Quantifying Ecosystem Services in an Agricultural Region in Southern Ontario Using a GIS-Based Approach and Open Source Data

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ABSTRACT

There has been a land use battle in Pickering, Ontario between conservation groups and Transport Canada over the development of another International Airport in Southern Ontario on valuable farmland. The purpose of this research is to quantitatively assess the claims made by the conservation groups about the importance of the local farmland for maintaining the area's water quality. The research has three objectives: (1) to determine whether or not the use of publicly available data and a GIS-based approach is appropriate for an ecosystem services survey related to water quality and nutrient loading in the area of the proposed airport; (2) to examine the relationship between crop yield and nutrient loading to understand if the ecosystem disservice related to excess nutrient export can be reduced without reducing crop yield; (3) to make spatially explicit recommendations on mitigating efforts that farmers in the PLA region take to reduce nutrient loading for both nitrogen and phosphorus. The results of this study suggest that the coarse resolution of publicly available data results in multicollinearity that renders the GIS-approach ineffective at quantifying spatial relationships among ecosystem (dis)services at this spatial scale. The GIS-based nutrient indices approach will likely be more effective at larger (e.g. multiple counties, provincial) spatial scales and is still a useful tool for identifying key areas for prioritizing the implementation of agricultural best management practices. The most affective mitigating efforts to reduce nutrient loading include changing fertilizer application methods to non-broadcast methods and to improve land use types in areas that are close to surface waters and headwaters.

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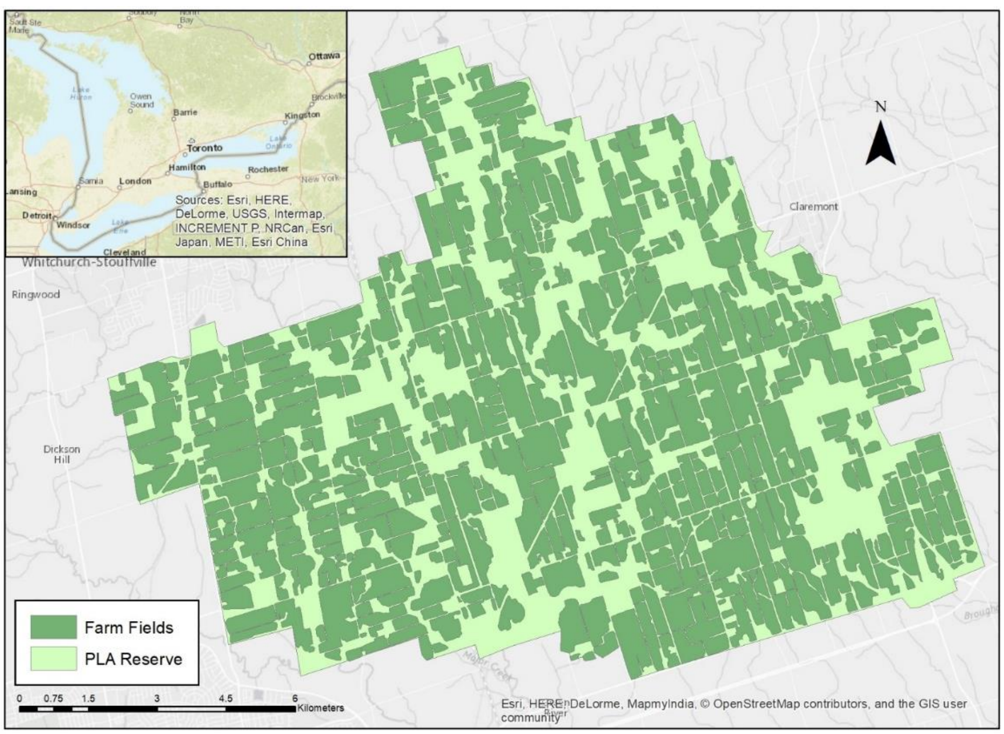
Chapter 1: Introduction

1.1 Statement of Research Problem

The population in Southern Ontario is increasing which has spurred on higher demand for agricultural output from farms. This combined with a rapid decrease in available soils has created a need for efficient farming with higher outputs per hectare (Miller, 2013). A large swath of farmland is currently threatened by proposed development of an airport in Pickering, Ontario (Figure 1.1). Given the need for higher food outputs, the Pickering Lands Airport (PLA) has become a controversial topic in Southern Ontario with respect to conservation, crop yield, and water quality. Many stakeholders claim that this farmland should remain unpaved because it benefits Ontario's food security and helps maintain good water quality for Lake Ontario. The focus of this study is to examine these two claims in depth using a quantitative, spatially explicit, ecosystem services approach and to inform future agricultural practices in the area. This study is not looking to compare disservices provided by farmland and airports.



Source: Land Over Landings (2017)

Figure 1.1: Pickering Lands Airport Lands Reserve and Farm Fields Outline

Whenever a crop is harvested and removed from the agricultural ecosystem, its nutrients, that would normally be returned to the soil when that plant decomposes, are removed as well (Miller, 2013). To maintain suitable soils for efficient crop growth, new forms of nutrients must be added back into the ecosystem. One way to meet the growing demands for food and maintain soil suitability is to use fertilizers and nutrient rich manures. Nitrogen and phosphorus are common in these fertilizers as they are key compounds in plant growth. Unfortunately, not all crops uptake these nutrients at the same rate and there are often excess nutrients left in the soils in less usable forms (Rens et al., 2016). Once the crop is harvested, remaining nitrogen is turned to nitrate (NO_3) which is water soluble. Similarly, the remaining phosphorus, which is bound to soil organic matter, becomes more susceptible to erosion due to lack of root structure. Depending on differing farming practices such as fertilizer application rates and crop row orientation, these excess nutrients can be transported through leaching or erosion. Eventually, they will reach surface waters (Sharip et al., 2011) which can lead to negative impacts on the health of the surrounding water shed (Daniel et al., 2009). Eutrophication of freshwater systems is the most common concern related to the release of excess nutrients (Sharip et al., 2011). Eutrophication is the process in which excess nutrients in a water body cause increased algal growth. As more biomass accumulates, sediments will get deposited and the water body will fill in (Shinozuka et al., 2016) as well as kill fish populations through lack of oxygen (Kangur et al., 2013). While eutrophication is a natural process, elevated nutrient concentrations due to fertilizer use in agricultural watersheds are rapidly increasing eutrophication rates and destroying aquatic habitats. (Shinozuka et al., 2016; Dupas et al., 2015; Sharip et al., 2011).

1.2 Research Purpose and Questions

The purpose of this study is to evaluate the usefulness of a GIS-based and open source data approach to quantifying ecosystem services and disservices provided by agricultural land in the PLA region. Several key research questions will be addressed in this study, including:

1) What mitigating efforts should farmers in the PLA region take to reduce nutrient loading for both nitrogen and phosphorus?
2) Can a correlation be found between nutrient loading and crop yield in the PLA region? Doing so will enable the examination of whether it is possible to reduce nutrient loading without reducing crop yield or if the two are closely linked.

3) How does the use of publicly available data affect the statistical analysis of an ecosystem services survey compared to studies which use soil sampling techniques?

This study aims to answer these questions through the completion of these four objectives:

1) To complete the calculations of a phosphorus index and a nitrogen leaching index to create spatial data sets of these scores;
2) To perform statistical analysis on these index scores along with a spatial data set of crop yield to find and examine any correlation;
3) To evaluate publicly available data's role in performing this sort of study commonly reserved for field studies;
4) To perform statistical analysis to identify areas of improvement that will reduce the index scores for nutrient loading in the PLA region.

1.3 Background Information

In 1972, after a decision to add new runways to Pearson International Airport in Toronto, Ontario was reversed, 18,600 acres of land was acquired by the federal government (figure 1.1) for the Pickering Lands Airport in North Pickering, Ontario (Land Over Landings, 2017). The purpose of this airport was to address increasing demands on the transportation sector in the GTA and relieve some of the stress that Pearson International Airport was experiencing in the late 1960s. This was met with grassroots opposition known as *People Over Planes* (Land Over Landings, 2017). *People Over Planes* made use of peaceful protest, sit-ins at expropriated farm houses, political demonstrations and lobbying to tell the federal government that an airport was not wanted. On March 6th, 1972, the Pickering Township Council passed a motion which requests "that both the Government of Ontario and the Government of Canada, through their respective responsible authorities, announce publicly that this airport will not be located in Pickering Township, or in close proximity to the Township" (City of Pickering, 2012). In 1974, the Airport Inquiry Commission found that the PLA region was not suitable for environmental, regional economic, passenger convenience, and flight operation reasons (Gibson, 1974). The following year, construction of the airport was halted. Since then, Transport Canada has held control of the PLA region which is leased to farmers on 1-year contracts. (Land Over Landings 2017). In response to the second round of evictions in 2003 on the PLA region, a new grass roots movement was started in homage to *People Over Planes* titled *Land Over Landings* (Land Over

Landings, 2017). This group has positioned itself as an environmental and agricultural advocacy group which uses sustainability rhetoric “to persuade Ottawa to preserve the [PLA] lands, long earmarked as the site of a future airport, as a secure source of food and fresh water for Canada's largest urban center." The organization's goal refers to limiting the amount of pollution that an airport can create from entering Lake Ontario since all of the PLA region eventually drains there. As of 2015, close to half of PLA region has been annexed by Rouge National Urban Park and *Land over Landings* now aims to protect and preserve the remaining ~9000 acres of farmland (figure 1.3) (Land Over Landings, 2017).

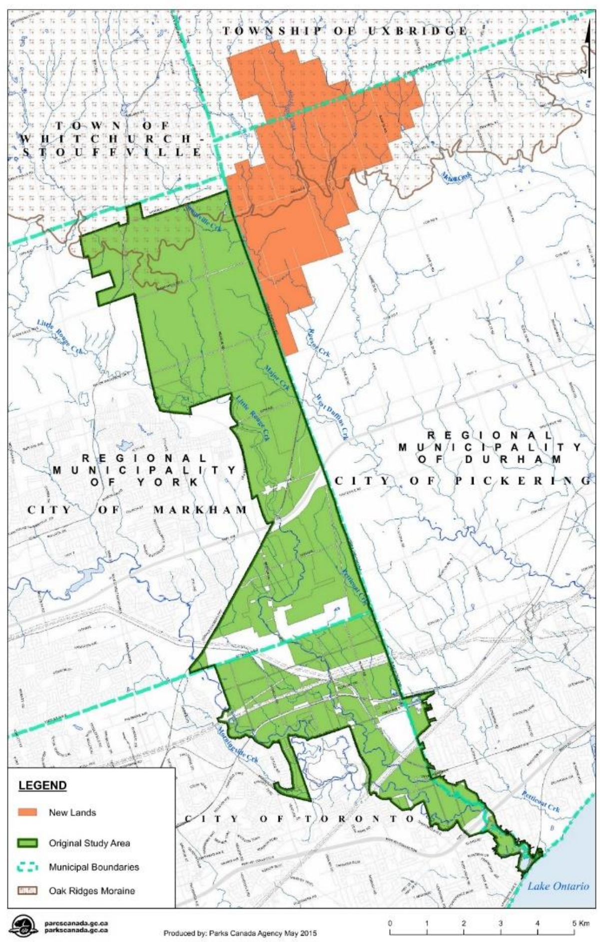


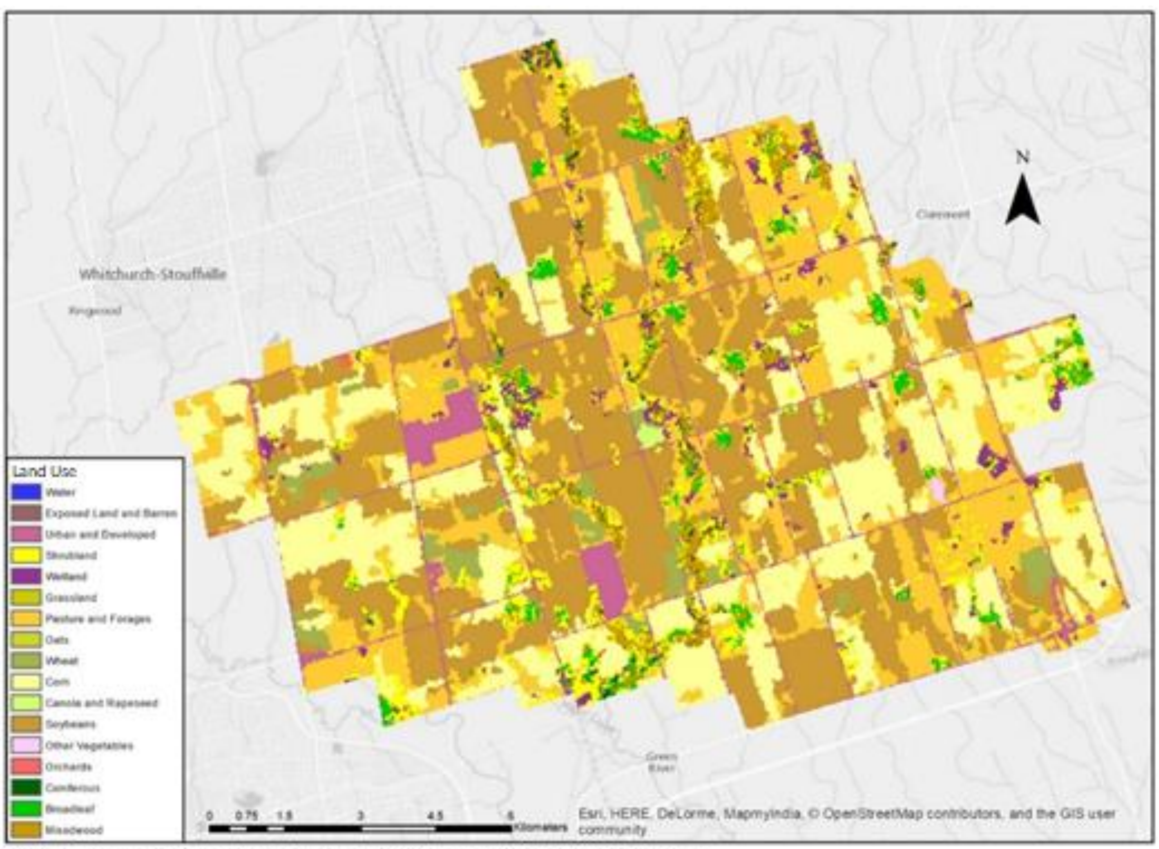
Figure 1.2: PLA Region Annexed by Rouge National Urban Park

