

TEACHING THROUGH WATER

The Influence of Effluent: A School and Community- Based Course Experience

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Abstract

Nature-based solutions (NBS), such as constructed wetlands, leverage natural processes to address societal challenges, including the return of effluent to communities. Despite scientific support, public acceptance of NBS remains limited, and rural communities are rarely included in conversations. We developed paired case studies grounded in real data, in partnership with a rural wastewater treatment plant. Our goal was to help undergraduate and secondary school students bridge the gap between their knowledge of water reuse and their willingness to adopt it. Infusing case studies with original field data allowed us to advance a genuine research question about

the constructed wetland and to immerse the students in an authentic local problem. Our data suggest measurable gains in knowledge, where gains could be made, and a trend towards acceptance of water reuse. This pilot project shows the promise of a course-based case study approach to help build public trust in nature-based solutions in Texas and beyond.

Introduction

Water scarcity poses an increasing but unevenly distributed challenge to communities across Texas and beyond. This issue is further exacerbated by the misuse of these resources and by personal, agricultural, and industrial practices that contaminate our limited supplies and hinder existing conservation efforts (Leijnse et al., 2024; Schumacher, 2025). It is now critical that we diversify our dwindling supplies through the development of alternative water sources, which include treated wastewater effluent. We are increasingly returning treated water to rivers, streams, and aquifers that serve as freshwater sources for surrounding communities (Texas Water Development Board, n.d.). One method for remediating this treated wastewater is to create artificial wetlands at the point of release into freshwater bodies, as is being done in rivers, at the City of Castroville WWTP (Ayaz, 2008) and elsewhere. While each of these methods of recycling treated water has substantial merits, each one also provides a pathway for biological and pharmaceutical micropollutants to cycle back into these communities. Despite potential consequences and the lack of studies on this topic, the reuse of treated non-potable effluent is one of the most promising methods for addressing the growing challenge of water sustainability (Reznik et al., 2019). Using a constructed wetland is among the Nature-Based Solutions (NBS), the next frontier in environmental management, leveraging natural processes to address water quality as it is reintroduced for community use. Along with constructed wetlands, these practices may make it possible to harvest rainwater or water from industrial processes. As a result, communities around the globe are looking towards NBS as both a primary and a secondary means of water remediation.

Despite growing support for NBS, these practices have only recently begun to capture the interest of the public and of what researchers refer to as "stakeholders," with co-benefits as the primary motivators of support (Giordano et al., 2020). The term "stakeholders" can be broadly defined as individuals or bodies that impact or are impacted by the design, implementation, or performance of NBS (De Trift et al., 2026). Without clearer lines drawn between these NBS approaches and improved public health and increased financial opportunities, it

may take longer to inspire the same confidence and support in communities where traditional, grey infrastructure dominates the landscape of environmental engineering practices. A key issue with implementation is a lack of knowledge and education regarding the role of NBS and alternative water sources in such communities where grey infrastructure dominates. So-called stakeholders are concerned with the viability of NBS options in terms of cost-effectiveness and reliability compared with traditionally engineered options (Seddon et al., 2020).

The Local Context

Many governing and conservation bodies have implemented grants, fines, incentives, and signage to educate the public, but when funds are misused, these efforts may falter (Gibson et al., 2023). Locally, the San Antonio River Authority (SARA) has a dedicated education team that provides curricula, river camps, pre-made presentations, and hands-on experiences to motivate people of all ages to engage meaningfully with community waterways. In a similar vein, the San Antonio Water System (SAWS) has specialized education programs aimed at establishing a water-literate community through youth engagement. Both educational and community-forward engagement have been shown to increase public acceptance, outperforming passive education in many other areas of research (genome editing, renewable energy projects, biotechnology), so why not in the context of water resources (Abdulkareem et al 2024; Etchegary et al., 2015; Jimenez et al., 2022; Pathiranage et al., 2024)?

Our goal was to help students from a local secondary school and undergraduates undertaking a biology degree to engage with NBS through case studies and to understand the vital role of informed decision-making in determining whether a community would accept or reject water reuse. We partnered with the Castroville Wastewater Treatment Plant and developed a pair of case studies, along with a knowledge and attitude survey, to test whether a narrative-style, local, data-driven case study could help them move towards engagement with and acceptance of water reuse and the benefits of NBS.

