Assessment of the State of Atmospheric Nitrogen and Phosphorus in the Lower Fraser Valley (LFV)

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Executive Summary

Nitrogen (N) and Phosphorus (P) are critical nutrients in limiting the growth of plants and organisms. However, high-level atmospheric N and P can cause adverse effects on the receiving water, air, and soil ecosystems, triggering numerous environmental problems. This study focuses on the state of atmospheric nitrogen and phosphorus in the Lower Fraser Valley, British Columbia, Canada, and aims to find primary sources of emissions of nitrogen and phosphorus into the atmosphere. In the study area, there is a total of 25960 tonnes of N emitted into the atmosphere. Both agricultural and urban ecosystems contribute to N emissions. The agricultural emission is approximately 8260 tonnes of N, accounting for 71% of total NH_3 emission and 10% of total NO_x emission, mainly from fertilizer and manure volatilization and rural fuel combustion. In contrast, the emissions of NO_x in the LFV is dominated by the urban ecosystem due to municipal solid waste incineration and fuel combustion. As for P emission, even though there is no robust data to quantify the emission sources, the finding suggests that dust emission and food waste incineration are the main drivers. With the increasing awareness of adverse effects associated with excessive atmospheric N and P, the government in British Columbia should pay more attention to this issue and develop relevant policies and management practices, and encourage more programs to focus on nutrients elimination mitigation.

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1 Introduction

1.1 Natural Cycling of N and P

Nitrogen (N) and phosphorus (P) are generally considered essential components that are critical for the environment and the survival of living organisms. In the atmosphere, nitrogen existing as dinitrogen gas (N_2) is abundant, accounting for nearly 78% of the Earth's atmosphere by volume. It is largely unavailable to most organisms in this form. The process of nitrogen fixation can convert N_2 into ammonia (NH_3), which is biologically available. Then, the nitrification process converts NH_3 to nitrite (NO_2^-) and nitrate (NO_3^-) (Figure 1). To maintain a global balance, the denitrification process converts NO_3^- back to N_2. When organisms die or excrete wastes, nitrogen existing in the tissues of plants and organisms is transferred from organic nitrogen (such as amino acids) to ammonia (inorganic forms) and then released into the ecosystem through the ammonification process.

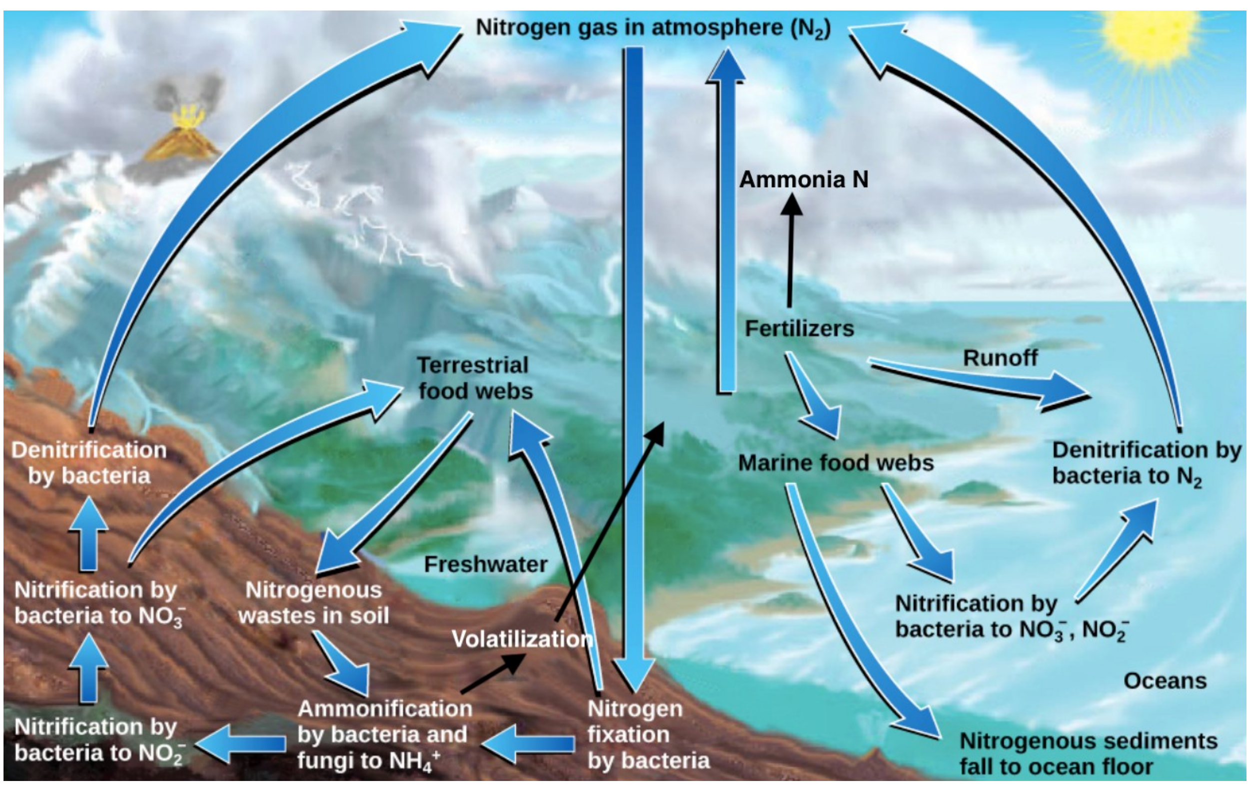

Figure 1. Natural cycling of Nitrogen (Modified based on *Biogeochemical cycles: Figure 4* by OpenStax College, Concepts of Biology.).

