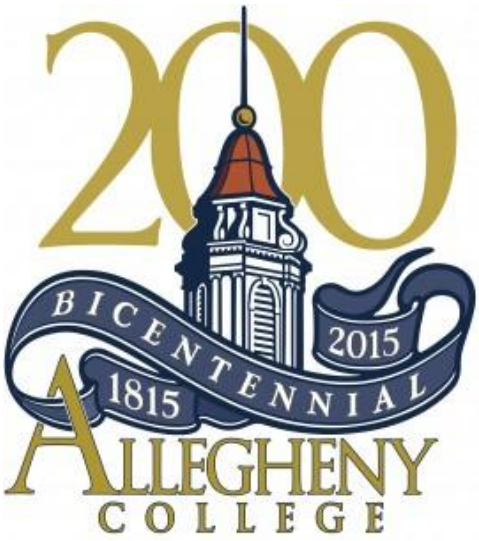
Landuse Analysis of Agricultural Decline and Urban Development upon Nutrient Content Loading of Conneaut Lake Watershed and Tributaries

By
Michaela Baxter
May 2015



Allegheny College
Department of Environmental Science

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A Senior Comprehensive Project in Partial Fulfillment of the Requirements for a Bachelor of Science Degree from Allegheny College

I hereby recognize and pledge to fulfill my responsibilities as defined in the Honor Code and to maintain the integrity of both myself and the College community as a whole.

Michaela Baxter
Pledge

Approval by the Senior Thesis Committee:

Christopher Shaffer
Mr. Christopher Shaffer

Dr. Milton Ostrofsky

Acknowledgments

Thank you, Dr. Eric Pallant, for assisting me with my academic endeavors and supporting me throughout my time at Allegheny College. I truly appreciate all of your help.

Dr. Milt Ostrofsky, thank you for the time you spent as a part of my comp committee. Your guidance was extremely beneficial for the completion of this project.

Mr. Christopher Shaffer, thank you for your time and dedication in being my comp advisor. I am grateful for all of your assistance.

Most of all, I would like to thank all of my friends and family for their emotional and moral support. I would not be here today without you.

Overall, I owe this accomplishment to each and every one of you. Thank you all.

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Major: Environmental Science
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Title: Landuse Analysis of Agricultural Decline and Urban Development upon Nutrient Content Loading of Conneaut Lake Watershed and Tributaries

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The goal of this study was to determine the cause of increasing phosphorus levels by analyzing landuse changes over time in Conneaut Lake. Increasing aquatic vascular plant growth within Conneaut Lake has been noted since the mid-20th century. Conneaut Lake was and is valued both recreationally and economically throughout northwestern Pennsylvania. The ill health of Conneaut Lake is causing difficulties for both pleasure boaters and local businesses within the region, in addition to the loss of native species in the lake. This study analyzed historical landuse changes in the Conneaut Lake watershed through the use of a geographical information system (GIS). The goal is to determine the source of the increasing phosphorus levels with current decreasing agricultural runoff in addition to increasing residential development within the Conneaut Lake watershed. In the seventy year study period it was determined by use of digitization polygons that the Conneaut Lake region has transitioned from agricultural to residential with an increasing forest trend. Therefore, the increase in phosphorus loading and aquatic vascular plant growth may be attributed to developed landuse.

Introduction

In the United States, many freshwater bodies have faced an assortment of challenges throughout history. For example, in the early 19th century, New York City discharged sewage into its harbor believing 'dilution was the solution' to water pollution (Pielou, 1998). In addition to this, both chemical and industrial wastes were directly deposited into the nearby rivers and streams. Throughout many cities, no swimming signs were displayed prominently along the shores of many water bodies due to their foul smell and color. Large water bodies were no exception to water pollution. In the Great Lakes region, cities would often continue the practice of river pollution causing the water supply to Lake Erie and other lakes to become extremely contaminated. Excess phosphorus levels caused massive algal blooms and industrial wastes caused the rumor of Lake Erie to be 'dying' (Lake Erie Waterkeeper, n.d.). A tributary of Lake Erie, Ohio's Cuyahoga River caught fire on multiple occasions, first in 1936 but most notably in 1952. The final time it caught on fire was in 1969, due to the accumulation of oil and other forms of debris (Adler, 2014). But this was not the only river to catch fire throughout the United States. Although the Cuyahoga had caught 13 times, rivers in Baltimore, Detroit, Philadelphia, and Buffalo had burned as well. These displays of utter contamination of a water source may have influenced a series of constructive state and federal Environmental Protection Agency pollution regulations that were soon developed and passed in 1972 (EPA, 2008).

However, it is evident that the United State's regulations need to be further revised and expanded upon. In 2011, Lake Erie once again suffered a massive algal bloom that left residents in Northwest Ohio without safe tap water to drink (Lee, 2014). Soon after, experts disclosed that the cause of the algal bloom came from multiple sources. These sources ranged from point pollution of leaking septic tanks, agricultural fertilizers, and lawn chemical treatments as well as

the general warming trend of freshwater bodies due to climate change (Lee, 2014). In 2008, researchers at Kansas State University calculated that polluted water sources were costing Americans approximately 4.3 billion dollars a year from just phosphorus and nitrogen runoff (Dodds et al., 2008). Assortments of polluted waterways throughout the world can be traced to all of the continents, such as Lake Karachay in Russia, Ganges River in India, and Chaohu Lake in China (Queen, 2012). Therefore, both historical and present day water sources are at a great risk from nearby human activity. The United States is a clear example of what detrimental effects may occur to water sources if they are not protected from point and nonpoint pollution, such as improper sewage disposal and runoff.

In a small town in northwestern Pennsylvania, Conneaut Lake is suffering from what seems to be an excess of phosphorus within its waters. Increasing growths of aquatic vascular plants within the watershed are causing detrimental effects both ecologically and economically with a decrease of agricultural output. Therefore, the goal of this study is to determine the source of the increasing phosphorus levels with current decreasing agricultural runoff in addition to increasing residential development within the Conneaut Lake watershed by means of a geographic information system (GIS).

