EXPLORING THE USE OF SUBSURFACE WATER QUALITY DATA AS A FEEDBACK MECHANISM FOR IMPROVING CONSERVATION: A CASE STUDY IN THE RIVER RAISIN WATERSHED

By

Alaina Nicole Nunn

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ABSTRACT

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For decades, conservation has been approached through providing monetary incentives to individual farmers, with success being a measurement of acres enrolled or the number of best management practices (BMPs) installed. However, as the health of Lake Erie continues to decline there are growing calls for a paradigm shift. This two part study explored the use of subsurface water quality data as a feedback mechanism for increasing farmer awareness of nutrient loss issues specific to their farm, as well as to better assist them in adjusting farm practices that could lead to more positive water quality outcomes. In part one, three farmers, whose land contributed a total of five tile drains to be studied, were given summaries of their water quality reports from the year 2017 and part of 2018. In-depth interviews revealed that access to field specific data led to greater awareness of nutrient loss occurring on the farm, and ultimately led to discussions regarding how they could better address those losses. In part two, a survey was administered at a farmer-led meeting to gain insights regarding the perceived usefulness and need for this information. Results indicated significant interest in having access to water quality data, as well as a high likelihood that farmers would use this information to reach environmental goals through changing practices. This study demonstrates the potential of using subsurface water quality data as a source of feedback to move from practice-based to outcome based methods, and assist farmers in making land management adjustments that will ultimately lead to improved environmental outcomes.

This thesis is dedicated to Flower the cat for
sticking by my side throughout this entire writing process...literally.

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KEY TO ABBREVIATIONS

BMP - Best Management Practice

DAP - Domestic Action Plan

DRP - Dissolved Reactive Phosphorus

EPA – Environmental Protection Agency

GLRI – Great Lakes Restoration Initiative

GLWQA - Great Lakes Water Quality Agreement

HAB - Harmful Algal Bloom

Kg/ha/day – Kilograms per hectare per day

L/s – Liters/second

MCLG – Maximum Contaminant Level Goal

NASS – National Agricultural Statistics Service

NO3-N – Nitrate as Nitrogen

NOAA – National Oceanic Atmospheric Administration

NPDES - National Pollutant Discharge Elimination System

NPS - Nonpoint Source

NRCS – Natural Resource Conservation Service

NYT – New York Times

P – Phosphorus

P-index – Phosphorus Index

PO4-P – Orthophosphate as Phosphorus

Ppm – Parts per Million

SCI – Soil Conditioning Index

TP - Total Phosphorus

WLEB - Western Lake Erie Basin

INTRODUCTION

Since the mid-1990s, high production farming systems and changing weather patterns have contributed to significant increases in dissolved reactive phosphorus (DRP) to the Western Lake Erie Basin (WLEB). As a result, harmful algal blooms (HABs), which thrive on DRP as a food source, are increasing in size and toxicity. This was seen in 2011 when a thick mat of slime covered approximately one sixth of the entire lake, and was recorded as the largest bloom on record until 2015 when a bloom the size of New York City (roughly 300 square miles) spanned across the Central Basin.

This record setting bloom concerned the public and government officials alike who feared this to be a harbinger for Lake Erie's future if drastic action was not taken soon. In response, two key agreements were initiated in 2015 towards commitments to progress in Lake Erie. The Collaborative Agreement, which was led by the states and a Canadian province was signed in June of 2015, while the U.S. and Canada worked on a federal level to develop a framework for action under Annex 4 of the Great Lakes Water Quality Agreement (GLWQA). It was agreed that total phosphorus loading to Lake Erie must see a 40% reduction by 2025, and in commitment to this each party developed a domestic plan of action with objectives specific to achieving each state or provinces loading reduction goals. Progress, however, remains slow.

Some argue that this may be the result of natural time lags between land management changes and the detection of water quality improvement (Meals et al., 2009), but others would disagree. According to Richard Stumpf at the National Oceanic Atmospheric Administration (NOAA), Lake Erie can respond to these changes relatively quickly; but, it is anticipated that best management practices (BMPs) would need to be implemented at an unprecedented scale to achieve this (Erickson, 2016).

Unfortunately, government agencies have had little success in obtaining wide scale adoption. Traditional conservation programs are often criticized for their standardized and uniform approach, as well as being slow to learn that “more dollars do not necessarily translate into more conservation” (Nowak, 2011). It is estimated that government agencies spend nearly 600 million dollars annually in combined federal funds to implement these programs (Perez, 2017), but modelling studies are recommending that traditional programs “are simply not sufficient to reach these environmental goals, and that new complementary policies and programs are needed” (Erickson, 2016).

Research is now going in a number of different directions in an attempt to understand how to best allocate monetary resources while also achieving the greatest phosphorus reductions. Computer-simulated models have become particularly popular as they help to pinpoint nutrient hotspots, ensuring resources are poured into those regions first, but the original problem remains - motivating farmers to adopt the necessary practices.

The heuristic model of environmentally relevant behavior would suggest that key elements to activating new behaviors or norms, such as a more thoughtful and outcome-oriented approach to conservation, are missing in these traditional and voluntary approaches. In this model, the three fundamental steps needed to activate new behavior include 1) consciousness of environmental problems 2) consciousness of relevance to one’s behavior and 3) consciousness of one’s possibilities, but rarely are farmers able to make a connection between their farm management decisions and its impact on water quality (Matthies, 2005).

This is particularly relevant to productivist farmers who are less likely to think about the long-term value of their land or act to reduce soil erosion voluntarily through a traditional conservation program (McGuire et al., 2015). Additionally, several studies have determined that the productivist identity ultimately dictates the decision-making process (Burton, 2004; Burton and Wilson 2006; Chouinard et al., 2008; Herndl et al., 2011), meaning program design must more closely consider what is required to activate positive environmental norms amongst this group.

One area of research that has shown promise in shifting the behaviors of productivist farmers are projects that incorporate environmental feedback, also known as performance indicators. Thinking back to the model of environmentally relevant behavior, feedback is crucial to activating new behavioral norms. As mentioned in the model, an individual must first become conscious of an environmental problem. Today, most farmers are in agreement that agriculture is leading to worldwide water degradation, but for some it might not be a matter of accepting there is a problem as much as it is accepting that their own farm is potentially contributing to it.

Some of the performance indicators that have shown promise in recent research include the cornstalk nitrate test, the Phosphorus Index (P-index), and the Soil Conditioning Index (SCI) (McGuire, 2013); but uncertainty regarding the accuracy of these tools has put their use into question (Moebius, et al., 2011; Nelson, et al., 2012). Additionally, these tools do not provide farmers with a form of feedback that can be directly related to water quality using sound scientific data.

Regular reporting of water quality data (most commonly from streams) has been shown to renew land-water stewardship ethic but, again, this information does not assist farmers in understanding whether water quality improvements can be attributed to their farm management decisions, or if on-farm issues remain (Perez, 2016). Therefore, this is a critical component of the heuristic model of environmentally relevant behavior that is missing. Lake Erie is not expected to drastically improve without the increased implementation of thoughtful and targeted conservation throughout the WLEB, but this will be difficult to achieve when farmers simply have no way of knowing whether they are directly contributing to the problem, or if there is more they could be doing.

Therefore, this study aimed to explore the potential of sub-surface water quality data as a form of informational feedback that farmers could incorporate into their everyday decision making. Sub-surface water quality data was chosen due to the commonality of this practice in Michigan, as well as the significance of tile drainage water as a transport mechanism for DRP (King et al., 2015; Algoazany et al., 2007; Ball Coelho et al. 2012; Gentry et al., 2007; Morrison et al., 2013). It was hypothesized that providing farmers with this type of information could bring awareness to potential farm management issues, and in turn help farmers manage those issues accordingly, ultimately leading to the activation of more effective conservation behavior.

To test this hypothesis five tile drains were selected in the River Raisin watershed (the largest contributing watershed in Michigan to Lake Erie) where DRP (ppm), nitrate (ppm), and flow (L/s) were monitored weekly over the course of sixteen months. Participating farmers were then able to review their water quality results, and information regarding how this data impacted the three components to norm activation was recorded during one-on-one in-depth interviews.

This study also aimed to understand whether farmers would like to have access to this form of feedback in the future. Opinions regarding the usefulness of this information, farmer likelihood of using it as a decision-making tool, level of trust associated with the data, and ways in which this method could be improved were gathered during a farmer focus group, held during the 2018 Spring Farmer-led Conservation Meeting.

CHAPTER 1

LITERATURE REVIEW

1.1 Background

Phosphorus is a fundamental nutrient needed to support biological processes and is considered harmless to the environment when a proper balance is maintained. An overabundance of phosphorus, however, can lead to devastating impacts, such as the "death" of Lake Erie in the late 1960s. During this time, chemical waste from farmland, city sewers, and factories seeped into the lake and its tributaries like a slow poison, supporting the growth of massive algal blooms. As a result, the lake was gradually converted into a eutrophic state, which is created as bottom dwelling bacteria decompose algae and consume large amounts of dissolved oxygen in the process.

These suffocating conditions led to massive fish kills, polluting Lake Erie's shores with the site and smell of decay. Details of these conditions could often be found in local and national newspapers, as was seen in a New York Times article from 1965 that stated, "beaches along the lakeshore where residents use to enjoy themselves have had to be closed, one after another, because of bad water. Sport fishing that once diverted thousands has dwindled because the fish are not there" (Hill, 1965).

These events led to the realization that Lake Erie was in trouble, and by the 1970s it had become undeniable that industry must be placed under strict regulations if conditions were to improve. In response, permits were introduced under the National Pollutant Discharge Elimination System (NPDES), which regulated discharge from sewage treatment plants and municipalities (USEPA, 2016). The Clean Water Act of 1972 played a fundamental role in this as well, as it allowed the Environmental Protection Agency (EPA) to set enforceable wastewater standards. As a result of these efforts, drastic reductions in total phosphorus loading were documented throughout the late 1980s and Lake Erie was restored back to a non-eutrophic state (Dolan, 1993).

During the mid-1990s, however, the lake's health began to decline again. This was later confirmed to be the result of increasing levels of dissolved reactive phosphorus (DRP), the most bioavailable form of phosphorus to plants (DePinto et al., 1981). It was found that while TP loading during this time remained fairly constant, the fraction of TP that was DRP had more than doubled from a mean of 11% in the 1990s to 24% in the 2000s (Scavia, 2014). Evidence of this increase was also observed through long-term data collection that was conducted in four major contributing watersheds to Lake Erie (**figure 1**).

