Impact of Phosphorus Concentrations in Rivers on the NDVI Values of the Surrounding Land Vegetation in Montana

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Abstract

Areas with high levels of agriculture can lead to fertilizer runoff in the surrounding rivers, which can cause high levels of phosphorus, a major component of fertilizer, in the water. In this study, the concentrations of phosphorus in rivers were measured in various locations throughout the regions of Great Falls and Missoula in Montana. Normalized Difference Vegetation Index, NDVI, was used to measure photosynthetic productivity of the vegetation along the riverbanks at each location where samples were taken using an UAV (unmanned aerial vehicle). The aim of this study was to determine whether or not phosphorus concentrations in rivers have an effect on the NDVI values, which indicates plant health, on the surrounding land vegetation. The data collected suggest phosphorus concentration in water had a weak positive correlation with the NDVI values of the land vegetation within 5 m of the edge of the river, although further research would have to take place in order to better investigate this finding as this study only included a small sample size.

Introduction

Fertilizer contamination of surface water, including rivers, lakes, and streams, have become a major environmental issue for bodies of water around large agricultural fields. Nitrogen and phosphorus are essential nutrients for plant growth and nourishment, hence, they are both components of agricultural fertilizer. Therefore, fertilizer runoff into rivers often causes higher levels of nitrate and phosphorus in the water. Fertilizer can runoff into surrounding streams and rivers as a result of a variety of causes. Tilling of agricultural land often leads to loose topsoil. This topsoil can then be transported into surrounding water by wind, farming activities, rainfall, etc. Since this is topsoil from agricultural land, it is often mixed with fertilizer, which includes large amounts of nitrate and phosphorus. Hence, nitrate and phosphorus will build up in water if it is contaminated by this topsoil (Awuchi et al., 2020). Irrigation for agriculture can also lead to fertilizer contamination of water. By irrigating soil excessively, the water being used in irrigation can become polluted. This polluted water can then make its way back into larger bodies of water causing lakes and rivers to become contaminated (Awuchi et al., 2020).

Further, nitrate in the soil can travel to groundwater. In the soil, fertilizer is converted to nitrate by microorganisms through a process called nitrification. Because nitrate is negatively charged, it can reach and contaminate groundwater. Even in ideal conditions, only about 50% of nitrogenous fertilizers are used by plants. Out of the excess, about 2-10% of the nitrate from fertilizers will end up reaching groundwater (Savci, 2012). This groundwater can eventually reach streams, rivers, and lakes, increasing their nitrate levels. Only about 30% of the phosphorus in fertilizers are used by plants, leaving 70% that will either be lost to the atmosphere or immobilized as surplus nutrients in the soil, which can be transported to surface water via runoff from rainwater or wind (Withers et al., 2014). Groundwater stores of these nutrients impact waterbodies long after the fertilizer was initially applied, even as long as 50 years later, by providing a long-term, readily-available source of the nutrients (Withers et al., 2014).

Phosphorus in high levels can become very hazardous to aquatic ecosystems. This is because high phosphorus levels is a major driver of eutrophication, which is the over-enrichment of water with various minerals, including phosphorus and nitrate. These excess minerals lead to an increase in the amount of autotrophs in the aquatic ecosystem, specifically algae and cyanobacteria. As organisms such as these die, they take up the dissolved oxygen in the water as they decompose, leading to low levels. Low levels of dissolved oxygen in the water can be extremely hazardous to many aquatic organisms such as fish who depend on dissolved oxygen for respiration. This lack of oxygen thus can cause large-scale fish kills, releasing phosphorus which is normally bound to bottom sediments, reinforcing eutrophication (Correll, 1998).

In addition to environmental concerns, nitrate contamination of groundwater can also be very problematic for human health. This is because when nitrate contaminated drinking water, it can have multiple negative effects on human health. For example, high levels of nitrate can lead to methemoglobinemia in infants under six months of age (Spalding and Exner, 1992). Methemoglobinemia is a condition in which there is a higher-than-normal amount of methemoglobin in the blood, causing tissues to not be able to get enough oxygen, which can lead to death (Johnson, 2019).