In contrast to N, P does not have a stable gaseous phase in the Earth's atmosphere (Figure 2). In nature, most phosphorus exists in the form of phosphate ions. Volcanic ash, aerosols, and mineral dust have a large fraction of phosphate compounds (Braghney *et al.*, 2015; Gross *et al*., 2020). Phosphate compounds stored in the soil can be absorbed by plants and then transferred to animals. Phosphate can be returned to the soil through the function of detritivores when plants die, or animals excreted wastes. It also can be carried to water bodies where aquatic organisms can consume phosphate compounds.

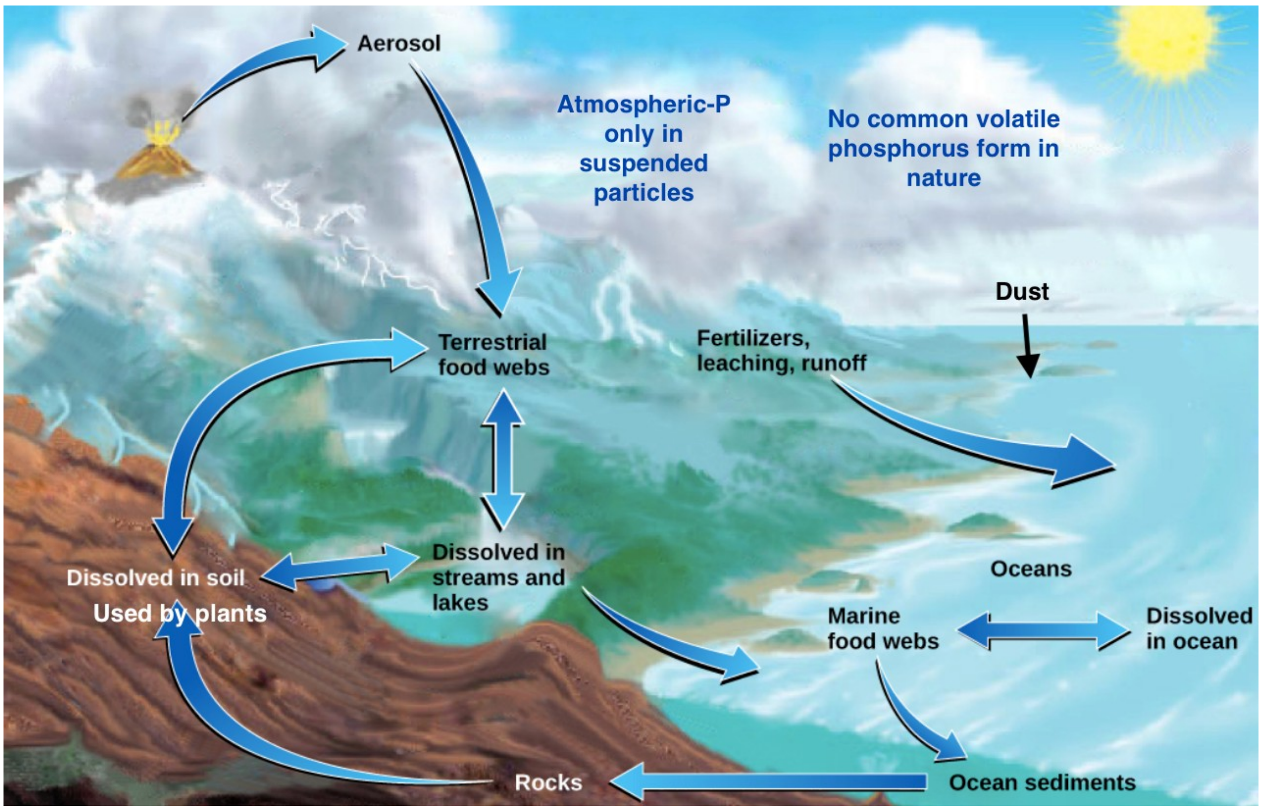

Figure 2. Natural cycling of Phosphorus (Modified based on *Biogeochemical cycles: Figure 5* by OpenStax College, Concepts of Biology.).

1.2 Risks Associated with Atmospheric N and P

As principal macronutrients, N and P supplied through atmospheric deposition play essential roles in determining ecosystem productivity and species composition (Baker *et al*., 2007). However, high-level atmospheric N and P can cause adverse effects on the receiving water, air, and soil ecosystems. These effects trigger numerous environmental problems, such as aquatic ecological system decline (Hu & Cheng, 2013), drinking water quality (Bao *et al*., 2012), and the occurrence of endemic diseases (Zhao *et al.,* 2012). The aquatic environment can receive large amounts of nutrients from the atmosphere and is sensitive to changes in nutrient inputs. Excess N and P loadings may induce eutrophication (Figure 3), which is the accelerated production of plant-based organic matter, such as algal blooms. Eutrophication can lead to deficient oxygen concentrations, thus decreasing the biodiversity of the aquatic ecosystem notably aerobic organisms (Liang *et al*., 2014; Sharpley & Wang, 2014). In addition, ammonia, one form of atmospheric N, can react with sulphuric and other strong acids to form fine particles (PM 2.5), which is considered a public health hazard (Wang et al., 2018; Giannadaki et al., 2018). Other than N_2, high volumes of atmospheric nitrogen are often associated with detrimental consequences, such as acid rain caused by nitrogen oxide (NO_x) and the greenhouse effect caused by nitrous oxide (N_2O) (Morford, Houlton & Dahlgren, 2011). Thus, in terrestrial ecosystems, N and P are considered growth-limiting nutrients (Elser *et al.,* 2007). The imbalances of N and P loadings can significantly influence the supplies of bioavailable N and P, influencing plant growth (Zhu et al., 2016). Meanwhile, N and P in terrestrial ecosystems can be transferred into oceans, lakes, and rivers through precipitation and erosion, posing a threat to aquatic organisms and their habitats.

