Eastern Shore Ammonia Air Monitoring Project

March 13, 2023

The Environmental Integrity Project (EIP) and Assateague Coastal Trust (ACT) monitored gaseous ammonia levels at residential properties near large poultry operations in Somerset and Worcester Counties using passive samplers. Samples measured two-week average concentrations from June 2020 through June 2022 within 72-122 meters (236-400 feet) of active, large poultry operations, with a density of 36 chicken houses (and 1.26 million chickens) within a one-mile radius. This white paper summarizes methods, findings, and recommendations based on the outcome of the community monitoring project.

Ammonia emissions impact the environment and environmental and public health impacts. When released into the surrounding atmosphere, ammonia deposits into soil or natural waters and can contribute to both groundwater contamination and the degradation of surface water quality. When inhaled by people (or animals, including chickens), it quickly absorbs into the upper respiratory tract, and at high concentrations can cause irritation in the throat and lungs, increasing the risk of respiratory diseases.[1] Continued exposure to ammonia can reduce people's ability to smell the pollutant.

In December 2022, the Delmarva Land and Litter Collaborative issued a white paper[2] that characterized ammonia levels measured at several Maryland Department of Environment (MDE) monitoring sites on the Lower Eastern Shore using continuous monitors. These sites aimed to measure ambient, regional levels of ammonia, not levels near poultry houses that could pose health risks to people living in close proximity. The sampler that MDE sited to measure ammonia levels in an area with a high density of poultry houses was located 539 meters (1,770 feet) from the nearest poultry house, with a density of 30 poultry houses (and 793,000 chickens) within a one-mile radius. This community air monitoring project, by contrast, aimed to monitor ammonia levels much closer to large, active poultry operations, and in an area where many more chickens are raised.

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[1] The Maryland Department of Environment has adopted a 1-hour risk screening level of 350 ppb and an 8-hour risk screening level of 250 ppb.

[2] Delmarva Land and Litter Collaborative, "Ammonia Emissions from Poultry Production", 2022, Link: https://delmarvalandandlitter.net/wp-content/uploads/2022/12/Updated-ammonia-paper-high-res-1.pdf

Key Findings:

1. At least 174 poultry operations on Maryland's Eastern Shore are located within 122 m (400 ft) of a neighboring residence. Community monitoring data indicate that residents living within 122 m (400 ft) of poultry houses are exposed to higher levels of gaseous ammonia than residents living farther away.

2. Two-week average concentrations measured at a monitoring site located within 72 m (236 ft) of a poultry operation, in an area with the highest number of chickens per square mile in the state, ranged from 6-487 parts per billion (ppb) between June 2020 and June 2022, with an average concentration of 60.5 ppb over the two-year monitoring period.

3. Monitoring data from a site located 122 m (400 ft) from a poultry operation detected similar two-week average concentrations, ranging from 4.3-149.6 ppb between December 2020 and June 2022.

4. Ammonia levels at these two sites likely exceeded MDE's one-hour risk screening level (350 ppb) multiple times. Over a two-year period, the highest hourly concentrations measured at MDE's Pocomoke City monitoring site were, on average, 6.9 times greater than the two-week average. Assuming that hourly concentrations at the sites monitored by EIP and ACT followed a similar pattern, one or more hourly concentrations during 21 two-week monitoring periods likely exceeded MDE's one hour risk screening threshold.

5. Monitoring data from a site located 122 m (400 ft) from a poultry operation with a newly planted voluntary vegetative buffer, and data collected three years later at the same location, showed that the buffer is not yet making a measurable difference in average ammonia concentrations.

