An In-depth Analysis of the Mokelumne River Water Quality Near Lodi Lake

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ABSTRACT

Water pollution and its effects are a rising global issue, especially in the Central Valley of California. The Mokelumne River is a member of the Sacramento-San Joaquin Delta system in which pollution and declining water quality has become a major risk. This multi-faceted river system feeds Lodi Lake, canals used for irrigated agriculture, and provides a home for recreational users and endemic species alike. To ensure the water quality is being monitored, the Storm Drain Detectives program was created in 2001. The SDD are a group of teachers, students, and community members that monitor the Mokelumne River monthly at several different sites where stormwater enters the river. Using the SDD data and discharge/flow data from the US Geological Survey, I analyzed the overall water quality over the last two decades. Water quality fluctuated greatly during the study period, but overall, has declined over the last number of years. This was indicated by rising pH, rising annual temperatures, increased electrical conductivity and increased nitrate contamination. The only variables indicating any water quality recovery were decreased measures of turbidity and steady dissolved oxygen content. Additionally, drought had significant negative impact on water quality, having affected five out of six of the water quality variables, nitrate contamination being the only exception. Lastly, the land cover change analysis revealed significant increases in agricultural and urban sprawl, both factors that could contribute to declining water quality in the Mokelumne River.

KEYWORDS

Nitrate contamination, land cover change, drought severity, water pollution, community involvement

INTRODUCTION

There are significant inputs of pollution to waterways in California, as well as variables that confound its effects. Tracing the path of these different pollutants in groundwater and soils indicates that numerous chemicals identified in fertilizers and pesticides used throughout the agricultural process are polluting our waters (Kumazawa 2002). These pollutants have the potential to cause harm to the entire ecosystem from top to bottom. Studies show pollutants having negative effects on fish populations (Tiwari et al. 2017), causing algal blooms, habitat destruction from sedimentation, and poisoning populations of people and other wildlife (Akpor et al. 2014). Pollutants in our natural bodies of water vary in number. Multiple different types of pollutants were found in the waters of the Central Valley in California (Weston et al. 2004), more specifically in the San Joaquin Valley (Saiki et al. 1987). The contamination of rivers and streams is a growing concern, especially in the Central Valley, where immense amounts of freshwater are used for irrigation and agriculture.

The Mokelumne River is a member of the Sacramento-San Joaquin Delta system that stretches 95 miles from the Sierra Nevada's down through the Central valley of California. It is a vital component contributing to the health of the surrounding ecosystem. The river is a breeding ground for several endemic fish species, a freshwater source for farms and landowners, and a playground for families. The river flows through Lodi, California, and stretches into farther towns (Ahearn et al. 2005). The Lower Mokelumne River, flowing below the Camanche Dam is an important irrigation source as well as a supplier of water to the San Francisco Bay Area. It is vital for farmers and consumers alike and the misuse of our natural sources of water has caused irreparable damage to the ecosystem (Fredenburg 2012). Unfortunately, the Mokelumne River is vulnerable to numerous modes of pollution through runoff. Heavy metal contamination from wastewater is a leading cause of degradation of plant life, animal health and a concern to human health (Akpor et al. 2014). In California, almost 400 rural towns have no access to clean water due to nitrate pollution, a major nonpoint source of pollution diminishing water quality and byproduct of using fertilizers and manure in agriculture (Dowd et al. 2008). From runoff and trash, to uses of pesticides, herbicides and fertilizers, the Mokelumne river is under extreme pressure and water monitoring is needed to ensure that water quality does not suffer due to anthropogenic inputs.

A staggering 51% of the Mokelumne's surrounding land-area is cultivated for vineyards. Throughout the growth of grapes in these vineyards, heavy amounts of pesticides are used, with sulfur as the main culprit (HDR 2015). In an effort to assess and ultimately mitigate the negative effects of runoff and water pollution, the City of Lodi, Public Works Department established Storm Drain Detectives (SDD). The SDD are a group of teachers, students, and community members that monitor the Mokelumne River monthly at several different sites where stormwater enters the river. Using water quality tests, visual assessments, and toxicity tests, the Storm Drain Detectives collect and record data to analyze the effects that storm drain runoff has on the river. Yearly, the participants in SDD summarize the data and analyze and assess the overall health of the river. However, they have never done a long-term analysis of the collected data, only analyzing yearly snapshots in time. A long-term analysis is necessary to address larger trends sometimes lost in small-scale analysis such as the overall changes in water quality in the last twenty years. When assessing the overall health of an ecosystem, it is important to understand trends over time. In addition, the San Joaquin County Resources Conservation District requires farmers to test their impacts on the Mokelumne to attain the proper permits. The SJCRCD started the Lower Mokelumne River Watershed Stewardship Steering Committee which is responsible for educating and enforcing an individual responsibility to maintain and improve the Mokelumne. It is these essential community engagement programs that are responsible for the future health of California's waterways, specifically the Lower Mokelumne River.

The central research question for my study is centered around identifying trends of water quality in the Mokelumne River through a smaller, more focused study using previously collected data. This study aims to answer the following questions. **CRQ:** What is the overall health of the Mokelumne River near Lodi Lake and how has it changed? **SQ1:** Over the last two decades, how has water quality changed in the river? **SQ2:** What are the effects of drought on water quality in the Mokelumne River? **SQ3:** How has the landscape changed over the last two decades?

I hypothesize that over time, water quality has decreased significantly in the Mokelumne River. The surrounding land is used for agriculture, allowing for the possibility of runoff carrying harmful pollutants. In addition, Lodi Lake is surrounded from the south by the entire city of Lodi, increasing the likelihood of pollution from large runoff events from the urban landscape. Drought has a significant impact on water supply and quality. I predict that in years of drought, the water quality in the Mokelumne River will be far worse than in years without drought. This is because drought exacerbates the effects of pollution and has its own negative effects on water quality. Historically, agriculture is one of the major nonpoint sources of pollution to water supply, and I predict this will be no different in the Mokelumne. Through the application of pesticides and herbicides, runoff from farmland could potentially carry harmful chemicals into the water supply. Irrigated agriculture is a prime mode of agriculture surrounding the Mokelumne River, where flowing water is diverted into hundreds of canals, which can also disrupt ecosystems and negatively impact water quality.

