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Assessing the Efficacy of the Washington Ban on Phosphorus Fertilizer

Pilar Deniston
June 2024
Abstract

Freshwater lakes are essential ecosystems, providing crucial services for humans, plants, and animals. However, eutrophication, a process driven by an excess of nutrients such as phosphorus, poses a significant threat to lake health and water quality. To mitigate excess phosphorus and eutrophication, many states, including Washington, have implemented bans on phosphorus-containing fertilizers.

This study evaluates the efficacy of Washington State's 2013 phosphorus-containing fertilizer ban, focusing on 58 lakes in western Washington. This study organized, filtered, and analyzed data from multiple counties' monitoring programs to examine total phosphorus concentrations before and after the ban. Additionally, this study involved a land cover analysis in assessing the relationship between land use changes and phosphorus concentrations.

The results of this study revealed a variety of outcomes. While there was no significant overall reduction in phosphorus concentrations across all lakes, analysis at the county level revealed significant decreases in Snohomish County post-ban. The results showed that while there is a negative relationship between land cover changes and phosphorus concentrations, it is not significant, suggesting other factors may influence total phosphorus concentration. These findings underscore the complex interplay of environmental factors in shaping lake nutrient dynamics. While the phosphorus-containing fertilizer ban has shown promise in some areas, its effectiveness varies across regions and requires further investigation. Future research should explore additional factors like public awareness campaigns, septic systems, and land use effects that influence lake phosphorus concentrations and should consider broader implications for freshwater ecosystem management.
Acknowledgments

My study uses data from western Washington lakes that are located on the ancestral homelands of the Coast Salish Peoples. I would like to give my thanks and gratitude to the Stillaguamish, Tulalip, Snoqualmie, Muckleshoot, Puyallup, and Nisqually peoples for their enduring care and protection of the land and waters.

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I would also like to thank each of the government employees who collected, organized, and shared the data for this project: Marisa Burghdoff, Jennifer Oden, and Yair Torres from Snohomish County, Wafa Tafesh and Beth LeDoux from King County, Bryan Mohlman from Pierce Conservation District, and John Haberlin from Thurston County. Additional thanks go to Tim Clark who provided valuable insight when brainstorming and designing this project and to Dominick Leskiw and Kathryn Queen whose feedback resulted in informative and beautiful visuals that I can be proud of.

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Introduction

Freshwater lakes play a vital role in our ecosystems. They are home to countless aquatic species ranging from the smallest phytoplankton to large lily pads, and from tiny zooplankton to huge fish. For humans, lakes provide recreational opportunities, drinking water, and ecosystem services. It is imperative that lakes are protected for plant, animal, and human well-being.

Among the significant challenges facing lakes, eutrophication stands out as a critical issue. Characterized by an excess of nutrients, eutrophication fuels rapid plant and algae growth. Eutrophication leads to diminished water quality, algal blooms, and impaired recreation (Dodson, 2005; Schindler, 2006). Algae blooms can become toxic which can harm waterfowl, native flora, pets, and even people. Moreover, the decomposition of excess algae consumes oxygen, resulting in anoxic conditions detrimental to lake organisms like macroinvertebrates and fish (Deeds et al., 2021).

Phosphorus tends to be the limiting factor in aquatic ecosystems (Dodson, 2005), meaning that algae and plant growth is restricted due to the lack of available phosphorus. Phosphorus occurs naturally in sedimentary rocks and enters the ecosystem when these rocks erode (Dodson, 2005). Additionally, phosphorus originates from atmospheric deposition, animal feces, and plant decomposition. Human activity can also introduce phosphorus via failing septic systems, pet waste, and fertilizers (Dodson, 2005). Phosphorus often enters water bodies through runoff that collects pollutants from impervious surfaces and lawns (Vlach et al., 2010). In order to reduce phosphorus pollution and eutrophication in lakes, there have been public engagement measures to educate people about how their pet waste is hurting lakes as well as policy measures to ban fertilizers containing phosphorus.
Policy measures, like bans on phosphorus-containing fertilizers, aim to address the root causes of eutrophication. These measures not only safeguard lake health but also offer economic benefits, given phosphorus's high demand and escalating costs (Brownlie et al., 2023). Agricultural soils often require the addition of phosphorus-containing fertilizer, as the soils are depleted of nutrients at a much faster rate than urban areas due to erosion and plant uptake (Alewell et al., 2020). Urban areas, however, often have sufficient phosphorus levels in the soil without additional fertilization which is why they are the target area for fertilizer bans (Lee & McCann, 2018).