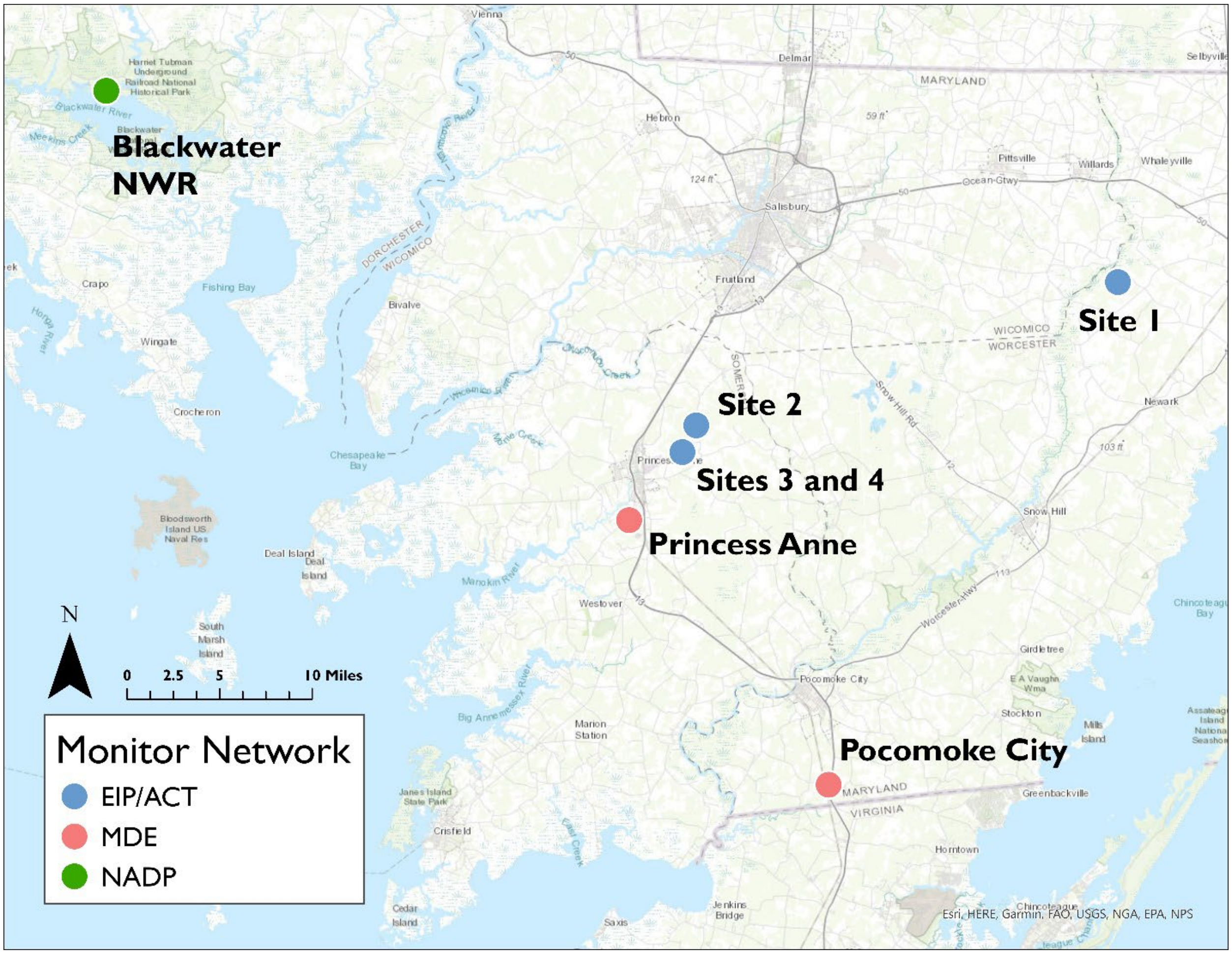
Recommendations:

1. High-resolution ammonia monitoring is needed to characterize impacts on fenceline communities. While low-cost passive samplers with a two-week averaging time are adequate for determining average concentrations far from poultry operations, continuous (hourly) monitoring is needed to evaluate whether concentrations in fenceline communities close to poultry operations exceed existing health- or risk-based thresholds.

2. Fenceline air monitoring should be required whenever a large poultry operation is located within 122 m (400 ft) of a neighboring residence (which is true of at least a third of poultry operations on Maryland's Eastern Shore). The Maryland Department of the Environment should develop a fenceline action level for ammonia, require large poultry operations to conduct fenceline air monitoring, and if the action level is exceeded, require the operation to do a root cause analysis and take corrective actions to reduce ammonia levels.

3. Efficacy of vegetative environmental buffers should be routinely monitored to ensure they are designed and are being maintained to mitigate off-site concentrations of ammonia and other pollutants.

Figure 1. Map of monitoring locations on the Eastern Shore



Introduction

According to the U.S. Environmental Protection Agency's (EPA) 2017 National Emissions Inventory (NEI), agriculture (including livestock waste and fertilizer application) is responsible for 81 percent of ammonia emissions, or 3.5 million tons. In Maryland, as of 2019, the Eastern Shore was home to 503 active poultry farms, with a total of 2,178 poultry houses. These operations raised approximately 300 million chickens and produced roughly 600 million pounds of manure.[3] This manure is a significant source of ammonia emissions,

[3] Environmental Integrity Project, "Blind Eye to Big Chicken", October 2021, Link: https://environmentalintegrity.org/wp-content/uploads/2021/10/MD-Poultry-Report-10-28-21.pdf

including while chickens are growing in poultry houses, between flocks, when it is stored, and when it is spread on cropland.

To characterize ammonia concentrations found in fenceline communities, EIP and ACT began a two-year community monitoring project on the Eastern Shore to measure gaseous ammonia concentrations at properties located next to or in close proximity to poultry houses. The monitoring project began in June 2020 and ended in June of 2022. Passive samplers were installed at five properties. Two sites were selected to be consistent with community monitoring conducted by EIP in 2016 and 2017, and one site was selected to serve as a background monitoring site.

Background

A. Ammonia Formation and Emissions from Poultry Houses

Nitrogen exists naturally in two main forms, as an inert gas (N_2), meaning it doesn't easily react with other chemicals or compounds, or in biologically active forms like ammonia (NH_3) and nitrate and nitrite (NO_3^- and NO_2^-). Through both natural and industrial means, nitrogen is converted from its inert gas form into biologically active components, a process called nitrogen fixation. Most nitrogen fixation is performed by microorganisms, like bacteria and algae, but some occurs through a process known as the Haber-Bosch method,[4] which is used in the production of inorganic nitrogen fertilizers. Converting nitrogen from a gas into biologically active forms is important because both plants and animals need nitrogen to make protein, which poultry get by consuming feed. However, excess nitrogen in poultry is converted into uric acid, which is then excreted by the birds and converted into gaseous ammonia by bacteria living in the poultry litter.