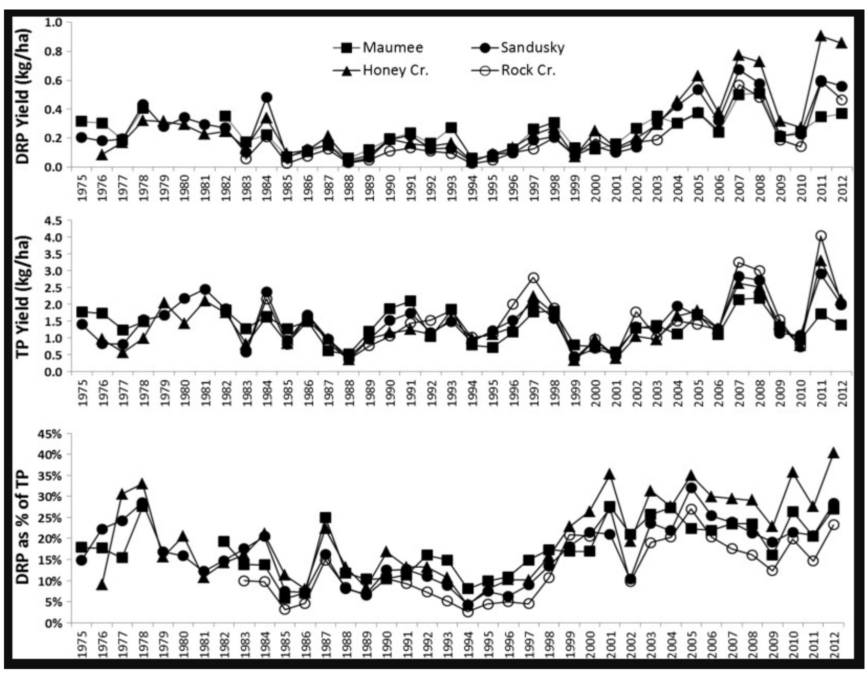


Figure 1. Yields of Total Phosphorus (TP) and Dissolved Reactive Phosphorus (DRP), as well as DRP Yield as a % of TP, from Four Agricultural Watersheds in the West and Central Basins of Lake Erie, 1976–2012 (Scavia, 2014)

Research has since confirmed that agriculture has played a significant role in the rise of DRP. Agricultural changes over the past few decades, such as the use of less diversified crop types, installation of agricultural drainage, and changes in tillage intensity have contributed to exacerbated phosphorus losses (Dinnes, et al., 2002). Additionally, fluctuating commercial fertilizer consumption, which hit its peak at 24 million tons in 1981(USDA ERS, 2013), has contributed to a buildup of legacy phosphorus. An increase of 215 percent was seen from 1960 to 2004 for nutrient pounds applied per acre per year (**appendix A**), contributing to a build-up of solid-phase P in the soil that can be mobilized directly as particulate phosphorus or indirectly as DRP during large rain events (McDowell and Sharpley, 2002; Sharpley, 1996; Sharpley et al., 2004).

Countless government conservation programs have been put in place over the years to reduce these phosphorus stores, and ultimately lower P contributions from agricultural runoff; but large inputs of money and effort have led to few noticeable improvements. Algal blooms today are larger than they've ever been (**figure 2**), and are becoming increasingly more toxic. In 2014, a harmful algal bloom (HAB) developed directly over top the Toledo municipal water intake, contaminating the drinking water of 500,000 residents over a period of three days. The water had become contaminated with microcystin, a toxin produced by *Microcystis aeruginosa* (a species of blue green algae), which is known to target primarily the human liver if ingested (Rinehart et al., 2016).

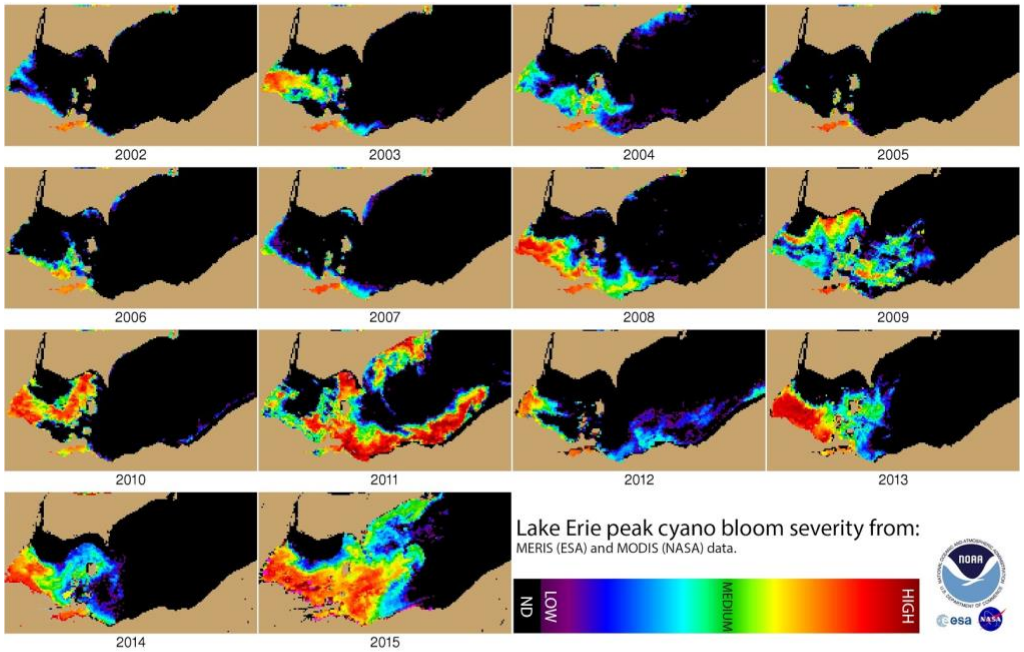


Figure 2. Lake Erie Peak Cyano-bloom Severity from 2002-2015[1]

Additionally, in 2015, The National Oceanic Atmospheric Administration (NOAA) reported on a record setting bloom, which covered nearly 300 square miles. This was the result of unusual weather patterns, leading to large runoff events during the month of June, and providing ideal growing conditions throughout the warm summer months. Climate projections have indicated that storms will become more intense and frequent throughout the spring and winter seasons, ultimately exacerbating phosphorus losses from farmland and increasing the size of future algal blooms if proper measures are not taken (Bosch et al., 2014, Daloğlu et al., 2012; Sharpley et al., 2012).

These increasing threats to Lake Erie, as well as to human health have put several government collaborations and plans into motion. In 2015, Governor Rick Synder, Premier Kathleen Wynne of Ontario, and Lieutenant Governor Mary Taylor of Ohio signed the WLEB Collaborative Agreement, committing each party to providing a domestic action plan

[1] Contact Richard Stumpf at the National Oceanic Atmospheric Administration's (NOAA) National Center for Coastal Ocean Science for access to this image.

(DAP). Michigan released their DAP in June of 2017, calling for a 40 percent reduction in spring total and dissolved reactive phosphorus loading from the Detroit, Maumee, and River Raisin by 2025. Some of the specific objectives within the DAP consisted of identifying priority areas throughout Michigan's portion of the Maumee watershed, as well as implementing P control actions throughout the River Raisin watershed. Modelling studies anticipate, however, that best management practices (BMPs) would need to be implemented at an unprecedented scale to achieve this (Erickson, 2016).

Unfortunately, government agencies have had little success in obtaining wide scale adoption. For decades, government programs have taken a silver bullet approach to conservation, and as a result farmer participation today remains low. Pete Nowak describes these programs in *The Conservation Journey* as "uniform" and "standardized", and brings attention to the need for recognizing landscape and management diversity (Nowak, 2011). Additional problems with traditional conservation programs is the lack of feedback they provide. Farmers typically receive little to no information regarding the impact the practices they implement have on water quality, often leading to outcomes such as disinterest in adopting additional conservation measures or discontinuing practices altogether.

This was seen in a study completed by the USDA Conservation Effects Assessment Program which reviewed all BMP contracts made from 1991-1997 in the Little Bear River Watershed. They found that 16% of contracted BMPs were never implemented, and greater than 20% of implemented BMPs were no longer being maintained. Additionally, 68.1% of non-maintained BMPs were discontinued by farmers who still farmed, while 31.9% of BMPs were discontinued by farmers who no longer farmed (Smith, et al., 2010)

It is clear from the issues surrounding traditional programs that a new approach to engaging farmers in conservation is needed. This is particularly true of productivist farmers who are less likely to think about the long-term value of their land or voluntarily join a conservation program. This is concerning because several studies have determined that the productivist identity ultimately dictates the decision-making process (Burton, 2004; Burton and Wilson 2006; Chouinard et al., 2008; Herndl et al., 2011), meaning program design must more closely consider what is required to engage this group.

1.2 The Heuristic Model of Environmentally Relevant Behavior

According to the heuristic model of environmentally relevant behavior three fundamental components must be present before new behaviors or norms can be activated in individuals, such as productivist farmers. As seen in **figure 3**, the three building blocks required to achieve this change in behavior include 1) consciousness of environmental problems 2) consciousness of relevance to one's behavior and 3) consciousness of one's possibilities.

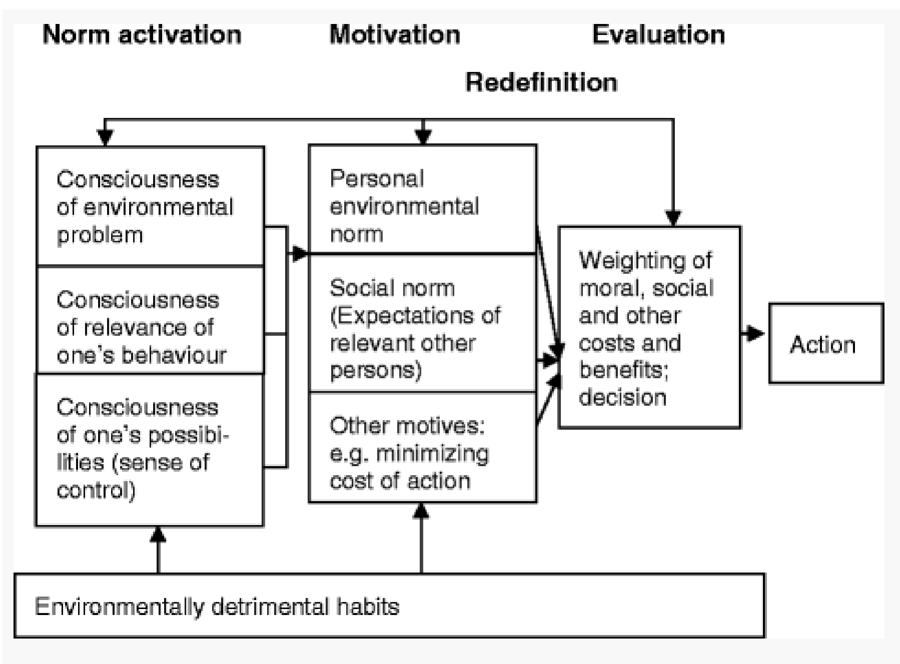


Figure 3. The Heuristic Model of Environmentally Relevant Behavior (Fischer, 2008)

This model is discussed in-depth in a study done by Corinna Fischer who used it to explain the role feedback plays in decreasing household energy consumption (Fischer, 2008). This study was very relatable to the issues discussed here, because like energy, nutrient loss from farm fields (especially through subsurface drainage) is essentially invisible. Therefore, how do you get a mass population to pay close attention to something they cannot see? Homeowners cannot physically see how much energy they are consuming, just like farmers cannot physically see how much of their nutrient inputs are being lost to the environment.

In Fischer's explanation of the model she begins by distinguishing between two types of action: habitual behavior and conscious decisions. In the circumstances described in this paper, habitual behavior can be thought of as the everyday choices farmers make without water quality feedback available to suggest they should do otherwise. In the actual model this is labelled as "environmentally detrimental habits". A conscious decision, however, is what is required for these behaviors or habits to be broken; and in the model this occurs when the three building blocks to norm activation are encountered.

