# Influence of Volkswagen Settlement Agreements on Chesapeake Water Quality

August 20, 2018

## Background

The U.S. Environmental Protection Agency (EPA) and California Air Resource Board (CARB) filed a complaint against the Volkswagen Corporation and its subsidiaries (VW) that alleged that VW violated the Clean Air Act (CAA) by selling motor vehicles with emissions defeat devices that would contribute to more vehicle air pollutant emissions of nitrogen oxides (NOx) than allowed under the Act. Atmospheric NOx is harmful to human health because it is a precursor to ground level ozone and to fine particulate matter ($PM_{2.5}$), both damaging to the lung.

The emissions defeat devices involved about 590,000 motor vehicles containing 2.0 and 3.0 liter diesel engines in model years 2009 to 2016. Through three partial settlements, agreements were reached between the U.S. Justice Department and VW. Volkswagen agreed to pay $16.35 billion to settle allegations of emissions standard cheating. The settlement is divided into four separate parts:

- $10 billion will be used to buy back or modify offending diesel vehicles from consumers.
- $2 billion will be on zero emission vehicles (ZEV) infrastructure and programs and brand neutral media activities aimed at increasing public awareness of zero emission vehicles. The amount will be divided between California ($800 million) and the rest of the U.S. ($1.2 billion).
- $1.45 billion civil penalty for the alleged civil violations of the CAA and conjunctive relief to prevent future violations.
- $2.9 billion will be used to establish an Environmental Mitigation Trust (Trust), which states and territories may use to invest in eligible transportation projects to reduce NOx emissions.

To mitigate the impact of the higher emissions and for violating the CAA, the settlement requires VW to invest $2.9 billion in an Environmental Mitigation Trust (Trust) to fund eligible mitigation actions. All of the States, including the Chesapeake Bay Program (CBP) partnership States and the District of Columbia (DC), have been allocated a portion of the trust based on the number of violating vehicles in their jurisdiction and must file as "beneficiaries" to receive their allocations. Such filings cannot occur until the Trust agreement is finalized by the court. All requests for funding made by beneficiaries must be approved by a court appointed Trustee. Trust funds can only be spent on 10 categories of eligible mitigation projects defined in the final settlement agreements.

Governmental and nongovernmental entities are eligible to apply for Trust funds. Beneficiaries, including the CBP partnership States and DC, are required to develop a "beneficiary mitigation plan" that provides a high-level summary of how they intend to spend their allocated funds.

Beneficiaries are required to submit a mitigation plan 30 days in advance of submitting a funding request to the Trustee.

Eligible mitigation actions include projects to reduce NOx from heavy duty diesel sources near population centers, such as large trucks that make deliveries and service ports, school and transit buses, and freight switching railroad locomotives. Thus, for example, eligible mitigation actions could include replacing or repowering older engines for newer engines at a rail switchyard, or could include replacing older city transit buses with new electric-powered transit city buses. Eligible mitigation actions may also include, in a more limited capacity, charging infrastructure for light duty zero emission passenger vehicles. Beneficiaries have the flexibility to choose which projects on the list of eligible mitigation actions are the best options for their citizens. (https://www.epa.gov/enforcement/volkswagen-clean-air-act-civil-settlement#partners)

## An Example: Virginia's Approach to the Volkswagen Settlement with Consideration to Nitrogen Loads to the Chesapeake Bay

The CBP partners are just beginning to determine how the Trust funds could be implemented in their states, but Virginia has been forward-leaning in this work. Approximately16,000 offending 2.0 liter and 3.0 liter VW vehicles are in Virginia.

Virginia's Trust allocation is ~$93.6 million, and the State Trust Agreement was approved by the court on Oct. 2, 2017. Virginia was approved by the Trustee of the Environmental Mitigation Trust as a Beneficiary on January 28, 2018. The Department of Environmental Quality (DEQ) is the lead agency and will administer these funds through a state mitigation plan. A working group has been formed to develop a proposed state mitigation plan for Virginia. Beneficiaries have up to 10 years post Trust Effective Date to spend 85% their allocations.

