Article

Impact of dams in Santa Clara County on the nitrification of the surrounding ecosystem

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SUMMARY

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 the water conductivity, total dissolved solids, size, and age of the dams. We hypothesized that if the dams were impacting the nitrification rates in their ecosystems, then the nitrification rates would be higher upstream of the dams than downstream of the dams. We found that the soil nitrate levels are lower downstream than they are upstream, supporting other research that claims that dams can alter the nitration cycle of their surrounding environment.
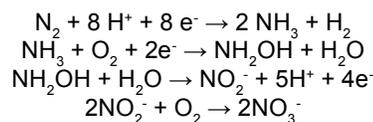
INTRODUCTION

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 significantly different if not 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 caused by dams critically affect their surrounding ecosystems and cause the interruption of river continuity (longitudinal and lateral, fish migration, sediment and nutrient transport), siltation of riverbed and clogging of interstitial, homogenization of habitats, downstream riverbed incision, alteration of river-groundwater exchange, and downstream flow and water quality alteration (3).

The nitrogen cycle is a biogeochemical process with many stages that allows nitrogen to take 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 biosphere 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 (NH_3) and contain it using the reaction mentioned below. The plants

are then able to absorb the ammonia, and it is used to make organic molecules (5). 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).

$$N_2 + 8 H^+ + 8 e^- \rightarrow 2 NH_3 + H_2$$
$$NH_3 + O_2 + 2e^- \rightarrow NH_2OH + H_2O$$
$$NH_2OH + H_2O \rightarrow NO_2^- + 5H^+ + 4e^-$$
$$2NO_2^- + O_2 \rightarrow 2NO_3^-$$

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 because the sediment-deprived water released from the dam does not have enough substrate to support large populations of nitrifying bacteria, which results in a decrease in ammonia production, further lowering nitrification rates. A good indicator of nitrification is the nitrate concentration in the soil. High levels of nitrogen can impact many other processes in addition to the nitrogen cycle. It can lead to a nutrient imbalance in plants that can alter their health and cause 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, we asked how the dams in Santa Clara county impact the nitrification rates of their surrounding ecosystems. Reservoirs can damage their surrounding ecosystems through high levels of ammonia, which can inhibit the nitrification process and, as a result, severely damage their environments (10). Based on this information, the results were used to discern if there were any correlations between the water conductivity, total dissolved solids (TDS), and size and age of the dams since sedimentation may impact these variables. Understanding these metrics could be important in discerning how the dams might affect the soil and water differently. The hypothesis posed was that if the dams are impacting the nitrification rates in these ecosystems, then the nitrification rates will be higher upstream of the dams than downstream of

Dam	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

Table 1: The table contains the age, water capacity, and surface area of the selected dams for study.

the dams. From the 10 local dams and reservoirs in the Santa Clara Valley, our research focused on the Almaden Dam and the Anderson Dam because these dams have the largest difference in their ages and sizes (**Table 1**) (7). 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 inform how future projects may damage the environment.

RESULTS

In order to test the hypothesis, a field study has to be performed at the Anderson Dam and Almaden Dam. The site locations of the sample collections and the distance of each location upstream or downstream from the dam are displayed in **Figure 1**, and subsequent experiments were performed. The cadmium reduction method, a colorimetric method that involves contact of the nitrate in the sample with cadmium particles, causing nitrates to be converted to nitrites (8, 9), has been used to measure the soil and water nitrate levels. Water conductivity and total dissolved solids were measured with the standard instrumentation used in irrigation water studies.

There were three trials conducted at each site. On average, the soil nitrate levels were noticeably higher upstream than they were downstream for both the Anderson Dam and the Almaden Dam (**Figure 2**). However, there were no significant differences between the averaged water nitrate levels, TDS, and water conductivity values upstream and downstream of both the dams (**Figure 3, Figure 4, and Figure 5**).