METHODS

Study site description

The study site is located in Lodi, California and includes locations surrounding Lodi Lake and the Lower Mokelumne River. Lodi Lake is a man-made lake located at the heart of Lodi, California. The SDD data was collected at several different storm drain sites that empty into the lake and Mokelumne River. The Mokelumne River is 95 miles long and stretches from the Sierra Nevada's, south through the Central Valley. The river is divided into two sections, the Lower Mokelumne River and the Upper Mokelumne River. My study focused on the Lower Mokelumne River. Lodi Lake is fed by the Mokelumne River. The lake is drained annually in order to maintain the Woodbridge dam and clean up the lake. Both bodies of water are home to several endemic fish species. The lake and river are sites for recreation including boating, fishing, swimming and many more activities.

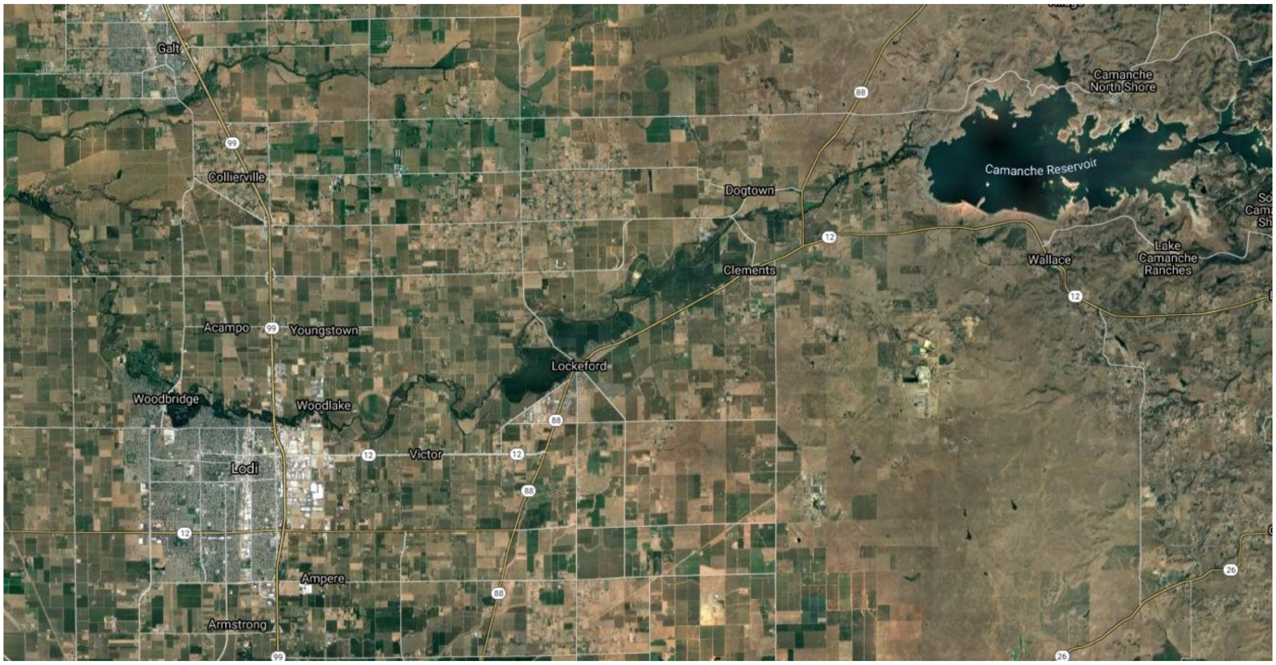

Figure 1. Satellite image of the Lower Mokelumne River and the city of Lodi

Storm Drain Detectives data collection

The SDD are a group of teachers, students, and community members that monitor the Mokelumne River monthly at several different sites where stormwater enters the river. Using water quality tests, visual assessments, and toxicity tests, the Storm Drain Detectives collected and recorded data, dating back to 2001, and analyzed yearly trends in the river. The participants in SDD have summarized the data every year and performed an analysis to assess the overall health of the river but have not assessed long term trends in data or interannual variation. These measures include pH, temperature, Dissolved Oxygen content, turbidity, electrical conductivity, and Nitrate concentration. I transcribed the data from their reports into a spreadsheet for long term analysis.

Using the Storm Drain Detectives data

I used the Storm Drain Detectives data to help answer my first two objectives. To answer Sub-question 1, I looked at the data from the founding of SDD (2001) to 2021. In order to visualize trends in the data, I took each of my variables, subset by Site No., and graphed against Date on the x-axis. From here I was able to identify trends in the data. Once the graphs had been created, I fit a line indicating rate of change to visualize the change over time. I also performed a repeated measures ANOVA test and assessed relationships among my variables that may have affected these results. Primarily, the ANOVA test was used to determine the statistical significance of my variables' relationship with date and season.

To answer Sub-question 2 regarding drought, I created a drought severity number using Flow Data from the US Geological Survey (USGS) database and a linear model analysis in R. I calculated the mean flow by day of year and divided this number across each flow measurement taken over the last 20 years to assess drought severity. This value was then used in my linear model to test statistical significance of drought on my variables. The linear model determined if drought had a significant impact on the fluctuations in water quality variables taken by the Storm Drain Detectives.

Supervised Classification in Google Earth Engine

Google Earth Engine combines a multi-petabyte catalog of satellite imagery and geospatial datasets with planetary-scale analysis capabilities to detect changes, map trends, and quantify differences on the Earth's surface. I used Google Earth Engine to produce several images of the landscape of the Mokelumne River and surrounding area. These images were taken from the years 2001 and 2020 from the Landsat 7 Satellite. For both images, I completed a supervised classification of the landscape. This image classification highlighted the image by different land-use classes that were inputted and mapped by hand. From here I had two images I qualitatively compared for change over the last two decades surrounding the Mokelumne River, with a focus on urban and agricultural expansion.

RESULTS

PH change

The study showed that pH varied from year to year, with a steady increase seen over the entire study period across all sites (Figure 2). It is important to note the small gaps in data clearly visible at Site 2 from 2018 to 2020, Site 5 from 2010 to 2015, and Site 9 from 2017 to 2019. Despite these gaps in the data, the rate of change at all three sites is consistently increasing and positive. In addition, following the gap in data at Site 5, average pH had increased from 7.3 to 7.7, following the same trend as all other sites and increasing in pH at the end of the test period. Site 8 had the highest mean pH at the end of the study at 7.73. A repeated measures ANOVA test was performed to assess the relationships between my variables. The ANOVA test revealed that the only variables with any relationship with pH were Date and Season, where there was a statistically significant increase in pH as date increased, or as time went on, as well as the seasons cycled. Seasonality did not contribute to pH change as significantly as date, but the post-hoc test revealed the season contributing most to pH change was the winter season.