Background

Impacts of Riparian Buffer Zones

Watershed ecosystems are sensitive to anything that can be put into the water, whether it is natural or synthetic. Ecosystems within watersheds typically rely on a buffer zone to protect from harmful items to infiltrate the water body. This 'buffer zone' is typically referred to as a riparian buffer zone and are composed of vegetation, i.e. shrubs, trees, grasses, and flowers that

surround the body of water's edge and can range in size from 25-100 feet (Hawes & Smith, 2005). If riparian zones are not wide enough or not present at all, negative aspects such as lower water quality values, reduced wildlife and fish populations, serious property damage, bank erosion, increased water temperature, decreased dissolved oxygen levels and loss of valuable agricultural land may occur (Hawes & Smith, 2005). Increased sediment loading also causes reduced stream flow in addition to providing extra material for invasive aquatic vascular plant growth (Hawes & Smith, 2005). In contrast, maintenance of riparian buffers is one of the most effective means of protecting water quality, hydrology, unique species and natural communities, and watershed ecosystem function (Hawes & Smith, 2005).

One of the largest inputs into watersheds is derived from agricultural practices which range from grain agriculture to livestock agriculture (Hawes & Smith, 2005). Both types of agriculture have negative impacts upon watershed health which generally includes the input of excessive amounts of nitrogen and phosphorus. Input occurs from land surface runoff due to the lack of buffer zones to the tributary or body of water. These elements from fertilizers and animal waste, as well as other pollutants originating from pesticides and herbicides, often bond to soil particles (Hawes & Smith, 2005). The nutrient loaded sediment contained in surface runoff then flows to the nearest waterbody and is deposited. This process is the primary cause of accelerated eutrophication of lakes and rivers (Hawes & Smith, 2005).

Lake Processes

Lakes of larger depth often have a yearly mixing cycle, also known as lake stratification. In autumn, cooler air temperatures cool the lake's surface. When the surface water cools, it becomes denser and sinks to the bottom of the lake (EPA, 2005). In spring, the ice melts and the

surface water begins to warm. Due to the changes in temperature, the colder and warmer water mix together in a cycle called spring turnover. After this step, most of the lake water is then at the same temperature allowing the water to mix together further (EPA, 2005). Due to mixing, nutrients, such as phosphorus, often are then equally distributed in the lake's waters (EPA, 2005).

Phosphorus and Population Induced Runoff

Phosphorus, naturally added by geological weathering, is a limited resource. Globally, phosphorus is an issue mainly pertaining to ocean anoxic events, where eutrophication and other such events occur (Elser, 2012). Phosphorus influxes into the ocean also depend upon the detergent and sewage flow into the ocean. However, it would take 10,000 years to double the amount of phosphorus in the ocean. And at the current rate, triggering of an ocean anoxic event would take 1000 years (Dupas et al., 2015). The effects of phosphorus pollution have already affected the earth in a negative way by creating algal blooms and other unhealthy vegetation growths. This can also be seen on a local scale, in the form of smaller water bodies, such as lakes. These unhealthy algal growths occur due to an excess of nutrients in the body of water, the source of which generally is tied to phosphorus fertilizers and their runoff (Xu et al., 2014). Throughout the 'Green Revolution' of the mid-20th century, agriculture began using multiple forms of pesticides that contained high phosphorus content which benefitted the health of the row crops, but ultimately increased the levels of phosphorus contained within a body of water, causing eutrophication (Mullins, 2009). This 'eutrophication' problem has been the focus of considerable scientific work and regulatory actions for many decades (Serediak & Prepas, 2014). The United States is not alone in facing eutrophication of water bodies (Dodds et al., 2008). The majority of eutrophication can be a resultant of over fertilization, and fertilizer use patterns can be used to designate global trends of eutrophication. Aquatic vascular plant abundance increases

with excess nutrients until conditions become eutrophic causing excess plant growth within the waterbody (Dodds et al, 2008). If excess aquatic vascular plant growth is not treated the waterbody may not be as effectively utilized as it was in the past. Boating, recreation, and natural lake processes, and visual appeal of the waterbody all can be affected negatively by increased aquatic vascular plant growth (Dodds et al., 2008). According to Dodds et al. (2008), treatment costs for a variety of aquatic weeds range from $1,247 to $19,227 per hectare for mechanical harvest and $246 to $1,190 per hectare for chemical treatment. If "just 1% of major surface waters in the U.S. needed aquatic vascular plant control because of eutrophication induced aquatic vascular plant growth, it would cost an average of $1.2 billion annually for mechanical harvest or $105 million dollars annually for herbicide treatment" (Dodds et al, 2008).

Formation of Conneaut Lake

In addition to eutrophication in general, the gradual increase of residential, impervious, commercial, and municipal areas throughout the Conneaut Lake watershed has increased the amount of water that is being put into the watershed. This increase has increased the amount of non-source pollutants present in Conneaut Lake. The history of Conneaut Lake spans throughout eras. Conneaut Lake is part of a unique category of natural lakes that were formed during the last 13,000 years. The majority of this category is composed of natural lakes formed during the last glacial period (Hopey, 2000). According to Hopey, Pennsylvania's glacial lakes are all kettle lakes (2000). These lakes were formed in the late Pleistocene period when large sections of ice broke free from a retreating continental ice sheet, in this case the Wisconsin Glacier (Hopey, 2000). As the ice blocks melted they filled the depressions, or "kettles," in which they sat, creating the lakes (Hopey, 2000).

Present Nutrients within Conneaut Lake

As a state, Pennsylvania is home to 50 natural lakes (Pennsylvania Visitor's Network, 2014). Conneaut Lake is the largest of them all. These natural lakes all have natural processes that are unique to their shape, size, and depth. Throughout Conneaut Lake's history various nutrients and wastes have been added or even removed from the body of water. These nutrient amounts have varied greatly due to the source of the input, ranging from leaking septic tanks to canals connecting to other bodies of water. The publication of Rachel's *Silent Spring* in 1962 brought further attention to the accumulating environmental issues throughout the United States during this era (Carson, 2002). Particularly with the implementation and passing of the Clean Water Act ten years after Carson's insight into the state of the environment, testing of water became much more prominent throughout the nation (EPA, 2008).