Urban areas are also targeted by fertilizer bans because they have many impervious surfaces that cause an increase in runoff (Zhou, 2019). Impervious surfaces are an important type of land cover because they include things characteristic of urban areas, like streets, rooftops, and sidewalks. When forests or pastures are developed into impervious surfaces, there is more runoff that carries pollutants like phosphorus from fertilizers (Lee & McCann, 2018; Zhou, 2019). This change in land cover from a natural area to a developed area is considered a negative change. While urbanization can lead to more runoff and more phosphorus pollution, it can also lead to improved human waste management. Compared to low-density, forested areas, high-density developments can be correlated with improved water quality due to the type of waste system in use (Kammer, 2004). High-density developments are usually connected to well-maintained sewer systems while more rural areas tend to use septic systems that can degrade and leak (Kammer, 2004; Moore et al., 2003). This complicates the association between urbanization and increased pollution because while increased development is correlated with higher runoff rates, the development density determines the human waste system, which reduces or introduces other sources of phosphorus pollution.
To reduce phosphorus pollution via runoff, many states, as well as individual counties, have enacted bans on phosphorus-containing fertilizers (Lee & McCann, 2018). The 12 states that have a ban on phosphorus-containing fertilizers are Connecticut, Illinois, Maine, Maryland, Michigan, Minnesota, New Jersey, New York, Vermont, Virginia, Washington, and Wisconsin (Miller, 2012). Some of these states have seen reductions in phosphorus runoff; in Minnesota, phosphorus pollution was reduced by 12-15% from urban residential developments (Vlach et al., 2010). In Michigan, a similar study found that total phosphorus was reduced by 11-23 percent (Lehman et al., 2011). Phosphorus has been decreasing each year in the Chesapeake Bay due to legislative actions from the many states in its large watershed (Chesapeake Bay Program, 2010).

Total phosphorus is a measure of all the phosphorus in a sample, both the readily bioavailable soluble reactive phosphorus and the organic and inorganic particulate forms of phosphorus (Carlson & Simpson, 1996; Dodson, 2005).

In the hopes of similar results, Washington State passed a ban on phosphorus-containing fertilizers in 2011 which went into effect in 2013. The ban’s objective was to reduce excess nutrients in lakes, rivers, and streams by limiting the sale of fertilizers containing phosphorus. This ban targets primarily urban areas, specifically those that are residential; agricultural areas, newly established lawns, garden beds, and golf courses are exempt from the ban (WA Senate, 2011). In Washington, for Puget Lowland lakes, the action limit is > 20 μg/L, which means that if a mesotrophic lake, or a lake with an intermediate level of productivity, exceeds this limit, then action may be taken to reduce excess nutrients, otherwise the lake may reach a eutrophic status (Washington Department of Ecology, 2004). Before the phosphorus-containing fertilizer ban, Washington had passed legislation that limits phosphorus in laundry detergent, dish soap, and
dishwashing detergent (WA Senate, 2011). These policies propelled the ban on fertilizer containing phosphorus through the Washington State Senate (WA Senate, 2011).