Figure 2. PH Change over Time. All data taken by the Storm Drain Detectives from the City of Lodi online archives. The sample size was 450 measurements taken over the span of 20 years. PH increased across all sites throughout the study period. The ANOVA test revealed the winter season (p-value: 0.00243) was having the most significant effect of pH.

Temperature

Temperature exhibited change at both extremes of yearly season fluctuation with minimum and maximum yearly temperatures changing dramatically. Temperature fluctuations over time remained relatively constant, increasing and decreasing with the changing seasons. Over the study period, the minimum temperature reached per year remained relatively constant over time, however the maximum temperature reached per year increased significantly at sites 2, 8 and 9 (Figure 3). Maximum temperature spiked significantly from 2010 to 2015 across all sites where temperature increases of nearly 10ºC can be seen at sites 1, 2, 8, and 9(Figure 3). There was less fluctuation in terms of minimum temperature reached throughout the year, however, the trendline shows a steady increase throughout the study period. Site 8 showed the highest increase in temperature fluctuation as well as the widest range of temperatures measured. Site 5 exhibited no significant change following the gap in data. The steady increase in maximum temperature recorded at Site 9 is also evident when graphing temperature changes over time (Figure 4). Additionally, I graphed temperature change over time with a line indicating rate of change throughout the study period. The graphs are difficult to visualize without a trend-line due to seasonal fluctuations and yearly ranges in temperature change. Temperature increases overall were small across most sites. All sites trended upward, however, Sites 2 and 9 exhibited the fastest rate of change throughout the study period. An ANOVA test was performed and found that similar to pH, seasonality and date had significant relationships with temperature change. As time went on, temperature increased overall (Figure 4).

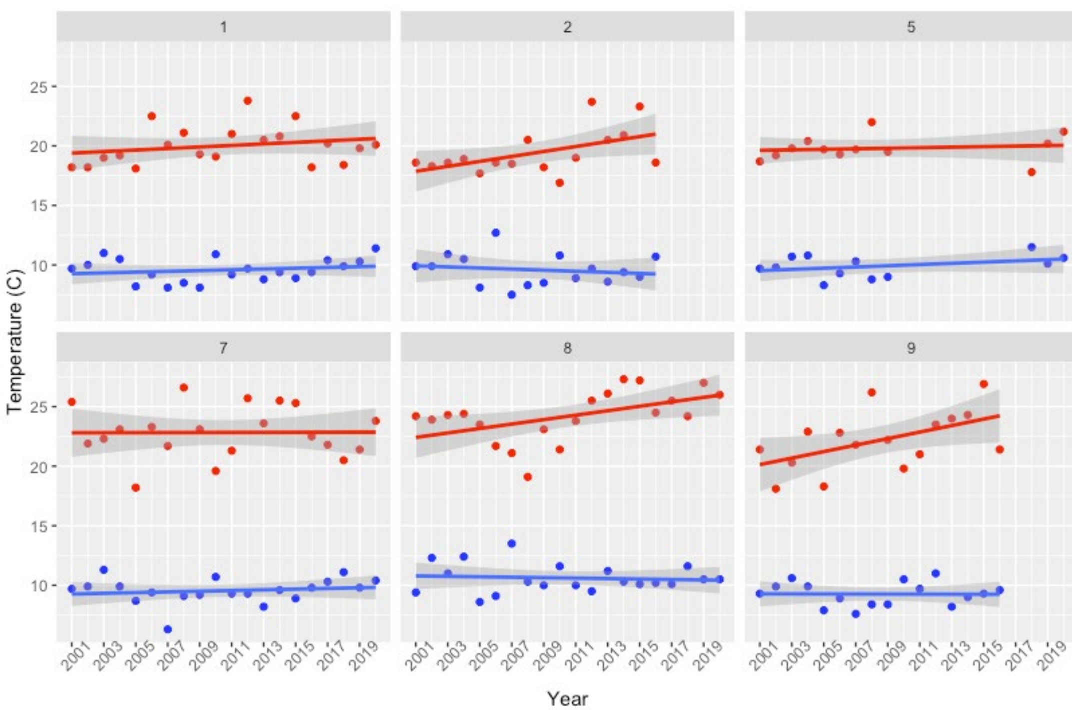

Figure 3. Maximum Annual Temperatures. Maximum temperatures are highlighted in red while minimum temperatures are highlighted in blue. Maximum temperatures were recorded during summer months (June, July, August) while minimum temperatures were recorded during winter months (December, January, February). Minimum temperatures remained fairly constant while maximum temperatures increased significantly at sites 2, 8 and 9.

