JOURNAL OF
EMERGING INVESTIGATORS

Article

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

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## SUMMARY

**As the world continues to battle the novel coronavirus or COVID-19, many states in the USA have restricted outdoor human activity, intending to reduce the number of viral infections. In turn, the number of cars on the streets and factories in operation has decreased. This unique time for the world has created an opportunity to study the impacts of reduced human activity. We collected water and air quality data through field data collection and remote data sites to test how the change in human activity affected the concentration of pollutants in water and air. Throughout California, we studied three test sites in June and July from 2015 to 2020 to compare the collected field or monitored water and air quality data over the past five years. We hypothesized that with the reduction of human activity, and therefore car emissions, the air and water pollutants in all three test locations would decrease for June/July 2020 compared to the last five years. In our study, the air quality improved from 2015 to 2020 in terms of the oxides of nitrogen ($NO_x$) and ozone ($O_3$), especially at Lake Tahoe's Placer County. However, the water quality remained relatively constant for the test sites over the course of the study, while it significantly improved Sonoma County's Russian River. Overall, the air pollution in California for June and July somewhat decreased from 2015 to 2020, while the water quality remained fairly constant in June and July during California's shelter-in-place order.**

## INTRODUCTION

The outbreak of severe acute respiratory syndrome COVID-19, casused by coronavirus 2 (SARS-CoV-2), was deemed a pandemic on March 11, 2020, by the World Health Organization. In California, USA, Governor Newsom issued a shelter-in-place order on March 19, 2020. The shelter-in-place order required citizens to only leave their homes for essential trips, and many nonessential businesses, like restaurants, were closed. As of July 2020, over 19 million cases of COVID-19 were confirmed worldwide, with 541,000 cases in California alone (1). The COVID-19 pandemic offers a unique time to study the effects of a worldwide shutdown. Water and air quality directly affect human health. If pollutant concentrations of either are above the standard, it can lead to human health problems including respiratory infections, lung cancer, and heart disease (2). The pandemic allows us to observe the effects of reduced human activity on the environment.

The worldwide shutdown limited the number of many people in the streets, cars used for transport to work, and the operation of businesses and factories (3, 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 (3). The baseline is an average value of collected movement in a specific location. Apple determined the baseline from the median of a five-week period between January 3rd and February 6th of 2020. The baseline is used to illustrate changes due to COVID-19 and does not account for seasonality or daily changes. Apple calculated this baseline from a time when some people may have already started to reduce activity (5). Similarly, Google's Mobility Tracking showed that California public transit use was down 42% below the same baseline as of July 27, 2020. The Bureau of Transportation Statistics reported that 28.3% of Californians stayed indoors as of July 30, 2020 (6, 7). Reduced human activity corresponded with decreased human-induced emissions from vehicles and industrial operations (8). Particulate matter (PM) and nitrogen oxides ($NO_x$) decreased, and likely other pollutants (9, 10). The U.S. Environmental Protection Agency (EPA) monitors pollutants in the air and water to protect human health (11). PM, $NO_x$, and ozone ($O_3$) are criteria air pollutants and have natural and anthropogenic sources. The EPA also monitors water quality indicators, such as total dissolved solids (TDS) and pH, for human health.

PM is microscopic particles or liquid suspended in the air. $PM_{2.5}$ refers to PM that is 2.5 μm or less in diameter. Due to its fine size, $PM_{2.5}$ can be harmful to humans since it can enter the bloodstream or lungs (12). $PM_{10}$ has a diameter of 10 μm or smaller and cannot move as far as $PM_{2.5}$ because larger-sized particles tend to deposit to surfaces closer to sources (13). Automobile engines produce $NO_x$ and release partially combusted hydrocarbons as a result of burning fossil fuels. Factories also emit pollutants, such as PM and $NO_x$. $NO_x$ emitted from these sources can lead to the formation of $O_3$. $O_3$ is necessary in the stratosphere to protect life on earth from intense ultraviolet (UV) radiation from the sun, but it is not beneficial in the troposphere (14). $O_3$ at ground level contributes to smog, which can cause health problems and