Furthermore, the creation of the Environmental Protection Agency in 1970 brought upon even more changes and additions in legislation relating to the environment (Percival, 1991). One of the initial crucial reports relating to freshwater phosphorus levels released by the EPA (in cooperation with the Pennsylvania Department of Environmental Protection) was the National Eutrophication

A. Point Sources:

1. Known municipal - None
2. Known industrial - None

B. Annual Total Phosphorus Loading - Average Year:

1. Inputs -

Source	kg P/yr	% of total
a. Tributaries (non-point load) -		
Unnamed Stream (B-1)	100	5.2
Unnamed Stream (D-1)	655	34.0
b. Minor tributaries & immediate drainage (non-point load) -	1,075	55.8
c. Known municipal STP's - None	-	-
d. Septic tanks - None	-	-
e. Known industrial - None	-	-
f. Ducks and geese -	30	1.6
g. Direct precipitation* -	65	3.4
Total	1,925	100.0

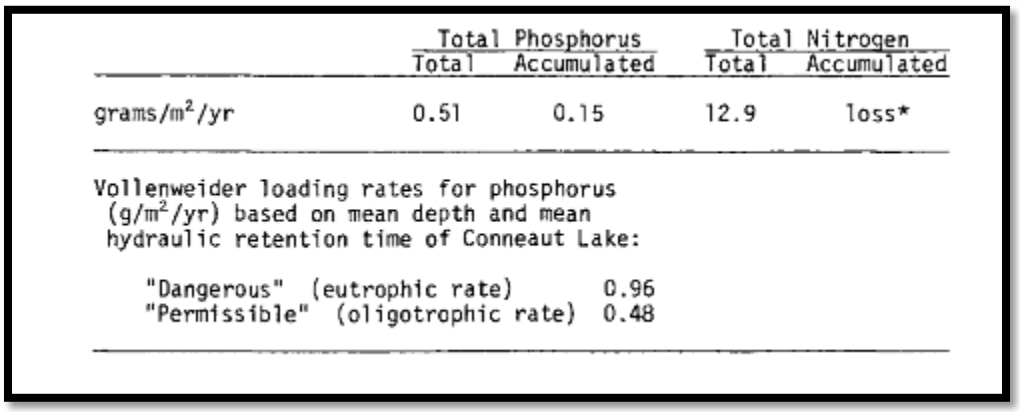
2. Outputs -

Lake outlet - Conneaut outlet 1,345

3. Net annual P accumulation - 580 kg.

Figure 1 Conneaut Lake Phosphorus Levels (EPA, June 1975)

Survey initiated in 1972 with the Conneaut Lake's version published in 1975. This survey established vital information that was not previously recorded at national level. In doing so, it established that phosphorus is the major nutrient that is in shortest supply in relation to the nutrient needs of most vegetation. Generally, it can be said that if you can control the amount of phosphorus entering a lake you will be able to control the vegetation growth (EPA; NERC, 1975). As seen in Figure 1, it was established by the Environmental Protection Agency that Conneaut Lake, in the year of 1975, did not have issues with septic tanks, surrounding municipal/industrial runoff, and other lakeshore inputs. Instead the tributaries (B-1 & D-1) at 39.2%, and minor tributaries/ drainage at 55.8% combined to make up 95% of the phosphorus input into Conneaut Lake at this time (EPA; NERC, 1975). However, in 1996, DEP listed Conneaut Lake under Section 303(d) of the Clean Water Act as impaired due to excess nutrient and suspended solids loadings (Balog, 2001).



	Total Phosphorus		Total Nitrogen	
	Total	Accumulated	Total	Accumulated
grams/m^2/yr	0.51	0.15	12.9	loss*

Vollenweider loading rates for phosphorus ($g/m^2/yr$) based on mean depth and mean hydraulic retention time of Conneaut Lake:

"Dangerous" (eutrophic rate)	0.96
"Permissible" (oligotrophic rate)	0.48

Figure 2 Total Amounts of Phosphorus and Nitrogen in 1975 (EPA, 1975)

This listing by the DEP as Conneaut Lake as an 'impaired' body of water only occurred approximately 20 years after the previous study in 1975 (Accumulation of phosphorus in 1975, see figure 2). Presently, phosphorus has continued to accumulate within the waters of Conneaut

Lake. The excess presence of nutrients has affected the health of the lake negatively, which could be partially related to the increase of human usage throughout recent years.

Ecosystem of Conneaut Lake

Although the lake is classified as a natural body of water formed during the glaciation of Pennsylvania, human presence has dramatically declined the health of the lake. With a size of approximately 925 acres and maximum depth of 60 feet, Conneaut Lake currently is home to a multitude of fish species, the most common of which include bluegill and bass (Ensign, 2012). Almost one-third of the organisms in the body of water have been introduced in the past 30 years, a surge coinciding with the opening of the St. Lawrence Seaway in 1959 (Mills et al., 1993). The increase of species within Conneaut Lake may be loosely linked with the increase of invasive species within the Lake Erie watershed due to the transfer of boats between the two bodies of water by seasonal visitors. Recreation of such boats may also add to the eutrophication of the lake due to the spillage of gasoline, human waste, and other disadvantageous activities (Limburg, 2009). The cultural eutrophication of freshwater, estuarine, and coastal marine ecosystems can cause ecological and toxicological effects that are either directly or indirectly related to the proliferation of primary producers. The decline in dissolved oxygen concentrations can also promote the formation of reduced compounds, such as hydrogen sulphide, resulting in higher toxic effects on aquatic animals (Carmargo & Alonso, 2006). The occurrence of toxic algae can significantly contribute to the extensive kills of aquatic animals.

In addition to this, the natural content of phosphorus and nitrogen may also influence the growth of the vegetation within the lake causing negative effects upon fish and other species using the lake by decreasing sunlight, oxygen levels, etc. Conneaut Lake has approximately 28

different types of vegetation and 12 nonstocked species of fish (French Creek Watershed Program, no date). If vegetation growth continues to occur at its present rate, we may begin to see a decline in diversity of species in Conneaut Lake. Processes that occur in all freshwater bodies such as stratification may also be affected by the surrounding land use. The runoff from the surrounding areas around the lake affects the nutrient content from fertilizers and phosphorus levels (Han, 2012).