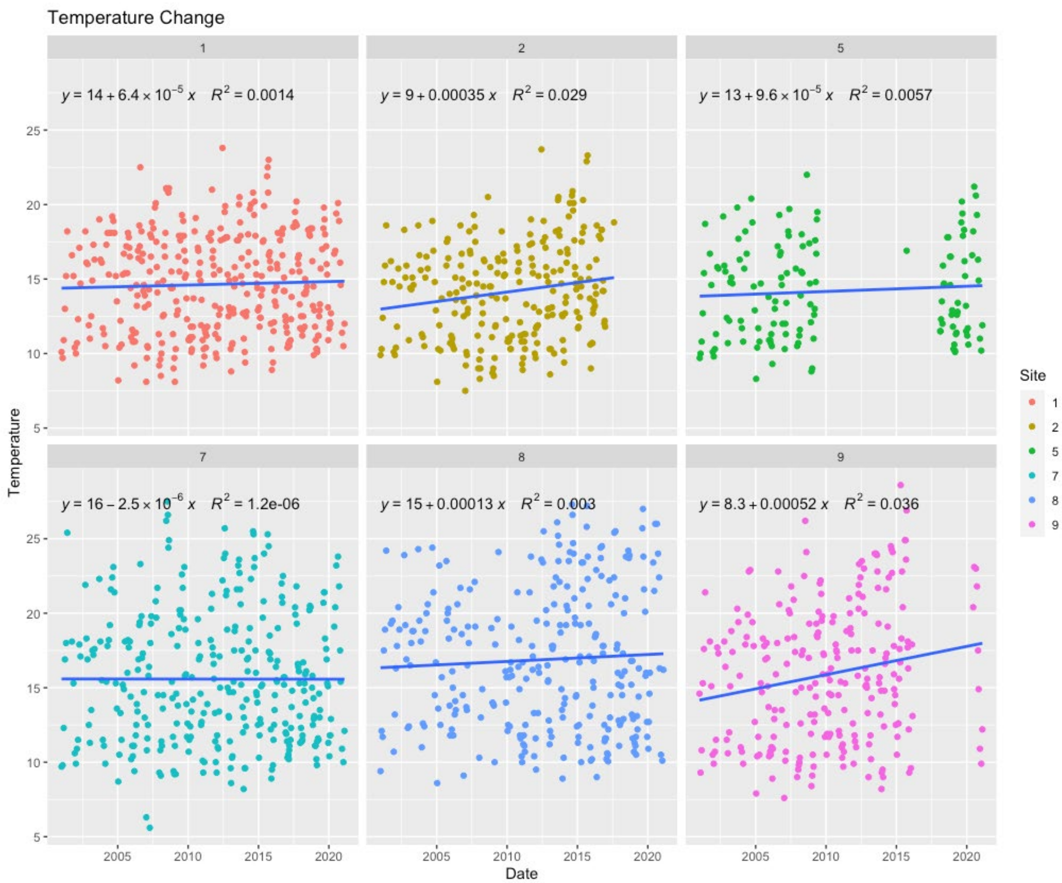

Figure 4 Temperature Change over Time. The yearly and seasonal fluctuation in temperature of the Mokelumne River from 2001 to 2021. Temperatures recorded between 2001 and 2020 varied with seasonality. The most drastic changes occurred during the winter and summer seasons, increasing substantially during the drought experienced from 2011-2016.

Dissolved oxygen content

Dissolved Oxygen(DO) ranged from 6 to 12 mg/L. Mean DO content across all sites is healthy. There were a number of outliers that may have affected Sites 1 and 9. There was not much change in DO over the study period (Figure 5). Sites 1, 2, 5, 7, and 8 all saw slight increases in DO content while Site 9 was the only site exhibiting a decrease in DO over the study period. The ANOVA test revealed a seasonal and temporal relationship causing fluctuations in DO content throughout the study.

Figure 5. Dissolved Oxygen Change over Time. Dissolved oxygen increased across all sites except site 9. DO content fluctuates with the time of day, as well as with changing seasonal temperatures. Mean DO content across all sites remained in a range between 9.45 and 10.0.

Turbidity

Turbidity exhibits no specific trend across any sites during the study period. Fluctuations in turbidity occur across all sites randomly throughout the sample. While Site 8 showed heavily increased turbidity levels from 2001 to 2008, Sites 1 and 2 exhibited low measures of turbidity. The same can be said reading Site 2, where it was the only study site to show signs of increasing turbidity from 2008 to 2012. Overall, the study sites showed decreasing turbidity throughout the study period (Figure 6). The ANOVA test revealed no relationships among variables that explained these fluctuations in turbidity.

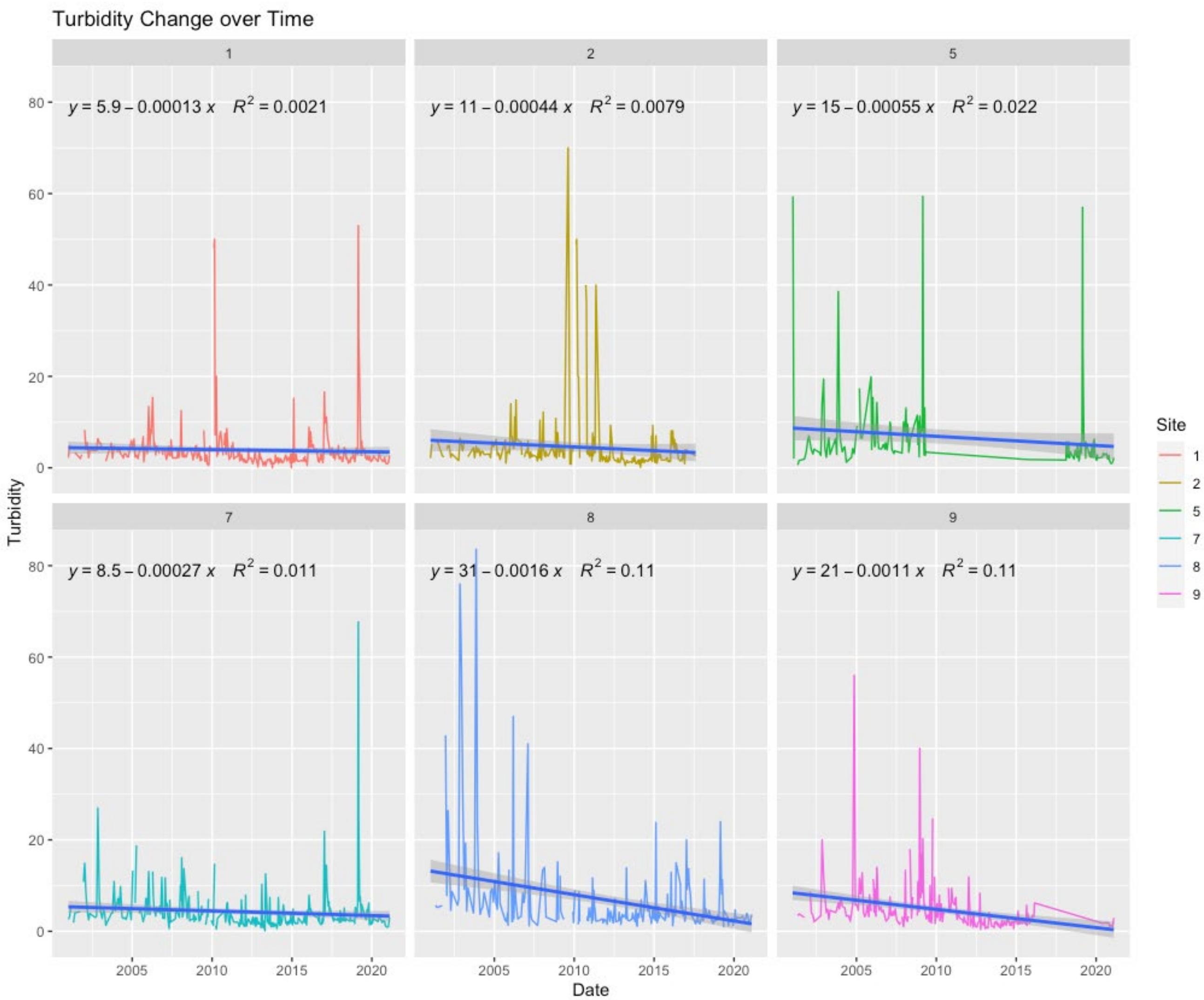

Figure 6. Turbidity Change over Time. Turbidity is the measure of opacity, the cloudiness of the water. Turbidity measures ranged from 0 to 80 throughout the study period. Overall, turbidity decreased throughout the study period.