While bans on phosphorus-containing fertilizers in other states and bans on phosphorus-containing detergents and soaps in Washington have resulted in decreases in phosphorus, until now, there has been no evaluation of Washington’s phosphorus fertilizer ban. This study aims to fill in this gap and seeks to evaluate the efficacy of the phosphorus-containing fertilizer ban through an analysis of the total phosphorus data across lakes in western Washington. The secondary objective is to examine the relationship between total phosphorus concentration and land cover. The final objective of this study is to compile a comprehensive database that contains total phosphorus data from lakes across western Washington. I predict that total phosphorus concentrations in lakes will have decreased after phosphorus-containing fertilizer was banned in 2013 due to the reduction of phosphorus sources. Additionally, I predict that total phosphorus concentrations will decrease significantly in lakes where the land cover has changed negatively, particularly in residential areas targeted by the ban due to their higher likelihood of development.

**Methods**

**Study Area**

Western Washington has a temperate climate with relatively cool, dry summers and mild, wet winters. The climate is regulated by the Pacific Ocean and the Puget Sound. Located to the east of Puget Sound are Snohomish, King, Pierce, and Thurston counties. The western halves of these counties are more densely populated than their eastern counterparts. Within these counties lie dozens of Puget Lowland lakes in urban areas. The land cover surrounding these lakes is often a mix of impervious surfaces, grassy areas, and forests in residential areas.
Data Collection

This study obtained data from 44 lakes in Snohomish County, 21 lakes in King County, 3 lakes in Pierce County, and 12 lakes in Thurston County (Figure 1). Snohomish, King, Pierce, and Thurston counties monitor the health of their lakes through established sampling programs which often include volunteer networks. The Snohomish County lakes program is run through Surface Water Management which is part of the Department of Conservation & Natural Resources. The King County Lakes program is run through the Water and Land Resources Division which is part of the Department of Natural Resources and Parks. The Pierce Conservation District collects lake data for Pierce County. At Thurston County, the Environmental Health program which is part of the Public Health and Social Services Department collects lake data.
Data collection occurred during the summer months either biweekly or monthly, depending on county-specific protocol. Some water quality parameters were measured in the field using multiparameter data sondes, while others required water samples to be stored on ice for laboratory analysis. Data sondes were used to collect temperature, pH, dissolved oxygen, conductivity, and chlorophyll-a data. Laboratory analysis quantified nitrate, nitrite, ammonia, soluble reactive phosphorus, and total phosphorus concentrations. To measure total phosphorus, samples were digested to oxidize the organic matter, and then the sample was read using colorimetry (Standard Methods Committee of the American Public Health Association et al.,
Site information such as watershed and lake area, maximum, and average depth were also recorded (Figure 2). These data are publicly available and were shared courtesy of the lake monitoring programs in the respective counties.

Data Analysis

Each monitoring program recorded its data differently and used different laboratories to analyze the total phosphorus samples. Once all the data was shared, it was first sorted and organized to allow for comparison between counties. The number of samples and the number of lakes were tallied for a total of 84 lakes and 24,902 samples (Table 1).
Table 1: Table displaying the number of lakes and the number of samples at the beginning of the data analysis process versus at the end.

<table>
<thead>
<tr>
<th>County</th>
<th>Start</th>
<th>End</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td># of Lakes</td>
<td># of Samples</td>
</tr>
<tr>
<td>Snohomish</td>
<td>44</td>
<td>6,782</td>
</tr>
<tr>
<td>King</td>
<td>21</td>
<td>12,981</td>
</tr>
<tr>
<td>Pierce</td>
<td>3</td>
<td>459</td>
</tr>
<tr>
<td>Thurston</td>
<td>16</td>
<td>4,680</td>
</tr>
<tr>
<td>TOTAL</td>
<td>84</td>
<td>24,902</td>
</tr>
</tbody>
</table>

The initial step was to remove lakes that had received alum treatments (4 lakes). Measurements were then standardized to the metric system and total phosphorus was converted to micrograms per liter (μg/L). Samples that had no total phosphorus value recorded (2,525 samples), had no depth recorded (2 samples), were flagged as having a bad blank during analysis (30 samples), or were flagged as a non-defensible value (1 sample) were removed.