It is well known that most farmers are already aware of environmental problems within their watersheds, along with the role agriculture plays in this; but it is anticipated that farmers are not as aware of these things on a finer scale. For example, a farmer might be well informed about water quality issues in Lake Erie, and may have BMPs in place in an effort to reduce their farms contribution to the problem, but they likely remain completely unaware if those decisions are leading to positive water quality results. As mentioned before, this is problematic for productivist farmers who are less likely to voluntarily adopt conservation practices or join programs unless they know there is a problem on their own farm to begin with. For example, a productivist farmer who sees that they are losing a significant amount of nutrients through their tiling system (what they would consider an economic loss) might use that feedback to implement conservation practices that they otherwise wouldn't have had interest in.

Conservationist farmers could benefit from this, as well, because even though they typically are already engaged in conservation they could use to the feedback to learn if the practices they've implemented are effective in reducing high nutrient losses. This is especially important considering the amount of research that has indicated uncertainty regarding which BMPs or combination of BMPs are most effective (Inamdar et al., 2001; Park et al., 1994; Bosch et al., 2013). Landscape, cropping systems, and hydrology varies across farms meaning BMPs implemented on one field may not necessarily be appropriate or effective enough for another. Feedback would allow this group to evaluate management strategies, and adjust practices for the best possible outcome.

1.3 The Role of Environmental Feedback in Activating Conservation Behavior

It was anticipated that environmental feedback would play a successful role in activating a more effective approach to conservation because it has already shown promise in past research. The effectiveness of feedback has been tested in many industries, but one of the more extensive literatures exists in the energy sector. As discussed earlier, Fischer used the heuristic model of environmentally relevant behavior to understand how feedback changed human behavior in terms of energy consumption, and reported on the forms of feedback that were most successful. Similarly, Darby was interested in the impact feedback had on homeowners, and looked at the effectiveness of including feedback on monthly electric bills. It was found that this could reduce energy consumption by up to 20 percent (Darby, 2006).

Additionally, Faruqui et al. explored the use of in-home displays as a form of direct feedback and found that consumers who actively used these were able to reduce their consumption of electricity by about 7 percent (Faruqui et al., 2010). Jeong et al. found similar results in a study which focused on water consumption. Data collected from nearly 4700 occupants revealed that water consumption represented in terms of gallons and associated embodied energy led to a statistically significant reduction in use.

In the agricultural sector, McGuire et al. found that performance indicators such as the Iowa Phosphorus Index, the corn stalk nitrate test, and the Soil Conditioning Index (SCI) helped to successfully transition productivist behaviors to those more common of conservationist farmers. Participants were provided with one year of baseline data (collected from the performance indicators), and each year after that specialists met one-on-one with farmers to explain the results. This allowed participants to adjust their farm management as they saw fitting and results were shared amongst the entire watershed group during annual meetings. Over a four-year period, farmer interviews revealed a drastic shift in behavior towards conservation. Farmers continued to use the performance indicators to make management changes that addressed water quality where prior to this source of feedback many of those same farmers openly discussed that they did not think they were responsible for agricultural pollution (McGuire et al., 2013).

Decision support tools are another form of feedback that have been developed and put to use more recently. These are typically a software based tool that use computer simulated modelling to predict the impact a select BMP or combination of BMPs will have on the environment. More specifically, farmers can learn things such as how much phosphorus loading will be reduced before they even adopt the practice, allowing them to base their decision on which practices will produce the best results.

The capability of this predictive software in accurately representing complex hydrological systems, however, remains under debate due to the number of variables which can drastically change model outputs (Cho, J., et al., 2009). Additionally, anecdotal evidence would suggest that farmers who have been exposed to these tools are skeptical, as well. As a farmer speaking to Minnesota Public Radio put it, "some of the assumptions and predictive models developed by groups, such as the Minnesota Pollution Control Agency, don't always square with what's really happening on the land." Similarly, uncertainty regarding the accuracy of the performance indicators mentioned earlier has put their use into question (Moebius, et al., 2011; Nelson, et al., 2012), leaving farmers in need of feedback that is not only specific to their operations, but that can also be trusted.

1.4 The Potential of Subsurface Water Quality Data as a Feedback Mechanism

Discrete, subsurface water quality data was chosen as the feedback mechanism to test in this study due to its significance in the River Raisin watershed, as well as the increasing farmer support there is for this kind of data. Regular reporting of water quality has been shown to be a successful method for renewing land-water stewardship ethic, and is essential to understanding how land management impacts phosphorus loss (NRCS, Water Quality Success Stories).

In the River Raisin, installing subsurface drainage is common, as it is across the Midwest where approximately 18 to 28 million hectares of cropland use this practice (King et al., 2015a). The installation of tile drains, however, changes the hydrology of fields and increases the infiltration of water (Reid et al., 2012). As a result, this reduces overland runoff, which helps to decrease soil erosion and the loss of particulate phosphorus, but has the unintended consequence of increasing DRP loss through the subsurface instead.

This should be of concern to farmers during large rain events because the most significant DRP losses have been observed to occur during periods of high flow (Algoazany et al., 2007; Ball Coelho et al. 2012; Gentry et al., 2007; Morrison et al., 2013). It is also well known that approximately 70-90 percent of phosphorus loading occurs during the highest 20 percent of flows, or during approximately 10 storm events a year (Baker et al., 2014).

For these reasons, water quality data is becoming increasingly more interesting to farmers who would prefer to keep nutrients in place rather than see them washed away through their tiling systems. In a 2014 survey distributed to Wisconsin farmers it was found that sixty-one percent of farmers wanted to see more water quality monitoring because they wanted to ensure conservation practices were effectively keeping nutrients in place. Additionally, forty-five percent said that they'd be willing to have the monitoring done on their own property (Lower Fox River Basin Survey, 2014).

It was anticipated that farmers in the River Raisin watershed would be just as receptive to receiving water quality data, particularly subsurface data, due to the amount of interest farmers in this region are already showing. The local farmer-led watershed group currently has over 100 members where farmers routinely gather to hear presentations from an assortment of WLEB water quality experts. This group also actively participates in a summer program called the "Tall Ship Sails" where farmers climb aboard sailboats and enjoy lunch on Lake Erie. Therefore, this farmer-led group was likely to want this type of information and would be comfortable with allowing sampling to be done on their farms.

1.4.1 Interpreting Subsurface Water Quality Data

Dissolved Reactive Phosphorus (PO4-P)

To understand how water quality data impacted the components of norm activation in relation to conservation behavior, farmers first needed to interpret the data from their farm's tile drains. This was difficult to do, however, based on the lack of tile drain studies done on farms that could be directly comparable to the farms in this study. Variables such as soil type, landscape, hydrology, cropping systems, tillage, nutrient management, and weather patterns all play a significant role in the movement of phosphorus and nitrogen through tile drain systems (Randall et al., 2001; Donner et al., 2007), and must be considered when attempting to find a point of reference.

Ideally, comparable subsurface water quality data would come from farms within the same watershed, but because data that close in proximity could not be found a study done in the Macatawa watershed was chosen instead (Clement & Steinman, 2017). This watershed is located in southwestern Michigan and covers approximately 174 square miles, making it about two tenths the size of the River Raisin. Like the River Raisin though, this watershed's dominant land use is row crop agriculture (45%) making nearby water bodies such as Lake Macatawa susceptible to nutrient pollution.

Additionally, this study collected phosphorus data (DRP and TP) from nine tile drains all of which were under similar cropping systems (corn and soybeans) with similar soil types (clay and sandy loams). The most significant differences found between these studies was land management. Only one of the nine sites in the Macatawa study used a winter cover crop compared to this study where all five sites used a cover crop. Additionally, six out of nine sites in the Macatawa study used some form of spring or fall tillage where in this study all but one site practiced conservation tillage.

The Macatawa watershed study reported on the mean DRP concentration (ppm) of samples collected monthly over the course of one year from all nine sampling sites. They also reported on the mean discharge rate (L/s) of these sites, enabling them to see a strong correlation between discharge and DRP loading. The same parameters were measured in this study as well, allowing for farmers to see how their water quality results compare to those on the opposite side of the state.

An additional strategy used to interpret water quality results involved comparing sample concentrations to guidelines set by the Environmental Protection Agency (EPA). According to the EPA, phosphorus (TP or DRP) can cause nuisance plant growth contributing to eutrophic conditions at as low as 0.1 ppm. There is currently no national water quality criterion, however, to protect surface waters. This is because the effects of phosphorus vary by region and are dependent on a number of physical factors including the size, hydrology, and depths of rivers or lakes (USDA, 2013).

Another water quality standard considered for this study was the maximum concentration of phosphorus that municipal and industrial waste water treatment plants can discharge. Guidelines set by the National Pollutant Discharge Elimination System (NPDES) limit point source total phosphorus discharges to 1 ppm, meaning DRP concentrations must be even lower (USEPA, 2016). This is because DRP is the soluble form of phosphorus compared to total phosphorus which contains all forms of phosphorus (soluble and particulate); therefore, TP is typically always a higher value than DRP, but in some circumstances the values can be equal.

The 1 ppm standard set by the NPDES was the primary guideline used when determining whether farmers were releasing too much phosphorus into the environment, with the assumption being that if point sources can't discharge above this limit then farms probably shouldn't either. This is especially true during high flow periods where farms were releasing as much as 1.8 lbs of DRP in a single day (assuming flow stayed constant for a 24-hour period). Farmers could observe how often samples had concentrations above this 1 ppm guideline in graphs like the one shown in **figure 6**. In that example, samples were found to be above 1 ppm forty-four percent of the time.

Farmers could also observe phosphorus loading levels (lbs DRP lost/day) in graphs like the one shown in **figure 7**. This graph showed an average of how much phosphorus was lost from tile drains per day throughout different months of the year. In this example, the highest losses occurred during the month of March and July, likely due to the large storm events recorded during those months. This is comparable to what a compilation of 400 tile drain studies reported on in 2015, mentioning that most DRP export occurred outside of the growing season with the highest concentrations occurring between February and July (Christianson, et al., 2015).

Additionally, Christianson et al. reported average DRP loads in tile drainage water to be approximately 0.1 - 0.9 kg/ha/yr under dry and wet conditions, so this was also used as a general guideline when interpreting load values. This value was converted to kg/ha/day, however, to match the units used in this study. Loading was estimated on a per day basis because continuous flow data was not collected for this study. Flow data was limited to an average of four readings per month (recorded during weekly grab samples), therefore much less error would be associated with assuming flow remained constant over a 24-hour period versus a full week.

Nitrate (NO3-N)

Interpreting nitrate values from tile drains was much easier than interpreting DRP because its behavior is far more consistent than phosphorus. This is because nitrate is very soluble (due to its negative charge) and moves freely through most soils, meaning it responds to variables like weather and nutrient management in a much more predictable way than more immobile compounds like DRP. For this reason, an accumulation of studies have been able to determine what concentrations of NO3-N found in tile drainage water can be associated with potential farm management issues.

Using several studies conducted throughout the Midwestern United States, Purdue University developed a table which summarizes what NO3-N concentrations were common amongst particular land management practices. As can be seen in **Table 1**. concentrations found in tile drains greater than 20 ppm were typically associated with poor nitrogen use efficiency in a row crop production system. Anything below 20 ppm, however, was rather associated with optimal nitrogen efficiency (10-20 ppm), or not applying enough nitrogen during the previous growing season (5-10 ppm).