Figure 3. Lake eutrophication (Image credit: Soil-net.com).

1.3 Global Distribution of Atmospheric N and P Sources

Over the past few decades, anthropogenic activities have significantly changed the global patterns of N and P, resulting in increasing fluxes of the two elements throughout the atmosphere (Galloway *et al.*, 2004; Hundey *et al*., 2014; Mahowald *et al.,* 2008). Primary sources of atmospheric N include agriculture, industry, and transportation (Nanus *et al.,* 2018). Agricultural sources mainly contribute to NH_3 emission, fossil fuel burning industries account for a significant fraction of total NO_x emission, and both agricultural sources and natural sources lead to N_2O emission. As for P, mineral aerosols are the dominant source of atmospheric total phosphorus (TP) on a global scale, accounting for 82% (Graham & Duce, 1979; Mahowald *et al*., 2008). In non-desert regions, other sources also include primary biogenic particles and combustion sources (such as fossil fuel, biofuels, biomass burning), and the proportions are 12% and 5% respectively (Mahowald *et al*., 2008). It is estimated that sea salt and volcanic sources account for a small fraction of atmospheric TP input, except for areas that are adjacent to volcanic activity (Mahowald *et al*., 2008).

Given the rising human population, increased demand for food, and climate change. The impacts caused by global N and P cycles are expected to be more critical in the following decades. Therefore, to protect terrestrial and aquatic ecosystems, there is a growing need to identify, quantify, and mitigate the sources of atmospheric N and P, which is crucial for introducing appropriate and effective environmental management measures including regulations, monitoring, restoration measures, and allocation of funding.

2 Project Objectives

The objectives of this paper include:

- Understand how anthropogenic activities disturb the natural N and P cycles,
- Identify the primary sources of N and P emissions into the atmosphere,
- Understand the current environmental conditions of the study area in terms of atmospheric N and P, and
- Provide beneficial management options that can be used to control the input of the atmospheric N and P and mitigate the adverse effects

3 Scope of Project

N and P exist almost everywhere in the environment and can be found in soil, biota, surface water, groundwater, and the atmosphere (Paerl, 2009). There is a variety of sources that emit nutrients (N and P) from other environments to the atmosphere as a result of anthropogenic activities. This paper will focus on N and P existing in the airshed environment and explore the primary sources contributing to the input of N and P. Previous research has paid much attention to the terrestrial ecosystem and aquatic environment, as these nutrients play vital roles in primary productivity and species composition (Brahney *et al.,* 2015). However, the global cycles of N and P have been altered over the last century, and there is an increased influx of N and P through the atmosphere. Therefore, the investigation of atmospheric N and P and solutions is required.

4 Study Area

4.1 Location, Climate and Land Use

The study area is the Lower Fraser Valley (LFV), which is located in southwestern British Columbia (BC) and surrounded by mountains, the international border with the US, and the Pacific Ocean. It is a peri-urban region. As shown in Figure 4, the agricultural areas are light green, urban areas are grey, and mountains are dark green (Bittman *et al.,* 2019). This area has advantages in agricultural development since it has the most fertile soil in Canada. The LFV also enjoys a Pacific Maritime climate with a long growing season, mild winters, and abundant rainfall, which means the LFV is highly suitable for a diverse range of agricultural production (Bittman, Sheppard & Hunt, 2017). In addition, the LFV is home to a large number of poultry and dairy farms, generating excess manure, which must be applied to neighbouring farms (Bittman *et al.,* 2019). Animal manure plays a significant role in providing plant-available nutrients, as it contains abundant macronutrients like nitrogen, phosphorus, potassium, and micronutrients (i.e. metals and organic matter). However, excess manure and the improper use of manure can cause negative impacts on air quality owing to the emissions of NH_3 and N_2O (BCAC, 2004; Hou *et al*., 2016). In addition, for on-farm production, all the mineral fertilizer N, a significant contributor to NH_3 emission, applied in the LFV is imported from other regions.

Figure 4. Map of the study area --- Lower Fraser Valley (Bittman *et al*., 2019).

4.2 Urban Area

The urban area in the LFV has undergone rapid growth in population, experiencing a 9% increase between 2005 and 2011 (Bittman *et al.,* 2019). This area is characterized by worldwide urbanization; meanwhile, increasingly wealthy populations concentrate on the LFV, leading to an increase in the demand for nutrients in food, amenities, and locally produced fresh food (Bittman *et al.,* 2019). As a consequence, many urban regions in the LFV have become massive sinks for nutrients resulting from food waste. Although several cities have launched programs to recycle organic waste and these are useful to reuse the C in the waste, recycling waste does not have a significant impact on controlling or mitigating other nutrients like N and P. Limited amount of N can be returned to areas where food and feed are produced to help replace fertilizer inputs. However, nearly all the N is either emitted as NH_3 and other gas forms or leached into the aquatic environment, creating environmental burdens in the LFV.