Biodiversity and Downstream Impacts

Conneaut Lake is located in the southwestern side of the French watershed. In being farther downstream, it therefore has more water that has already travelled through other streams and tributaries, allowing for a higher accumulation of nutrients. A similar situation occurred in an article by Struger and Fletcher (2007), which determined in the Don and Humber River watersheds held a variety of pesticides in testing sites. Both of these rivers are tributaries to Lake Ontario which would then possibly accumulate in its watershed. In the testing that occurred between 1998 and 2002, they recorded information on both dry and wet days to signify the type of source this pollution was coming from. Eleven pesticides and one metabolite were in surface waters of the Don and Humber rivers, with approximately 72% of samples containing at least one pesticide attributable to lawn care use (Struger and Fletcher, 2007). The pesticides and pesticide metabolite detected in this study included 2,4-D, atrazine, bromacil, carbofuran, chlorpyrifos, cypermethrin, diazinon, dicamba, MECOPROP, metolachlor, metribuzin, and an atrazine metabolite. Therefore, the water that comes to and from Conneaut Lake may be having multiple effects, both within and outside its watershed. The supporting tributaries landuse will be critically analyzed in order to determine the present day affects upon the lake.

Possible Benefits of Excess Aquatic Vascular Plant Growth

Although excess invasive aquatic vascular plant growth is not necessarily a benefit, there may be benefits to aquatic vascular plants growth in freshwater bodies. Paul and de Neys (2008) have found that vegetation and algae in freshwater bodies has been able to filter excess phosphorus and nitrogen to manageable levels. This would be of benefit to Conneaut Lake since there is an excess content of these nutrients. Aquatic vascular plants in particular can effectively strip nutrients from waste matter prior to its release to the environment. Characteristics that make aquatic vascular plants particularly effective as biofilters are high growth rates, pliable reproductive modes and simple habitat requirements. Aquatic vascular plants typically have high growth rates in nutrient-rich aquaculture runoff as nutrients are no longer a limiting growth factor as they often are in nature (Neori et al., 2000;Nagler et al., 2003;Hernandez et al., 2006).

Methods

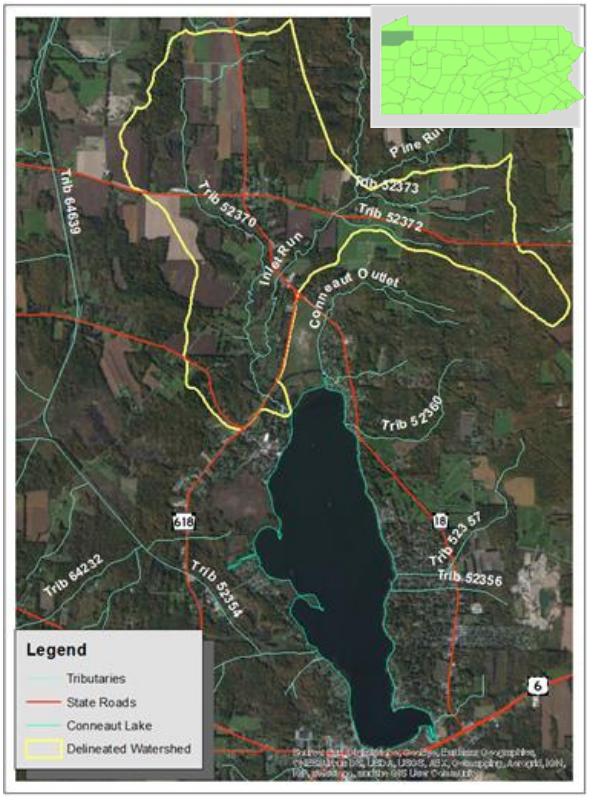


Figure 3: Map of Conneaut Lake (ArcGIS 10.2.2, 2015; PennDOT, 2015; Eastern Pennsylvania Coalition for Abandoned Mine Reclamation, 2014; Western Pennsylvania Conservancy, 1993)

Study Site

Conneaut Lake is the largest of the natural, inland lakes formed over 10,000 years ago during the last glacial episode in Pennsylvania (Ensign, 2012). The lake is located within the boundaries of Crawford County (41° 37' 30" N / 80° 18' 22" W). The Commonwealth of Pennsylvania owns the lake and private parties own the surrounding land. The maximum depth of the lake is approximately 60 feet and occupies 925 surface acres (Ensign, 2012). Conneaut Lake has been found to be a eutrophic lake. A eutrophic lake is one that is characterized by high algal biomass, extensive macorophyte beds, and hypolimnetic oxygen depletion during winter and summer stratification (Ostrofsky et al., 1989). All of these symptoms are consequences of high concentrations of nutrients, specifically-phosphorus. Other lakes in Crawford County are also eutrophic (Canadohta, Sugar, Tamarack, Crystal), and it may be successfully argued that these latter lakes are substantially more eutrophic than is Conneaut (Ostrofsky et al., 1989). However, Conneaut Lake is by far the most heavily used resource in the county. The lake is highly utilized by recreational boaters and sportsmen. It attracts many users for a variety of recreational pursuits and as a consequence it is a resource of extraordinary value to the economy of the county. The large proportion of the county's total employment created by tourism and recreation indicates the value of the lake.

Research Design

In order to determine the presence of various nutrients found throughout the lake, the naturally occurring phosphorus and nitrogen must be determined. This can be found within the sediment, stream flow, and internal load of the lake (Ostrofsky et al., 1989). In addition to this, the changing that have occurred to landuse surrounding Conneaut Lake and its tributaries was

analyzed using aerial photography using GIS. By doing so, the historical phosphorus output and runoff was estimated by the area of the land as well as its classification, which was then calculated by using a runoff formula. The total landuse areas for each selected study year was used in the phosphorus calculation formula to provide an estimate for each year's phosphorus content. The study includes photographs encompassing the study region in 1938, 1959, 1969, 1982, 1993, 2001, and 2010.

Data Collection

The study region covered the Inlet Run and the partial Pine Run watershed in addition to the regions inside of the area surrounded by the Pennsylvania State Roads 18, 6 and 618. Due to the lack of historical water quality records of the Conneaut Lake watershed it was necessary to rely upon spatial data to estimate the possible phosphorus content of the waterbody. In addition, time constraints restricted the research area to the lower Inlet Run adjacent region. Aerial photographs for years 1938, 1959, and 1969 were acquired from the PennPilot online aerial photography repository (See Data Dictionary, Appendix B). Next, years 1982, 1993, 2001, and 2010 were acquired from the United States Geological Survey Global Visualization Viewer (GloVis) by both the National High Altitude Photography (NHAP) and National Aerial Photography Program (NAPP) online repository (USGS, 2014). Further details of photographs can be found in the data dictionary (Appendix B).

