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Kayla Brand collects water quality data during the summer research program.

Forward

The articles you see in this publication are the result of months of hard work from students in Headwaters Science Institute's 2020 Summer Research Program. While they are not peer-reviewed in typical journal fashion, they have been reviewed by Headwaters staff and professional scientists. The caliber of these projects speaks loudly to these students' accomplishments. Allow us to also highlight a few of the most special parts of this program here.

Part of what made this program possible was participation by a great array of professional scientists, post-docs, and graduate students from institutions across the country. These scientists not only brought great technical knowledge to the program but also shared with students their own invaluable experience in navigating the winding path of original scientific research. Thank you to all of the scientist mentors who made these student projects possible.

One of the unique outcomes of this course was that all of the articles in this text are the students' own original ideas. Each one of these manuscripts started as part of a list of scientific questions brainstormed by students. From there, students shaped and molded the questions they were interested in based on current scientific knowledge and access to field sites or existing datasets. Students revised their questions, collected preliminary data, and revised again, honing their scientific skills along the way. The diversity of research questions in this publication is not only evidence of the incredible creativity inside all students but also honors the wonderful job the scientist mentors did in nurturing this curiosity.

To the students who authored these papers: congratulations! All of you have worked incredibly hard to complete these manuscripts. More than having your name on this paper, be proud of all that it represents. Each one of you overcame setbacks, roadblocks, time crunches, and uncertainty to get to this point. The skills you practiced along the way will serve you well in whatever you choose to do next.

Spencer Eusden

Program Director - Headwaters Science Institute

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How has California's Shelter in Place due to COVID-19 and the Resulting Reduction in Human Activity Affected Air and Water Quality?

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ABSTRACT

As the globe continues to battle the novel coronavirus or COVID-19, many states across the United States have restricted human activity, intending to reduce the number of viral infections. In turn, the number of cars on the streets and operational factories have decreased. This unique time for the world has created an opportunity to study the impacts of reduced human activity. Water and air quality data were collected both through field data collection and remote data sites to test how the change in human activity, as a result of the shelter in place order, affected the water and air pollution levels. Three test sites throughout California were studied for June and July from 2015 to 2020 to compare the water and air quality over the past five years. Air quality in Lake Tahoe's Placer County significantly improved from 2015 to 2020 while Lake Tahoe's water quality remained relatively the same. San Francisco County's air quality somewhat improved in terms of NO_x and O_3 but the water quality of North Lake from Golden Gate Park stayed fairly constant in the past 5 years. Finally, the water quality of the Russian River at Guerneville significantly improved from 2015 to 2020 and the air quality in Sonoma County for Guerneville somewhat decreased in terms of NO_x concentrations but O_3 was not heavily impacted by the reduction in human activity. Overall, the air pollution in California for June and July somewhat decreased from the studied months in 2015 to 2020 while the water quality of the tested bodies of water remained fairly constant during the change in human activity due to California's shelter in place order.

INTRODUCTION

The respiratory disease caused by the novel coronavirus, SARS-CoV-2, originated in China but has spread internationally. SARS-CoV-2, commonly referred to as COVID-19, was deemed a pandemic on March 11, 2020 by the World Health Organization, and California's shelter in place order was issued on March 19, 2020. Over 19 million cases have been confirmed worldwide with 541,000 in California alone (1).

As the global pandemic of COVID-19 continues, everyday life is being altered and affected around the world. The worldwide shutdown limited how many people wandered the streets, how many cars were taken to work each day, and how businesses and factories operated (2, 3). Since March of 2020, life in California has not been the same; With reduced human activity, there is a decrease in human-induced emissions from vehicles and industrial operations (4). Apple's COVID-19 Mobility Tracking found that driving rates in April 2020, the height of the shelter in place order, in California dropped 65% below the baseline, and were 18% above the baseline at the end of July 2020 (2). The baseline is an average value of collected movement in a certain location. This value is determined from the median of a 5 week period between January 3rd and February 6th of 2020 that remains constant to determine a change due to COVID-19, which does not account for seasonality or daily changes (5). The baseline is determined from a time where COVID-19 was already around and it is possible that some had started to reduce their human activity on their own. Similarly, Google's Mobility Tracking showed that California public transit use was down 42% below the baseline as of July 27, 2020 (6). The Bureau of Transportation Statistics reported that 28.3% of Californian's are staying indoors as of July 30, 2020, which is one of the higher percentages for a state out of the country (7). While COVID-19 is keeping people indoors and less active, air quality around California is beginning to show signs of clearing up in terms of particulate matter and NO_x emissions (8, 9).

Partially combusted hydrocarbons lead to particulate matter which are microscopic particles or liquid suspended in the air. Particulate matter can come from natural sources such as sea salt, pollen, and vegetation, as well as viral DNA and bacteria (10). It can also be a product of anthropogenic sources such as fire smoke and truck, industrial, or power plant emissions. $PM_{2.5}$ refers to particulate matter that is 2.5 micrometers or less in diameter. Due to its fine size, $PM_{2.5}$ can be harmful to the human body since it can enter the bloodstream or lungs (11). On the other hand, PM_{10} is particulate matter with a diameter of 10 micrometers or smaller and can be produced through fires, farms, and dust (12). PM_{10} moves slower and is unable to move as far as $PM_{2.5}$ because larger sized particles tend to deposit to surfaces closer to sources (12).

Automobile engines produce oxides of nitrogen: nitrogen dioxide and nitrogen monoxide (NO_x) and release partially combusted hydrocarbons as a result of burning fossil fuels, while factories emit similar greenhouse gases and pollutants. NO_x can be emitted from a car engine and lead to the formation of ozone (O_3). The free radical hydrocarbon (ROO•) contains only a single valence electron making it unstable and highly reactive. ROO• reacts with NO to form NO_2 and RO• (ROO• + NO RO• + NO_2). Nitrogen dioxide is essential in the formation of O_3 as well. The NO_2 NO + •O reaction requires sunlight to occur, which is why the formation of O_3 fluctuates with the number of UV rays. The free radical •O that formed when NO_2 decomposed, reacts with the O_2 and M (a reaction intermediate) to create ozone (•O + O_2 + M O_3 + M). The O_3 can then decompose back into O_2 and O when sunlight is present (O_3 O_2 + •O). There are other ways in which these reactions could occur but this is the most likely because usually, only two molecules must collide in the correct way for the reaction to happen. The •O is a free radical and highly reactive. It reacts with water to create a hydroxyl that can somewhat clean or purify the air because it can break down other pollutants (•O + H_2O 2•OH). The •OH hydroxyl decomposes other pollutants but is also a pollutant and contributes to smog and leads to the formation of aldehydes. If RCHO represents the aldehyde and O_2 represents the hydroxyl which acts as a catalyst, the overall smog reaction would be: RHC_3 (partially combusted hydrocarbon) + $2O_2$ + 2NO RCHO + $2NO_2$ + H_2O. Aldehydes are formed when the partially combusted hydrocarbon reacts with a hydroxyl since the hydroxyl breaks down hydrocarbons. Aldehydes contribute to smog and can have detrimental human health effects. Finally, because NO_2 is also formed, the smog reactions continue.

O_3 is necessary in the stratosphere to protect life on earth from intense ultraviolet radiation from the sun but it is not so beneficial on the ground level in the troposphere (13). O_3 on the ground level contributes to the health issues with smog because it can irritate eyes, throat, and lead to congestion, but can also harm crops and building materials (12). During the summer months, there is more UV radiation present due to an increase in sunlight so O_3 creation increases. However, as a result of COVID-19, there are fewer cars on the roads which could lead to less O_3 formation.

On the other hand, water quality is also greatly affected by human activity and since traffic has reduced, the San Francisco Bay is seeing a significant decrease in water pollution (14). Many factors contribute to water quality, including total dissolved solids and pH. Total dissolved solids (TDS) are the inorganic and organic substances in a body of water. The term encompasses any minerals in the water but the most commonly found include, calcium, magnesium, potassium, sodium, carbonates, nitrates, bicarbonates, chlorides, and sulfates (15). These minerals can be present in water both naturally due to the ground beneath the water or due to human activity. The EPA states that a TDS concentration below 300 ppm is drinkable water quality and anything above 1200 ppm is considered unhealthy and undrinkable. For example, tap water tends to range from 100-200 ppm TDS. High TDS can lead to hard water which can clog pipes and drains due to mineral buildup and makes it difficult for soap to dissolve and can dry out the skin or lead to future health issues from high concentrations of specific ions such as nitrate, arsenic, aluminum, copper, or lead. Turnover in a body of water can alter the measurements of TDS (14). Similarly, high turbidity in water means the TDS will be elevated.

pH of the water measures the number of hydrogen ions present in the water. pH is measured on a logarithmic scale from 0 to 14. A pH value below 7 demonstrates an acidic substance, whereas a value above 7 is a basic or alkaline substance. A pH value of 7 is neutral which is also the pH of pure water. The pH of a body of water affects the type of ecosystems able to survive in that water. Human activity can play a role in the acidity or alkalinity of water but natural

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influencers such as rocks, soil, and plant life can also affect the pH. Surface water tends to have a pH between 6.5 and 8.5 and throughout the summer lake surface water typically has a pH between 7.5 and 8.5 (16). Human input and air pollutants can alter the pH. For example, when carbon dioxide or nitrogen dioxide from the air dissolves in water, they tend to bond with a hydrogen ion to create carbonic acid or nitric acid which in turn lowers the pH of the water. The surface water of a lake tends to be more basic than the deeper levels because of sunlight and plant photosynthesis. The algae and plants present in the lake or body of water use up the CO_2 from air that dissolves into the water and creates O_2 and glucose: $6CO_2 + 6H_2O$ + light --> $C_6H_{12}O_6 + 6O_2$. In turn, while sunlight is present, the surface of the body of water will be more basic than pure water at a pH of 7 (17).

The quality of water is a product of many different factors and can change based on the surroundings. The water quality of a city pond compared to a high alpine lake will vary due to differences in human activity as well as elevation, temperature, and many other factors. Based on these background concepts, I hypothesized that the decrease in human activity due to California's shelter in place because of COVID-19 would improve the air and water quality in all three test locations, Russian River, Lake Tahoe, and North Lake in Golden Gate Park. There should be fewer contaminants polluting both the air and freshwater bodies. Water data was collected manually for June and July 2020 data, but available remote air data and water data for the previous 5 years was used. Through my collected and remote data, COVID-19 has somewhat improved California's air quality in San Francisco, Placer, and Sonoma counties, but water quality has remained fairly constant in these locations.

METHODS

San Francisco County's North Lake in Golden Gate Park (37.7699° N, 122.5024° W) with an elevation of 80 meters, is located approximately 122 meters from a well-used road, Fulton Street. Sonoma County's Guerneville, California lies along the Russian River, which runs along a road for most of its length, with a population of 4,808 as of 2018 (33). The Russian River location (38.50803° N, 122.9874° W) at an elevation of 18 meters was not near the road but is a well swum in river, flowing through many towns. On the other hand, Lake Tahoe in Placer County's Tahoe City (39.1687° N, 120.1424° W) is similarly not near a road but is at a much higher elevation of 1,905 meters and is fed from fresh snowmelt. Out of these three data sites, San Francisco felt a stronger decrease in human activity by the shelter-in-place due to its higher population and human activity (2).

Water quality was measured by a TDS and pH meter as well as an API Freshwater Test Kit. The Ketotek KT-3 Portable pH Meter can detect pH levels from 0.00 to 16.00 with +/- 0.01 pH accuracy. The Ketotek KT-2 Portable TDS Meter can detect total dissolved solids from 0 to 9990 ppm with a +/- 2% accuracy. In Tahoe City, Lake Tahoe, measurements were taken off of a pier where the water's depth was approximately 2 meters. Each of the meters has a 5-centimeter section that can be submerged in water, so the data represents the surface water of each site. The data from the Russian River near Guerneville was taken at the end of a dock that was 3 meters long but the depth of the water was about 3.5 meters. Lastly, at the North Lake in Golden Gate Park, data was taken from the shore off of a ramp in the water. The water was only 30 centimeters deep at this location.

To test the nitrate and nitrite levels in the water, the API Freshwater Test Kit was used where 5 mL of each water sample was tested by following the instructions to use the liquid test bottles. For the nitrite testing, 5 drops of the solution were put into the water sample and the color would appear after shaking the test tube and letting it sit for 5 minutes. The process for nitrate was very similar except The color of the water sample would change based on the amount of each analyte present and the best fit choice was determined regarding the new color of the water. This process was repeated 3 times for each analyte per water site. The API test kit was able to measure nitrite levels in 0.25 ppm intervals whereas nitrate levels were measured in 5.0 ppm intervals and both were based on the color of the sample compared to a reference color supplied with the kit.

U.S. Geological Survey (USGS) remote water data from the National Water Information System (NWIS) was used for Russian River water quality from June 2015 to July 2020 (34). Remote data previously collected by another source and used for this research. To collect that data, isokinetic sampling methods were used for flowing water. Isokinetic sampling captures particles that flow through a certain area to determine the concentration of the compound or particle. Since the dam for the Russian River opens mid-June each year and closes on the 1st of October, isokinetic sampling was performed due to the water flowing through the river. Since the remote water quality data from USGS and NWIS provided conductivity data but TDS data was collected for this experiment, conductivity was converted into TDS:

$$TDSppm_{500} = 500 * \frac{C(\mu S/cm)}{1000} mS/cm.$$

The San Francisco Estuary Institute (SFEI) collected water samples and data for North Lake using the Seabird CTD, YSI 556, WTW 340i meter (35). This instrument is able to measure many water quality functions and provides nitrate, nitrite, and total nitrogen data for North Lake in San Francisco's Golden Gate Park (36). However, there was no pH data available for North Lake.

UC Davis Tahoe Environmental Research Center provided nitrogen concentration data for Lake Tahoe through their State of the Lake Reports. The nitrogen data is collected from a Shimadzu UV-1700 series Spectrophotometer that uses light absorption to determine the concentration of matter in a solution (37). The pH and TDS standards for the lake from Keep Tahoe Blue were determined by the handheld Hanna pH meters with a 0.02 unit resolution and a handheld Oakton TDS Tester Conductivity meter that has a 10 µS/cm resolution (23).

The Bay Area Air Quality Management District (BAAQMD) provided air quality data for San Francisco (38). To obtain NO_x data, a chemiluminescent analyzer is used (39). Chemiluminescence is based on the amount of light given off when nitric oxide and O_3 react to determine the concentration of nitric oxide. To determine the concentration of NO_2 in an air sample, the samples are passed through a catalyst to reduce NO and are then measured by chemiluminescence to quantify the NO_x emissions (39). The minimum sensitivity of the analyzer is +/- 2% of the full scale. Particulate matter is measured isokinetically through stack glasses and filtered through glass fibers. The weight of the particulate matter is determined gravimetrically after separating from excess water. The minimum sensitivity of particulate matter measurements is 0.001 gr/SDCF (40). Finally, to measure the O_3 concentration in the air, BAAQMD uses a Thermo Electron/Thermo Environmental Instrument Model 49i. This instrument is placed at each monitored site and analyzes the amount of O_3 in the air from 0.05 to 1000 ppb (41). Air filters through between every 10 and 300 seconds to continuously collect data measurements for the O_3 air concentration (42).

The California Air Resources Board (CARB) provided air quality data for the Russian River through Sonoma County and for Lake Tahoe through Placer County (43). Particulate matter concentration is determined through Optical Particle counters (OPC) which measure the light scattered by particles to determine the number and size of particles in the air. OPC uses lasers and detectors to capture the light. Spectroscopy is also used to collect data in terms of particulate matter. Light is passed through an air sample and the amount of light that is absorbed is directly proportional to the compound or particles. Once the air samples are filtered and have gone through isolation processes, spectroscopy is also used for gaseous pollutants: NO_x and O_3. These gaseous pollutants are measured through testing the conductivity of each water sample as well. Conductivity quantifies the varying flow of electricity between two electrodes. The change in electrical conductivity is directly proportional to the concentration of the measured compound. Thermal conductivity works by measuring the varying resistance across a circuit in relation to a reference circuit because of the increased concentration of a gaseous compound.