NO_3-N Concentration (ppm)	Interpretation
≤ 5	Native grassland, CRP land, alfalfa, managed pastures
5 – 10	Row crop production on a mineral soil without N fertilizer Row crop production with N applied at 45 lbs./acre below the economically optimum N rate† Row crop production with successful winter crop to "trap" N
10 - 20	Row crop production with N applied at optimum N rate Soybeans
≥ 20	Row crop production where: • N applied exceeds crop need • N applied not synchronized with crop need • Environmental conditions limit crop production and N fertilizer use efficiency • Environmental conditions favor greater than normal mineralization of soil organic matter

Table 1. General Guidelines for Interpreting Nitrate Concentrations in Tile Drainage Water

Farmers could interpret their own nitrogen use efficiency by comparing graphs like the one shown in **figure 8**. to Purdue's interpretation. In this example, nitrate levels were above the 20 ppm limit twenty-nine percent of the time with the majority of those increases occurring during late winter and early spring. This would suggest that the farmer may have over applied nitrogen during the previous growing season, and may want to re-evaluate their nutrient management plan.

An additional way of interpreting nitrate results was considering EPA water quality standards. Unlike phosphorus, nitrate has been placed under a maximum contaminant level goal (MCLG) of 10 ppm due to the health risk it places on humans. Nitrate contamination in groundwater has often been linked to methemoglobinemia, which results in the decreased oxygen carrying capability of hemoglobin in babies (also known as blue baby syndrome). Therefore, it would be considered ideal that concentrations of nitrate remain below this level during periods of high flow to reduce the risk of elevating nitrate concentrations in surrounding water bodies.

Lastly, two studies were reviewed to gain an understanding of what nitrate concentrations and loading values have been seen throughout the Midwest in similar soil types and cropping systems. Randall et al. documented the flow-weighted averages of NO3-N concentrations in Minnesota tile drains under a number of different cropping systems (two of which were the same as the cropping systems seen in this study). It was found that the average NO3-N concentration in tile drainage water after continuous corn was 32 ppm, and NO3-N concentrations after a corn-soybean rotation was 24 ppm (Randall, et al., 1997).

Another study that was reviewed explored the impact of manure treatment on nitrate leaching in Michigan. This was of interest because two out of the three farmers in this study apply manure to their fields. The study found that of the treatments tested (no fertilizer, manure, inorganic, or compost) the highest amount of NO3-N leaching occurred in manure treated fields with an annual average of 55 kg NO3-N/ha (Basso, et al., 2005). This was found in a corn-alfalfa rotation, however, which does not represent the cropping systems used in this study (continuous corn and corn-soybean), but was still useful for understanding how manure might have impacted nitrate results on the fields that received it annually.

CHAPTER 2

METHODS

2.1 Research Questions

This study reports on the participation of three farmers in a subsurface water monitoring program in the River Raisin watershed and aims to understand how environmental feedback (e.g. subsurface water quality data) impacts norm activation (e.g. conservation behavior) through the following research question:

1. How does subsurface water quality data impact the following components to norm activation in participants?
    - consciousness of environmental problem
    - consciousness of relevance to one's behavior
    - consciousness of possibilities (sense of control)

Additionally, this study seeks to understand whether farmers would like this type of information to be more accessible in the future, and in what format they find it to be most useful. This knowledge will be key to incorporating successful forms of feedback into a farmer's decision making toolbox and will be explored through a second and third research question:

2. Are farmers supportive of using water quality data as a type of feedback for on-farm decision-making?

2.2 Hypotheses

It is anticipated that the three components to norm activation will be impacted differently when farmers have feedback specific to their farm operation versus when they do not. For example, it is hypothesized that participating farmers will be very aware of environmental problems in their watershed, such as the algae blooms in Lake Erie and its connection to agriculture because they are members of a farmer-led group; but they will not necessarily associate these issues with their farm or land management decisions. This is because all participants are involved in conservation to some extent (cover crops, drainage control structures, grassed waterways, etc.), and would have no reason to assume they should be doing more.

These attitudes were anticipated to change, however, once farmers were provided with water quality data as a form of feedback. These changes will of course be dependent on how farmers interpret the information though. For example, if the farmer is concerned by the water quality results they may have an increased awareness of environmental issues on their own farm, and may feel obligated to take increased responsibility for improving water quality. In contrast, if the farmer is content with the results and interprets them as a job well done then this will likely result in an opposite effect. The farmer may have fewer environmental concerns associated with their farm, and a decreased sense of responsibility to improving water quality through additional efforts; however, positive outcomes would potentially be an increased sense of confidence in the effectiveness of the conservation practices they have already put in place. A summary of these hypotheses can be found in **tables 2-3**.

Consciousness of Environmental Problem	It is hypothesized that farmers will be most aware of and concerned with watershed scale issues vs on-farm issues
Consciousness of Relevance to One's Behavior	It is hypothesized that farmers will agree agriculture is mainly responsible for environmental issues, but not necessarily the actions taken on their own farm
Consciousness of One's Possibilities (Sense of Control)	It is hypothesized that farmers will feel they are making a positive impact through the BMPs they have already implemented

Table 2. Summary of Hypotheses Regarding the Components of Norm Activation before Farmers are Exposed to Water Quality Data

Consciousness of Environmental Problem	*If farmer interprets results as "bad":* It is hypothesized that the farmer will become more aware of potential issues on-farm
	If farmer interprets results as "good": It is hypothesized that the farmer will not find any issues with their farms management
Consciousness of Relevance to One's Behavior	*If farmer interprets results as "bad":* It is hypothesized that the farmer will become more aware of on-farm decisions that could be leading to poor water quality results
	If farmer interprets results as "good": It is hypothesized that the farmer will find no issues with their farm management decisions
Consciousness of One's Possibilities (Sense of Control)	*If farmer interprets results as "bad":* It is hypothesized that the farmer will have a decreased sense of control until they figure out exactly what is causing nutrient loss on their farm
	If farmer interprets results as "good": It is hypothesized that the farmer will have an increased sense of control because they will be more confident that their conservation choices are effective.

Table 3. Summary of Hypotheses Regarding the Components of Norm Activation After Farmers are Exposed to Water Quality Data

2.3 Establishment of Water Monitoring Program

This study explored these research questions through a qualitative case study in the River Raisin watershed. This involved recruiting farmers from a farmer-led watershed group to participate in a subsurface water monitoring program where they could view and discuss their water quality results upon project completion during one-on-one in-depth interviews. Additionally, water quality findings from each farm (location remained confidential) was presented to the entire farmer-led watershed group at their semi-annual spring meeting to gain an understanding of farmer support for this type of data, and whether or not they found the information to be useful. Details regarding the implementation of the subsurface water monitoring program can be found below.

2.3.1 Participant Recruitment

Participating landowners were recruited during the 2015 winter semi-annual farmer-led conservation meeting, which occurs twice a year in Lenawee County, MI. During this meeting details of the project were given during a short presentation where afterwards three farmers volunteered to participate. This group represented a variety of farm types including beef, dairy, and cash crops with operations ranging in size from 35-1500 acres. Additionally, all three farmers were Caucasian males ranging from ages 40-65.

It was determined that this group was representative of the farmer population in Lenawee County based on data available from the United States Department of Agriculture's National Agricultural Statistics Service (NASS), which can be found in **appendix B**. According to NASS, the average farm size in Lenawee County is 213 acres with most farmers growing corn or wheat to be used for grain (48%). Two out of the three farmers in this study grew corn or wheat for this purpose. The remaining farmer grew corn for silage, which represents about 2.4% of the population in this county. Raising livestock is also common, representing 25.8% of the population. Of this 25.8%, 13% raise beef and 8% raise dairy with the remaining 4.8% raising sheep or pigs. Of the farmer participant group one farmer owned a beef cattle operation and another owned a dairy operation. None of the participating farmers raised sheep or pigs.

Lastly, all participants were asked to sign a consent form before data collection could begin to ensure confidentiality. All personal information (names, farm locations, email addresses, etc.) were kept on password protected computers and field sites were identified using only assigned numbers. The consent form also provided farmers with a detailed description of project goals and objectives, as well as the contact information of myself if they had questions or concerns. The consent form used for this study can be found in **appendix C**.

2.3.2 Site Description

The River Raisin watershed (United States Geological Hydrologic Unit Code: 04100002) was an ideal location to perform this study due to its close proximity to Lake Erie and because over 75% of its land use is dedicated to agriculture. This watershed covers an area of approximately 1,059 square miles (677,800 acres) in southeastern Michigan and drains into Lake Erie at Monroe Harbor. The River Raisin covers most of Lenawee County, along with smaller portions of Monroe, Washtenaw, Jackson and Hillsdale counties in Michigan, as well as a piece of Fulton County in northeastern Ohio.

Farmers were recruited specifically from the South Branch (**figure 4**.) because of its geographical priority amongst federal agencies, such as the Great Lakes Restoration Initiative (GLRI). This sub watershed contains some of the most erosive soils in the county where slopes are 3-7%, and modelling studies have identified it as a major contributor of phosphorus, nitrogen, and sediment loadings.

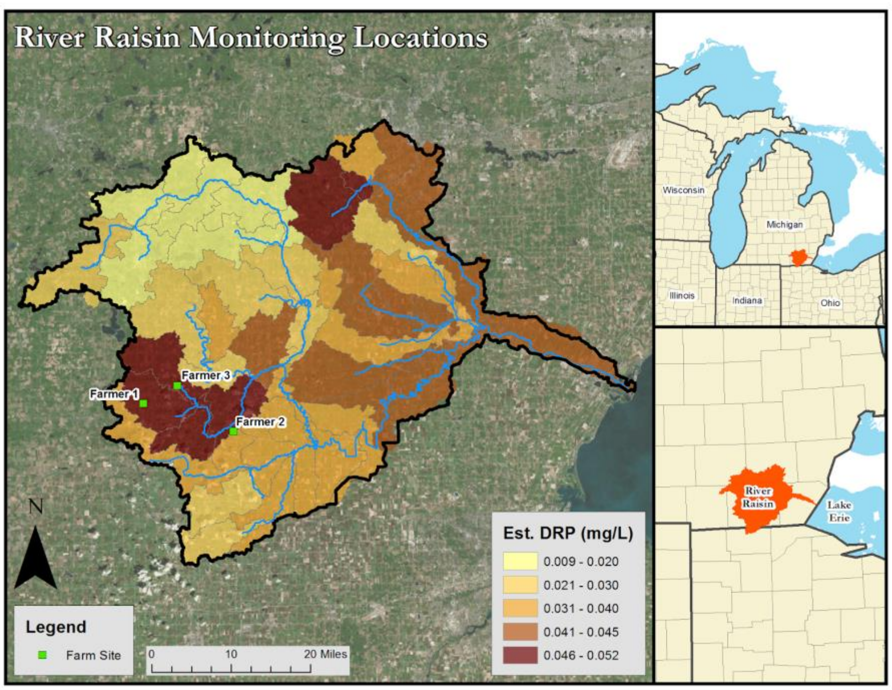


Figure 4. Map of River Raisin Watershed with Farmer Participant Locations, as well as Estimations of DRP Concentrations from Contributing Sub-watersheds

Additionally, the predominantly silty-clay soils in this region have required the increased installation of subsurface drainage (also referred to as tiling), meaning the majority of farmers in this area would have tile drains that could be sampled from. Subsurface flow was chosen to be collected instead of overland flow for several reasons. The first being ease of data collection (overland flow would require expensive edge of field monitoring equipment), and the second being the significance of tile drainage as a P transport mechanism.