Since the aerial photographs were not registered to real-world coordinates, they were georeferenced using Esri's ArcGIS Desktop 10.2 software (Esri, 2014). The reference data from which coordinates were acquired was the Pennsylvania Department of Transportation's (PennDOT, 2014) State Road data files acquired from the Pennsylvania Spatial Data Access

(PASDA) website (PennDOT, 2015). The state roads layer was first projected into Universal Transverse Mercator Zone 17 North American Datum 1983 which was appropriate for the geographic region and scale under investigation. Control points were digitized at strategic locations throughout the photographs and link to corresponding locations within the state roads layer. The total RMS error for each photograph, which is an indicator of the accuracy of transformation, can be found in Appendix A below.

Each time series was examined for landuse composition and density of cottages. Cottages, defined as livable dwellings were digitized in the area between Route 6, 18 and 618. A point was placed for each dwelling deemed suitable for habitation. Land area was calculated for the dwelling region with the exception of the land that Conneaut Lake occupies and was found to be 710.74 Ha.

Total Number of Cottages/Total Land Area (Ha) = Cottage Density

These regions were digitized using a heads-up or on-screen approach to create polygons around each discrete landuse type. The polygons and points included classifications for agriculture, urban, forest, and waterbody. Each polygon was digitized at a constant scale of 1:5000. These polygons were then used to measure the overall area in hectares of each landuse class for each time series in determining the results of possible phosphorus content. Each polygon was entered into a geodatabase depending upon the classification of landuse. Once the landuse was digitized the landuse total was provided by the geographic information system (GIS).The phosphorus content was then derived from a formula based upon Reckhow et al. (1980) export coefficients (Appendix). The export variable landuse P was composed of usually two or more variables representative of the landuse within Conneaut Lake.

Landuse P (kg/Ha/yr) x Area (Ha) = Yearly P (kg)

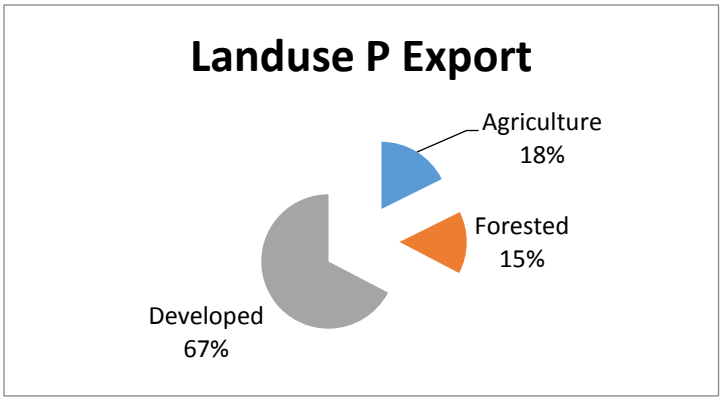


Figure 4: Denotes the phosphorus (P) export coefficients in terms of the average landuse category exportation. Developed landuse is composed of business and residential, agriculture of pasture and cattle, forested of hardwood and coniferous coefficients from Reckhow et al., 1980.

Results

The results of this study were to determine the source of the increasing phosphorus levels. Each landuse category is represented within the Conneaut Lake region and Inlet Run watershed. After digitization, each landuse category's area was recorded in the proper unit of measurement (Table 1). Waterbody's surface area remains near the same area due to the relatively stable water level of the lake (i.e. canals added for shipping in early 20th century modified the body of water). Cottages were of specific importance due to the possibility of excess nutrient input running into the lake from unforeseen residential

	Agriculture	%	Forest	%	Waterbody	%	Developed	%	Total
1938	932.23	45%	577.5	28%	385.71	18%	182.42	9%	2077.86
1959	798.41	39%	596.8	29%	387.17	19%	274.71	13%	2057.99
1969	610.94	30%	729.86	35%	390.7	19%	329.81	16%	2061.31
1982	438.83	21%	839.04	41%	392.22	19%	390.35	19%	2060.44
1993	372.37	17%	950.13	45%	394.55	19%	394.12	19%	2111.17
2001	354.57	17%	955.73	45%	396.1	19%	393.35	19%	2099.75
2010	256.68	12%	1104.99	52%	394.74	18%	377.75	18%	2134.16

Table 1: Landuse category and residential areas were calculated in order to determine the phosphorus export of each respective category. Agriculture, Forest, Waterbody, and Developed are recorded in hectares. Houses are measured by each individual unit.

contaminants. As seen in Figure 1, there has been a trend of decreasing forest throughout the Conneaut Lake region. In addition to this, an increasing trend in both forest and developed landuse categories.

Year	Houses
1938	381
1959	642
1969	962
1982	1061
1993	1089
2001	1257
2010	1389

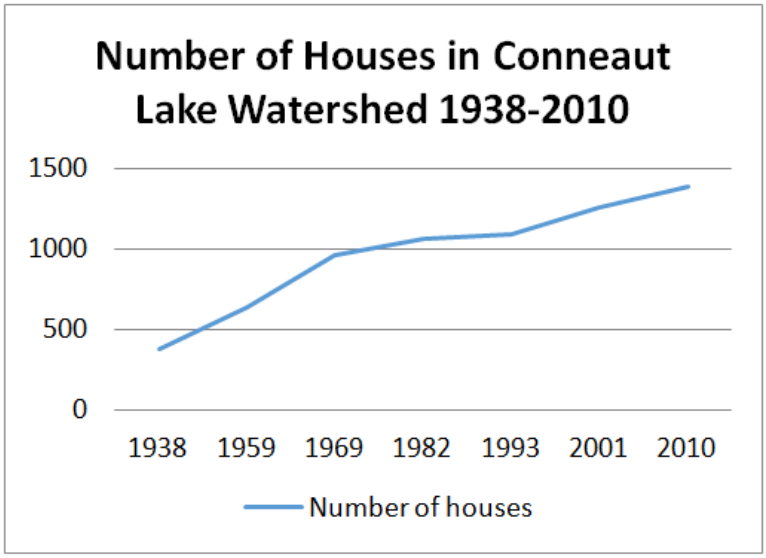


Figure 6 Number of houses contained within the study extent from 1938-2010.

