EPA
United States
Environmental Protection
Agency

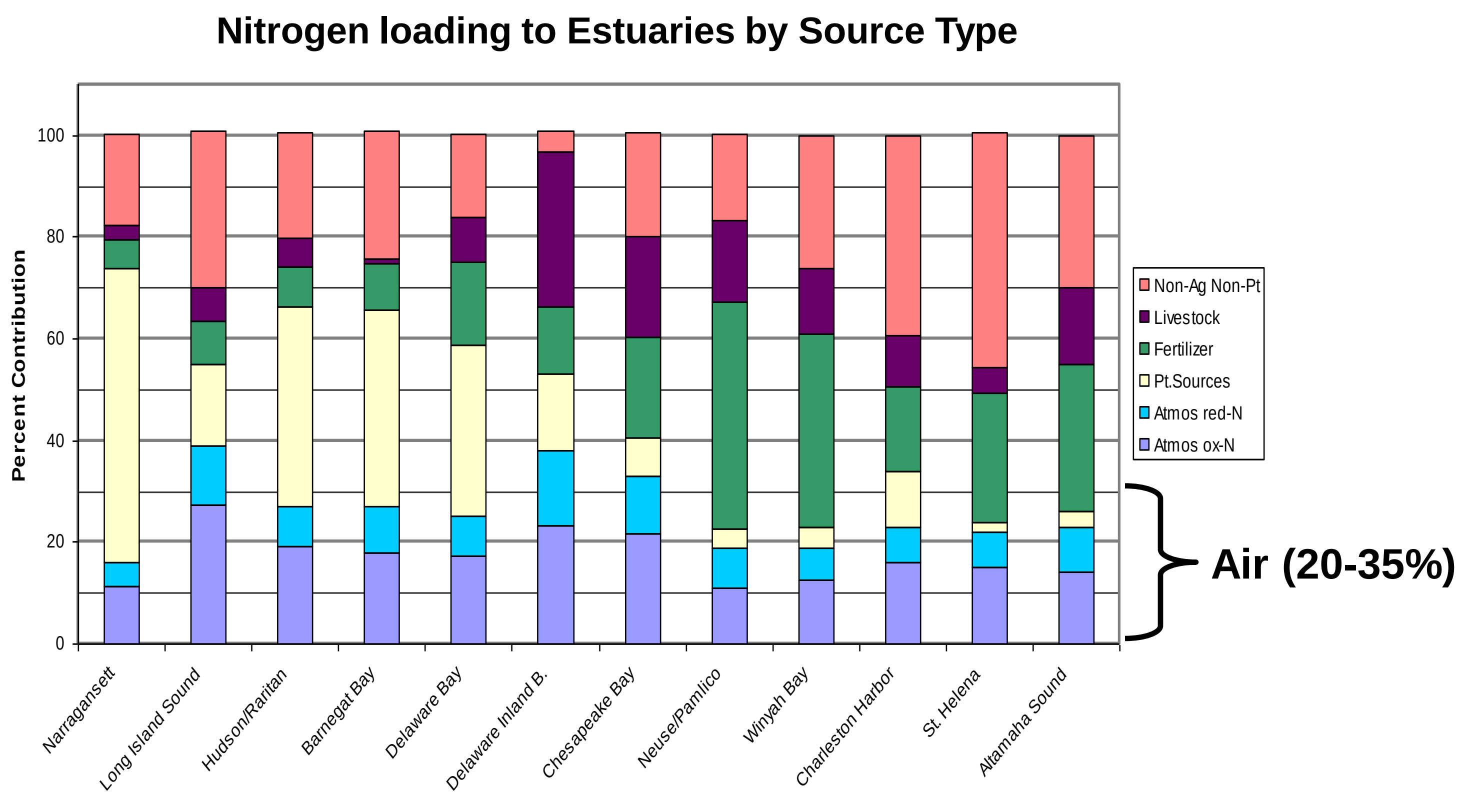
Atmospheric Deposition Fields and Source Attribution from CMAQ for the Chesapeake Bay TMDL Process

Robin L. Dennis, Sergey Napelenok
Atmospheric Modeling and Analysis Division
NERL, EPA
Lewis Linker
Chesapeake Bay Program, EPA

Quarterly Bay Modeling Meeting
January 11, 2012
Annapolis, MD

Atmospheric Deposition Fields and Source Attribution from CMAQ for the Chesapeake Bay TMDL Process

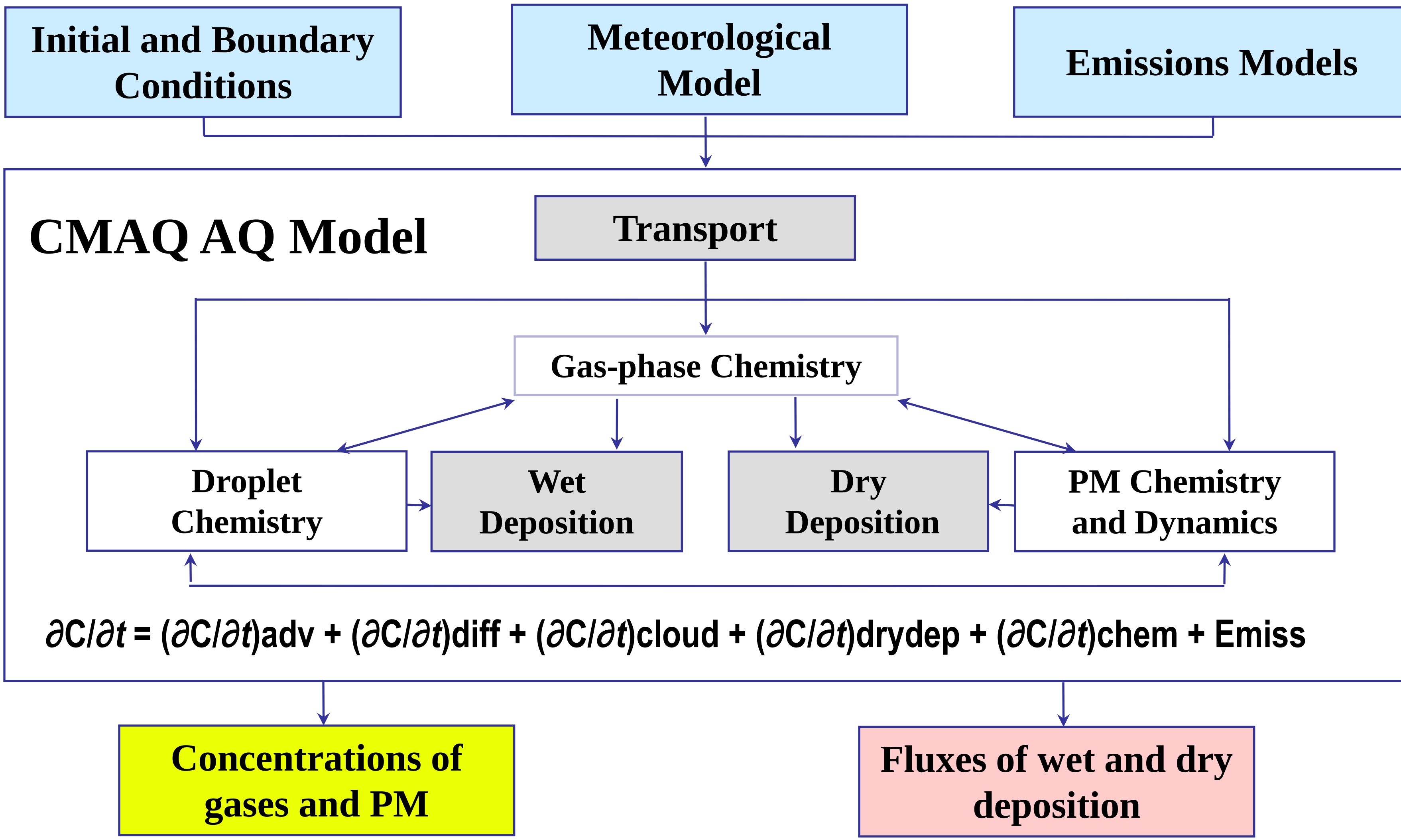
The atmospheric contribution to nutrient loading in estuaries is significant



- **Accounts for 20-35% of N loading to estuaries (both indirect and direct)**
- **Often ignored for watershed and TMDL (Total Maximum Daily Load) management**

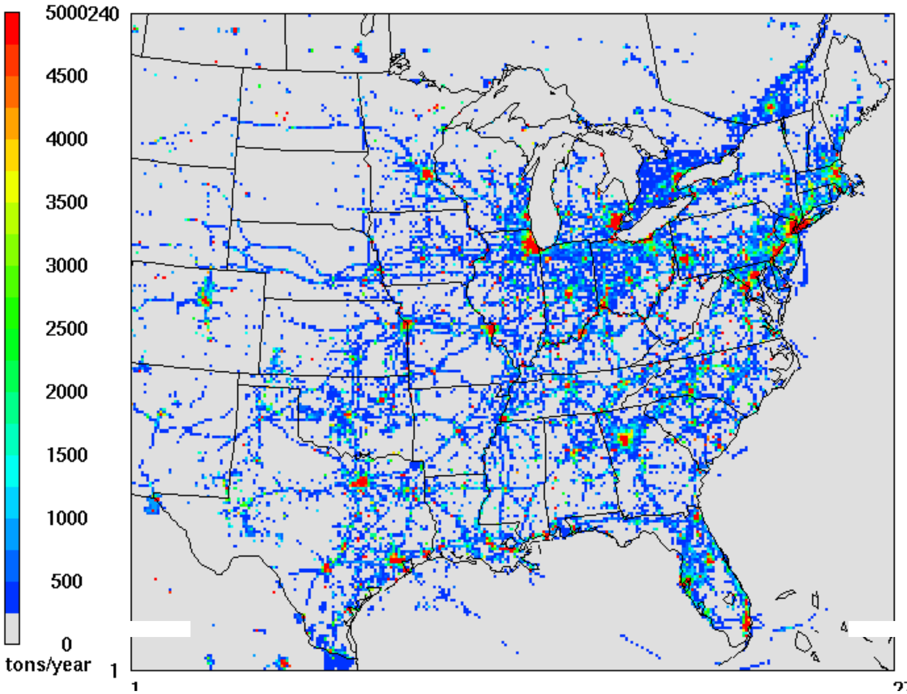
We use a regional air quality model, the Community Multiscale Air Quality (CMAQ) model, to convert air emissions of NO_X (oxidized nitrogen) and NH_3 (reduced nitrogen) to atmospheric deposition of oxidized and reduced N