As of May 15th, 2017, tenant laws have been updated on the remaining 9000 acres which allow tenants to take out ten-year leases on the lands rather than the previous one-year limitation. This was done to promote economic stability and enable longer term agriculture practices and strategies (Transport Canada, 2017). This decision goes against the 2010 needs assessment conducted by the Greater Toronto Airport Authority and submitted to Transport Canada which found this site to be the most appropriate site for a second international airport in the GTA (Greater Toronto Airport Authority, 2010). *Land Over Landings* has now focused on having the remaining 9000 acres be included in Ontario's Greenbelt claiming that "Our clean water sources and the fields that feed us are finite in number and among our province's most valuable resources" (Delaney, 2016). The preservation of agricultural lands and water quality is important to *Land Over landings*, but there has been little discussion on how this farm land will help maintain a clean water source. Now that plans for a future airport have been halted for the second time, no environmental assessments have been triggered (Government of Canada, Public Works and Government Services Canada, 2015) There is no information on the *Land Over Landings* website on how agricultural land keeps an area's water clean and research typically argues that agriculture is detrimental to clean water sources. This study hopes to examine this knowledge gap and evaluate whether the claims made by *Land Over Landing's* that agricultural practices help maintain clean sources of drinking water are accurate. To be clear, *Land Over Landing's* criticisms against the Pickering Lands Airport argue that the development of an international airport will be worse for a fresh water system compared to farmland. It is still important to challenge these arguments and promote agricultural best practices which will mitigate nutrient loading. Doing so will also strengthen *Land Over Landing's* rhetoric by improving the accuracy of their statements.

1.4 Study Area

The study area chosen for this project is on the original 18,600 acres plot of land reserved to the Pickering Lands Airport located in the north of Pickering, Ontario which is to the east of Toronto. The PLA region is located just north of Highway 407 and between Brock Road and the Municipality of Whitchurch-Stouffville, Ontario (figure 1.1). The airport has been in the planning stage since the 1972, and is met by grassroots resistance amongst farmers, conservationist, and those living in the surrounding municipalities (Land Over Landings, 2017). Using environmental and conservationist rhetoric, these groups have so far been successful in holding off development of the airport with the support of local minister of parliament, Mark Holland (Gibson, 2017). Federal support of the project has stopped and a recent victory for the conservationists saw around half of the land reserve shift from being controlled by Transport Canada to being annexed by Rouge National Urban Park on April 1st, 2015 (Land Over Landings, 2017). No environmental assessments have been triggered for the airport since 1972 and little research has been conducted to evaluate the environmental impacts that an airport might have on the PLA region.

This contentious area contains a variety of land uses including urban development, row crops, pastures, wetlands, grasslands and forests (figure 1.2). The break down of the study area by land use type can be seen in table 1.1. It is clear from this table that a significant portion of the area is used for agricultural purposes. The three most common land use types are pastures and forages (22.82%), corn (22.93%), and soybeans (31.72%) which totals to more than 77% of the entire study area. This compared to the 5.16% of land used for urban development, it is clear that the study area is most widely used for agricultural purposes.



Source: Land over Landing (2017) and Department of Agriculture and Agri-Food Canada

Figure 1.3: PLA Region by Land Use Type

Table 2.1: Land Use by area (m^2) and by Percentage of the PLA Region

Land Use	Area (m^2)	Percentage of Study Area
Water	810	0.02
Exposed Land and Barren	780	0.02
Urban and Developed	267210	5.16
Shrubland	330180	6.38
Wetland	103020	1.99
Grassland	6450	0.12
Pasture and Forages	1180980	22.82
Oats	990	0.02
Wheat	131010	2.53
Corn	1186680	22.93
Canola and Rapeseed	9450	0.18
Soybeans	1641780	31.72
Other Vegetables	3600	0.07
Orchards	1620	0.03
Coniferous	21990	0.42
Broadleaf	107670	2.08
Mixedwood	181740	3.51

Source: Government of Canada, Agriculture and Agri-Food Canada (2016)

The study area is on the eastern most boarder of ecoregion 6E, Lake Simcoe-Rideau (Crins et al., 2009) which extends from Lake Huron in the west to the Ottawa river in the east and includes most of the Lake Ontario's shoreline. The study area's climate is mild and moist with cool winters and hot and humid summers which allows for long growing seasons between 205 and 230 days (Crins et al., 2009). Excellent soils for farming conditions are also present here. Table 1.2, shows that more than 50% of the study area has loam as its uppermost level of soil and ~25% of the study has a clay loam mixture as its uppermost soil level. Loams ability to retain nutrients while enabling excess water to drain creates excellent soil and farming conditions (Lerner, 2017). This high percentage of loam in the study area at the uppermost soil level and long growing seasons for Ontario helps support *Land Over Landings'*s claims that the PLA region is some of the most productive farm land in Canada (Land Over Landings, 2017).

The land formations present here were created by glacial retreat which buried bedrock underneath deep layers of soils (Crins et al., 2009) These processes created moraines and rolling hills throughout the study area which add to the study area's excellent drainage into Lake Ontario (Crins et al., 2009). The Oak ridges moraine lies just north of the study area and two streams flow through the PLA region. These streams eventually drain into Lake Ontario via Duffins Creek in Pickering.

Table 1.2: Soil Type, Drainage Class, and Percentage of the Study Area

Soil Name	Drainage	Percentage of Study Area	Soil Type	Percentage by Soil Type
BRIGHTON SANDY LOAM	Well	3.33	Sandy Loam	3.35
PONTYPOOL SANDY LOAM	Rapidly	0.03		
WOBURN SANDY LOAM	Well	0.00		
JEDDO CLAY LOAM	Poor	0.19	Clay Loam	24.94
KING CLAY LOAM	Well	0.72		
PEEL CLAY LOAM	Imperfectly	24.03		
KING SILT LOAM	Well	1.44	Silt Loam	1.44
GILFORD LOAM	Poor	1.22	Loam	50.59
WOBURN LOAM	Well	19.57		
MILLIKEN LOAM	Imperfectly	29.80		
CASHEL CLAY	Well	0.38	Clay Loam	9.27
PEEL CLAY	Imperfectly	8.89		
BOTTOM LAND	Variable	9.58	Other	10.41
BUILT UP AREA	NA	0.48		
MUCK	Variable	0.36		

Source: Land Information Ontario (2012)

Chapter 2: Literature Review

2.1 Ecosystem (Dis)Services Associated with Agricultural Land

Ecosystem services refer to the benefits provided by a healthy ecosystem (Preston et al., 2017). These benefits make life easier, more enjoyable, or can generate revenue for those that live there (Preston et al., 2017). These services are divided into four distinct categories: supportive, regulatory, provisional, and cultural (Grunewald & Bastion, 2016). While there are many services that can be examined, an ecosystem service survey typically examines a few services that are relevant to the study area and its land uses. The ecosystem services selected are also depended on scope and data availability. Relevant ecosystem services pertaining to agricultural lands typically include food production/yield, mineral fixation, biofuel production, and carbon sequestration (Sandhu et al., 2015, Firbank et al., 2013, Sandhu et al., 2010, Kokkinidis, 2013). These studies which look at a wide variety of ecosystem services do so through field measurements or through experiments held in labs to evaluate and quantify these services. One ecosystem service that typically deteriorates when other ecosystem services improve is water quality (Preston et al., 2017). For example, when crop yield is increased caused by increased fertilization, the ecosystem's ability to regulate water quality is diminished (Preston et al., 2017). Zhang et al (2007) discuss ecosystem disservices. This is the phenomena where the provision of one ecosystem services causes the degradation of another. This trade off between services goes against the rhetoric used by *Land Over Landings* which claim that these farmlands help maintain a source of "food and fresh water for Canada's largest urban center." (Land Over Landings, 2017). To evaluate these claims, this ecosystem service study will examine whether there is any correlation between water quality and food production in the PLA region.

2.1.1 Water Quality

Water quality is a regulatory service which plays a pivotal role for many actors and industries. Not only does it affect those living around a water source, but down stream effects of changing water quality can be equally detrimental (Smuckler et al., 2012). One of the largest influences on water quality caused by farming is nutrient loading into fresh water systems (Verhoeven et al., 2006). Excess nutrients, particularly nitrogen and phosphorus which are common in fertilizers, accelerate eutrophication of fresh water systems (Anderson et al., 2014; Dupas et al., 2015; Rukhovets et al., 2010). Eutrophication is the overstimulation of aquatic plants and algae growth. As plant and algae growth is accelerated, less light can penetrate the surface which leads to less dissolved oxygen in the water which changes the lake's characteristics (Perlman, 2017). This leads to changing fish populations, reduced fresh water supply, and increased blue-green algae blooms (Verhoeven et al., 2006). To best understand farming's impacts on water quality, this study will examine the mobility and availability of nitrogen and phosphorus as well as look at how these nutrients are able to load into the fresh water ecosystems inside the PLA region. Understanding these two nutrients will then help inform future farming practices as well as provide insight for potential environmental assessments of the area.

2.1.2 Nitrogen

Nitrogen is a key component for crop growth and is used to cheaply enhance yield. (Anderson et al., 2014). Nitrogen that is left in the soil after harvest typically experiences nitrification. This creates nitrate (NO3) which is very water soluble and has the potential to leach into the water table and contribute to eutrophication (Shinozuka et al., 2016 & Daniel et al., 2009). As water percolates through the soil, either from rain fall or irrigation, soluble nitrates will combine with water and be transported through ground water flow or overland flow (Perlman, 2017). If nitrates enter a water body, eutrophication can be accelerated which reduces the lake's water quality, as explained above. The two most crucial factors of nitrate leaching are availability and mobility (Shaffer & Delgado, 2002). These two factors will be discussed later on.

In natural systems, plants release their nitrogen back into the soil through decomposition or through animal waste. This cycle is partially broken in agricultural systems because nitrogen is removed from the cycle when the plant is harvested. Crop residues can mitigate the amount of supplemental nutrients required, lower cost, and provide a slow release of nitrogen into the soils, but these residues are also used for cheap animal feed or biofuel sources (Blanco-Canqui & Lal, 2009). Regardless of crop residues, supplemental supplies of nitrogen are often required through the forms or fertilizers, manure, or both to maintain profitable crop growth (OMAFRA, 2009). Studies have found that a crop's ability to uptake nitrogen increases as more nitrogen is added to the soil which leads to increased yields and profitability (Rens et al., 2016, Gheysari et al., 2009; Huang et al., 2014). These same studies have also found that an increase in nitrogen fertilizers, regardless of a crop's uptake abilities, also results in more nitrates being left in the soil after harvest which can lead to increased eutrophication (Rens et al., 2016, Gheysari et al., 2009). This shows that supplemental nitrogen applications do not get completely absorbed by any crop. This contributes to nitrate availability. Rens et al (2016) found that average N-fertilizer uptake efficiency across the entire study area was only ~45%, which means that ~55% of N-fertilizer is not used by the crop and left in the soil after harvest.