RESULTS

With the COVID-19 pandemic shifting daily life across the globe, it is a unique time to study the effects of a worldwide shutdown. California's air and freshwater quality could be improving as a result of less human activity. To test the water quality of the Russian River, Lake Tahoe, and North Lake in San Francisco, pH, NO_x, and TDS levels were measured using API

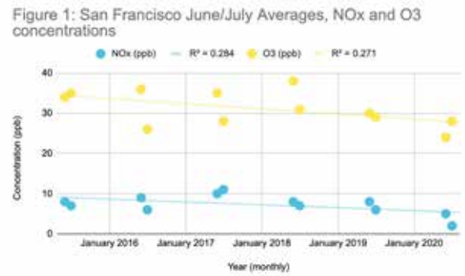

Figure 1: The y-axis represents the concentration, in ppb, of O_3 (yellow) and NO_x (blue), while the x-axis is time from 2015 to 2020 for North Lake in San Francisco County.

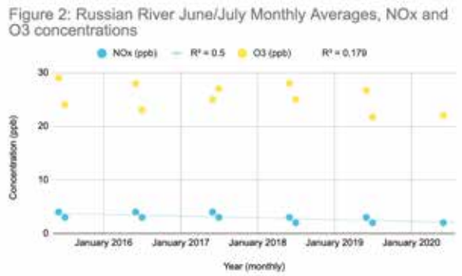

Figure 2: The x-axis is time from 2015 to 2020 while the y-axis represents the concentration, in ppb, of O_3 (yellow) and NO_x (blue) in Sonoma County for the Russian River at Guerneville.

Freshwater Kit, Ketotek's pH and TDS meter, as well as remote data from U.S. Geological Survey (USGS), the National Water Information System (NWIS), and San Francisco Estuary Institute (SFEI). Data for each county's air quality was collected from the Bay Area Air Quality Management District (BAAQMD) and California's Air Resources Board (CARB). The reported p-values are based on an alpha of 0.05 for statistical significance. The overall results show minimal change in air and water quality during the June and July sample periods with reduced human activity due to COVID-19 throughout California compared to data from the previous five years, though there were some differences likely due in part to reduced human activity.

The average nitrogen concentration of Lake Tahoe in 2018 was 20.9 ppb and the maximum allowable concentration is 210 ppb. The total nitrogen content between 1980 and 2012 had always been between 13 and 19 ppb for Lake Tahoe. The standard pH for the lake is between 7.0 and 8.4 which is the accepted range of values for pH in Lake Tahoe. Additionally, the average TDS for the lake is 47.5 ppm.

Figure 1 graphs the concentration of NO_x and O_3 in parts per billion (ppb) from 2015 to 2020 in San Francisco County. The mean O_3 concentration in June/July of 2020 (26, n=2) was lower than the mean ± SD O_3 concentration between 2015 and 2019 (32 ± 3.9 ppb, n=10) with an unpaired t-test p-value of 0.06 meaning the data is not quite statistically significant. The mean NO_x concentration in June/July of 2020 (3.5 ppb, n=2) was lower than the mean ± SD NO_x concentration between 2015 and 2019 (8.0 ± 1.6 ppb, n=10) with an unpaired t-test p-value of 0.01 meaning the data is statistically significant. The r^2 values suggest that there is a weak negative correlation between the NO_x concentrations (r^2 = 0.28) as well as the O_3 concentrations (r^2 = 0.27) in June and July 2015 to 2020.

Figure 2 shows the concentrations of NO_x and O_3 from 2015 to 2020 in Sonoma County. The mean O_3 concentration in June/July of 2020 (23.5 ppb, n=2) did not present a difference in comparison to the mean ± SD O_3 concentration between 2015 and 2019 (25.7 ± 2.4 ppb, n=10) with an unpaired t-test p-value of 0.25 meaning the data is not statistically significant. The mean NO_x concentration in June/July of 2020 (2 ppb, n=2) was lower than the mean ± SD NO_x concentration between 2015 and 2019 (3.10 ± 0.74 ppb, n=10) with an unpaired t-test p-value of 0.07 meaning the data is not quite statistically significant. The r^2 (r^2 = 0.27) value suggests that there is little correlation between the O_3 June/July concentrations between 2015 and 2020. However, the NO_x concentrations have a moderate correlation (r^2 = 0.28) with the change in time.

Figure 3 shows the concentration of NO_x and O_3 in the air in Placer County for Lake Tahoe. The mean ± SD O_3 concentration in June/July of 2020 (43.00 ± 2.83 ppb, n=2) was lower than the mean ± SD O_3 concentration between 2015 and 2019 (47.90 ± 4.04 ppb, n=10) with an unpaired t-test p-value of 0.14 meaning the data is not statistically significant. The mean ± SD NO_x concentration in June/July of 2020 (3.50 ± 0.71 ppb, n=2) was lower than the mean ± SD NO_x concentration between 2015 and 2019 (5.78 ± 0.97 ppb, n=10) with an unpaired t-test p-value of 0.01 meaning the data is statistically significant. The r2 value (r2 = 0.18) suggests that there is no linear correlation between the June/July

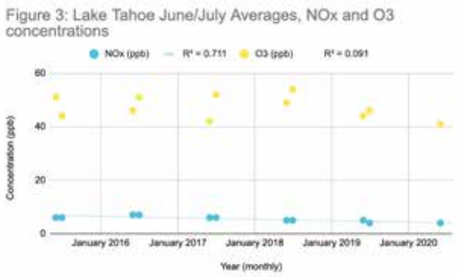

Figure 3: The x-axis is time from 2015 to 2020 while the y-axis represents the concentration, in ppb, of O_3 (yellow) and NO_x (blue) for Lake Tahoe in Placer County.

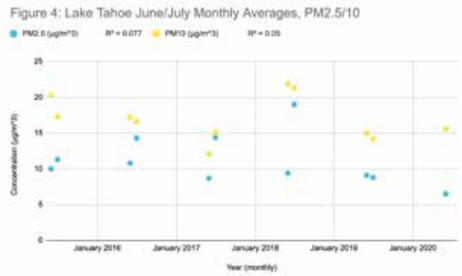

Figure 4: The x-axis demonstrates time from 2015 to 2020 and the y-axis represents the concentration, in µg/m3, of $PM_{2.5}$ (blue) and PM_{10} (yellow) for Lake Tahoe in Placer County.

O_3 concentrations from 2015 to 2020. However, the NO_x concentrations are negatively correlated (r^2 = 0.5) from 2015 to 2020.

Figure 4 is a graph of the particulate matter in the air for Tahoe City in Placer County. The mean ± SD $PM_{2.5}$ concentration in June/July of 2020 (5.75 ± 1.06 µg/m3, n=2) was lower than the mean ± SD $PM_{2.5}$ concentration between 2015 and 2019 (11.58 ± 3.34 µg/m3, n=10) with an unpaired t-test p-value of 0.04 meaning the data is statistically significant. The mean ± SD PM_{10} concentration in June/July of 2020 (16.30 ± 0.99 µg/m3, n=2) was not statistically different than the mean ± SD PM_{10} concentration between 2015 and 2019 (17.100 ± 3.215 µg/m3, n=10) with an unpaired t-test p-value of 0.74 meaning the data is not statistically significant. The r^2 values for both $PM_{2.5}$ (r^2 = 0.077) and PM_{10} (r^2 = 0.05) in Tahoe City air around Lake Tahoe suggest no correlation between the concentration of particulate matter over the past 5 years.

Figure 5 is a graph of the $PM_{2.5}$ in the air of Sonoma County for Guerneville. The mean $PM_{2.5}$ concentration in June/July of 2020 (5.40 µg/m3, n=2) was not statistically different than the mean ± SD $PM_{2.5}$ concentration between 2015 and 2019 (5.21 ± 1.28 µg/m3, n=10) with an unpaired t-test p-value of 0.84 meaning the data is not statistically significant. The r^2 value (r^2 = 0.147) suggests a little to no correlation between the change in concentration of $PM_{2.5}$ and the past 5 years from 2015 to 2020.

Figure 6 shows the concentration of $PM_{2.5}$ in San Francisco County for the past 5 years. The mean $PM_{2.5}$ concentration in June/July of 2020 (7.85 µg/m3, n=2) was no statistically different than the mean ± SD $PM_{2.5}$ concentration between 2015 and 2019 (6.38 ± 1.96 µg/m3, n=10) with an unpaired t-test p-value of 0.33 meaning the data is not statistically significant. The r^2 value (r^2 = 0.58) suggests a mild positive correlation between the change in monthly average over the past 5 years and the concentration of $PM_{2.5}$ present in the San Francisco air.

DISCUSSION

While most of the collected data showed a slight decrease in air pollution in 2020 during June and July due to altered human activity as a result of COVID-19's shelter in place, most of the difference in pollution concentration was found to be not statistically significant based on an alpha of 0.05. The difference in means from 2015 through 2019 compared to 2020 for NO_x in Lake Tahoe at Tahoe City was statistically significant (p-value = 0.01). The drop from an average of 5.78 ± 0.97 ppb for 2015 to 2019 to 3.5 ppb in 2020 shows a significant difference in NO_x air pollution. Since NO_x is a product of car emissions reacting with particles in the air, it is possible that this reduction is partially explained by a lack of human activity in Tahoe City due to the shelter in place order for COVID-19. However, while this average concentration has decreased, the automobile activity in Placer County has increased 50% over the baseline as of July 26, 2020, after dropping 60% below the baseline in mid-April, amidst the height of the lockdown order, according to Apple's COVID-19 Mobility Tracking (2). The baseline is an average value of collected movement in a certain location between January 3rd and February 6th, 2020. The concentration of O_3 present in the air of Placer County during June and July of 2020 did not demonstrate statistically

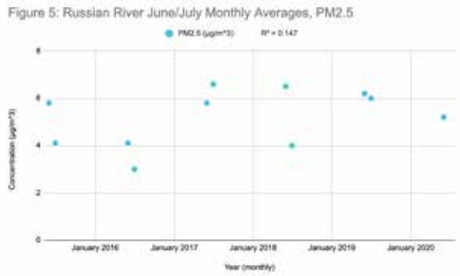

Figure 5: The x-axis represents time from 2015 to 2020 and the y-axis represents the concentration, in µg/m3, of $PM_{2.5}$ for the Russian River in Guerneville of Sonoma County.

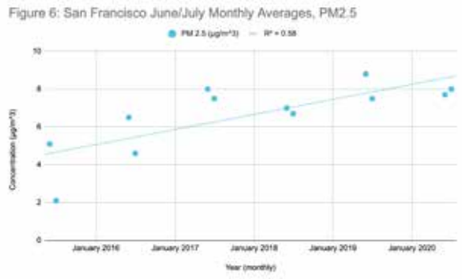

Figure 6: The x-axis represents time from 2015 to 2020 and the y-axis represents the concentration, in µg/m3, of $PM_{2.5}$ for San Francisco County.

significant results (p-value = 0.14). Tahoe City has a population of 2,151 as of 2018 and 60% of North Lake Tahoe's business' workers were laid off as a result of the shelter in place order issued on March 22 (18,19). 70% of North Lake Tahoe's homeowners are vacation homes meaning the homeowners live full-time elsewhere (18). With the closing of ski resorts in March and a decrease in tourism during the past few months, which began to escalate at the beginning of June for the summer months, there was a lack of activity on the roads and in the water of Lake Tahoe. O_3 is created when reacting with sunlight, NO_x, and partially combusted hydrocarbons. When there are fewer hydrocarbons and NO_x present, the production of O_3 occurs less frequently between these molecules.

On the other hand, $PM_{2.5}$ and PM_{10} in the air at Lake Tahoe had also slightly decreased from 2015 to 2020 (r^2 = 0.07) with the difference in $PM_{2.5}$ being statistically significant (p-value = 0.04) and PM_{10} being not statistically significant (p-value = 0.74). The reduction in $PM_{2.5}$ present in the air from an average of 11.58 ± 3.34 µg/m3 during June and July between 2015 and 2019 to 5.75 ± 1.06 µg/m3 in 2020, could have resulted from a decrease in industrial activity. $PM_{2.5}$ can come from fires, trucks, and power plants and the COVID-19 shelter in place affected the activity levels of all of these. This reduction in $PM_{2.5}$ can be partially attributed to the decrease in human activity. The notably higher $PM_{2.5}$ in July 2018 and PM_{10} concentrations in June and July of 2018 are likely a result of the California wildfires that year (20, 21). The Ferguson fire near Yosemite in Mariposa County began in early July and was put out by the end of July (21). The Carr fire near Redding, CA also occurred in late July, which would heavily impact PM caused by smoke in Northern California near Lake Tahoe due to its proximity. However, despite the slight drop in PM_{10} pollution, the data was not statistically significant and cannot be deemed a result of the change in human activity because of the shelter in place order. $PM_{2.5}$ will stay suspended in the air longer than PM_{10} cannot stay suspended for long periods so the PM_{10} concentrations could have been affected by the difference in human activity in March/April but likely went back to normal concentrations in June/July when shelter in place restrictions lessened. PM_{10} are larger particles that can come from dust, farms, construction sites, mines, and riverbeds (12). While the activity surrounding these sites could have been altered due to COVID-19, the emissions or resulting PM was not highly affected in June/July, but it could have been affected more significantly during the lowest points of human activity in March/April. The air quality in terms of $PM_{2.5}$ and NO_x around Tahoe City at Lake Tahoe slightly improved due to the altered daily life and change in human activity because of COVID-19.

The pH of Lake Tahoe has standard measurements between 7 and 8.4 pH. Due to sunlight and photosynthesis, the surface water of a lake tends to be more basic than the deeper levels. Additionally, minerals from the basin of the lake or carbonate will create a more alkaline body of water. The average pH of Lake Tahoe between June 27th and 29th of 2020 was 7.65 which falls in the standard range, implying that the shelter in place order, lessening human activity on and off the water did not have much impact on the pH of Lake Tahoe. The TDS concentration is another indicator of water quality. Lake Tahoe's desired limit for conductivity is 95 µm/cm or 47.5 ppm for TDS. The average TDS level for the aforementioned dates in June was 39.5 ppm. The turnover of the water heavily impacts the TDS readings but based on the average, which is in the higher range of acceptable concentrations, the change of human activity did not seem to heavily impact the TDS levels of the water.

Between 1980 and 2012 the total nitrogen concentration of the lake had been between 0.013 and 0.019 ppm, while the average nitrogen content in 2018 was 0.21 ppm (22, 23). The data taken in 2020 revealed 0 ppm of both nitrite and nitrate in Lake Tahoe, along with the Russian River and North Lake in San Francisco. The detection limit of the API Freshwater Test Kit was between 0 and 5 ppm of each contaminant. Based on the previous concentrations of nitrogen in Lake Tahoe, it is likely that the concentrations in 2020 were in the same range and were thus within the 0-5 ppm measurement of the API measurement kit but did not allow for a comparison of the data. Similarly, the nitrogen concentrations at the Russian River in Guerneville were undetectable by the API Freshwater Kit with daily averages from June 2, 2011, at 0.193 ppm nitrate, 0.0032 ppm nitrite, and 0.331 ppm total nitrogen. Therefore, the data collected cannot be properly analyzed and used to determine an effect from the shelter in place in Guerneville on the river's water quality in terms of nitrogen concentrations. Lastly, with the same issue, North Lake in San Francisco's Golden Gate Park had measured daily averages from June 16, 2014, with a nitrate concentration at 1.575 ppm, nitrite at 0.0365 ppm, and total nitrogen at 2.765 ppm, while the API kit measured 0-5 ppm for all nitrogen levels.