CMAQ System

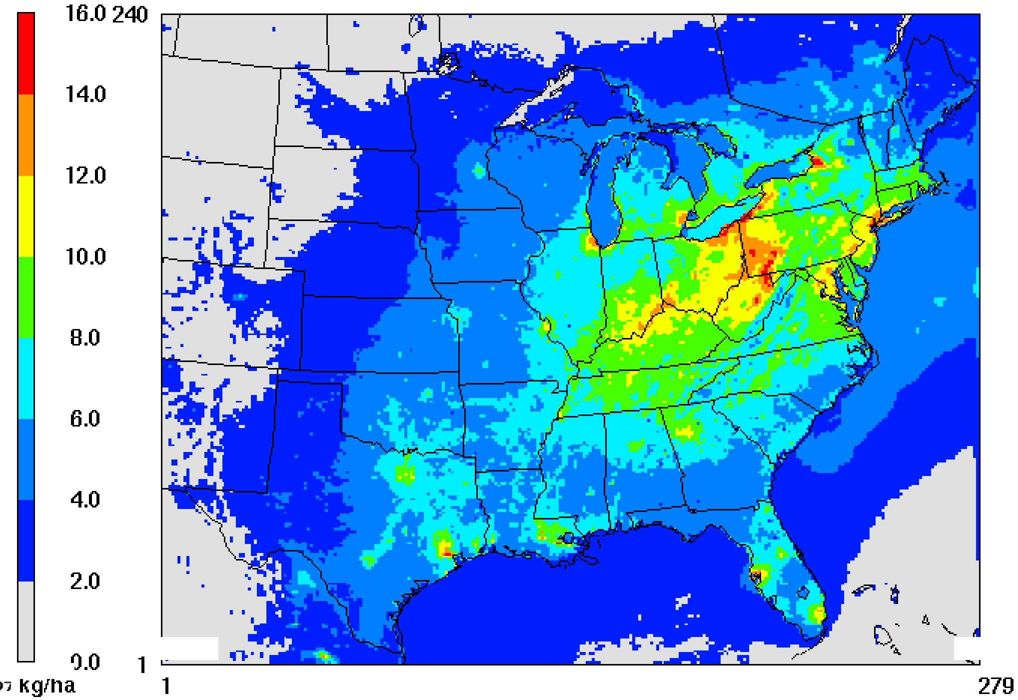


Turning Emissions into Deposition

2002
NO_X Emissions



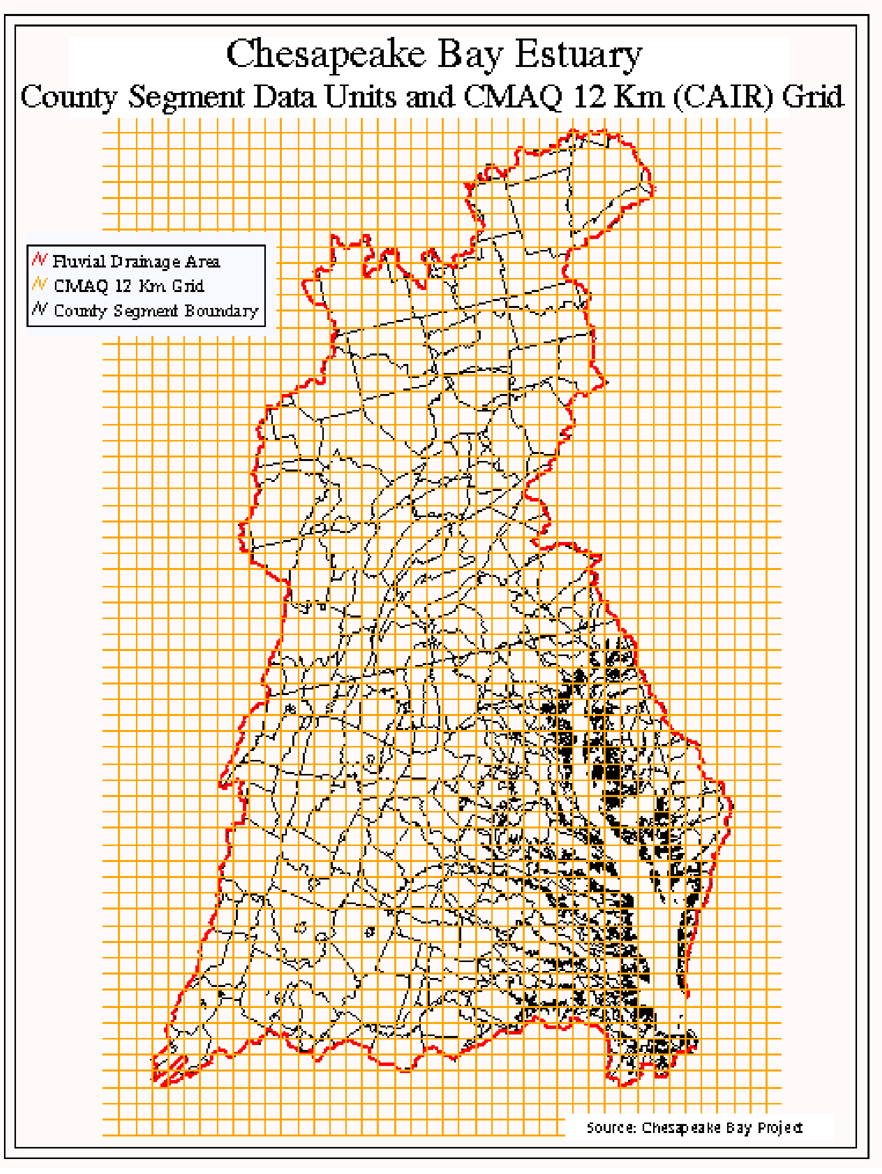
2002 CMAQ
Oxidized-N Deposition



12km Grid

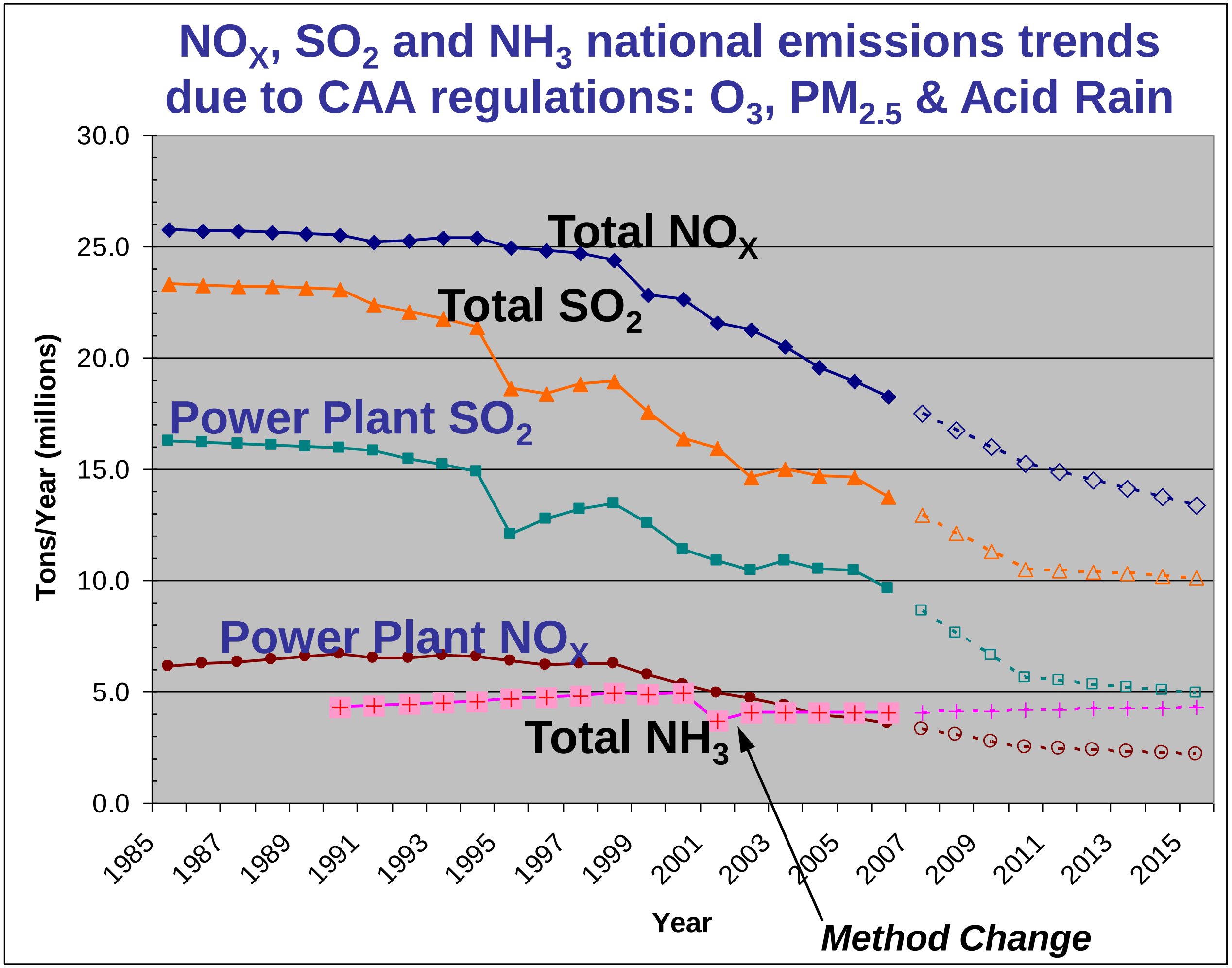
Oxidized-N = Ox-N = sum of all species in the oxidation of NO_X expressed as N (= $NO + NO_2 + HNO_3 + NO_3^- + PAN +$ higher PAN's $+ N_2O_5 + HONO +$ etc.)