As discussed above, crops do not completely absorb available nitrogen in the soils, but it is still an important component in nutrient budgeting. Different plants have different nitrogen uptake abilities. For example, soybeans have very high nitrogen uptake capabilities and require little to no nitrogen based fertilizer because they absorb nitrous oxide($N2O$) from the air (OMAFRA, 2006; Rotundo et al., 2014; Wagner-Riddle et al., 1997). Trees also have very high nitrogen uptake and storage capabilities (Daniel et al., 2009). Oats have relatively low nitrogen uptake capabilities but also require less nitrogen to grow (OMAFRA, 2016). The more nitrogen that is taken up by crops or vegetation means less nitrate remains in the soil after harvest. Another component that can affect the amount of nitrates remaining in the soil is denitrification which is a microbial process in which nitrogen in the soil is eventually converted into $N2O$ and released into the atmosphere as a gas (Beauchamp, 2015; Helgason et al., 2005; Wagner-Riddle et al., 1997).

There are many other factors that can affect nitrogen availability such as crop rotation (Lee et al., 2016), tilling practices (Torbert et al., 2009), soil acidity, nitrogen fixation, fertilization timings, depths, and many others (Rens et al., 2016). These factors are all interactive, dependent, and difficult to model. Without the use of soil sampling or lab experiments, these factors are beyond the scope of this project.

Nitrate mobility determines how quickly nitrates can move through the soil. If nitrates are mobile, there is a higher chance for them to reach surface waters or ground water. Because nitrates are water soluble, its mobility is dependant on water transportation, whether through overland flow or ground water flow (Gheysari et al., 2009). This is determined by Percolation and water availability (Ketterings et al., 2003). Percolation looks at soil structures and how easily water can pass through that soil. Sands that have large particles and void spaces will allow water to quickly percolate through while tightly packed clays tend to obstruct such movement

(Ketterings et al., 2003). Studies looking at percolation and nitrate mobility will often use Hydrologic Soil Groups to classify different soils by their percolation capabilities. These studies will use the soil groups to generate scores through a percolation index which measures a soil's impedance of percolation (William & Kissel, 1991; Ketterings et al., 2003). The amount of water that flows through soil is also a determinant of nitrate mobility (Shaffer & Delgado, 2002; Ketterings et al., 2003). Even if a soil has high permeability, the absence water regularly flowing through it means nitrates will have little opportunity to become a solution and be transported (Ketterings et al., 2003). Common practices have used a seasonal index which assesses average precipitation values (Shaffer & Delgado) in the study area to generate a score which represents the amount of water that will pass through the soil. A Leaching Index (LI) is calculated by multiplying the percolation index and seasonal index together which generates a relative risk score. This solution has been used by U.S department of Agriculture-Natural Resources Conservation Service and New York State (Shaffer & Delgado, 2002; Ketterings et al., 2003). It is considered a simple solution which uses publicly available data. Its main criticisms are that this index ignores nitrogen budgets and agricultural management practices.

Many models have been developed to assess nitrate leaching with varying degrees of complexity across different fields of research (Shaffer & Delgado, 2002). Soil and Water Assessment Tools (SWAT) have been developed to accurately model nitrate leaching using soil chemistry, soil sampling, ground truthing, and site specific calibration to quantify the amount of nitrate leaching that an agricultural system allows (Akhavan et al., 2010). Other models have been developed, both in labs and in farm fields to quantify nitrate leaching on a single field given site specific parameters. These studies still require soil sampling to obtain many variables such as nutrient content, organic matter, water content, and microbial activity (Cuny et al., 1998; Chandna et al., 2010). Finding soil samples is beyond the scope of this project which means more simple modeling will be required to determine the availability and mobility of nitrogen in the PLA region such as LI. The studies by Shaffer & Delgado (2002), and Van Es et al., (2002) have both called for an improved Nitrate Leaching index that does not ignore nitrogen availability and field management practices.

A study by Cuny et al., (1998) addressed LI's lack of nitrogen availability information. This study found that by multiplying the amount of available nitrogen in a study area's soil by the area's LI, a relative Nitrogen Leaching Index (NLI) score could be created. By doing this, areas within the study area could be compared. This study found that the results generated from the NLI were not accurate enough to quantify nitrate leaching characteristics. However, the scores generated were still accurate for relative comparisons to be done from within the study area.

2.1.3 Phosphorus

Phosphorus is another element commonly used in fertilizers which contributes to increased yields and can also have negative impacts on water quality by accelerating eutrophication **(**Rukhovets et al., 2010). Phosphorus shares some similarities with nitrogen in terms of the mechanisms that enable it to enter fresh water systems and contribute to eutrophication. Supplementing soils with fertilizers containing phosphorus increases its availability in the soil which means more phosphorus is available for transport into fresh water systems (Hilborn & Stone, 2016). Crop types and crop rotation practices also play a key role in phosphorus uptake and phosphorus availability. Different crop types uptake phosphorus with different efficiencies, which means there is variability in the amount of phosphorus remaining in the soil (He et al., 2013). Unlike Nitrogen, tilling results in higher Phosphorus uptake and less available phosphorus in the soil after harvest (Whittington et al., 2007). This is because phosphorus tends to accumulate at the top layers of soil where it is more vulnerable to over land flow. Tilling mixes phosphorus into deeper layers of soil where it is more available for root uptake (Whittington et al., 2007). However, when phosphorus is incorporated into the soil through tilling, it also becomes more available for transport through soil erosion. Phosphorus is not as soluble compared to nitrogen and needs to adhere to a particulate to be transported (Busman, 2002) Phosphorus's main transport mechanisms are erosion, particulates caught in over land flow, and sediment transport in streams and rivers (Perlman, 2016). A tool has been created by OMAFRA which calculates phosphorus loss on farmlands (Hilborn & Stone, 2016). This tool, called the Phosphorus Index (P-Index) uses erosion characteristics of soils, water runoff, phosphorus availability in soil, fertilizer use and methods, and manure use and methods. It was designed so farmers could accurately assess how much their fields are contributing to phosphorus loss and advise them on what mitigation methods they should use to slow phosphorus loading. Despite its original purpose, this tool can be used on a much larger scale to examine the spatial distribution of phosphorus loading within the entire study area if the necessary data is available. This index does not consider phosphorus mobilized in groundwater flow or in tile drainage systems.

2.1.4 Crop Yield

Crop yield is a provisional service which measures the amount of food produced per unit land area. This provisional service is valuable because it determines food availability. The sale of produce can also generate revenue for those who live in the ecosystem. This is especially important as global demand for food increases and more emphasis is placed on food production rather than the environmental impacts of increased yield and output (Miller, 2013). In literature, revenue and yield are often compared against the other ecosystem services being examined. For example, Tobert et al., 2009 compared tillage and no tillage crops effects on nitrogen uptake, but also included yield in the analysis as a secondary bench mark. This was done to understand the trade off between crop yield, profitability, and nitrogen up take. This study wanted to look at whether improved tilling techniques could be used to improve nitrogen uptake without affecting crop yield. OMAFRA offers best practice methods for crop fertility to balance nutrients uptake and cost of fertilizer (OMAFRA, 2009). This will also help in understanding the balance that the PLA region takes between profitability and phosphorus loading.

2.2 Land Use Adjacent to Surface Waters

Land use around surface water features is a crucial factor which when discussing water quality and eutrophication. Eutrophication can be mitigated if appropriate distances and vegetation coverage are kept between the nutrient sources and surface water. When agricultural lands are right next to surface waters, nutrient loading and eutrophication will increase (Sharip et al., 2011; Houlahan & Findley, 2004; Daniel et al., 2009). The study by Houlahan and Findley (2004) found a correlation between agricultural lands and nutrients loading into surface waters even up to 4000m away. Various setbacks were recommended to mitigate agricultural effects on nutrient loading including a 4000m distance to stop phosphorus loading and a 500-1500m setback for nitrates. Other studies provide smaller setbacks to mitigate nutrient loading. OMAFRA has varying recommendations depending on types of crop land in question, slope, and fertility management practices. Wand (2016) saw that an effective setback would have a minimum distance of 150m in areas that saw regular nutrients inputs. A 150m setback is also consistent with the P-Index which examines slopes of top banks within 150m of surface waters.

Hilborn &Stone (2016) used a field's P-Index score and fertilizer application method to define minimum setback distances ranging from 10m (low P-Index scores) to 200m (high P-Index scores). Zones of non-agricultural vegetation can also help reduce the amount of land required to mitigate nutrient loading. By using permanent vegetation, such as trees and shrubbery, to slow the movement of nutrients, studies have found that zones from 15m to 100m wide of forest or wetlands can remove nitrogen and/or phosphorus from surface waters and soils (Kuusemts & Mander, 1999; Castelle et al., 1994). OMAFRA recommends a minimum 3m buffer zone of permanent vegetation adjacent to the top of the bank of any surface water feature (OMAFRA, 2003).

Chapter 3: Methods

3.1 Data Acquisition

One goal of this study is to evaluate two ecosystem (dis)services: water quality, and yield. Water quality will be rendered and evaluated using two indexes. The P-Index, which was developed for use in Ontario by OMAFRA, generates scores for a field's potential to contribute to phosphorus loading into surface water features (Hilborn & Stone, 2016). The Nitrogen Leaching Index (NLI), is commonly used in studies that examine nitrate mobility. All the data sets required for these indices were acquired from the federal government of Canada websites, Ontario government websites, peer reviewed journals, or generated through visual analysis of free satellite imagery. OMAFRA was particularly important in providing data dealing with crop fertility and recommended farming practices.

3.1.1 Crop Type

The Annual Crop Inventory is produced by the Earth Observation Team of the Science and Technology branch within the department of Agriculture and Agri-Food Canada (Government of Canada, Agriculture and Agri-Food Canada, 2016). This open data set has a 30m resolution and classifies all of Southern Canada. Optical (Landsat-8) and radar (RADARSDAT-2) based satellite images are used by the Earth Observation Team to generate the following land classifications in the PLA region: water, exposed land and barren, urban development, shrub land, wetland, grassland, pasture and forages, oats, wheat, corn, canola, soybeans, other vegetables, orchards, coniferous, broadleaf, and mixed wood (Government of Canada, Agriculture and Agri-Food Canada, 2016). Ground truthing techniques and collaborations with provincial agricultural departments are also used to increase the accuracy to the minimum goal of 85%. The 2015 data set was selected because it has the highest accuracy out of the available years of 89.5% (Government of Canada, Agriculture and Agri-Food Canada, 2016). Its high accuracy means that the spatial distribution of crop types, surface water features, and forests can be identified with confidence. This data is important because it identifies the crop types within the study area which are paramount in understanding nutrient uptake and fertility management practices. While not needed for this project, the annual nature of the land survey would also provide crop rotation data for future multi-temporal studies.

Yield is one of the ecosystem services being examined in this study and this data will help inform how the PLA region are contributing to this provisional service. Crop yield data was acquired from the OMAFRA (2009) website. These data sets include information on average acres seeded, acres harvested, yield (bushels/acre), production in bushels, and production in tons, and tons per acre. These data were then converted to tonnes per hectare. The OMAFRA crop yield data sets are broken down by region/county and as such, the yield and production data for this study were extracted for Durham Region because it contains 75% of the study area.

3.1.2 Digital Elevation Model

Land Information Ontario provided a 20m resolution Digital Elevation Model (DEM) of the study area which was developed by the Ontario Ministry of Natural Resources and Forestry - Provincial Mapping Unit (2007). This DEM was used to compute the slope angles in the PLA region which is an important component of erosion and phosphorus mobility. The DEM also enables the creation of a stream network using the ArcMap hydrology toolbox. Knowing the location of the stream network in the study area is important for assessing the risk posed by fertilizer application to nearby surface waters. Also included in this data set is a contour shape file which contained Isolines at 5m increments which was used for visual analysis of the study area.

Natural Resources Canada provided the CanVec data packaged which was published in 2013. This data package, which covers most of Canada, contains topographical information in vector form including surface water features like lakes and streams. While a stream net work was made using the DEM and the Arc Hydro toolbox, these shape files were still useful in checking the accuracy of these generated streams.

3.1.3 Meteorological Data

Meteorological data, specifically the Canadian Climate Normals (1981-2010) from the Toronto Buttonville Airport station, was used in the computation of the Seasonal Index component of the Leaching Index. The parameter of particular interest was average monthly precipitation in millimeters (Environment and Climate Change Canada, 2017).

3.1.4 Fertilizer Application Rates, Tillage Practices and Crop Yields

Fertilizer application rates (in kg/ha) and application methods, needed for computing the Phosphorus and Nitrate Leaching indices, were acquired through the OMAFRA (2009) website, where fertilizer budgeting tools are provided for farmers to use. Interviewing farmers about their fertilizer practices was beyond the scope of this study considering the size of the study area and with approximately 500 fields. Nitrogen and phosphorus fertilizer application rates in the OMAFRA farmer guidelines were chosen based on the crop types present in the study area. The OMAFRA fertilizer application rate recommendations are based on crop requirements throughout the province of Ontario and are not specific to the PLA region.

Tillage practices, used in the computation of the soil erosion factor in the P-Index, were also obtained through online OMAFRA (2009) recommendations and were chosen based on crop type.