4.3 Air Quality

As population and agricultural intensification grows in the LFV, air pollution is becoming an increasingly important issue. Every spring and summer, a white haze arises in Chilliwack and Abbotsford carries loads of toxins that penetrate the lungs, leading to an increase in mortality and hospital visits in BC. The poor air quality and low visibility in the LFV also has impacts on outdoor recreation and outdoor tourism (Bittman, Sheppard & Hunt, 2017).

5 Methods

5.1 Literature Survey

This report is based on papers and research reports focusing on nutrients cycling and gas emissions in their titles, abstracts, and keywords, especially those conducted in the Fraser Valley. In the published work, I also reviewed literature associated with N_2O emission, greenhouse gas (GHG) emission and ammonia emission, which have connections with N emission into the atmosphere and those that received attention for the study region. The wet and dry atmospheric deposition of N and P is not included in this study, since the data is sparse for the study area. This paper synthesized information on beneficial management practices that have been adopted and those that have not been implemented, and helpful to control the emissions of N and P, in addition to the official websites of Canada and BC Province and other governmental documents.

5.2 Measurements Made in the Present Research

5.2.1 Research Conducted at UBC

Patrick (2019) carried out a research project to quantify year-round emissions of greenhouse gases including carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4)

the exchange over a conventionally managed highbush blueberry field located on Westham Island in the LFV using the eddy-covariance (EC) method. The conventional management here refers to the operations of interrow mowing, blueberry pruning, and the application of NH_4NO_3 fertilizer. While several previous studies used the static and dynamic chamber to measure GHG emissions (Rochette *et al.,* 2018), Patrick (2019) chose to use the EC method, which is considered a more accurate and reliable approach for GHG measurement. The EC system included one three-dimensional sonic anemometer and two gas analyzers, IRGA, and LGR. The air in the study region was sampled independently by IRGA and LGR with flow rates of 15-18 L min^{-1} and 20 L min^{-1} respectively, and they were calibrated manually every 1 or 2 weeks in the field during the experimental stage. The EC fluxes were calculated half-hourly in the field and then transferred to UBC for further data analysis using MATLAB (Patrick, 2019). This research did not include P. The emission of N_2O has a more considerable impact than CO_2 in causing global warming (Johansson, Persson & Azar, 2006). This research can reveal how agricultural managements influence the fluxes of atmospheric N.

5.2.2 Research Conducted by Agriculture and Agri-Food Canada

Bittman *et al*. (2019) investigated nitrogen cycling in the LFV. They built a budget model to quantify the various pathways of influx, efflux, and internal flows of N in the study area. In general, the estimations of influxes and effluxes for the area were obtained by multiplying the per person, per animal, or per hectare quantities and the corresponding populations in the area. This model was an annual accounting process, and thus final units were shown as N mass per year. The number and types of residents and the proportion of urban regions were collected from Statistics Canada published online. The number of livestock and poultry animals and crop acreages were obtained from the Census of Agriculture data and the BC Ministry of Agriculture. (More input data and detailed calculations can be found in the Appendix of the published report). The model separated the LFV into two parts, one was the agricultural ecosystems, which produces marketable products on agricultural land, and the other was the urban ecosystem, which occurs primarily but is not limited to cities and towns. Bittman *et al.* (2019) calculated the N budget for different activities associated with N flows in both ecosystems. N fluxes in agricultural productions are related to fertilizer import, feed import, animal product imports and exports, and edible crop production and effluxes. As for the urban ecosystem, N fluxes are related to activities such as food consumption, horse and pet feed, lawn, golf course, and park fertilization. Through the comprehensive analysis of nutrient cycling and regional activities, the sources of N emissions and effective mitigation solutions were identified.

Similarly, Bittman *et al.* (2017) used the same method to build a model to assess the P budget in the LFV, but this model did not include the P in the atmosphere. This model separated the LFV into agricultural and urban ecosystems and quantified the influxes and effluxes of P inside the boundaries of the LFV. In the agricultural ecosystem, activities such as fertilizer imports, feed imports, and animal products were associated with P flows, while the P fluxes in the urban ecosystem are mainly related to food consumption and food waste.

6 Key Findings and Discussion

Based on the extensive literature survey, it was found that atmospheric N emissions have received more attention than P emissions. This may be because P does not have a gaseous state in nature and the majority of P in the atmosphere adheres to dust, which makes the monitoring and P budget estimations within the system more complicated. Only a few studies have estimated and quantified the sources of atmospheric P through the method of observation and building models (Graham & Duce, 1979; Mahowald *et al*., 2005; Mahowald et al., 2008). The results have significant uncertainties because of the inadequate agreements between the two methods, and the atmospheric fluxes of P have often been ignored. Therefore, there is a large gap in the knowledge of atmospheric P sources, especially in the study area. For N emissions, most studies focus on forms of N in the atmosphere excluding N_2 such as NO_x, N_2O, and NH_3 because N_2 does not degrade the environment, and some reliable methods such as modelling are applied in the estimation of

N cycles and the results agree with observations. The results are provided in the following sections.