The amount of gaseous ammonia released into the atmosphere from poultry operations is dependent on several factors in the environment of a given poultry house, like its airflow, temperature, humidity, litter pH, litter moisture, and diet of the chickens themselves. High-velocity airflow in the house increases the amount of ammonia emitted.[5] Additionally, increased temperature, humidity, and moisture levels in the poultry litter also promote formation of ammonia. Diets with higher pH levels (above seven) can increase the overall ammonia concentration in chicken manure, along with those high in protein (aimed to spur growth in chickens) as they cause an increase in amino acids in the body.[6]

The diet of broilers is a significant source of the high levels of ammonia production observed in poultry houses. As noted previously, high protein diets are a major contributing factor in increased ammonia production, as chickens are unable to absorb all the extra amino acids given to them and subsequently release this unused surplus in the form of uric acid in their litter. These diets are used to grow the birds as big in size as possible, as quickly as possible. As poultry operations continue to grow in both flock size and individual bird size, so too

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[4] ScienceDirect, Haber-Bosch Process, Link: https://www.sciencedirect.com/topics/engineering/haber-bosch-process

[5] Sadia Naseem and Annie J. King, "Ammonia production in poultry houses can affect health of humans, birds, and the environment—techniques for its reduction during poultry production" *Environmental Science and Pollution Research*, 2018. Link: https://link.springer.com/content/pdf/10.1007/s11356-018-2018-y.pdf

[6] *Ibid.*

does the amount of the litter that is produced. Nationally, the average market weight for a broiler chicken in 2018 was 6.26 pounds, an increase of 12 percent from 5.58 pounds a decade earlier.[7] While the overall number of broilers produced by the states in the Chesapeake region in 2017 compared to 2007 increased 6 percent, there was a 16 percent increase in the amount of manure produced during the same time.[8]

Industrial poultry operations monitor ammonia levels inside their broiler houses to ensure that chickens are not exposed to unsafe concentrations, generally recommended by the industry to be less than 25 ppm.[9] It has been shown that higher levels can affect bird health, particularly impacting their respiratory systems.[10] Many facilities will utilize tools such as Colorimetric Tubes (known as Detector Tubes) and Diffusion Tubes (known as Passive tubes or Dosimeter tubes) that are low in cost to measure ammonia levels and ensure that they do not exceed 25 ppm.[11] To help maintain a safe environment for their chickens, many poultry facilities utilize modern ventilation systems equipped with large exhaust fans to remove the ammonia from the house and put it out into the surrounding environment.

Litter management practices inside and outside of poultry houses can impact ammonia formation and emissions. [12,13] If litter storage conditions cause the internal temperature of the poultry litter to increase or if the litter becomes wet, then these conditions promote ammonia formation. To prevent this, litter should be kept in covered sheds with proper ventilation. Maryland farmers are allowed to temporarily stockpile poultry litter outside on cropland before spreading it as fertilizer, exposing litter to the elements and likely causing more ammonia formation.

Another method for managing poultry litter inside poultry houses, called windrowing, has grown in prevalence in recent years. It is used to reduce pathogens and the spreading of diseases between flocks within a broiler house, and it allows operators to reuse litter. The process involves piling used poultry litter into long triangle-shaped rows within a poultry house, allowing bacteria in the litter to heat the pile, and then spreading it back out. While it reduces the number of total cleanouts and litter costs and the spread of disease between flocks, research suggests that windrowing can result in short term increases in emissions of ammonia and nitrous oxide, a potent greenhouse gas.

In one study, maximum hourly ammonia emission rates per house using litter windrowing were recorded at over three times higher than a house utilizing a practice known as litter

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[7] *Ibid*.
[8] Environmental Integrity Project, "Poultry Industry Pollution in the Chesapeake Region", 2020. Link: https://environmentalintegrity.org/wp-content/uploads/2020/04/EIP-Poultry-Report.pdf
[9] Eileen Fabian, "Detecting Ammonia in Poultry Housing Using Inexpensive Instruments" *PennState Extension*, 2019. Link: https://extension.psu.edu/detecting-ammonia-in-poultry-housing-using-inexpensive-instruments
[10] Naseem and King, 2018.
[11] Fabian, 2019.
[12] Philip A Moore, Jr., et al., "Evaluation of Ammonia Emissions from Broiler Litter" *American Society of Agricultural and Biological Engineers*, 2008. Link: https://www.researchgate.net/publication/47504651_Evaluation_of_Ammonia_Emissions_from_Broiler_Litter
[13] Philip A Moore, Jr., et al., "Ammonia Emission Factors from Broiler Litter in Barns, in Storage, and after Land Application" *Journal of Environmental Quality*, 2011. Link: https://www.researchgate.net/publication/51597701_Ammonia_Emission_Factors_from_Broiler_Litter_in_Barns_in_Storage_and_after_Land_Application

turning.[14] Another study compared ammonia emissions from two different poultry houses, one that used windrowing, and the other did not. The study found that the poultry house that used the windrowing method resulted in an increase in daily ammonia emissions of around twice as much as the other house, while windrowing was happening.[15] Both studies outlined several factors, such as house size or the amount of down time before windrowing, which could have also impacted emissions. However, both studies found high emission rates during windrowing.