The Method Detection Limit (MDL) of total phosphorus differs between laboratories according to their standards and methods. For King County, the MDL for total phosphorus was 5 μg/L, so all samples recorded as <MDL were changed to 2.5 μg/L to account for the range of possible values (141 samples). This decision was made to limit biases while retaining data points with trace levels of total phosphorus (George et al., 2021). For Pierce County, the MDL for total phosphorus was 10 μg/L, so all samples recorded as <MDL were changed to 5 μg/L to account for the range of possible values (48 samples). For Snohomish and Thurston counties, samples below the detection limit were removed or averaged before sharing the data.

Next, the data was filtered for only surface-level samples. The epilimnion is the upper layer of a lake and is influenced by surface runoff (Dodson, 2005). The lower layer of a lake is
called the hypolimnion and many factors are involved, for example, the sediment can release phosphorus under anoxic conditions (Deeds et al., 2021; Dodson, 2005). Therefore, to reduce confounding factors, hypolimnetic samples and all samples deeper than 2.5 meters were removed (6,173 samples). One exception was made, Lake Beecher in Snohomish County had a maximum depth of 3 meters, so samples deeper than 2 meters were removed.

The next significant reduction in data was filtering the samples by year and month. To ensure comparable data, any samples taken earlier than 2002 and later than 2023 were removed (2,153 samples). This spans the 2013 phosphorus-containing fertilizer ban by 11 years on either side. Additionally, all four counties collected lake water samples from June to September, so any samples taken outside of these months were removed (2,813 samples). After this filtering was achieved, 75 lakes and 7,147 samples remained.

To ensure robust data on either side of the phosphorus-containing fertilizer ban, lakes that were sampled for two years or less before or after 2013 were removed. Lakes that were sampled \( \leq \) ten times before or after 2013 were also removed. This decreased the data to 60 lakes and 6,642 samples. For each lake, every sample value was averaged over 11 years before the 2013 ban to produce a single value that represents the total phosphorus concentration before, and the same was done after the ban. The slope of each lake was calculated based on the difference between the 11-year total phosphorus averages. This value was then sorted into quartiles. Slopes in the 75th percentile and above were classified as having a positive slope, slopes between the 25th and the 75th percentile were classified as having a neutral slope, and slopes in the 25th percentile and below were classified as having a negative slope.

Pierce County was initially included in this study, but due to observed inconsistencies in laboratory results, all lakes in the county were removed, decreasing the data further, to 58 lakes,
6,447 samples, and three counties.

**Land Cover Analysis**

The Geographic Information Systems (GIS) team in the Surface Water Management Division at Snohomish County conducted a land cover analysis in 2022 for their Critical Area Regulations (CAR) monitoring and adaptive management program. This analysis compares high-resolution imagery of a subset of Snohomish County lakes from 2009 to 2021. The group used high-resolution imagery, ground control points, and deep learning methods to compile accurate land cover and change detection maps (Snohomish County, 2024a). Land cover was classified as forest, impervious, pasture/grassland/bare land, water, or agriculture, and acreage cover was measured. The 2009 land cover analysis was then compared to the 2021 land cover analysis and a change map was created (Snohomish County, 2024a). The group then deemed each change as a negative, neutral, or positive change in land cover based on ecosystem services and runoff (Table 2). This change analysis was applied to a subset of all Snohomish County lakes, and the changes between each land cover group were quantified as an area and a percentage of the lake basin.
Table 2: Table defining land cover changes as a negative, neutral, or positive change.