Each landuse category was assigned a phosphorus content average by the calculations based upon export coefficients in Reckhow et. al 1980. Agriculture was based upon an average export of 55 kg per hectare. Within this category it was determined that dairy, pasture, and grazing were representative of the mixed agriculture within the Conneaut Lake watershed. Forest also had a similar export of 46.6 kg per hectare due to the multitude of trees within the watershed, such as birch, maple, beech, pine, oak, and hickory. Developed landuse had the highest export coefficient of 209.5 with the residential and business district located near the lakeshore. Phosphorus export calculations were completed for the years 1938, 1959, 1969, 1982, 1993, 2001, and 2010. These calculations are presented Figure 2 with all calculations represented in kg/Ha/yr.

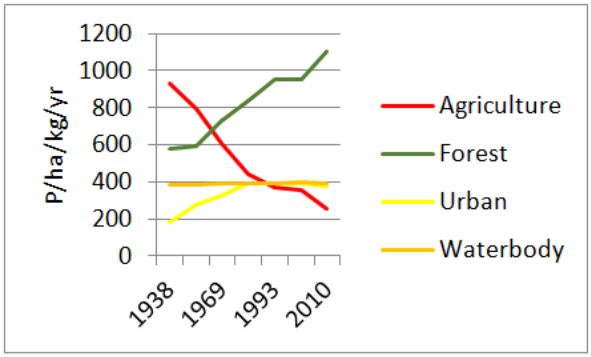


Figure 7: Comparison of Agriculture, Forested, Waterbody, and Developed land area throughout the selected time period.

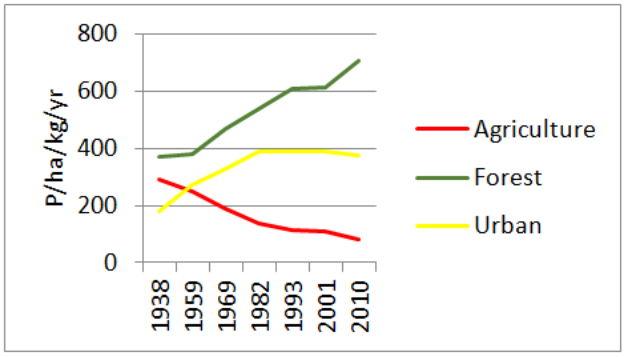
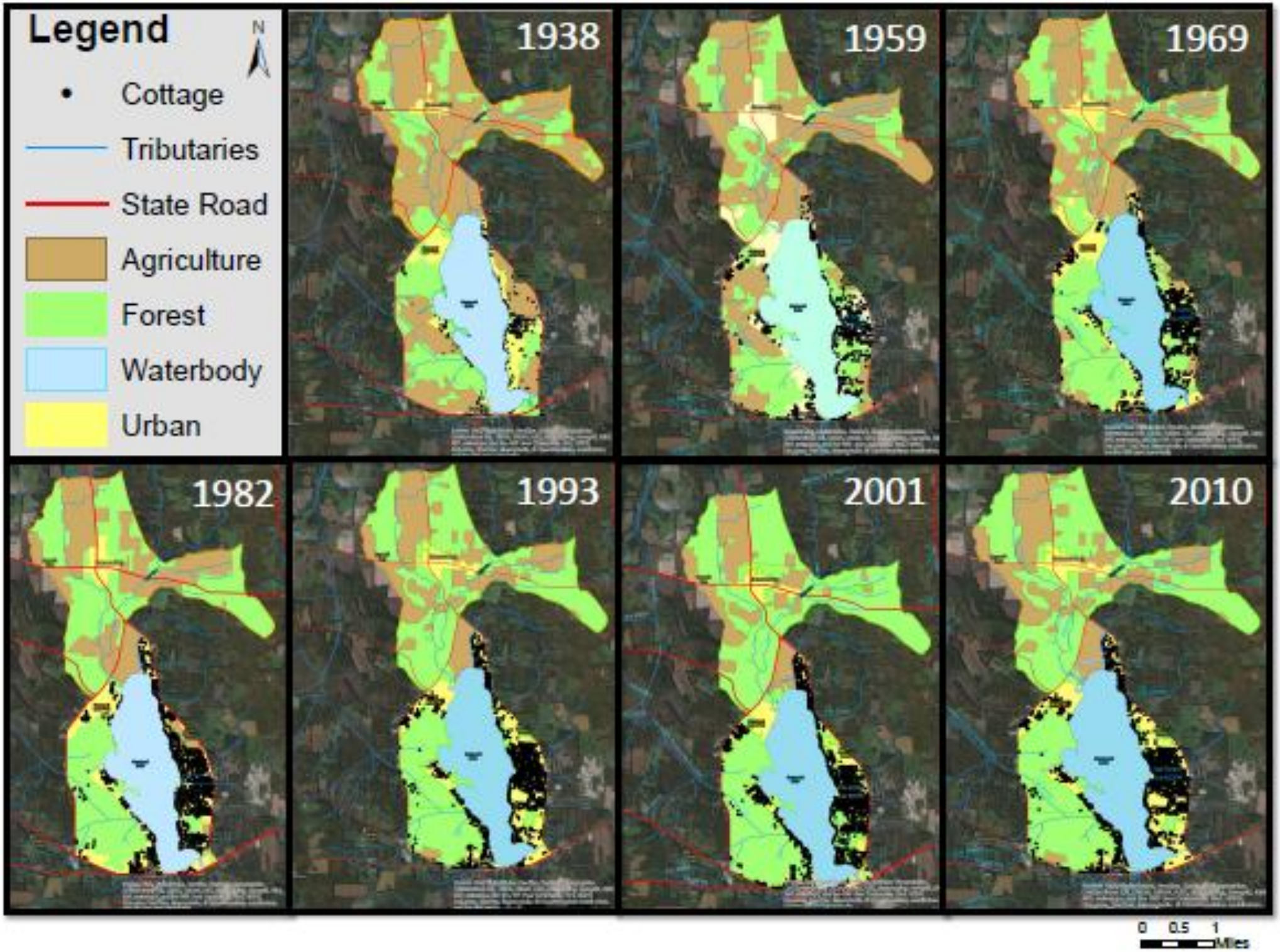


Figure 8 Yearly comparison of phosphorus export in Agriculture, Forested, and Developed areas.