We then pass these deposition estimates to the watershed and water quality model to compute the loading to the estuary using an overlay of the 12km grid onto the watershed and water quality model segments



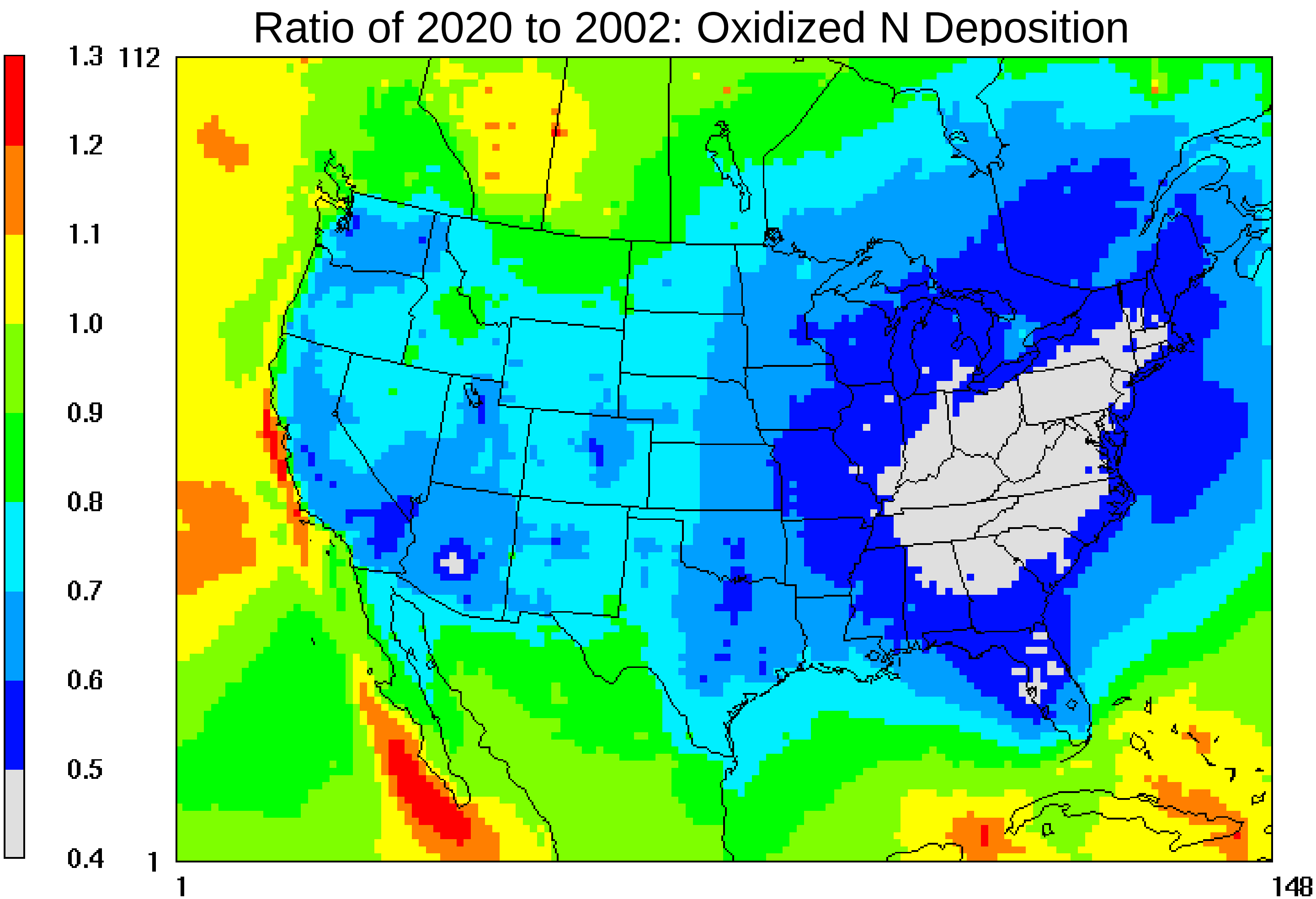
United States Environmental Protection Agency

Due to regulations in the Clean Air Act, designed to protect the population from ozone and fine particulate health impacts, emissions of SO_X and NO_X are to be reduced now and in the future

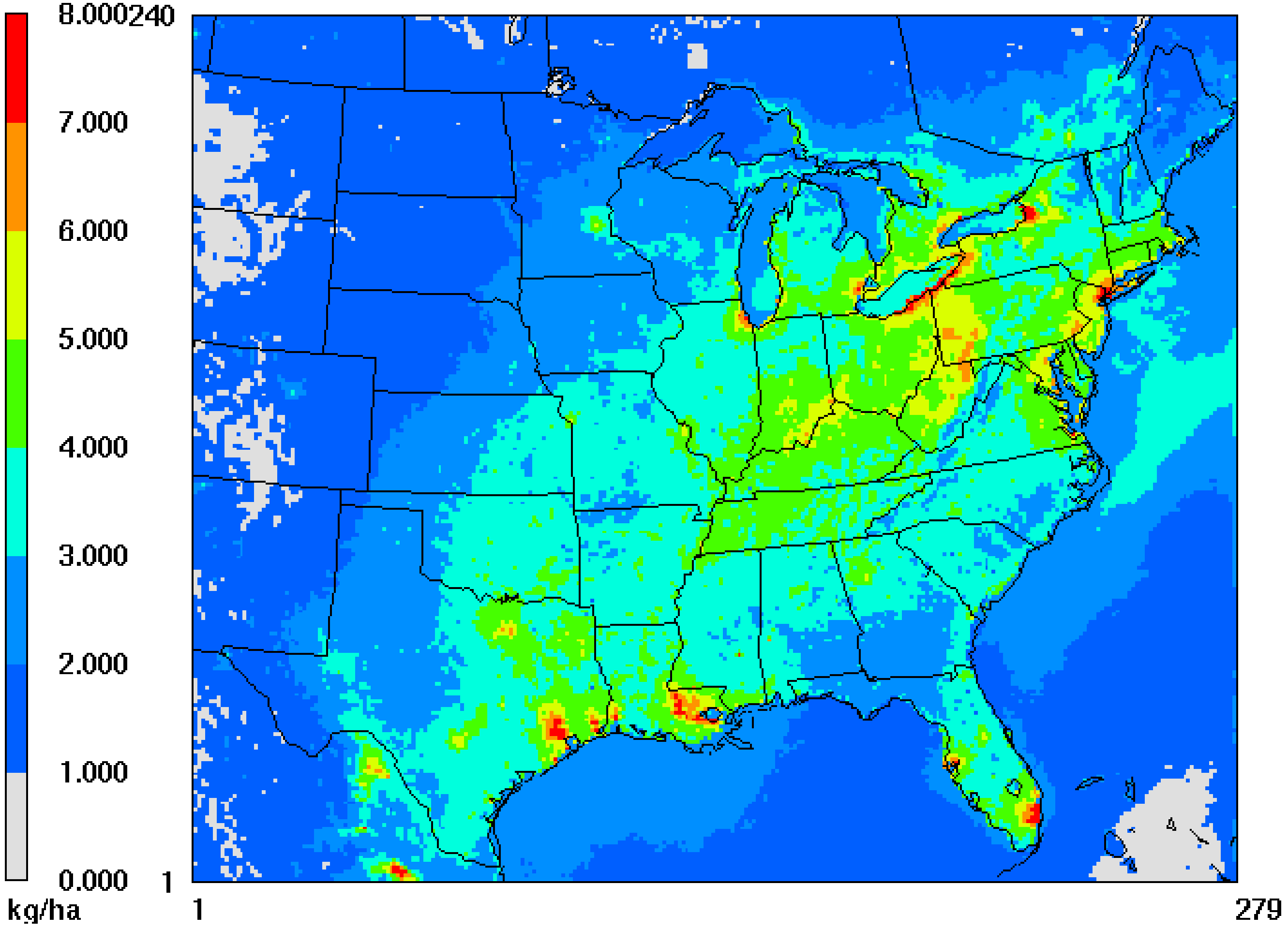


Estimated contribution of CAA regulations to trends in deposition using CMAQ passed to watershed model for TMDL analysis:

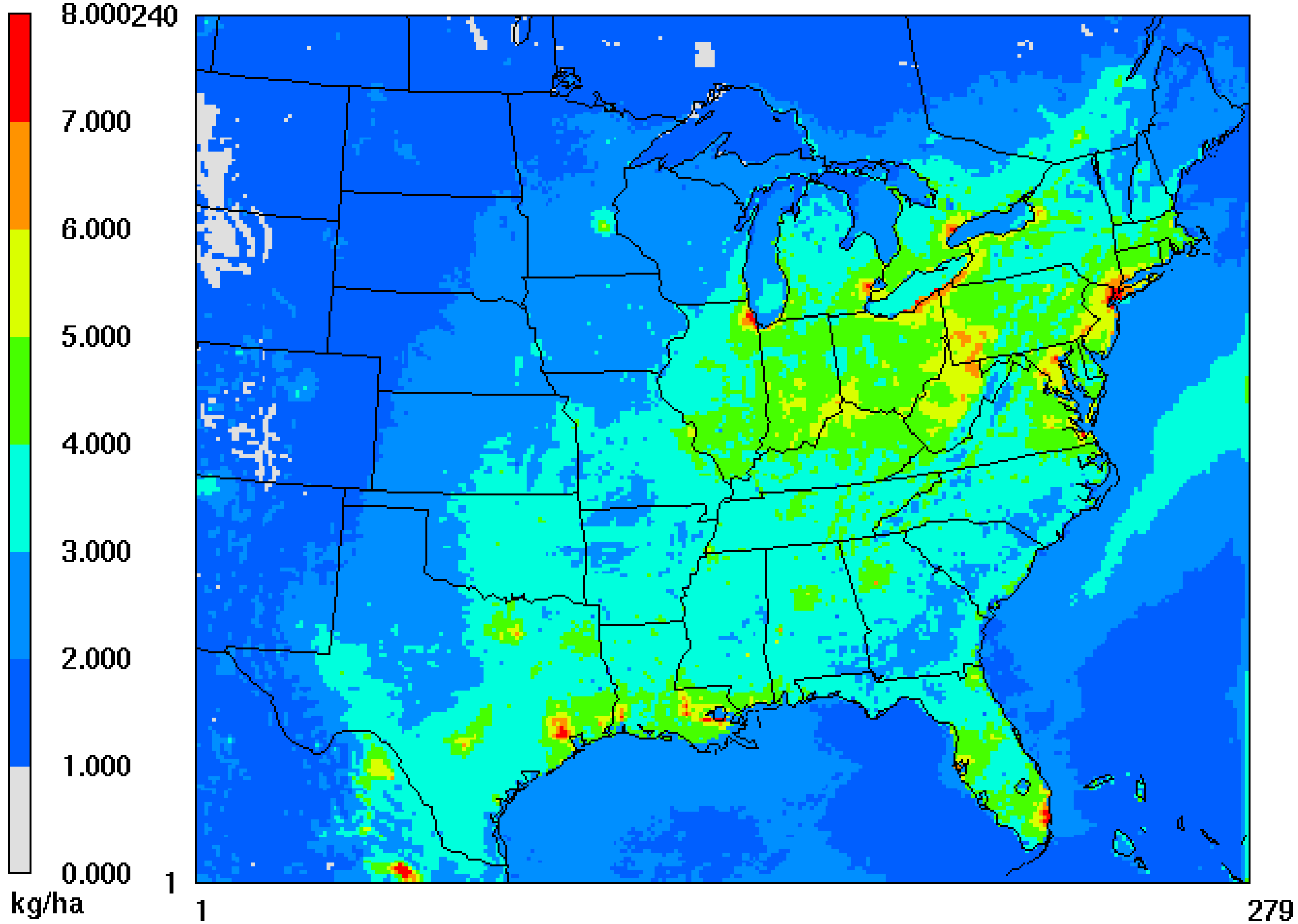
>50% Reduction in Oxidized-N Deposition for Ohio Valley and Mid-Atlantic Parts of US