There are multiple studies that assess the impact of nitrate and phosphorus on aquatic plants, such as a 2003 study by Grinnell College in which it was found that both nitrate and phosphate positively affect the growth of algae species (Fried et al., 2003). There are also studies on how phosphorus impacts land vegetation, such as one study that found that phosphorus levels have an effect on sugar beet plants in multiple ways, one of which included increasing photosynthetic productivity (Terry et al., 1974). Although a lot of research can be found about how nitrate and phosphate affects the plant life in the water, there is not a lot of research available about how fertilizer contamination in rivers can affect the vegetation on the surrounding riverbanks. A popular way to monitor land vegetation productivity is by taking Normalized Difference Vegetation Index (NDVI) images. NDVI is calculated as the ratio between the amount of red (R) and infrared (NIR) light being reflected by an object. The more photosynthetically productive the plant is, the more NIR light being reflected when compared to the amount of red light being reflected, and the higher the NDVI value is (Huang et al., 2020). NDVI images are often taken with satellites or unmanned aerial vehicles (UAVs) to evaluate the health of plants over large areas. Taking NDVI images from above allows the photosynthetic productivity of trees to be assessed since the satellites and UAVs are imaging the canopy of the trees. Using UAVs are beneficial as they can provide more precise data since they are a lot closer to the vegetation being imaged when compared to satellites. Drones are also not as impacted by cloud cover, since they are closer to the earth and therefore under most clouds.

In Montana, USA, there are multiple major rivers, such as the Missouri River, the Yellowstone River, the Bighorn River, the Blackfoot River, the Bitterroot River, the Clark Fork River, as well as many others. Regions of the Rocky Mountains can be found in Montana, leading both mountains and valleys to be found in the state. Different types of vegetation will grow in Montana depending on the type of terrain. Near bodies of water, native plants such as western wheatgrass, beaked sedge, inflated sedge, creeping spikerush, and cattail may be found, according to a Montana field guide by David Webmaster.

In order to test the impacts of fertilizer contamination of rivers on the surrounding land vegetation, an unmanned aerial vehicle (UAV) was used to take NDVI images of land vegetation along rivers around Missoula, MT, and Great Falls, MT. Using water samples and NDVI images, it was evaluated whether or not high levels of phosphorus in rivers, which could be caused by fertilizer contamination, have an impact on the photosynthetic activity of the surrounding land vegetation. It was predicted that if phosphorus positively affects the growth of plants, then plants along the banks of rivers with higher levels of phosphorus and nitrate will have higher NDVI values, indicating healthier vegetation. As shown in Figures 1.1 and 1.2 there are farms upstream along 6 of the 8 locations, which are shown in more detail in figures 2.2 - 2.9, tested in the 2 to 3 km range surveyed. This could have played a significant role in the phosphorus connotations found in these rivers and therefore the NDVI values of the vegetation along the banks of these rivers.

Methods and Materials

Eight different locations in Montana along both major rivers and smaller creeks were chosen to conduct 2 main tests. Four of these sites, Wing Dam Fishing Access Site (FAS), Largent Bend FAS, Chaos Bridge FAS, and Neihart Cemetery are located near Great Falls, MT, along the Missouri River, Sun River, Smith River, and Belt Creek, respectively. The other four, Lolo Creek Campground, Marco Flats FAS, Kelly Island FAS, and Florence Bridge FAS, are near Missoula, MT located on the Lolo Creek, Blackfoot River, and Bitterroot River, respectively. The eight locations are pictured in the context of Montana in Figure 2.1, and individually in Figures 2.2 - 2.9.

Great Falls and Missoula have different types of vegetation and land features which allows for comparison and compilation of data that represents a much larger region of the state. Additionally, each site in those cities is located in different areas to allow for even more diversity and samples, even if they are along the same river. A different location was traveled to each day.

Figure 1.1, Farms located upstream from the sites in Great Falls are highlighted in yellow. Farm runoff could be a reason for higher phosphate levels in the tested areas.

Figure 1.2, Farms located upstream from the sites in Missoula are highlighted in yellow. Farm runoff could be a reason for higher phosphate levels in the tested areas.