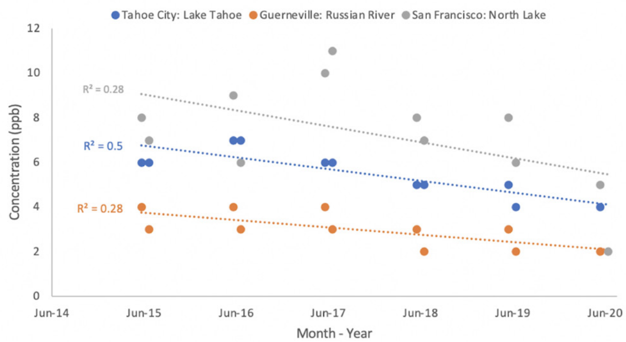


**Figure 1. NOx Air Quality Concentrations Reduced from 2015 to 2020.** The $NO_x$ concentration (ppb) at three locations in California — Lake Tahoe (blue), Russian River (orange), and North Lake (grey) — was measured in June and July from 2015 to 2020. $r^2$ values represent a linear regression analysis.

| Table 1: Water Quality | | | | | | |
|---|---|---|---|---|---|---|
| *Location:* | Tahoe City: Lake Tahoe | | San Francisco: North Lake | | Guerneville: Russian River | |
| *County:* | Placer County | | San Francisco County | | Sonoma County | |
| *Measurement:* | pH | TDS (ppm) | pH | TDS (ppm) | pH | TDS (ppm) |
| mean: 2020/15–19 | 7.65/NA | 39.58/NA | 8.82/NA | 190.73/NA | 8.02/8.10 | 124.67/132.43 |
| +/- SD: 2020/15–19 | NA | NA | NA | NA | 0.46/0.17 | 0.29/5.87 |
| p-value: 2020 to 2015–2019 | NA | NA | NA | NA | 0.53 | 0.004 |

**Table 1. Water quality data for Russian River, Lake Tahoe, and San Francisco's North Lake.** pH and TDS concentration in each water source was measured. The change in TDS in the Russian River at Guerneville over the 5 years was statistically significant. The nitrogen content in each body of water could not be thoroughly analyzed due to the precision of the tools used.

also harm crops and building materials (15). The $NO_2 \rightarrow NO + \bullet O$ reaction requires sunlight to occur. During the summer months, more UV radiation is present due to an increase in sunlight, resulting in an increase in $O_3$ creation.

Water quality is also affected by human activity, and since traffic decreased due to COVID-19, there was decreased pollution from toxic particles from car exhaust entering the San Francisco Bay (15). Many factors contribute to water quality, including TDS and pH. TDS are the inorganic and organic substances in a body of water that encompasses any minerals present (16). TDS can be a product of urban and natural runoff from storms, minerals in the water, and industrial wastewater. The EPA states that a TDS concentration below 300 ppm constitutes drinkable water, and above 1200 ppm is considered unhealthy and undrinkable. High TDS can lead to health issues from high concentrations of specific ions, such as nitrate, arsenic, aluminum, copper, or lead (16).

The pH of water is a measure of the number of hydrogen ions present in water. Human activity can affect the acidity or alkalinity of water through industrial and agricultural runoff or wastewater discharge, but natural influences such as rocks, soil, and plant life also alter pH (17). Algae and plants in the lake or body of water consume the dissolved CO2 in the water and create O2 and glucose. Surface water tends to have a pH between 6.5 and 8.5, but throughout the summer, lake surface water typically has a pH between 7.5 and 8.5 (18). While sunlight is present, the water surface will be more basic than a pH of 7 (18). Human input and air pollutants can alter the pH.