Reusing poultry litter for different flocks (even without windrowing) has been found to increase ammonia emissions from poultry houses as well. One study found that broilers raised on new litter each flock had a reduced ammonia emissions rate of 0.47 grams of ammonia per bird per day than flocks raised with reused litter under similar conditions.[16]

B. Health and Environmental Impacts of Ammonia

Once emitted from poultry houses, gaseous ammonia generally remains in the atmosphere for a short period of time before depositing back into the environment. Ammonia's atmospheric lifetime depends on a variety factors, like wind speed and direction, temperature, humidity, and terrain, but a majority of ammonia emitted is deposited within half a mile of where it is released, via wet or dry deposition.[17] Ammonia is also a highly reactive gas that tends to form fine particles in reaction with nitrogen oxides (NOx) and other gases.[18] These fine particles stay aloft in the for a longer period of time, allowing them to travel much farther from the source, but as NOx emissions have decreased, ammonia is more likely to deposit in gaseous form.[19] Since ammonia concentrations are higher closest to the fans and area immediately surrounding the poultry houses, this puts community members who live adjacent to these operations at risk for adverse health effects.

Exposure to ammonia pollution can adversely impact the respiratory system, as ammonia is quickly absorbed into the upper respiratory tract. At high levels, ammonia irritates the throat, lungs, and eyes, even causing chemical burns or scarring.[20] Prolonged exposure to gaseous ammonia can irritate the eyes and respiratory tract, as well as increase the risk of

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[14] Y. Liang, et al., "Systematic evaluation of in-house broiler litter windrowing effects on production benefits and environmental impact" *Journal of Applied Poultry Research*, 2014. Link: https://www.sciencedirect.com/science/article/pii/S1056617119303344

[15] Kyoung S. Ro, et al., "Ammonia and Nitrous Oxide Emissions from Broiler Houses with Downtime Windrowed Litter" *Journal of Environmental Quality*, 2017. Link: https://www.ars.usda.gov/ARSUserFiles/60820500/Manuscripts/2017/Man1029.pdf

[16] Eileen F. Wheeler, et al., "Ammonia Emissions from Twelve U.S. Broiler Chicken Houses", *Iowa State University: Agricultural and Biosystems Engineering Publications*, 2006, Link: https://pubag.nal.usda.gov/download/1464/pdf

[17] Colorado State University. Best Management Practices for Reducing Ammonia Emissions. https://extension.colostate.edu/topic-areas/agriculture/best-management-practices-for-reducing-ammonia-emissions-1-631/

[18] Koziel, Jacek, « Gas-to-Fine Particle Conversion Process between Ammonia, Acid Gases, and Fine Particles in the Atmosphere", 2006, Link: https://dr.lib.iastate.edu/entities/publication/6b610546-60f8-47a8-a36a-d08a05d8d4fa

[19] Pinder, R.W., et.al., "Environmental impact of atmospheric NH3 Emissions under present and future conditions in the eastern United States", 2008, Link: https://agupubs.onlinelibrary.wiley.com/doi/pdf/10.1029/2008GL033732

[20] Environmental Protection Agency, "Toxicological Review of Ammonia Noncancer Inhalation: Executive Summary," September, 2016. Link: https://iris.epa.gov/static/pdfs/0422_summary.pdf

respiratory diseases, such as bronchitis or asthma.[21] It also has environmental impacts. As ammonia deposits into soil or natural waters, it can contribute to eutrophication and groundwater contamination.[22] According to the EPA, ammonia is responsible for approximately 17 percent of the nitrogen influx that causes algae blooms and dead zones in the Chesapeake Bay.[23] These effects not only decrease biodiversity and degrade water quality, but the increased prevalence of harmful algae blooms can also directly affect human health.

Additionally, when ammonia reacts with other contaminants, such as nitric and sulfuric acid, it can form particulate ammonium nitrate, which has a longer atmospheric lifespan, travels longer distances, and can cause more severe health impacts. Particulate ammonium nitrate is a fine particulate matter that, due to its small size, can be absorbed deeper into the respiratory tract and lung tissue, increasing the prevalence of asthma, bronchitis, and other ailments.[24]

According to the EPA, continuous inhalation of ammonia above 0.5 milligrams per cubic meter (or 720 parts per billion) can have long-term consequences to health, but health impacts have also been observed at lower concentrations.[25] The Agency for Toxic Substances and Disease Registry (ATSDR) set a chronic Minimal Risk Level of 100 ppb. This is a level which long-term exposure through inhalation, above the listed concentration, could pose an increased non-cancer health risk to the general population.[26] The ATSDR defines long-term as any time period greater than 365 days. The Maryland Department of Environment (MDE) has adopted a 1-hour risk screening level of 350 ppb and an 8-hour risk screening level of 250 ppb.[27] The odor threshold for ammonia, meaning the concentration at which people can smell it, varies by individual, but there seems to be a consensus that most people cannot smell ammonia unless the concentration exceeds 5,000 ppb.[28,29,30] It's also important to note that ammonia causes olfactory fatigue, meaning after prolonged exposure to ammonia at low concentrations, an individual is less likely to smell ammonia in the air.