The working group, led by DEQ, developed the proposed state mitigation plan for Virginia using a data-driven approach to target high emission sectors. The primary goal of the proposed state mitigation plan is to implement eligible mitigation projects that will achieve the greatest NOx emissions reductions and expedite the deployment and widespread adoption of zero emission vehicles. An ancillary goal is to reduce nitrogen loads to the Chesapeake Bay in support of Virginia's Chesapeake Bay Watershed Implementation Plan (WIP). The proposed DEQ mitigation plan is available at: http://deq.state.va.us/Programs/Air/VWMitigation.aspx. The mitigation plan has not been finalized, and DEQ continues to receive comments on the proposed plan.

The mitigation projects being considered by DEQ include:

- Medium and heavy duty trucks*
- School, shuttle, and transit buses*
- Locomotive freight switch engines*
- Ferries/tugs*
- Forklifts and port cargo handling equipment*
- Airport ground support equipment*

- Marine shore power systems (provides electric auxiliary power from shore while a ship is docked to allow a vessel's engines to turn off and remain off while vessels are docked)
- Up to 15 percent of funding for light duty zero emissions vehicle supply equipment:
    - Electric vehicle charging equipment (e.g. Level 1, Level 2, and DC fast chargers)
    - Fuel cell vehicle supply equipment

*Repower or replacement with new diesel, alternative fuel or all- electric option + charging infrastructure (Funds cannot be used for fossil fuel/alternative fuel infrastructure.)

## Methods

The CBP airshed model is a combination of a regression model of wet deposition (Grimm and Lynch, 2000; 2005; Grimm, 2016) and a continental-scale Community Multiscale Air Quality (CMAQ) Model application for estimates of dry deposition, with North America as the model domain (Dennis et al. 2007; Hameedi et al. 2007). The regression and deterministic airshed models that provide atmospheric deposition input estimates have gone through a series of refinements, with increasingly sophisticated models of both applied over time (Linker et al. 2000; 2013; Grimm and Lynch, 2000; 2005; Lynch and Grimm, 2003; Grimm, 2017).

The Phase 6 Model has atmospheric deposition of nitrogen as one of the major nitrogen land use inputs in the watershed and also as a direct load to the tidal Bay. In the case of estimated NOx reductions brought about by the VW Settlement, or other management practices that can change the estimated emissions to the atmosphere of NOx or ammonia, it is necessary to estimate the effect that this change in emissions has on deposition loads to the watershed and tidal Bay. The CBP Modeling Workgroup determined on September 22, 2016 that the following analysis applies to all tracked actions that change nitrogen emissions (Modeling Workgroup Minutes September 22, 2016).

The nitrogen load reduction to the tidal Bay from reduced NOx emissions is relatively small because of loss mechanisms in the atmosphere, on land, and in Chesapeake watershed streams and rivers. As an example of the loss mechanisms, only about 50 percent of the NOx emitted in in the Chesapeake watershed falls back to the Chesapeake watershed, with the remainder transported by winds beyond the Chesapeake watershed boarders. Of the 50 percent of the nitrogen load that is deposited throughout the Chesapeake watershed, about 90 percent is taken up by plants and soil or is denitrified. After transport from the land to streams and rivers, about another 25 percent is lost through riverine denitrification and other mechanisms. Therefore, the total nitrogen contribution to tidal waters is a few percent of the original NOx reductions. For example, for 100 lbs NOx as nitrogen (N) reduced, about 4 pounds of total N is removed from contributions to the tidal Bay.

When translating reductions in NOx emissions to nitrogen loads to the Bay, a careful consideration of the stoichiometry of the units used must be applied. In water programs the nitrogen mass is always measured "as N". That is, only the nitrogen elemental mass is counted in the different nitrogen nutrient species such as nitrate, ammonia, or organic nitrogen. The methodology considers the many transformations that fixed reactive nitrogen undergoes in watersheds, rivers, and estuaries. In contrast, air programs typically measure NOx as a molecular mass, (counting all elements of nitrogen and oxygen in their correct ratios). Therefore, the correct stoichiometric adjustments need to be made when translating mass measures of nitrogen between air and water programs. The tables and equations below assume all nitrogen mass is "as N".