While this practice is critical for enhancing crop productivity, increased infiltration and subsurface flows have enhanced movement of agrichemicals to surface waters (Hoorman & Shipitalo, 2006). In fact, as much as 49% of DRP loss has been found to occur through subsurface drainage (King et al., 2015; Algoazany et al., 2007; Ball Coelho et al. 2012; Gentry et al., 2007; Morrison et al., 2013), making it a significant source of DRP loading to Lake Erie.

2.3.3 Field and Laboratory Methods

Five field sites were selected in the South Branch of the River Raisin. Sites were chosen based on landowner cooperation, proximity to water quality lab, and accessibility of tile drain. All sites were within thirty miles from one another, but varied in acreage, soil type, crop rotations, and farm management. A summary of field characteristics can be seen in **table 4**. Samples and flow data were collected weekly over a sixteen-month period from PVC outlets which drained into open ditches.

Samples were refrigerated after collection and analysis occurred within a 24-hour period. The water quality parameters measured included nitrate (NO3-N) and DRP (PO4-P). Analysis occurred following standard water quality protocol with quality control measures in place.

2016 - 2017

Site	Acres drained	Crops	Winter cover crops	Fertilizer	Tillage	Dominant soil type
1	35	Soybeans	Yes	Manure in fall; inorganic fertilizer at spring planting	No-tillage	Clay loam
2	50	Soybeans	Yes	Manure in fall; inorganic fertilizer at spring planting	No-tillage	Clay loam
3	40	Soybeans	Yes	Manure in fall; inorganic fertilizer at spring planting	No-tillage	Clay loam
4	15	Soybeans	Yes	Inorganic fertilizer incorporated with planter in spring	No-tillage	Clay loam
5	30	Continuous corn	Yes	Manure incorporated in fall; inorganic fertilizer at spring planting	Manure incorporated	Sandy loam

Table 4. Land and Management Factors per Sample Site

2.4 Process

2.4.1. Farmer Water Quality Reports

After sixteen months of subsurface water monitoring the data was summarized into reports, which represented the year 2017 and part of 2018. A number of different graphs were included within the report to help farmers gain a better understanding of how much nutrient loss was occurring throughout the year. Using field #5 as an example, images of the aggregated data that was shown to farmers can be seen in **figures 6 - 9**. Information regarding the guidelines used to interpret these graphs can be found in the analysis section.

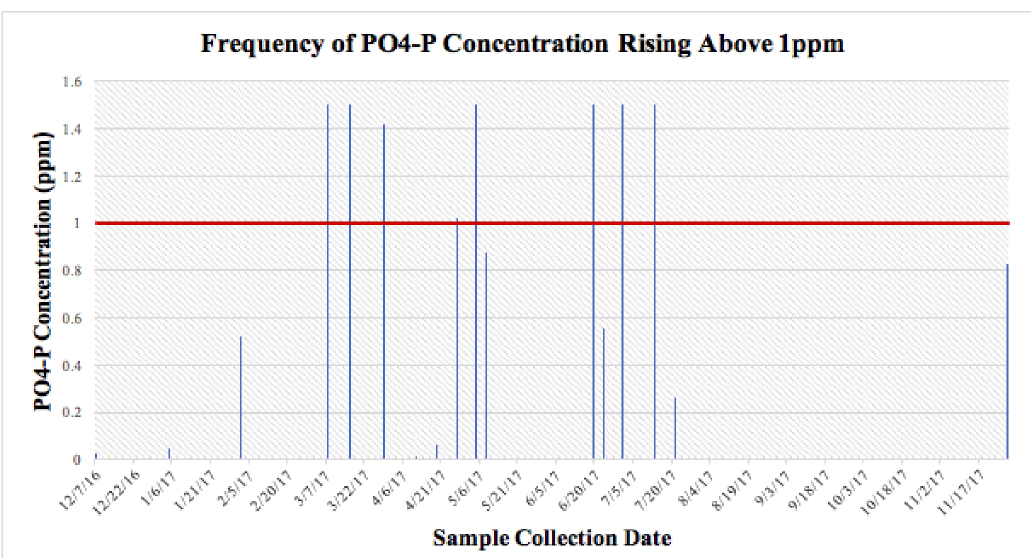


Figure 5. The Frequency of Samples Collected with a DRP Level Above 1ppm

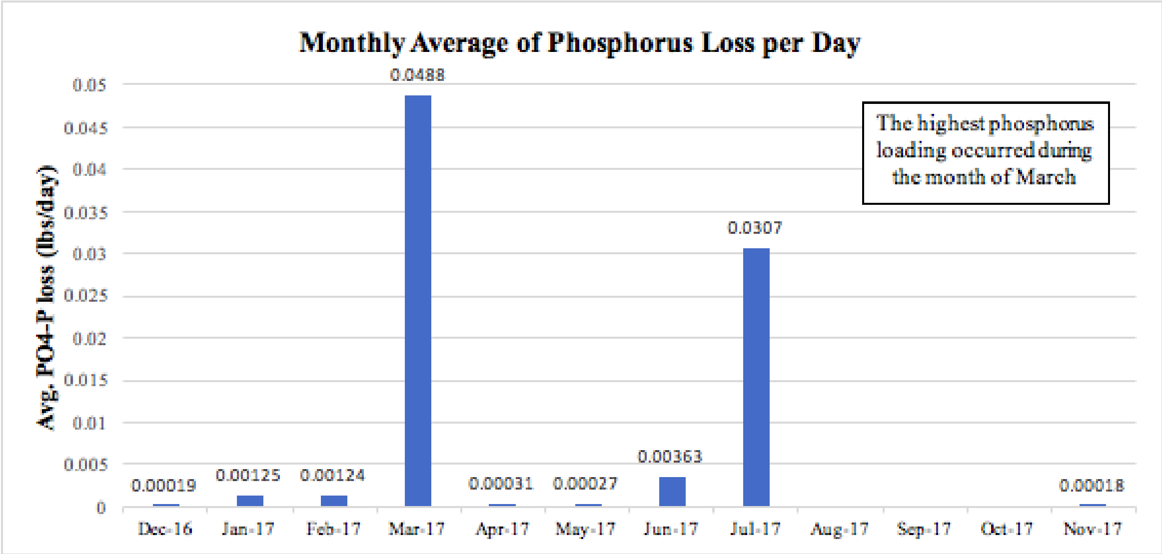


Figure 6. The Monthly Average of DRP Lost in lbs/day

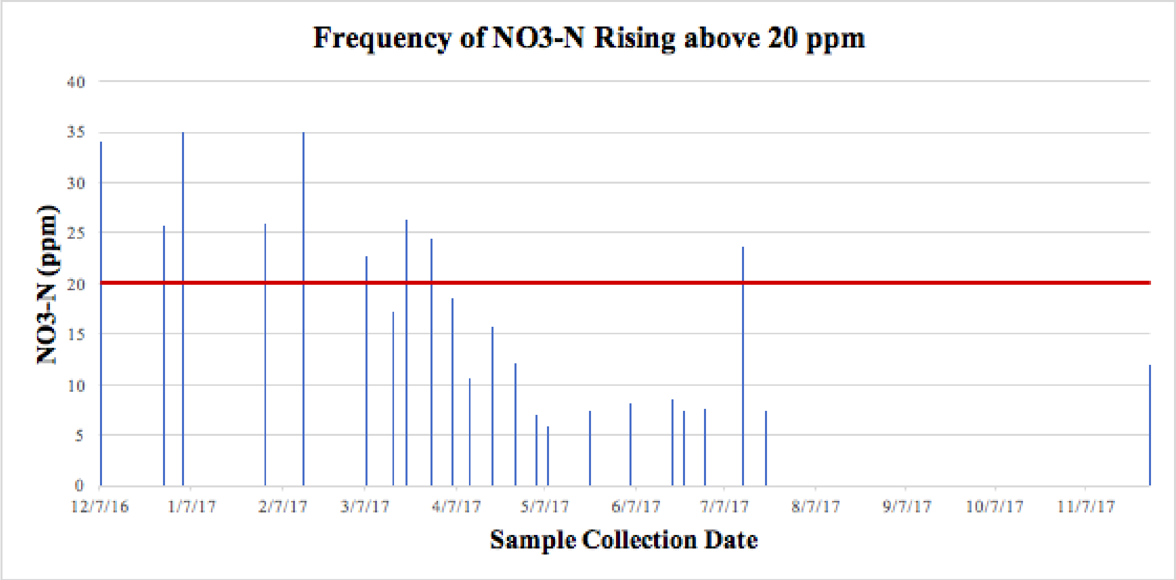


Figure 7. The Frequency of Samples Collected with a Nitrate Level Above 1 ppm

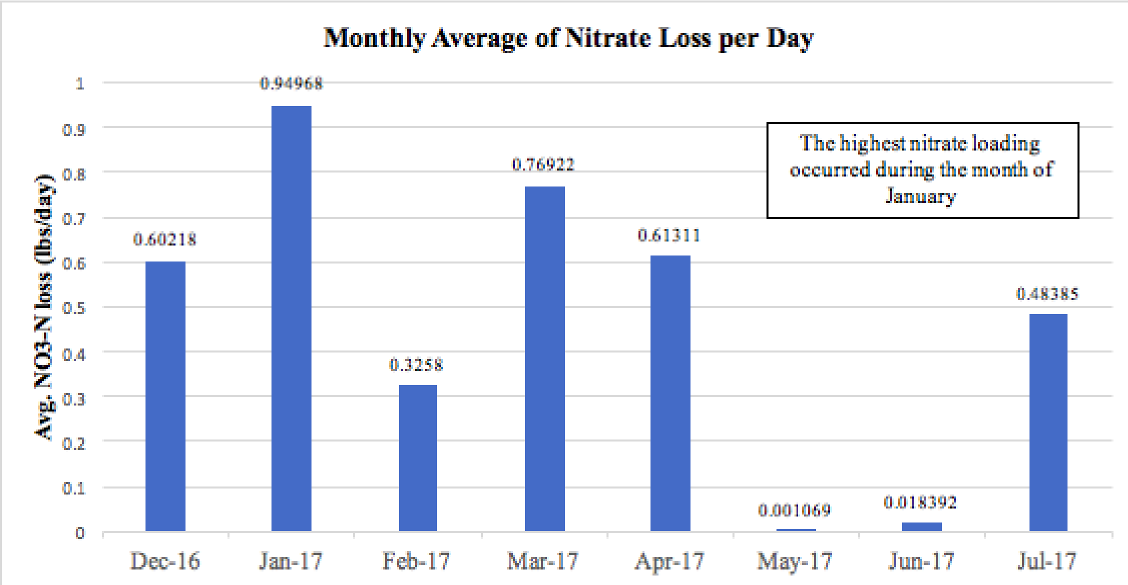


Figure 8. The Monthly Average of Nitrate Lost in lbs/day

2.4.2 One-on-One In-depth Interviews

To better understand how the water quality data described above impacted the three components of norm activation, each farmer was asked to participate in a one-on-one in-depth interview. Each interview was semi-structured in nature, allowing for a series of purposeful questions to be asked, but in a more relaxed atmosphere. This encouraged a more natural conversation with the benefit of additional insights from the farmer.