Many different factors impact water and air quality, such as the surroundings. The water quality of a city pond compared to a high alpine lake will vary due to differences in human activity and elevation, temperature, and other factors. The air quality can be affected by human-induced pollution and natural sources, such as wildfires and pollen. Based on these concepts, we hypothesized that the decrease in human activity due to California's COVID-19 shelter-in-place would result in a decrease of air and water pollutants at all three test locations: Russian River, Lake Tahoe, and North Lake in Golden Gate Park. We collected water data manually for June and July 2020. We used available air and water data from monitoring networks for the previous five years and compared it with our collected data for June and July 2020. Analysis of collected samples and monitoring data indicates that decreased human activity due to COVID-19 has likely improved California's air quality in San Francisco, Placer, and Sonoma counties. In contrast, water quality has remained fairly constant in these locations in June and July 2020.

## RESULTS

To test the water quality of the Russian River, Lake Tahoe, and North Lake in Golden Gate Park, pH, $NO_x$, and TDS we measured these concentrations with a testing kit and various meters, and compared it to data pulled from monitoring networks including, the U.S. Geological Survey (USGS), the National Water Information System (NWIS), and the San Francisco Estuary Institute (SFEI). Data for each county's air quality were collected from the Bay Area Air Quality Management District (BAAQMD) and California's Air Resources Board (CARB). 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 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 with a maximum allowable of 210 ppb. The standard pH for the lake was between 7.0 and 8.4, which is the accepted range for pH values in Lake Tahoe. Keep Tahoe Blue states that the average TDS for the lake is 47.5 ppm (19).

$NO_x$ concentrations significantly decreased from June/July 2015 to 2020 in San Francisco ($p$-value = 0.01) and Tahoe City of Placer County ($p$-value = 0.01). However, the change in concentration for Guerneville of Sonoma County ($p$-value = 0.07) was not statistically significant (**Table 2**). In San Francisco, the mean concentration of $NO_x$ in June/July of 2020 (3.5 ppb, $n$ = 2) was lower than the mean concentration for 2015 to 2019 (8.0 ± 1.6 ppb, $n$ = 10). The $r^2$ value ($r^2$ = 0.28) suggests a weak negative correlation for $NO_x$ concentrations

| Table 2: Air Quality | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Location:* | Tahoe City: Lake Tahoe | | | | Guerneville: Russian River | | | San Francisco: North Lake | | |
| *County:* | Placer County | | | | Sonoma County | | | San Francisco County | | |
| | $NO_x$ (ppb) | $O_3$ (ppb) | $PM_{2.5}$ (µg/m³) | $PM_{10}$ (µg/m³) | $NO_x$ (ppb) | $O_3$ (ppb) | $PM_{2.5}$ (µg/m³) | $NO_x$ (ppb) | $O_3$ (ppb) | $PM_{2.5}$ (µg/m³) |
| 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 |
| +/- SD: 2015–2019 | 0.95 | 4.04 | 3.34 | 3.22 | 0.74 | 2.39 | 1.28 | 1.63 | 3.94 | 1.96 |
| p-value: comparing 2020 mean to 2015–2019 mean concentration for June/July | 0.01 | 0.14 | 0.04 | 0.74 | 0.07 | 0.25 | 0.84 | 0.01 | 0.06 | 0.33 |

**Table 2. June and July monthly averages for $NO_x$ for Tahoe City's Placer County, Guerneville's Sonoma County, and San Francisco County.** $O_3$ concentrations in ppb, and $PM_{2.5}$ and $PM_{10}$ in µg/m³