Additionally, two-sample t-tests were conducted on all the recorded data values (**Table 2**), which confirms that there was a statistically significant difference in the soil nitrate levels upstream and downstream of the Almaden Dam and Anderson Dam. However, there are no notable statistically significant differences in the water nitrate, TDS, and water conductivity levels upstream and downstream of both dams.
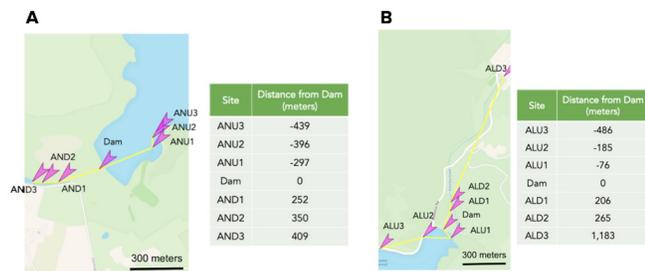

Figure 1: Diagrams showing how far apart each of the six data collection sites were from the dams. A: Anderson Dam. **B:** Almaden Dam.

DISCUSSION

Figure 1 shows the soil nitrate levels, water nitrate levels, TDS, and water conductivity values at their different measurement locations. The abbreviation AN indicates that the site is the Anderson Dam, and the abbreviation AL indicates that the site is the Almaden Dam. The U1 location is upstream and closest to the dam, while the U3 location is also upstream but furthest from the dam. The D1 location is downstream and closest to the dam, while the D3 location is also downstream but furthest from the dam.

Since there were notable differences in the soil nitrate levels upstream and downstream of the dams, this reveals that reservoirs may impact the nitrate levels of their surroundings (**Figure 2**). Our hypothesis stating that the rates would be higher upstream of the dams than downstream of the dams was supported in both the studies of the Anderson Dam and the Almaden Dam. This is supported by the fact that 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).

Additionally, a t-test was conducted by assuming the null hypothesis that the averaged upstream and downstream data sample values were not statistically different. The p-values were greater than 0.05 for the soil nitrate levels upstream and downstream of both the Anderson Dam and Almaden Dam, indicating that this invalidates the null hypothesis. Therefore, we can conclude that there is a statistically significant difference between the averaged upstream and downstream values of the soil nitrate levels for both dams (**Table 2**).

However, there is no difference between the averaged water nitrate levels, TDS, and water conductivity values upstream and downstream of both the dams, signifying that these factors most likely do not play a role in the difference
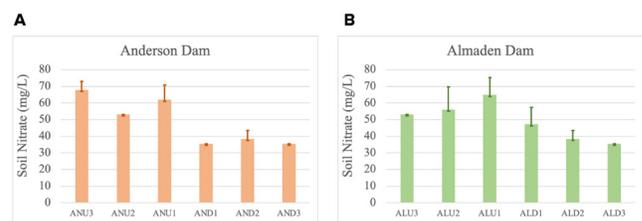

Figure 2: Graphs showing the difference between the soil nitrate levels measured upstream and downstream of the dam. A: Anderson Dam. **B:** Almaden Dam.
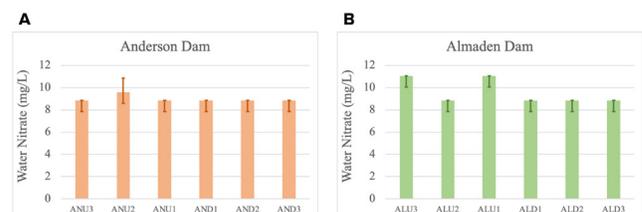

Figure 3: Graphs showing the difference between the water nitrate levels measured upstream and downstream of the dam. A: Anderson Dam. **B:** Almaden Dam.
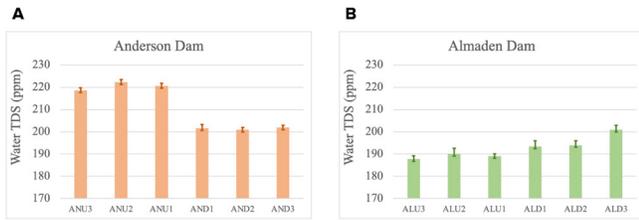
Figure 4: Graphs showing the difference between the water TDS values measured upstream and downstream of the dam. A: Anderson Dam. **B:** Almaden Dam.
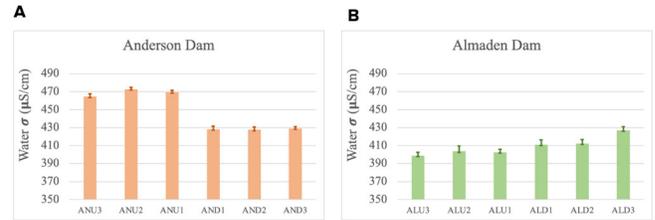