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[21] Hribar, Carrie, "Understanding Concentrated Animal Feeding Operations and Their Impact on Communities," 2010. Link: https://www.cdc.gov/nceh/ehs/docs/understanding_cafos_nalboh.pdf

[22] U.S. EPA. National Emission Inventory – Ammonia Emissions from Animal Husbandry Operations, Draft Report. January 30, 2004. https://www3.epa.gov/ttnchie1/ap42/ch09/related/nh3inventorydraft_jan2004.pdf

[23] Environmental Integrity Project, "Ammonia Emissions from Poultry Industry More Harmful to Chesapeake Bay than Previously Thought," January 22, 2018. Link: https://environmentalintegrity.org/news/ammonia-emissions/

[24] Colorado State University. Best Management Practices for Reducing Ammonia Emissions. https://extension.colostate.edu/topic-areas/agriculture/best-management-practices-for-reducing-ammonia-emissions-1-631/

[25] Environmental Protection Agency, "Toxicological Review of Ammonia."

[26] ATSDR Toxicological Profile: Ammonia, Link: https://www.atsdr.cdc.gov/toxprofiles/tp126.pdf

[27] Lower Eastern Shore Ambient Air Quality Monitoring Project, Maryland Department of the Environment, Link: https://mde.maryland.gov/programs/air/AirQualityMonitoring/Pages/Lower-Eastern-Shore-Monitoring-Project.aspx

[28] Wisconsin Department of Health Services: Ammonia, Link: https://www.dhs.wisconsin.gov/chemical/ammonia.htm

[29] Occupational Safety and Health Administration, Link:https://www.osha.gov/sites/default/files/2019-03/fs5-howsmelly.pdf

[30] ATSDR

C. Ways to Mitigate Ammonia

There are a variety of best management practices (BMPs) and technological solutions that farmers could use, alone or in combination, to reduce ammonia emissions from their poultry operations. Some of these practices are aimed at reducing the amount of ammonia formed, like reducing the protein content in poultry feed. Chickens can only convert so much nitrogen (which comes from protein) into body mass before the rest is excreted as uric acid, which is then converted into ammonia. Since increased temperature and moisture levels promote the formation of ammonia, another option to reduce the amount of ammonia formed is by storing the litter in a covered area and providing adequate ventilation. Changing litter more frequently would also reduce ammonia emissions.[31] The addition of aluminum sulfate (alum) to poultry litter can also prevent the formation of ammonia gas by reducing the pH of the litter to be more acidic. Under acidic conditions, ammonium is created in excess of ammonia, which isn't volatile like ammonia. Ammonia emissions from litter treated with alum has shown to be up to 70 percent lower than litter that has been left untreated.[32]However, the addition of certain additives like aluminum sulfate to litter has been shown to increase, rather than decrease, ammonia emissions when the litter is reused numerous times.[33]

Other BMPs aim at reducing the amount of ammonia already formed that travels offsite, like vegetative environmental buffers. Planting vegetative buffers, which are rows of trees and shrubs, along the perimeter of the property to help block and absorb ammonia and other pollutants emitted from exhaust fans. While studies that quantify results are somewhat limited, those that have been done indicate that properly designed and placed VEBs can help mitigate ammonia emissions by 13 to 46 percent.[34] In addition to vegetative buffers, placing hay bales next to the exhaust fans help reduce offsite ammonia emissions by absorbing the ammonia (and other gases and particles) blown out of the poultry houses. Installing and operating scrubbers are another, more technical option. A scrubber can be installed on the outside of an exhaust fan to filter out pollutants from the air passing through. Research conducted into determining the effectiveness of wet scrubbers on removing ammonia from poultry house exhaust found the scrubbers to reduce ammonia emissions by 30 to 70 percent.[35] The effectiveness of these scrubbers depends on a number of factors, including airflow rate.

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[31] One tradeoff here is that it would generate more litter that would need to be hauled away and disposed of, which would increase costs of operation. More frequent cleanouts in Maryland were normal back around 2013.
[32] Philip Moore, "Treating Poultry Litter with Aluminum Sulfate (Alum)", *USDA,* Link: *https*://www.ars.usda.gov/ARSUserFiles/np212/LivestockGRACEnet/AlumPoultryLitter.pdf
[33] Namanda Sara Senyondo, "Mitigation of Ammonia Emissions from Broiler Houses Using a Biodegradable Litter Ammendment", 2013
[34] A. Adrizal, et al., "Vegetative buffers for fan emissions from poultry farms: 2. ammonia, dust and foliar nitrogen" *Journal of Environmental Science and Health, Part B: Pesticides, Food Contaminants, and Agricultural Wastes, 2008.* Link: https://dr.lib.iastate.edu/server/api/core/bitstreams/1b1b9efc-bce6-48db-8a87-0ed6215463a3/content; George Malone, et al., "Efficacy of Vegetative Environmental Buffers to Capture Emissions from Tunnel Ventilated Poultry Houses" *Agricultural Air Quality*, 2006. Link: Malone et al. 2006.pdf; Ro, et al., "Enhanced Dispersion and Removal of Ammonia Emitted from a Poultry House with a Vegetative Environmental Buffer" *MDPI*, 2018. Link: Ro et al. 2018.pdf; Qi Yao, "Assessing the Effectiveness of Vegetative Environmental Buffers in Mitigating Poultry Emitted Air Pollutants" *University of Maryland, College Park*, 2017. Link: Yao 2017.pdf.
[35] Spray Acid Wet Scrubbers to Recover Ammonia Emission from Poultry, *OSU*, Link: https://oied.osu.edu/technologies/spray-acid-wet-scrubbers-recover-ammonia-emission-poultry

Community Air Monitoring Project

A. Monitoring Locations

EIP and ACT monitored gaseous ammonia levels on five Eastern Shore properties between June 2020 and June 2022. Originally, we had four monitoring locations across the Eastern Shore: One in Princess Anne, two in Berlin, and one in Bishopville. Two sites (one in Berlin and the Bishopville site) served as background monitoring sites during the first year, and were subsequently moved.[36] By June 2022, we had one monitoring station in Berlin (Site 1) and three monitoring stations in Princess Anne (Sites 2-4).