<table>
<thead>
<tr>
<th>Land Cover Change</th>
<th>Change Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest to Impervious</td>
<td>Negative</td>
</tr>
<tr>
<td>Forest to Pasture</td>
<td>Negative</td>
</tr>
<tr>
<td>Forest to Water</td>
<td>Negative</td>
</tr>
<tr>
<td>Pasture to Impervious</td>
<td>Negative</td>
</tr>
<tr>
<td>Pasture to Water</td>
<td>Negative</td>
</tr>
<tr>
<td>Water to Impervious</td>
<td>Neutral</td>
</tr>
<tr>
<td>Impervious to Water</td>
<td>Neutral</td>
</tr>
<tr>
<td>Impervious to Forest</td>
<td>Positive</td>
</tr>
<tr>
<td>Impervious to Pasture</td>
<td>Positive</td>
</tr>
<tr>
<td>Pasture to Forest</td>
<td>Positive</td>
</tr>
<tr>
<td>Water to Pasture</td>
<td>Positive</td>
</tr>
<tr>
<td>Water to Forest</td>
<td>Positive</td>
</tr>
</tbody>
</table>

Statistical Analyses

Three paired t-tests were conducted to evaluate the null hypothesis that total phosphorus concentration before the ban would not influence the total phosphorus concentration after the ban. One paired t-test assessed the difference between total phosphorus concentration before and after the ban across all lakes, and the other two paired t-tests assessed the differences within counties. The assumptions of a normal distribution of the differences were tested. After the removal of one outlier lake from Snohomish County, the assumptions were met. Thurston County lakes failed the assumption of a normal distribution due to the small sample size.

Additionally, a regression was performed to evaluate the relationship between changes in total phosphorus concentration and land cover changes in Snohomish County. The assumptions
of a normal distribution and equal variance of the residuals were assessed and met once two outliers were removed. The chosen alpha value for the statistical analyses was $\alpha = 0.05$.

**Results**

**Data Analysis Results**

A scatterplot was created to display the total phosphorus concentration across all counties and lakes (Figure 3). Notably, the majority of the data points fall within a small range, predominantly falling below or near the action limit of 20 $\mu$g/L defined by the Washington Department of Ecology (Washington Department of Ecology, 2004).

![Figure 4: Scatterplot of the total phosphorus concentrations across all three counties.](image)

A series of plots were generated to display the change in total phosphorus concentration before and after the ban in each county (Figure 4). A second series of plots were produced using...
the slope values that had previously been sorted into positive, neutral, and negative quartiles (Figure 5). This organized the changes in total phosphorus into three distinct categories and allowed for the comparison of trends between and within counties (Figure 5).
Figure 4: Trend in total phosphorus in relation to the phosphorus fertilizer ban by county a) Snohomish County, b) King County, c) Thurston County. The data points in the before column are an average of all the samples from 2002 to 2012, and the data points in the after column are an average of all the samples from 2013 to 2023. The error bars were calculated by dividing the standard deviation by the square root of the number of samples in the mean.
Figure 5: Plot a) shows the distribution of slope values which were calculated based on the difference between the 11-year total phosphorus averages. This distribution was then used to sort the lakes into one of three categories: those with a) positive, c) neutral, or d) negative slope. Colors are used to distinguish which lakes are from each county.
Land Cover Analysis Results

A stacked bar chart was created to depict land cover changes for a subset of Snohomish County lakes (Figure 6). This shows the percentage of land cover change as negative change, positive change, and no change for each lake between 2009 and 2021.

![Bar chart showing land cover changes](Image)

Figure 3: Land cover change was classified as a positive change, no change, or negative change from 2009 to 2021. This bar chart displays these changes as a percentage of the watershed area for a subset of Snohomish County lakes.

Statistical Analysis Results

The results of the paired t-test for all lakes indicate that the phosphorus-containing fertilizer ban has not had a significant effect on phosphorus concentrations in lakes (Table 3). Due to the counties having different management and policies, a paired t-test was also run for each county separately. Snohomish County has one extreme outlier, Lake Beecher, which was removed from the analysis because it is extremely shallow and has the largest watershed area-to-
lake area ratio out of all the lakes, which introduces many confounding factors. The results show that the phosphorus fertilizer ban did have a significant effect on phosphorus concentrations in Snohomish County lakes. The paired t-test results for King County show that the phosphorus fertilizer ban has not had a significant effect on phosphorus concentrations in King County lakes, although it is only marginally above the p < 0.05 threshold. Finally, the assumptions of a paired t-test were not met for the Thurston County lakes.