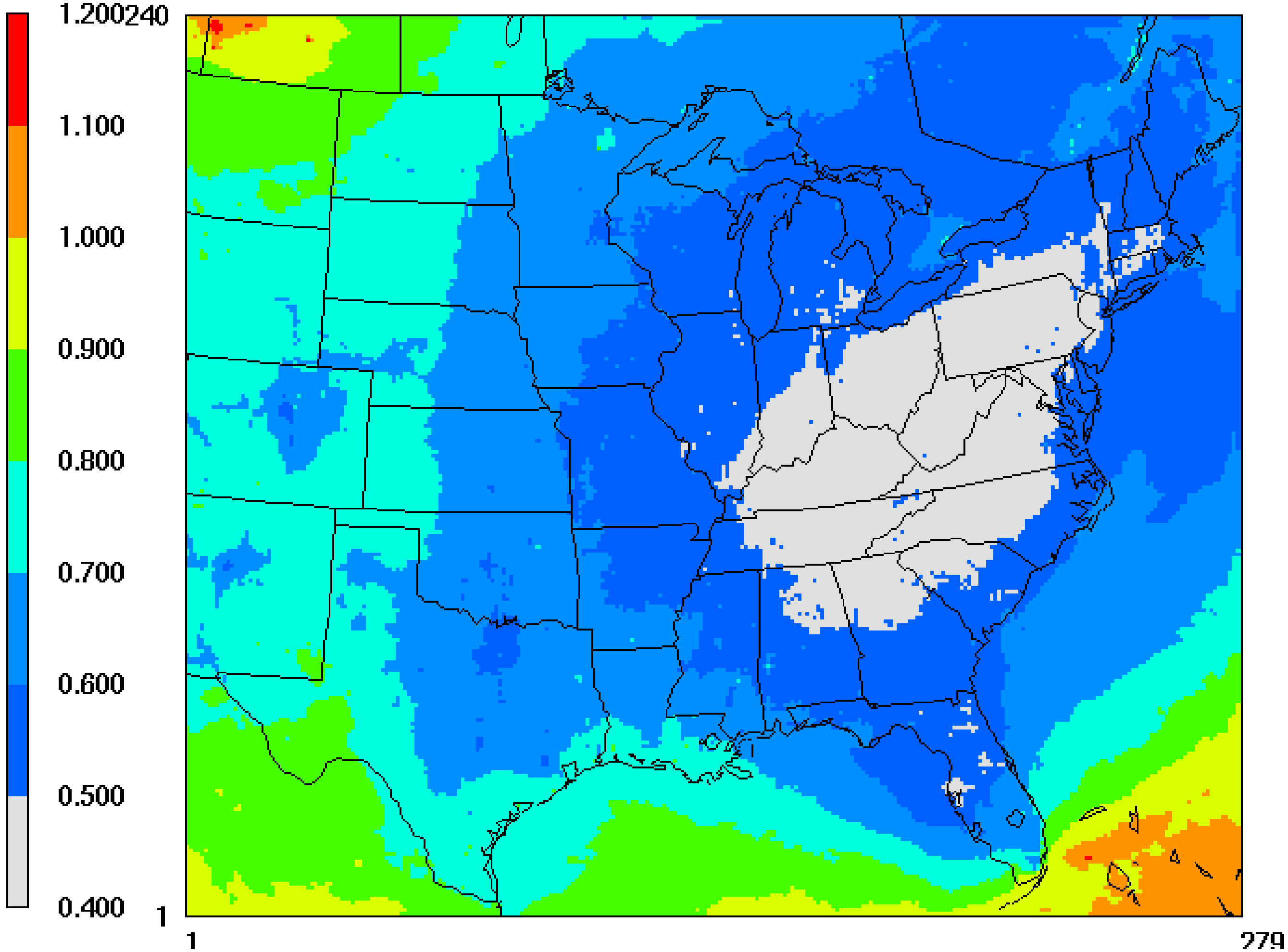
2020 CAIR



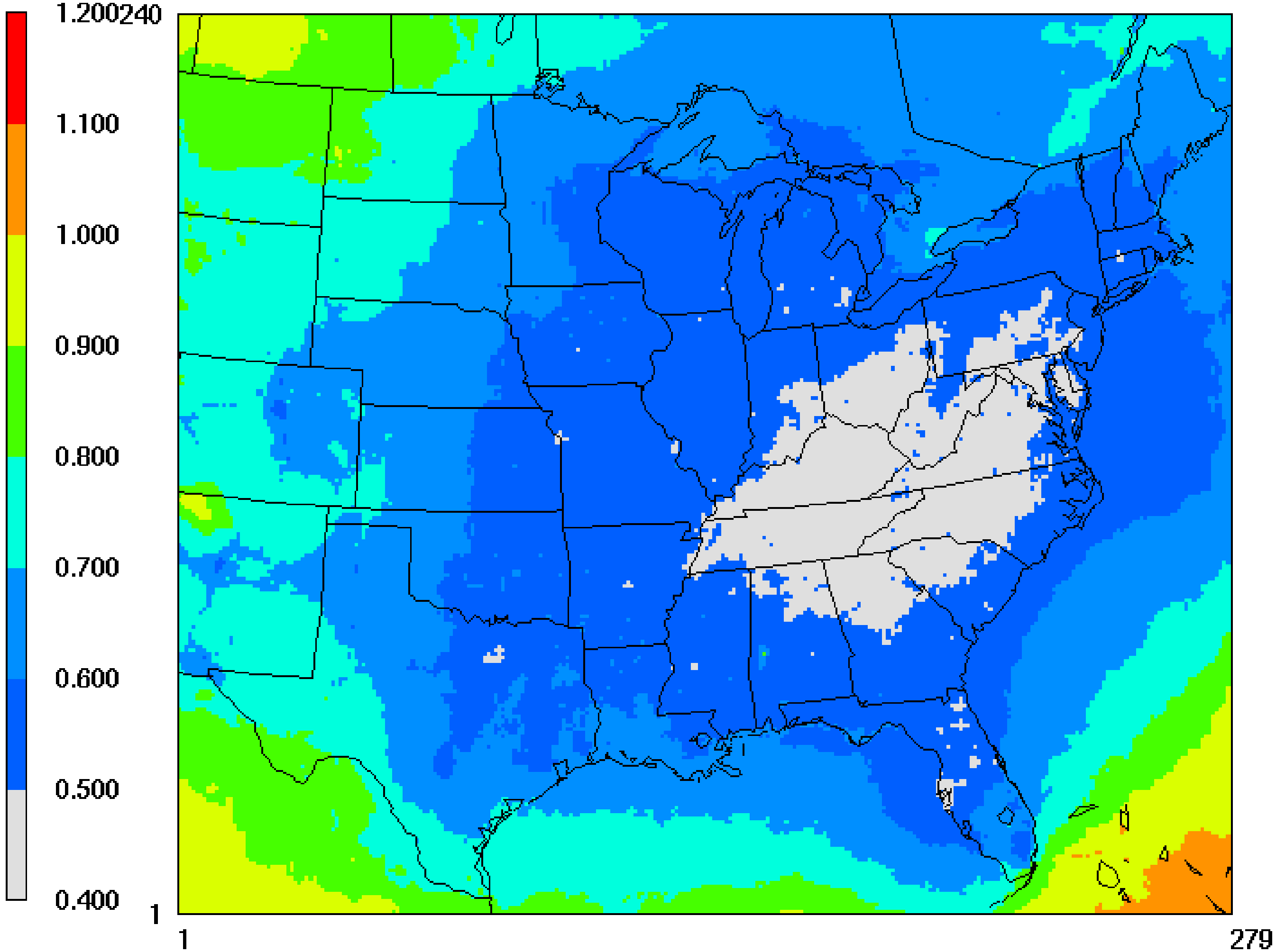
2030 CSAPR



2020 CAIR/2002 Base



2030 CSAPR/2005 Base



Estimated contribution of CAA regulations to future deposition for older and newer estimates using CMAQ:

Oxidized-N Deposition				
	Watershed		Bay	
	(kg-N)	% chg	(kg-N)	% chg
2002 Base	141,988,028		7,571,386	
2005 Base	136,211,948		7,317,867	
2020 CAIR	66,569,100	-53.1%	3,936,401	-48.0%
2030 CSAPR	67,697,372	-50.3% 2005	3,758,123	-48.6% 2005
		-52.3% 2002		-50.4% 2002
2020 LOT	58,626,590	-58.7%	3,484,176	-54.0%

Estimated contribution of CAA regulations to future deposition for older and newer estimates using CMAQ:

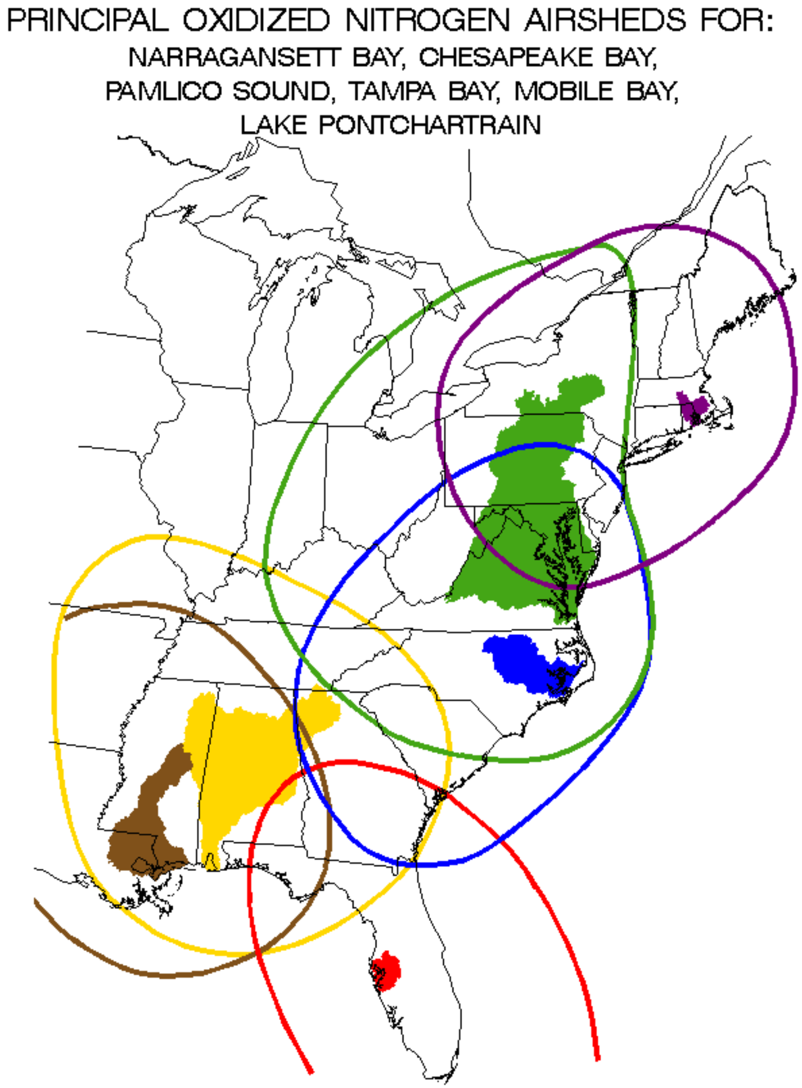
Oxidized-N Deposition				
	Potomac		Susquehanna	
	(kg-N)	% chg	(kg-N)	% chg
2002 Base	30,948,103		60,990,109	
2005 Base	30,486,722		55,428,736	
2020 CAIR	14,032,062	-54.7%	28,546,064	-53.2%
2030 CSAPR	14,784,826	-51.5% 2005	28,266,549	-49.0% 2005
		-52.2% 2002		-53.7% 2002
2020 LOT	12,367,296	-60.0%	24,880,020	-59.2%

Estimated contribution of CAA regulations to future deposition for older and newer estimates using CMAQ:

Oxidized-N Deposition				
	James		Rappahannock	
	(kg-N)	% chg	(kg-N)	% chg
2002 Base	20,896,200		6,166,545	
2005 Base	21,610,649		6,019,845	
2020 CAIR	9,845,516	-52.9%	2,921,633	-52.6%
2030 CSAPR	10,502,330	-51.4% **2005**	2,948,364	-51.0% **2005**
		-49.7% **2002**		-52.2% **2002**
2020 LOT	8,939,715	-57.2%	2,582,881	-58.1%

Airsheds are much larger than watersheds

The emissions from watershed states account for a major portion of the deposition to the watershed, but not all of it



2020 State Attribution to Chesapeake Bay Watershed (12km)	
State	%
New York	6.8
Pennsylvania	19.1
Maryland	10.5
Virginia	18.1
Delaware	1.4
West Virginia	6.1
D.C.	0.8
States+DC Combined	62.8

Atmospheric deposition reductions for the TMDL process are mainly associated with national CAA rules.

States may, however, go beyond national CAA rules to meet CAA air quality standards locally

It could be important to the TMDL process to take advantage of air emissions reductions that would occur for other reasons.

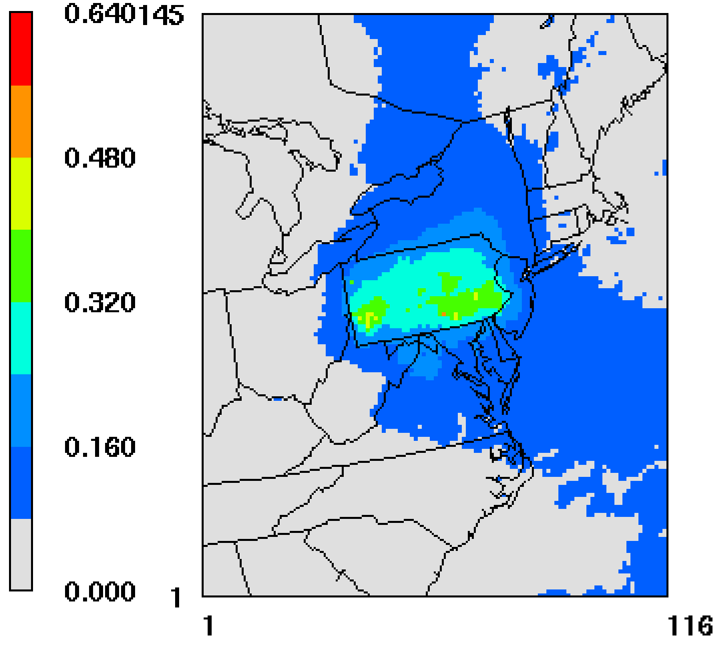
Because of the complex chemistry and transport and transformation we need to make a calculation of the incremental benefit with an air quality model. We would like to do this without having to run the regional air quality model many times over because it is computationally expensive.