In addition, the location of the NOx emissions and deposition matters. Emissions that are on the eastern side of the watershed and airshed have relatively more atmospheric transport out of the Chesapeake watershed because of the prevailing westerly winds and therefore, have less impact on Chesapeake water quality. Figure 1 shows estimated airsheds for oxidized and reduced nitrogen emissions. Reduced nitrogen emissions, such as ammonia volatilized from animal manures, have relatively less atmospheric transport than NOx emissions. Also nitrogen deposition in the upper Bay regions such as the Susquehanna watershed have a relatively higher influence on water quality than deposition of nitrogen in the lower Bay.

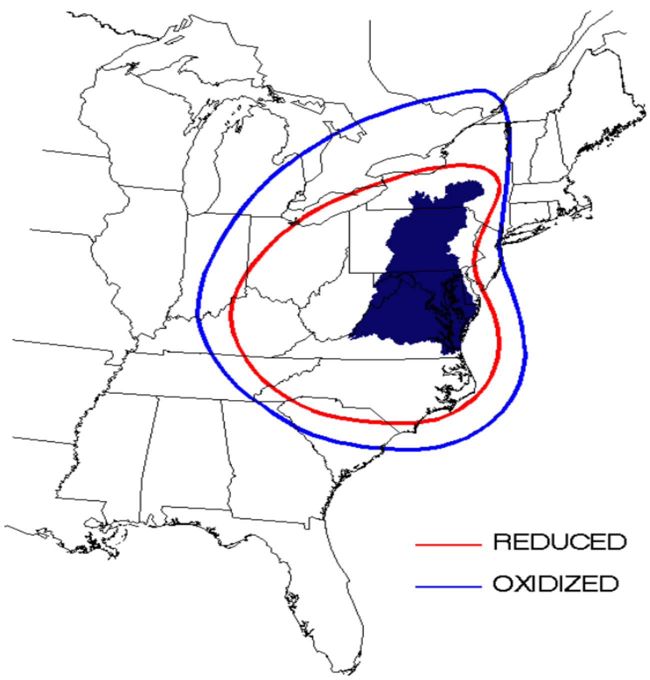


***Figure 1: Estimated oxidized N (NOx) and reduced (ammonia) airsheds.***

**Credit for emission reductions are attributed directly to the state that implemented the management practice**

The CBP considered two approaches to translating nitrogen emissions to estimated delivery of nitrogen to the tidal Bay. Changes in atmospheric emissions from a single point result in a change in deposition to the entire watershed, and far beyond the Chesapeake watershed boundaries. In this approach the NOx or ammonia emission reduction would result in a change in deposition in each land use, in each land-river segment, and in the entire Chesapeake watershed by an infinitesimal amount. Therefore, the estimated delivered nitrogen load to the tidal Bay for the emission reduction would be the multitude of small deposition changes on land uses and in State-basins throughout the Chesapeake watershed.

As an example, consider manure treatment technologies, which are Best Management Practices (BMPs) that restrict ammonia emissions. If credit for ammonia emission reductions due to a particular manure treatment BMP were to accrue to individual land uses throughout the watershed, a typical acre would get about a millionth of a pound reduction for a typical manure treatment BMP reducing ammonia emissions, and the benefit from the manure treatment BMP emission reduction would accrue to all Chesapeake watershed State-basins. In addition, the BMP ammonia emission reduction would also cause a change in deposition to the surface of the tidal waters that would be uncounted in any State-basin. Therefore, to counter the management and computational difficulties with that approach, the CBP Modeling Workgroup (Modeling Workgroup Minutes August 9, 2016) recommended that the credit for the estimated nitrogen load reduction for both tidal deposition and watershed deposition, with subsequent delivery to tidal waters, be attributed directly to the State that implemented the emission reduction BMP.

