CITIZEN SCIENCE:
THEORY AND PRACTICE

Illuminating Collaborative Opportunities in the Creation of a Community Science Tampling Program

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KELLY ALBUS
ASPEN NAVARRO
DESIREE JACKSON
DELANEY HANKINS
BENTON HENDRICKSON
CHRISTINA LOPEZ
MADISON MITCHELL

*Author affiliations can be found in the back matter of this article

ABSTRACT

Expanding access to meaningful participation in community science is essential for achieving more equitable representation and addressing persistent gaps in data collection. Herein, we describe the collaborative development of Tampling—a low-cost, community citizen science program that uses passive optical brightener samplers (tampons) to indicate the presence of human wastewater contamination in surface waters. Initially designed as a classroom learning activity linking water literacy and pollution concepts with field-based methods, Tampling evolved through collaboration between two programs, the Active Citizen and Community Education for Science Standards and Texas Stream Team, into a state-approved community citizen science monitoring program that augments professional sampling and meets state agency standards. The method provides a clear, visual result that is both engaging and scientifically meaningful. Implementation across Texas through educational workshops and field testing in North and Central Texas helped demonstrate the method's value for water education, volunteer engagement, and detection of contamination. Although the approach is limited to simple presence/absence observations, its accessibility and adaptability—reinforced by formal community partnerships—have inspired broad public participation in the water quality monitoring program. This work demonstrates that an educational tool co-developed with community partners can evolve into a state-supported community citizen science program that democratizes data collection and catalyzes community-driven water stewardship.

CORRESPONDING AUTHOR:
Benton Hendrickson
Department of Biological Sciences, University of North Texas, US
BenHendrickson@my.unt.edu

KEYWORDS:
Knowledge construction; optical brighteners; water resources; water quality; co-creation; community science

TO CITE THIS ARTICLE:
Albus, K., Navarro, A., Jackson, D., Hankins, D., Hendrickson, B., Lopez, C. and Mitchell, M. 2026. Illuminating Collaborative Opportunities in the Creation of a Community Science Tampling Program. *Citizen Science: Theory and Practice,* 11(1): 14, pp. 1–15. DOI: https://doi.org/10.5334/cstp.964

INTRODUCTION

MANAGING WATER QUALITY FOR THE ENVIRONMENT

It is increasingly evident that successful management of shared natural resources, like water, requires sustained and collaborative participation of diverse communities, including professionals, researchers, landowners, agencies, and regional stakeholders (Newig et al. 2023). Under the federal Clean Water Act (CWA), when surface waterbodies do not meet water quality standards, communities and managing entities have the option to implement a watershed protection plan (WPP) to restore water quality. These voluntary, non-regulatory plans include adaptive management measures by major stakeholders and community members within the watershed to improve water quality. WPPs are funded via state agencies to local stakeholders so that waterbodies maintain "fishable and swimmable" status by meeting state water quality standards (Houck 2014; Adler 2013).

Nearly all WPPs require education, outreach, and water quality monitoring for implementation. The education and outreach components are designed to strengthen community understanding of anthropogenic water quality issues, such as nonpoint source (NPS) pollution, water conservation, septic system maintenance, and groundwater protection, among others, and are often accomplished by efforts conducted by water managers and other environmental education entities (Floress et al. 2017).

Water quality monitoring is often wrapped into WPP development with the goal of delisting the watershed, as these data determine the status of a watershed and provide insights for adaptive management. Monitoring frequency, duration, and extent of monitoring sites vary by watershed condition and available funding. Watersheds that are listed as impaired (not meeting state water quality standards) are typically prioritized for monitoring and restoration funding; however, healthy watersheds may also be monitored proactively.

As water pollution becomes an increasingly critical challenge, efficient water quality monitoring is more urgent than ever (Finegan and Hasenmuller 2023; Dubber and Gill 2017; Telci et al. 2009; Strobl and Robillard 2008). However, with limited funding and a growing number of impaired waterbodies, professional monitoring programs often lack the capacity to cover the full geographic scope and frequency needed statewide. To address these limitations, professional agencies have begun to manage or partner with volunteer networks to help fill data gaps and expand monitoring coverage (Poisson et al. 2019). Community volunteers typically monitor more frequently and adopt sites they visit regularly, giving them valuable local insights into pollution threats.