There is a special source attribution version of CMAQ (DDM) that can track the individual contribution of emissions, that are labeled by source or region, to the total deposition.

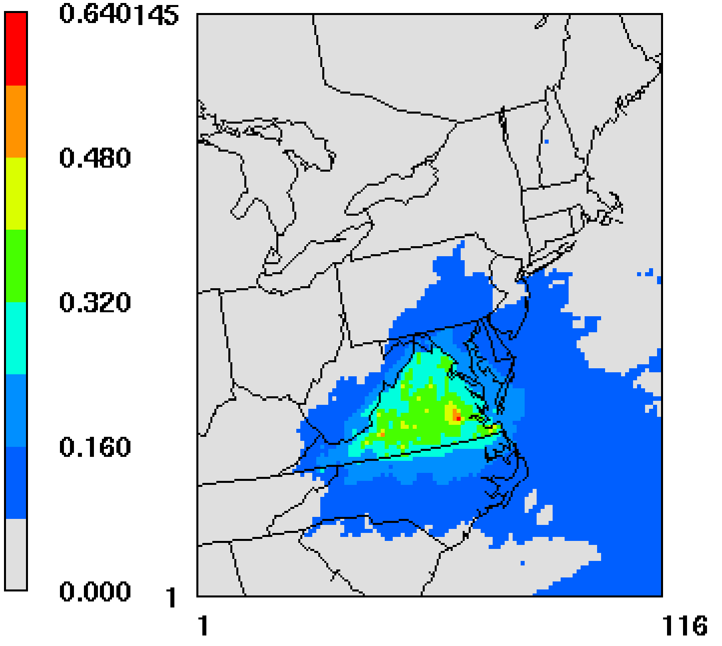
Our approach is to use this CMAQ version to set up simplified delta emissions–to-delta atmospheric deposition transfer calculations by state, since air regulations are generally at the state level, for the states to use

Example of the fraction of oxidized-N deposition from PA and VA 2020 NO_X emissions

Pennsylvania Ox-N Deposition due to Pennsylvania NO_X emissions



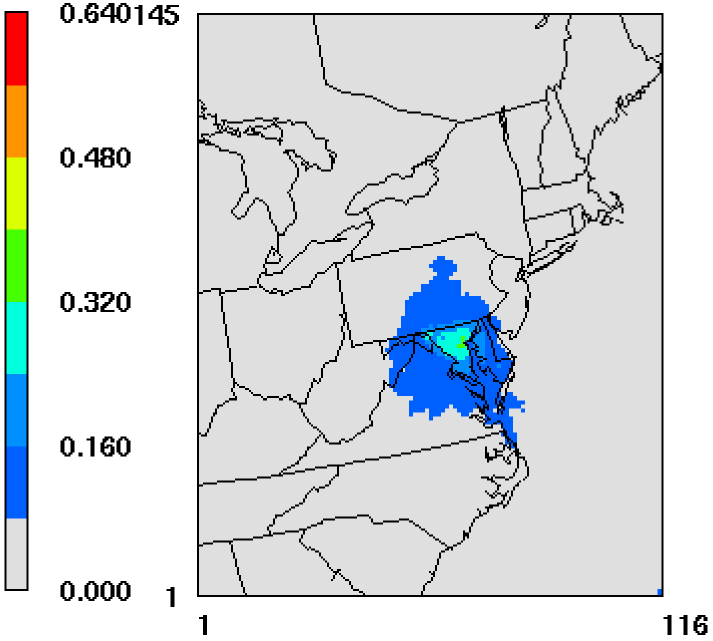
Virginia Ox-N Deposition due to Virginia NO_X emissions



Example of the fraction of oxidized-N deposition from MD and NY 2020 NO_X emissions

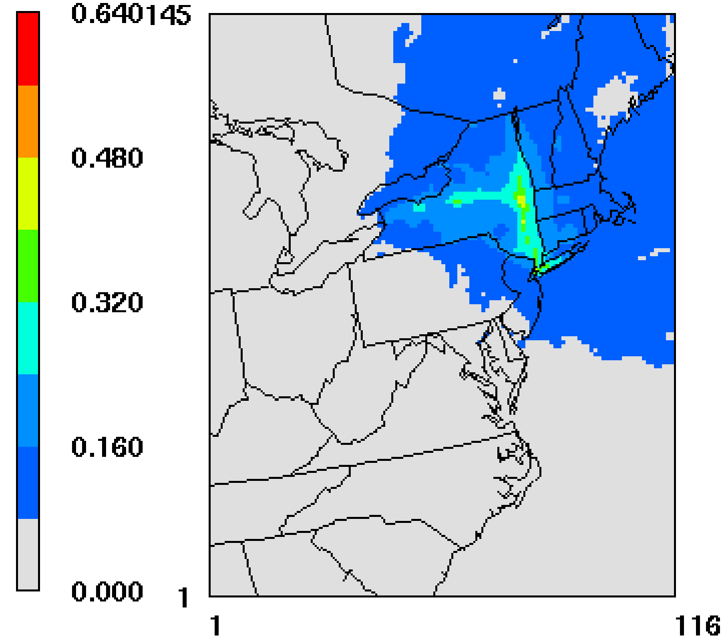
Maryland
Ox-N Deposition
due to Maryland NO_X emissions

Fraction



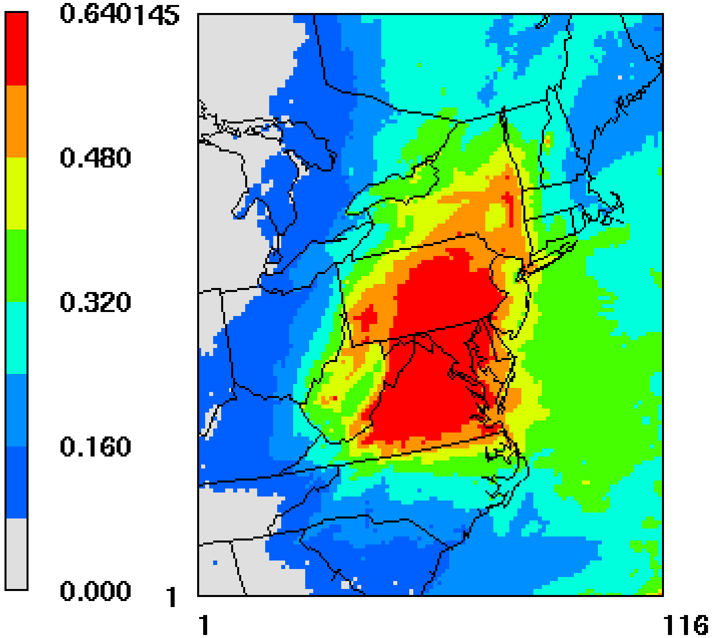
New York
Ox-N Deposition
due to New York NO_X emissions

Fraction

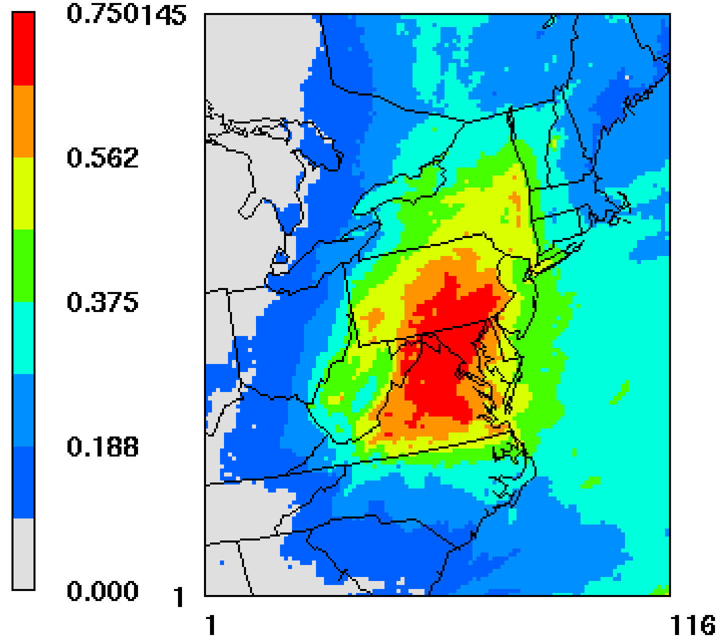


Example of the fraction of oxidized-N deposition from MD and NY 2020 NO_X emissions