Electrical Conductivity

All sites, excluding Site 8, showed no significant change in electrical conductivity over time. Sites 7 and 9 showed some spikes, however, when looking through the data, these outliers were identified as incorrect measurements. Site 8 exhibits spikes in electrical conductivity from the start of the study period until the end. The largest spikes occurred between 2001 and 2013 and decreased in volume and frequency by 2020. Electrical conductivity was decreasing steadily at

Site 8 while increasing negligibly at all other sites (Figure 7). Performing the ANOVA test revealed strong relationship with seasonality, indicating changes in electrical conductivity were fluctuating with the changing seasons.

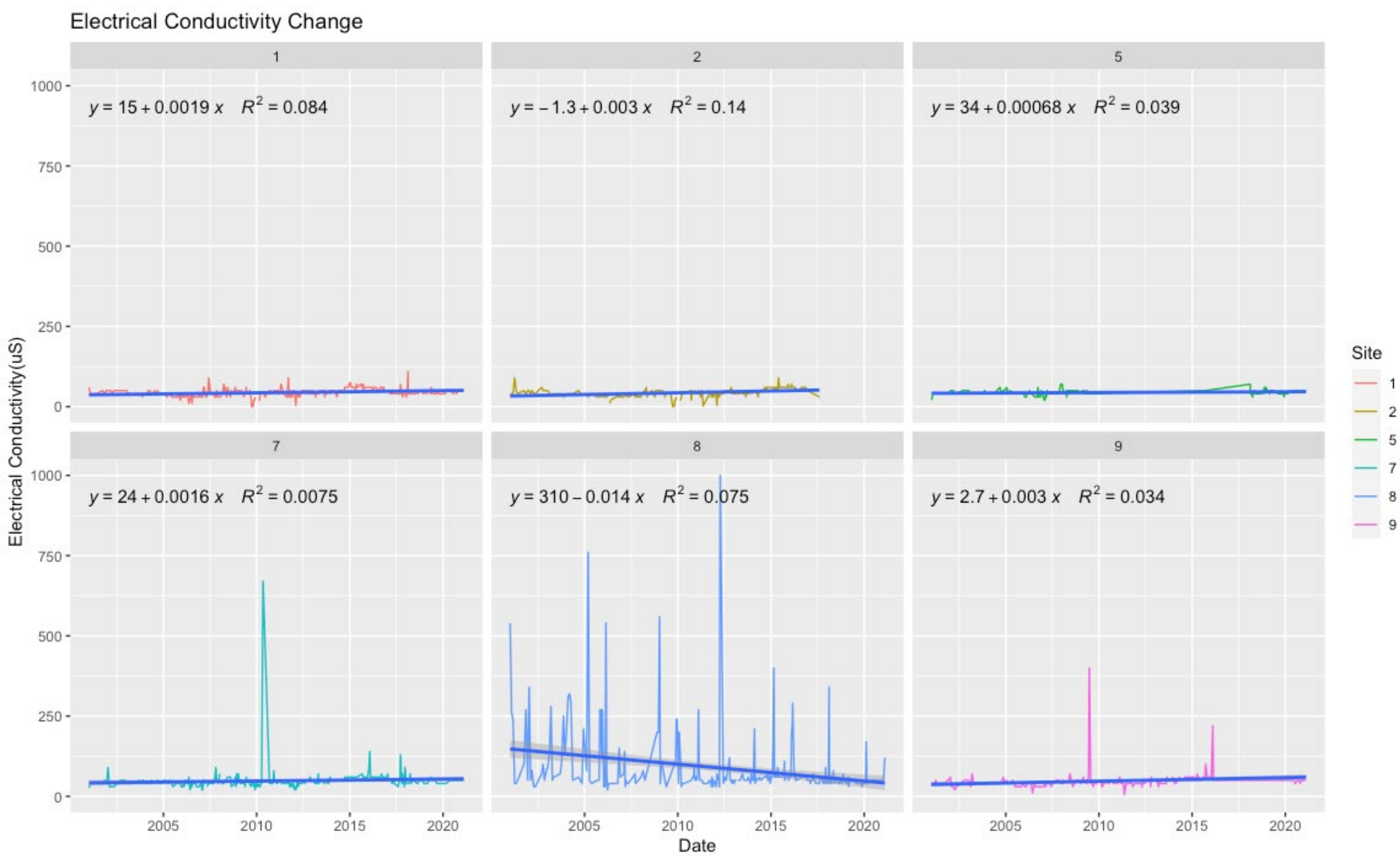

Figure 7. Electrical Conductivity Change over Time. Electrical Conductivity measures the number of inorganic materials present in a sample of water. Mean electrical conductivity increased across all sites except Site 8. ANOVA test revealed relationship with seasonality and the post hoc test revealed a strong relationship with the winter season (p-value: 0.012).

Nitrate Concentration

Nitrate concentration increased across all sites during the study period. The number of detections of Nitrate in water samples increased significantly after 2010, continuing to increase through 2015 and the present. Sites 1 and 2 included outlier concentrations of Nitrate higher then 9 milligrams per liter (Figure 8). Site 8 saw highest volume and number of detections of Nitrate at 54 detections throughout the study period, twice as many as the next most contaminated site.

Nitrate contamination clearly increased throughout the study period, being most severe at sites 2 and 9. The ANOVA test revealed a positive and significant relationship with Date, meaning as Date increased, Nitrate concentration did as well, especially after 2015.