Citizen science or community science (hereafter referred to as CCS), or the "public" in scientific research (Bonney et al. 2009), is an effective tool for engaging communities in water quality initiatives (Ramírez et al. 2023; Albus et al. 2020). In addition to education and outreach outcomes, community members involved in data collection become crucial in water quality monitoring where professional resources are insufficient to meet sampling needs (Warner et al. 2024; Starkey et al. 2024; López-Esquivel et al. 2024). This is demonstrated by thousands of active CCS monitoring programs nationwide that raise awareness about water quality issues and help inform community actions to mitigate environmental impacts (Lopez et al. 2025; Poisson et al. 2019; Stepenuck and Green 2015). Significantly, participants in CCS programs often report developing strong pro-environmental attitudes (Crall et al. 2013; Toomey and Domroese 2013; Brossard et al. 2005), resulting in positive gains for environmental action and stewardship (Ballard et al. 2024). Despite positive outcomes associated with CCS, programs can be exclusive to those of certain backgrounds and cultures, which creates inherent accessibility issues for diverse stakeholders.

PURPOSE

Herein, we describe the collaborative development of a CCS water quality monitoring program jointly created by two partner organizations (the project team) working to design a model acceptable by the Texas Commission on Environmental Quality (TCEQ). The program's purpose is to reach diverse participants through accessible and hands-on education opportunities structured around local waterways, while also collecting useful data relating to impairments. Through shared expertise and coordinated planning, we (the project team) sought to expand educational goals with regulatory standards to ensure the CCS program's long-term viability and formal acceptance for bacteria-related water pollution in rapidly diversifying and urbanizing populations. Field testing took place in two regions of Texas, USA: the Central Texas Austin-San Antonio corridor and the North Texas Dallas-Fort Worth Metroplex, both among the fastest developing regions in the nation (Figure 1).

BACKGROUND

CITIZEN AND COMMUNITY SCIENCE

Many types of CCS programs play considerable data-collection roles in various fields such as ornithology, astronomy, climate science, ecology, and watershed