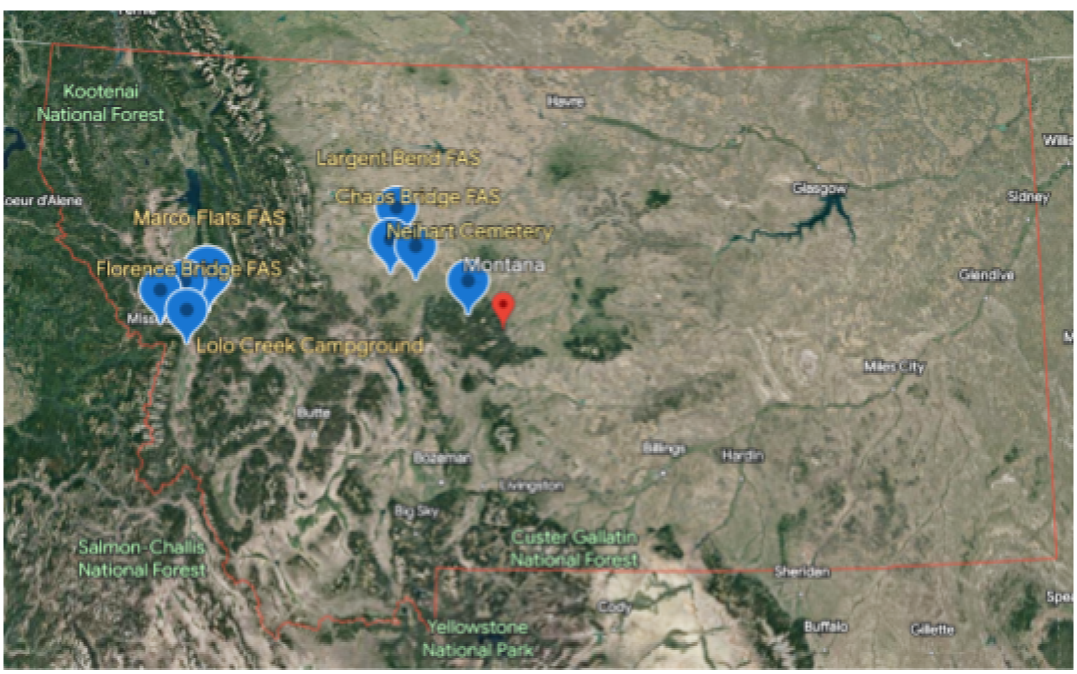

Figure 2.1, The eight research sites, located in Montana

Figure 2.2, Wing Dam FAS in Cascade, MT.

Figure 2.3, Largent Bend FAS near Vaughn, MT.

Figure 2.4, Chaos Bridge FAS near Eden, MT.

Figure 2.5, Neihart Cemetery in Neihart, MT.

Figure 2.6, Lolo Creek Campground in
Lolo National Forest, MT.

Figure 2.7, Marco Flats FAS near Bonner Junction, MT.

Figure 2.8, Kelly Island FAS in Missoula, MT.

Figure 2.9, Florence Bridge FAS in Florence, MT.

Data collection near Great Falls

Date	Location
May 19th	Wing Dam FAS
May 20th	Largent Bend FAS
May 21st	Chaos Bridge FAS
May 22nd	Neihart Cemetery

Data collection near Missoula

Date	Location
May 26th	Lolo Creek Campground and Picnic Area
May 27th	Marco Flats FAS
May 28th	Kelly Island FAS
May 29th	Florence Bridge FAS

Table 1: Data collection dates and locations

At each location, shown in Table 1, two related experiments were conducted. First, there was an experiment to test for phosphorus concentrations in the river. To do this, LaMotte phosphorus testing tablets that come in the LaMotte low cost water monitoring kit were used. To use the phosphorus testing tablets, 10 mL of the river water is collected in a glass vial. Then, 1 tablet is added to the water sample and the vial is capped. Both samples are mixed by inverting the vile until the tablets are totally dissolved, which takes around 2 min. After the tablets are dissolved, a 5 min wait period is required before running the sample through the spectrometer, which would create an absorbance versus time graph at the wavelength of 805.8 nm through LoggerPro software. This method was used to take three samples of water from each location each day. Each sample was from a different location along the river that can be accessed at the sites. These values will be compared to an equation established by taking the absorbance of solutions with known nitrate and phosphorus values.

To make this graph, a prior lab experiment was conducted to determine the absorbance at a specific wavelength of solutions with known contractions of phosphorus. To choose the wavelength to monitor, a spectrometer and LoggerPro were used to experimentally determine the wavelength with the highest level of absorbance of the solution that was most concentrated with phosphorus, and therefore the most pigmented. By using this method the wavelength chosen to monitor was 805.8 nm. The absorbance at 805.8 nm of solutions with phosphorus concentrations of 0 ppm, 1 ppm, 2 ppm, 3 ppm, 4 ppm, and 5 ppm were taken. Then, these values were graphed using excel, which can be seen in Figure 3. A trendline was then fit for the data, again by using excel. The best trendline fit for the data that was offered through excel was a cubic function, so a cubic function was empirically fit to the data set. This function was then used as the calibration curve. In order to convert the measured absorbance values into phosphorus concentrations, the absorbance values were plugged into the y-value of the cubic function and then the x-value, which would be phosphorus concentration, was solved for.