Site 1 was located 250 meters (820 ft) away from the closest poultry operation and was separated by a farm field. Site 2 was separated from the nearest poultry operation by a road and a stand of evergreen trees, but still within 122 meters (400 ft). Sites 3 and 4 were located on the same property, which is directly adjacent to a six-house poultry operation. The two monitors on this property were 72 (236 ft) and 87 meters (285 ft) away from the closest poultry house. (A map of the monitoring locations is on page 3.)

B. Methods

This project used Radiello diffusive samplers provided through the National Atmospheric Deposition Program (NADP). NADP operates a national, long-term Ammonia Monitoring Network (AMoN) to collect ambient ammonia concentrations. The cost of each sample was $100, and includes the sample itself, analysis, and shipping. Additional costs included travel blanks and duplicates (for quality control purposes, also $100 each) and posts to hold the sample shelter. Aside from site selection, we followed the same procedures and sampling schedule as sites that were part of AMoN. All results were analyzed and validated by the NADP laboratory. All sample tube changeouts were conducted by trained EIP and ACT staff.

The sorbent tubes are unobtrusive, low-cost, and don't require any electricity, which made them an affordable choice for this community monitoring project. The interior cartridges of the sorbent tubes are impregnated with phosphoric acid and work by absorbing gaseous ammonia passively from the atmosphere. In the field, the tubes themselves are placed inside an inverted plastic shelter that is permanently attached to an aluminum bracket, which is then fastened to a post so that the lower edge of the shelter is at least two meters (80 inches) off the ground. Trained staff from EIP and ACT visited the sampling locations every two weeks to collect and install new sample tubes and shipped the tubes to the lab using NADP-

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Livestock and Poultry Environmental Learning Community, "Using Wet Scrubber to Reduce Ammonia Emission from Broiler Houses", Link: https://lpelc.org/using-wet-scrubber-to-reduce-ammonia-emission-from-broiler-houses/
In the study conducted by the Livestock and Poultry Environmental Learning Community, one scrubber only exhibited 11% efficiency, but this was attributed to inadequate acid solution and a higher emission rate.

[36] Monitoring at Site 2 didn't start until December of 2020, after data from Bishopville showed minimal concentrations of ammonia. Monitoring at Site 4 began in July of 2021, after ACT moved offices.

provided packaging. The NADP lab then conducted a flow injection analysis to determine the average two-week concentration.

Though it would have provided more context for our analysis, we did not install meteorological sensors at our monitoring sites, due to the requirement for electricity. We also did not monitor for additional pollutants that alone or in combination with gaseous ammonia could impact the health of nearby residents.

We compared monitoring results with data collected by the Maryland Department of the Environment (MDE) from a continuous monitor in Pocomoke City and a NADP AMoN monitoring site in Blackwater National Wildlife Refuge.

C. Results

Table 1 shows that our monitoring stations were between 72 (236 ft) and 250 meters (820 ft) from the nearest poultry house. This is significant because there are at least 174 poultry operations in Maryland's Eastern Shore within 122 meters (400 ft) of a residence. MDE's Pocomoke City monitoring station, on the other hand, which MDE has defined as being in an area with a "high density of poultry houses," is at least 540 meters (1,772 ft) from the closest poultry house and is separated from those houses by forest buffers.

Table 1. Average two-week mean concentrations recorded at each location

Site (Operator)	Sample Dates	Closest Poultry House	Mean Two-Week Average Concentration (ppb)	Range of Concentrations (ppb)*
Site 1 (ACT/EIP)	8/4/2020 to 6/21/2022	250m (820ft)	10.1	0.4 – 50.3
Site 2 (ACT/EIP)	12/8/2020 to 6/21/2022	122m (400ft)	33.2	4.3 – 149.6
Site 3 (ACT/EIP)	6/9/2020 to 6/21/2022	72m (236ft)	60.5	6.2 – 487.2
Site 4 (ACT/EIP)	7/6/2021 to 6/21/2022	87m (285ft)	47.3	8.3 – 98.0
Blackwater (NADP)	8/4/2020 to 6/21/2022	Background	0.98	0.32 – 1.99
Pocomoke City (MDE)	June 2020 – June 2022	540m (1,772ft)	10.4	2.1 – 72.3

** The range in concentrations presented here for Pocomoke City is the range in hourly concentrations over the sampling date range, while for the other four sites, the range presented is the range in two-week average concentrations.*

Over the course of this monitoring project, the average two-week concentrations of ammonia measured along the fence line at Site 1 were similar to average concentrations measured at MDE's monitoring location in Pocomoke City, while average concentrations measured at Site 2 were about 3 times greater than MDE's.[37] For Sites 3 and 4, which are located on the same property, average ammonia concentrations were 5 to 6 times higher than the MDE monitor. At least three of the sites were located closer to a poultry operation and in a higher density poultry area than MDE's "high density poultry operation" monitoring site in Pocomoke City.[38] The average concentrations measured at Sites 2 through 4 are also much higher than average concentration measured at NADP's ammonia monitor located in Blackwater National Wildlife Refuge, an AMoN site on the Eastern Shore. Average concentrations were 34 to 62 times higher at Sites 2 through 4 than they were at Blackwater.