Table 3: Table showing paired t-test results. Thurston County is included in All Lakes but did not meet assumptions to be tested individually. Lake Beecher was removed from Snohomish County.

<table>
<thead>
<tr>
<th>County</th>
<th>p-value</th>
<th>t-value</th>
<th>df</th>
</tr>
</thead>
<tbody>
<tr>
<td>Snohomish</td>
<td>0.0027</td>
<td>-3.2842</td>
<td>28</td>
</tr>
<tr>
<td>King</td>
<td>0.0567</td>
<td>-2.0225</td>
<td>20</td>
</tr>
<tr>
<td>All Lakes</td>
<td>0.7923</td>
<td>-0.2646</td>
<td>57</td>
</tr>
</tbody>
</table>

A scatterplot was created to display the relationship between the change in land cover and the change in total phosphorus concentration (Figure 7). The change in land cover was determined by subtracting the percentage of land cover change between 2009 and 2021 in the watershed that was defined as positive from the percentage of land cover change that was defined as negative (Table 2). The change in total phosphorus concentration was determined by subtracting the 11-year total phosphorus average value after the 2013 ban from the 11-year total phosphorus average value before the 2013 ban.

The statistical regression evaluated the relationship between the net land cover change and the net total phosphorus change in Snohomish County ($R^2 = 0.0899$, $F_{1,26} = 2.568$, $p = 0.1211$; line of best fit: TP change (ug/L) = -3.3572 + -0.2246* land cover change (%)). The results show that while the change in land cover is negatively related to the change in total phosphorus concentrations in Snohomish County.
phosphorus, it is not statistically significant. To meet the assumptions of regression, Lake Beecher was removed from this analysis for the aforementioned reasons, and Storm Lake was also removed from this analysis because of its dramatic land cover change; in 2013, a large portion of its watershed was cleared for development but then was sold to the County and is now being restored into a park. With all Snohomish County lakes, including Lake Beecher and Storm Lake, the estimate of the slope was $b = -0.1230$, but when Lake Beecher and Storm Lake are removed, the estimate of the slope is $b = -0.2246$ (Figure 7).
Discussion

Washington State’s ban on phosphorus-containing fertilizers thus far does not seem to have had the desired effects on nutrient concentrations in western Washington urban lakes. This study does not provide enough evidence to support the first hypothesis that total phosphorus concentrations in lakes will decrease after phosphorus-containing fertilizer was banned in 2013. The paired t-test shows that the ban has not had a significant effect on phosphorus concentrations.
in lakes. However, it is unclear whether phosphorus is increasing with time without a set of lakes to act as a control (Vlach et al., 2010). The fertilizer ban could be causing decreases in total phosphorus while more development could be causing increases in total phosphorus, on a graph, this would appear as if the ban has not been effective in decreasing phosphorus in lakes.

The difference in county seen when grouping lakes by overall trend is intriguing, as there are no Thurston County lakes that had a negative slope, and there are very few Snohomish County lakes that had an overall positive slope (Figure 5). While the lack of decrease in total phosphorus concentration in Thurston County lakes is interesting, the data did not meet the assumptions of the paired t-test, leading to inconclusive results. The Snohomish County data, however, did meet the assumptions once Lake Beecher was removed and the paired t-test did yield statistically significant results, demonstrating that there was a notable and significant decrease in total phosphorus concentrations after the ban was enacted. King County lakes were spread across all three slope graphs, although weighted more heavily toward neutral slopes. The results of the paired t-test were not significant, although the p-value was near to the chosen alpha value. A possible explanation for the differences in slope trends between counties could lie in differences in watershed management and land cover. When graphing Pierce County samples, the total phosphorus values fell strictly on intervals of 5 or 10 μg/L, when all other samples from other counties were spread across all integers. In 2019, this changed, and total phosphorus values fell between the 5 or 10 μg/L intervals. These inconsistencies suggest a change in laboratory methods and led to the removal of Pierce County lakes entirely.