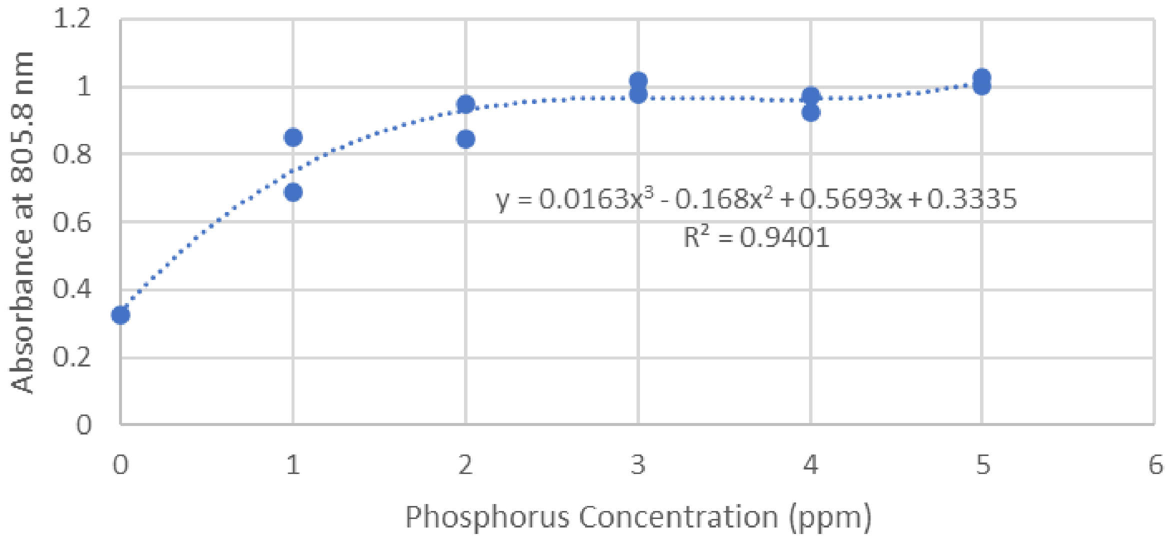

Figure 3, This graph displays the relationship established through a lab experiment of Phosphorus Concentration in ppm vs the absorbance at 808.5 nm.

Secondly, The average NDVI value of the surrounding area next to the rivers was determined. In order to collect this data, the Swellpro Splash Drone 4 (Figure 4) was flown manually along the edge of the bodies of water, to ensure that images captured were of the same areas where water sampling occurred. Equipped to the UAV was the SENTERA Double 4K Inspection Sensor AG+ (Figure 5), which takes both RGB and NIR (Near Infrared) images. For this experiment, five points were chosen at each location to collect images from, with the three middle points being where samples were collected from. For the majority of flights, the drone height was 30m, though some locations required a greater height in order to avoid taller trees in the flight zone. Since the NDVI data can be very skewed by differing levels of light, shadows, cloud cover, and angle of the sun due to time of day, at each location a calibration image was taken, an example of which can be seen in Figure 6. The calibration image uses several sheets of colored construction paper of which the reflectance values were predetermined after a prior experiment. The code developed in order to create the NDVI images used those values and compared them to the values in the calibration image in a graph (Figure 7). The slope of the line of best fit was stored and later used to adjust the actual images.

Once each flight was completed, the RGB and NIR images were transferred onto a computer to be used in creating NDVI images. This is done using a macro code developed for this experiment through the program ImageJ, an image processing software, as seen in Figure 6. The code used the NDVI formula shown in Figure 8, along with the necessary Red and NIR color calculations needed as outlined in the "Sentera Double 4K Multispectral - NDVI and NDRE Calculations Doc # 27063 Rev A".

Figure 4: The Swellpro Splash Drone 4 was used for all flights while collecting NDVI data

Figure 5: The Sentera Multispectral Camera was attached to the UAV and took the necessary RGB and NIR images

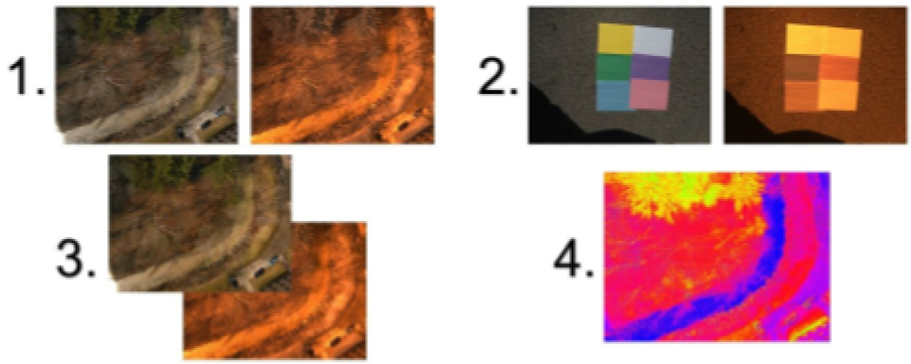

Figure 6: Overview of the code used to create NDVI images in ImageJ
1. Matching RGB and NIR Images are opened in ImageJ.
2. Each color paper is selected on the calibration image and adjusted based on the light. This adjustment value is stored.
3. The matching images are aligned due to the slight differences in camera location.
4. Using the adjustment values and NDVI formula, and after applying the LUT, a color NDVI image is created.