3.1.5 Field Attributes

Two final data sets had to be generated through visual analysis using a combination of ArcMap and Google earth. To create these data sets, individual fields had to be highlighted manually by tracing polygons around fields inside of ArcMap. A combination of Google Earth, Landsat 8 images, and base maps provided by ArcMap were all used to inform the tracing process of these 489 fields (Figure 1.1). While there are remote sensing techniques that can be used to delineate farm fields, researching and performing this quicker process is beyond the scope of this paper. Once a field was identified, two attributes were also generated through visual inspection of the high-resolution images from Google Earth. The first attribute was the longest length of a field parallel to the slope. This was done using a contour line layer provided by the Ontario Ministry of Natural Resources and Forestry (2007). The contour lines were used to inform the slope's aspect and the ruler tool in ArcMap was used to measure the longest distance in the field that ran parallel to the slope. This data informs the slope/length factor which will be discussed later. The second attribute was crop row orientation. The contour lines discussed above helped inform which way crop rows were oriented relative to the slope. Through visual inspection, a decision was made whether the crop rows were oriented perpendicular or parallel to the isolines. Google Earth was preferred over a Landsat 8 image due to its high resolution, ease of access, and ability to zoom in and out of the study area. These data provided attributes for the supporting practices component in the erosion factor which will be discussed later. Manual segmentation of each field resulted in a high accuracy assessment in PCI Geomatica of 98% using 500 sample pixels.

3.2 Phosphorus Index

The P-Index, developed for use in Ontario by OMAFRA, is a tool designed to rank the relative risk of surface water contamination from phosphorus application on crop lands, select management strategies that can reduce these risks, and set restrictions on rates of phosphorus application in the forms of fertilizer and manure (Hilborn & Stone, 2016). The tool is readily available to the public and is intended to be used by farmers assessing their own fields. Only land existing on farm fields is considered in the phosphorus index. This means that no analysis beyond the field scale can occur. The P-Index was selected for this study for two reasons: First, its coefficients have already been adapted to suit the local farming conditions of Ontario (Lemunyon & Gilbert, 2013). Second, the index provides flexibility in the event of data scarcity. Since primary, field-scale data collection was beyond the scope of this project, the P-Index was deemed a suitable approach to evaluate the relative risk that farm land on the PLA region pose to surface water quality and downstream eutrophication. This is done by measuring each of the seven site characteristics and then assigning them a score from 1-16. A score of 1 is means a low chance to contribute to phosphorus loading and a score of 16 means a high chance to contribute to phosphorus loading. These scores are then multiplied by their respective weightings. The weighted scores are then added together to find a field’s of study area’s final P-Index score (equation 1).

$$P - Index = (E * 2) + (W * 1) + (P * 2) + (F_R * 0.5) + (F_M * 1.5) + (M_R * 0.5) + (M_M * 1.5) \qquad (1)$$

Table 3.1: Site characteristics and their respective weightings

Site Characteristic	Weighting
Erosion (E)	2
Water Runoff (W)	1
P Soil Test (P)	2
Fertilizer Rate (F_r)	0.5
Fertilizer Method (F_M)	1.5
Manure Rate (M_R)	0.5
Manure Method (M_M)	1.5

The first site characteristic of interest is soil erosion, which is strongly related to P transport. Phosphorus based fertilizers are not very soluble in water and instead bind to soil particles, which are easily mobilized via the erosion of sediment from fields and stream banks (Busman, 2002; Hilborn & Stone, 2016). In this index, soil erosion is calculated using the Universal Soil Loss Equation (USLE) (Equation 1) seen below which predicts the long term average annual rate of erosion on a field slope based on rainfall patterns, soil types, slope-length factor, cropping systems, and management practices (Stone & Hilborn, 2012).

$$A = R * K * LS * C * P \qquad (2)$$

In equation 1, A represents the potential long-term average annual soil loss in tonnes per hectare per year and it is calculated by multiplying the five other factors together (Stone & Hilborn, 2012). R is the rainfall and runoff factor (R Factor) which indicates how much overland flow is occurring in an area. R factors are provided by OMAFRA based on weather station data, storm intensities, and storm durations (Stone & Hilborn, 2012). The Regional Municipality of Durham and York Region which contain 75% and 25% of the PLA respectively both have R factors of 90.

K is the soil erodibility factor measured in tonnes per hectare and is based on the erosion that will occur on different soil texture classes at a standard slope length of 22.13m and a slope steepness of 9 degrees (Stone & Hilborn, 2012). This factor examines how easily different soil texture classes succumb to erosion. Table 3.2 shows the K factor for different soil texture classes at different levels of organic matter content. For sake this study, the average organic matter content score was used which are highlighted in table3.2.

Table 3.2: K Factor by Soil Texture Class

Textural Class	K Factor tonnes/hectare (tons/acre)		
	Average OMC*	Less than 2% OMC	More than 2% OMC
Clay	0.49 (0.22)	0.54 (0.24)	0.47 (0.21)
Clay loam	0.67 (0.30)	0.74 (0.33)	0.63 (0.28)
Coarse sandy loam	0.16 (0.07)	–	0.16 (0.07)
Fine sand	0.18 (0.08)	0.20 (0.09)	0.13 (0.06)
Fine sandy loam	0.40 (0.18)	0.49 (0.22)	0.38 (0.17)
Heavy clay	0.38 (0.17)	0.43 (0.19)	0.34 (0.15)
Loam	0.67 (0.30)	0.76 (0.34)	0.58 (0.26)
Loamy fine sand	0.25 (0.11)	0.34 (0.15)	0.20 (0.09)
Loamy sand	0.09 (0.04)	0.11 (0.05)	0.09 (0.04)
Loamy very fine sand	0.87 (0.39)	0.99 (0.44)	0.56 (0.25)
Sand	0.04 (0.02)	0.07 (0.03)	0.02 (0.01)
Sandy clay loam	0.45 (0.20)	–	0.45 (0.20)
Sandy loam	0.29 (0.13)	0.31 (0.14)	0.27 (0.12)
Silt loam	0.85 (0.38)	0.92 (0.41)	0.83 (0.37)
Silty clay	0.58 (0.26)	0.61 (0.27)	0.58 (0.26)
Silty clay loam	0.72 (0.32)	0.79 (0.35)	0.67 (0.30)
Very fine sand	0.96 (0.43)	1.03 (0.46)	0.83 (0.37)
Very fine sandy loam	0.79 (0.35)	0.92 (0.41)	0.74 (0.33)

Source: Stone & Hilborn (2012)

LS factor, shown in table 3.3, is a score derived from the ratio between soil loss on a control hill (22.13m long at 9%) and soil loss on other slopes of varying angles and lengths. This factor states that the steeper and longer a slope is, the more soil loss it will experience. The USLE is intended to be applied at the field-scale. The average slope steepness of the field and the length of the field traveling directly down the slope are used to find the LS factor per field. For this study, this data had to be generated manually. A slope raster generated from the DEM was used to create multiple LS rasters which will populate each pixel with an LS Factor score which corresponds to its slope and correct field length. Table 3.3 shows the LS factor score for fields with a slope length of 30.5m, but there are tables for a large range of slope lengths going up to 975m (Stone & Hilborn, 2012). As the slope length increases, its LS factor increases as well.

Table 3.3: LS Factor at 30.5m Slope Length

Slope Length: m (ft)	Slope (%)	LS Factor
30.5 (100)	10	1.38
	8	1
	6	0.67
	5	0.54
	4	0.4
	3	0.3
	2	0.2
	1	0.13
	0	0.07

Source: Stone & Hilborn (2012)

C represents the crop/vegetation management factor. Different crop types have varying root structures which can strengthen the soil structure compared to bare land. For example, fruit trees and pastures offer more support to soils compared to corn or canola which helps prevent soil erosion and phosphorus transportation (Stone & Hilborn, 2012). Different categories of crops have been assigned different crop factors scores. The way in which the ground is prepared for these crops to be planted also plays a role in soil stability. Tilling disturbs the soil, which breaks up compaction and decreases soil stability (Hajabbasi & Hemmat, 2000). Different tilling practices have also been given factor scores dependent on how much they disturb the soil. This factor encourages no till systems because soil becomes more susceptible to erosion when it is churned and mixed. The factors corresponding to crop type and tillage system are then multiplied together to create the C Factor.

The last factor included in the USLE is supporting practices. These include different methods that farmers can take to slow the rate at which erosion can occur. This factor is the ratio at which soil loss occurs between straight-row farming along the slope and other cropping practices such as cross slope cultivation and contour farming. These different practices can create barriers to soil loss and slow down erosion. For example, strip cropping along contour lines ensures that rows of barren soil never run perpendicular to the slope of a hill. This creates barriers of crops running across flow paths. These practices diminish soil erosion compared to having rows of crops running parallel to the hill slope. Because OMAFRA does not provide recommendations for these supporting practices by crop type, these values had to be generated manually using a combination satellite images, digital elevation models, and contour lines. Once these factor scores are placed in the USLE, the soil erosion can be calculated in tonnes per hectare over one year. This variable then becomes the first factor in the rest of the P-Index. It is important to note that the USLE is intended only for calculating sheet or rill erosion and does not take aeolian or fluvial aspects into account.

The next factor in the P-Index is Water Runoff which has a weighting of 1.0. This class estimates the potential for surface runoff from a field based on the soil's Hydrologic Soil Group (Hilborn & Stone, 2016). Surface runoff is important because it mobilizes P from fields to streams. These hydrologic soil groups correspond to different soil series found in Ontario and range from rapid drainage, known as Group A, to very slow drainage, known as Group D. Table 3.4 details the combinations of these drainage groups with slopes within 150m of surface waters. While there is evidence of phosphorus loss in agricultural fields through tile drains as a solution (Zhang et al., 2015), the phosphorus index does not take this into account. This is one limitation on the accuracy for a farmer evaluating their own field, but collecting data on artificial drainage systems for each field in the study area is beyond the scope of this project.

Table 3.4: Water Runoff Classification by Drainage Class and Slope

Hydrologic Soil Group (Drainage Class)	**Maximum Field Slope within 500 ft (150 m) of Top of Bank of Surface Water**			
	< 3%	**3 - < 6%**	**6 - < 9%**	**9 - 12%**
A (Rapid)	Very Low (1)	Very Low (1)	Low (2)	High (8)
B (Moderate)	Very Low (1)	Low (2)	Mod (4)	High (8)
C (Slow)	Low (2)	Mod (4)	High (8)	Very High (16)
D (Very Slow)	Mod (4)	High (8)	High (8)	Very High (16)

Source: Hilborn & Stone (2016)

The phosphorus soil test (P Soil Test) measures phosphorus currently in the soil and is typically used by farmers to inform their fertilization rates and whether their soil needs more phosphorus added to it. The more phosphorus currently in the soil means there is more phosphorus available to erosion and water runoff (Hilborn & Stone, 2016). To the best of our knowledge, no databases containing spatial information on these tests exist because they are designed to inform farmers on their field's needs rather than to develop a comprehensive dataset (Hilborn & Stone, 2016). Since this study does not have the P soil test values, the default score of very high (16) will be used for every pixel as per OMAFRA recommendations. Table 3.5 shows the values associated with the P Soil Test. Since the P soil test has a weighting of 2, the entire study area will have a minimum score of 32 in the final phosphorus index score. This may cause some of the values for the final phosphorus index score to be overestimated.

Table 3.5: P Soil Test

P Soil Test (ppm)	**Rating**
< 15	Very Low (1)
15 – 30	Low (2)
31 – 60	Moderate (4)
61 – 100	High (8)
> 100	Very High(16)

Source: Hilborn & Stone (2016)

Phosphorus application rate is fundamental to the availability of phosphorus in the soil. Table 3.6 lists application amounts and their ratings in the P-Index. The more Phosphorus based fertilizer used in a field means more phosphorus is available for transport.

Table 3.6: Fertilizer Application Rates

Fertilizer Application Rate (kg P2O5)/ha	**Rating**
< 25	Very Low (1)
25 – 50	Low (2)
51 – 75	Moderate (4)
> 75	High (8)

Source: Hilborn & Stone (2016)

The values for fertilizer application rates were derived from the OMAFRA Crops database which provide different recommendation of application rates based on P soil test scores (OMAFRA, 2009). A sample of these recommendations is present in Table 3.7. The fertilizer application recommendations used in this study are based on the values used for fields that received P soil test scores of 10-12ppm.