6.1 N Emissions in the LFV

6.1.1 N Emissions in the Agricultural Ecosystem

As shown in Figure 5, the N budget estimated by Bittman *et al.* (2019), both agricultural and urban ecosystems contribute to the N emission in LFV. In the agricultural ecosystem, there are a total of 26900 tonnes of N influxes into the system, and 6730 tonnes of this is NH_3-N to the atmosphere. An additional 1890 tonnes of NO_x-N are emitted from rural fuel combustion. All the NH_3 emission is induced from residual N in agricultural soils (8281 tonnes). In fact, this residual N left in soils is the N from manure, fertilizer applications, and atmospheric deposition minus crops requirement. As mentioned in section 4.1, the LFV has a variety of poultry and dairy farms. It is estimated that livestock within the LFV released 17300 tonnes of N annually (9750 tonnes N on dairy farms and 6100 tonnes N on poultry farms). A large amount of manure produced on poultry farms is applied to horticultural crops, especially raspberries or forages where the manure can be used as a C source or to produce compost for farm operations. The remaining manure from poultry farms may be exported to other farms outside the LFV. However, all manure generated on dairy farms is kept on-farm and applied to corn and grass fields. Additionally, most liquid dairy manure is stored in tanks at low temperatures throughout the whole winter. It is believed that the content of N_2 released by chemical denitrification is relatively small because this process normally occurs in lagoons in warm environments (Harper *et al.*, 2004). Although manure also releases other forms of N in the gaseous stage, NH_3 is the most dominant proportion in the emission (Olivier *et al.,* 1998). After the manure emission, there remain 10700 tonnes of N in the LFV, which is about twice the N requirements of crops grown in the LFV. Nevertheless, a great deal of fertilizer is imported to the study region every year. As displayed in Figure 2, fertilizer import of 4521 tonnes of N is the second largest inflow of N in the agricultural ecosystem. It may be possible to minimize or avoid this influx since there is excess manure N in the LFV. However, manure cannot completely replace fertilizer because part of N in manure is fixed by organic compounds (Bittman *et al.*, 2017) and results in lower efficiency than commercial fertilizer. Hence, fertilizer N is necessary when crops require rapid N uptake, including livestock operations. Atmospheric deposition of 1811 tonnes of N is relatively small and it is not an anthropogenic input of N; thus, there is no need for further discussion.