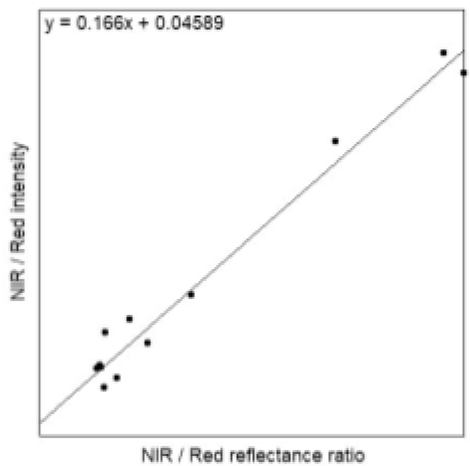

Figure 7: An example calibration graph. The y-axis is the measured values from the calibration image, and the x-axis is the predetermined reflectance values. Since they are unequal, the slope of the line of best fit is used to adjust the images in the set so the color is correct and constant between research days.

$$\frac{\textbf{NIR - Red}}{\textbf{NIR + Red}}$$

Figure 8, NDVI Formula

Once the code finishes running, two sets of images are created, one color image created using a look-up table (Figure 9) to assign each NDVI value a color as seen in Figure 10.1. Secondly is a “raw” NDVI image in grayscale. While the color image is helpful in visualizing the health of the area, by using the measure function on ImageJ the exact NDVI value of an area can be determined using the raw data. Because this experiment only seeked to look at vegetation health of areas directly along the water’s edge, the only measured area was vegetation within 5 meters of the river, by using the set scale feature on ImageJ to convert pixels to meters. The outline created using the freehand draw tool is shown in yellow in Figure 10.2.

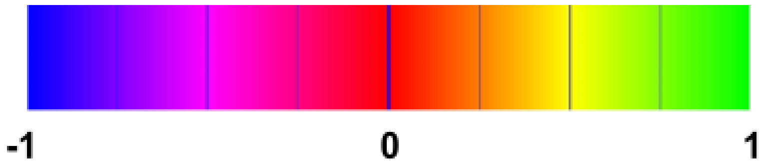

Figure 9, This Look-Up Table (LUT) was used in the color NDVI images to more clearly display the differences in values