Some of the two-week average concentrations measured at Sites 2-4 are cause for concern, as hourly or shorter-term levels were likely higher. MDE's monitoring data show that concentrations vary over time, and that there will be short-term spikes that are far greater than the two-week average. For example, the highest hourly concentrations measured at MDE's Pocomoke City site were, on average, 6.9 times greater than the average concentration measured during a two-week period. Assuming that hourly concentrations at the sites monitored by EIP and ACT followed a similar pattern, one or more hourly concentrations during 21 two-week monitoring periods (42 weeks) likely exceeded MDE's one hour risk screening threshold. Similarly, concentrations at Site 2 likely exceeded the same threshold during 10 two-week monitoring periods (20 weeks).

Table 2. Estimated Hourly Peak Concentrations

Site	No. of Two-Week Monitoring Periods where Estimated Hourly Peak Concentrations > 350 ppb	Range of Estimated Hourly Peak Concentrations > 350 ppb
Site 2	10 weeks	355 – 1,032 ppb
Site 3/4	21 weeks	367 - 3,361 ppb

**These estimated hourly peaks were calculated by multiplying the two-week average concentration measured at each location by 6.9, which was, on average, how many times greater the maximum value recorded at the MDE monitor was than the average concentration measured in a two-week period.*

Additionally, there were nine two-week periods at Site 2 and Sites 3/4 where the two-week average was higher than the ATSDR minimum risk level of 100 ppb. Results from MDE's Pocomoke City monitoring location never exceeded 100 ppb.

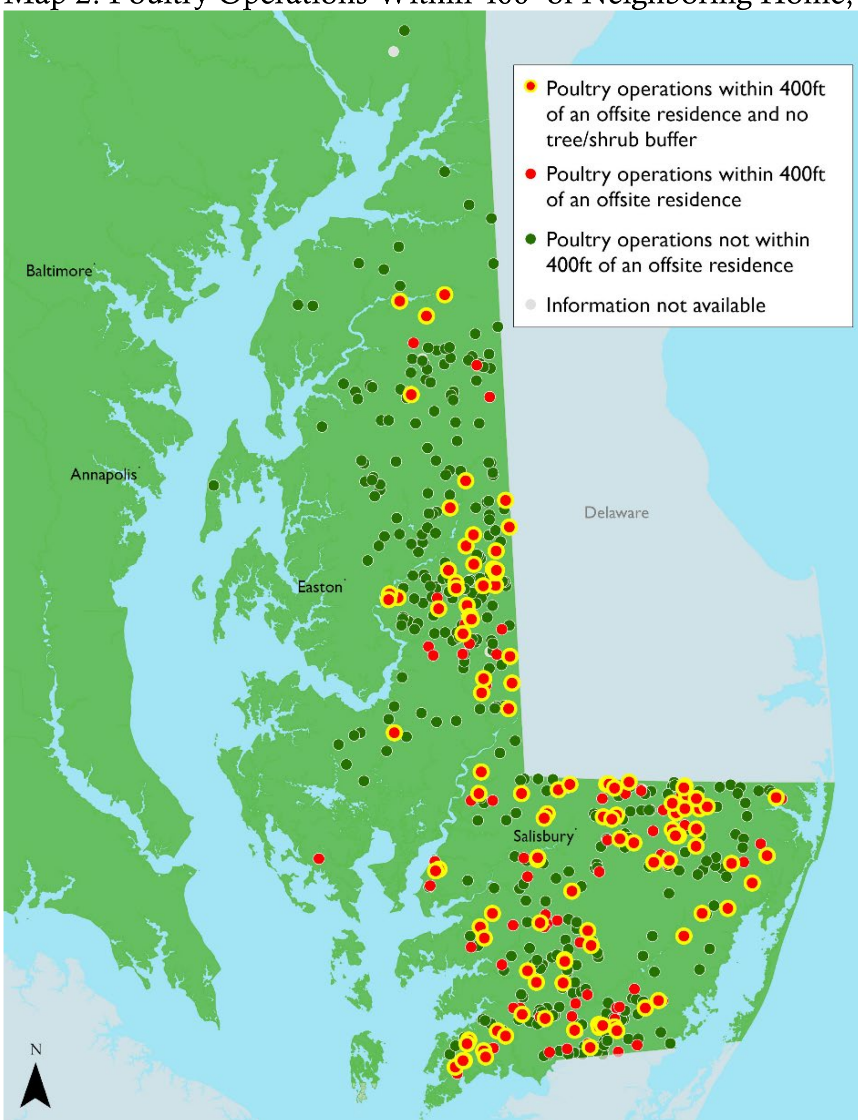
[37] Site 2 is located 400 feet from the nearest poultry operation, which has 6 poultry houses and a capacity for 320,000 chickens.