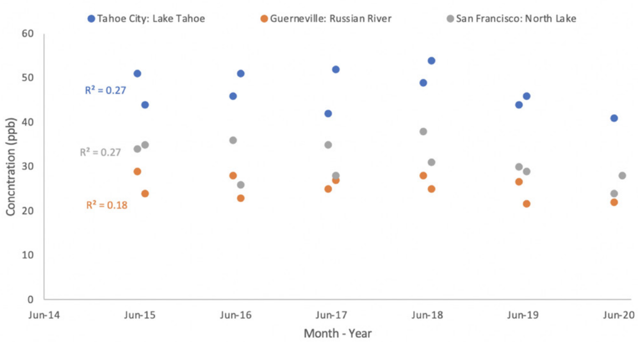


**Figure 2. $O_3$ Air Quality Concentrations Remained Fairly Constant from 2015 to 2020.** The $O_3$ concentration (ppb) at three locations in California — Lake Tahoe (blue), Russian River (orange), and North Lake (grey) — was measured in June and July from 2015 to 2020. $r^2$ values represent a linear regression analysis with only San Francisco County being significant ($r^2 = 0.27$).

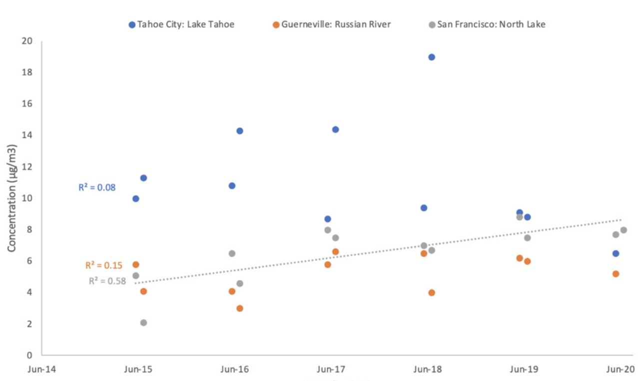


**Figure 3. $PM_{2.5}$ Air Quality Concentrations Increased in San Francisco County from 2015 to 2020.** The $PM_{2.5}$ concentration (µg/m³) at three locations in California — Lake Tahoe (blue), Russian River (orange), and North Lake (grey) — was measured in June and July from 2015 to 2020. $r^2$ values represent a linear regression analysis. The change in $PM_{2.5}$ in Tahoe City and Guerneville did not present a significant correlation over time ($r^2 = 0.077$, r2 = 0.147) while the increase in $PM_{2.5}$ in San Francisco over the 5-year period was significant ($r^2 = 0.58$).

over time. The mean $NO_x$ concentration in Sonoma County for June/July of 2020 (2 ppb, *n* = 2) was lower than the mean concentration for 2015 to 2019 (3.10 ± 0.74 ppb, *n* = 10), with a weak correlation ($r^2 = 0.28$) over time (**Figure 1**). Tahoe City of Placer County $NO_x$ concentrations in June/July of 2020 (3.50 ppb, *n* = 2) were lower than the mean concentration from 2015 to 2019 (5.78 ± 0.97 ppb, *n* = 10) and had a negative correlation ($r^2 = 0.5$) over time.

$O_3$ concentrations at all three locations were not significantly different (**Table 2**). The mean $O_3$ concentration in San Francisco County for June/July of 2020 (26 ppb, *n* = 2) was lower than the O3 concentration between 2015 and 2019 (32 ± 3.9 ppb, *n* = 10) with a p-value of 0.06 and the weak negative correlation ($r^2 = 0.27$) over time. Additionally, the $O_3$ from 2015 to 2020 in Sonoma County with a mean $O_3$ concentration in June/July of 2020 (23.5 ppb, *n* = 2) was not significantly different (*p*-value = 0.25) in comparison to the mean concentration from 2015 to 2019 (25.7 ± 2.4 ppb, *n* = 10). The $r^2$ value (0.27) suggests a weak negative correlation between the O3 concentrations of June/July between 2015 and 2020 (**Figure 2**). For Placer County, the $O_3$ concentration in June/July of 2020 (43.00 ± 2.83 ppb, *n* = 2) was lower than the $O_3$ concentration between 2015 and 2019 (47.90 ± 4.04 ppb, *n* = 10) but was not statistically significant (*p*-value = 0.14). The $r^2$ value (0.18) for Placer County suggests no linear correlation between the June/July $O_3$ concentrations from 2015 to 2020.

