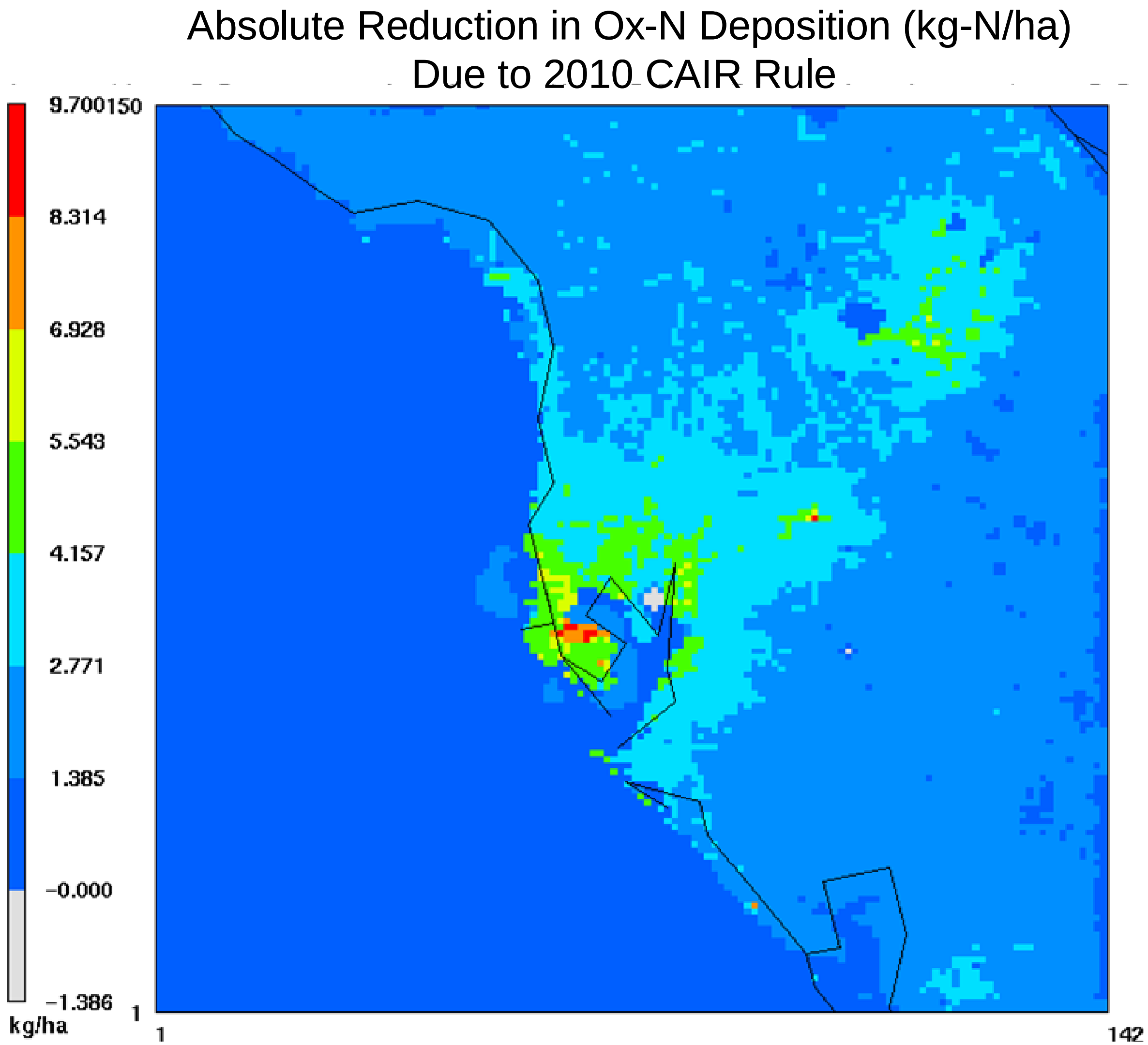

Figure D-1. Absolute Reduction in Total Annual Oxidized-Nitrogen Deposition (Dry plus Wet) from the 2002 Base Case in kg-N/ha Predicted by CMAQ-UCD for the 2010 CAIR Rule.