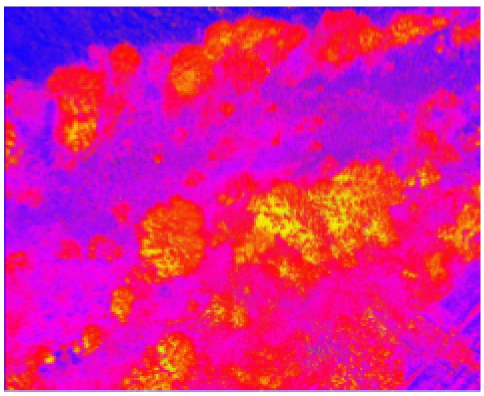

Figure 10.1, NDVI Color Image created with a LUT

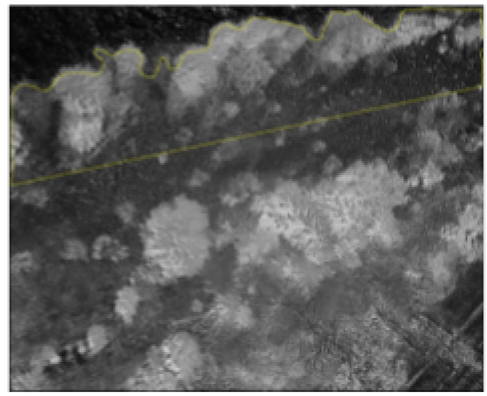

Figure 10.2, NDVI Raw Image with Outline showing the measured area

Results

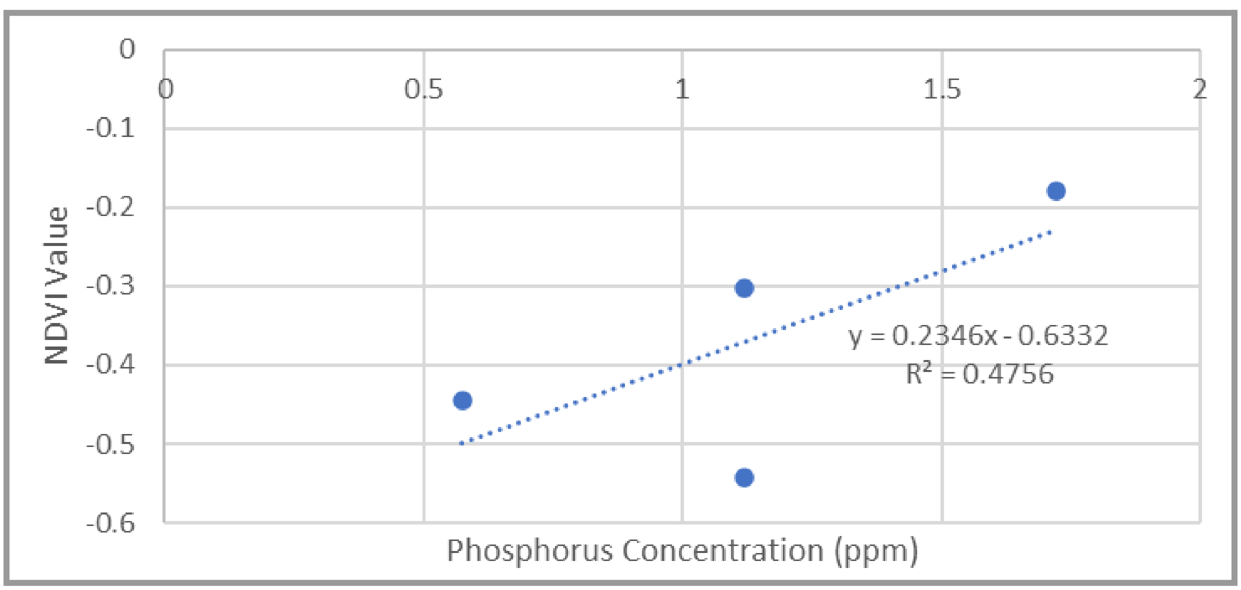

Figure 11, Relationship between phosphorus concentration and NDVI values in Great Falls, Montana.

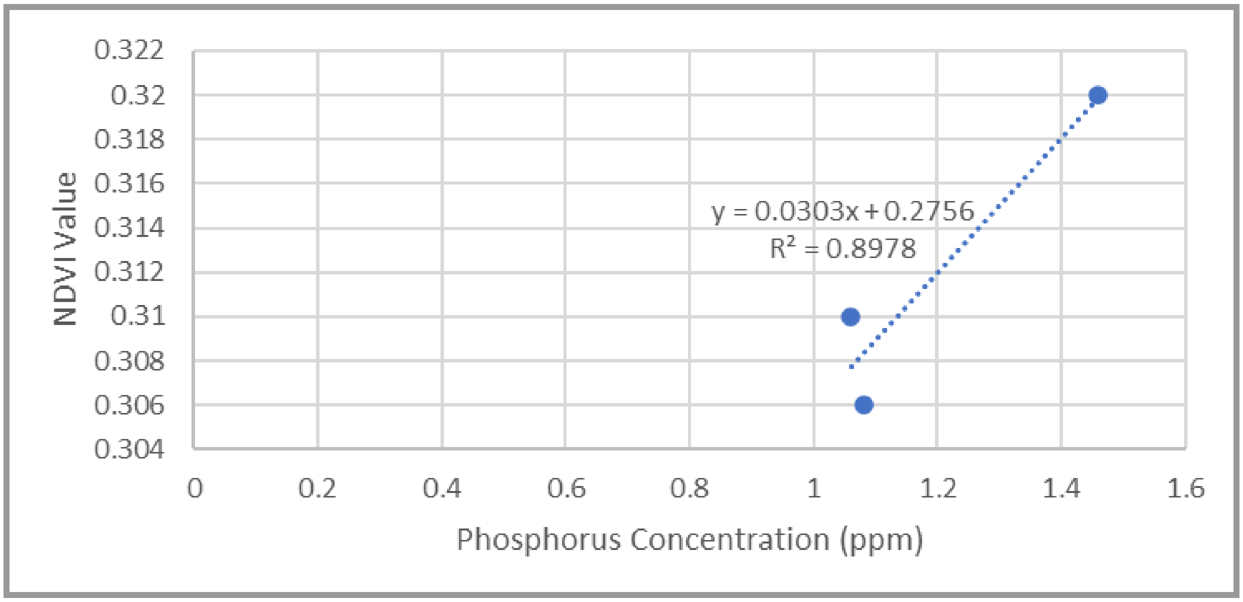

Figure 12, Relationship between phosphorus concentration and NDVI values in Missoula, Montana.