The average pH of North Lake in 2020 taken from daily averages between June 30, 2020, and July 2, 2020, was 8.82. The alkalinity of the lake can be attributed to many ecosystems residing in it, including plants, algae, and fish. The population of fish increases the need for dissolved oxygen for survival which in turn increases the pH of the body of water. There was no pH data over the past 5 years accessible for North Lake making a comparison of the pH unavailable. The average TDS levels of North Lake from the June and July 2020 dates was 190.73 ppm. The average TDS level from 1988 read at 264.5 ppm. While the 32-year difference makes it extremely difficult to compare the TDS concentrations, it is apparent that the minerals and ions present in the water have greatly decreased but interpreting this difference as attributable to limited human activity because of COVID-19 and the shelter in place, would be unsupported.

AIR QUALITY

Location:		Tahoe City: Lake Tahoe				Guerneville: Russian River			San Francisco: North Lake		
	Month:	NOx (ppb)	O3 (ppb)	PM2.5 (µg/m^3)	PM10 (µg/m^3)	NOx (ppb)	O3 (ppb)	PM2.5 (µg/m^3)	NOx (ppb)	O3 (ppb)	PM2.5 (µg/m^3)
	June 2020	4	41	6.5	15.6	2	22	5.2	5	24	7.7
	July 2020								2	28	8
	June 2019	5	44	9.1	15	3	26.7	6.2	8	30	8.8
	July 2019	4	46	8.8	14.2	2	21.7	6	6	29	7.5
	June 2018	5	49	9.4	21.9	3	28	6.5	8	38	7
	July 2018	5	54	19	21.3	2	25	4	7	31	6.7
	June 2017	6	42	8.7	12.1	4	25	5.8	10	35	8
	July 2017	6	52	14.4	15.1	3	27	6.6	11	28	7.5
	June 2016	7	46	10.8	17.2	4	28	4.1	9	36	6.5
	July 2016	7	51	14.3	16.6	3	23	3	6	26	4.6
	June 2015	6	51	10	20.3	4	29	5.8	8	34	5.1
	July 2015	6	44	11.3	17.3	3	24	4.1	7	35	2.1
p-value: comparing 2020 mean to 2015-2019 mean concentration during June and July		0.01	0.14	0.04	0.74	0.07	0.25	0.84	0.01	0.06	0.33
SD: 2020/15-19		0.71/0.95	2.83/4.04	1.06/3.34	0.99/3.22	0/0.74	2.12/2.39	0.28/1.28	2.12/1.63	2.83/3.94	0.21/1.96
mean: 2020/15-19		3.50/5.78	43.00/47.90	5.75/11.58	16.30/17.10	2.00/3.10	23.50/25.74	5.40/5.21	3.50/8.00	26.00/32.20	7.85/6.38

Table 1: June and July monthly averages are shown above for NO_x and O_3 concentrations in ppb, and $PM_{2.5}$ and PM_{10} in µg/m3 for Tahoe City's Placer County, Guerneville's Sonoma County, and San Francisco County.

Instrument	Use	Precision	Detection Limit
API Freshwater Test Kit	Nitrate concentration	0.25 ppm	5.0 ppm
API Freshwater Test Kit	Nitrite concentration	5.0 ppm	160 ppm
Ketotek TDS meter	TDS levels	0.01 ppm	9990 ppm
Ketotek pH meter	pH levels	0.01 pH	16 pH

Table 2: Precision of Instruments (Used in Field Data Collection).

San Francisco is a heavily populated city of 883,305 people as of 2018 (24). The shelter in place order decreased driving activity by 75% below the baseline in April 2020, and remains 26% below the baseline as of late July 2020, while many were laid off or switched to remote working schedules (2). The lack of car emissions in the city likely affected the air quality in San Francisco. While by June and July of 2020, the shelter in place restrictions had been somewhat lifted, human activity remains below average for this time of year. While the NO_x concentrations in San Francisco County dropped from an average of 8 ± 1.6 ppb in June and July of 2015 to 2019 to 3.5 ppb in 2020, the drop is statistically significant (p-value = 0.01) and therefore can be partially attributed to the difference in activity levels due to COVID-19 and the shelter in place. The decrease in O_3 concentrations from 32 ± 3.9 ppb in 2015 through 2019 to 26 ppb in 2020 is not quite significant enough (p-value = 0.06) to be a result of the reduced human activity due to the shelter in place. A revision to the 2008 Ozone National Ambient Air Quality Standards (NAAQS) was made to reduce O_3 emissions as well. The new NAAQS was 70 ppb instead of the 75 ppb standard placed in 2008 (25). This nationwide policy would cause all counties to work harder in reducing their O_3 emissions and can also be a partial explanation for San Francisco's decreasing O_3 concentration from 2015 to 2020. Even though the p-value is based on an alpha of 0.05 for statistically significant, a p-value of 0.06 is very close to 0.05. Though the data is not quite statistically significant, it could have been significant with more data points to support the p-value. While the air quality in San Francisco improved as a result of the lack of human and road activity, these results do not fully support this change in air pollution (26). While the NO_x and O_3 concentrations slightly decreased, the $PM_{2.5}$ concentrations in San Francisco did not show a difference and the results are not statistically significant. However, eLichen's determined that the shelter in place order caused a 19.7% decrease in $PM_{2.5}$ in the San Francisco area from late March to early April (27). While the collected data for my study was conducted in June and July of 2020, the increase in $PM_{2.5}$ does not agree with previous studies, but is not statistically significant and cannot be supported by the decrease in human activity.

While at the height of California's shelter in place order in April 2020, driving in Sonoma County had decreased 45% below the baseline, whereas by July 2020 driving had gone back up to 18% over the baseline (2). The Russian River $PM_{2.5}$ levels were not statistically significant (p-value = 0.84) so the concentrations of $PM_{2.5}$ did not change noticeably. On the other hand, both NO_x and O_3 air concentrations resulted in not statistically significant data for the same period and these results were relatively similar to the previous 5 years and did not see a significant change in concentration. Since the data did not turn out to be statistically significant there can be no determined correlation between the shelter in place order due to COVID-19 and the reduced human activity it caused and air quality in Sonoma County.

Since June and July of 2015, the pH of the Russian River near Guerneville has remained fairly constant around a pH of 8. The difference in mean pH (8.10 ± 0.17) from June and July 2015 through 2019 is not statistically significant in comparison to the mean pH (8.02 ± 0.46) from 2020. The human activity changes as a result of COVID-19 did not noticeably impact the pH of the Russian River's water. The mean of 132.43 ± 5.87 ppm in June and July 2015-2019 compared to the mean from 2020 of 124.67 ± 0.29 ppm is statistically significant (p-value = 0.004) and might have been impacted by the reduction in human activity due to the shelter in place order around California. TDS can be a product of urban and natural runoff from storms, minerals in the water, and industrial wastewater. With a lack of human activities, many sources for ions to enter the water have been curtailed and changed the TDS concentration of the Russian River. 2020's snowpack only measured 53% of the average snow for April, meaning it was a dry snow season in California (28). Less snowpack leads to less snowmelt entering California's water system which would reduce the sediment and suspended ions in the Russian River as well.

The null hypothesis, that the shelter in place order did not affect either the water or air quality in any of these three locations cannot be fully rejected for most of the data, but it is clear that the lack of human activity might have contributed to improvements to NO_x and $PM_{2.5}$ for air quality in Placer County, Lake Tahoe as well as TDS in the Russian River at Guerneville. The hypothesis that the pollutants in water and air would decrease in all locations was not fully supported by the collected and analyzed data.

While collecting and analyzing data there are always sources of error to account for. This data set encompasses June and July daily and monthly averages from 2015 to 2020 for Sonoma County, Russian River; San Francisco County, North Lake; and Placer County, Lake Tahoe. In these three locations, air and freshwater quality were tracked over time to determine if California's shelter in place order due to the COVID-19 pandemic affected air and water pollution levels. Lake Tahoe, Russian River, North Lake, and their counties do not fully represent the effect on air and water quality around California due to their small sample size in comparison to the state. Additionally, varying time of day and weather can affect the turnover of the water which would impact the TDS readings. Similarly, though all the water quality data was collected during the day while the sun was present, the pH levels could have also been affected by the difference in the time of day the samples were collected. The remote water quality data for Lake Tahoe and North Lake are averages and standards which are compared to daily averages to demonstrate an overall understanding of the lack of change or differences in water quality but cannot be compared directly. Some of the remote data used had to have unit conversions to compare water and air quality data accurately, but the procedures required rounding which could have led to slightly altered outcomes and affected the data comparison. Personal bias is also a source of error where the data and results may have been subconsciously skewed to generate a certain outcome. Lastly, the methods used for collecting the field water data were much less precise than the remote data methodology which would make the remote data more reliable than the field data. In turn, the comparison made of field to remote data cannot be fully accurate due to differences in how the data was collected.

Each data site represents a different location type in California. The urban environment of San Francisco compared to the rural town of Guerneville and the high sierra area of Lake Tahoe entails varying situations and differences amid the shelter in place order. In San Francisco, Bay Area, driving is down below baseline average by 18%, walking has decreased by 42%, and public transit lines have decreased to 66% below the baseline, all for July of 2020 (2). But, with a denser population of people in the city and a bigger difference in transportation than Guerneville and Tahoe City, the difference in air pollution, except for NO_x from 2020 and 2015 through 2019 does not vary notably from the other counties. The values of air pollutants in San Francisco are significantly higher because more automobiles move through the city daily. However, the O_3 concentration in Tahoe City is higher than that of San Francisco. Since San Francisco is located on the Pacific Ocean, the sea breeze brings the cold air to the land thus causing the warmer air in the city to rise creating a circular flow of air. The O_3 concentration in San Francisco is then impacted by this cycle, which also depends on the air temperatures and sunlight, and transports the O_3 through this cycle or to a location where it can get trapped (29). For example, a mountain range or valley. Lake Tahoe is surrounded by the Sierra Nevada mountains which hold in and contain the O_3, therefore increasing the O_3 concentration despite a smaller population of people and automobiles. The air pollution from the Sacramento valley due to vehicle emissions travels up the mountains and can reach the Lake Tahoe basin, thus potentially increasing the O_3 concentration (30, 31). The mixing caused by the cumulonimbus clouds that form in Lake Tahoe can increase the concentration of O_3 in the troposphere because they act as wet chemical reactors and increase NO_x production through lightning, therefore expanding ozone production as well (32).

Overall, the analyzed data demonstrated a slight decrease in air pollution and a decrease in water pollution in the Russian River while water quality remained stable in the other locations. The difference in location sites affects the air and water quality of each county and body of water. The data used and collected does not fully support the hypothesis that air and water pollution would decrease in all three locations. However, the data does not represent all of California and is not precise enough to assume large or no change in the three testing sites.

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Assessing the water quality at Pescadero Creek, CA: does water turbidity and the creek's composition affect the water quality?

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ABSTRACT

Right now in the world, there are many factors affecting the world's environment. Environments, ecosystems, and weather throughout the world are changing due to the anthropocene. Humans are affecting the water quality of creeks and rivers throughout the United States, often through pollution and agricultural run-off. Large amounts of nitrogen in water can affect a creek's ecological surroundings. With the water quality changing, aquatic species and its ecological surroundings are now being affected as well. In my research, I studied the water quality at Pescadero Creek to find the relationship between water turbidity and the creek's composition, to the water quality. My research suggests how "murky" water contains large amounts of ammonia, compared to clear water. This is because the sediment contains larger amounts of ammonia levels. The large amounts of ammonia in the sediment of the creek is affecting the aquatic life and ecological surroundings of the Pescadero Creek. My research also suggested how the nitrite levels at rocky surroundings were larger than nitrite levels at sandy surroundings. This may be due to all the fertilizers and sewage in the water sinking into the sediment of the creek, causing there to be less nitrite levels at sandy surroundings since there is lots of sediment compared to water in rocky surroundings.

INTRODUCTION

Environments, ecosystems, and weather are all changing around the world. These changes have to do with human involvement in climate change. Life in the anthropocene is creating a novel or new environments through pollutants, land changes, and more. Research has shown us how urbanization and agriculture are two human activities that have been affecting the water quality at rivers across the whole United States (Edwards G. Stets, Lori A. Spargue, Gretchen P. Oelsner, Hank M. Johnson, Jennifer C. Murphy, Karen Ryberg, Also V. Vecchia, Robert E. Zuellig, James A. Falcone, and Melissa L. Riskin, 2020). Due to the anthropocene affecting water quality in rivers and more, species could be affected as well. With everything now changing throughout the world, species are now facing a dramatic decline, estimating that around 1 million plant and animal species are now being threatened with possible extinction (Sustainable Development Goals, 2019).

One animal that has faced rapid population declines is the steelhead trout (oncorhynchus mykiss). Steelhead trout are native to the US west coast and for 35 years, outrageous amounts of steelhead trout have been dying (Canadian Science Publishing, 2017). Steelhead trout are very abundant in fisheries and make up a large portion of their economy. But the steelhead trout population has been declining especially in California (Jacob Katz & Peter B. Moyle & Rebecca M. Quiñones & Joshua Israel & Sabra Purdy, 2013). A majority of steelhead trout populations are associated with a creek in California that runs from Santa Cruz and San Mateo countries, called Pescadero Creek. They believe that the steelhead trout at Pescadero Creek has decreased over the years through rainfall and other natural occurrences, the sand barrier reopened, which had been closed off for years. Since the sand barrier had been closed off for so long, this change caused some chemical and physical changes in Pescadero Creek (Chandra M. Richards, Oliver Moal, Celine Pallud, 2017), as well as factors like climate change and anthropogenic impacts (Paul J. Wood and Patrick D. Armitage, 1997). These factors are why the water quality at Pescadero Creek is important, it's affecting aquatic life in the creek.

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It's important to understand the water quality of the Pescadero Creek, to better understand how changing nutrient compositions could be affecting steelhead trout and other aquatic species dependent on this habitat. Water quality is classified by the amounts of different chemical compounds found within the water, as well as the acidity/basicity of the water. These compounds found within the water can either harm or help water quality. As well as how nitrogen in water helps with the growth of plants, but too much nitrogen in water adds excessive amounts of nutrients (USGS). Approximately78% of steelhead trout is projected to be killed off in the next century (Jacob Katz & Peter B. Moyle & Rebecca M. Quiñones & Joshua Israel & Sabra Purdy, 2013). Water quality, especially in creeks and rivers, is something that can be fairly influenced by human activities. My research question is: how does the water turbidity and the creek's composition affect water quality at Pescadero Creek?

METHODS

I collected water samples from three locations along the Pescadero Creek: location A (37.26669, -122.411802), B (37.266523, -122.411634), and C (37.266400, -122.410833). At each location, samples were obtained from both sides of the creek, which varied in river composition (rocky and sandy terrain). Six samples were collected from each terrain type. The first three samples that I collected were surface water, then the second three samples were collected after creating a high turbidity mixture, by kicking up the sediment from the creek, to better understand macronutrients that had settled in the creek bed. Location A was a portion of the Pescadero creek near the ocean, location B was a portion of the creek that was between the ocean and the larger part of the creek, and location C was of the larger portion of the creek. Samples from each location were collected within a 15-foot span. The samples were collected within five days of each other on July 8th, 10th, and 12th. All of the water samples were collected in plastic containers and were stored in a large cooler to ensure that living organisms in the water samples don't use up all the nutrients. I tested the water samples the day after collection.