[38] The sampler that MDE sited to measure ammonia levels in an area with a high density of poultry houses was located 539 meters (1,770 feet) from the nearest poultry house, with a density of 30 poultry houses (and 793,000 chickens) within a one-mile radius, while the monitors EIP/ACT maintained at Sites 3 and 4 were located 236 feet away from the closest poultry house in an area with a density of 36 chicken houses (and 1.26 million chickens) within a one-mile radius.

One monitoring period in January 2021 at site 3 detected a two-week average concentration of 487.2 ppb. This result was validated by the NADP lab, and it is a plausible value for ammonia levels next to a poultry house under certain conditions. It clearly exceeded MDE's risk screening thresholds, and actual shorter-term concentrations within this period were likely much higher.

Living close to poultry houses can expose residents to elevated levels of ammonia, dust, and noxious odors, especially when these emissions are unmitigated and uncontrolled. One method of mitigating these emissions, which has already been mentioned, is with properly designed and maintained vegetative environmental buffers (VEBs).

Map 2. Poultry Operations Within 400' of Neighboring Home, 2019



EIP's review of 2019 aerial imagery found that 174 poultry operations on the Eastern Shore have poultry houses sited within 400 feet (122 m) of an offsite residence. Of those, only 68 (or 39 percent) had rows of trees and vegetation or forests around their poultry houses. Map

2 and the attached spreadsheet identify poultry operations that are located within 400 ft (122 m) of a neighboring residence and characterizes the presence or absence of a forested or vegetated buffer. EIP's analysis did not explore whether these forested or vegetated buffers were designed, installed, or maintained to function as "vegetative environmental buffers."[39]

Monitoring data from Site 2 suggests that the efficacy of vegetative environmental buffers needs to be closely evaluated if the practice is going to be used to mitigate emissions and ammonia deposition. EIP monitored gaseous ammonia emissions in this location between May 2017 and August 2017 and resumed monitoring in the same location again with ACT in December 2020. In 2017, the closest poultry operation had a newly planted stand of evergreen trees (see picture A), and according to its Comprehensive Nutrient Management Plan, had installed a voluntary buffer. By 2020, that buffer of trees was much taller (see picture B), and we expected to measure lower ammonia concentrations as a result.

Picture A. EIP/ACT Site 2 (view of newly planted buffer in front of monitor, taken May 2017)

[39] See: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs144p2_027434.pdf

Picture B. EIP/ACT Site 2 (view of buffer, after three years of growth, in front of monitor, taken December 2020)[40]

Table 3 below compares the average and range of concentrations at Site 2 detected in 2017 and in 2020-2021. The average two-week concentration was 33.1 ppb (with a concentration range of 9.93 to 87.74 ppb) in 2017, when the trees were just planted, but after three to five years of growth, when they were large enough to obstruct the view of the poultry house, the average two-week concentration was 35.8 ppb (with a range of 4.3 to 149.6 ppb).

Table 3. Average concentrations recorded during each time period

Buffer Maturity	Sample Dates	Number of Samples Collected	Average Concentration (ppb)	Range in Average Concentration (ppb)
Young Buffer	May – August 2017 (Samples collected weekly)	12	33.1	9.93 - 87.74
Same Buffer, three to five years of growth	May – August 2021 (Samples collected biweekly)	8	33.8	9.4 – 149.6
	December 2020 – June 2022 (Samples collected biweekly)	40	33.2	4.3 – 149.6

[40] This photo wasn't taken at the same angle as the photo from May 2017. The buffer is the shorter trees on the right-hand side of the photo, not the larger forest of trees on the left-hand side.

The EIP/ACT community monitoring site was not sited to monitor the efficacy of the CAFO's voluntary buffer. However, monitoring results suggest that the efficacy of VEBs needs to be evaluated, especially in areas with many poultry operations in close proximity.

Conclusion

In December 2022, the Delmarva Land and Litter Collaborative issued a whitepaper that characterized ammonia levels from several MDE monitoring sites on the Lower Eastern Shore.[41] The paper acknowledges that more data are needed to understand emissions from poultry operations in the region and the implications for water modeling. As mentioned earlier, MDE's "high density" poultry monitoring site was 1,770 ft from the nearest poultry operation with no clear line of sight to that operation. As a result, monitoring data reflect ambient levels far from a poultry operation and are lower than what would be detected close to the emission source, given how ammonia deposits on the land and its chemical behavior.

Monitoring conducted by ACT and EIP sought to measure what level of ammonia people living next door to a poultry operation may be exposed to, at their property line. Monitoring data from low-cost, two-week passive samplers indicate the need for higher resolution and precision monitoring very close to poultry operations, but the lack of expensive precision monitoring to date should not be a barrier to government action. Additional health-focused studies are underway. Poultry operations monitor ammonia in their poultry houses as a way to safeguard their chickens, and they could be required to report monitoring results and net emissions on their annual implementation reports. The burden for monitoring and reducing emissions from the chicken industry should not fall on its neighbors. To protect the health of residents who live very close to large poultry operations, MDE could also establish an action level based on current science and low-cost monitoring sensors, and require poultry operations within 400' of a neighbor's residence to install a fenceline air monitoring network that signals when a root cause analysis and corrective actions are required.

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[41] Delmarva Land and Litter Collaborative, "Ammonia Emissions from Poultry Production", 2022, Link: https://delmarvalandandlitter.net/wp-content/uploads/2022/12/Updated-ammonia-paper-high-res-1.pdf