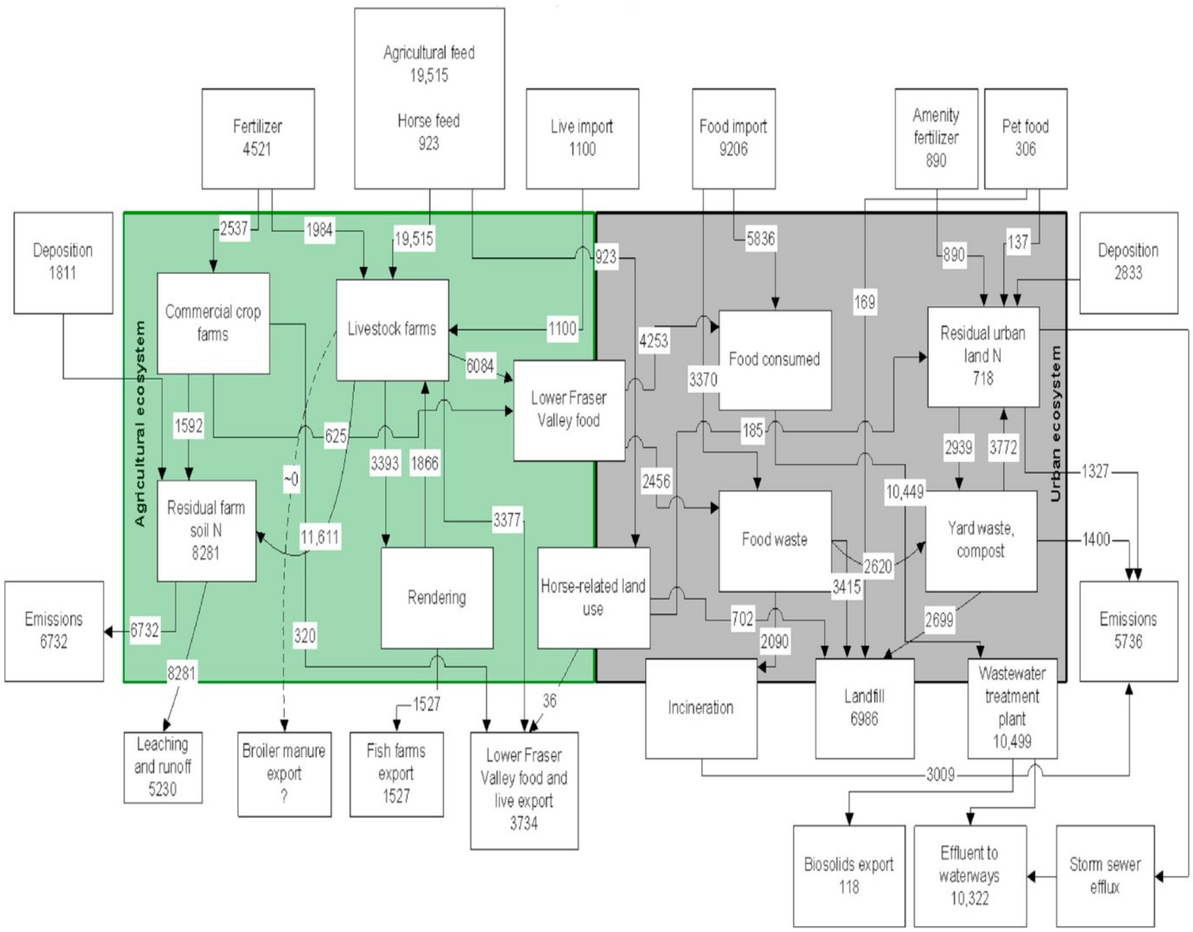

Figure 5. Flow chart of the estimation of N influxes and effluxes in the LFV, the unit of N budget is tonnes per year (Source: Bittman, Sheppard, Poon & Hunt, 2019)

6.1.2 N Emissions in the Urban Ecosystem

In urban ecosystems, there was a total of 19230 tonnes of N emitted into the atmosphere. In Figure 2, the N emissions come from three sources: N in urban soils, yard waste compost, and incineration, contributing 1327, 1400, and 3009 tonnes of N, respectively. As mentioned in section 4.2, food import and food production within the LFV increased rapidly in recent years in the urban sector, and food waste has become a serious problem in the LFV. Food waste, designated as municipal solid waste (MSW), is normally handled with three approaches, composting, incineration, and landfill. Composting waste is considered a sustainable strategy. In the LFV, waste management is also evolving to promoting composting of all food waste, while most lawn and yard waste is already been composted. However, composting can lead to the emission of NH_3-N and it accounts for approximately 2730 tonnes of N emitted in the form of NH_3 from the LFV to the atmosphere. In addition, 3000 tonnes of N in MSW is incinerated, and it is assumed that N is transferred into NO_x and is fully discharged to the atmosphere. While composting contributes to N emissions into the atmosphere, it is a better management option than incineration of waste. On the other hand, reducing the volume of food waste is helpful to mitigate the N emissions in the LFV. As people become wealthier and have more choices on food, the situation tends to be exacerbated by discretionary diet (Benis and Ferrão, 2017), which exceeds the necessary nutrients human require and only add varieties to people's diet. Finding clean and effective approaches to handling food waste is as important as altering the dietary habits of residents.

Furthermore, urban fuel use also contributes to a larger amount of NO_x emission, and the emission is estimated to reach 13500 tonnes of N, and this undoubtedly is harmful to the environment and requires regulations to control emissions. Emissions from transportations and vehicles are not included in this study because of the lack of data.

6.1.3 Overall N Emissions in the LFV

Overall, 25960 tonnes of N is emitted into the atmosphere in the LFV. As shown in Figure 6, emissions of NH_3-N are dominated by the agricultural ecosystems, and the agricultural emission accounts for 71% of total NH_3-N emissions in the LFV, which is consistent with other regions in Canada (Ayres et al., 2010). Emissions of NO_x-N in the LFV are dominated by the urban ecosystem due to MSW incineration and fuel combustion, and the amount is almost nine times higher than emissions caused by fuel combusted in rural areas. In addition to these massive emissions, Patrick (2019) found the agricultural sites are the sources of year-round N_2O emission, and increased emissions are associated with N fertilization on agricultural soil. Therefore, the situation of N emissions is not optimistic in the LFV, and there is a need to mitigate N efflux into the atmosphere for public and environmental health.