I used JNW Direct Aquarium 150 Tests Strips and API Pond-Pond Master Test Kit for my water sample testing and followed the protocol included in the instructions. Briefly, I separated all the water containers by location, then used one test strip for each sample. Each test strip was submerged in a water sample and compared to the color on the color chart provided. I also used an API Pond-Pond Master Test Kit to test each water sample. I poured the water sample into 4 vials and then added the number of drops from each chemical directed by the instructions. I shook the vials and then would wait for 5 minutes for ammonia and nitrite vials, 3

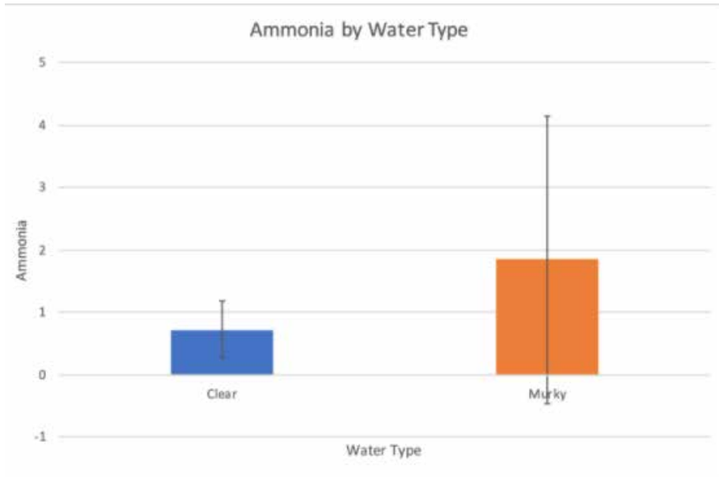

Figure 1: Ammonia levels in clear and murky water types. Ammonia levels were higher in the "murky" water type, or within water that had a higher turbidity than clear water ($t(106)=3.47$, $p=0.0007$). The total of ammonia in murky water types averaged to 1.8426 ppm (sd = 1.347), while ammonia levels in clear water types averaged to 8.093 (sd = 1.53).

minutes for phosphate vials, and would just shake the phosphate vial once. I then used the color chart provided by API Pond-Pond Master kit to compare my sample. I ran my samples outside of my home because I was dealing with chemicals and didn't want something to go wrong inside of my home.

RESULTS

In total, 108 water samples were collected throughout a five-day period. Using the JNW Direct Aquarium 150 Test Strips and the API Pond, Pond Master Test Kit, I was able to test Pescadero Creek's macro- and micro-nutrient composition, general hardness, total alkalinity, carbonate, and pH. The average for each one of those elements are iron (0), copper (0.5), nitrate (1.53), nitrite, (0.03), general hardness (282.4), free chlorine (0.6), total alkalinity (80.65), carbonate (91.76), and pH (7.2). While the API Pond, Pond Master Test Kit tested wide range (pH), ammonia, nitrite, and phosphate. The averages from these elements were wide range (8.02), ammonia, (1.3), nitrite (0.02), and phosphate (0.05). I ran these tests on each water sample because I know that pH, ammonia, nitrite, and phosphate are all important chemicals in water quality. Once I finished all of my data, I also ran t-tests to see if there were differences between the turbidity of the water and water quality, as well as comparing the water quality with the creek's composition at both sides of the creek. Two tests were significant. Ammonia levels in murky water was higher than ammonia levels in clear water ($t(106)=3.47$, $p=0.0007$). Nitrite levels were significantly different from each other when comparing different creek bed terrains. The rocky side had higher nitrite than the sandy side ($t(106)=2.099$, $p=0.038$).

DISCUSSION

My study suggests that the turbidity of the water and ammonia levels (Figure 1) have a relationship. I found ammonia levels in murky water were much larger than the ammonia levels found in clear water. When I went to Pescadero Creek to collect the water samples, I had to kick up the sediment from the creek, in order to get murky water. By kicking up the sediment from the creek, larger levels of ammonia were found. Ammonia is commonly found in sediment due to bacterial decomposition, so our results were consistent with this understanding. When bacterial decomposition happens the matter builds up in the sediment (EPA). The amount of nitrogen in creeks can either help the creek, or negatively affect the creek. Some level of nitrogen is important in water because it helps with the growth

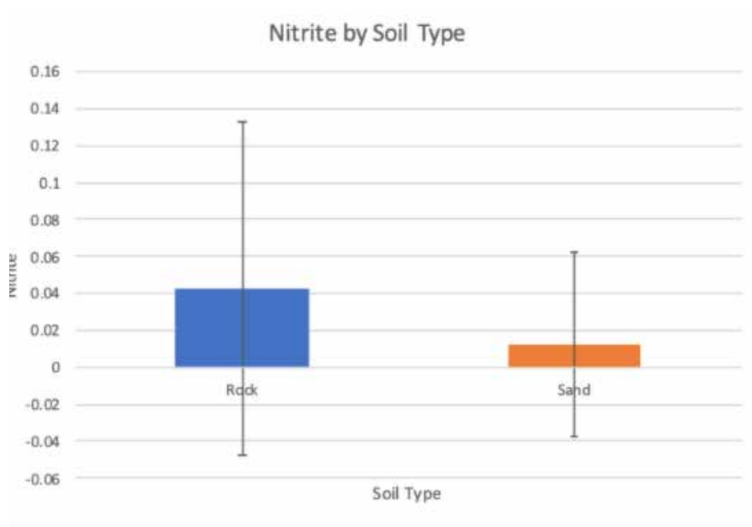

Figure 2: Nitrite levels in rocky and sandy soil types. Nitrite levels were higher in rocky soil types than sandy soil types ($t(106)=2.099$, $p=0.038$). The total of nitrite in rock soil averaged to 0.0426 ppm (s = 0.0918 ppm), while nitrite levels in sand soil types averaged to 0.012 ppm (sd = 0.0549 ppm).

of plants and animals, but too much nitrogen can affect the health of organisms in the water and it's ecological surroundings (USGS). The sediment in the murky water containing ammonia levels is affecting the water quality at Pescadero Creek. Potentially harming organisms and the ecological surroundings at the creek.

Nitrite levels found in rocky surroundings were larger than nitrite levels found in sandy surroundings (Figure 2). Nitrite levels come from fertilizers and sewage water (EPA). Why would there be more nitrite levels in rocky surroundings, rather than sandy surroundings? When I had gone to Pescadero Creek to collect water samples, I noticed how the water near rocky surroundings had less sediment. Rather than how the water near sandy surroundings had more sediment. Due to bacterial decomposition, the matter builds up in the sediment (EPA). So all the fertilizers and sewage in the water all go down with the sediment. Explaining how the sandy surroundings have less nitrite levels since all the nitrite goes down with the sediment, while the water near rocky surroundings stay in the water since there is little to no sediment in the water.

Since we know that nitrogen can affect the ecological surroundings of a creek, there could be a relationship between ammonia levels in murky water and nitrite levels at rocky areas. When I collected water at the rocky side of the creek, it was much harder to kick up the sediment from the creek because it would sink down rapidly. The answer for this can be related to how the nitrogen and the ammonia levels in the sediment can affect the ecological surroundings of the creek. Causing there to be much more nitrogen in the water with rocky surroundings, than sandy surroundings.

I found water turbidity and creek-bed composition at Pescadero Creek is affecting the water quality. Ammonia and nitrate levels significantly differed, which could be due to sediment settling. Knowing that the turbidity of the water increases ammonia levels in Pescadero creek, creek turbidity through human-activities may be having effects on aquatic life. For instance, when human activities draw up creek sediment, steelhead fish may be exposed to higher levels of nitrogen. This higher level of nitrogen may affect the health of the steelhead fish, possibly leading to death. It's not safe to say that these results are true for the entire creek, but these results do suggest that for the portion of the creek that I collected the water samples from, ammonia l evels in sediment and nitrite levels in rocky soil are impacting the water quality.

ACKNOWLEDGMENTS

Thank you to the Headwaters Science Institute for this amazing opportunity to create my own research project and thank you to my mentor Anne Espeset for accompanying me throughout this journey.

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Effects of Airport Runoff Pollution on Water Quality in Bay Area Sites Surrounding San Francisco and Oakland Airports

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ABSTRACT

Airports contribute to pollution through point source and non point source pollution, which can have a negative effect on water quality and aquatic life. The purpose of the study was to determine if runoff pollution from SFO and OAK airports impacts water quality in the Bay Area. We tested water quality at 12 sites surrounding two airports in the Bay Area. We tested for pH and the presence of specific metals and nitrates. As a result of the analysis, we found that the presence of zinc, copper, chromium and nitrate increases as we get closer to the airport. The pH remained constant throughout the sites. We concluded that airport pollution is a likely source of elevated concentrations of some heavy metals and nitrates in the San Francisco Bay.

INTRODUCTION

Pollutants from airport runoff can contaminate nearby waters and have a negative impact on the local ecosystems. The EPA controls and authorizes airport discharge into water through point sources of pollution in an attempt to diminish negative effects on water quality (1). However, unregulated pollution can also reach bodies of water through runoff. This contaminated runoff can have a negative effect on surrounding water since it holds a lot of contaminants. Pollutants in surrounding water around airports can kill fish, cause algae blooms, and contaminate the waters (2).

Unrestricted airport pollutants can reach bodies of water through a few ways. They can reach surrounding bodies of water through non-point sources and runoff pollutants. Pollutants from jet fuel and construction, as well as other chemicals, can gather on runways and other surfaces and can be washed into surrounding bodies of water by storms (1). Runoff pollutants may include oils, greases, de-icing chemicals, jet fuel excess, and metals (1). Chromium, Zinc, and Copper are common metals found in airport runoff, as well as nitrates (3). An increase of Chromium in bodies of water can cause harm and even death to aquatic species, particularly fish (4). An excess of zinc in water can cause damage to the organs and tissues of aquatic animals and may even cause death (5). An excess of copper also causes damage to organs and systems, such as the nervous system and the immune system of aquatic animals. Eventually, toxic levels of copper in water can lead to the death of aquatic organisms (6). An excess presence of nitrate in a body of water can cause an excessive growth of algae. Excess growth of algae causes unstable amounts of dissolved oxygen, which causes stressful conditions for fish and other aquatic species and may cause them to die off (7). Airport runoff can also affect the pH of surrounding waters. When the pH of a body of water is either too high or too low, the aquatic organisms living in that water will die (8).

To determine the relationship between pollution from airports and surrounding waters, we tested whether water quality decreased near an airport. Surrounding areas near two airports were studied to see how airports might impact water pollution. We tested three sites north of each airport and three sites south of each airport. The two airports we tested were San Francisco International Airport and Oakland International Airport. We measured ph, hardness, and sampled for the presence of metals and nitrates to test the hypothesis that water quality would decrease as proximity to an airport increased. Data from both airports showed that the water quality decreased as we got closer to the airport, showing that pollution from airports impacts the surrounding waters.

Figure 1: Sample location maps, map A is of SFO and surrounding sites I tested at. Map B is of OAK and sites I sampled surrounding it.

METHODS

I tested 12 sites by two airports, San Francisco International Airport and Oakland International Airport during July 4-5, 2020. I tested for pH and the presence of specific metals in three sites north of each airport and three sites south of each airport. To test pH, I immersed the VIVOSUN pH meter into the bay and waited until the reading stabilized. I then recorded the reading and cleared the pH meter by cleaning with pure water and drying it. I then repeated this process two more times. I repeated this process to measure the precision of my results. To test the presence of specific metals, I took a test strip from the Ultimate Drinking Water Test Strips (life2O) and immersed it in the bay for two seconds. I then removed it from the water and waited 60 seconds. After the 60 seconds I recorded the results. I then repeated this process once and compared my results to measure precision of the test strips.

Figure 2: Zinc levels near the SFO and OAK airports and surrounding areas. Moving north away from the airports zinc decreased and moving south away from the airports zinc decreased. The most zinc was detected at the sites closest to the airport.

Figure 3: Copper levels near the SFO and OAK airports and surrounding areas. Moving north away from the airports copper decreased and moving south away from the airports copper decreased. The most copper was detected at the 2 sites closest to the airport.

Figure 4: Chromium levels near the SFO and OAK airports and surrounding areas. Moving north away from the airports chromium decreased and moving south away from the airports chromium decreased. The most chromium was detected at the 2 sites closest to the airport.

RESULTS

The effect of airport pollution on water quality was tested through measuring parameters of water quality in sites surrounding airports. I tested three sites north and three sites south of two airports, San Francisco International Airport and Oakland International Airport (see figure 1).

I tested for pH and the presence of zinc, copper, chromium, and nitrate. I took multiple measurements at each site to assess the precision of my results. The levels of zinc in the water increased as we got closer to the airport (figure 2). The zinc levels were highest at the sites closest to the airport (N1 and S1), ranging from 8 to 10 mg/L, and lowest at the sites farthest from the airport (N3 and S3), ranging from 3 to 5 mg/L. The levels of copper and chromium also increased near the airport (figures 3 and 4). The copper levels were highest at the sites closest to the airport (N1 and S1), at 0.1 mg/L. They were lowest at the sites farthest from the airport (N3 and S3), situated at 0.5 mg/L. The levels of chromium were highest at the sites closest to the airport (N1 and S1), at 4 mg/L. The levels were lowest at the sites farthest from the airport (N3 and S3), set at 2 mg/L. Nitrate was detected at the sites closest to the airport (10 mg/L), but was not detected at the sites farthest from the airport (figure 5). The pH levels remained fairly consistent throughout the sites, with a slight increase as we got closer to the airport (about 1). The Oakland sites had a slightly higher pH (at around 9) than the corresponding San Francisco sites, at around 8 (figure 6).

Figure 5: Nitrate levels near the SFO and OAK airports and surrounding areas. Moving north away from the airports nitrate decreased and moving south away from the airports nitrate decreased. Nitrate was detected at the 2 sites closest to the airports and at the middle site north of SFO.

Figure 6: pH levels near the SFO and OAK airports and surrounding areas. Moving north away from the airports pH increased and moving south away from the airports pH decreased. The pH was higher at the sites in Oakland than it was at the sites in San Francisco.

DISCUSSION

Data shows an increase in levels of zinc, copper, and chromium as proximity to an airport increased, indicating that airport pollution impacts water quality. The findings presented in this study support my hypothesis that water quality will decrease as proximity to an airport increases. An excess of Chromium in bodies of water can cause harm and even death to aquatic species, particularly fish (4). Zinc and copper can cause damage to the organs and tissues of aquatic animals and may even cause death (5 and 6). Excess nitrate can cause an excessive growth of algae, which causes unstable amounts of dissolved oxygen. Unstable amounts of dissolved oxygen creates stressful conditions for fish and other aquatic species and may cause them to die off (7). However, I did not observe the expected decrease in pH, a reason for this may be because of inaccurate readings and instrument error. Alternatively, it might be that airport pollutant runoff is not acidic, so it doesn't affect the pH, or that it is acidic but is buffered by the existing chemistry of the water. Overall, the results of this study strongly suggests that pollution from the SF and Oakland airports are impacting water quality in the SF bay. However, other potential sources of pollution such as shipping traffic and human pollution, like litter, as well as other variables, like weather, input from streams and canals, and storm runoff could also influence the results. Additional testing on types of airport pollution and parameters of water quality would help to better understand how airports affect water quality.

Further research could include additional sampling of more sites in the Bay and of different canals that flow into the Bay, testing of more parameters, and testing at different times. This experiment would need to be tested at sites surrounding more airports in different cities and countries to see if the same results would appear and remain consistent. Further testing on the appearance of specific metals and other parameters of water quality, as well as other types of chemicals found in airport pollution, could help further clarify how airport pollution affects surrounding bodies of water. My experiment was testing for pollution from non-point sources and runoff pollution, which can be washed into bodies of water by storms. Therefore, future testing could include testing sites around SFO and OAK during different seasons and at different times of day. Taking data at times when there is more airport traffic, as opposed to less airport travel, would also be important to test. These suggestions for future research would help to further understand how airports affect water quality and aquatic life and would help the communities who depend on these bodies of water.