The Great Falls and Missoula data were separated, the reason to separate these data sets rather than compare them together is because overall all of the Great Falls average NDVI values were negative and all of the Missoula average NDVI values were positive. This indicates that there were most likely other factors influencing these NDVI values rather than just nitrate and phosphorus concentrations. One factor that could have caused this variation between Great Falls and Missoula NDVI values is the weather. Average temperatures and precipitation has been linked to affecting NDVI values, with higher temperatures causing higher NDVI values (Ghebrezgabher et al., 2020). Since Missoula and Great Falls had different weather patterns and data collection around each city began a week apart from each other, varying weather could have had substantial effects on average NDVI values. Great Falls and Missoula also have different elevations, which can also affect NDVI values (Li et al., 2015). Therefore, in order to try to compare the data and determine trends with as few outside variables as possible, it is better to compare the Great Falls and Missoula data separately. Example images from both sites can be seen in Figures 13.1 and 13.2.

The data collected at Florence Bridge in Missoula was omitted as an outlier, leaving only 3 data points for Missoula. The reason that the data from Florence was omitted as an outlier was because the average absorbance value at this location was 1.08, which was over 0.1 above all of the other data points. According to the calibration curve, an absorbance of 1.08 would indicate a phosphorus concentration of 5.42. This is higher than the equipment is reliably capable of measuring, as the original color chart of the testing kit only went up to 4 ppm. It can also be seen in the calibration curve that concentration values of roughly 3 ppm and above are nearly indistinguishable from each other, making the testing tablets unreliable for accurately predicting phosphorus concentration values. For this reason, the Florence data outlier, which would have caused the Missoula best fit line slope to be negative, was chosen to be omitted from the data set.

In Great Falls, the phosphorus concentration had a positive correlation with NDVI values with a slope of 0.23 and r-squared value of 0.48. In Missoula, the phosphorus concentration had a positive correlation with NDVI values with a slope of 0.030 and an r-squared value of 0.90.

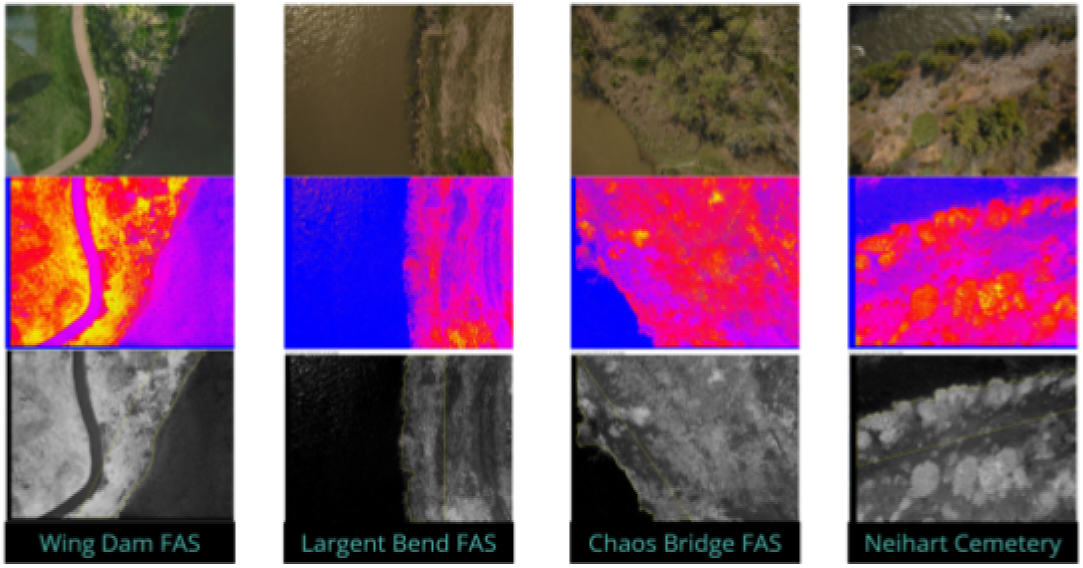

Figure 13.1, Example images from Great Falls. For each site an RGB image of the land, a color NDVI image, and a raw NDVI image with the selected measurement area are shown