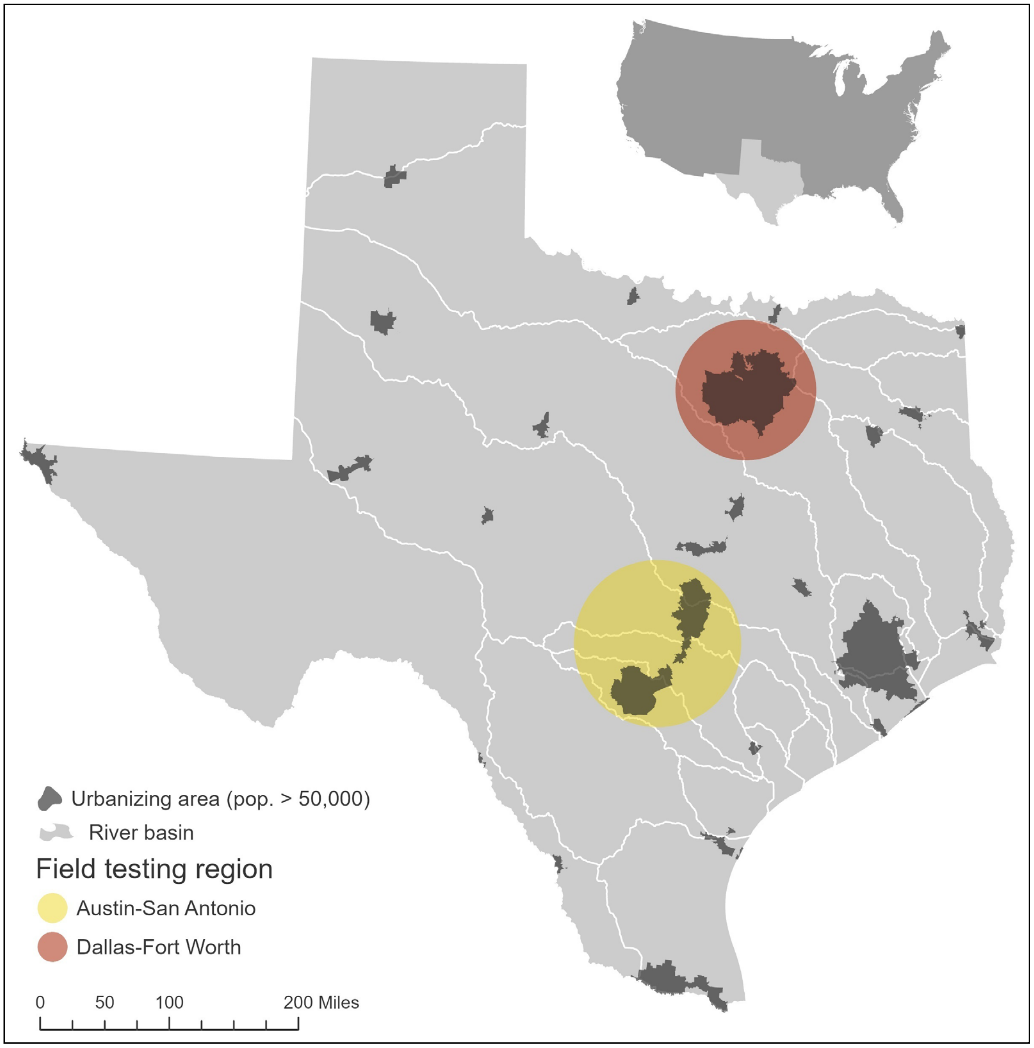

Figure 1 Highlights the two field testing regions in Texas: Dallas-Fort Worth Metroplex (*red*, Phase I) and the Austin-San Antonio corridor (*yellow*, Phase II).

science (Allf et al. 2022; Lopez 2021; Walker et al. 2020; Gouraguine et al. 2019; Ries and Oberhauser 2015). This paper focuses on CCS for watershed science, specifically water quality monitoring. This type of CCS programming typically begins by onboarding volunteers through structured training that reviews approved field protocols with a qualified trainer, demonstrates equipment use, and assesses method competency (Ramírez et al. 2023). Upon completion of the training, volunteers are certified to collect data and collaborate with the sponsoring program to establish a routine monitoring site consistent with the program's goals. Site choice often reflects a place volunteers are connected to, while program procedures ensure the location also contributes comparable, management-relevant information to the broader watershed dataset (Starkey et al. 2024; Ramírez et al. 2023; Buckland-Nicks et al. 2016). The active role participants take in a CCS program can bridge the gap between learning scientific methods and environmental education, teaching participants research skills accompanied by stewardship values related to environmental resources, ultimately fostering greater resilience within socio-ecological systems (Jadallah and Ballard 2025; Wals et al. 2014).

Collaborative frameworks of CCS provide participants with opportunities to reflect on the real experiences they gain. Studies show that education programs are most likely to support WPPs if they are place-based and firmly rooted in the local context (Lopez et al. 2025; Hamilton and Marchini-Polk 2023; Phillips et al. 2019; Chandler and Lerner 2015). The inclusion of CCS in education and outreach programming can be beneficial to meeting environmental goals, especially when supported by agency protocols and held to quality assurance standards (Albus et al. 2020). Many of these programs are also publicly accessible, which can feed into local management decisions, especially for large-scale projects when data are made open access and have sufficient spatial and temporal resolution (Hadj-Hammou et al. 2017).

EFFECTIVE AND INCLUSIVE CITIZEN AND COMMUNITY SCIENCE PROGRAMMING

Because measurable water quality improvements typically require widespread and geographically distributed uptake of best management practices (BMPs), under-engagement of entire demographic groups reduces the likelihood of achieving watershed-scale impact (Yoder et al. 2019). For CCS programs to reach watershed-level impact, they must be accessible, inclusive, and relevant to diverse communities (Varga et al. 2023; Roche et al. 2020). Studies show that environmental education programs are expected to foster not only short-term knowledge gains but also behavior changes that collectively support pro-environmental behavior at the watershed scale (Marcum-Dietrich et al. 2021; Santori et al. 2021; Ardoin et al. 2020).

Internationally, many existing water education and volunteer monitoring opportunities remain elective, resource-intensive, or disconnected from community priorities. Thus, they often attract a narrow subset of participants and fail to engage the broader populations whose behaviors most directly influence local water quality. Programs that require less resources and are community-driven, action-oriented, and grounded in personal and cultural connections to water are more likely to lead to sustained behavioral change. Building social frameworks for continued collaboration, fostering peer-to-peer information sharing, and integrating education with ongoing research have proven crucial to achieving lasting improvements in watershed health (Wang and Chermak 2021; Everett et al. 2021; Ardoin et al. 2020).