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Access to Public Parks, Drinking Fountains, and Clean Public Drinking Water Across Income Brackets in the Bay Area

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ABSTRACT

Access to green space and clean drinking water can be unequally distributed in urban spaces, often associated with income inequality. Little is known about public drinking water and green space inequities in the Bay Area. For our study, we asked, "How do public park access, drinking fountain access, and the quality of public drinking water differ across income brackets in the Bay Area?" and hypothesized that there would be a significant positive correlation between income and the number of drinking fountains, the number of parks, and drinking fountain water quality. For each Bay Area sub-region, water samples from four drinking fountains from four different ZIP codes were analyzed, and the number of parks and fountains was recorded in relation to income for eight different ZIP codes, resulting in 20 analyzed fountains and 40 analyzed ZIP codes. On a large scale, encompassing all sub-regions, water quality was generally high, and there was no significant relationship between income and park access, fountain access, and fountain water quality. However, smaller-scale instances of inequalities were observed in select sub-regions, particularly San Francisco and the South Bay. Further research directions could involve investigating San Jose Water's infrastructure and water treatment techniques, the health effects related to consuming cyanuric acid and ammonium chloride in water, and San Francisco's possibly inequitable distribution of public drinking fountains.

INTRODUCTION

Environmental injustice, residential segregation, and gentrification remain present-day issues that continue to affect access to green space and clean drinking water in America. Across 10 metropolitan areas—New York, Los Angeles, Chicago, Houston, Seattle, Phoenix, Indianapolis, Jacksonville, Portland, and St. Louis—income and higher education were found to be positively and significantly associated with access to green space (1). Although nationwide studies on drinking fountain access have yet to be conducted, researchers say fountains are fading from America's parks, schools, and stadiums (2). Additionally, breaches in drinking fountain water quality are not uncommon: in 2016, several public water fountains in Chicago were closed down after 445 out of the city's 1,891 water fountains not only tested positive for lead in the water, but also had lead levels over the EPA's action level, which is 15 parts per billion (3). A report published in 2018 found that in 12 states—those with available data on the lead content found in schools' drinking water—12% of all water samples tested had a lead concentration at or above the state's action level (4). In California, while 2% of community water systems in California receive drinking water that does not meet all primary drinking water standards, 8% of small community water systems violate one or more health-based drinking water standards and many of these are in communities where the median household income is less than 80% of the state median (5). This evidence points to significant relationships between income and green space and between income and clean drinking water access, which could have implications in a large urban sprawl such as the Bay Area.

To better understand how public park and clean drinking water access differed across the Bay Area, we investigated the accessibility of parks and drinking fountains, and the water quality of the latter in each sub-region of the Bay Area: the city of San Francisco, Marin County, the East Bay, the San Francisco Peninsula, and the South Bay, also known as Santa Clara Valley. We put an environmental justice lens on the question that guided our research: How do public park access, drinking fountain access, and the quality of public drinking water differ across income brackets in the Bay Area? The hypothesis was that there would be a positive correlation between median household income and the number of drinking fountains, the number of parks, and the quality of drinking fountain water. Data from the study indicated that while there was no correlation observed between income and drinking fountain water quality, income and park access, and income and drinking fountain access on a large scale, there appeared to be instances of inequality on a sub-region scale.

METHODS

To test water quality, four drinking fountains were selected from public parks in each of the five main sub-regions of the San Francisco Bay Area including: San Francisco, supplied by the San Francisco Public Utilities Commission (SFPUC), Marin County, supplied by the Marin Municipal Water District (MMWD), the East Bay, supplied by the East Bay Municipal Utility District (EBUD), the San Francisco Peninsula, predominantly supplied by San Francisco Public Utilities Commission and supplementary water utilities, and the South Bay, predominantly supplied by the San Jose Water Company. The four water fountains for each sub-region were selected through the WeTap mobile app, by availability (many public parks were closed due to the COVID-19 pandemic), by ZIP code variability (all fountains are from different ZIP code areas), and by variability in Esri's 2018 household median income estimates, although there was less variability in certain sub-regions where income estimates were generally uniform (6). Water fountain sampling locations can be seen in Figure 1 and data be accessed interactively here.

Water from the drinking fountains was collected in stainless steel water bottles and kept in the refrigerator for four hours, or until the temperature of the water reached around 70 °F; this was measured with HoneForest's Temperature, Total Dissolved Solids (TDS), and Electrical Conductivity (EC) meter. Each bottle of water was tested one at a time. From each bottle, four cups of water were emptied into a shallow glass container, which was washed after every sample. The temperature was recorded a second time to ensure it was close to 70 °F, then the TDS and EC levels were measured, all by using the meter described above. To test for Bromate, Iron, Copper, Lead, Nitrite, Nitrate, Ammonium Chloride, Total Chlorine, Fluoride, Chromium/CR(VI), Total Alkalinity, pH, and Cyanuric Acid levels, Test Lab's Drinking Water Test Strips were used. Instructions from the Test Lab's test strips were followed, involving dipping a strip into the water container for 2-3 seconds before placing it on a paper towel to dry for one minute. Then, the resulting colors were matched with their corresponding substance amounts on the bottle. This process was repeated twice per water sample, involving two strips each time. To test if there was a correlation between income level and water quality, charts were constructed through an online spreadsheet database. Each substance that was measured, via the strips and meter, was plotted against the median household incomes of the 20 ZIP code areas where the fountains were located.

For the park and drinking fountain access component of the study, four more ZIP code areas—in addition to the four that were already chosen for water sampling—were selected for each sub-region through ArcGIS. Each sub-region, therefore, had eight total ZIP code areas analyzed for drinking fountain and park numbers; four had drinking water quality data, and four did not. For sub-regions with less income variability (principally San Francisco, Marin, and the Peninsula) the four additional ZIP code areas were chosen randomly, and for sub-regions with more income variability (the East Bay and South Bay), the ZIP code areas were chosen to represent the varying incomes of the sub-region. The data informing the selection of ZIP code areas was Esri's feature layer, 2018 Popular Demographics in the United States, where 2018 median household income values were used. When the ZIP codes were being selected, only Esri's Population Demographics layer was taken into account—the park and fountain layers were not, in order to avoid bias. To collect the number of drinking fountains per ZIP code area, a layer with the coordinates of the 20 fountains that were accessed for water quality and a layer containing water fountain locations from OpenStreetMap database (last updated in 2016), were overlaid on top of Stanford's Census ZIP Code Tabulation Areas shapefile (7, 8). From there, the number of drinking water fountains per selected ZIP code was recorded.

To obtain the number of parks per ZIP code, the same Esri demographic layer was combined with The Trust

Figure 1: Map of ZIP codes analyzed for drinking fountain and park access, and drinking fountains analyzed for water quality. An interactive map is available: https://arcg.is/0arTrz.

for Public Land's ParkServe® layer—which includes location for all open-access parks in the US—and the number of public parks per ZIP code area was recorded (9). To calculate the number of parks and fountains per square mile for each ZIP code area analyzed, the recorded numbers of parks and fountains were divided by the water and land area for each ZIP code (10). To measure park and fountain access in relation to population, the numbers of parks and fountains were divided by the 2018 total population for each ZIP code. The quotient was then multiplied by 10,000 to obtain the number of parks and fountains per 10,000 people. Scatter plots in an online spreadsheet software were created. The number of fountains per 10,000 people, the number of parks per 10,000 people, the number of fountains per square mile, and the number of parks per square mile were plotted against the median household income. Four graphs encompassed all 40 ZIP codes analyzed, and 20 were created by sub-region—four graphs for each of the five sub-regions, with each sub-region composed of eight ZIP codes.

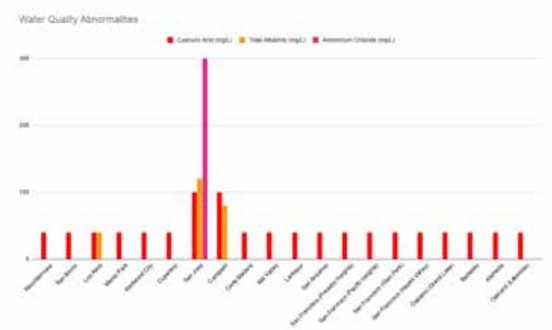

Figure 2: San Jose, Campbell, and Los Altos were all locations where higher levels of alkalinity, cyanuric acid, and ammonium chloride were exhibited and all three receive their water from the San Jose Water Company. All three substances are unregulated.

RESULTS

The relationship between median household income and park access, drinking fountain access, and water quality of drinking fountains was examined by testing four water fountains from four different ZIP code areas in each of the five Bay Area sub-region, resulting in a total of 20 water fountains sampled. Additionally, the number of parks and fountains per square mile and the number of parks and fountains per 10,000 people was counted for eight ZIP code areas per sub-region.

The water was tested for TDS, EC, Bromate, Iron, Copper, Lead, Nitrite, Nitrate, Ammonium Chloride, Total Chlorine, Fluoride, Chromium/CR(VI), Total Alkalinity, pH, and Cyanuric Acid levels. By examining the raw data, no measured substance levels exceed any drinking water standard limits, and there is little variability (Table 1).

The only variability observed was in TDS, EC, cyanuric acid, total alkalinity, and ammonium chloride levels. TDS and EC were found to have no significant correlation with median household income when tested. Only three ZIP codes—in Los Altos, Campbell, and San Jose—had alkalinity levels above 0. San Jose and Campbell samples also exhibited higher levels of cyanuric acid compared to the rest of the samples. San Jose had a high concentration of ammonium chloride, compared to all other ZIP code locations, which contained none (Figure 2).

	TDS (ppm)	Conductivity (µs/cm)	Bromate (mg/L)	Iron (mg/L)	Copper (mg/L)	Lead (PPB)	Nitrite (mg/L)	Nitrate (mg/L)	Ammonium Chloride (mg/L)	Total Chlorine (mg/L)	Fluoride (mg/L)	Chromium/CR(VI) (mg/L)	Total Alkalinity (mg/L)	pH (mg/L)	Cyanuric Acid (mg/L)
MCLG (mg/L)	n/a	n/a	0	n/a	1.3	0	1	10	n/a	MRDLG=4	4	0.1	n/a	n/a	n/a
MCL or TT (mg/L)	n/a	n/a	0.01	n/a	Action Level=1.3	Action Level=0.015	1	10	n/a	MRDL=4.0	4	0.1	n/a	n/a	n/a
Secondary MCL	500 mg/L	n/a	n/a	0.3 mg/L	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	6.5 - 8.5	n/a
Mountainview	207	440	0	0	0.05	0	0	0	0	0	0	0	0	7	30-50
San Bruno	62	131	0	0	0.05	0	0	0	0	0	0	0	0	7	30-50
Los Altos	207	440	0	0	0.05	0	0	0	0	0	0	0	40	7	30-50
Menlo Park	15	31	0	0	0.05	0	0	0	0	0	0	0	0	7	30-50
Redwood City	14	29	0	0	0.05	0	0	0	0	0	0	0	0	7	30-50
Cupertino	157	334	0	0	0.05	0	0	0	0	0	0	0	0	7	30-50
San Jose	363	772	0	0	0.05	0	0	0	300	0	0	0	120	7.5	100
Campbell	202	429	0	0	0.05	0	0	0	0	0	0	0	80	7	100
Corte Madera	77	163	0	0	0.05	0	0	0	0	0	0	0	0	7	30-50
Mill Valley	76	164	0	0	0.05	0	0	0	0	0	0	0	0	7	30-50
Larkspur	89	189	0	0	0.05	0	0	0	0	0	0	0	0	7	30-50
San Anselmo	86	182	0	0	0.05	0	0	0	0	0	0	0	0	7	30-50
San Francisco (Presidio Heights)	24	51	0	0	0.05	0	0	0	0	0	0	0	0	6.5	30-50
San Francisco (Pacific Heights)	26	55	0	0	0.05	0	0	0	0	0	0	0	0	7	30-50
San Francisco (Glen Park)	18	38	0	0	0.05	0	0	0	0	0	0	0	0	7	30-50
San Francisco (Hayes Valley)	25	53	0	0	0.05	0	0	0	0	0	0	0	0	6.5	30-50
Oakland (Grand Lake)	36	76	0	0	0.05	0	0	0	0	0	0	0	0	7	30-50
Berkeley	37	77	0	0	0.05	0	0	0	0	0	0	0	0	7	30-50
Alameda	30	63	0	0	0.05	0	0	0	0	0	0	0	0	7	30-50
Oakland (Lakeside)	43	91	0	0	0.05	0	0	0	0	0	0	0	0	7	30-50

Table 1: Raw water quality measurements. No significant correlation between any substance levels and ZIP code median household income.

Maximum Contaminant Level Goal (MCLG) - The level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs allow for a margin of safety and are non-enforceable public health goals.

Maximum Contaminant Level (MCL) - The highest level of a contaminant that is allowed in drinking water. MCLs are set as close to MCLGs as feasible using the best available treatment technology and taking cost into consideration. MCLs are enforceable standards.

Lead and copper are regulated by a treatment technique that requires systems to control the corrosiveness of their water. If more than 10% of tap water samples exceed the action level, water systems must take additional steps. For copper, the action level is 1.3 mg/L, and for lead is 0.015 mg/L.

National Secondary Drinking Water Regulations (NSDWRs) - Non-mandatory water quality standards for 15 contaminants. EPA does not enforce these "secondary maximum contaminant levels" (SMCLs). They are established as guidelines to assist public water systems in managing their drinking water for aesthetic considerations, such as taste, color, and odor. These contaminants are not considered to present a risk to human health at the SMCL. More information can be found at https://www.epa.gov/sdwa.

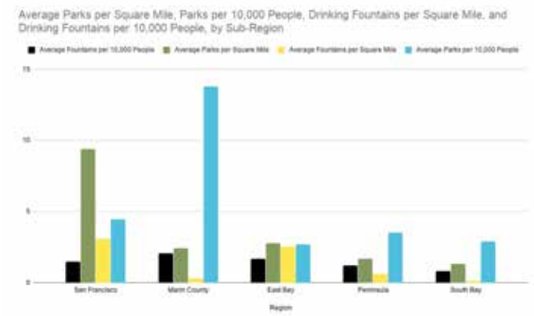

Figure 3: There is no significant relationship between the averaged values of all four variables and averaged median household income on a large scale, encompassing all sub-regions.

San Jose, Campbell, and Los Altos were all locations where higher levels of alkalinity, cyanuric acid, and ammonium chloride were exhibited and all three receive their water from the San Jose Water Company (11).

To explore whether a correlation existed between median household income and park and drinking fountain accessibility, eight ZIP codes—four of which were also analyzed for drinking fountain water quality—were examined in each sub-region. The number of water fountains per square mile, the number of parks per square mile, the number of fountains per 10,000 people, and the number of parks per 10,000 people was calculated and plotted against the median household income by ZIP code. To summarize all the data collected, a bar graph was constructed, using the averages of these four variables per sub-region. There is no significant relationship between the averaged values of all four variables and averaged income on a large scale, encompassing all sub-regions (Figure 3).

A scatter plot was created using the total dataset for parks per 10,000 people, fountains per 10,000 people, and income values to investigate whether there were correlations. Both trend lines appear to be positive, with a greater correlation between income and parks per 10,000 people than the former and fountains per 10,000 people; however, the coefficients of determination for both trend lines indicate that there is no significant correlation between ZIP code area income and parks per 10,000 people, and no significant correlation between income and fountains per 10,000 people in the Bay Area ZIP codes selected (Figure 4).

Additionally, while a slight negative correlation could be perceived in the relationship between income and parks per square mile, and the relationship between income and fountains per square mile, the coefficients of determination indicate no significant correlation (Figure 5).

Income was then plotted against parks/fountains per square mile and parks/fountains per 10,000 people on a sub-region scale. In San Francisco, there appeared to be a relatively significant positive correlation between income and fountains per 10,000 people (Figure 6).

In the South Bay, there was a strong positive correlation between income and parks per 10,000 people, while at the same time, there also is a strong negative correlation between income and parks per square mile (Figure 7).