The PM2.5 data shows a significant decrease (**Figure 3**) in concentration for Tahoe City with a concentration in June/July of 2020 (5.75 ± 1.06 µg/m³, *n* = 2) that was lower than the $PM_{2.5}$ concentration between 2015 and 2019 (11.58 ± 3.34 µg/m³, *n* = 10, *p*-value = 0.04). The $r^2$ value (0.08) for Tahoe City around Lake Tahoe suggests no correlation between the concentration of $PM_{2.5}$ over the past five years. In both San Francisco and Guerneville, the variation in $PM_{2.5}$ was not statistically significant (**Table 2**). In San Francisco, the mean PM2.5 concentration in June/July of 2020 (7.85 µg/m³, *n* = 2) was not statistically different from 2015 and 2019 (6.38 ± 1.96 µg/m³, *n* = 10, *p*-value = 0.33). The $r^2$ value (0.58) demonstrates a mild positive correlation between the $PM_{2.5}$ concentrations over the five years. The mean $PM_{2.5}$ concentration in June/July of 2020 (5.40 µg/m³, *n* = 2) was not statistically different than the PM2.5 concentration between 2015 and 2019 (5.21 ± 1.28 µg/m3, *n* = 10, *p*-value = 0.84) for Guerneville in Sonoma County. The $r^2$ value (0.15) suggests no correlation between the change in the concentration of

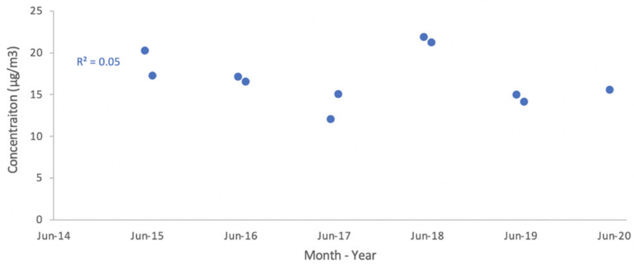


**Figure 4. $PM_{10}$ Air Quality Concentrations Remained Constant in Lake Tahoe's Placer County from 2015 to 2020.** The $PM_{10}$ concentration (µg/m³) at Lake Tahoe in Placer County (blue) was measured in June and July from 2015 to 2020. The $r^2$ value ($r^2$ = 0.05) represents a linear regression analysis.

PM2.5 and the past five years.

The PM10 concentration in Tahoe City for June/July of 2020 (16.30 µg/m³, n = 2) was not statistically different (Table 2) than the $PM_{10}$ concentration between 2015 and 2019 (17.100 ± 3.215 µg/m³, $n$ = 10, $p$-value = 0.74). The $r^2$ value (0.05) suggests no correlation of the mean $PM_{10}$ concentration over the past five years (**Figure 4**).

## DISCUSSION

As the COVID-19 pandemic continued to affect human activity, we tested how this daily change carried over to the environment through the air and water quality of three locations in California from 2015 to 2020. The TDS and pH levels of Lake Tahoe and North Lake in San Francisco did not see a significant change, but the TDS concentrations in the Russian River decreased significantly. While most of the collected data showed a slight decrease in air pollution in 2020 during June and July, likely due to altered human activity resulting from the COVID-19 shelter-in-place order, most of the difference was not statistically significant. Water quality was not affected by the decrease in human activity, except for the Russian River, which showed a significant decrease in TDS. San Francisco is a heavily populated city of 883,305 people within 47 mi2 as of 2018 (20). The shelter-in-place order decreased driving activity by 75% below the baseline in April 2020 and remained 26% below the baseline as of late July 2020 (3). The reduction in car emissions in the city likely affected the air quality in San Francisco. The closing of ski resorts in March and a decrease in tourism contributed to the decrease in human activity on the roads and the water of Lake Tahoe (21, 22).