The statistical analysis failed to support the second hypothesis that total phosphorus concentrations will decrease significantly in lakes where the land cover has changed negatively. In Snohomish County, there is a negative relationship between change in total phosphorus and
change in land cover as hypothesized, however, the relationship is not statistically significant (Figure 7). Only 8.99% of the variation in change in total phosphorus concentration can be explained by land cover change, the rest may be due to random chance alone. This suggests that there are other factors involved in the overall decrease of total phosphorus, such as the phosphorus-containing fertilizer ban or public awareness campaigns. Snohomish County has worked hard in recent years to spread awareness about phosphorus contamination from pet waste and failing septic systems (Snohomish County, 2024b), and these efforts could be paying off. Septic systems start to fail and leak phosphorus-containing pollutants with time (Kammer, 2004; Moore et al., 2003), so the replacement and maintenance of septic systems, encouraged by public engagement could be aiding these desirable results.

One limitation of this study is the lack of a set of control lakes. This would provide a baseline for total phosphorus concentrations as well as a baseline for unchanging land cover during this period. Another limitation is the chosen timescale for this study. Choosing a larger or smaller set of years on either side of the 2013 phosphorus-containing fertilizer ban may yield different results. Averaging 11 years of data hides details that could provide different insights into the efficacy of the phosphorus-containing fertilizer ban.

Future work should entail a comparison to Oregon lakes where there is not a phosphorus-containing fertilizer ban. Because these lakes are in the same ecoregion as the lakes in this study, they could act as a set of comparable control lakes. Additionally, examining differences between urban and alpine or rural lakes in Washington would provide a valuable comparison to assess the efficacy of the fertilizer ban. These alpine or rural lakes would have much lower human interference and runoff would likely not contain any human-induced phosphorus. Moreover, it would be interesting to compare other water quality parameters to the phosphorus concentration
in relation to the fertilizer ban. These parameters could include nitrogen, chlorophyll-a, or Secchi depth, and could each provide insight into changes made by phosphorus concentration, as well as provide a baseline for how lakes may be changing with time and with climate change. Lastly, precipitation patterns on a smaller time scale could shed light on how runoff influences phosphorus concentration.

**Conclusion**

The findings of this study are meaningful and notable, although not desired. The results of the paired t-test do not support the hypothesis that total phosphorus concentrations will decrease after phosphorus-containing fertilizers were banned in 2013. They instead show that there are no statistically significant changes in total phosphorus concentration in western Washington lakes. This suggests that Washington’s phosphorus-containing fertilizer ban has not had the desired results of decreasing phosphorus concentration in lakes. There are many possible confounding factors in this study, for example, land cover type and changes, sewage systems, natural fluctuations in phosphorus concentrations, and public awareness campaigns.

When narrowing the study to only Snohomish County, the results of the paired t-test, dispute the results of no significant change in total phosphorus concentration after the ban was enacted. The results demonstrate that there has been a significant reduction in total phosphorus concentrations in this county, indicative of the fertilizer ban’s effectiveness. To expand upon these findings and test the second hypothesis, a regression analysis was conducted using the Snohomish County total phosphorus data and land use analysis. The results of the regression do not support the second hypothesis that total phosphorus concentrations will decrease significantly in lakes where the land cover has changed negatively. Although the decrease in
Snohomish County's total phosphorus was significant, less than 9% of the variability in changes in total phosphorus can be explained by changes in land use. This suggests that there are confounding factors that have a greater impact on total phosphorus concentrations than changes in land cover alone. Further examination of the effects of land cover, septic systems, and public awareness campaigns may reveal more information on phosphorus inputs into western Washington lakes.
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