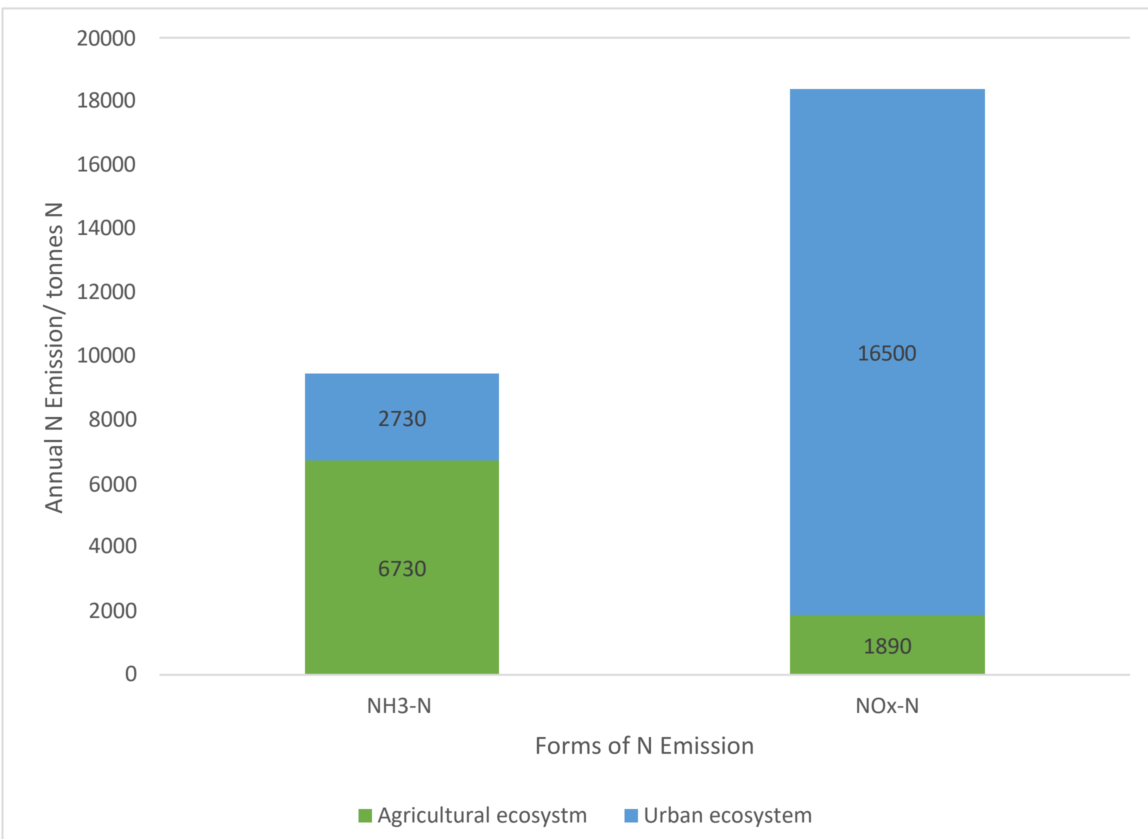

Figure 6. N budgets for emissions in the agricultural and urban ecosystems.

6.2 P Emissions in the LFV

The sources of atmospheric P cannot be quantified due to a lack of data. Still, the related studies can help identify the possible sources of airborne P in the LFV, which will aid to inform beneficial management practices to improve the environment. Dust emission is the dominant pathway of P emissions into the atmosphere. Fryear (1981) and Sundram *et al*. (2004) found a direct correlation between soil nutrient loss and increased dust emission and transport. Weathering of P from rocks and soils, and subsequent deposition is the major source of P to the aquatic ecosystems, but anthropogenic activities have disturbed the natural P cycles (Peñuelas *et al.,* 2013). The application of mineral P fertilizer is considered as the main anthropogenic driver (Wang *et al.,* 2014). In the LFV, based on the model built by Bittman *et al.* (2017), the annual import of mineral fertilizer is estimated to have 1400 tonnes of P. Of this, 1100 tonnes of P are imported to the agricultural ecosystems for croplands and animal feed, and 300 tonnes of P is applied to urban lawns, golf course, and parks. Manure from livestock production within the LFV is an input of P to land. When wind erosion occurs, manure and fertilizer could be potential sources of P to the atmosphere.

Secondly, fuel combustion is the major source of P emitted into the atmosphere in urban ecosystems. Generally, industry P emissions include the phosphate industry and stationary combustion sources (Wang *et al.*, 2014). The LFV does not have phosphate industries, but the food waste incineration can emit P into the atmosphere. Additionally, the fugitive dust sources in urban areas (e.g. from unpaved roads, high traffic roads, and construction sites) contribute to P emissions. These P-rich particles generated from both agricultural and urban ecosystems can deposit in ocean, lake, and soil, possibly leading to excess P in a certain area and pose a threat to regional microorganisms and plants. These particles can be transported from outside the LFV to the study area; hence, the nutrients in the surrounding airshed are also important but will not be discussed in this study due to limited data.

P cycles in nature, unlike N cycles, which have significant atmospheric components, only have a small reservoir of P in the atmosphere, and P cycles appear to be one-way flows

(Bouwman *et al.,* 2009). In addition to other environmental risks, there is another concern regarding the finite supply of P, because there are no substitutes for P. Hence, the overuse of P resources is a threat to ecosystems and it is also a concern of economic loss since the valuable P is not available for productions. Mitigation of P losses and increase of P use efficiency may help protect the environment (Metson *et al.,* 2012).

7 Recommended Solutions

7.1 Existing Guidelines and Management of Atmospheric N and P

On the global scale, NH_3 is regarded as a pollutant controlled by a number of international directives, in particular the UNECE Convention for Long-Range Transport of Air Pollutants (CLRTAP, http://www.unece.org/info/ece-homepage.html), and the European National Emission Ceilings. In Canada, NH_3 is considered one of the Criteria Air Contaminants (CAC, https://www.canada.ca/en/environment-climate-change/services/air-pollution/pollutants/common-contaminants.html), posing threats to public and environmental health. As estimated by Ayres *et al*. (2010), approximately 86% of NH_3 emission originates from agriculture. However, there currently is no federal or provincial governments in Canada which have launched programs to control and mitigate the emissions of NH_3 from farms and only several mitigation practices have been accepted in varying degrees by farmers in Canada (Bittman *et al.,* 2014), including (i) selection of low- emission application practice for mineral fertilizer, such as side-bending and gas injection; (ii) adoption of phased feeding on pig and poultry farms. This method changes the protein concentrations in feed according to the ages and protein requirements of the animals. Reducing excess protein in feed has been shown that it is useful to reduce the ammoniacal N excreted by animals, thus decreasing the NH_3 emissions; (iii) adoption of manure storage (Bittman *et al*., 2017). Manure can be stored with natural cover and low storage temperature because NH_3 tends to have lower volatilization rates under such conditions.