6 Bay States+DC
Ox-N Deposition
due to Bay State NO_X emissions

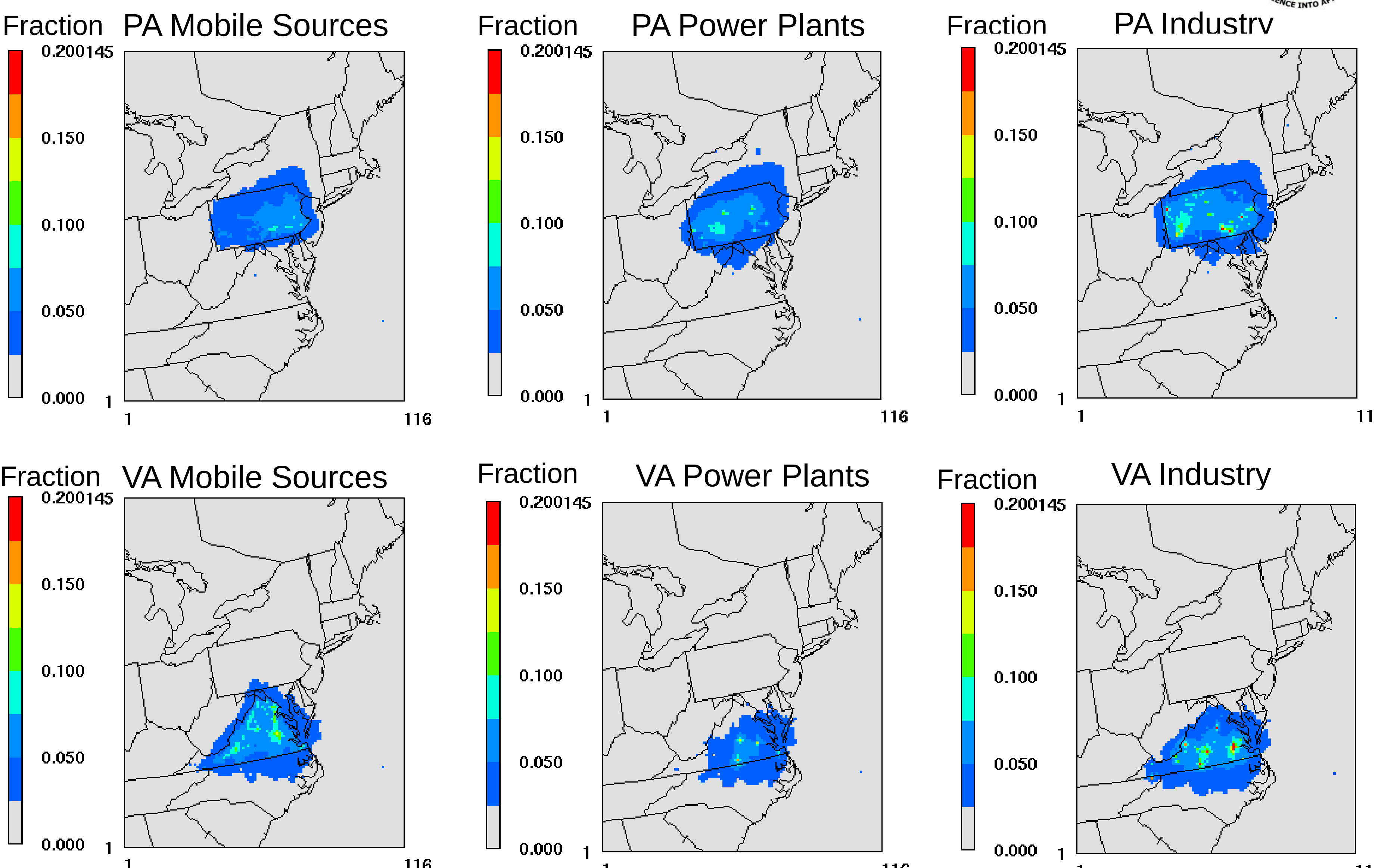


6 Bay States+DC
Ox-N Deposition
due to Bay State NO_X emissions

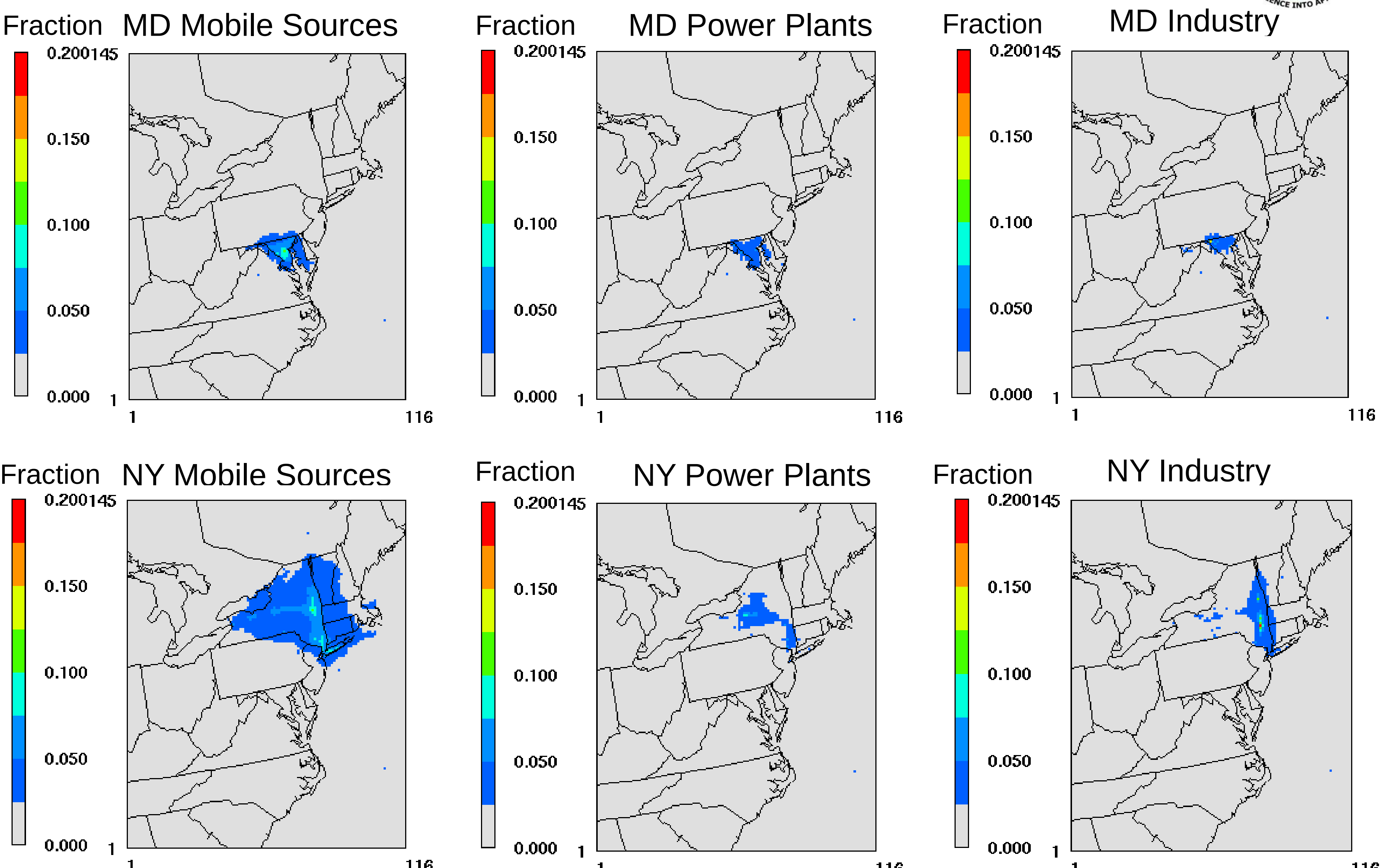


EPA United States Environmental Protection Agency

The states will be interested in fraction of deposition by sectors since rules will be by sector



The states will be interested in fraction of deposition by sectors since rules will be by sector



State Contribution

Fraction of kg-N contributed to tributary deposition by state

State	Potomac AFL	SusquehannaAFL	James AFL		Potomac AFL	Susquehanna AFL	James AFL
	fraction	fraction	fraction		kg-N Dep	kg-N Dep	kg-N Dep
PA	0.171	0.263	0.106		1,792,102	7,615,474	762,538
VA	0.205	0.083	0.342		2,143,307	2,400,793	2,461,158
MD	0.132	0.077	0.072		1,378,989	2,233,529	519,321
NY	0.047	0.097	0.034		487,454	2,818,109	247,256
WV	0.114	0.050	0.079		1,194,541	1,461,434	567,682
Total Tributary N Deposition (kg-N)					10,460,193	28,980,303	7,204,204

AFL = Above the Fall Line

State Contribution

Fraction of kg-N contributed to Watershed and Bay deposition by state

State	Bay Watershed	Tidal Bay		Bay Watershed	Tidal Bay
	fraction	fraction		kg-N Dep	kg-N Dep
PA	0.191	0.124		12,717,344	482,323
VA	0.181	0.224		12,054,985	872,118
MD	0.105	0.122		6,959,515	476,543
NY	0.068	0.053		4,510,744	204,509
WV	0.061	0.038		4,071,651	148,115
Total N Deposition (kg-N)				66,469,574	3,895,624

State Sector

Fraction of kg-N contributed to tributary deposition by state sector

Pennsylvania

PA	Potomac AFL	SusquehannaAFL	James AFL		Potomac AFL	Susquehanna AFL	James AFL
Sector	fraction	fraction	fraction		kg-N Dep	kg-N Dep	kg-N Dep
Mobile	0.028	0.048	0.015		295,400.2	1,383,738.2	107,534.9
EGU's	0.036	0.052	0.020		374,779.4	1,506,042.4	143,851.4
Industry	0.034	0.059	0.018		350,391.5	1,693,951.4	131,531.9
Area	0.022	0.037	0.012		226,921.8	1,062,881.6	88,536.2
OffRoad	0.019	0.027	0.014		200,353.7	773,884.2	101,885.7
Total Tributary N Deposition (kg-N)					10,460,193	28,980,303	7,204,204