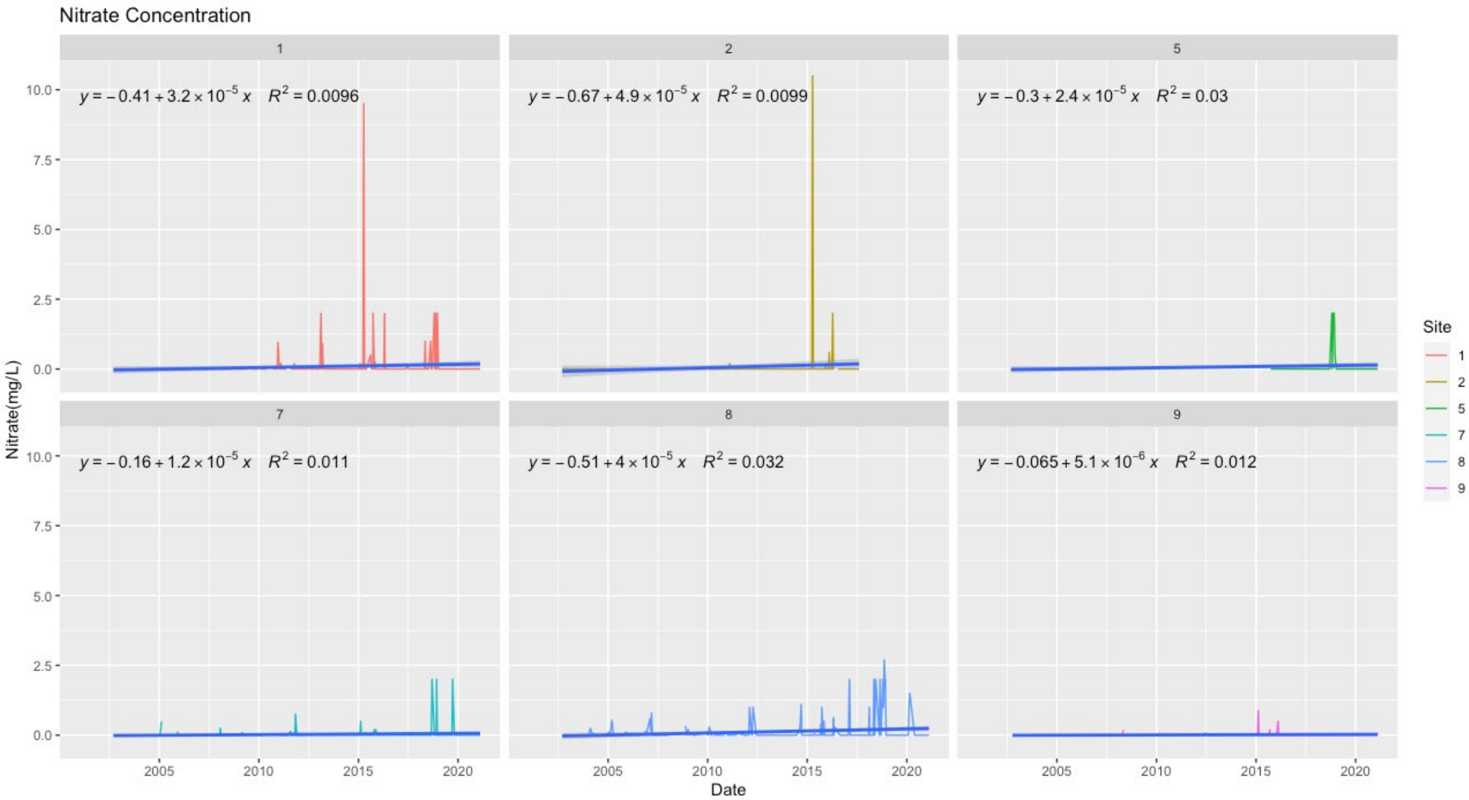

Figure 8. Nitrate Concentration Change over Time. Nitrate is a common chemical pollutant that jeopardizes natural bodies of water. Nitrate contamination steadily increased across all sites after 2010. At Site 1 mean nitrate concentration increased from 0 to 0.08. Site 2 increased from 0 to 0.06. Site 5 increased from 0 to 0.07. Site 7 increased from 0 to 0.03. Site 8 was the highest and increased from 0 to 0.13. Site 9 increased from 0 to 0.01.

Drought Analysis

The linear model revealed strong relationships between declining water quality and drought severity. Drought severity increased throughout the years of 2011 and 2016 of my study. The analysis revealed statistically significant relationships between drought severity and five of the six water quality measures taken; pH, temperature, DO content, turbidity, and electrical conductivity. When analyzing pH, the p-value was $1.6x10^{-6}$. For temperature the p-value was $2.0x10^{-16}$. For DO content the p-value was $9.0x10^{-5}$. For turbidity the p-value was $2.1x10^{-14}$, and lastly for electrical conductivity the p-value was $4.1x10^{-4}$. Given these values, drought had the most impact on temperature change throughout the study period. Surprisingly, there was no relationship found between drought severity and increased in nitrate concentration. Increases in drought severity coincided with increases in pH, temperature, turbidity and electrical conductivity. Alternatively, increases in drought severity coincided with decreases in DO content. Overall, temperature was most impacted by drought.

Land Cover Change Analysis

In Google Earth Engine, four feature classes were chosen to define the landscape, urban, agriculture, bare earth, and water. The landscape has changed significantly in all categories over the last two decades. More specifically, there has been a large increase in land used for agriculture and an increase in urban sprawl. Agricultural expansion has increased by several hundred acres combined with significant development in urban landscape (Figure 9). Most of this land was qualitatively assessed to be mostly used for viticulture. Lodi Lake is surrounded completely by agriculture and urban areas.