Legend
N
Cottage
Tributaries
State Road
Agriculture
Forest
Waterbody
Urban
1938
1959
1969
1982
1993
2001
2010
0 0.5 1
Miles

Discussion

Conneaut Lake has had significant increases in aquatic vascular plant growth throughout the mid-20th century to present day. Increase in aquatic plant growth has caused both residents and boaters to reach out to the local and state governments for solutions. As predicted, the highest phosphorus export coefficient was determined to be the developed landuse area with increasing values as houses within the region continues to expand. Within this figure, forested region increases while the agricultural land in the area tends to be on the decline for the majority of the time series. Of which, includes both herbicidal and mechanical removal of invasive and native aquatic vascular plant growth. The results of this study determined that both forested and developed landuse in the Conneaut Lake region have been steadily increasing. In comparison, agricultural landuse has dramatically declined. It is possible to correlate the increasing non-point pollution to the residential portion of the developed landuse class due to the higher weighting as derived from Reckhow et al. (1980). Therefore, the increasing development surrounding the lake ultimately led to its current unhealthy eutrophic state. There are multitudes of variables related to the development of the lake that contributed to this eutrophic state.

First, the lack of riparian buffer zones in lakeshore residences causes significant issues within the body of water. There is no natural vegetation to filter and disperse the direct runoff in rainfall or other precipitation. Second, Conneaut Lake is 'phosphorus limited' so any of the excess phosphorus is most likely coming from an outside source (Ostrofsky & Owen, 1989) (DEP, 2001). Although the actual source is not currently determined it can be noted that: runoff, sedimentation, and other non-point pollution are main contributors to Conneaut Lake's current state. Third, modification and development by the lakeshore may cause more damage than agricultural practices. In the digitization of the time series, introduction of the canals to connect

Conneaut Lake to the canal system implemented in the early to mid-20th century seemed to correlate with a spike in phosphorus content. This may be due to the rise in increasing residences but the possibility of a small contribution of phosphorus from development still remains. In addition to this, the pull of Conneaut Lake Park (CLP) cannot be overlooked. Conneaut Lake Park is a small theme park established on the west side of the lake in 1892 (CLP, 2015). In the early part of its lifespan, Conneaut Lake Park attracted many visitors to the region. This began the development of cottages in the lakeshore for visitors to have summer homes near the lake. Many temporary hotels and inns also have dotted the shores of the lake, with the only remaining being Hotel Conneaut. Development such as this caused influxes of phosphorus in the form of raw human waste and other contaminants. Currently, the lake is continuing to develop at a slower pace since there is a small amount of land left vacant and complex zoning ordinances.



Figure 5: The photo on the right displays a typical residential lawn before connecting to the shore of Conneaut Lake. Recently, the DEP approved development upon Conneaut Lake's Wolf Island, adjacent to where this photograph was taken (Schepner, 2014).

One of the major developments that have recently been approved by the Pennsylvania Department of Environmental Protection is Wolf Island opening to public real estate. Previously, the island had not been touched by developers and had only seen a few fishermen use its shores since it is the only island within the lake. Bridges and other modifications to reach the island

have been approved. This development will most likely continue to increase the phosphorus export into the lakeshore.

Similar studies have researched historical landuse effects upon the phosphorus and nitrogen content upon various lakeshores. For example, Lilly Pond in Maine had a historical review of phosphorus content by the Maine Department of Environmental Protection (MDEP) in which a phosphorus control action plan (PCAP) and total maximum daily load (TMDL) report were compiled in 2005 (MDEP, 2005). Although Lilly Pond is significantly smaller than Conneaut Lake (max. depth=24 feet and 12 hectares in size), much of the surrounding landuse is quite similar. Algae blooms were quite noticeable in the waters since the 1980's, even though the main source of agricultural and industrial runoff had closed down (MDEP, 2005). With landuse categories composed of farmland, undeveloped, residential, and open field MDEP was able to determine using GIS that the majority of the phosphorus runoff was from roads in the residential area. MDEP determined that the area roads basically "transported" the phosphorus into the nearby watershed allowing for easy access to the waters of Lilly Pond. In closing of the report, MDEP recommended for individuals adjacent to Lilly Pond to use phosphorus-free fertilizers and promote natural vegetation (MDEP, 2005). Conneaut Lake's situation is very similar to Lilly Pond. Although the residents of Conneaut Lake have not experienced consistent algal blooms, it soon may become a natural occurrence with the impending climate changes and warming waters within the next few decades.

The Pennsylvania Department of Environmental Protection (PADEP or DEP) in concurrence with the Environmental Protection Agency completed a Total Maximum Daily Load (TMDL) study upon Conneaut Lake in 2001. This review determined that Conneaut Lake was in fact suffering from excess nutrients due to the nonpoint source of urban runoff and storm sewers

(DEP, 2001). In this report the department issued that the landuse was currently 50% forested while developed and agriculture account for 15% individually. The report noted that 50% of the phosphorus in the lake comes from watershed runoff. The report then called for a 40% reduction in phosphorus with the majority of the problematic phosphorus coming from the bottom sediments of the lake since best management practices (BMPs) and sanitary sewer overflows (SSOs) have been contained (DEP, 2001).

Therefore, with inferences from the Pennsylvania Department of Environmental Protection it is possible to estimate that the majority of phosphorus collecting within the Conneaut Lake watershed has accumulated from development surrounding the lake only to settle within the sediment. Once the phosphorus has attached to the particulates within the bottom of the lake in the sediment it becomes possible for the phosphorus to be released under different environmental conditions (Nikolai & Dzialowski, 2014). If this happens, it can cause anoxia which inhibits the amount of oxygen within the water column. Ostrofsky & Owen determined that the peak anoxic period for Conneaut Lake during the year is the summer, particularly from June until September (Ostrofsky & Owen, 1989). This three month period of time is when activity upon the lake is at its highest with the arrival of the boating and swimming season. Possible solutions for the excess phosphorus content within the Conneaut Lake watershed are to cease phosphorus runoff and solve the internal loading phosphorus issue. Both of these issues are solvable, but may be controversial. The first of which is to discontinue the usage of phosphorus fertilizers near the Conneaut Lake watershed. There are "phosphorus-free" fertilizers that may temporarily provide relief to the watershed. Second, aluminum sulfate (interchangeable with iron and calcium salts) can hold and inactivate the internal phosphorus within the sediment of the lake (WDOE, 2014).