In-depth interviews were completed after sixteen months of water sampling. These interviews were done at the farmer's home and consisted of three phases. The first phase began with a series of questions regarding environmental issues (if any) they were concerned with (on-farm or off-farm) before the project started, how they thought those issues related to their farm management, and whether they felt they had control over environmental outcomes. Phase two involved an in-depth discussion about each participant's water quality results. Farmers were first asked to look over the data and develop their own interpretations to avoid accidently persuading them to react in a way that would be favorable.

Lastly, during phase three farmers were asked a series of questions like those asked during phase one. The purpose being to understand how the water quality data changed their awareness of environmental issues, awareness of the relevance of their behavior to those issues, and the sense of control they felt they had over dealing with those issues. The questionnaire used for these interviews can be found in **appendix E**.

2.4.3. Farmer-led Watershed Group Presentation & Survey

The survey for this study was distributed at the 2018 Spring Semi-Annual Farmer-led Conservation Meeting in Lenawee County, MI. The survey was handed out to willing participants after presenting the findings of this study to the entire farmer-led group, which consisted of approximately 25 members. The purpose of the presentation was to first demonstrate to farmers what others could gain from having water quality data accessible to them, and second to discuss next steps, such as how this information could be provided to farmers in the future. The survey was then distributed to eight farmers immediately after the presentation. Key topics addressed in this survey included: usefulness of information, how data could improve, likelihood to use data to manage farm practices, and level of trust farmers had in the information. The questionnaire used to conduct this focus group can be found in **appendix F**.

2.5 Analysis

2.5.1 One-on-One In-depth Interviews

Qualitative data collected during the one-on-one in-depth interviews was analyzed using open coding. This method of analysis helped in the recognition of re-occurring themes, which were identified by noting interesting pieces of conversation that were had throughout the interviews. Thematic codes were then applied line by line to each transcript using color coding, so as to easily identify the frequency in which these themes appeared (Miles et al., 2014).

Determining the frequency of themes then allowed for the detection of thematic patterns, which are identified in the findings section.

2.5.2 Farmer-led Watershed Group Survey

Analysis of the responses to the farmer-led watershed group survey was merely looking at the minimum, mean, and maximum scores, as participants' responses were based on a 1-10 scale for all but five questions. Scores to corresponding questions can be found in **table 7**. The remaining five questions that were not based on a scale of 1-10 were recorded as either qualitative or quantitative data in **table 8**.

CHAPTER 3

FINDINGS

3.1 One-on-One In-depth Interviews

3.1.1 Themes - before water quality data

Component to Norm Activation	Themes
Consciousness of Environmental Problem	Farmers did not anticipate much nutrient loss to be occurring on their fields
Consciousness of Relevance to One's Behavior	Farmers attributed nutrient loss to a mix of things, including their own practices, as well as things they could not control
Consciousness of One's Possibilities (Sense of Control)	Two out of three farmers felt confident that their current land management was keeping nutrient loss at a minimum. The remaining farmer was unsure because he did not have data to prove it.

Table 5. Resulting Themes from Interviews Conducted Before Farmer Participants Received Water Quality Reports

3.1.2 Themes - after water quality data

Component to Norm Activation	Themes
Consciousness of Environmental Problem	Each farmer became more aware of when and how much nutrient loss was occurring throughout the year
Consciousness of Relevance to One's Behavior	Each farmer attributed these nutrient losses to their own behavior
Consciousness of One's Possibilities (Sense of Control)	Each farmer discussed things they wanted to do differently the following growing season to reduce nutrient losses

Table 6. Resulting Themes from Interviews Conducted after Farmer Participants Received Water Quality Reports

3.1.3 Discussion

<u>Before water quality results - consciousness of environmental problem</u>

Findings of farmer participant one-on-one in-depth interviews revealed that, without field specific water quality data, farmers who have already implemented at least one or two best management practices are likely to assume there is little nutrient loss occurring on their fields. While conducting the interviews farmers were asked whether or not they believed nutrient leaching through their tile drain was an issue and one farmer responded: *"I didn't think I had a problem field on my hands...the reason we went with that field was because it fit the criteria to do the testing on."*

This demonstrated that the farmer did not expect nutrient loss to be a major issue, and chose that field to be a part of this study because it met the criteria we were looking for. Another farmer responded in a similar way, except this farmer acknowledged that it seemed unreasonable to assume there was zero nutrient loss occurring: *"I don't think we have much of a problem, but I'm not gonna flat out say we don't have an issue at all."*

By saying this, it is assumed that this farmer also did not anticipate high losses, but likely felt uncomfortable denying that there was at least some nutrient loss happening on their field. The third farmer responded similarly, as well; however, this farmer's response differed in that he expressed more concern than the others that phosphorus leaching in particular might be occurring on their land due to its steep slope and yearly manure applications. Overall though, this farmer was only mildly concerned and did not expect to see problematic losses happening on their field.

<u>Before water quality results - consciousness of relevance to one's behavior</u>

During this stage of the interview farmers were asked whether they thought their farm management decisions might be contributing to nutrient losses on their fields, and responses to this question were mixed. One farmer responded: *"I don't go out there and just spread a bunch of nitrogen...if anything I under apply...I think that phosphates is more easily moved through the tile drains than the nitrates so that's why I said my phosphorus loss might be moderate."*

This response indicated that the farmer believes his farming methods are not contributing to nutrient loss, however, he anticipates that phosphorus will be lost more easily than nitrogen because he believes it moves through the soil more easily. Therefore, they predicted that their phosphorus loss might be greater than their nitrate loss in the preliminary questionnaire (**appendix E**) given to them before the phone interview.

The remaining two farmers responded differently in that they attributed any small potential losses that may be occurring to their own behavior. One farmer mentioned that they have to spread their dairy cows manure on fields that they know are already very fertile simply because weather does not always allow them to take the manure to less fertile fields farther down the road. Additionally, the last farmer mentioned that potential nutrient loss on their field could be the result of them having to incorporate manure every fall due to an informal contract they have with a CAFO they sell silage to. This same farmer also mentioned that: *"there's a small amount of muck ground near that outlet and that's high in nitrogen, and I think that's mother nature and we can't change that."*

This indicates that this farmer partially attributes nutrient losses to farm practices, but also believes that there are some things that are out of their control, such as having muck on their farm that is high in nitrogen content.

<u>Before water quality results - consciousness of one's possibilities (sense of control)</u>

At this time farmers were asked if they believed their current practices were keeping nutrient loss under control, and two farmers felt confident that their farm management was preventing problematic losses, while one farmer was hopeful that losses were low, but had no way of actually knowing this: *"I guess I don't have any way to know if what I'm doing...other* *than what I'm being told...if practices will lower the chances...but as far as raw data coming off that field...you're the first person who has ever helped me do any studies on that."*

This response demonstrates that even though this farmer had good practices in place they still had no way of knowing if those practices were actually effective, giving them little sense of control over the problem at hand.

<u>After water quality results - consciousness of environmental problem</u>

After reviewing the water quality reports with each farmer and discussing the implications of the results there was an obvious shift in how farmers started to perceive nutrient loss on their fields. Each farmer was in some way surprised by what they learned, and became much more aware of how much nutrient loss was occurring on their fields, as well as when the greatest losses were occurring. One farmer was especially surprised by the increase in flow that occurred during the non-growing season: *"I was surprised that there was so much flow in the non-growing season. I mean, I knew there was more, but I didn't realize how much more. I mean it's dramatic, it's huge."*

The remaining farmers were also surprised by what the results showed during the non-growing season, but they were more interested in the nutrient loss that was occurring at this time versus the change in flow rates: *"When the growing season was over it (phosphorus) ran up and you could tell there wasn't anything taking up the phosphorus, or any nutrients at that point."*

This part of the interview revealed that farmers were surprised by the results, and could learn something they would not have known about their fields otherwise. Each farmer was able to gain a better understanding of when they could anticipate the highest losses, and approximately how much they were losing during those times of the year.

<u>After water quality results - consciousness of relevance to one's behavior</u>

After farmers realized when the greatest losses were occurring and approximately how much was occurring, each farmer began to think what they could have done differently the previous growing season to prevent those losses. One farmer admitted that for the first time in many years he had not used a cover crop due to financial reasons, but regretted it after seeing his water quality report: *"from what I see, the data from this year (2018) so far is higher than last year and I attribute that to me not putting a cover crop on that field last fall...yeah, this was the first year in like 5 years that I did not apply cover crops on any of my ground and I didn't think that I'd see a difference but obviously it does make a difference. I knew it was good for the soil and the health and all that stuff and keeping erosion control, but I guess I didn't realize it'd hold nutrients as much as it does...It was purely a financial reason this year...I wanted to do it and I should do it, but when you're coming up at the end and you're in the red it doesn't...ya know... it was one area that I could cut...so I chose to cut it, and I wish I wouldn't have."*

The two remaining farmers also attributed losses to their own behaviors, with one farmer discussing difficulties with getting their cover crop in soon enough to establish a good root system. They believed that this may have impacted why nutrient losses were occurring so much more during the non-growing season. The last farmer brought up what he had suspected in the beginning that applying manure on fields he knew were already fertile was likely contributing to more nutrient loss, but after seeing the data he felt that this was more confirmed.

After water quality data - consciousness of one's possibilities

At this time farmers spent the remainder of the interview discussing specific changes they could make to their farm management that they felt would make a positive impact on water quality. As discussed before, the farmer concerned with applying manure to fields already high in fertility, mentioned that he would try to keep manure off the fields tested during this study because they all showed high phosphorus loss throughout the non-growing season. Additionally, another farmer discussed their options for ensuring that they get a cover crop in every single year despite financial difficulties: *"If commodity prices are low and things are really super tight, or if it means the difference between being able to pay my seed bill or my land payment, or putting on cover crops... well obviously, I'm not going to do something that's optional because my fixed expenses are not optional. I mean I have to pay my bills, but I think what it says to me is that I need to maybe cut somewhere else. Maybe look at the cover crops and the fertilizer placement as…make it more of a priority then it already is and maybe cut something else in my system."*

The remaining farmer discussed how they planned to overcome challenges with getting a cover crop established sooner to ensure it was keeping nutrients in place during the non-growing season which is where they saw the greatest nutrient losses: *"Right, but we didn't plant the rye until probably three weeks after the silage was cut because we were waiting for them to put the manure on because they would then incorporate it. The same time as when we incorporate it is when we planted the rye. So, if it would allow us to immediately plant the rye then maybe we could get a good growth on it, put the manure on in the fall, or do it in the spring, or split it even."*

Overall, these responses demonstrate how different each individual farm is and the variability in adjustments that were discussed as a means for improving water quality. This also verifies the need for less "one size fits all" conservation programs and more which focus on an outcomes-based methodology.

3.2 Farmer-led Watershed Group Survey

3.2.1 Results of Farmer-led Watershed Group Survey

Question:	Min.	Avg.	Max
On a scale of 1-10, how useful do you think this information would be to you for making future farm management decisions related to reducing subsurface nutrient losses?	7	8.375	10
On a scale of 1-10, how necessary do you think this information is for helping farmers to achieve on-farm environmental goals, such as reducing subsurface nutrient losses?	8	9.125	10
On a scale of 1-10, how confident are you that this data is an accurate representation of average nutrient losses throughout the year?	5	6.875	8
On a scale of 1-10, how willing would you be to have this data collected on your own farm?	8	8.875	10
On a scale of 1-10, if results indicated water quality results that concerned you how motivated would you be to implement additional best management practices?	8	8.75	10
How supportive are you of researchers pursuing the development of low-cost equipment that could provide field-specific water quality data to you?	8	8.875	10

Table 7. Farmer Responses to Survey Reported as Minimum, Average, and Maximum.