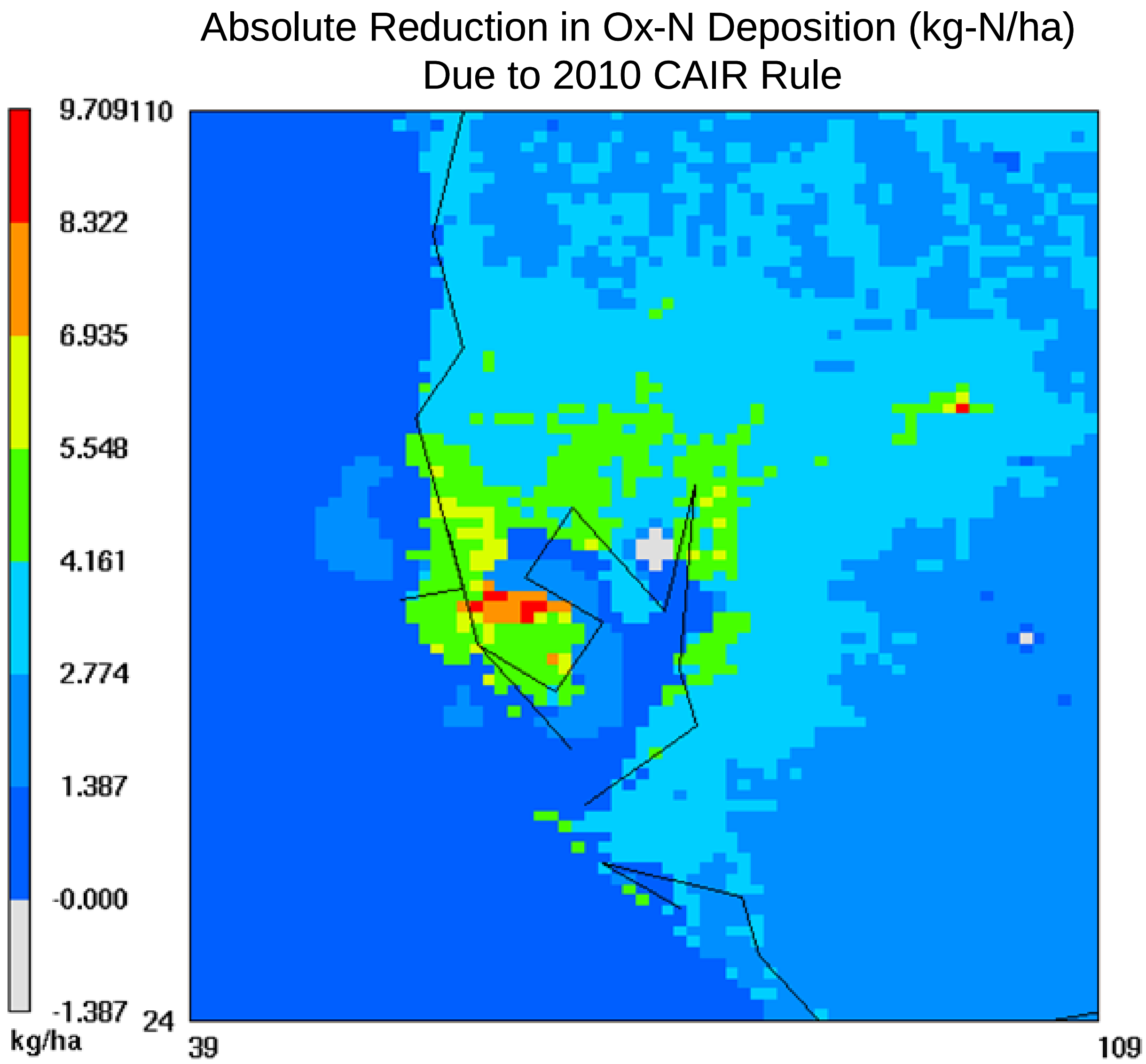

Figure D-2. Absolute Reduction in Total Annual Oxidized-Nitrogen Deposition (Dry plus Wet) from the 2002 Base Case in kg-N/ha Predicted by CMAQ-UCD for the 2010 CAIR Rule, zoomed to cover Tampa.