Figure 5: Graphs showing the difference between the water conductivity values measured upstream and downstream of the dam. A: Anderson Dam. **B:** Almaden Dam.

in nitrification (**Figure 3-5**). The *t*-test for these variables was also inconclusive, so no conclusions can be made for the correlation of the water nitrate levels, TDS, and water conductivity values upstream and downstream of both dams (**Table 2**). The TDS and water conductivity values upstream of the Anderson Dam were higher than they were downstream of the dam. However, this was not observed in the Almaden Dam. It is difficult to conclude whether this difference is due to the size of the dam without measuring additional data samples from other dams. No correlation between the age of the dams has been found, which may be due to the fact that the Anderson Dam and Almaden Dam were built only 15 years apart.

The difference in the soil nitrate levels upstream and downstream of the dams revealed the significant impact that dams may 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 (10). This can severely impact both the ecosystem and biodiversity of the dam (5). These findings should be taken into account when considering the implementation of dam expansion projects such as the Pacheco Reservoir Expansion Project, 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 (11, 12).

The future work that can be done should focus on studying more dams in order to gather a larger sample size. Since all of the study 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 the levels. Additionally, dams with significantly different ages can be studied to help 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 notable differences in the soil nitrate levels.

	Soil Nitrate	Water Nitrate	Water TDS	Water Conductivity
Anderson Dam	0.3424	0.1705	0.0187	0.0433
Almaden Dam	0.8029	NA	0.9214	0.9206

Table 2: The table displays the *p*-values of the recorded data values upstream versus downstream of the selected dams.

MATERIALS AND METHODS

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 six data collection locations were from each dam in meters.

Nitrate (NO_3^-) Measurement of Soil

For each of the two dams, three soil samples upstream and three soil samples downstream were collected to determine the nitrate levels of the soil. The samples were taken from the top 12" of soil at varying distances and at spots close to the dam. 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 them. After the samples were dried, a small bar was used to crush the samples, and they were passed through a 2-mm soil sieve. The samples were stored out of direct sunlight.

Calcium sulfate extraction is used to extract nitrate-nitrogen from soils. For this, the demineralizer bottle was first filled with tap water and was shaken for at least two minutes. The demineralized water was then ready to use. The demineralized water was added to the test tube up to the 20 mL mark. The level spoon from the test kit 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. Ten grams of the sieved soil sample was added to the tube. Calcium sulfate was also added to the tube using one level spoon. The tube was mixed thoroughly by shaking for one minute. The tube was then placed into one beaker. The funnel was placed on top of the other beaker. A filter paper disc was folded to form a cone and was placed into the funnel to filter the sample. The extracted sample in the beaker was then used for analysis.

The following method, which was used to determine the nitrate in the soil, was repeated three times for each soil sample. First, a pipette was used to fill two glass vials with 5mL of the extracted sample. One of the vials was inserted into the left-hand opening of the checker disc. This was called the blank. One 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

Soil	Nitrate (NO$_3^-$)	HI 38050 Nitrate Test Kit, Hanna Instruments [13]
Water	Nitrate (NO$_3^-$)	HI 38050 Nitrate Test Kit, Hanna Instruments [13]
	TDS	TDS, EC and Temp Meter, HoneForest [14]
	Conductivity (σ)	TDS, EC and Temp Meter, HoneForest [14]

Table 3: The table displays the instrumentation used for the measurements of the soil and water samples.

a light source illuminated the samples from the back of the windows. It was kept at a distance of 30-40cm (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.

Nitrate (NO$_3^-$) Measurement of Water

For each of the two dams, three water samples upstream and three water samples downstream were collected. The following method, which was used to determine the nitrate in the water, was repeated three times for each water sample. First, a plastic pipette was used to fill two glass vials with 5mL of the 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. One 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 30-40cm (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 mg/L of nitrate (NO$_3^-$). This reading process was performed three times for each water sample and the average value was reported.

TDS and Conductivity Measurement of Water

The following method, which was used to determine the TDS and water conductivity of the water, was repeated three times for each water sample. First, the protective cap of the probe was 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.

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