If equipment could be provided through a cost-share program what is the maximum amount you'd be willing to pay?	Yes - $500, $2500, $1000 No - 4 said no Maybe - 1 said “depends”
Age	56-65 (3), 66 or above (5)
Gender	Male (8), Female (0)
Acres owned	51-100 (2), 101-250 (1), 251-500 (2), 501-750 (1), 751-1000 (2)
Acres rented	0 (1), 1-50 (2), 51-100 (1), 101-250 (1), 251-500 (2), 501-750 (1)

Table 8. Demographic Information of Farmer Respondents & Responses to Future Application Question

3.2.2 Discussion

This survey aimed to understand whether farmers were supportive of using subsurface water quality data as a source of information for making farm management decisions that would likely help them to improve water quality. To determine this a series of questions were asked that related to whether or not they would be supportive of using water quality data for this purpose (their level of trust in the data, whether they thought it was useful, whether they thought it was necessary, etc.).

Survey responses revealed that farmers were generally very supportive of using this form of data. **Table 7**. shows that the average response was above 8 for every single question, except for confidence in the data. Survey responses to this question differed in the survey compared to the interviews because during the interviews each participating farmer said they felt confident that this data was representative of their farm field: *"No I believe in the accuracy 100 percent; you guys have done a very thorough job of analyzing and collecting the data. I mean much more than I expected. I was thinking you'd take a sample here and there and just show me what the results were vs. comparing it to other farmers and analyzing all the practices and everything that goes along with it."*

It is possible that non-participating farmers who completed the survey felt less confident in the data simply because seeing a presentation of what was collected and how it was collected was not as convincing as seeing an in-depth water quality report from their own field. However, this is something that will need to be considered when approaching new farmers with this idea. Overall, though, this survey demonstrates that farmers are very supportive of this approach and would likely use subsurface water quality data to make specific adjustments to their farm management practices.

CHAPTER 4

CONCLUSIONS

4.1 Implications

The results of this study demonstrate the potential of two key approaches to assisting farmers in better meeting on-farm subsurface water quality goals: 1) partnering with local colleges to implement a cost-effective water monitoring program and 2) providing farmers with annual field-specific water quality reports as a form of environmental feedback.

Often, farmers have little to no understanding of phosphorus or nitrate levels coming from their tile drains due to the expense associated with water monitoring; however, the monitoring model used in this study was able to keep expenses low. Through the recruitment of undergraduate students at Adrian College, high labor costs were avoided by hiring students to complete field collections and lab analysis in exchange for university research credits, or through providing free campus housing during the summer months.

The benefits to collaborating with a small or large university in this way was clearly demonstrated through the responses from participating farmers during in-depth interviews, as well as through feedback provided from non-participating farmers through a survey administered at a farmer-led watershed meeting. Using the subsurface water quality data as a source of environmental feedback proved to be very enlightening and useful to the farmers who received a summarized water quality report at the end of this study.

Results indicated that before these farmers had access to field specific water quality data they had very little to no awareness of how much nutrient loss was occurring on their fields. In general, all participants were anticipating some nutrient loss to be occurring, but this was attributed to a mix of factors, including their own farm management decisions, mother nature, and physical land characteristics. As a response to these concerns for nutrient loss, each farmer already had a number of different BMP's in place. Two farmers admitted, however, that they had no idea whether those conservation practices were leading to positive water quality results, but all three participants remained optimistic that they were. Therefore, each farmer felt content with their farm management styles, with the exception of additional BMP's they said they'd be interested in implementing if they felt it was necessary to do so.

Upon farmer review of their water quality reports, though, each participant became increasingly more aware of how much nutrient loss was occurring on their fields. This inevitably led to a more in-depth review of which farming practices were used the previous growing year(s) in an effort to pinpoint what was contributing to what the farmers interpreted as "good" or "bad" water quality results. Each farmer discussed things they could have or wished they had done differently, and because of the information provided to them, they felt more in control of what they could do during the next growing season to lower nutrient loss from their fields.

In conclusion, these interviews revealed something very important to consider moving forward, which is that farmers in this study did not feel it was necessary to adjust land management or implement additional BMP's unless they had information that suggested otherwise. All participants were content with their current management styles and were optimistic that the BMP's they had in place were keeping nutrient losses low. Water quality results from each tile drain, however, showed that three of the five fields studied had DRP concentrations above 0.03ppm greater than 90 percent of the time; and all fields studied had DRP concentrations above 0.03ppm greater than 50 percent of the time.

Additionally, it is important to recognize that each farmer came up with a very different strategy, specific to their farm's needs, in an effort to lower nutrient losses. As Pete Nowak mentions in *The Conservation Journey*, each farm is very diverse both in its physical characteristics and its management (Nowak, 2011), and uniform conservation programs cannot be expected to reduce nutrient losses in the most efficient or effective way. Therefore, the results of this study suggest that in order to better meet watershed water quality goals, such as a 40 percent reduction in total phosphorus loading to Lake Erie, farmers will need field-specific water quality data to better assist them in implementing conservation practices that will be most effective, and for tracking improvements along the way.

It is also anticipated that farmers will be open to using water quality data for this purpose because results from the farmer-led watershed group survey demonstrated significant interest in having access to it, as well as a high likelihood that they would use the information to reach environmental goals through changing practices. This will be important information moving forward as we decide whether farmers would want to use this data as a form of feedback, and how it would potentially impact on-farm conservation decisions if this model were to be used on a larger scale.

4.2 Limitations

As with any case study, the sample size of participants in this work was small. Only three farmers were recruited to receive water quality data from their tile drains; however, this allowed for the collection of more detailed information regarding the way subsurface water quality data impacted each farmers approach to conservation. For example, having a small sample size allowed for more frequent phone calls and visits to be made throughout the year to confirm what farmers were planning to do for that years growing season, and to discuss ways in which their farm management was changing as more water quality data became available.

Another limitation that must be considered is that the participants chosen for this study were not fully representative of farmers within the River Raisin watershed. Although participants represented 100% of field crops grown in this region (corn, soybeans, and winter wheat), there were notable differences amongst participant farmer values compared to other farmers in this region. Each participant was recruited from the same farmer-led watershed group, meaning these farmers were already interested in conservation and looking for ways to reduce their farms impact on the environment. These farmers also had an extensive knowledge regarding which BMPs should be most effective, as well as a shared concern for meeting watershed goals. Therefore, participants may have been more willing to make on-farm changes in response to the feedback provided than farmers who were not members of the farmer-led group.

Additionally, the sample size of farmers who participated in the survey was low. This was due to poor attendance at the spring farmer-led meeting where the survey was distributed; however, of the farmers who attended (eight members) all eight participated in the survey and responded positively to it. As mentioned above, though, these farmer-led group members are not fully representative of farmers residing within the River Raisin watershed. Group members are much more likely to be open to using subsurface water quality data as a form of feedback, as well as being more receptive to the idea of implementing additional conservation practices if data suggests they should. This is because farmers who join farmer-led groups typically do so to learn more about the benefits of conservation, as well as issues within their watershed. Therefore, this study would benefit from testing this methodology on farmers outside of a farmer-led watershed group.

Lastly, it should be acknowledged that due to time constraints, the in-depth interview transcripts were not tested for inter-coder reliability, meaning it is possible that researcher bias is present in the thematic analysis of this study. Recruiting individuals who were disconnected from this study would greatly reduce any researcher bias, and time should be allotted in the future for this task if a similar study were to be completed.

4.3 Future Applications

Since the sample size of this study was small, gaining more farmer input from a variety of farm sizes and farm types would be beneficial in understanding how feedback, in the form of subsurface water quality data, impacts decision making. This can be done in a cost-effective manner using the methods mentioned in this study involving collaboration with nearby universities. This not only offers research opportunities to undergraduate students, but drastically cuts the cost of water sampling when using research credits as a tradeoff for hourly wages.

Another interesting possibility is the idea of using a citizen science approach. This would allow farmers to collect the water samples themselves (after some brief training), and drop them off to the students who will be completing the analysis. This will cut the added cost of travel; however, much more uncertainty will be placed on the quality of the sample received. This may help overcome the barrier, though, of farmers not feeling comfortable with allowing outside organizations to sample from their property.

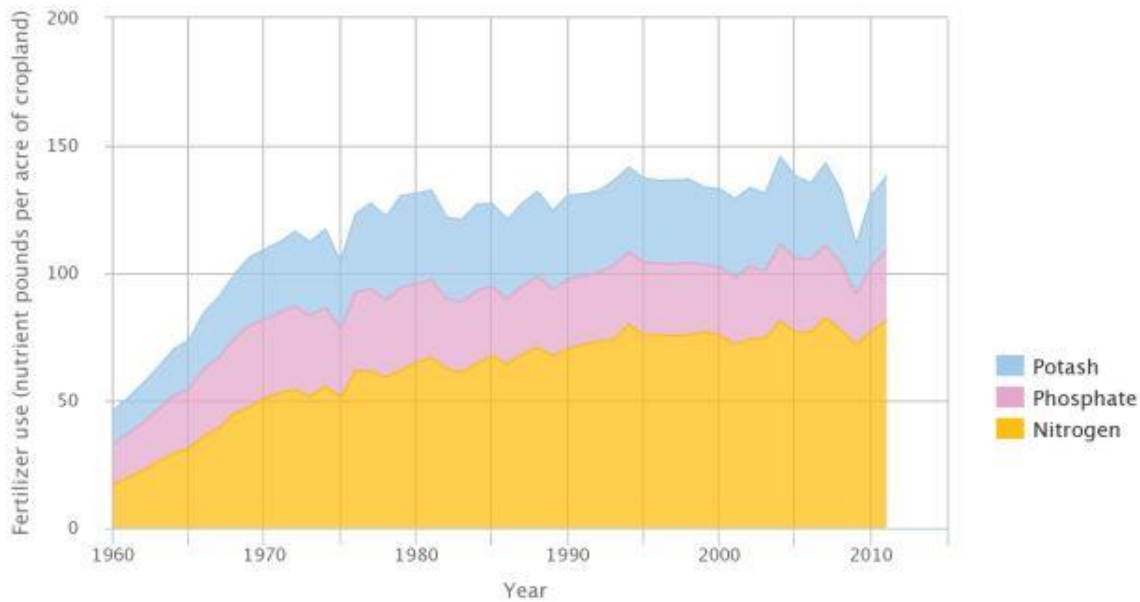
Lastly, it would be beneficial to understand how farmers respond to additional forms of environmental feedback. For instance, providing rainfall data, soil moisture, and soil pH levels throughout the year alongside their water quality data. This would provide a greater understanding of which types or combinations of environmental feedback are most useful to farmers' conservation decision making.

APPENDICES

APPENDIX A:

Commercial Fertilizer Use in the U.S., 1960 – 2011

Exhibit 1. Commercial fertilizer use in the U.S., 1960-2011



Based on sales data. Per-acre use based on the total acreage of harvested or failed cropland, as determined by USDA's National Agricultural Statistics Service.