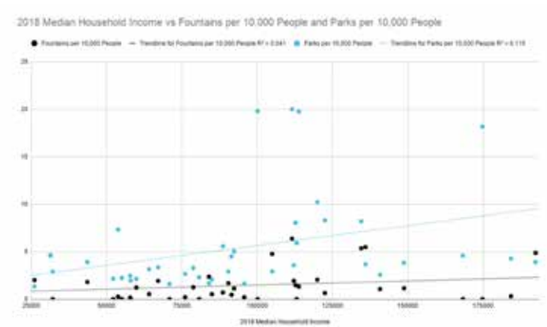

Figure 4: There is no significant correlation between income and parks per 10,000 people, and no significant correlation between income and fountains per 10,000 people in the selected Bay Area ZIP codes.

Figure 5: There is no significant correlation between income and parks per square mile, and no significant correlation between income and fountains per square mile in the selected Bay Area ZIP codes.

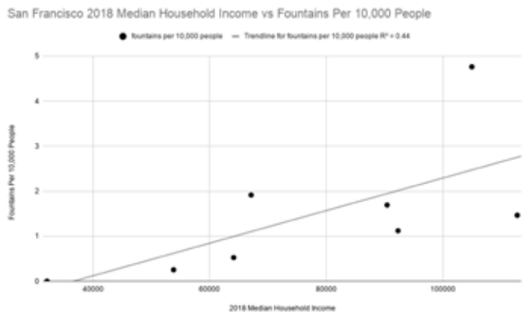

Figure 6: There is a relatively significant positive correlation between income and fountains per 10,000 people in San Francisco.

DISCUSSION

The water quality component of the study indicated that the water quality—defined by TDS, EC, Bromate, Iron, Copper, Lead, Nitrite, Nitrate, Ammonium Chloride, Total Chlorine, Fluoride, Chromium/CR(VI), Total Alkalinity, pH, and Cyanuric Acid levels—of all the drinking fountains measured across the Bay Area was generally high, substance levels met all regulatory standards, there was little variability, and there was no significant relationship between income and quality (Table 1). This result contrasts several nationwide studies that have demonstrated that low income and minority communities are disproportionately exposed to poor quality drinking water (12). It is hopeful to see a lack of positive association between income and water quality in the Bay Area, indicating that residents usually have access to high-quality drinking water, no matter their income level. The presence of contaminants in water can lead to adverse health effects, including gastrointestinal illness, reproductive problems, and neurological disorders. Infants, young children, pregnant women, the elderly, and people whose immune systems are compromised may be especially susceptible to illness from some contaminants (13). It is reassuring to know that Bay Area drinking water is generally not posing any significant health risks for residents.

The overall lack of variability in the water quality results could be attributed to the limited range of the test strips. Additionally, the few places where variability appeared could be attributed to possibly faulty test strips; however, each sample was tested twice to try to ensure accuracy. The high levels of ammonium chloride, alkalinity, and cyanuric acid in San Jose, of cyanuric acid and alkalinity in Campbell, and of alkalinity in Los Altos, call for further research into San Jose Water's and the local governments' services and infrastructure (Figure 2). The San Jose ZIP code that water was sampled from had a 2018 median household income of $57,824—$37,824 below the average median household income for all analyzed ZIP codes and $12,665 below the median household income for California, suggesting that in some parts of the Bay Area, income can make a difference in water quality (14).

Alkalinity in drinking water is not regulated, but drinking water usually is between 20 and 200 mg/L. Drinking alkaline water is generally perceived to be safe for the body (15). Cyanuric acid is unregulated in drinking water and is generally used in pools as a chlorine stabilizer, binding to free chlorine and releasing it slowly, extending the time needed to deplete each dose of sanitizer (16). Any amount of cyanuric acid above 90 ppm in pools has been shown to potentially cause sickness if swallowed; the amount found in the San Jose and Campbell fountains was 100ppm, indicating a potential health hazard (17). Ammonium chloride is a water-soluble salt, primarily used as a component in fertilizers, and also unregulated in drinking water (18). Repeated exposure to ammonium chloride has been found to cause effects secondary to hyperchloremic metabolic acidosis in laboratory animals, which is characterized by decreased bodyweight, decreased pH in blood and urine, increased serum calcium related to bone demineralization, enlargement of kidney, and adrenal gland hypertrophy (19). At a dose of more than 100 mg/kg of body weight per day, ammonium

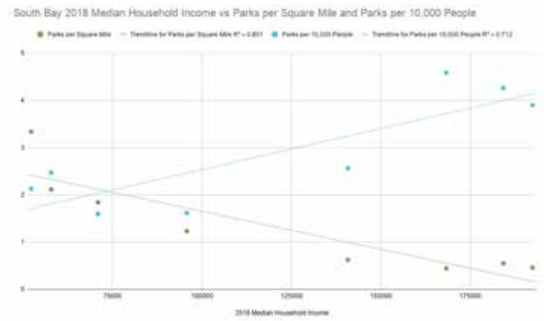

Figure 7: There is a strong positive correlation between income and parks per 10,000 people, while at the same time, there also is a strong negative correlation between income and parks per square mile in the South Bay.

chloride influences metabolism by shifting the acid-base equilibrium, disturbing the glucose tolerance, and reducing the tissue sensitivity to insulin (20). For the average American male, weighing 88.8 kg, consuming 888 mg of ammonium chloride in one day would predispose him to health issues. This equates to about 3 liters of water from the selected San Jose drinking fountain—a concerning fact, considering that 3 liters is not a very large amount. Because both cyanuric acid and ammonium chloride are unregulated in drinking water, high levels were reported, and they potentially impose a health risk, further research needs to be conducted on the health effects of these substances in drinking water to determine whether the EPA should regulate these substances in drinking water.

For the drinking fountain and park access component of the study, there was no significant positive correlation between income and fountain access, and income and park access, on a large scale, encompassing all 5 sub-regions (Figure 4, Figure 5). The lack of relationship between income and park access and income and drinking fountain access contrasts several nationwide studies that exhibit inequities in park and public drinking water access (1, 21, 22). These results are reassuring: a Bay Area resident's income does not seem to impact their access to parks or drinking fountains, amenities that greatly contribute to one's health and wellbeing (23, 24).

The lack of a significant correlation between income and park/fountain access could be attributed to the fact that park area was not taken into account, although larger parks, such as reserves, could generally be split up into multiple smaller green spaces to ensure accuracy. Marin County exhibited a substantially high number of parks per 10,000 people—this is most likely due to the large number of nature reserves scattered throughout the sub-region. The average median household income of the Marin ZIP codes was also $25,092 higher than the average of all selected ZIP codes, suggesting that the generally high incomes of Marin residents could possibly be linked to the great amount of green space. The relatively strong positive correlation between income and fountains per 10,000 people in San Francisco calls for further research into what could be causing this inequality and which neighborhoods need more drinking fountains. In the South Bay, the significant positive correlation between income and parks per 10,000 people coupled with the significant negative correlation between income and parks per square mile could be explained by variabilities in population density, park size, and income of the selected South Bay ZIP codes (25). In certain wealthier, less populated, suburban regions of the South Bay, the parks are generally more spread out, larger, and less crowded—due to the lower demand—which could account for the high number of parks per 10,000 people and the low number of parks per square mile for high-income ZIP codes. Whereas in low income, highly populated, urban centers, the parks are generally tightly packed together, smaller, and more crowded—due to the higher demand—hence the high number of parks per square mile and low number of parks per 10,000 people for low-income ZIP codes. This goes to show a potential inequality in park access in South Bay ZIP codes, as lower-income urban areas seem to not have a high enough supply of green space for the high number of residents, whereas the opposite is true in higher-income suburban areas.

In conclusion, while there were no significant relationships between income and park access, income and drinking fountain access, and income and public drinking water quality on a large scale, instances of injustice in San Francisco's fountain distribution, and in the South Bay's water quality and park distribution, were observed.

ACKNOWLEDGMENTS

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Effect of Fertilizer on Water Quality of Creeks Over Time

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ABSTRACT

Many people use fertilizer for commercial use in the U.S, but are unaware of their harmful impacts. The main two ingredients in fertilizer are phosphorus and nitrogen, and high nitrate levels in drinking water can cause methemoglobinemia in infants. In this experiment, I studied the effects of fertilizer on the water quality of Saratoga Creek over time. Over a period of four days, the total dissolved solids (TDS), pH, and nitrate levels of eight creek water samples were measured and analyzed through RStudio with the tidyverse package. Results showed that fertilizer had a significant effect on all three indicators, with TDS levels substantially exceeding the 500 ppm level suggested in the U.S. Secondary Maximum Contaminant Levels and nitrate concentrations surpassing the 10 ppm standard in drinking water set by the Environmental Protection Agency. TDS concentrations for the three fertilizer treatments at four days exceeded the standard by around 6 times, 12 times, and 20 times respectively, while the pH levels dropped below the acceptable range of 6.5-8.5. Nitrate levels spiked at two days, then gradually returned to their original levels. Linear regression tests revealed that TDS and pH both had a strong positive relationship with time. Although TDS does not pose as great a health risk, high nitrate and pH levels in water can have damaging effects on people's health if consumed and can contaminate the habitats of aquatic species. Therefore, I suggest that people limit their fertilizer use to protect the environment and their peers.

INTRODUCTION

To better comprehend the effects of fertilizer on water quality in creeks over time, I studied the changes in nitrate, total dissolved solids (TDS), and pH levels in water samples I collected from a local creek in the Bay Area after the addition of fertilizer.

Millions of people use fertilizer in their farms and backyards to increase their crop yield or enhance the growth of their plants. However, improper use of fertilizer combined with runoff can contaminate the groundwater of streams and creeks and degrade their water quality. There is concern that the additional nutrients in fertilizer could cause nutrient build ups in streams, lakes, and rivers, stimulating the unwanted growth of algae and other aquatic plants (1, 2). Furthermore, the nutrient enrichment could lead to reduced dissolved oxygen concentrations; without sufficient dissolved oxygen, fish and other aquatic species could suffocate (2).

Fertilizer is primarily made up of two nutrients: nitrogen and phosphorus (3). Although phosphorus is mainly responsible for algal blooms in surface waters and can cause eutrophication (4), its low solubility renders the loss of phosphates in water insignificant, especially in comparison to quantities released by industrial wastes (1). On the other hand, nitrogen is highly soluble and can leach down through the soil and contaminate groundwater (1, 3). The U.S. Public Health Service set the limit for nitrate levels in domestic water supplies to be 10 ppm (5). High nitrate levels in drinking water can cause babies to develop methemoglobinemia, a disorder which interferes with oxygen intake in the circulatory system (2, 3, 6).

The addition of fertilizer can also drastically change the pH of water, making it drop past the acceptable level of 6.5-8.5. Waters of low pH could leach toxic metals including iron, manganese, copper, lead, and zinc, create damage to metal piping, and have a bitter taste (7). Many species of fish and aquatic life are also sensitive to changes in water temperature and composition and could be harmed due to acidification (7). TDS levels are also an important indicator of water quality. The U.S. guideline for TDS is 500 ppm, and high levels of dissolved solids can stain household supplies, corrode pipes, and cause a metallic taste (7). Similar to pH, increased TDS levels may suggest that harmful metals like bromide, sulfate, and iron are present in the water (7).

Due to these effects, monitoring the nitrate, pH, and nitrate levels will help determine if fertilizer negatively impacts the water quality. My hypothesis was that as the amount of fertilizer in the creek increases, the water quality of Saratoga Creek will decrease. Data from my experiment illustrates that after the addition of fertilizer, the TDS and nitrate levels increased past the acceptable level in drinking water, while the pH levels decreased drastically, as the water turned acidic. Over time, the TDS levels continued to climb; however, the nitrate and pH levels began to gradually return to its original levels with the nitrate concentration decreasing, and the pH increasing. As a result, this experiment reveals that continual uses of fertilizer degrade the water quality of creeks, rendering it dangerous for aquatic species to live in and for human consumption.

METHODS

Eight 12 oz water samples were stored in a house at room temperature over a period of four days to study the effect of fertilizer on water quality. The 12 oz water samples were collected using measuring cups in identical mason jars from Saratoga Creek in Saratoga, California at 3:30 pm from a section of still water partially covered by shade from trees. The measuring cups helped ensure that an equal amount of creek water was in each of the jars. The jars were then taken to the house and labeled. The TDS, pH, and nitrate levels of the water in each of the eight jars were measured using a Total Dissolved Solids meter, pH meter, and nutrient strips respectively. The HM Digital TDS-3 Handheld TDS meter measures the TDS from 0 to 9,990 ppm, while the pH meter calculates the pH from 0-14, with a resolution of 0.01 pH. The nutrient strips used (Tetra EasyStrips 6-in-1 Test Strips) measure nitrate, alkalinity, hardness, pH, nitrite, and chlorine, but for this experiment, only the nitrate concentration was recorded.

Three different fertilizer treatments would be applied to six jars. Each of the three treatments of 0.5 tsp, 1 tsp, and 1.5 tsp had two replicates. Before fertilizer was added, the TDS, pH, and nitrate levels were measured to ensure that all of the water samples in the eight jars had similar levels to avoid possible confounding variables. Two jars were also not given any fertilizer and acted as the control for the duration of the experiment. After the different amounts of fertilizer (Miracle-Gro Water Soluble All Purpose Plant Food) were poured into their respective jars, the lids were put back on, and the jars were gently shaken for fifteen seconds to thoroughly mix the fertilizer into the water. The lids were then taken off, and the TDS, pH, and nitrate levels measured. Once the measurements were recorded, the jars were stored in a room at room temperature. The measurements were repeated at 2 days and 4 days.

In order to determine the fertilizer's effect on water quality, the time, TDS, pH, nitrate, fertilizer treatment, and jar # were recorded in an Excel spreadsheet. Using the tidyverse package in RStudio, the R2 and p-value for each of the three fertilizer treatments and control were calculated for TDS and pH using linear regression lines. Nitrate measurements were visualized with a line graph.

RESULTS

This experiment was conducted to study the effect of fertilizer on the water quality of creeks. Data was collected by measuring the change in TDS, pH, and nitrate levels over a period of four days after the addition of three different fertilizer treatments. The TDS and pH meter I used are good ways to calculate the TDS and pH as they are affordable (under $20) with an accuracy of +/- 2%. The 6-in-1 nutrient strips are a cost-efficient way to measure nitrate as they are cheaper than nitrate specific tests, but have relatively the same accuracy. I chose to run the experiment for four days, because it seemed like a reasonable time frame for observable changes to occur. Future iterations may be performed over a longer time period.

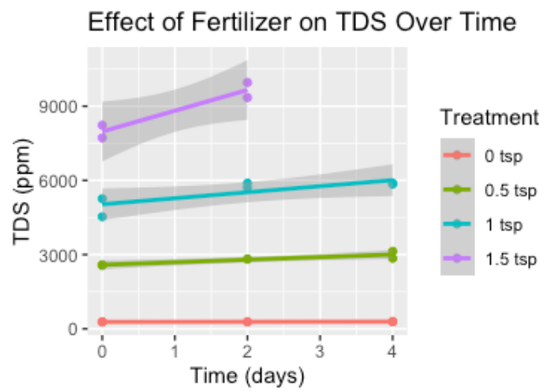

Figure 1: Fertilizer treatments had a significant effect on the Total Dissolved Solids (TDS) of Saratoga Creek ($p<0.01$), and there is a moderately strong association between TDS and time ($0.5<r2<0.9$).

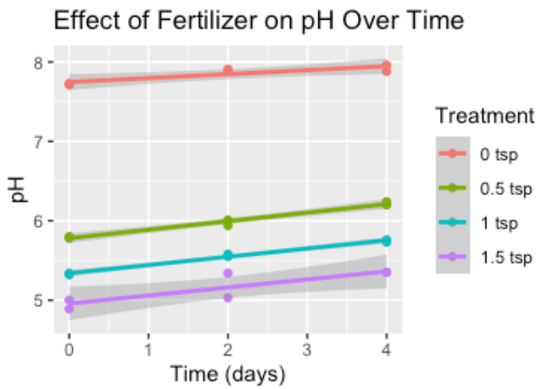

Figure 2: Fertilizer treatments had a significant effect on the pH of Saratoga Creek ($p<0.01$), and there is a strong positive correlation between pH and time ($r2 > 0.6$).