Table 3.7: Phosphorus Recommendations based on P Soil Tests

Sodium Bicarbonate Phosphorus Soil Test (ppm)	Spring Barley, Spring Wheat, Mixed Grain		Oat, Spring Triticale, Spring Rye	
	Rating[1]	Phosphate (P_2O_5)[2] Required kg/ha	Rating[1]	Phosphate (P_2O_5)[2] Required kg/ha
0-3	HR	110	HR	70
4-5		100		60
6-7		90		50
8-9		70		30
10-12	MR	50	MR	20
13-15		20		20
16-20		20	LR	0
21-25	LR	0		0
26-30		0		0
31-40	RR	0	RR	0
41-50		0		0
51-60		0		0
61+	NR[3]	0	NR[3]	0

Source: OMAFRA (2009)

Fertilizer application method refers to the way that phosphorus is applied to the soil. Table 3.8 shows what ratings an application method will receive. This table demonstrates that application methods that place the phosphorus closer to the seed and further from the surface reduce the risk of phosphorus becoming mobile. Fertilizers placed with the seeds are the most available for uptake and the least susceptible to erosion and runoff due to their placement in the soil (OMAFRA, 2006). Fertilizers not incorporated into the soil are the most susceptible to mobilization due to their placement at the top of the soil. The data for this factor is derived from fertility management practice recommendations by crop type. OMAFRA recommends different fertilizer application methods for various crops based on plant needs and the promotion of profitable agriculture (Omafra[2], 2009).

Table 3.8: Fertilizer Application Method

Fertilizer Application Method	Rating
Placed with Planter	Very Low (1)
Incorporated < 2 weeks	Low (2)
Incorporated > 2 weeks	Moderate (4)
Not Incorporated	High (8)

Source: Hilborn & Stone (2016)

The final two factors in the P-Index are manure application rates and methods. There are no recommendations for application rates of manure/biosolids in OMAFRA's fertility management sections. This is because OMAFRA considers manure as a substitute or alternative for fertilizers and states that where manures are applied, fertilizer applications should be reduced accordingly to still achieve the recommended nutrients levels (Hilborn & Stone, 2016; Ketterings et al., 2003). Since no manure amounts are recommended by OMAFRA, both manure application rates and application methods receive scores of 0 in the P-Index as per the instructions provided by OMAFRA (Hilborn & Stone, 2016). There are studies done by OMAFRA which examine how manure from pastures and forages contribute to phosphorus loading. Unfortunately, there is not exact data present on how much an average pasture or farm will contribute to phosphorus loading due many variables. These include, feeding practices used by each farmer, feeding schedules, cow density, and dairy vs meat (Calberry, 2004; Potter, 2005; Wright, 2003). Obtaining data on manure concentration per pasture and forage would require data on these practices and cattle density which is beyond the scope of this study.

After all the site characteristics have been measured and assigned a score from1-16, the P-Index is calculated by multiplying these scores by their respective weighting and added together to find the final P-Index score.

3.3 Nitrogen Leaching Index

In the absence of primary field data, the *leaching index* (LI; Ketterings et al., 2003) was used to assess the availability and mobility of nitrates through the soils and the overall spatial distribution of nitrate leaching to surface waters in the PLA study area. The LI has been adapted from the U.S department of Agriculture-Natural Resources Conservation Service and is commonly used in research studies concerned with nitrate leaching (William & Kissel, 1991;

Van Es et al., 2002; Ketterings et al., 2003). One advantage that LI has over other nitrate mobility and availability indices, such as a Soil Water Assessment Tool (SWAT) or Nitrate-N Availible for Leaching (NAL), is that the data used to calculate it is readily available to the public (Shaffer & Delgado, 2002). NAL has complex data requirements that require on site soil sampling which is beyond the scope of this project (Shaffer & Delgado, 2002). Studies using SWAT models have been able to simulate many of these variables and can accurately assess many soil and water issues including erosion and nitrate leaching; however, calibration data are required to achieve reliable model performance (Akhavan et al., 2010). In this study, the data used to compute LI came from the Soil Survey Complex dataset compiled by the Ontario Ministry of Natural Resources which contain a GIS data set of soil classes including hydrologic soil groups, and Environment and Climate Change Canada's open meteorological datasets. The LI is a relatively simple equation that incorporates a percolation index and a seasonal index (Ketterings et al., 2003). The percolation index incorporates information on areas that have a high potential for nitrate mobility due to porous soils. Unlike phosphorus, nitrogen is very water soluble and its primary form of transport is through ground water flow (Ketterings et al., 2003). The percolation index is calculated using a pair of coefficients calculated by Willam & Kissel (1991), and average annual precipitation (Equations 3-6) (El & Delgado, 2006). Each soil hydrologic group has a different pair of coefficients based on drainage patters, flow rates, and soil porosity (William and Kissel 1991). Annual precipitation (in inches) is necessary because it determines how much water is available for percolation and hence nitrate leaching.

$$Hydrologic\ Group\ A: PI = \frac{(P_A - 10.28)^2}{(P_A - 15.43)} \tag{3}$$

$$Hydrologic\ Group\ B: PI = \frac{(P_A - 15.05)^2}{(P_A - 22.57)} \tag{4}$$

$$Hydrologic\ Group\ C: PI = \frac{(P_A - 19.53)^2}{(P_A - 29.29)} \tag{5}$$

$$Hydrologic\ Group\ D: PI = \frac{(P_A - 22.67)^2}{(P_A - 34.00)} \tag{6}$$

The seasonal index contains precipitation data which is important when examining leaching and percolation. The more precipitation that occurs within a year means there is more water available for leaching. The seasonal index can be used for a single year or the average of multiple years. First, the precipitation data was converted from millimetres to inches. The seasonal index is then computed by dividing the total precipitation in fall and winter (from October through March) by the average annual precipitation (equation 7). The focus on the fall and winter periods in the seasonal index reflects the importance of these seasons with respect to the conditions and processes that facilitate nitrate leaching. For example, nitrate leaching increases in the absence of roots and vegetation, a condition that exists after the fall harvest period (Van Es & Delgado, 2006). The percolation and seasonal indices are multiplied together to derive LI and a score is produced that represents an area's leaching potential. A score of <2 is considered to have low leaching potential, a score from 2-10 has a moderate leaching risk, and a score of >10 has a high leaching risk and a high potential to contribute towards surface water eutrophication (Ketterings et al., 2003).

$$SI = (2 * P_W/P_A)^{1/3} \tag{7}$$

The simplicity of computing the LI also presents some limitations. Shaffer and Delgado (2002) pointed out that this index does not consider fertility management practices which can have a significant impact on nitrate leaching (Shinozuka et al., 2016 & Daniel et al., 2009). Nitrogen uptake, crop residue, denitrification, and application practices are also disregarded in this index. Other indexes do exist including NAL and SWAT, but thier data requirements are complex and would require on site soil sampling and calibration which is beyond the scope of this project (Shaffer & Delgado, 2002; Akhavan et al., 2010).

3.4 Nitrogen Budget

A study by Cuny et al (1998) found that even when specific soil science data was not available, a simple model could still be used to assess the relative risk of nitrate leaching within a study area. This study saw that multiplying a simplified nitrogen budget and a leaching index could still accurately predict relative risk of nitrate leaching when compared to soil samples taken from fields with similar conditions.

To understand nitrate concentrations left in the soil, a nitrogen budget must be made using fertility recommendations provided by OMAFRA (2009), nitrogen uptake values, denitrification values, and recommended crop residues which will be derived from peer reviewed journals. Balancing nitrogen losses and gains will enable the creation of a simplified nitrogen budget. Nitrate leaching increases as more nitrogen is left in the soil after harvest (Gheysari et al., 2009; Rens et al., 2016). The budgets for each crop type were derived by subtracting nitrogen removed from harvest and denitrification values from the sum of nitrogen fertilizer used and nitrogen left over in the form of crop residue (Table 3.9).

The data for nitrogen loss through denitrification and crop residues recommendations were acquired from studies by Wagner-Riddle et al (1997) and Oo & Lalonda (2009). This survey by Wagner-Riddle et al (1997) summarized denitrification loss and accounts for 95% of cropland in Ontario. It took place near Guelph, Ontario and provides data on all the crop types that are being examined in this study. This data is vital for understanding the nitrogen budget and nitrogen availability in the area. The report by Oo & Lalonda (2009) derived its data from five year averages (2007-2011) OMAFRA field crop statistics. While table 3.9 shows that soybeans result in a negative nitrogen budget, this is not completely accurate. Soybeans use nitrogen fixation which absorbs nitrogen from the atmosphere. A meta analysis found that on average, the nitrogen budget for soybeans is typically neutral or slightly negative depending on harvesting and crop rotation practices (Salvagiotti et al., 2008). Because of this, the nitrates left for mobilization for soybeans will be set to 0 in the final nitrate leaching index raster.

Table 3.9: Nitrogen Budget by Crop Type (kg/hectare)

Crop	N Fertilizer	N Uptake	N removal	N Left in Residue	Denitrification Losses	Nitrates Left for Mobilization
Oats	35	78.4595	52.67995	25.77955	3.4	4.70
Wheat	70	162.52325	96.3931	66.13015	3.4	36.34
Canola	160	151.31475	100.8765	50.43825	3.6	105.96
Soybeans	0	257.7955	209.59895	48.19655	4.8	-166.20
Orchards	150	184.94025	0	184.94025	0	334.94
Corn	150	173	97	76	3.1	125.90

Source: Wagner et al., (1997); OMAFRA (2009); Oo & Lalonda., (2012)

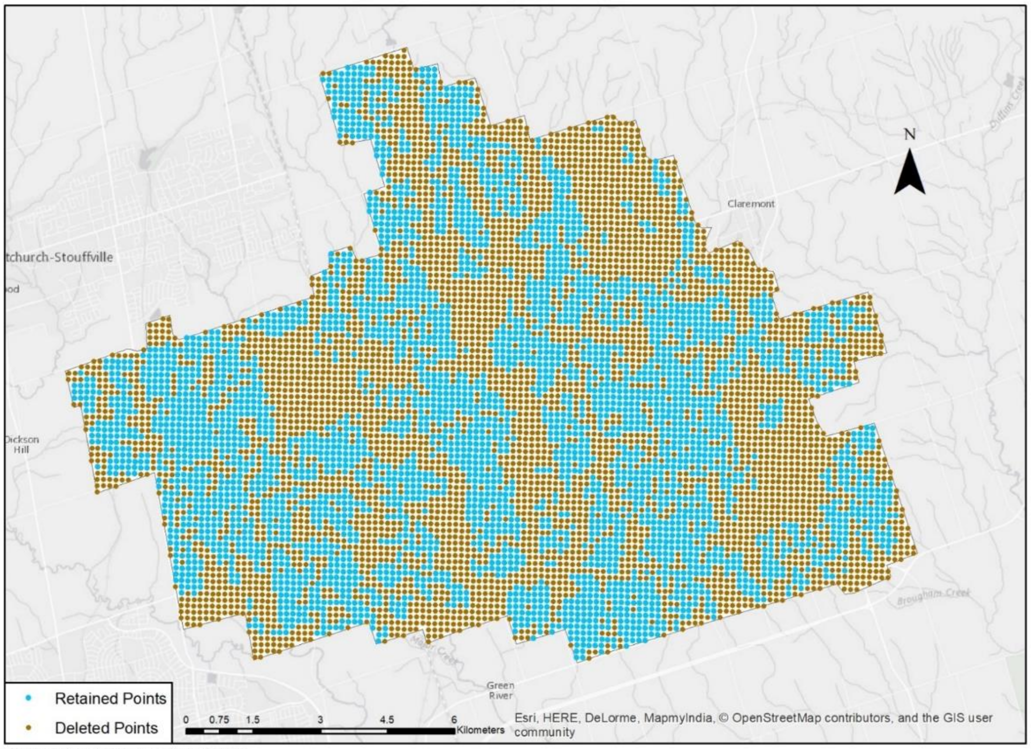
To assess the relative risk of nitrate leaching in the PLA region, the values found from the leaching index will be multiplied against values generated from the nitrogen budget. This new factor will be considered N-LI. This will give insight on both the mobility and availability of nitrogen in the soil. This will highlight any uneven dispersion of nitrogen rich fertilizer in the PLA region. Non-agricultural lands such as forest, riparian zones, and soybeans do not need nitrogen fertilizers and therefor contribute little to nitrate leaching. To only use the leaching index without comparing its values to a nitrate availability score would be assuming that all soils and land uses have the same nitrate concentrations. This would not provide an accurate assessment of nitrate availability and completely ignores the value that non-agricultural lands have at mitigating nitrate leaching (Daniel et al., 2009). By using nitrogen fertilizer recommendations and the leaching index together, this study examines both the availability and mobility of nitrates in the PLA region. Doing so will then allow an assessment of relative nitrate leaching risk.

3.5 Spatial Statistical Methods

3.5.1 Relationship Between Crop Yield and Nutrient Indices

Linear regression was used to explore the relationship between the two index scores (nitrogen and phosphorus loading as a disservice), and estimated crop yield (service). This was done to see whether or not there is a correlation between areas with a high potential to export excess nutrients and yield. Originally, the spatial regression tool in ArcMap was to be used to measure any possible correlation between yield and index scores. After ArcMap presented errors, SPSS was used to run linear regression on the original data sets and on log-transformed data to remove the effects of positive skewness in the original data.

