The Emission, Transport and Deposition of Aeolian Ammonia From Poultry Farm to Pumicestone Passage: Use of TAPM to Estimate Annual Loading.

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ABSTRACT

The Air Pollution Model (TAPM) was used to investigate the transport of ammonia across the Sunshine Coast region, following its emission to the atmosphere from 41 poultry farms in the district. Both the dry and wet deposition of ammonia, directly into the Pumicestone Passage water body and also onto the surrounding catchment, were simulated for each hour over the entirety of 2005. The simulations indicate that most of the ammonia deposition occurs within a relatively short distance from the farms, although the annual loading into the water body is not insignificant and may contribute to the formation of algal blooms.

INTRODUCTION

In addition to its aesthetic and recreational value, the Pumicestone Passage in Southeast Queensland (SEQ) is home to significant marine life and birds. An increase in observed outbreaks of *Lyngbya Majuscule*, a species of green algae, over the last decade has lead to concern over the sources of nutrients that enter the water body (Albert et al., 2005; Hannington, 2007; King et al., 2006; Watkinson et al., 2005). This concern focuses on the contributions of nutrients from high intensity agricultural activity, and specifically in this study, poultry. A preliminary survey of the poultry industry in the Pumicestone Passage Catchment identified at least 40 poultry facilities housing over 6,600,000 birds at any given time (King, 2008).

Intensive poultry production in other regions of the world has been linked to significant environmental degradation due to the emission of pollutants such as dust, ammonia and methane. Examples include eutrophication of surrounding water bodies in Delaware Bay, USA (Scudlark et al., 2005; Tabler, 2006) and the Gulf of Mexico (Tabler, 2006) through atmospheric deposition of the ammonia emissions. Previous water quality studies for the Brisbane and Moreton Bay region identify atmospheric deposition as a significant source of nutrient loading into local waters and catchments (SEQRWQS, 1997).

Among the many environmental pollutants released by agricultural activity is gaseous ammonia (NH_3) (Ritz et al., 2004), which may be transported over large distances through the atmosphere before deposition to land or water. Ammonia is a source of nitrogen for catchments and coastal waters and can potentially result in eutrophication.

BACKGROUND

Poultry In SE Qld and Ammonia Production

In 2006 there were 32 poultry housing facilities in the Pumicestone catchment, with anywhere from 270 000 to 600 000 animals housed within each facility. The current number of poultry is estimated to be significantly higher than the 2006 figures, with a large number of farms receiving recent approval for construction (King et al., 2006).

An estimate of farm numbers, size and location was constructed using information provided by the National Pollutant Inventory 2006-2007 (NPI), combined with personal observation within the region. 41 poultry facilities were identified within the region, housing over seven million birds at any given time (King, 2008).

The ammonia that is emitted from poultry farms is not produced directly by the poultry, but is formed by bacterial decomposition of the faecal matter. In order to simplify the estimation of total ammonia production, the NPI specifies factors for annual ammonia emission per animal and are specific to different types of stock, such as laying hens and broilers (NPI, 2002).

Ammonia Transport and Deposition

Ammonia can travel with the wind for several days (Tabler, 2006) and can leave the atmosphere through chemical transformation, wet deposition or dry deposition. The most important reaction of ammonia is with acid gases and aerosol particles to form the corresponding salts. These reactions are generally rapid and result in the gaseous ammonia being converted to “particulate ammonia”, which is readily deposited via dry or wet deposition. Wet deposition is simply the uptake of ammonia into precipitation while dry deposition is the exchange of ammonia at air-water/land/plant surfaces (Hertel et al., 2006). Wet deposition and dry deposition to water surfaces is a significant removal process from the atmosphere due to the high solubility of ammonia in water.

Following ammonia emission from a point source, particulate ammonia is generally dry deposited within a few kilometers, whereas wet deposition dominates the relative deposition quantity at locations several hundred kilometers from the source (Asman et al., 1998).

Impact of Ammonia on Pumicestone Passage

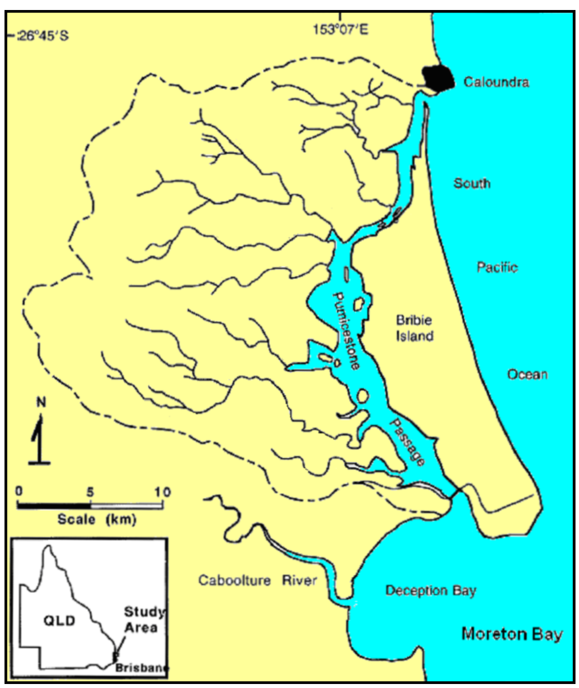

Figure 1: Pumicestone Passage and Catchment Area (adapted from Eyre & France, 1997)