Information on the statistical significance of the trends in this exhibit is not currently available. For more information about uncertainty, variability, and statistical analysis, view the technical documentation for this indicator.

Data source: USDA ERS, 2013b, 2014

Figure 9. Commercial Fertilizer Use in the U.S., 1960-2011

APPENDIX B:

River Raisin Farm Statistical Data

River Raisin Farm Statistical Data

	Hillsdale	Jackson	Lenawee	Monroe	Washtenaw
# Farms	1530	1073	1618	1144	1236
Acres of land in farms	262,363	183,111	344,347	214,506	170,154
Avg size of farm (acres)	171	171	213	188	138
# beef cattle farms	191	178	124	69	114
# milk cattle farms	85	30	26	6	29
# hogs and pigs farms	48	38	35	37	43
# sheep and lamb farms	87	80	42	39	109
# corn for grain farms	392	305	482	454	294
# corn for silage or greenchop farms	84	41	39	12	54
# wheat for grain farms	141	119	298	206	210
# Full owner farms	1131	741	1088	679	837
# Part owner farms	362	304	414	390	331
# Tenants in farms	37	28	116	75	68
Acres of owned land in farms	77,990	59,081	101,621	52,809	50,808
Acres of rented land in farms	98,329	69,518	133,659	107,720	62,366

Table 9. River Raisin Farm Statistical Data by County. Statistics were taken from the USDA National Agricultural Statistics Service (NASS) database (2012)

APPENDIX C:

Farmer Participant Consent Form

River Raisin Water Monitoring Study
Landowner Participation Agreement

EXPLANATION OF THE RESEARCH and WHAT YOU WILL DO:

You are being asked to participate in a research study of water quality measurements taken directly from tile drains or run-off from your farm fields. This study will be performed in collaboration with the Institute of Water Research at Michigan State University, Lenawee Conservation District, Adrian College and the River Raisin Watershed Council ("Study Sponsors"). Information obtained from the water monitoring will develop a better understanding of nutrient movement (phosphorous and nitrogen) through the soil profile and the effectiveness of best management practices (BMPs). Study sponsors will measure and monitor total phosphorous, soluble reactive phosphorous, nitrate, total suspended solids, pH, dissolved oxygen, water velocity, water height, and water temperature.

You will not be responsible for assisting with any portion of this project other than giving us access to a sampling location on your field. Attached to this consent form is a survey which would give us further insight into farm management practices, but is completely voluntary. If you do not wish to provide information regarding farm management you may refuse to do so at any time.

The success of this study depends on the voluntary participation of landowners willing to provide access to collect water samples. This document describes the scope of farm owner participation in the study and study sponsor commitments in exchange for that participation.

Scope of Farm Owner Participation

By voluntarily participating in this Study, the Farm Owner agrees to:

1. Provide access as described below to the study sponsors to measure and monitor water quality data to meet the study purposes including total phosphorous, soluble reactive phosphorous, nitrate, total suspended solids, pH, dissolved oxygen, water velocity, water height, and water temperature.

2. Consider requests regarding field data (tillage operations, tile drainage systems, etc.) by the study sponsors for additional information that would assist in calculating nutrient loads coming from farm fields for the purpose of improving the understanding of how well BMPs are reducing nutrient losses.

3. The participant will not be responsible for the health or safety of anyone conducting research on their property. In the case of an injury, Adrian College will be responsible for all student interns working for the university.

1

Cell number/Email address of Farm Owner

Access Sites

Please provide the following information for sites to which you are providing access for purposes of this Study. List road crossings near sites that are available to monitor water in rivers, streams, county drains, etc. Please also list if there is access to a farm lane at the various sites. Only fill in as many sites as there are available at farm location.

Site 1

(Please check appropriate) _____River _____Stream _____County Drain ____Ditch ____Lake
Access to farm lane Yes or No (circle one)
Road nearest to surface water____
Nearest crossroad __________________________________

Site 2

(Please check appropriate) _____River _____Stream _____County Drain ____Ditch ____Lake
Access to farm lane Yes or No (circle one)
Road nearest to surface water____
Nearest crossroad __________________________________

Site 3

(Please check appropriate) _____River _____Stream _____County Drain ____Ditch ____Lake
Access to farm lane Yes or No (circle one)
Road nearest to surface water____
Nearest crossroad __________________________________

CONTACT INFORMATION FOR QUESTIONS AND CONCERNS

If you have questions or concerns about this study, such as scientific issues, how to do any part of it, or to report an injury, please contact the researcher:

Alaina Nunn
1405 S. Harrision Rd
101 Manly Miles Building
East Lansing, MI 48823
nunnalai@msu.edu
(517)243-6320

If you have questions or concerns about your role and rights as a participant, would like to obtain information or offer input, or would like to register a complaint about this study, you may contact, anonymously if you wish, the Michigan State University's Human Research Protection Program at 517-

YOUR RIGHTS TO PARTICIPATE, SAY NO, OR WITHDRAW

Participation in this research project is completely voluntary. You have the right to say no. You may change your mind at any time and withdraw. You many choose not to answer specific questions or to stop participating at any time.

Study Sponsor Commitments

In appreciation of your voluntary participation in providing data that will assist in a better understanding of nutrient loading into water sources and the effectiveness of BMPs, the study sponsors commit to the following:

1. Keep farm owner information confidential. Farms participating in this study will be assigned a number. Study farm numbers will be kept separate from farm contact information and physical address of farm. At no point in time will contact information or physical addresses be revealed to anyone but the study sponsors. All information will be kept on password protected computers and inside locked file cabinets. The only information to be made available to the public will be the number assigned to each farm, along with its corresponding data.

2. Prevent the release to third parties of information obtained under this agreement unless the Farm Owner provides permission. Information obtained from the participating farms may be requested by the United States Department of Agriculture, the Natural Resources Conservation Services, and the Michigan Agriculture Environmental Assurance Program to enhance the understanding of the effectiveness of BMPs in controlling nutrient movement from farm fields to water sources. Before releasing such information, study sponsors will seek farm owner permission through a document that describes who is requesting the data, the purpose of that request, and details regarding confidentiality.

3. Provide the farm owner a copy of any monitoring results from his or her farm free of charge. Data will be compiled monthly and sent to farm owners by the first day of the following month. For example, if we begin collecting data once a week starting on April 1st, you will receive results for that month by May 1st.

Farm Owner Information

____

Printed Name

____

Address of Farm Headquarters

____

355-2180, Fax 517-432-4503, or email irb@msu.edu or regular mail at Olds Hall, 408 West Circle Dr, Rm 207, East Lansing, MI 48824.

DOCUMENTATION OF INFORMED CONSENT

Your signature below means that you voluntarily agree to participate in this research study:

____

Farm Owner Signature Date

Your signature below indicates that you are agreeing to be a representative of all study sponsors involved and take full responsibility for keeping farmer information (physical address, name, farm management practices), which is shared amongst other study sponsors, confidential from public view.

____

Study Sponsor Representative Signature Date

____

Printed Name Title Organization

APPENDIX D:

<u>One-on-One In-depth Interview Preliminary Questionnaire</u>

1. Describe what you think the severity of the following issues are on your field. Place an "x" in the box that best describes the level of severity.

	Not an issue	Mild	Moderate	Severe
Dissolved reactive phosphorus leaching through tile drain				
Nitrate leaching through tile drain				

2. On a scale of 1-10, how confident are you that the BMPs you've put in place are helping to achieve water quality results you can be proud of on this field?

Not confident 1 2 3 4 5 6 7 8 9 10 confident

3. According to a 2016 NRCS report, 42% of acres are accounting for 78% of phosphorus runoff and 80% of sediment loss. Do you think it's possible that your field is included in that 42 percent?

a. Yes
b. No
c. I'm not sure

4. Do you think there is anything more you could or should be doing to reduce subsurface nutrient losses and improve water quality?

a. Yes
   Please describe any additional practices you think should be implemented: ______________________________
   ____
   ____
b. No
c. I'm not sure

APPENDIX E:

One-on-One In-depth Interview Question Guide

Phase I - Before Water Quality Data

Consciousness of Environmental Problem

- Please describe environmental concerns that you have on your own farm

Consciousness of Relevance to One's Behavior

- Who or what do you find most responsible for the environmental concerns mentioned above?

Consciousness of One's Possibilities (Sense of Control)

- What do you think can be done to control these environmental outcomes?

Phase II - Review Water Quality Data

Interpretation of Data

- Looking at your results what stands out to you most?
- Would you say you are content or concerned with these results?
- What do you think is the most likely cause of these results?
- Do you trust that this data accurately represents your field?
- Do you think this information is representative of how your farm is managed?

Usefulness of Data

- Was this data useful to you in any way? If so, how? What did you learn from it?
- Could this form of data play into your farm management in some way? If so, how?

Suggestions for Improvements

- What would make this data more useful to you?
- Was information missing that you wish you would've had?

Phase III - After Water Quality Data

Consciousness of Environmental Problem

- After reviewing this data are there any new environmental issues that you are concerned about?

Consciousness of Relevance to One's Behavior

- What do you think is most responsible for your new environmental concerns?

Consciousness of One's Possibilities (Sense of Control)

- Do you feel better equipped with the knowledge necessary to make a more positive environmental impact?
- What do you think can be done to control these environmental outcomes?
- Are there any changes you'd consider making?

APPENDIX F:

<u>Farmer-led Watershed Group Survey</u>

To ensure confidentiality, please do not sign your name on this sheet

This survey is being conducted by a graduate student at Michigan State University. Participation is completely voluntary; however, your insight will provide valuable information regarding farmer support for the continued collection of sub-surface water quality data, which will be discussed in today's presentation. Thank you!

1. On a scale of 1-10, how useful do you think this information would be to you for making future farm management decisions related to reducing subsurface nutrient losses?

   not useful 1 2 3 4 5 6 7 8 9 10 *very useful*

2. On a scale of 1-10, how necessary do you think this information is for helping farmers to achieve on-farm environmental goals, such as reducing subsurface nutrient losses?

   not necessary 1 2 3 4 5 6 7 8 9 10 *very necessary*

3. On a scale of 1-10, how confident are you that this data is an accurate representation of average nutrient losses throughout the year?

   not confident 1 2 3 4 5 6 7 8 9 10 *very confident*

4. On a scale of 1-10, how willing would you be to have this data collected on your own farm?

   not willing 1 2 3 4 5 6 7 8 9 10 *very willing*

5. On a scale of 1-10, if results indicated water quality results that concerned you how motivated would you be to implement additional best management practices?

   not motivated 1 2 3 4 5 6 7 8 9 10 *very motivated*

6. How supportive are you of researchers pursuing the development of low-cost equipment that could provide field-specific water quality data to you?

   not supportive 1 2 3 4 5 6 7 8 9 10 *very supportive*

7. If equipment could be provided through a cost-share program what is the maximum amount you'd be willing to pay? ________________________ (write $0 if you do not want this type of equipment)

8. Please circle your age 18–25 26-35 36-45 46-55 56-65 66 or above

9. Please circle your gender Male Female

10. Acres owned? 1-50 51-100 101-250 251-500 501-750 751-1000 1001-1500 1501 or above

    Acres rented? 1-50 51-100 101-250 251-500 501-750 751-1000 1001-1500 1501 or above

Please direct any questions/comments/concerns to alaina.nunn09@gmail.com

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REFERENCES

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