The indices generated within ArcMap are very large files which mean there are limitations in the processes that could be done with them within ArcMap. To mitigate the impact of file size on the efficiency of these processes, a fishnet method was used in ArcMap to create a standard grid array of points. The value of each index and their factors at every point were then recorded and stored in this shapefile (figure 3.1). Any points that received no values for any of the variables were omitted from the analysis. For example, the nitrogen leaching index contains areas of NoData because certain soil types such as muck and bottomland were not given hydrological soil classes. The final fishnet layer contains 3569 points with attributes for yield, nitrogen leaching index, and the P-Index. With these data contained within a single shape file, regression methods can be more easily be done in SPSS.



Source: Land over Landing (2017)

Figure 3.1: Dots Created by Fishnet Method

3.5.2. Spatial Analyses of Agricultural Best Management Practices in the PLA Region

To assess the spatial distribution of P-Index scores and N-LI scores around surface waters, a 150m buffer was computed around all streams and water bodies. These buffer zones were then used to mask off farmland adjacent to surface water bodies and areas of high and low nutrient index scores were identified manually. This information was then used in conjunction with OMAFRAs recommendations for lowering field-scale P-index and N-LI scores to develop a custom set of agricultural best management practices that will reduce the diservices provided by the PLA region.

The buffer exercise was also used to determine to what extent minimum setback distances recommended by OMAFRA (Hilborn & Stone 2016) are adhered to in the PLA. For the PLA region to mitigate nutrient loading, setbacks of 150m should be used to prevent immediate runoff and restrict nutrients ability to get to surface waters.

3.5.3 Statistical Model for Phosphorus and Nitrogen

To develop recommendations that will mitigate nutrient loading, other analysis approaches are needed to understand which components of the P-Index contributes most to its final P-Index scores. To do so, a second fishnet methodology will be taken in order to understand the distribution of all of the factors involved in calculating the P-Index score. Fishnet is a process in which ArcMap develops a series of points in a grid at equal intervals. This grid of points is used to sample data from rasters files and reduce the computational complexity of the methodology.

P-Index is based on the summation of all of the components multiplied by their weights, therefore contributions of each component can be summarized individually without the need of complex spatial analysis. From these statistics, the components that contributed the most the final P-Index score will be revealed. This will then help in deciding what mitigation efforts should be undertaken first to reduce the PLA region's P-Index scores. A slightly different approach was taken with nitrogen and the leaching index.

Since the leaching index only contains two variables and the nitrogen budget delivers a single value for each of the crops, more visual analysis will be done. The spatial distribution of leaching index scores and land use types, especially within a 150m surface water features, will be analysed to understand the farming practices taking place in these vulnerable areas. From this information, recommendations can be made.

Chapter 4: Results and Discussion

4.1 Crop Yields Across the PLA Region

Spatial patterns in crop yield for the PLA region are shown in Figure 4.1. Soybeans, which provide 3.1 tonnes of food per hectare, is the most common food grown in the region followed by corn (9.9 tonnes per hectare), wheat (6.1 tonnes per hectare), Canola (2.3 tonnes per hectare), oats (3.2 tonnes per hectare), and apple orchards (26.4 tonnes per hectare). Since all the data on crop yield is reported on at the county level, there is no variation in this data between similarly classed fields. Because of this, possible spatial variation amongst similar crop types is ignored. For example, the yield reported on soybeans in the northeast corner and soybeans in the southwest corner of the PLA region will have identical yield characteristics despite any potential spatial variation.

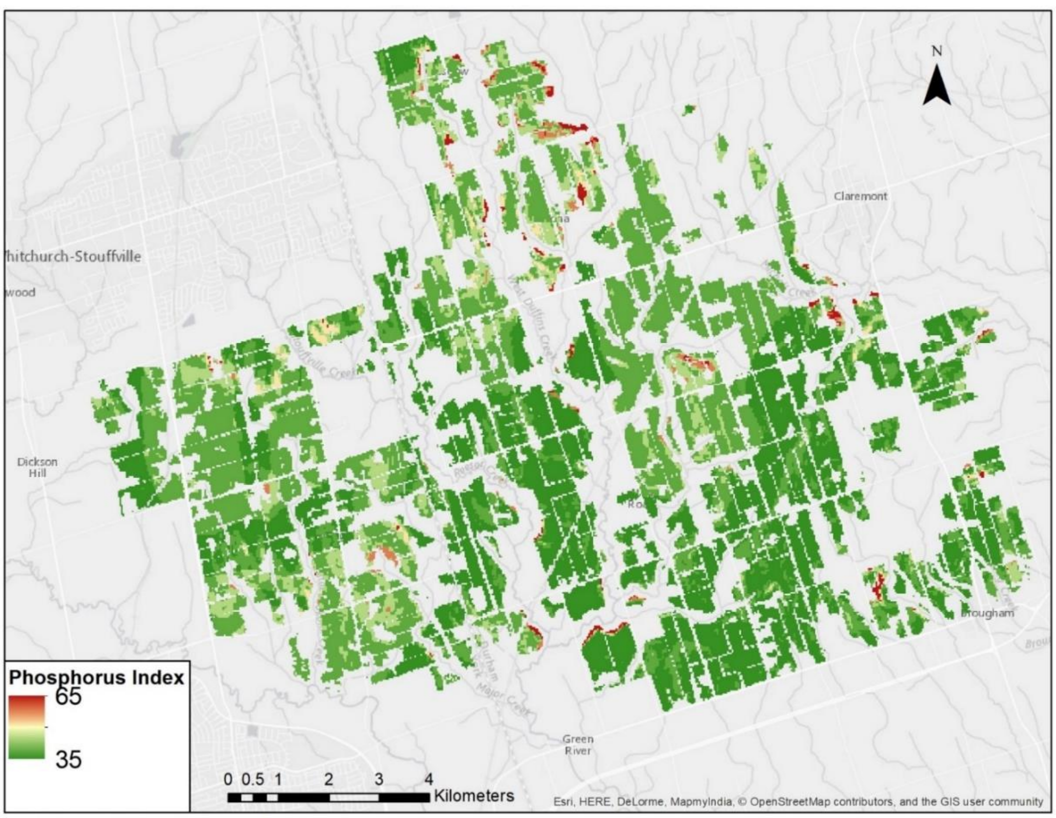
Source: Land over Landings, 2017; OMAFRA, 2009;

Figure 4.1: Map of crop yield (in tonnes per hectare) across the PLA region.

4.2 Nutrient Indices Across the PLA Region

4.2.1 Phosphorus Index

The scores from the P-Index all fell within the range of 35-65 points with the majority of the region receiving a score close to 35 and only a small area receiving relatively high scores (Figure 4.2). Based on the OMAFRA's P-Index recommendations and these estimated scores, the PLA region has a moderate to high potential for phosphorus transport to surface waters. A moderate potential for phosphorus movement (30-50) means that remedial actions must take place especially in areas close to surface waters. These areas of moderate risk should also have minimum setback areas of 10m when phosphorus is applied until crop removal and a minimum set back area of 200m after crop removal. Areas of high risk should have a 100m set back if phosphorus applications occur before crop removal and no phosphorus applications after crop removal (Hilborn & Stone, 2016).



Source: Land over Landings, 2017; Hilborn & Stone., 2016

Figure 4.2: Map of Phosphorus Index values across the PLA region.

Considering that these scores are derived from county averages and OMAFRA recommendations, there may be improvements that farmers and representatives of PLA region should pursue to mitigate phosphorus loading. Doing so would also better align the farming practices with the water sustainability rhetoric used by farmers and *Land Over Landings*.

To determine recommendations which will lower the P-Index score, the factors that contribute most to these high scores will need to be identified. To do this, the P-Index scores were broken down by their contributing factors to see which site characteristic added the most to the PLA region's final P-Index score.

The tables (4.1 & 4.2) below have been provided to explain how much each site characteristic contributed to the final P-Index score. Table 4.1 breaks each site characteristic into the five potential scores (1,2,4,8,16) and the percentage of study area that received these scores. For example, 96.99% of the study area received an erosion factor score of 1, and 2.76% of the study area received an erosion score of 2. Table 4.2 integrates these scores and the site characteristic weightings to see how much each site characteristic contributes to the final P-Index score as a percentage. For example, fertilizer method contributed 18.89% to the final P-Index score

Table 4.1: Percentage of Study Area Receiving Particular Scores for Each Phosphorus Index Site Characteristic

Scores given	Erosion	Fertilizer Method	Fertilizer Rate	Water Runoff	P Soil Test
1	96.98811893	0	0.351525804	37.37687406	0
2	2.759785296	39.95676637	99.6484742	46.70649757	0
4	0.176105181	0	0	12.3976797	0
8	0.075990592	60.04323363	0	2.981107233	0
16	0	0	0	0.53784143	100

Table 4.2: Contributions of Site Characteristic for Phosphorus Index Score

	Erosion	Fertilizer Method	Fertilizer Rate	Water Runoff	P Soil Test
Weighting	2	1.5	0.5	1	2
Total Points Contributed	3888	21440	7437	7411	59600
Points with Weighting	7776	32160	3718.5	7411	119200
Percentage of Contribution	4.566985091	18.88814822	2.183942137	4.352614	70.008311
Total points	170265.5				

Now, each site characteristic and its contributions to the final P-Index score can be evaluated. The Phosphorus Soil Test score refers to the build up of phosphorus already in the soil through previous phosphorus applications after crop removal. The more phosphorus in the soil after crop removal the higher the P Soil Test. There is no cumulative data set of these values which means that the default value recommended by OMAFRA of very high (16) is to be applied to the entire study area (Hilborn & Stone, 2016). Since the P Soil Test is given a weighting of 2, which is the highest rated variable in the index due to its importance, the lowest possible P-Index score that a pixel can receive is 32. If P Soil Tests were available and segments of the study area received a high (8) or a moderate (4) P Soil Test rather than a very high (16) score, their final P Soil Test would have been reduced by 16 and 24 points respectively. Unfortunately, this variable was not available and the assumption of very high (16) had to be maintained. Of the total points allocated to the final P-Index score for the entire PLA region, the P Soil Test contributed to ~70% of those points. While this may inflate the final phosphorus index score and obscure low phosphorus soil test scores, areas of high (>50) phosphorus index scores are still clearly highlighted and can easily be identified.

Beyond the P Soil Test, the factor that contributed the most to the final P-Index score is the fertilizer application method. The application methods recommended by OMAFRA for the crop types grown in the PLA region mostly consisted of broadcasting which involves no mixing of fertilizer into the soils and making phosphorus more available for transport. The majority (~60%) of the applicable study area received a score of 8 out of a maximum 16. The rest of the study area was given a score of 2. These high scores combined with OMAFRA's high weighting of 1.5 means that any crop in the PLA region that uses broadcasting will add 12 points to the final P-Index score. The fertilizer application method score contributed 8.6 times more points than the application rate score and 4.1 times more than the erosion factor. Of the total points allocated to the P-Index score, application method accounted for 18.8%.

Given how important the literature suggests the application rates of fertilizers are to the P-Index, it is interesting to note that of the total points allocated, application rate only contributed ~2.2% towards the final P-Index score.

The water runoff score contributed to ~4.4% of the final P-Index score. This component is dependant on the soil type and the vast majority (~84%) of the study area received water runoff scores of 1 or 2 out of a maximum 16. This is due to the study area's low slope and soils that fall under rapid or moderate drainage classes. The only areas that received high or very high water runoff scores were in and around surface waters. Since most of these areas do not contain farmland, they were not included in the study.

With a weighting of 2, the erosion factor is an important component of the phosphorus index (Hilborn & Stone, 2016). Despite this high weighting, the erosion factor had little impact on the final results of the P-Index. The vast majority (97%) of the study area received a very low (1) erosion factor rating. Despite its importance, its low score resulted in it only accounting for ~4.6% of the end results.

After identifying 150m buffer zones around the surface water features in the PLA region, these buffers were used as masks to extract P-Index scores and crop type data within 150m of a surface water feature. The buffered P-Index scores were classified into two groups: moderate (35-50) and high (>50). The moderate scores accounted for >99% of the total area within 150m of a surface water feature. Land use types within this area were divided into three groups: agricultural land, no vegetation, and non-agricultural vegetation. Agricultural land refers to any land that would be considered farmland that has the possibility to receive supplemental fertilizer applications. No vegetation refers to lands that do not have a direct impact on phosphorus availability such as development. Non-agricultural vegetation counts as lands that may impede phosphorus movement through uptake such as trees, shrub land, and grassland. Pastures and forages were not counted in this analysis because livestock have their own impacts on nutrient loading which is beyond the scope of this project. This analysis found that ~44.3% of the land within the 150m buffer zone is still farmland despite the importance that large buffer zones have on maintaining water quality (Wand, 2016). This is particularly problematic considering the moderate to high P-Index scores that the PLA region received. The P-Index states that lands receiving moderate scores should have a setback of 200m from surface waters if phosphorus is applied after crop removal. Similarly, any high (>50) P-Index score should not have any fertilizer applied to it after crop removal.