Box 1. Research Questions Guiding the Project

- What is the existing acceptance of NBS across varied contexts? Which models of community engagement are most strongly associated with public acceptance of NBS in these varied contexts?
- Can exposure to a case study that embeds local data increase acceptance and understanding of NBS?
- How does effluent release impact parameters in a local water body with a wetland? Does proximity to the wetland reduce the impact? Is the impact sustained as the distance increases from the wetland?
- To what extent does involvement in a case-study "research experience" improve students' engagement with and appreciation of nature-based solutions?

Materials and Methods

The project combined an original field-based data collection effort with a course-based curriculum. This meant that the data being analyzed in the classroom were the same data being generated to answer our research questions about the wetland's capacity to remediate the wastewater plant effluent. Samples were collected monthly from three sites along a constructed wetland that receives effluent from the Castroville plant, as well as upstream and downstream sites on the Medina River, from February to July, 2026 (Figure 1). Samples were analyzed for nitrate and for phosphates using a portable spectrophotometer, and DNA extracted from the samples was sequenced to characterize the wetland's microbial community (by *Plasmidsaurus*). These data showed a modest but consistent decline in nitrates as the effluent moved along the wetland, and a detectable presence of DNA from taxa associated with antibiotic resistance in the effluent, which became the backbone of the data in the case studies rather than a hypothetical scenario typical of existing case studies. The research was thus used to construct two linked case studies for use in both K-12 and undergraduate settings. The first case study is a narrative-based one: the students follow a fictionalized resident of a small Texas town as she attends a city council meeting and hears from a variety of

FIGURE 1. Sites for Collection of Water Samples



stakeholders, including the plant operator and a panel of concerned citizens, each with a different stake in whether or not the town's treated wastewater effluent should be used to irrigate the city's park. The second case study was more data-driven, with the students playing the role of consultants employed by the same town council. They must interpret real data on nitrate and phosphate concentrations, as well as *Escherichia coli* (*E. coli*) counts. They would compare the upstream and downstream locations and consider policy options before making a recommendation in the form of a memo. At either end were pre- and post-tests that measured knowledge, engagement, and attitudes. This two-set case study design would enable us to determine whether combining a story with a data-driven experience would have a greater impact than either alone.

This project formed the basis of the first author's master's thesis research. The materials were piloted with undergraduate students at Texas A&M University-San Antonio, under IRB oversight, and modified versions were administered to K-12 students, with effectiveness being self-reported by their classroom teacher. A further

subset of seven students tested the material over the summer as part of an NSF Research Experiences for Undergraduates (REU) program, where participants conducted research at a constructed wetland in a local water body, adding real field-based experience to the case study they completed.

Box 2. Case Study and Field-Based Activities by Participating Students

- Reading and discussing a narrative case study depicting a community considering the fate of its treated wastewater
- Interpreting real data on phosphate and nitrate concentrations along with numbers of E. coli from a partner wastewater treatment plant
- Comparing upstream and downstream water quality data compared with that of the constructed wetland
- Drafting a written memo making a recommendation to the fictional city council that would make mention of the data
- Monthly field collection of water samples at three wetland sites as well as the upstream and downstream controls
- Water analysis in the lab for nitrate and phosphate concentrations using a portable spectrophotometer
- Nucleic acid extraction and sequencing (done by a company) to characterize the wetland microbial community
- Completion of a paired pre- and post-test instrument that measures knowledge, attitudes, and engagement

Both case studies and associated materials are available for download as resources in the QUBES hub available here: <https://qubeshub.org/publications/6186/1>

Results and Discussion

How Students Were Evaluated

To ensure that the students participated honestly and to the best of their ability, our pre- and post-tests were ungraded, and we emphasized to the students that this

was an assessment and study of their level of understanding as part of the research study. To us, honest answers were more valuable than expected ones. We actively discouraged them from "googling" the answers (this would be a concern for future at-home implementations). The instrument was designed to measure three dimensions:

- Knowledge – five multiple-choice items and two open-response questions scored against a four-level rubric
- Attitudes – twelve statements rated on a Likert scale
- Engagement – four open-ended reflection questions, with responses in the student's own words

We used a Wilcoxon signed-rank test to analyze the knowledge and attitude items. As the sample size was small, we conducted a sensitivity analysis by excluding two respondents who were flagged for unusually strong reversals between pre- and post-test attitude scores. Students' identities were not collected. Responses were coded prior to analysis. Participation was voluntary, and consent was obtained under the PIs' IRB protocol. For K-12 students, where a full quantitative instrument was not appropriate, effectiveness was assessed qualitatively through the teacher's self-reflection.