Future Study

Although well intended, this study does not encompass all existing variables. If this study was permitted more time, it should include slope and soil information to provide a more detailed summary of the Conneaut Lake watershed. Including current fish and plant species, census information, seasonal visitor records, Conneaut Lake borough tax address information, invasive species effects upon the water column (i.e. zebra mussels), and other variables would be beneficial to further validate the information exposed by the basic correlations discussed previously. In addition to this, the geospatial limitations and errors within this study could be corrected. For example, digitization errors like sliver polygons and other information could be corrected. Sliver polygons affect the area of each category causing variations that may miscalculate land space. A future study could look upon the lake sedimentation and the internal phosphorus load to determine the amount of inactive phosphorus within the water column.

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Appendix A

Root Mean Square Error Information									
Series	#	Region	CP	Scale	RMS Error	Geographic Reference Layer	Scale	GRL Source	Year
1938	1	NW	4	1:20,000	4.76885	PA State Roads	1:24,000	PennDOT	2014
1938	2	W1	4	1:20,000	5.92607	PA State Roads	1:24,000	PennDOT	2014
1938	3	W2	4	1:20,000	5.98157	PA State Roads	1:24,000	PennDOT	2014
1938	4	E	4	1:20,000	6.32019	PA State Roads	1:24,000	PennDOT	2014
1938	5	S	4	1:20,000	9.42026	PA State Roads	1:24,000	PennDOT	2014
1959	1	N1	4	1:20,000	2.40015	Pa State Roads	1:24,000	PennDOT	2014
1959	2	N2	4	1:20,000	2.44232	Pa State Roads	1:24,000	PennDOT	2014
1959	3	M	4	1:20,000	7.66046	Pa State Roads	1:24,000	PennDOT	2014
1959	4	S	4	1:20,000	4.7321	Pa State Roads	1:24,000	PennDOT	2014
1969	1	N	4	1:20,000	2.25595	PA State Roads	1:24,000	PennDOT	2014
1969	2	C	4	1:20,000	6.37837	PA State Roads	1:24,000	PennDOT	2014
1969	3	S	4	1:20,000	7.07009	PA State Roads	1:24,000	PennDOT	2014
1982	1	C	4	1:20,000	9.63675	PA State Roads	1 :24,000	PennDOT	2014
1993	1	N1	4	1:20,000	4.25165	PA State Roads	1:24,000	PennDOT	2014
1993	2	N2	4	1:20,000	2.82652	PA State Roads	1:24,000	PennDOT	2014
1993	3	C	4	1:20,000	5.77987	PA State Roads	1:24,000	PennDOT	2014
1993	4	S	4	1:20,000	5.04801	PA State Roads	1:24,000	PennDOT	2014
2001	1	NE	4	1:20,000	5.19812	PA State Roads	1:24,000	PennDOT	2014
2001	2	NW	4	1:20,000	7.26465	PA State Roads	1:24,000	PennDOT	2014
2001	3	C	4	1:20,000	3.7549	PA State Roads	1:24,000	PennDOT	2014
2001	4	S	4	1:20,000	7.31879	PA State Roads	1:24,000	PennDOT	2014
2010	1	NW	4	1:20,000	N/A	PA State Roads	1:24,000	PennDOT	2014
2010	2	NE	4	1:20,001	N/A	PA State Roads	1:24,000	PennDOT	2014
2010	3	SE	4	1:20,002	N/A	PA State Roads	1:24,000	PennDOT	2014
2010	4	SW	4	1:20,003	N/A	PA State Roads	1:24,000	PennDOT	2014

Appendix B-Data Dictionary

Year	Dataset	Originator	Producer	Contractor	Map Scale	Data Model	Format	Coordinate System	Datum
1938	ape_17_94	PennPilot	USDA Agricultur	Continental Aer	1:20,000	Photograph	TIFF	UTM Zone 17N	NAD_1983
	ape_17_95								
	ape_17_97								
	ape_45_11								
	ape_45_12								
1959	ape_13v_147	PennPilot	USDA Commod	Woltz Studios, I	1:20,000	Photograph	TIFF	UTM Zone 17N	NAD_1983
	ape_13v_148								
	ape_13v_150								
	ape_13v_151								
1969	ape_5jj_74	PennPilot	USDA Agricultur	Keystone Aerial	1:20,000	Photograph	TIFF	UTM Zone 17N	NAD_1983
	ape_5jj_76								
	ape_5jj_77								
1982	NC1NHAP820107143	GloVis	National High Al	United States G	1:20,000	Photograph	TIFF	UTM Zone 17N	NAD_1983
1993	N10NAPPW0558722	GloVis	National High Al	United States G	1:20,000	Photograph	TIFF	UTM Zone 17N	NAD_1983
	N10NAPPW12211151								
	N10NAPPW05587220								
	N10NAPPW05587219								
2001	N10NAPPW0558722	GloVis	National Aerial	United States G	1:20,000	Photograph	TIFF	UTM Zone 17N	NAD_1983
	N10NAPPW12211123								
	N10NAPPW12211122								
	N10NAPPW12211121								
2010	M_4108022_SE_17_	EarthExplorer	National Agricul	United States G	NA	Photograph	JPEG	UTM Zone 17N	NAD_1983
	M_4108022_SW_17_1_20100530_20100630								
	M_4108030_NE_17_1_20100530_20100630								
	M_4108022_SW_17_1_20100530_20100630								
2014	Pennsylvania - small	Eastern Pennsy	Pennsylvania S	Pennsylvania St	NA	Shapefile	.shp	GCS_North_Americ	NAD_1983
2015	Pennsylvania State R	Pennsylvania D	Pennsylvania S	Pennsylvania State Universit		Shapefile	.shp	NAD_1983	D_North_American_1983
1993	Boundary of Conneau	Western Penns	Pennsylvania S	Pennsylvania St	NA	Shapefile	.shp	NAD_1927	D_North_American_1927

Appendix C- Total Phosphorus Export per year

Year	Agriculture	Forest	Urban	TOTAL (kg/yr)
1938	288.99	369.02	180.59	838.6
1959	247.51	381.35	271.96	900.82
1969	189.39	466.38	326.51	982.28
1982	136.04	536.15	386.44	1058.63
1993	115.43	607.13	390.18	1112.74
2001	109.92	610.71	389.42	1110.05
2010	79.57	706.08	373.97	1159.62