As previously discussed, credit for nitrogen loads to the Bay from emission reduction BMPs are expected to be low in terms of absolute pounds reduced because of the low ratio of emission loads in the atmosphere that eventually reach the Bay. The Modeling Workgroup had insufficient resources to support a full series of atmospheric model runs for detailed spatial resolution so approximate methods, based on available data, were used to develop tidal Bay nitrogen load reductions related to air source reductions at the spatial level of the State.

### Oxidized (NOx) nitrogen ratio of emission to deposition

The CMAQ tool estimates the attribution of reduced NOx or ammonia atmospheric emissions to the tidal Bay nitrogen load by any Chesapeake watershed State. Responding to a CBP request, Robin Dennis made a presentation of CMAQ results to the Modeling Workgroup on January 8, 2013 (Modeling Workgroup Minutes January 8, 2013) giving relationships between oxidized nitrogen emissions by State and nitrogen deposition to each watershed State. Table 1 gives values for the kilograms of nitrogen deposited within the Chesapeake Bay watershed area of each state per U.S. short ton of oxidized nitrogen (as N) emitted in each state. Oxidized nitrogen in CMAQ corresponds to nitrate or $NO_3$ in the Phase 6 Model. These values are converted to percent in Table 2 (by converting into the same units for deposition (kilograms) and emissions (U.S. short ton) and calculating the percentage). Watershed position matters; note that states near the center of the watershed, such as Maryland, Pennsylvania, and Virginia have a return rate to the watershed of between 10 percent and 20 percent of what it emitted. States on the extremes of the watershed (New York, Delaware, and West Virginia) have between 5 percent and 10 percent return to the watershed.

***Table 1: State transfer coefficients for oxidized nitrogen to state watershed area (mixed units of kg N deposited per U.S. short ton N emitted)***

| | Emitter | | | | | |
|---|---|---|---|---|---|---|
| Receptor | DE | MD | NY | PA | VA | WV |
| DE | 5.4 | 2.31 | 0.44 | 0.87 | 1.1 | 0.44 |
| MD | 19.46 | 57.16 | 5.3 | 14.33 | 20.95 | 10.6 |
| NY | 5.31 | 7.25 | 11.5 | 10.47 | 4.76 | 4.73 |
| PA | 23.86 | 49.09 | 16.37 | 62.28 | 24.79 | 28.11 |
| VA | 19.55 | 43.34 | 7.84 | 20.59 | 85.05 | 27.7 |
| WV | 1.88 | 6.04 | 1.03 | 3.73 | 5.5 | 9.88 |
| Total | 75.46 | 165.19 | 42.48 | 112.27 | 142.15 | 81.46 |

***Table 2: State transfer coefficients for oxidized nitrogen to state watershed area (percent)***

| | Emitter | | | | | |
|---|---|---|---|---|---|---|
| Receptor | DE | MD | NY | PA | VA | WV |
| DE | 0.60% | 0.25% | 0.05% | 0.10% | 0.12% | 0.05% |
| MD | 2.15% | 6.30% | 0.58% | 1.58% | 2.31% | 1.17% |
| NY | 0.59% | 0.80% | 1.27% | 1.15% | 0.52% | 0.52% |
| PA | 2.63% | 5.41% | 1.80% | 6.87% | 2.73% | 3.10% |
| VA | 2.16% | 4.78% | 0.86% | 2.27% | 9.38% | 3.05% |
| WV | 0.21% | 0.67% | 0.11% | 0.41% | 0.61% | 1.09% |
| total | 8.32% | 18.21% | 4.68% | 12.38% | 15.67% | 8.98% |

## Reduced nitrogen (ammonia) ratio of emission to deposition

Table 1 was provided for oxidized nitrogen but was unavailable for reduced nitrogen, i.e., ammonia emissions, often from animal manures. To translate Table 1 to reduced nitrogen, more information on the transport of atmospheric nitrogen is needed. Dennis (1997) introduced the calculation of an airshed and made calculations of the percent of deposition that originated from emissions within the watershed. Paerl et al. (2002) extended the analysis to oxidized and reduced nitrogen. The values were updated in Dennis et al. (2010) and again in an analysis transmitted to the CBP on April 3, 2011. The 2011 analysis found that 50 percent of the oxidized nitrogen deposited in the Chesapeake Bay watershed and 75 percent of the reduced nitrogen deposited in the Chesapeake Bay watershed originated within the Chesapeake Bay watershed. These values can be used to translate the values in Table 2 to reduced nitrogen in Table 3 through the method graphically illustrated in Figure 2.