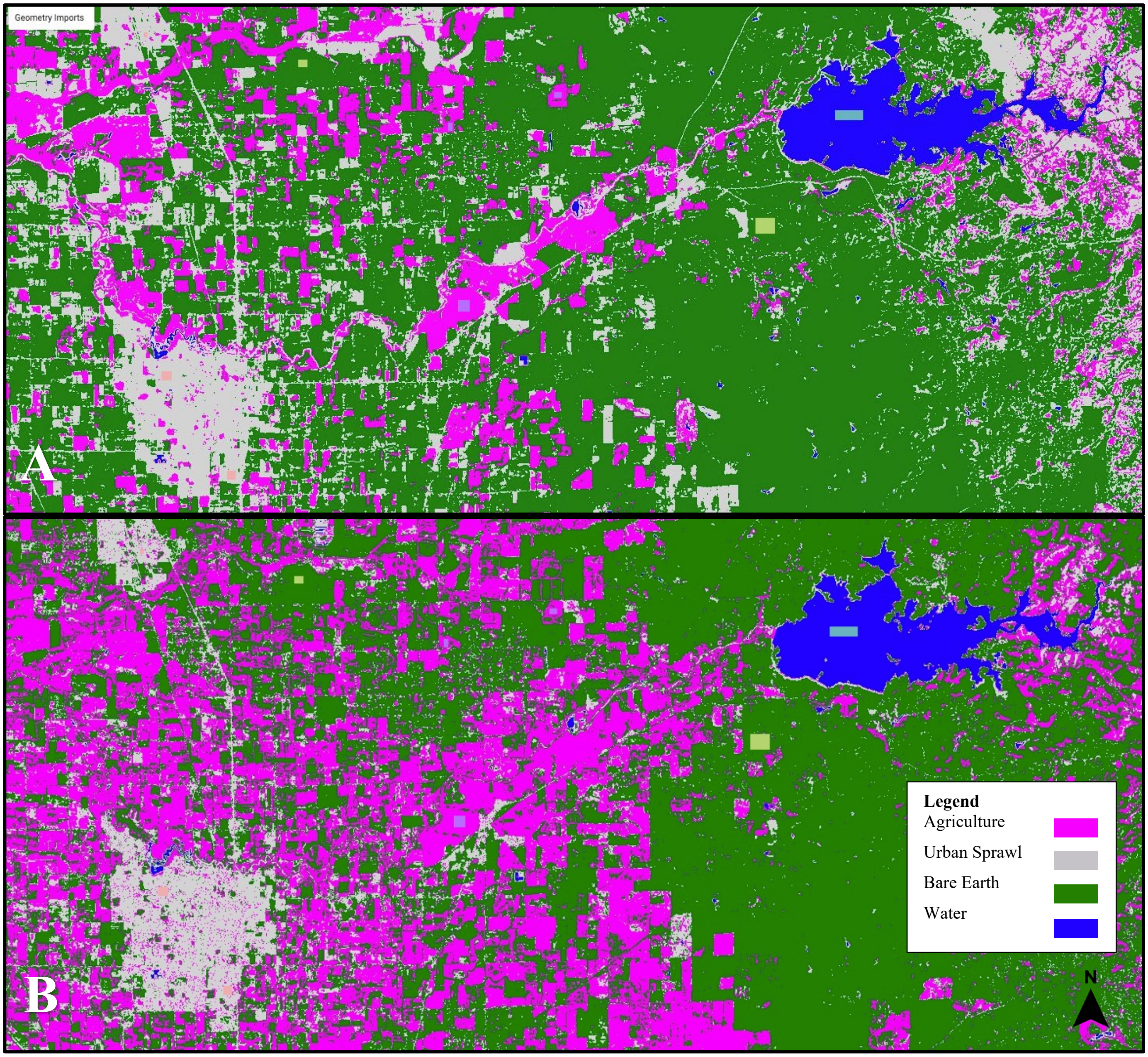

Figure 9. Google Earth Engine screen capture. Land cover classification of the landscape surrounding the Mokelumne River and Lodi Lake in 2001 (**A)** and in 2020 (**B**). There was significant increase in agriculturally productive land as well as a slight increase in urban development from 2001 to 2020.

DISCUSSION

Many long-term studies of the Mokelumne River have been performed to date, however, the Storm Drain Detectives data offers a close look at the long-term effects of urban areas on the Mokelumne River. Using water quality data spanning from 2001 to 2021, I analyzed a small and vital portion of the river. The Mokelumne River provides resources for the community and farmers while also providing natural refuge for wildlife from urban development. By performing this long-term analysis, I found that the water quality of the Mokelumne River near Lodi Lake has declined over the last twenty years. The warming global climate and drought events are key factors in this overall degradation of the ecosystem. These effects manifest in higher annual temperatures, and fluctuations in turbidity over the course of the two decades. The landscape also changed notably throughout the study period. The amount of land converted for agricultural use, and the expanding city of Lodi are a threat to the overall health of the Mokelumne River in a variety of ways.

The Changing Water Quality of the Mokelumne River

Water quality declined from 2001 to the end of 2020. Natural bodies of water must meet certain conditions to maintain the surrounding ecosystem. Generally, the pH of freshwater rivers is between 7 and 8. Over the study period, the Mokelumne River saw rises in pH from around 7.4 to values in the low 8s. This change may result in biodiversity loss, harmful algal blooms, hypoxic zones, and compromised water quality for human uses (Stets et al. 2020). The Mokelumne River and Lodi Lake are vital resources for farmers in addition to recreational users and native species. If the pH continues to rise, worsening water quality, there could be serious consequences on the regional biodiversity. In addition, the rising nitrate concentration in the river is a significant issue. Chemical pollutants concentrated in natural bodies of water have been identified in research dating back to the 1980s, and in recent years, nitrate pollution of groundwater subjects a significant number of households to consuming nitrate contaminated water (Balazs et al. 2011). California's Assembly Bill No. 685 declares that every human being has the right to safe, clean, affordable and accessible water adequate for human consumption, cooking, and sanitary purposes. Although there is legislation in place, according to data from the Office of Environmental Health Hazard Assessment**,** around 80% of community water systems reported some form of hazardous chemical contamination of drinking water. This is mostly due to nitrate contamination, among a number of other chemical pollutants (Savci 2012). The rising levels of nitrate found in the Mokelumne River indicates the lack of regulation on individuals polluting the water, as well as a lack of initiative to actively mitigate its presence and effects on rivers. Additionally, a number of the study sites are located near storm drains. Due to the proximity of the water to the city of Lodi, these storm drains could carry harmful pollutants from the streets directly to the water. A study of urban runoff in Orange County, California revealed that urban runoff events were increasing the number of harmful bacteria found in rivers and beaches along the coast (Dwight et al. 2002). In fact, frequent winter runoff events harmed a variety of water quality measures such as turbidity and electrical conductivity. I found similar results in the Mokelumne River and Lodi Lake during the winter, as these measures increased substantially at a number of test sites following rain events.