The Pumicestone Passage is at an increased risk of nutrient loading from agricultural atmospheric emissions due to the number of creeks that flow into the passage. Any atmospheric ammonia that is deposited into or around these creeks may ultimately end up in the Pumicestone Passage. Eyre et al. (1997) have identified the Pumicestone Passage as having no significant nutrient point sources (sewage effluent, etc.) so non-point sources are of particular interest. A preliminary report by Healthy

Waterways (2002) estimates total atmospheric deposition of ammonia into Moreton Bay, to which the Pumicestone Passage is connected, at around 1400 Tonnes/year (~20% of total nitrogen inputs to the Bay). In contrast to that report, the current paper investigates the contribution that poultry production makes to the total ammonia deposition in the Pumicestone Passage specifically, as distinct from other sources.

Computer Modelling of Atmospheric Transport and Deposition

The difficulties associated with quantifying atmospheric deposition of pollutants have lead to the majority of studies relying on the use of computer simulation. Direct measurements (atmospheric concentration, water quality parameters, etc.) are time consuming, costly, spatially limited and are unlikely to determine the impact of the poultry industry alone. Estimations of atmospheric nutrient loading must take into account several processes which include production, emission, transport, and wet/dry deposition. The complexities in each process must also be considered, including the horizontal and vertical spatial distribution of emissions, chemical transformations, multiple sources and the diverse terrain and complex wind patterns of the region of interest. Computer models are available which predict the behavior of pollutant emissions in the atmosphere and account for many of the complexities of the system being studied. Computer simulation is relatively fast with low cost and emissions from one or more sources can be simulated independently (Hurley, 2005).

From the many computer models available for air pollution studies, TAPM version 3 was selected as being the most suitable for this study. TAPM (The Air Pollution Model) is a relatively new prognostic model designed by the CSIRO for air pollution studies within Australia (Hurley, 2000) and can be run on a personal computer. TAPM uses input data from databases of surface information (terrain, land use, sea surface temperature, etc.) and synoptic meteorological analysis to predict winds, temperature, pressure and water vapour for the region specified, up to a year at a time, without the need for local meteorological data. TAPM has the ability to predict air flows that are important to local scale pollution, including sea breezes and terrain-induced flows (Hurley, 2005). The predicted meteorology can subsequently be used to simulate the transport and dispersion of aeolian pollutants. Processes such as photochemistry, aqueous chemistry, wet deposition, dry deposition and gravitational settling of aerosols can also be simulated. This makes TAPM an ideal tool for exploring the atmospheric behavior of aeolian ammonia emissions.

METHOD

An inventory provided by Rob King from Sunfish North Moreton identified a total of 41 poultry facilities within the Pumicestone Passage Catchment, which house approximately 9.8 million fowl. The locations of these 41 poultry facilities were used to define the location and boundaries of the study region, which is approximately 50km x 50km, centered on 27°00"00' latitude and 152°55"00' longitude. This study region was defined in TAPM and four nested grids (required for simulation of meteorology) were specified with dimensions of 1000, 400, 150 and 50 kilometers square. A series of simulation trials and validation studies concluded that all other model settings were best set to the TAPM defaults.

As the aim of the research was to estimate the total annual ammonia contribution, the year 2005 was selected for the simulation as it appeared to best represent 'average' weather conditions. The 2005 temperatures and total rainfall were approximately the same as the averages for the Brisbane region over the seven years 2001 to 2007. The meteorology of the study region was simulated for the entire 2005 year and was validated through comparison against monitoring data from the Bureau of Meteorology.

The emission rates of ammonia at each of the 41 poultry facilities in the region were estimated using numbers of poultry, facility type and emission factors that were sourced from the National Pollutant Inventory (NPI, 2002). The ammonia was represented in TAPM by Tracer 1 (TR1), with a particle size of 2.5 microns or less. This selection is based on the assumption that all emitted ammonia is quickly converted to particulate matter (particle size ≤ 2.5 μm) and is then deposited as particulate matter. A more accurate representation of ammonia using TAPM would rely on knowledge of sulphur dioxide and nitrous oxide concentrations (which influence rate of particle formation) or the use of a complex chemical mechanism, which is not available in TAPM version 3.

Once the model run was completed, wet and dry deposition data, as a function of grid location, were extracted from the TAPM output and used to estimate the total ammonia deposited directly into the Pumicestone Passage waterbody and also the total ammonia deposited onto the surrounding catchment area.

RESULTS AND DISCUSSION

The 41 poultry facilities identified within the Pumicestone Passage Catchment are estimated to emit as much as 1,822 Tonnes of gaseous ammonia into the atmosphere each year. A summary of the fate of these emissions is presented in Table 1.