Definition of Figure 2variables:

$E_{NO}$ = Chesapeake Bay watershed emissions of *oxidized* nitrogen.

$E_{NH}$ = Chesapeake Bay watershed emissions of *reduced* nitrogen.

$F_{NO}$ = Fraction of *oxidized* nitrogen emitted in the watershed that returns to the watershed. These are estimated values presented in Table 2.

$F_{NH}$ = Fraction of *reduced* nitrogen emitted in the watershed that returns to the watershed. These are the unknown values that must be estimated to credit practices such as manure treatment technologies.

IO ratio = Ratio of nitrogen leaving watershed to nitrogen entering watershed. Assumed the same ratio for oxidized and reduced nitrogen.

The relationship of these variables is represented in Figure 2. The amount of oxidized nitrogen emitted in the watershed that is deposited in the watershed is equal to $E_{NO}F_{NO}$. If 50 percent of the oxidized nitrogen that is deposited in the watershed is from outside the watershed, then the amount of deposited oxidized nitrogen that arrives from outside the watershed must also be equal to $E_{NO}F_{NO}$. The amount of oxidized nitrogen emitted in the watershed that leaves the watershed is $E_{NO}(1-F_{NO})$.

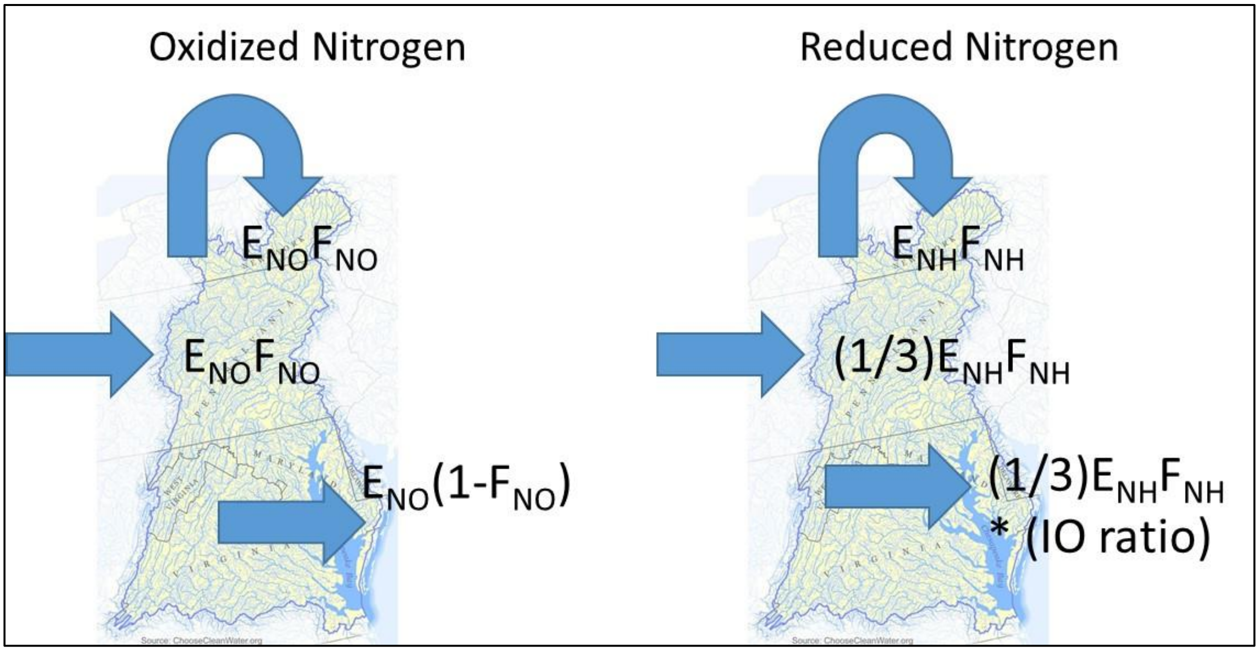


***Figure 2: Definition of atmospheric deposition variables.***

For reduced nitrogen, 75 percent of deposited nitrogen originates within the watershed, so if the amount of reduced nitrogen that is both emitted and deposited in the watershed is $E_{NH}F_{NH}$, then the amount that originates outside of the watershed is $(1/3)E_{NH}F_{NH}$. There is an assumed constant ratio of nitrogen leaving the watershed to nitrogen entering the watershed so the amount of reduced nitrogen leaving the watershed is (1/3)$E_{NH}F_{NH}R$. R for oxidized nitrogen is equal to $E_{NO}(1-F_{NO})/E_{NO}F_{NO}$.

The fraction of emitted reduced nitrogen that is deposited in the watershed can now be expressed as a function of $F_{NH}$ which is available in Table 2.

***Equation 1: Fraction of emitted reduced nitrogen that is returned to the watershed***

$$F_{NH} = E_{NH}F_{NH} / (E_{NH}F_{NH} + (1/3)E_{NH}F_{NH} * (E_{NO}(1-F_{NO})/E_{NO}F_{NO})$$

Equation 1 can be simplified to Equation 2.

***Equation 2: Simplified version of reduced nitrogen fraction***

$$F_{NH} = 3 / (2 + 1/F_{NO})$$