Student Success, Limitations and Reflections

Knowledge scores on the open-ended questions improved from the pre-test to the post-test for nearly all respondents (Figure 2). We also noted that item-level accuracy on the multiple-choice questions rose where there was room to grow. The most encouraging finding concerned public acceptance. At the outset of our project, during case study 1, most students were undecided about whether the town should use treated effluent to irrigate the city's park.

We observed more mixed results in our examination of attitudes (Figure 3). Most of the students already held favorable views towards resource conservation before the pre-test (not unexpected, given the course and their majors). There was a high ceiling of acceptance that limited how much movement was possible. However, two respondents showed a sharp negative swing in attitude

FIGURE 2. Individual Change in Open-Response Scores

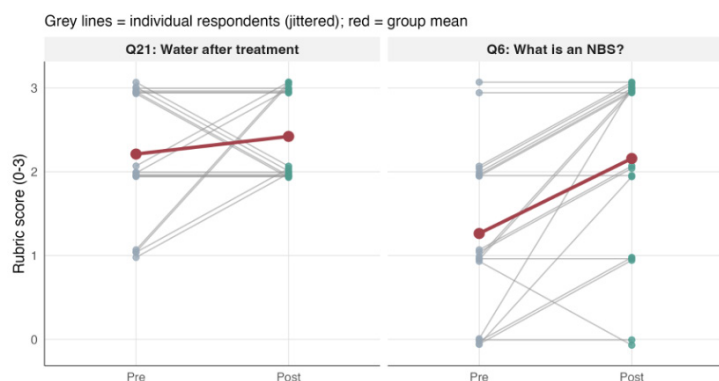
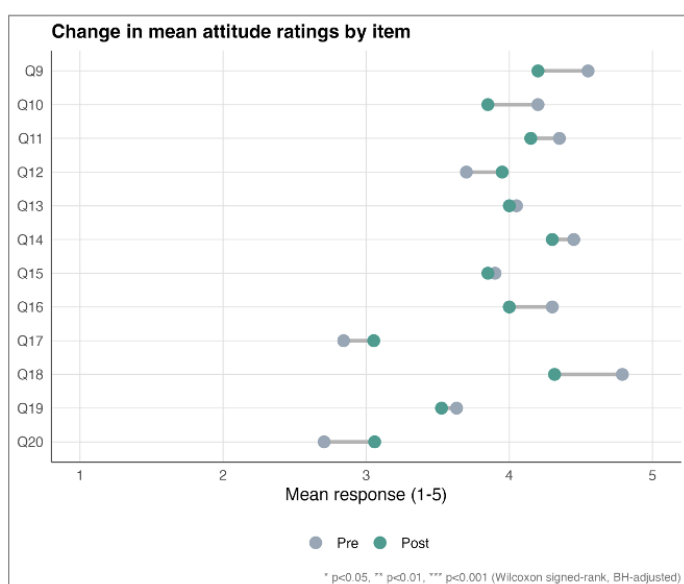


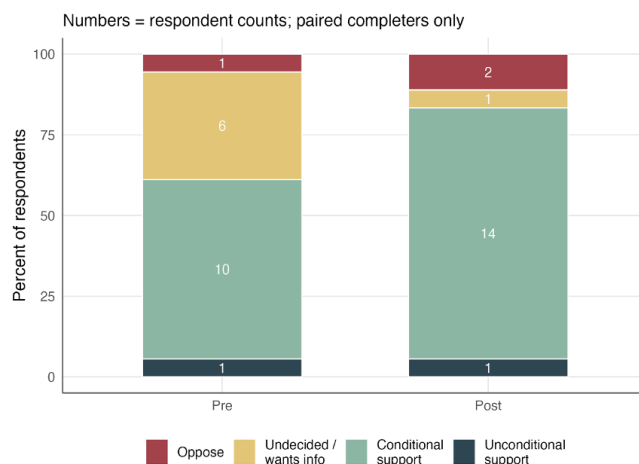
FIGURE 3. Barbell Chart of Change in Mean Attitudes by Item



scores. We suspect this may reflect a misreading of the scale or even a form of disengagement from the post-test, rather than a true reversal of attitude. Given this, the authors recognize the need to re-do and expand our pilot sampling beyond upper-level biology majors. Having completed both case studies, the gap among undecided students almost closed, with four individuals moving into conditional support and only one moving towards opposition (Figure 4).