EGU's = Electric Generating Units = Power Plants AFL = Above the Fall Line

EPA United States Environmental Protection Agency

State Sector

Fraction of kg-N contributed to tributary deposition by state sector

Virginia

VA	Potomac AFL	SusquehannaAFL	James AFL		Potomac AFL	Susquehanna AFL	James AFL
Sector	fraction	fraction	fraction		kg-N Dep	kg-N Dep	kg-N Dep
Mobile	0.049	0.018	0.072		515,887.9	508,008.3	516,367.3
EGU's	0.019	0.011	0.048		193,958.9	319,902.7	346,551.0
Industry	0.029	0.013	0.071		302,044.8	381,486.3	510,755.1
Area	0.047	0.016	0.071		487,630.3	475,105.8	507,732.0
OffRoad	0.026	0.010	0.030		273,818.9	278,885.4	218,050.4
Total Tributary N Deposition (kg-N)					10,460,193	28,980,303	7,204,204

EGU's = Electric Generating Units = Power Plants

AFL = Above the Fall Line

United States Environmental Protection Agency

State Sector

Fraction of kg-N contributed to tributary deposition by state sector

Maryland

MD	Potomac AFL	SusquehannaAFL	James AFL		Potomac AFL	Susquehanna AFL	James AFL
Sector	fraction	fraction	fraction		kg-N Dep	kg-N Dep	kg-N Dep
Mobile	0.027	0.016	0.013		284,977.6	458,184.5	93,867.4
EGU's	0.021	0.013	0.013		213,949.8	363,493.6	92,316.1
Industry	0.022	0.011	0.009		231,349.6	317,093.2	62,260.7
Area	0.022	0.014	0.010		228,270.8	392,020.4	75,143.7
OffRoad	0.017	0.010	0.012		181,268.3	290,786.9	87,631.5
Total Tributary N Deposition (kg-N)					10,460,193	28,980,303	7,204,204

EGU's = Electric Generating Units = Power Plants

AFL = Above the Fall Line

State Sector

Fraction of kg-N contributed to tributary deposition by state sector

New York

NY	Potomac AFL	SusquehannaAFL	James AFL		Potomac AFL	Susquehanna AFL	James AFL
Sector	fraction	fraction	fraction		kg-N Dep	kg-N Dep	kg-N Dep
Mobile	0.008	0.021	0.006		87,635.3	592,912.0	44,898.3
EGU's	0.005	0.012	0.003		46,866.2	343,671.7	22,086.4
Industry	0.005	0.011	0.003		48,158.9	307,149.6	23,864.9
Area	0.011	0.025	0.008		118,869.2	708,914.5	58,646.1
OffRoad	0.010	0.015	0.008		101,058.1	434,429.7	55,138.2
Total Tributary N Deposition (kg-N)					10,460,193	28,980,303	7,204,204

EGU's = Electric Generating Units = Power Plants   AFL = Above the Fall Line

State Sector

Fraction of kg-N contributed to Watershed and Bay deposition by state sector

Pennsylvania

PA	Bay Watershed	Tidal Bay		Bay Watershed	Tidal Bay
Sector	fraction	fraction		kg-N Dep	kg-N Dep
Mobile	0.033	0.020		2,192,557.2	79,308.3
EGU's	0.038	0.022		2,503,433.2	86,774.9
Industry	0.041	0.025		2,700,287.9	98,621.0
Area	0.026	0.018		1,725,169.5	70,722.8
Off Road	0.021	0.015		1,376,781.7	57,181.5
Total N Deposition (kg-N)				66,469,574	3,895,624

EGU's = Electric Generating Units = Power Plants

State Sector

Fraction of kg-N contributed to Watershed and Bay deposition by state sector

Virginia

VA	Bay Watershed	Tidal Bay		Bay Watershed	Tidal Bay
Sector	fraction	fraction		kg-N Dep	kg-N Dep
Mobile	0.039	0.041		2,616,512.7	159,603.9
EGU's	0.023	0.034		1,538,412.9	131,589.0
Industry	0.032	0.040		2,111,705.2	157,564.5
Area	0.037	0.042		2,437,336.8	162,196.5
Off Road	0.020	0.024		1,317,063.5	93,794.3
Total N Deposition (kg-N)				66,469,574	3,895,624

EGU's = Electric Generating Units = Power Plants

State Sector

Fraction of kg-N contributed to Watershed and Bay deposition by state sector

Maryland

MD	Bay Watershed	Tidal Bay		Bay Watershed	Tidal Bay
Sector	fraction	fraction		kg-N Dep	kg-N Dep
Mobile	0.022	0.025		1,450,266.0	96,133.1
EGU's	0.017	0.021		1,114,444.6	80,985.3
Industry	0.014	0.013		913,109.6	51,227.0
Area	0.018	0.021		1,184,365.3	80,275.8
Off Road	0.015	0.020		999,284.2	76,491.8
Total N Deposition (kg-N)				66,469,574	3,895,624

EGU's = Electric Generating Units = Power Plants

State Sector

Fraction of kg-N contributed to Watershed and Bay deposition by state sector

New York

NY	Bay Watershed	Tidal Bay		Bay Watershed	Tidal Bay
Sector	fraction	fraction		kg-N Dep	kg-N Dep
Mobile	0.014	0.010		904,979.3	39,151.5
EGU's	0.008	0.005		501,849.8	19,251.4
Industry	0.007	0.005		471,299.3	20,241.4
Area	0.017	0.015		1,141,701.2	57,287.6
Off Road	0.012	0.010		780,929.4	39,170.1
Total N Deposition (kg-N)				66,469,574	3,895,624

EGU's = Electric Generating Units = Power Plants

United States Environmental Protection Agency

Divide by emissions to create a deposition transfer function by state and sector which is then multiplied by a load transfer function from the watershed model

Pennsylvania

PA	Potomac AFL	SusquehannaAFL	James AFL	Tidal Bay		State-Sector Emissions
Sector	Xfer Fn*	Xfer Fn*	Xfer Fn*	Xfer Fn*		tons-N
Mobile	16.65	77.99	6.06	4.47		17,742.0
EGU's	17.69	71.09	6.79	4.10		21,183.9
Industry	15.54	75.11	5.83	4.37		22,552.1
Area	14.03	65.73	5.48	4.37		16,170.5
Off Road	21.38	82.56	10.87	6.10		9,373.2
*Xfer Fn = kg-N deposition/tons-N emissions						

Divide by emissions to create a deposition transfer function by state and sector which is then multiplied by a load transfer function from the watershed model

United States Environmental Protection Agency

Virginia

VA	Potomac AFL	Susquehanna AFL	James AFL	Tidal Bay		State-Sector Emissions
Sector	Xfer Fn*	Xfer Fn*	Xfer Fn*	Xfer Fn*		tons-N
Mobile	31.65	31.17	31.68	9.79		16,299.4
EGU's	16.04	26.45	28.65	10.88		12,094.5
Industry	21.46	27.11	36.30	11.20		14,071.9
Area	30.05	29.27	31.28	9.99		16,229.5
Off Road	42.94	43.73	34.19	14.71		6,377.5
*Xfer Fn = kg-N deposition/tons-N emissions						

Divide by emissions to create a deposition transfer function by state and sector which is then multiplied by a load transfer function from the watershed model

Maryland

MD	Potomac AFL	Susquehanna AFL	James AFL	Tidal Bay		State-Sector Emissions
Sector	Xfer Fn*	Xfer Fn*	Xfer Fn*	Xfer Fn*		tons-N
Mobile	36.24	58.27	11.94	12.23		7,862.6
EGU's	31.02	52.70	13.38	11.74		6,897.7
Industry	42.64	58.44	11.48	9.44		5,425.8
Area	34.76	59.70	11.44	12.22		6,566.5
Off Road	40.69	65.28	19.67	17.17		4,454.6
*Xfer Fn = kg-N deposition/tons-N emissions						

Divide by emissions to create a deposition transfer function by state and sector which is then multiplied by a load transfer function from the watershed model

New York

NY	Potomac AFL	Susquehanna AFL	James AFL	Tidal Bay		State-Sector Emissions
Sector	Xfer Fn*	Xfer Fn*	Xfer Fn*	Xfer Fn*		tons-N
Mobile	4.63	31.35	2.37	2.07		18,910.0
EGU's	4.56	33.46	2.15	1.87		10,272.1
Industry	4.93	31.43	2.44	2.07		9,771.3
Area	4.45	26.52	2.19	2.14		26,730.0
Off Road	7.42	31.89	4.05	2.87		13,624.5
*Xfer Fn = kg-N deposition/tons-N emissions						

For Perspective: What impact would Pennsylvania Diesel Rule NO_X emission reductions have?

Estimated reduction: 736 tons NO_X = 224.1 tons-N (0.3045 conversion)

Impact of PA State-wide Diesel Rule NO_X Emission Reduction					
	PA Mobile Xfer Fn	ΔKg-N Deposition (x 224.1)	% Trib. Deposition	Δkg-N load Delivered (x0.1107)	Δlb-N load Delivered (x 2.2)
Potomac AFL	16.65	3,731	0.036%	413	909
Susquehanna AFL	77.99	17,478	0.060%	1,935	4,257
James AFL	6.06	1,358	0.019%	150	331
Tidal Bay	4.47	1,002	0.026%	111	244

Summary

- There is not a simple relationship between air emission reductions and reductions of deposition to different tributaries because the deposition comes from many sources and only a fraction comes from emissions from within (each of) the Bay states
- A sophisticated air quality model can be used to create realistic, simplified equations approximating the complex relationship of an incremental emissions change in a state (or specified geographic region) to an incremental deposition change in designated tributaries
- These simplified equations can be used in the TMDL process to facilitate air-water trading and open up the possibility to take credit for additional air reductions required to meet human health standards and enhance efficiency and cost-effectiveness of the TMDL process
- The same approach taken here for NO_X can be taken for ammonia if so desired