While setback zones are important, the use of trees and non-agricultural vegetation is beneficial in slowing the mobilization of nutrients through uptake. Approximately 19.4% of the study area within the 150m buffer zone falls into this category. Upon visual analysis of satellite imagery as well as the classified land use data it appears that non-agricultural vegetative buffer strips are more common around higher order streams in the PLA region. To further examine the efficacy of current best management practices in the PLA region, the distribution of land use types within the 150m buffer zones was grouped into according to the adjacent stream order (high order streams; Strahler Order 4-6 and low order streams Strahler Order 1-3). Within the 150m buffer area, lower order streams are dominated by agricultural land use at 76.4% compared to higher order streams only having 46.9%. Headwater streams have been well established as the connections between terrestrial and aquatic ecosystems and they are integral to the health of downstream waters. While higher order streams in the PLA region could benefit from the implementation of vegetated buffer strips, it is clear that headwater streams should be the priority for re-vegetation.

Table 4.3: Percentage of 150-m Buffer Zone Area Around Low and High Order Streams

Stream Order	% of Total Buffer Zone Area	Land Use	% of Total Buffer Zone Area Attributed to a Specifc Stream Order Group
Low Order (1-3)	83.9	Other	7.8
		Agricultural Land	76.4
		Non-agricultural Vegetation	8.3
High Order (4-6)	16.1	Other	29.3
		Agricultural Land	46.9
		Non-agricultural Vegetation	23.8

4.2.2 Nitrogen Leaching Index

Maps of LI and N-LI are shown in Figures 4.3 and 4.4, respectively. LI can be classified as low (<2), medium (2-10) and high (>10) (Ketterings et al., 2003). Within these classifications, areas with low leaching index scores accounted for 0.2% of the study area, medium accounted for 97% of the study area, and high accounted for 2.8% of the study area. N-LI scores show areas with high potential to transport nitrates. Figure 4.4 shows the impact that the ubiquity of soybeans has on nitrogen loading in the PLA region. 31.72% of the study area received negative N-LI scores. While the literature makes is clear that positive nitrogen budgets combined with higher leaching capabilities leads to increased nutrient loading, (Van Es & Delgado, 2006;

Shaffer & Delgado, 2002) it was not made clear how negative nitrogen budgets and varying leaching capabilities affect one another. This is why areas in the PLA region that achieved a negative N-LI scores were changed to 0 in SPSS.

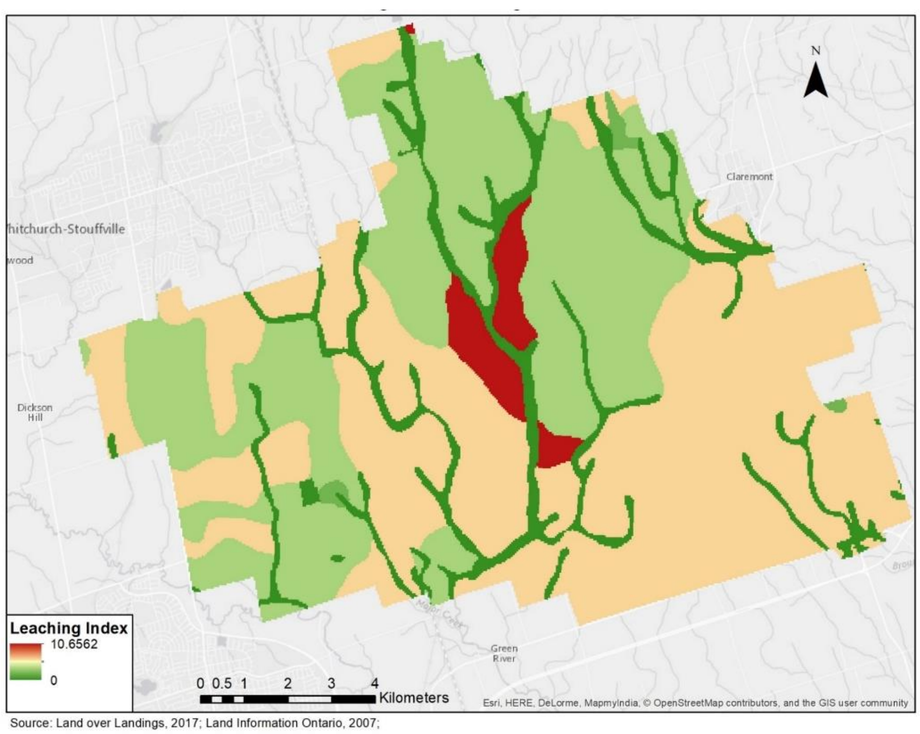
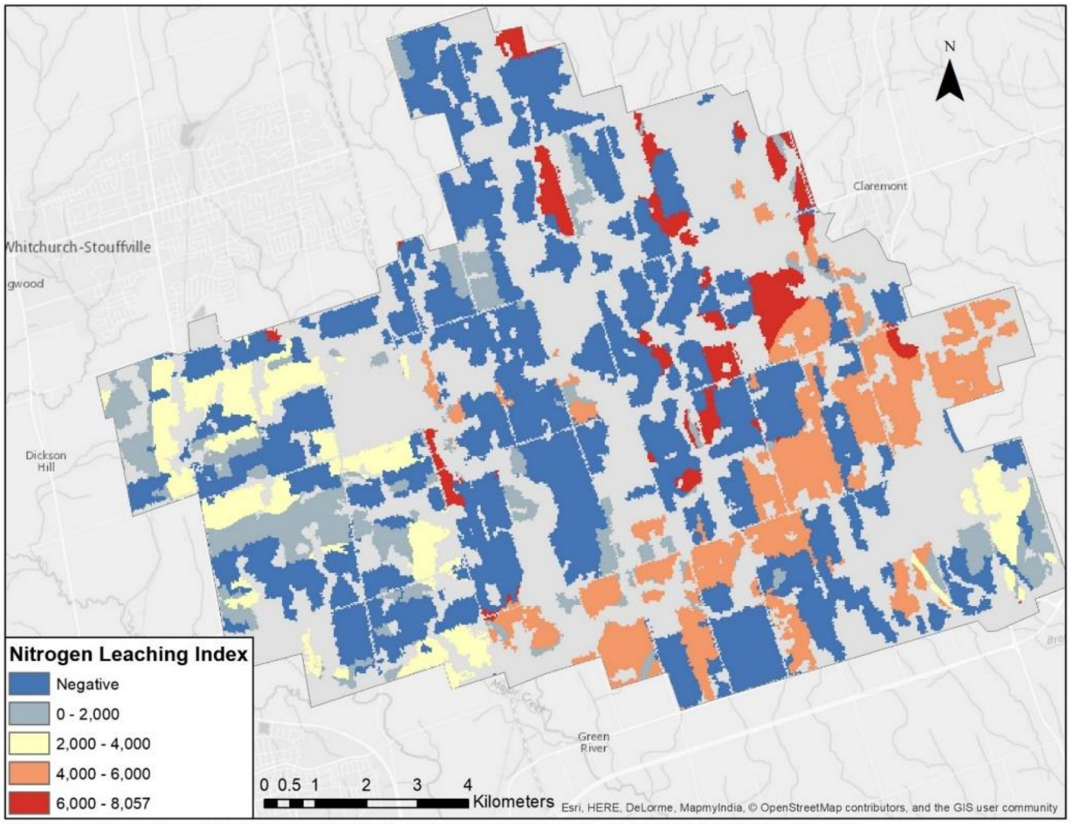


Figure 4.3: Map of Leaching Index values across the PLA region.



Source: Land over Landings, 2017; Land Information Ontario, 2007; Government of Canada, Agriculture and Agri-Food Canada. 2016

Figure 4.4: Map of N-Leaching Index values across the PLA region.

4.3 Spatial Relationship Between Yield and Nutrient Indices

A linear regression analysis using crop yield as the dependant variable and P-Index, and N-LI as the predictor variables resulted in a r^2 value of 0.697 and a $p<0.05$ (Tables 4.1 and 4.2). After logging the results to improve the skewness and kurtosis of the distributions, the r-squared test was reduced to 0.200. Even after logging, it is clear that the distributions of the variables were not normal (appendices 1-3) and could not create reliable statistical analysis.

Table 4.4: Model Summary of Original Values

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.835[a]	.697	.697	929.077

a. Predictors: (Constant), No_Neg_NLI, P

Table 4.5: ANOVA Results for Original Values

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	7082015729	2	3541007865	4102.264	.000[b]
	Residual	3078113471	3566	863183.811		
	Total	1.016E+10	3568			

a. Dependent Variable: Yield

b. Predictors: (Constant), No_Neg_NLI, P

While these results should show moderate correlation between the dependant and independent variables, multicollinearity renders these results unreliable. Collinearity diagnostics in SPSS resulted in many eigenvalues close to 0 in both the logged and non-logged data (Tables 4.6 & 4.7). Similarly, the Condition Index returned many values above 15 and 30 which indicates possible or very serious multicollinearity, respectively (Tables 4.6 & 4.7).

Table 4.6: Collinearity Diagnostics for Original Values

Collinearity Diagnostics[a]

Model	Dimension	Eigenvalue	Condition Index	Variance Proportions		
				(Constant)	P	No_Neg_NLI
1	1	2.449	1.000	.00	.00	.06
	2	.550	2.111	.00	.00	.93
	3	.001	50.294	1.00	1.00	.00

a. Dependent Variable: Yield

Table 4.7: Collinearity Diagnostics for Logged Results

Collinearity Diagnostics[a]

Model	Dimension	Eigenvalue	Condition Index	Variance Proportions		
				(Constant)	P_LOG	NLI_Log
1	1	2.994	1.000	.00	.00	.00
	2	.006	22.178	.00	.00	.99
	3	5.163E-5	240.793	1.00	1.00	.01

a. Dependent Variable: Yield_Log

For all of the factors that were dependant on crop type, there were only six crop types provided by the Annual Crop Inventory (apples, oats, wheat, Canola, soybeans, and corn) that could be inputted into the nutrient index computations. This means that there are only six possible outcomes of any variable that is dependent on crop type such as yield, recommended fertility practices, recommended crop residues, and nitrogen loss to denitrification. Since these variables are dependant on the crop type, there will be no change in one variable without a change in another, which results in multicollinearity. The same issue occurred for variables that were dependant on soil type. Both the P-Index and the Leaching Index are dependant on the soil's hydrological class, and hence soil type. Studies that use field-based soil sampling to validate their models will not have these issues because their data sets are not controlled by classifications. Rather, the collection of yield results is separate and independent from the collection of soil samples and fertility rates. Having independent variables not all defined by the same classifications should mitigate multicollinearity.

After running a linear regression model comparing yield and each of the nutrient indices separately, it is shown in tables 4.8 and 4.9 that the nitrogen leaching index has a moderate correlation with crop yield while there is no correlation between the phosphorus index and crop yield. While part of this moderate relationship between nitrate leaching and yield may be attributed to both of these variables being dependant on the same land classification, it is still shown that there is a correlation between crops with high nitrogen budgets and crops that produce high yields. What this means is that nitrogen loading mitigation efforts will need to be balanced with maintaining yield outputs. Doing so will require the prioritization of implementing nutrient loading mitigation efforts in the most vulnerable areas in the PLA region.

Inversely, the phosphorus index achieved a very low R-Square score which shows no correlation with crop yield. It is very interesting how low the correlation between these two (dis)services considering that many of their site factors are both dependant on the same land classification. Despite this, efforts to mitigate phosphorus loading should not have an impact on yield due to the low correlation. This means that a balance does not have to be struck between mitigating phosphorus loading and maintaining crop yield.

Table 4.8: Linear Regression of Crop Yield and Nitrate Leaching Index

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.835[a]	.697	.697	929.5168327

a. Predictors: (Constant), NLI_No_Neg

Table 4.9: Linear Regression of Crop Yield and Phosphorus Index

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.051[a]	.003	.002	1685.916095

a. Predictors: (Constant), P_Index_Score

4.4 Using the GIS-Based, Nutrient Indices Approach to Make Recommendations for Mitigating Agricultural Nutrient Loading

4.4.1 Recommendations for Mitigating Phosphorus Loading to PLA Region Surface Waters

Given the scores listed above (see Tables 4.1 & 4.2), several recommendations can be made to reduce the mobility and availability of phosphorus. Table 4.7 summarizes OMAFRAs recommendations for best management practices to reduce a field's P-Index score. A recommendation that can be made is to maintain vegetated buffer strips within a 150m buffer surface water features. In the PLA region most of the higher order streams are protected by some form of non-agricultural vegetation directly adjacent to the stream, but lower order (Strahler 1st and 2nd order) streams are not treated in the same way. In the PLA region, only 0.35% of the land area that received a P-Index score of high (>50) that lie directly adjacent to a stream. While ground truthing is needed to determine the width, if any, of current vegetative buffer strips along these fields, these are the areas of the region that could be given priority attention for this type of best management practice.