The mean $NO_x$ concentration from 2015 to 2019 was significantly more than that in 2020 for Lake Tahoe at Tahoe City (**Table 2**) could be a result of decreased human activity. However, automobile activity in Placer County had 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 (3). While the change in road traffic affected the $NO_x$ air quality concentrations in Placer County, the $O_3$ air quality remained fairly constant over the five year period. The return of automobile activity in July likely accounts for concentrations of $O_3$ in Placer County during June and July of 2020 (**Table 2**) that were not significantly different from the previous five years.

The $PM_{2.5}$ concentration in the air at Lake Tahoe slightly decreased (**Table 2**) significantly from 2015 to 2020, but the PM10 concentration did not significantly change. The reduction in $PM_{2.5}$ between 2015–2019 and 2020 could have resulted from a decrease in industrial 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 Ferguson wildfire near Yosemite in Mariposa County, which began in early July, and the Carr fire near Redding, CA, which occurred in late July (23, 24). The air quality in terms of $PM_{2.5}$ and $NO_x$ around Tahoe City at Lake Tahoe slightly improved due to the change in human activity because of COVID-19.

The significant drop in NOx concentrations in San Francisco from 2015 to 2020 (**Table 2**) may be partially attributed to the difference in human activity due to the shelter-in-place order. The decrease in average $O_3$ concentrations 2015–2019 compared to 2020 (**Table 2**) is not significant ($p$-value = 0.06) to signify an impact by the reduced human activity due to the shelter-in-place order. Though the data is not statistically significant, it could have been significant with a higher sample size. The $PM_{2.5}$ concentrations in San Francisco did not show a significant difference. However, eLichen's determined that the shelter-in-place order caused a 19.7% decrease in $PM_{2.5}$ in San Francisco from late March to early April (25). Our data was collected from June and July of 2020, when human activity had begun to increase again, which may account for statistically insignificant concentrations compared to previous years.

The Guerneville $PM_{2.5}$ concentration was not statistically significant (Table 2). $NO_x$ and $O_3$ air concentrations were also not statistically different from the previous five years. There can be no determined correlation between the shelter-in-place order due to COVID-19 and the reduced human activity and air quality in Sonoma County in June and July 2020.

Between 1980 and 2012, Lake Tahoe's total nitrogen concentration had been between 0.013 and 0.019 ppm, while the average nitrogen content in 2018 was 0.21 ppm (26, 19). The 2020 data revealed 0 ppm for both nitrite and nitrate in Lake Tahoe, Russian River, and North Lake. The detection limit of the API Freshwater Test Kit was between 0 and 5 ppm. Based on the previous concentrations of nitrogen in Lake Tahoe, it is likely that the concentrations in 2020 were in the same range within the 0–5 ppm measurement. Similarly, the nitrogen concentrations at the Russian River in Guerneville were undetectable by the API Freshwater Kit. The daily averages from June 2, 2011, were 0.193 ppm nitrate, 0.0032 ppm nitrite, and 0.331 ppm total nitrogen. The $NO_x$ data cannot be properly analyzed to determine an effect from the shelter-in-place on the river's nitrogen concentrations because those levels of nitrogen are undetectable by the API test kit. With the same issue, North Lake in San Francisco's Golden Gate Park had 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 concentrations.

The pH of Lake Tahoe has standard measurements between 7 and 8.4 pH. 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 affect the pH of Lake Tahoe. The average TDS measurement was within the acceptable range for Lake Tahoe, indicating the human activity change also did not affect TDS in the water during June and July 2020.

The average pH of North Lake in 2020, taken from daily averages between June 30, 2020, and July 2, 2020, was 8.82 (**Table 1**). There was no accessible pH data from the past five years for North Lake, making a comparison of the pH unavailable. The average TDS in North Lake from June and July 2020 was 190.73 ppm. To compare, the average TDS from 1988 was 264.5 ppm. Despite this 32-year difference, 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 is not reasonable.