One major limitation we identified early in the pilot was time. This practical barrier was owing to the limited time available in a single lab session. Conducting both the case studies and the pre- and post-tests takes time away from classroom activities. When time was short, the

FIGURE 4. Support for Irrigating Public Spaces with Treated Wastewater (Q22)



post-test was administered instead of the second case study. In future iterations, we will move the data-driven case study to an at-home, out-of-class assignment to be completed before class time. We also recognize that we need to consider the audience, a range of majors, and to include freshmen to seniors.

The need for greater implementation is evidenced by the course- and grade-level-based variation in K-12 students' ceiling of knowledge. 10th-grade students in an environmental systems class reported no knowledge of NBS at the outset of the pre-test, though they were often successful in selecting the definition when given multiple-choice options. 12th-grade students in a dual-credit biology course were able to correctly identify NBS in multiple-choice questions and offered robust short-answer responses. As previously discussed, time constraints prevented the implementation of the second case study. One of the greatest successes of our project was the connections that we made with the director of the Castroville Wastewater Plant. He was willing to share real, plant-specific data and discuss the issues. This real-world, locally sourced data likely had a much greater impact than a hypothetical scenario from elsewhere, and we now have an ongoing community-engaged project with real impact to build upon.

Box 3. Key Findings from the Pilot

- Nitrate concentrations declined significantly as the effluent moved through the constructed wetland (p values ranging from 0 to 0.042 across sites).
- Phosphate concentrations were more varied by date but remained consistently higher at the wetland sites than at the upstream and downstream control sites.
- *Burholderiaceae*, a taxon associated with antibiotic resistance, was the most abundant group we identified through sequencing water collected from the wetland.
- Knowledge responses measured with the rubric showed improvement from pre-test to post-test for all but one respondent.
- The number of students undecided about reusing water effluent for park irrigation decreased after using both case studies, with most moving towards unconditional support.

Summary and Future Directions

NBS like constructed wetlands are a proven tool for water remediation, mitigating the presence of nutrients, antibiotic resistance genes, and other water contamination concerns. We recognize that the efficacy of wetlands must be observed over a prolonged period to determine how well they withstand other factors, such as climate change and changes in pollutant types and concentrations. We must also consider equity in their construction and distribution. Educated and affluent communities are seeing the most direct benefits now, and the potential for these solutions to become class-specific looms. This is counterintuitive given the cost-efficiency of these designs, and resistance to NBS could be overcome through community engagement. We also recognize that we need to fund and support research on NBS, especially as we enter a more pivotal point than ever before regarding water accessibility. Government and government-adjacent bodies could seek a path forward that helps build trust among themselves, other stakeholders, the community at large, and the scientific community by funding and encouraging education on these practices. As the push for a more

ecologically mindful world grows, education remains the most conducive platform for community change.

In our efforts to promote data-driven decision-making, we paired our case studies with locally acquired data. Our pilot application with Texas A&M University-San Antonio biology students provides a multifaceted proof of concept and a model for a way forward. While the results of the initial wetland monitoring are nuanced, they paint a picture of an effective wetland remediation model with the potential for greater impact through expansion to match the suggestion that increased retention time correlates with greater remediation. Long-term monitoring built into the local school curriculum poses a real opportunity to learn about how attitudes toward NBS can be changed.

The deployment of the case studies offers an even more nuanced glimpse into the mindsets of young people with the greatest potential for community change. While the observed group of respondents scored high in both attitudes and knowledge, both groups saw gains, even with high ceilings. While a small percentage were swayed away from the validity of NBS, a large portion of uninformed and undecided respondents moved toward greater understanding and, with that, increased support of NBS. This model of engagement has the potential to expand acceptance of NBS across multiple levels of the community, thereby increasing the availability and acceptance of recycled water applications.

In future semesters, we intend to refine the timing of the two case studies, expand our K–12 pilot with a fuller instrument, and pursue long-term monitoring of the wetland. We need to better understand the durability of NBS and to consider equity of access to NBS. We are also especially interested in engaging with rural Texas communities, who are too often left out of both data collection and the conversations about water reuse. It is in these rural communities that NBS methods, adopted evenly and equitably along with stakeholder buy-in, could have the greatest impact on water scarcity.

About the Authors



Alexis D. Denn is a graduate student in biology at Texas A&M University-San Antonio and a secondary school science schoolteacher. Her thesis research combines wetland water quality monitoring with the design of case studies and research-based curricula aimed at increasing public understanding of nature-based solutions.



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