Applying Equation 2 to Table 2 results in the values in Table 3.

***Table 3: State transfer coefficients for reduced nitrogen to state watershed area (percent)***

| | Emitter | | | | | |
|---|---|---|---|---|---|---|
| Receptor | DE | MD | NY | PA | VA | WV |
| DE | 1.76% | 0.76% | 0.15% | 0.29% | 0.36% | 0.15% |
| MD | 6.17% | 16.79% | 1.73% | 4.59% | 6.62% | 3.43% |
| NY | 1.74% | 2.36% | 3.71% | 3.38% | 1.56% | 1.55% |
| PA | 7.50% | 14.65% | 5.22% | 18.11% | 7.77% | 8.75% |
| VA | 6.20% | 13.08% | 2.55% | 6.51% | 23.68% | 8.63% |
| WV | 0.62% | 1.97% | 0.34% | 1.22% | 1.80% | 3.20% |
| Total | 23.98% | 49.61% | 13.70% | 34.11% | 41.80% | 25.70% |

## Total delivered to tidal waters from watershed and direct deposition

To arrive at the total emission reduction in delivered load to the tidal Bay, the direct deposition to the tidal Chesapeake must be added to the watershed load, and the deposition to the watershed must be attenuated to account for terrestrial and non-tidal aquatic processing.

## Estimated direct deposition to tidal waters

The area of the tidal Chesapeake is 4,470 square miles. The area of the surrounding states of Maryland, Delaware, and Virginia within the Chesapeake Watershed is 31,362 square miles. The area of the Bay is 14.3 percent of the surrounding watershed area and so it is estimated to receive 14.3 percent of the combined deposition of the three receptor states (Maryland, Delaware, and Virginia) from each emitter state. The estimated direct deposition load to tidal waters is derived for any emitter state from the sum of the receptor states of Maryland, Delaware, and Virginia in Tables 2 and 3, and using the 100 percent delivery factor for "Bay" in Table 4 and the factor of 14.3 percent as described above to generate the "Bay" receptor percentages in Tables 5 and 6.

## Estimated terrestrial, stream, and riverine attenuation

The Beta 3 Draft Phase 6 CAST Watershed Model was run to estimate the percent of deposited nitrogen that reaches the Bay. The WIP scenario was run with the TMDL allocation atmospheric deposition and also with the current atmospheric deposition. The change in load was recorded in Table 4 as a percentage relative to the change in input.