TDS	R^2	P-value
0 tsp	0.6042	0.04247
0.5 tsp	0.7572	0.01518
1 tsp	0.5603	0.05326
1.5 tsp	0.8489	0.05169
pH	**R^2**	**P-value**
0 tsp	0.7091	0.02213
0.5 tsp	0.9693	0.0002275
1 tsp	0.9849	5.507e-05
1.5 tsp	0.682	0.02669

Table 1: The R^2 and p-values for the association between time and each of the three water indicators (TDS, pH, nitrate) are calculated for the different fertilizer treatments using linear regression models in RStudio.

As expected, the control samples remained at approximately the same levels with the nitrate concentrations staying at 0ppm and the TDS and pH levels slightly increasing. An interactive model revealed that the fertilizer treatments had a significant effect on all three indicators ($p<0.01$). As the amount of fertilizer increased, there was a clear increase in TDS and nitrate levels, and a decrease in pH. The model also demonstrated that there was a weak association between fertilizer and time for TDS ($p=0.0525$) and no association between fertilizer and time for pH ($p>0.05$) and nitrate ($p>0.05$).

Linear regression tests revealed that there was a moderately strong, positive relationship between time and TDS (Figure 1, Table 1). No value was recorded at 4 days for TDS, because the number exceeded the max limit in the TDS meter. Time and pH were also observed to have a strong positive relationship (Figure 2, Table 1). Nitrate levels spiked on the second day with levels for all three fertilizer treatments increasing by 10 ppm, and gradually returned to their original levels by the fourth day (Figure 3).

DISCUSSION

The main goal of this experiment was to study the effect of fertilizer on water quality over time. The drastic increases in TDS and nitrate levels and overall decrease in pH after fertilizer was added supports my hypothesis. I hypothesized that fertilizer would degrade the water quality since the primary nutrients in fertilizer, nitrogen and phosphorus, could lead to the growth of toxic algal blooms and reduced dissolved oxygen content (2, 3, 4). The data supported my claim as after the addition of fertilizer, TDS and nitrate levels exceeded the U.S. guidelines of 500 ppm and 10 ppm respectively, while the pH dropped below the acceptable range of 6.5-8.5.

Over the period of four days, TDS levels for all fertilizer treatments increased, with the samples given 1.5 tsp surpassing 9,990 ppm on the fourth day (Figure 1). TDS is the total concentration of dissolved ions (7); therefore, it makes sense that the TDS would increase after the soluble fertilizer dissolved into the water, which adds thousands of ions. The experiment concluded after four days, but I believe if the duration was increased, TDS levels would have continued to climb, highlighting the negative impact fertilizer has on water quality.

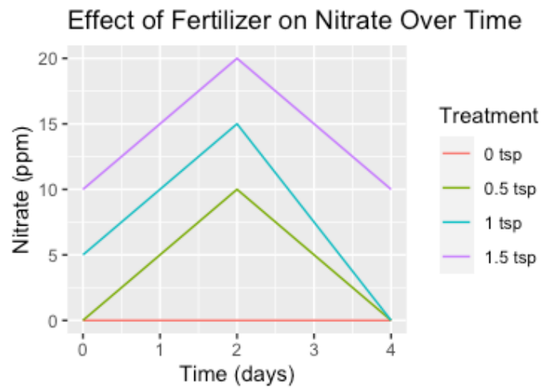

Figure 2: Fertilizer treatments had a significant effect on the nitrate levels of Saratoga Creek ($p<0.01$); there was little to no correlation between nitrate concentration and time as the nitrate levels spiked then decreased.

In this experiment, I used fertilizer to simulate the pollution from commercial activities on bodies of water, and the more fertilizer added, the lower the pH dropped (Figure 2). This decrease in pH is most likely caused by the nitrogen and phosphorus, which is abundant in fertilizer (3), since both elements are acidic. Over time, the pH levels slowly began to increase (Figure 2), but they were still substantially lower than where they started. Chemical pollution such as fertilizer causes bodies of water to turn acidic, which could be detrimental to species of fish (7), as the decrease in oxygen levels could cause certain aquatic species to suffocate (2).

Although nitrate levels gradually returned to its original levels by the fourth day (Figure 3), the spike on the second day can be dangerous for aquatic species and human consumption. The levels for all three fertilizer treatments were 10 ppm or above (Figure 3), passing the threshold of acceptable nitrate levels in water supplies. The decrease in nitrate levels over time can be attributed to denitrification (6), as between measurements, the lid was opened allowing nitrogen to be able to escape through the air. Over time, nitrogen levels could also decrease as a result from uptake by algae and aquatic plants present in the water (6).

Throughout the experiment, there were a few sources of error that may have affected my results. For example, the nitrate concentrations in the nutrient strips go directly from 0 to 20 ppm. As a result, my estimates could have been slightly off when calculating nitrate levels. Small dents in the measuring cups could have caused the amount of fertilizer given to each jar to differ marginally, which could impact the TDS, pH, and nitrate levels. Furthermore, since the TDS meter only measures up to 9,990 ppm, TDS values were unable to be recorded for the fourth day (Figure 1), which could have affected the linear regression line for the 1.5 tsp treatment.

This experiment was conducted on water samples from Saratoga creek, a local creek in the Bay Area; therefore, future experiments could test the effect of fertilizer on saltwater vs. freshwater sources. I used a specific brand of fertilizer, so different types of fertilizer including potassium, nitrogen, and phosphorus based fertilizers could be tested. The duration of the experiment could also be extended to study the long-term effects of fertilizer on water quality.

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Analysis of the Impact of Dams in Santa Clara County on the Nitrification of the Surrounding Ecosystem using the Cadmium Reduction Calorimetric Method

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ABSTRACT

Two dams in Santa Clara County were studied in order to determine how they impacted the nitrification rates of their surrounding ecosystems. Based on this information, the results were used to discern whether there were any correlations between their water conductivity, TDS, size, and age. Since it is reported that the locations upstream of dams typically have high nitrification rates and the locations downstream of dams often have low nitrification rates, the hypothesis formed was that if the dams are impacting the nitrification rates in these rivers, then the rates will be higher upstream of the dams than downstream of the dams. The results reveal that the soil nitrate levels are lower downstream than they are upstream, proving that dams are harmful to the environment because they cause nitrification rates to be higher upstream of the dams and lower downstream of the dams.

INTRODUCTION

Dams have many economic, environmental, and social benefits like recreation, flood control, water supply, hydroelectric power, waste management, river navigation, and wildlife habitat [1]. The economic and societal landscape of the United States would appear very different if it weren't for its 85,000 dams [2].

Even though dams provide many benefits to humans, they also have damaging effects on the environment. They significantly alter the physiography of watersheds, making them one of the most harmful human activities in river basins. Reservoirs critically affect their surrounding ecosystems and cause the interruption of river continuity (longitudinal and lateral, fish migration, sediment and nutrient transport), siltation of river bed and clogging of interstitial, homogenization of habitats, downstream river bed incision, alteration of river - groundwater exchange and downstream flow and water quality alteration [3].

Nitrogen Cycle is a biogeochemical process with many stages that allows nitrogen to take its many different forms, continuously passing from the atmosphere to the soil to the organism and back into the atmosphere [4]. Nitrogen is able to come into the world through bacteria and other single-celled prokaryotes that use the process of nitrogen fixation to convert atmospheric nitrogen (N_2) into biologically usable forms. While some species of nitrogen-fixing bacteria are free-living in soil or water, others live inside of plants and are beneficial symbionts. Nitrogen-fixing microorganisms are able to change atmospheric nitrogen into ammonia (NH3) and contain it with the following reaction. Plants are then able to absorb the ammonia, and it is used to make organic molecules [5].

$N_2 + 8\ H+ + 8\ e- \rightarrow 2\ NH_3 + H_2$

In the nitrogen cycle, nitrification is the step in the process that converts ammonia to nitrite and then to nitrate through oxidation. This step is carried out with the following reactions by a few different groups of microorganisms which include the ammonia-oxidizing bacteria, the ammonia-oxidizing archaea, and the nitrite-oxidizing bacteria [6].

$NH_3 + O_2 + 2e- \rightarrow NH_2OH + H_2O$

$NH_2OH + H_2O \rightarrow NO_2- + 5H+ + 4e-$

$2NO_2- + O_2 \rightarrow 2NO_3-$

Since reservoirs increase the settling of sediment upstream of the dam which is typically high in organic matter, this results in the decomposition and production of ammonia. Locations above the dams often have higher nitrification rates because of the build-up of sediments, while locations below the dam often have lower nitrification rates. This occurs due to the fact that the sediment-deprived water released from the dam does not have enough substrate to support large populations of nitrifying bacteria, and this results in a decrease in ammonia production, further lowering nitrification rates. A good signal of nitrification is nitrate concentration in soil. High levels of nitrogen can impact many other processes in addition to the nitrogen cycle. It can lead to nutrient imbalance in plants which can alter their health and changes in biodiversity and species composition that may lead to shifts in overall ecosystem function [5].

In order to determine how significantly dams harm their environments, the question asked was how do the dams in Santa Clara county impact the nitrification rates of their surrounding ecosystems? Based on this information, the results were used to discern if there are any correlations between the size and age of the dams, water conductivity, and TDS. Through background research, the hypothesis posed was that if the dams are impacting the nitrification rates in these rivers, then the nitrification rates will be higher upstream of the dams than downstream of the dams. From the ten local dams and reservoirs in the Santa Clara Valley, the research focused on the Almaden Dam and the Anderson Dam because of the significant difference in their ages and sizes (Table 1) [13]. The results of the experiments reveal that the soil nitrate levels are lower downstream than they are upstream, proving that dams are harmful to the environment because they cause nitrification rates to be higher upstream of the dams and lower downstream of the dams. This research on measuring the difference between the nitrification rates upstream and downstream of dams is important because it helps determine how significantly the surrounding ecosystems of the dams are being harmed and helps prevent future projects that can hurt the environment.

METHODS

For each of the two dams, 3 soil samples upstream and 3 soil samples downstream were collected in order to determine the nitrate levels of the soil. The HI 38050 Nitrate Test Kit was used to find the nitrate levels of all soil samples. The samples were taken from the top 12" of soil at varying distances and at spots close to the lake or creek. The large chunks of soil were then crumbled and distributed on plastic to air dry. A fan was used to dry the soil samples faster by moving air across it. After the samples were air dried, a small bar was used to crush the samples and they were passed through a 2-mm soil sieve. The samples were stored for less than 24 hours in a closed plastic bag in a cold place that was out of direct sunlight. They were not exposed to direct sunlight or heat.

The Calcium Sulfate Extraction was used to extract nitrate nitrogen from soils and could be used for all classes of soils. This method was repeatedly used to help determine the nitrate levels of each soil sample. The demineralizer bottle was first filled with tap water after its cap was removed. The cap was replaced and the bottle was shaken for at least 2 minutes. The demineralized water was now ready to use. The top of the demineralizer bottle cap was flipped open and the bottle was gently squeezed to add demineralized water to the test tube up to the 20 mL mark. The spoon was used to fill the sample cup with the sieved soil sample and to level the sample in the cup by discarding the excess soil with its handle. 10 g of the sieved soil sample was added to the tube. This was measured by adding 5 measures of the sample cup provided with the test kit. Calcium Sulfate was also added to the tube using 1 level spoon, which was provided with the test kit. The tube was capped and mixed thoroughly by shaking it up and down for 1 minute. It was then placed into one beaker. The funnel was placed on the top of the other beaker. A filter paper disc was then folded twice and one side of it was separated from the other three to form a cone. This folded filter disc was placed into the funnel and used to filter the sample. The extracted sample in the beaker was now ready for analysis.

The method used to determine the nitrate in the soil was repeatedly used for each soil sample. A pipette was first used to fill two glass vials with 5 mL of the extracted sample. One of the vials was inserted into the left hand opening of the checker disc. This was called the blank. 1 packet of HI 38050-0 reagent was then added to the other glass vial. The cap was replaced and the vial was thoroughly shaken for 1 minute. After waiting for 5 minutes, this became the reacted sample. The cap was removed and the reacted sample was inserted into the right hand opening of the checker disc. The checker disc was then held so that a light source illuminated the samples from the back of the windows. It was kept at a distance of 30-40 cm (12-16") from the eyes to match the color. The disc was rotated while looking at the color test windows and then stopped when the color match was found. The value in the result window was read and multiplied by 2 in order to obtain the nitrate-nitrogen value. The reading value could have also been multiplied by 2*4.43* to obtain the mg/L of nitrate (NO_3-). This reading process was performed three times for each soil sample and the average value was reported.

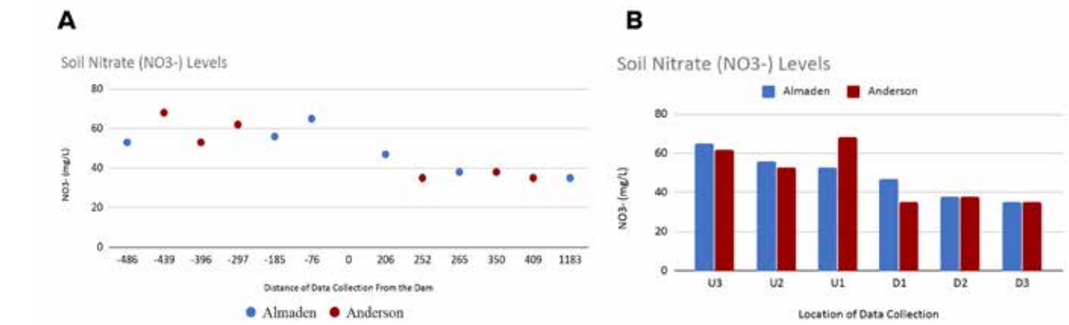


Figure 1: Graphs showing the difference between the soil nitrate levels measured downstream of the dam and upstream of the dam. A: Shows the distance of each sampling site from the dam. B: For the Almaden dam, the soil nitrate levels ranged from 44 to 71 mg/L upstream of the dam and from 35 to 53 mg/L downstream of the dam. For the Anderson dam, the soil nitrate levels ranged from 53 to 71 mg/L upstream of the dam and from 35 to 44 mg/L downstream of the dam.

For each of the two dams, 3 water samples upstream and 3 water samples downstream were collected in order to determine the nitrate levels, water conductivity, and TDS of the water. The HI 38050 Nitrate Test Kit was used to find the nitrate levels of all water samples. The TDS, EC, and Temperature Meter was used to find the water conductivity and TDS of all water samples. The samples were taken at varying distances away from the shore. The method used to determine the nitrate in the water was repeatedly used for each water sample. A plastic pipette was first used to fill two glass vials with 5 mL of water sample up to the mark. One of the vials was inserted into the left hand opening of the checker disc. This was called the blank. 1 packet of HI 38050-0 reagent was then added to the other glass vial. The cap was replaced and the vial was shaken vigorously for 1 minute. After waiting for 5 minutes, this became the reacted sample. The cap was removed and the reacted sample was inserted into the right hand opening of the checker disc. The checker disc was then held so that a light source illuminated the samples from the back of the windows. It was kept at a distance of 30-40 cm (12-16") from the eyes to match the color. The disc was rotated while looking at the color test windows and then stopped when the color match was found. The value in the result window was directly read as the mg/L (ppm) of nitrate-nitrogen (N-NO_3-). This reading was then multiplied by 4.43+ to obtain the

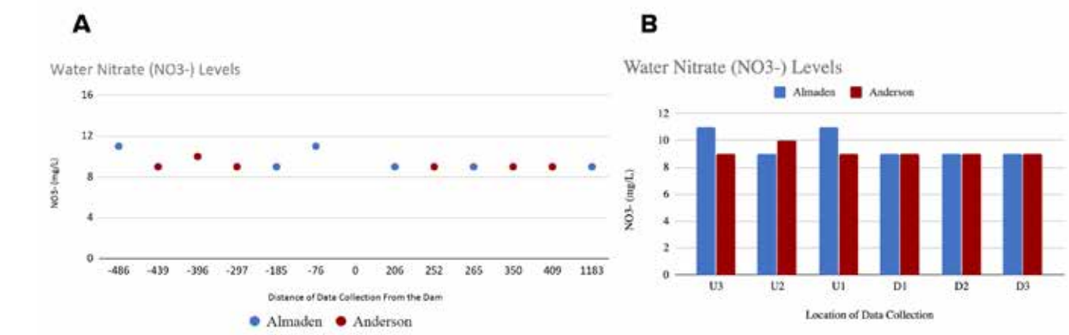


Figure 2: Graphs showing the difference between the water nitrate levels measured downstream of the dam and upstream of the dam. A: Shows the distance of each sampling site from the dam. B: For the Almaden dam, the water nitrate levels ranged from 9 to 11 mg/L upstream of the dam and always measured 9 mg/L downstream of the dam. For the Anderson dam, the water nitrate levels ranged from 9 to 11 mg/L upstream of the dam and always measured 9 mg/L downstream of the dam.