Since June and July of 2015, the pH in the Russian River near Guerneville has remained constant around a pH of 8. The difference in mean pH from June and July 2015–2019 was not statistically significant in comparison to the mean pH from 2020 and was not noticeably impacted by human activity changes as a result of COVID-19. The mean TDS in June and July 2015–2019 was significantly higher (**Table 1**) compared to the mean from 2020 and might have been impacted by the reduction in human activity due to the shelter-in-place order around California. With a lack of human activity, sources of ions entering the water may have been reduced, decreasing the TDS concentration of the Russian River. The snowpack in 2020 measured 53% of the average snow for April, meaning it was a dry snow season in California (27). Less snowpack leads to less snowmelt entering California's water system, which could also reduce the sediment and suspended ions in the Russian River.

The null hypothesis that the shelter-in-place order did not affect either the water or air quality in any of these three locations could not be fully rejected. It is possible that the decrease in human activity might have contributed to improvements in $NO_x$ and $PM_{2.5}$ concentrations in the air around Placer County and Lake Tahoe, as well as decreased 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 data.

In every scientific experiment, we must account for sources of error and limitations when collecting and analyzing data. This data set encompasses the 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. Air and water quality were analyzed to determine if California's shelter-in-place order due to the COVID-19 pandemic affected air and water pollution. Lake Tahoe, Russian River, North Lake, and their counties do not fully represent California's air and water quality due to their small sample size in comparison to the state. The sample size of two for 2020 also makes it difficult to offer a complete comparison from the five years before. Perhaps if there was a larger amount of data for 2020, the difference in pollution concentration would have been higher. Additionally, varying times of day and weather can affect the turnover of the water, which impacts the TDS readings. Though all the water quality data were collected during the day while the sun was present, pH could have also been affected by the difference in the time of the sample collection. The difference in the time of day for manually collected field data varies from that of the remotely monitored data from 2015–2019 and could impact the comparison of data, leaving room for error in the data analysis. The data for water quality from Lake Tahoe and North Lake monitoring networks are averages and standards, which cannot be directly compared to daily averages to demonstrate an overall understanding of differences in water quality. Lastly, the method and instruments used for manually collecting the water data were much less precise than the historical monitored data methodology. The comparison of field and monitoring data cannot be fully accurate due to differences in how the data was collected.

Each data site represented a different location type in California. The urban environment of San Francisco compared to the rural town of Guerneville and the high elevation mountain area of Lake Tahoe yields results about varying situations and different effects from the shelter-in-place order. In San Francisco, driving was below the baseline average by 18%, walking decreased by 42%, and public transit lines have decreased to 66% below the baseline for July of 2020 (3). However, with a denser population in the city than Guerneville and Tahoe City, the difference in air pollution, except for $NO_x$, from 2020 and 2015–2019 did not vary notably from the other counties. The air pollutant concentrations in San Francisco have been significantly higher because more automobiles move through the city daily. However, the $O_3$ concentration in Tahoe City was 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. The $O_3$ concentration in San Francisco is then impacted by this cycle, which also depends on the air temperatures and sunlight. It transports the $O_3$ to a location where it can get trapped like a mountain range or valley (28). Lake Tahoe is surrounded by the Sierra Nevada mountains, which may hold in and contain the $O_3$, increasing the $O_3$ concentration despite a smaller population of people and automobiles. Air pollution from the Sacramento Valley travels up the mountains to the Lake Tahoe basin, potentially increasing the $O_3$ concentration (29, 30). 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 and potentially increase $O_3$ by downmixing air from the stratosphere, therefore increasing ozone concentration (31).

Overall, our 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 since pollution concentrations vary based on environmental factors and activity levels. Our data did not fully support the hypothesis that air and water pollution would decrease in all three locations for June and July 2020. With the statewide shelter-in-place order, pollution concentrations had the potential to decrease and create a healthier living environment. While not all aspects of air or water quality demonstrated significant results, the reduced human activity highlights the ability to mitigate human-produced pollutants and potentially the effects of climate change.