Table 4.10: OMAFRA Recommendations for Lower Phosphorus Index Scores

Site Characteristic	Management Practices that will Lower P-Index	Example of Best Management Practice
Soil Erosion	Any practice to reduce soil erosion.	Reduce slope length; increase surface residue; plant cover crops.
Water Runoff Class	None	-
Phosphorus Soil Test	The management of fertilizer and manure application methods/rates will control the rate at which the phosphorus level in the soil changes.	The phosphorus level of a field can be lowered on a long-term basis by reducing or eliminating application rates of manure/fertilizer and/or using crops with higher P removal capabilities.
Commercial Fertilizer Application Rate	Applying less fertilizer to a field will lower the level of phosphorus accordingly.	A reduction in the commercial fertilizer application rate from 60 lbs P_2O_5/acre to 30 lbs P_2O_5/acre will reduce the P-Index by 1 point.
Commercial Fertilizer Application Method	The use of an application method that incorporates the fertilizer quickly and efficiently will result in a lower rating factor.	By changing the application method from Non-Incorporated to Placed with Planter, the P-Index is reduced by 10.5 points.

Another important step that should be taken to reduce the P-Index score is to improve the fertilizer application methods used for all of the crop types. OMAFRA has recommendations available for application methods to balance yield and crop profitability. Rather than using a broadcast method which does not incorporate the fertilizer into the soil, OMAFRA recommends placing the fertilizer with planter (fertilizer is planted simultaneously with seed at the start of the growing season) to ensure that the phosphorus is incorporated into the soil and bonds to the seed quickly. Switching from the broadcasting method to the placed with planter method will reduce a field's P-Index score by 10.5 points. Considering that ~60% of the crops in the study area have broadcasting as their recommended application method, this would be a massive improvement. This short term change would yield immediate improvement to a field's phosphorus index score.

The erosion factor has some components that are out of the control of farmers such as slope and the soil's hydrological class. Small changes can still be made to the management practices used by farmers in regard to crop orientation and the use of tree lines to decrease slope lengths. When examining the support practice factor which refers to crop row orientation relative to the slope as well as the use of strip cropping. This factor ranges from 0.25 for excellent support practices to 1.0 for poor support practices. Of the 489 fields extracted from the PLA region, only one received a score of 0.37 which was given to a field that used strip cropping which means that rows of trees were place intermittently in the field to slow erosion. 2.2% of the fields were given a score of 0.50 for using contour cropping which means the crop rows turn to follow the landscape's contours. 44% of the fields received a score of 0.75 for row crops which run perpendicular to the slope and 53% of the fields had crop row orientations that ran parallel with the slope. While the slopes in the PLA region are fairly flat, using strip cropping and improved crop row orientation can still reduce the potential for erosion and mitigate phosphorus mobility (Stone & Hilborn, 2012). The crop/vegetation and management factor is also in the hands of the farmers to improve their field’s P-Index score, but the majority of the PLA region scores excellent crop/vegetation and management factor scores. This is due to the commonly grown crops in the PLA region that require no-tillage systems as recommended by OMAFRA. The other factors that affect erosion are out of farmer’s hands such as slope, rainfall, and soil classes.

The final recommendation to reduce the PLA region’s P-Index scores would be reducing the amounts phosphorus based fertilizers applied to the crops. According to OMAFRA, changing an application rate from 27kg P_2O_5/hectare to 13kg P_2O_5/hectare will reduce the P-Index score by 1 point. This is a large reduction in fertilizer for only 1 point of reduction considering that the crops in the PLA region require 20-50kg P_2O_5/hectare. It is unknown to this study if this change in fertility practice would change crop yield and this presents potential opportunity for future research. Despite this small initial reduction, lowering the rate of fertilizer applications will also lower phosphorus soil test scores over a long term basis (Hilborn & Stone, 2016). Unfortunately, the absence of phosphorus soil test data makes quantifying these potential reductions impossible for this study.

4.4.2 Recommendations for Mitigating Nitrogen Loading to PLA Region Surface Waters

Nitrogen availability is an important factor when trying to assess how much an area is at risk to increasing nitrate leaching and eutrophication of nearby surface waters. By calculating the nitrogen budget for each crop type, it is easy to see how much nitrogen is available for transport in a certain area. This nitrogen budget combined with the land use data and the 150m buffer reveals how crop types can be used as a mitigating factor in nitrogen availability and mobility. Similar to trees and shrublands, soybeans are the only crops in the PLA to have negative nitrogen budget values. This is because soybeans require no supplemental nitrogen fertilizers to meet their fertility needs and soybeans do an excellent job at up taking huge amounts of nitrogen through the soils as well as absorbing nitrogen through the air in the form of N2O (Angle, 1990; Wagner-Riddle et al., 1997; Rotundo et al., 2014). Soybeans ability to efficiently uptake nitrogen mitigates the nutrients ability to mobilize and enter surface water features. Within the 150m buffer zones around high and low order streams, soybeans account for 13.0% and 29.3% respectively. This is inverse to how non-agricultural vegetation dominate high order stream buffer zones. What this shows is that there are nitrate leaching mitigating strategies in place despite the absence of trees and shrubs around these low order streams.

4.5 Recommendations for the Appropriate Scale to Apply the GIS-Based Nutrient Indices Approach

While the use of publicly available data such as average crop residues and average monthly precipitation amounts allowed for a simplified methodology without the need to conduct field observations, no meaningful results could be derived at the scale of the PLA study region. Excessive multicollinearity limits this studies ability to confidently quantify ecosystem services and disservices at this scale due to the limitations in the spatial variability of many of the publicly available data. For example, the majority of the PLA region falls within Durham Regional Municipality (also considered Durham County) which means that any variable that is recorded at the county level, such as average crop residue levels and crop yield, becomes static throughout the entire study area. Similarly, only one rain gauge was used to define precipitation values. The GIS-based nutrient index approach would likely be better suited to application at the provincial or national scale where the variation in data amongst each county would yield more granularity in the results. While this does not eliminate multicollinearity in variables such as fertility recommendations and hydrologic soil classes, it does eliminate the static nature of many others.

Chapter 5: Conclusion

Using publicly available data and GIS-based spatial analysis, this study has attempted to assess how agricultural practices contribute towards ecosystem (dis)services in the PLA region in north Pickering, Ontario. Specifically, spatial analysis of crop yields and nutrient risk indexes (for phosphorus and nitrogen) were compared. While crop yield, P-Index and N-Leaching Index were all successfully mapped at the field scale across the study area, the presence of multicollinearity in the data sets caused by multiple variables being dependent on the same classifications has meant that no reliable statistical results could be found regarding a relationship between water quality disservices and yield. Some correlation between nitrogen loading and yield was uncovered. This shows that attempts to mitigate nitrogen loading needs to be balanced with maintaining yield in the region. Should a future study attempt to use a similar approach, it is recommended that the scale of the project be expanded to encompass multiple counties so that fewer variables are static across the study region. Despite these limitations, the generation of raster layers of the P-Index, N-LI, and crop yield data have helped inform recommendations that should be prioritized in the PLA region to mitigate nutrient loading. Addressing these recommendations would both reduce the PLA region's nutrient loading scores and inform some of the rhetoric used by groups who oppose the Pickering Lands Airport and wish to see the farmland in the area preserved.

Appendices

Figure 1: Distribution of Yield Values (Logged)

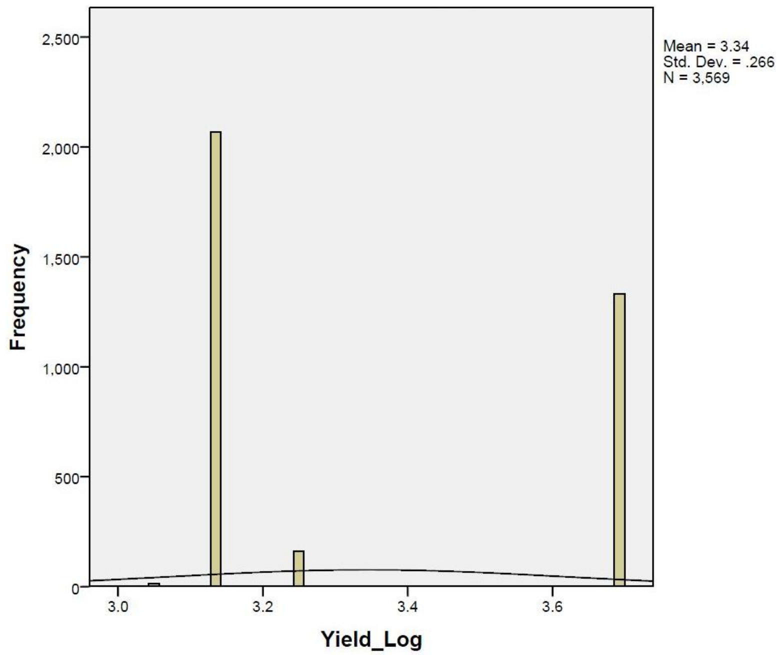


Figure 2: Distribution of the Phosphorus Index Score

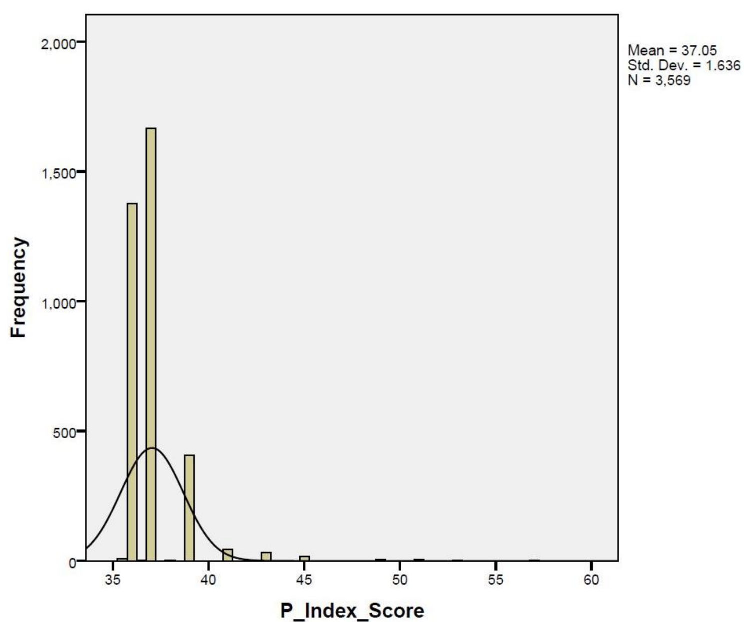
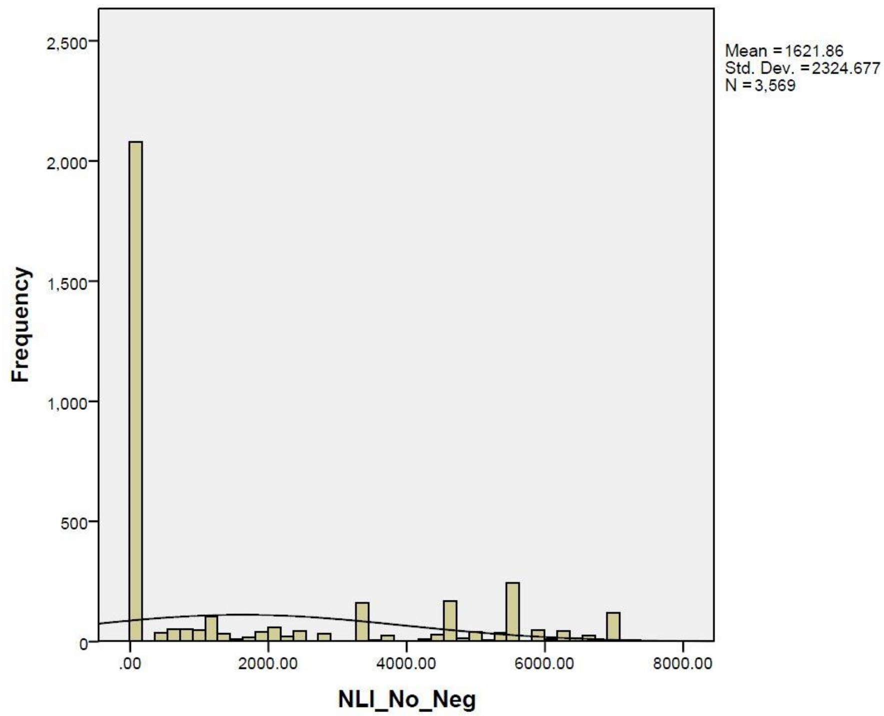


Figure 3: Distribution of the N-LI



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