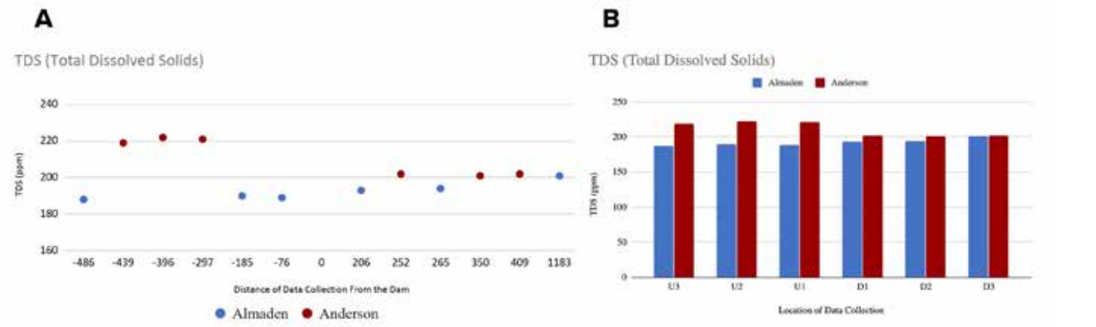


Figure 3: Graphs showing the difference between the TDS values measured downstream of the dam and upstream of the dam. A: Shows the distance of each sampling site from the dam. B: For the Almaden dam, the TDS values ranged from 186 to 192 ppm upstream of the dam and from 191 to 203 ppm downstream of the dam. For the Anderson dam, the TDS values ranged from 218 to 223 ppm upstream of the dam and from 200 to 203 ppm downstream of the dam.

mg/L of nitrate (NO_3-). This reading process was performed three times for each water sample and the average value was reported.

The method used to determine the TDS and water conductivity of the water was repeatedly used for each water sample. The protective cap of the probe was first removed and the "On/off" switch was pressed. The probe was then placed in the water sample up to the immersion line. The meter was stirred gently and after a few seconds, the TDS (ppm) reading was stabilized and locked automatically. The "mode" button was clicked to shift the instrument between TDS (ppm) and EC (us/cm). The "clear" button was then clicked to clear the current reading. The "On/off" switch was pressed for 3 seconds to switch off the meter. This process to determine the TDS and water conductivity was performed three times for each water sample and the average values were reported.

RESULTS

In order to test the scientific question, the relationships between many of the dams' other variables in addition to their nitrate levels had to be determined to see how the potential change in nitrification rates impacted them. The HI 38050 Nitrate Test Kit for Soil and Irrigation Water by Hanna Instruments was used to measure the soil and water nitrate levels and the TDS, EC and Temperature Meter by HoneForest was used to measure the water conductivity and TDS. For both the Anderson Dam and the Almaden Dam, 3 soil samples and 3 water samples upstream and 3 soil samples and 3 water samples downstream of the dam were collected. For each soil sample, the nitrate levels were measured three times with the HI 38050 Nitrate Test Kit, which uses the cadmium reduction method to measure the nitrate. Before measuring the nitrate levels, the Calcium Sulfate Extraction was used to extract the nitrate nitrogen from the soils. For each water sample, the nitrate levels were measured three times each using the HI 38050 Nitrate Test Kit and the TDS and water conductivity were measured three times each using the TDS, EC and Temperature Meter.

On average, the soil nitrate levels were noticeably higher upstream than they were downstream for both the Anderson Dam and the Almaden Dam (Figure 1). However, there were no significant differences between the averaged water nitrate levels, TDS, and water conductivity values upstream and downstream of the dams (Figure 2, Figure 3, and Figure 4).

	Year built	Water capacity (acre-feet)	Surface Area (acres)
Almaden Dam and Reservoir	**1935**	**1,590**	**62**
Anderson Dam and Reservoir	**1950**	**89,073**	**1271**
Calero Dam and Reservoir	1935	9,934	349
Chesbro Dam and Reservoir	1955	7,945	283
Coyote Dam and Reservoir	1934	23,244	635
Guadalupe Dam and Reservoir	1935	3,415	74
Lexington Reservoir and Lenihan Dam	1952	19,044	412
Stevens Creek Dam and Reservoir	1935	3,138	92
Uvas Dam and Reservoir	1957	9,835	288
Vasona Dam and Reservoir	1957	495	57

Table 1: The table displays the age, water capacity, and surface area of the 10 dams in Santa Clara County and bolds the 2 dams that the study focused on.

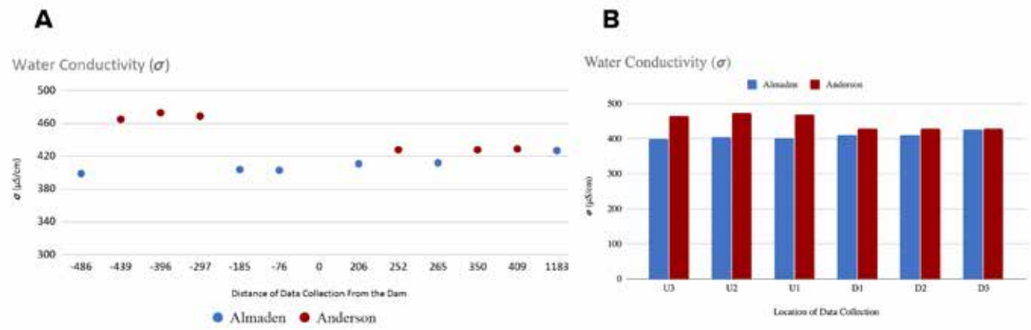


Figure 4: Graphs showing the difference between the water conductivity values measured downstream of the dam and upstream of the dam. A: Shows the distance of each sampling site from the dam. B: For the Almaden dam, the water conductivity values ranged from 395 to 408 µS/cm upstream of the dam and from 406 to 431 µS/cm downstream of the dam. For the Anderson dam, the water conductivity values ranged from 463 to 474 µS/cm upstream of the dam and from 425 to 431 µS/cm downstream of the dam.

When taking a closer look at the soil nitrate levels at each location for both dams and all trials, there was a significant discrepancy between the values upstream and downstream of the dam in comparison to the trials conducted for the averaged water nitrate levels, TDS, and water conductivity values (Table 2 and Table 3).

In order to determine the direct correlation between the values measured and the distance from the dam to each location, the DistMeasure app was installed on an iPhone and used to calculate how far away the 6 data collection locations were from each dam in meters (Figure 5).

Additionally, a two-sample t-test was conducted to determine if there was a difference in the soil nitrate levels between the Anderson Dam and the Almaden Dam. The p-value reported was 0.9125, revealing that the two population means were not equal since the p-value was much greater than 0.05. Therefore, the null hypothesis was accepted, and the alternative hypothesis was rejected.

DISCUSSION

As there was only a notable difference in the soil nitrate levels upstream and downstream of the dams, this reveals that reservoirs can harm the environment (Figure 1). Figure 1 visually shows the difference in soil nitrate levels, water nitrate levels, TDS, and water conductivity values depending on their distance away from the dam. U1 is upstream and closest to the dam, while U3 is upstream and furthest from the dam. D1 is downstream and closest to the dam, while D3 is downstream and furthest from the dam. Reservoirs increase the settling of sediment upstream of the dam which results in higher nitrification rates and causes the locations below the dam to have lower nitrification rates [5]. The hypothesis stating that the rates will be higher upstream of the dams than downstream of the dams was supported in both of the studies for the Anderson Dam and the Almaden Dam. This was confirmed by comparing the averaged soil nitrate levels upstream and downstream of both dams.

However, there were no notable discrepancies between the averaged water nitrate levels, TDS, and water conductivity values upstream and downstream of the dams, revealing that these factors most likely

		Soil	Water		
		Nitrate (mg/L)	Nitrate (mg/L)	TDS (ppm)	σ (µS/cm)
ANU3	Trial 1	71	9	218	463
	Trial 2	71	9	220	468
	Trial 3	62	9	218	463
	Average	68	9	219	465
ANU2	Trial 1	53	9	221	470
	Trial 2	53	11	223	474
	Trial 3	53	9	223	474
	Average	53	10	222	473
ANU1	Trial 1	71	9	220	468
	Trial 2	53	9	220	468
	Trial 3	62	9	222	472
	Average	62	9	221	469
AND1	Trial 1	35	9	200	425
	Trial 2	35	9	202	429
	Trial 3	35	9	203	431
	Average	35	9	202	428
AND2	Trial 1	35	9	200	425
	Trial 2	35	9	202	431
	Trial 3	44	9	201	427
	Average	38	9	201	428
AND3	Trial 1	35	9	202	429
	Trial 2	35	9	203	431
	Trial 3	35	9	201	427
	Average	35	9	202	429

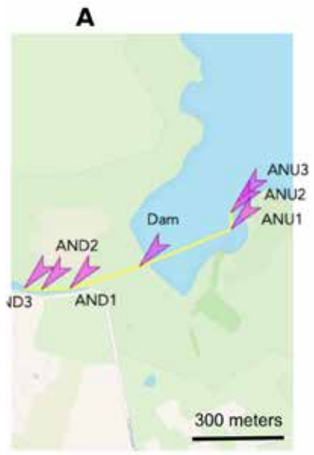
Table 2: The table displays the measurements of all the trials at the Anderson Dam that were conducted without averaging the values.

do not play a role in the difference in nitrate levels upstream and downstream of the dams (Figure 2, Figure 3, and Figure 4). Figures 2, 3, and 4 visually show the difference in soil nitrate levels, water nitrate levels, TDS, and water conductivity values depending on their distance away from the dam. U1 is upstream and closest to the dam, while U3 is upstream and furthest from the dam. D1 is downstream and closest to the dam, while D3 is downstream and furthest from the dam.

While there were no significant discrepancies between all the trials measuring water nitrate levels, TDS, and water conductivity values at each location, there were more drastic differences when observing all the trials that measured soil nitrate levels at each location (Table 2 and Table 3). This is a potential source of error because there was a wide range of values at specific locations that did not accurately represent the averaged value. If more measurements of the soil nitrate levels had been recorded at each location, then this data could have been analyzed further to determine why there were such significant differences in the values at the same locations. However, since only three measurements were taken at each location, there are no definitive conclusions that can be presented.

After the DistMeasure app was installed on an iPhone, the distance between the dam and each data collection location was measured (Figure 5). Using this information, the general pattern in the Almaden Dam revealed that the soil nitrate levels upstream gradually increased as the locations got closer to the dam and the soil nitrate levels downstream gradually decreased as the locations got further away from the dam (Figure 1). However, there was no distinct pattern that could be observed from the Anderson Dam's soil nitrate levels. To understand this, more measurements should have been taken at consistent intervals. If more than three trials of data had been taken at 100 meter intervals, this would have shown a more distinct pattern in the data and a more definitive conclusion could have been drawn as to why only the averaged soil nitrate levels in the Almaden Dam had a noticeable pattern.

In the two-sample t-test that was conducted in order to determine if there was a difference in the soil nitrate levels between the Anderson Dam and the Almaden Dam, it was revealed that the two population means were not equal to each other. The t-test contained a total of 36 values which represented the soil nitrate levels of the two dams. From this analysis, the question of why the populations were not equal to each other was answered. The reason why the Anderson Dam and the Almaden Dam were chosen for the study is because their ages and sizes differ the most from each other out of all the Santa Clara County dams. From this information, the conclusion was made that the size of the dams most likely plays a larger role in the difference of soil nitrate levels because both dams were built only 15 years



Site	Distance from Dam (meters)
ANU3	-439
ANU2	-396
ANU1	-297
Dam	0
AND1	252
AND2	350
AND3	409

Site	Distance from Dam (meters)
ALU3	-486
ALU2	-185
ALU1	-76
Dam	0
ALD1	206
ALD2	265
ALD3	1,183

Figure 5: Diagrams showing how far apart each of the 6 sites were from the dams themselves and whether the sites were upstream or downstream. A: Shows the distance of the sites from the Anderson Dam. B: Shows the distance of the sites from the Almaden Dam.

		Soil	Water		
		Nitrate (mg/L)	Nitrate (mg/L)	TDS (ppm)	⌀ (µS/cm)
ALU3	Trial 1	53	11	186	395
	Trial 2	53	11	189	402
	Trial 3	53	11	188	400
	Average	53	11	188	399
ALU2	Trial 1	53	9	187	397
	Trial 2	71	9	192	408
	Trial 3	44	9	191	406
	Average	56	9	190	404
ALU1	Trial 1	71	11	188	400
	Trial 2	71	11	190	406
	Trial 3	53	11	189	402
	Average	65	11	189	403
ALD1	Trial 1	53	9	196	417
	Trial 2	53	9	193	410
	Trial 3	35	9	191	406
	Average	47	9	193	411
ALD2	Trial 1	35	9	194	412
	Trial 2	44	9	196	417
	Trial 3	35	9	192	408
	Average	38	9	194	412
ALD3	Trial 1	35	9	203	431
	Trial 2	35	9	199	423
	Trial 3	35	9	201	427
	Average	35	9	201	427

Table 3: The table displays the measurements of all the trials at the Almaden Dam that were conducted without averaging the values.

apart in the 1900s. If the size of the data collection was larger and more dams of differing ages and sizes were studied, then a more comprehensive analysis could have been done to further support this correlation.

The difference in soil nitrate levels upstream and downstream of the dams reveals the significant impact that dams can have on their surrounding environments. High levels of ammonia can lead to more decomposition of NH_4+ above the dam, which can cause anoxic conditions in the sediment and inhibit the nitrification process [9]. This can severely impact both the ecosystem and biodiversity of the dam [5]. The results of this experiment reveal the extent to which dams can impact the environment. The results also have the potential to prevent future projects that will negatively impact the environment from occurring like the Pacheco Reservoir Expansion Project among Valley Water, which is an active project occurring in the San Benito Water District where they are attempting to increase the reservoir's operational capacity from 5,500 acre-feet to up to 140,000 acre-feet [7-8]. The results of my research can also help prevent the water district from carrying out seismic retrofit projects for the Anderson, Calero, Guadalupe and Almaden dams [7].

The future work that can be done should focus on studying more dams in order to gather a larger data collection. Also, the other factors of the dams can be focused on to see how the change in nitrification levels affect them. Since all of the study's data was collected during the summer when it was sunny, soil nitrate levels could be measured during different seasons at varying weather conditions to determine whether there is a difference in soil nitrate levels. Additionally, dams with significantly different ages can be studied to understand the correlation between age and soil nitrate levels. Dams in different locations can be studied and compared to the dams in Santa Clara County to see if there are any notable differences in their soil nitrate levels.

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