*Table 4: Percent of **deposited** atmospheric nitrogen that reaches tidal water*

| Receptor | Delivered |
|---|---|
| DE | 11.84% |
| MD | 15.48% |
| NY | 8.06% |
| PA | 19.28% |
| VA | 7.33% |
| WV | 6.91% |
| Bay | 100.00% |

Multiplying the delivery values in Table 4 by the fraction deposited in Table 2 and Table 3 gives the results in Table 5 and Table 6, which are summarized in Table 7.

***Table 5: Percentage of emitted oxidized nitrogen that reaches tidal waters***

| | Emitter | | | | | |
|---|---|---|---|---|---|---|
| Receptor | DE | MD | NY | PA | VA | WV |
| DE | 0.07% | 0.03% | 0.01% | 0.01% | 0.01% | 0.01% |
| MD | 0.33% | 0.98% | 0.09% | 0.24% | 0.36% | 0.18% |
| NY | 0.05% | 0.06% | 0.10% | 0.09% | 0.04% | 0.04% |
| PA | 0.51% | 1.04% | 0.35% | 1.32% | 0.53% | 0.60% |
| VA | 0.16% | 0.35% | 0.06% | 0.17% | 0.69% | 0.22% |
| WV | 0.01% | 0.05% | 0.01% | 0.03% | 0.04% | 0.08% |
| Bay | 0.70% | 1.62% | 0.21% | 0.56% | 1.69% | 0.61% |
| Total | 1.83% | 4.13% | 0.83% | 2.43% | 3.36% | 1.74% |

***Table 6: Percentage of reduced nitrogen that reaches tidal waters***

| | Emitter | | | | | |
|---|---|---|---|---|---|---|
| Receptor | DE | MD | NY | PA | VA | WV |
| DE | 0.21% | 0.09% | 0.02% | 0.03% | 0.04% | 0.02% |
| MD | 0.96% | 2.60% | 0.27% | 0.71% | 1.03% | 0.53% |
| NY | 0.14% | 0.19% | 0.30% | 0.27% | 0.13% | 0.12% |
| PA | 1.45% | 2.82% | 1.01% | 3.49% | 1.50% | 1.69% |
| VA | 0.45% | 0.96% | 0.19% | 0.48% | 1.74% | 0.63% |

| | | | | | | |
|---|---|---|---|---|---|---|
| WV | 0.04% | 0.14% | 0.02% | 0.08% | 0.12% | 0.22% |
| Bay | 2.02% | 4.37% | 0.63% | 1.63% | 4.38% | 1.74% |
| Total | 5.27% | 11.17% | 2.43% | 6.70% | 8.93% | 4.96% |

***Table 7: Percentage of emitted oxidized and reduced nitrogen that reaches the tidal waters***

| | Emitter | | | | | |
|---|---|---|---|---|---|---|
| | DE | MD | NY | PA | VA | WV |
| Reduced | 5.27% | 11.17% | 2.43% | 6.70% | 8.93% | 4.96% |
| Oxidized | 1.83% | 4.13% | 0.83% | 2.43% | 3.36% | 1.74% |

As a generalized equation summarizing the tables above for oxidized nitrogen for any emitter state, the estimated loads from the receptor watershed states would be summed in Table 5 and then added to the estimated direct load to the tidal Bay from the emitter state as follows:

**Oxidized N load to tidal Bay from emitter state = (Σ Table 5 Receptor State) + loads direct to tidal Bay**

In the case of oxidized emissions from Virginia:

**Oxidized N load to tidal Bay from emitter state = 1.67% + 1.69% (From Table 5) = 3.36%**

Alternately, the summary table of Table 7 can be used, which estimates that for oxidized N emissions from Virginia 3.36% are loaded to the Bay from the entire watershed and direct deposition to tidal water.

## Conclusions

The CBP has established protocols to effectively translate reductions of oxidized (NOx) or reduced (ammonia) emissions from air sources throughout the Chesapeake watershed to estimated nitrogen loads delivered to the tidal Bay at the state level. At the present time, data is unavailable to estimate impacts on the Bay from air emission reductions by locality. The established protocols and methods can therefore be readily adapted to any NOx reductions anticipated from the VM settlement at the state level.