Negative Environmental Impacts

Scientific research has indicated several negative environmental impacts associated with drought. California experienced extreme drought from 2011 to 2017 and the effects could still be having a significant impact on ecosystems state-wide (Yang 2017). The drought had a significant negative impact on the water quality of the Mokelumne River and Lodi Lake. In a recent study of the causes of declining Colorado streamflow, it was found that drought reduces the overall quantity of water available through increased plant consumption, evaporation and less snowpack (Xiao et al. 2018). The USGS discharge and flow rate data revealed significantly less flow during times of drought. This is because drought is associated with a sequential decline in precipitation, run off, soil moisture, groundwater levels and stream flow (Lake 2003). Many of these factors could play key roles in the diminished water quality of the Mokelumne River when accounting for drought severity. Turbidity, electrical conductivity, flow, amount of precipitation and runoff are extremely influenced by drought. Temperature was the variable most affected by drought severity. Increased turbidity measures decreased flow and amount of precipitation are all factors that can be used to explain the rise in temperatures in the Mokelumne River. However, it is important to understand the role of the warming global climate. Climate warming effects aquatic habitats in a number of ways. The flows and timing of rivers changes, increases in temperatures has significant effects on several fish species, and overall decrease in volume of water are all associated with climate change

(Schindler 2001). Additionally, drought has increased in frequency and intensity and will continue to do so as the climate continues to warm (Strzepek 2010). The effects of drought on the Mokelumne River and Lodi Lake provide a warning for the imminent dangers of future drought and the warming climate.

Effects of Land Cover Change

Land cover has changed significantly surrounding the Mokelumne River and Lodi Lake. There was an extreme increase in land used for agricultural production as well as a small increase in urban development. The process of urbanization results in the conversion of terrestrial vegetation to expanses of impervious surfaces, increasing the amount of runoff and nutrients entering streams and influence the natural flow regimes of bodies of water (Mantyka-Pringle et al. 2014). Eutrophication is a key factor causing the degradation of water quality and agriculture is recognized as a major source of water pollution. With a significant increase in land used for agriculture, these issues will become more prominent and difficult to manage. In a similar study aimed at determining the impact of agriculture on water quality and designate priority areas for implementing nitrogen reduction measures, it was determined that nitrate concentration increased when the surrounding land was mostly arable land (Lawniczak 2016). The land surrounding the Mokelumne River is mostly arable land, making the river subject to similar modes of pollution, specifically nitrate pollution. There was no correlation between drought severity and nitrate concentration, however, there was a noticeable increase over time. This is likely due to land-use change, and how the surrounding landscape is directly affecting the river. This can be mitigated using riparian buffers which are thought to be effective at intercepting and reducing nitrogen loads entering water bodies (Mayer et al. 2007). Increasing the number of ways to protect the Mokelumne River is vital for keeping it clear of contamination.

The Health of the Mokelumne River

The overall water quality of the Mokelumne River and Lodi Lake has declined over the last two decades. Though a large portion of this decline can be attributed to the drought experienced in the early 2010s, it is important to understand the effects of pollution and how these two variables interact. As the impacts of the drought caused increased temperatures, lower flow volumes and less rainfall, the Mokelumne River became more susceptible to the negative effects of pollution. Following the drought, there was an increase in nitrate contamination across all sites being tested. During years of drought, the Mokelumne River suffered higher temperatures while the surrounding landscape was being used as cropland. In wet years following the drought, increased runoff events could carry harmful chemical pollutants as more land is farmed over time. Increases in agriculturally productive land and urban expansion put the river at an increasingly higher risk for pollution, especially during years of drought recovery. As the number of threats to the ecosystem increases, it is important to track and assess the changes in the Mokelumne River and Lodi Lake to ensure its conservation.

Limitations and Future Directions

The range of the data collection sites the Storm Drain Detectives used was small and over the last two decades only nine different sites have been monitored, only six of which I was able to include in my study. The sites are located in a very small portion of the Mokelumne River and Lodi Lake, giving a window of assessment covering only a few square miles. This tight window prohibits any sort of upstream assessment, limiting the causes of change being examined. The raw data also had several gaps, indicating low temporal frequency and measurements are not being taken at the same time every year.

This study aimed to compile and assess the data collected by the Storm Drain Detectives. Moving forward, SDD needs to continue monitoring the health of the river and lake and keep the community involved. The most important aspect of the program is the community education component. Continuously involving young students in the scientific process and giving them first-hand experience in protecting the environment is vital for the community. Currently, the program follows the Quality Assurance Protection Plan, a set of criteria developed by the State Water Resource Control Board to ensure data is being collected correctly. SDD needs to continue to ensure the proper implementation of these criteria in order for the data they are collecting to be useful for analysis. Additionally, they should implement a digital recording system to compile all of the available and newly collected data. Currently, all data is manually tabulated on spreadsheets that are printed out for each sample date. These are then scanned into PDF form and posted online.

This is ineffective for anyone trying to analyze, clean or manipulate the data and should be improved. The land cover change analysis in my study could also be improved using software such as ArcMap. ArcMap can be used to perform an extremely accurate unsupervised classification of the landscape, assigning each pixel of an image a land-type class. This could then be implemented to accurately calculate percentage changes in land cover change over time. GIS could also be used to create a real-time water quality predictor based on land-use and land cover change.

Broader Implications

As the climate warms and natural disasters such as drought become more prominent, it is now more important than ever to actively protect the environment. SDD data is collected by instructors and their students as a way to get the community involved in conservation. Continuation and expansion of the program can benefit the entire community by enabling them to understand the changes in their environment and how to combat them. Nitrate contamination increase is evident at multiple sites located in the river as well as the lake. In order to mitigate these effects in agriculture-heavy areas, riparian buffers could provide an extra level of protection from the harmful chemical pollutants associated with fertilizers and pesticides. Due to the constant threat of pollution from urban runoff, the Storm Drain Detectives provide a buffer of relief by consistently monitoring these high-risk areas of the lake that are not protected. Ultimately, this research lays out the importance of the role played by the Storm Drain Detectives as well as the consistent analysis of water quality is vital for the conservation of the Mokelumne River and Lodi Lake.

ACKNOWLEDGEMENTS

First off, thank you to Kathy Grant, the city of Lodi’s Watershed Program Coordinator for organizing the Storm Drain Detectives program for the last two decades, as well as for providing me with the SDD data I needed to perform my analysis. Thank you to Sion and Jasmine, my two workgroup warriors who supported me through this whole process. Lastly, thank you to the ESPM 175 Team. Tina and Leslie, your constant encouragement and knowledge was astounding, and Kyle, thank you for providing me with the tools and tips I have needed to get through this.

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