## METHODS

With the ongoing COVID-19 pandemic, we wanted to test how the reduction in outdoor human activity affected the air and water qualities throughout California. To do so, we tested three bodies of water and their surrounding counties air quality to determine any changes in pollution levels. 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 within 10 mi2 as of 2018 (32). The Russian River location (38.50803° N, 122.9874° W) at an elevation of 18 meters is not near the road but is a well used river. In Placer County's Tahoe City (39.1687° N, 120.1424° W), Lake Tahoe is 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 saw a more substantial decrease in human activity by the shelter-in-place due to its higher population and human activity (3).

Water quality was measured by a TDS and pH meter as well as an API Freshwater Test Kit (Mars Inc., McLean, VA). The Ketotek KT-3 Portable pH Meter (Ketotek Corporations, Xiamen, Fujian) can detect pH from 0.00 to 16.00 with ± 0.01 pH accuracy. The Ketotek KT-2 Portable TDS Meter (Ketotek Corporations, Xiamen, Fujian) 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 with a water depth of approximately 2 meters. Each of the meters has a five-centimeter section that can be submerged in water, so the data represents the surface water at 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 concentrations in the water,

| Table 3: Precision of Instruments (Used in Field Data Collection) | | | |
|---|---|---|---|
| **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 concentration | 0.01 ppm | 9990 ppm |
| Ketotek pH meter | pH concentration | 0.01 pH | 16 pH |

**Table 3. Precision and method detection limits for the instruments used in collecting water samples through field data collection.**

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, five 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 five 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 three times for each analyte per water site per day and each site was tested for three consecutive days. Water was collected between 11 am and 3 pm for each test location. The API test kit was able to measure nitrite concentration in 0.25 ppm intervals, whereas nitrate was 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.

USGS remote water data from the NWIS was used for Russian River water quality from June 2015 to July 2020 (33). 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: $TDS ppm_{500}$ = 500 * (C(µS/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 (34). 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 (35). However, there was no pH data available for North Lake.

UC Davis Tahoe Environmental Research Center provided nitrogen data for Lake Tahoe through their State of the Lake Reports. The nitrogen data was collected from a Shimadzu UV-1700 series Spectrophotometer that uses light absorption to determine the matter concentration of a solution (36). The pH and TDS standards for the lake 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 (26).

The Bay Area Air Quality Management District (BAAQMD) provided air quality data for San Francisco (37). To obtain $NO_x$ data, a chemiluminescent analyzer was used (38). 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 (38). The minimum sensitivity of the analyzer is ± 2% of the full scale. Particulate matter was measured isokinetically through stack glasses and filtered through glass fibers. The weight of the particulate matter was calculated gravimetrically after separating from excess water. The minimum sensitivity of particulate matter measurements is 0.001 gr/SDCF (39). 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 $O_3$ in the air from 0.05 to 1000 ppb (40). Air filters through between every 10 and 300 seconds to continuously collect data measurements for the $O_3$ concentrations (41).

The California Air Resources Board (CARB) provided air quality data for the Russian River through Sonoma County and for Lake Tahoe through Placer County (42). PM concentration was 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 was 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 was also used for gaseous pollutants: $NO_x$ and $O_3$. These gaseous pollutants were 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.

A *t*-test was performed on the data to determine statistical significance and the reported *p*-values are based on an *alpha* of 0.05. The 2015–2019 data was compared to the 2020 data for both water and air quality to analyze any difference in concentration over the five year period. The data was formatted into figures and tables through Google Sheets and Excel computer programs.

## ACKNOWLEDGEMENTS

I would like to thank the Headwaters Science Institute for the opportunity to conduct research and my family for their constant support and patience throughout this project.

**Received:** September 3, 2020
**Accepted:** January 25, 2020
**Published:** February 15, 2021

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