With the increasing awareness of adverse effects on health and environment associated with nitrogen dioxide, international agreements and national legislation have been established to limit and mitigate the oxidized nitrogen emissions, such as the On-Road Vehicle and Engine Emission Regulations (SOR/2003-2), and the Federal Agenda on Cleaner Vehicles, Engines and Fuel (Reid & Aherne, 2016). In Canada, the air monitoring networks such as the National Air Pollution Surveillance (NAPS) Program has been set up and used to monitor the pollutants in the atmosphere, including NO_2. It helps determine the spatial and temporal patterns, monitoring the atmospheric concentration levels, informing and warning of likely health and environmental impacts, and supporting timely policy changes.

For phosphorus, most regulations and strategies focus on P leaching and runoff from soil to protect water quality (Kruse et al., 2015; Withers et al., 2019) because a large proportion of P loss to surface water bodies, which is easier to monitor and control than P loss to the atmosphere. There are various strategies to reduce the risk of water contamination caused by P, such as soil P test before fertilizer application, crop rotations, adoption of feed containing lower P content, and establishment of buffer zones. One thing that has been overlooked in the LFV is that P also can be held tightly with particles such as aerosols, and wind soil erosion which could be profound and last for several days, and the subsequent deposition can lead to a high risk to surrounding surface water bodies.

7.2 Proposed Strategies for the LFV

7.2.1 Mitigation Strategies for Atmospheric N

- ***Establishment of Regulations*.** In the LFV, N is inexpensive and hence often applied in excess of crops and plants demand in agricultural lands and home gardens, leading to a large proportion of NH_3 emission and aquatic environment contamination. Additionally, the excessive consumption of high protein foods, the increasing amount of food waste, and the imports of N fertilizer for the purpose of aesthetic enhancement contribute to the increase of atmospheric N. Therefore, the government needs to set up clear regulations to limit the use of N fertilizer and enforce the mitigation of N emissions.

- ***Effective Manure Application Techniques.*** The animals within the LFV can produce a substantial amount of manure. Because of limited storage capacity, applying manure in the fall is common to ensure farmers can store manures produced during the winter until spring. However, manure applied in the fall has a significant nutrient loss due to the cool and wet BC winters (Hafner et al., 2019). It is recommended to use several manure application techniques to reduce the nutrient loss from agriculture to the atmosphere, such as band-spreading and injection techniques, which allow a more accurate manure application than spreading slurry or solid manure over the land (Bittman, 2014).

7.2.2 Mitigation Strategies for AtmosphericP

- ***Establishment of Monitoring Programs.*** As mentioned above (Section 6), while both N and P are significant nutrients in ecosystems, atmospheric P has received less attention than N in the LFV. Hence, the first strategy is to establish programs to monitor P, and the government should encourage and give incentives for better usage of P resources in the study area.

- ***Crop Residues and No-till***. Crop residue management using an innovative system including no-till, ridge-till, mulch-till, and other forms of tillage that leave crop residues on the soil surface to protect against wind erosion and reduce dust emissions. This practice is considered to have minimum cost as it reduces fuel and equipment usage, and the only major costs are the seed and planting costs, thus it can be applied to all agricultural fields within the LFV.

- ***Enhancement of Natural Barriers.*** A row of vegetation, such as trees and shrubs, are suggested to be planted along unpaved roads and agricultural fields, which can be used to break winds and reduce the possibilities of wind erosion. In addition, natural barriers bring other benefits to the environment, including providing more diverse habitats for wildlife, preventing soil erosion, and protecting the aquatic ecosystem.

- ***Reduction of Dust Emissions from Roads.*** For unpaved roads, the widely used approach to reduce dust emission is chemical suppression, namely using calcium chloride or adding oil to the road surface. For paved roads, the standard method of limiting dust emissions is street sweeping. There are numerous pollutants on roads, especially on high-traffic roads, once the pollutants are carried into the atmosphere, the surrounding environment will be affected negatively.

8 Conclusion

In recent years, anthropogenic activities have altered the global cycling of N and P. The LFV is affected by farm practices and urban activities. The results of this study show that the losses of N and P into the atmosphere should be a concern in the LFV, and both agricultural and urban ecosystems are responsible for disproportionate contributions. For N emissions, the agricultural sector accounts for significant proportions of total NH_3 and N_2O emissions in the LFV, largely because of the application of N fertilizer and excessive manure produced on farmlands. On the other hand, the emission of NO_x is dominated by the urban ecosystem, and the sources include MSW incineration and fuel combustion. As for P, although it does not have a gaseous state in the atmosphere, it can be held tightly by aerosols such as dust particles, influencing the atmospheric P content and subsequent deposition. For P emissions, currently, there is no available data to quantify the emission sources, previous studies suggest that P fertilization, manure, and waste incineration can affect the input of P to air. It is apparent that N and P are not fully utilized in the LFV especially in the agricultural lands. The excess fertilizer and manure lead to excess nutrients in soils, and then the nutrients may discharge into nearby surface water bodies or be emitted into the atmosphere. In any case, the unnecessary accumulation of nutrition is a potential risk to microorganisms and the environment. Currently, the government in British Columbia has focussed their attention on leaching and soil erosion in terms of N and P losses. However, the atmospheric emissions also influence ecosystem services. Therefore, the sources of atmospheric N and P must be better understood so that beneficial management strategies for emission mitigations can be improved, contributing to better nutrient cycling. Better guidance on methods to improve the nutrients efficiency, analysis, and management in the LFV is needed. The limitations to assess the state of atmospheric N and P in the LFV include lack of regional data, uneven distribution of emitting sources, and seasonal variations, which need to be noticed for further studying.

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