Table 1: Ammonia deposition into the Pumicestone Passage and surrounding catchment (kg).

	Wet	Dry	Total
DEPOSITION ONTO PASSAGE WATERBODY:	2038	258	2296
DEPOSITION ONTO CATCHMENT:	50261	3248	53509
TOTALS:	52299	3506	55805

It is evident that only 3% of the total emitted ammonia is accounted for through deposition onto the study areas. This suggests that the majority of the emitted ammonia is deposited outside of the designated catchment area or simply transports out of the study region on the wind. While this ammonia has not been deposited directly into the Pumicestone Passage, the possible environmental impacts of this ammonia cannot be ignored as it may contribute to reduced water quality outside of the study grid, such as in Moreton Bay or dams, creeks, etc. within the larger southeast Queensland region.

Of the ammonia that does deposit within the study areas, only 4% (2.3 Tonnes) is deposited directly into the Pumicestone Passage and the remaining fraction is deposited onto the designated catchment area; this is attributed to the relatively small surface area of the passage, and also the fact that most deposition occurs near the sources, many of which lie within the catchment area. This value of 2.3 Tonnes was compared against data sourced from the preliminary report from Healthy Waterways (2002), in which it is estimated that approximately 1400 Tonnes of ammonia deposit into the Moreton Bay each year. After adjusting for relative surface area (3%) and relative source contribution (6.8% of all ammonia emissions are from poultry activity), it may be estimated from the Healthy Waterways data that 2.85 Tonnes of ammonia enter the Pumicestone Passage each year as a result of poultry activity within the region. Even though this figure is an approximation and relies on a number of assumptions, it gives support to the value of 2.3 Tonnes/year.

Although 96% (54 Tonnes) of the deposited ammonia is onto the catchment area, this does not necessarily all enter the Pumicestone Passage; a large amount may be deposited onto buildings, roads and other surfaces as well as into dams, rainwater tanks and other stationary water bodies. Additionally, a large amount of the ammonia is absorbed by vegetation and organic matter. While catchment deposition may not appear to impact the water quality in the Pumicestone Passage directly, it cannot be disregarded: impacts following land deposition include acidification of soils and over-fertilization of sensitive crops (Becker & Graves, 2004) as well as eutrophication of stationary water bodies. While it is unlikely that all of the ammonia deposited onto the catchment will reach the Pumicestone Passage, the topography of the catchment is such that a small but significant amount of the ammonia may ultimately end up in the Pumicestone Passage due to run-off and soil leaching, especially during flooding events common to the low-lying regions, rivers and creeks of the Southeast Queensland region. For example, even if only five percent of the ammonia deposited onto the catchment were to run-off into the passage, this could equal as much as 2.7 Tonnes per year, which is comparable to the direct deposition into the passage.

The deposition of ammonia directly into the Pumicestone Passage and also into the surrounding catchment is predominantly via wet deposition. Although not presented in detail in this paper, there is also significant variation in the relative contributions of wet deposition against total deposition across three sub-catchment areas (66%, 88% and 95%). It is possible that these differences are due to differences in rainfall patterns within the region. This observation may be extrapolated to a greater area: as the Pumicestone Passage receives a significant number of rainfall events, particularly during the warm summer months, the total deposition of ammonia may be greater compared to regions where rainfall events are less frequent. An additional point of discussion is the possible impact of climate change. The predicted increase in the intensity and frequency of rainfall events (AGO, 2002) will result in a greater amount of ammonia entering the Pumicestone Passage through both direct wet deposition and also catchment run-off.

It is difficult to confirm whether the ammonia entering the Pumicestone Passage from poultry activity is causing the eutrophication outbreaks in the Passage and wider Moreton Bay region; additional sources of nitrogen, phosphorus and organic carbon must also be identified in order to determine the relative impact of the poultry-sourced ammonia emissions. For example, the National Pollutant Inventory (2006-2007) indicates that a relatively small percentage of ammonia emissions (6.8%) are from poultry activity, which highlights the importance of other sources. However, it is clear that poultry-sourced ammonia is a contributor to the nitrogen budget of the Pumicestone Passage and has the potential to become more significant as the industry continues to grow.

CONCLUSION

This detailed modelling study indicates that, from the current stocking quantities of poultry in the Pumicestone Passage region, 2.3 Tonnes of ammonia are deposited directly into the Pumicestone Passage waterbody each year. This value is potentially multiplied several fold if just a small fraction of the 54 Tonnes of land-deposited ammonia is washed into the passage from rainfall run-off.

TAKE HOME MESSAGES

While the release, transport and impact of water-borne nutrients are well-studied, the contribution of air-borne nutrients, which include gases, dust and ash, must not be neglected when considering the total nutrient budget for large waterbodies and land areas. This study has shown that large quantities of ammonia, emitted from high-density agricultural production facilities, may be transported on the wind and deposited into water bodies that may be sensitive to the increased nutrient levels. As the control of such emissions can only occur at the source, careful consideration must be given to the location and nature of facilities that emit such pollutants.

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