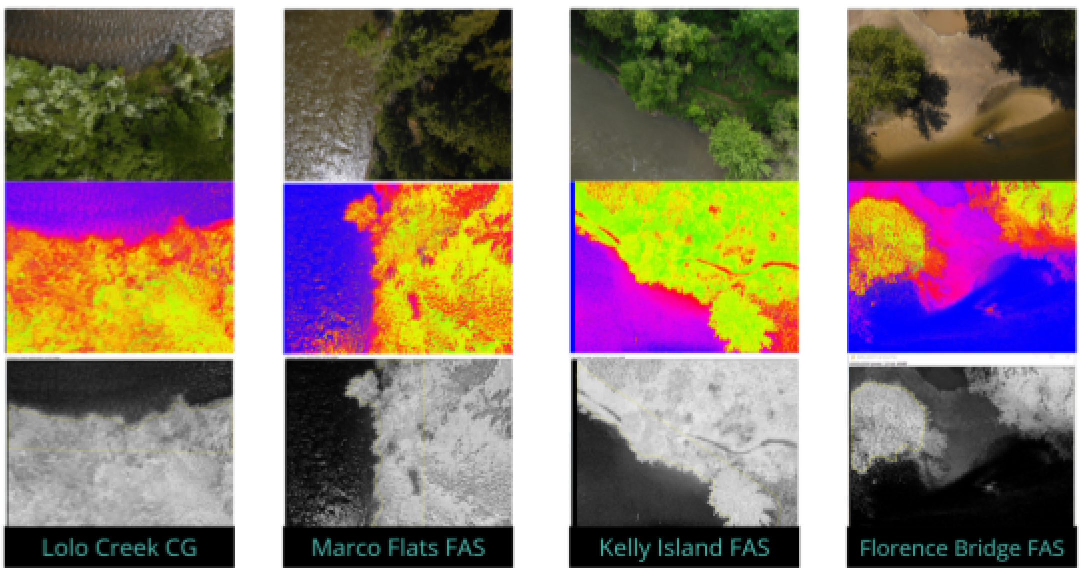

Figure 13.2, Example images from Missoula. For each site an RGB image of the land, a color NDVI image, and a raw NDVI image with the selected measurement area are shown

Discussion

The data shows a possible positive correlation between river phosphorus concentrations and the average NDVI values of the surrounding land vegetation 5 m away from the river's edge. However, more data would need to be collected in order to further establish this correlation, since this study had a very small sample size, with only 4 locations being analyzed in the Great Falls, MT region and only 3 locations being analyzed in the Missoula, MT region.

There are multiple limitations to this study which could have affected the data collected. Since the data was done outside and not in a lab, there were multiple variables that could not be controlled. Some of these variables include weather patterns, elevation, human activity, time of day, and type of vegetation. Different weather patterns have been shown to impact NDVI values, such as the air temperature (Ghebrezgabber et al., 2020). Time of day and cloud cover could have an effect on NDVI values as this can impact the amount of sunlight reaching the surface of the earth, hence impacting the amount of sunlight that can be reflected, changing the NDVI values. Although the calibration is meant to help counteract this issue, the calibration is not always perfect and therefore sunlight can still be a variable in the data. Different vegetation types were also found at different locations, which could also have an impact on the data. Further, since many of the sites in which data was collected were fishing access sites, human activity could have also had an impact on the type, amount, and health of vegetation along the shoreline, all of which can also have had an effect of the data collected in this study.

In the future, another study similar to this could be conducted to either help further establish a more accurate relationship between water phosphorus concentration and NDVI values of the surrounding land vegetation. Other nutrients important for plant health that are dissolved in the rivers could also be tested for and analyzed in a similar way to phosphorus in this study, such as nitrate. Further, a more controlled lab experiment could be conducted in which many of these studies limitations, such as temperature and vegetation type, are controlled allowing for a more accurate representation of how river nutrient concentrations affect NDVI values of surrounding land vegetation by limiting the amount of outside variables. Through all of these methods, more information can be gained on how water nutrients, and therefore water pollutants, affect land vegetation, allowing for a greater understanding of how the environment can be greater protected in the future.

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Budget

Swellpro Splash Drone 4 Filming Edition	**$2,498.00**
2pcs extra drone batteries	**$498.00**
2 pairs of extra propellers	**$70.00**
Sentera Double 4K Multispectral Camera AG+	**$3,499.99**
LaMotte TesTab Refills Nitrate	**$15.20**
LaMotte TesTab Refills phosphorus	**$15.95**
Go Direct SpectroVis Plus Spectrophotometer	**$449.00**
Earth Force Low-Cost Water Quality Monitoring Kit	**$48.25**
Total	**$7,144.39**