Regional water education programs raise awareness about hydrology, water quality, and conservation, while CCS can lead to greater engagement and long-term impact through organizational and social capital (Domínguez-Rendón et al. 2024; Stepenuck and Green 2015; Overdevest et al. 2004). However, even successful examples of this model like Texas Stream Team—a CCS program at The Meadows Center for Water and the Environment (The Meadows Center) with strong volunteer engagement and data collection across the state—report that participants are predominantly of a homogenous demographic—largely white, affluent, well-educated, and of retirement age (Lopez 2021). This pattern in participant demographics is linked to systemic factors, such as unequal access to leisure time, transportation, and green space, as well as differing levels of trust in scientific and governmental institutions (Johnson et al. 2014; Pandya 2012), and reflects longstanding barriers in environmental volunteerism.

Social networks, recruitment strategies, and program design often unintentionally reinforce exclusion by privileging existing participants or assuming prior environmental knowledge (Toomey et al. 2020). Moreover, when volunteer opportunities are framed around abstract ecological goals rather than community priorities like flooding, drinking water, or neighborhood health, they can appear irrelevant to many potential participants (Pandya 2012; National Academies of Sciences, Engineering, and Medicine 2017; Garlick and Fallon 2023). Addressing these structural and cultural barriers requires intentional design choices that make CCS programs more inclusive, culturally responsive, and locally meaningful.

CITIZEN AND COMMUNITY SCIENCE IN TEXAS

Expanding access to CCS opportunities is critical for Texas' rapidly urbanizing and diversifying regions. Texas Stream Team serves as a statewide CCS program that helps close these gaps by training volunteers to monitor local watersheds. Recognizing the size and complexity of the water environment, TCEQ established Texas Stream Team in 1990 to address data gaps in water quality monitoring. In 1999, administration moved to Texas State University, establishing a more collaborative and multifaceted program. Today, the program continues to facilitate environmental stewardship with upwards of 13,500 trained community scientists, more than 300 actively monitored sites across the state, and a network of more than 160 partner organizations.

To meet educational needs in Texas through inclusion of CCS in water education, the Active Citizen and Community Education for Science Standards (ACCESS) program launched in 2021. Administered by Dr. Albus while working with Texas A&M AgriLife and the Texas Water Resources Institute (TWRI), the program demonstrated substantial success in advancing watershed education and community-based CCS across Texas.

TOWARD INNOVATIVE CITIZEN AND COMMUNITY SCIENCE WATER QUALITY MONITORING

Fecal water contamination is a global NPS challenge with significant public health and economic risks (Finegan and Hasenmuller 2023; Lockmiller et al. 2019; Ishii and Sadowsky 2008). Effective management of contaminated waterbodies depends on accurate source identification to inform targeted interventions. Distinguishing between human and animal fecal sources is critical for developing successful management strategies (Khan and Gupta 2020; Dubber and Gill 2017; Romick and Johnson 2015; Chandler and Lerner 2015; Byappanahalli and Ishii 2011; Field and Samadpour 2007).

Current CCS bacteria monitoring indicates only the occurrence of fecal contamination, not its source (Byappanahalli and Ishii 2011; Field and Samadpour

2007). More advanced monitoring such as microbial source tracking can be expensive and slow, limiting effective responses to contamination (Finegan and Hasenmuller 2023). A simple, low-cost method that both supports fecal contamination source tracking and differentiates between human and animal waste can be fulfilled by monitoring optical brighteners (OBs).

OBs are chemical compounds added to laundry detergents, cleaning agents, textiles, and paper products, including toilet paper, to make them appear brighter (Cao et al. 2009). Because domestic wastewater includes a mixture of graywater from washing machines, toilets, sinks, and dishwashers, OBs are considered ubiquitous in human wastewater and serve as useful indicators of human fecal contamination when detected alongside *Escherichia coli* (Cao et al. 2009; Hartel et al. 2007a).

An OB water quality training was developed through the Texas Stream Team and ACCESS programs to enhance community engagement while advancing the role community scientists have when it comes to identifying NPS pollution and local management decisions (Figure 2).

EVOLUTION THROUGH PRACTICE AND COLLABORATION

The following sections detail how the pilot OB CCS monitoring program developed into an open-access program through Dr. Albus and a state-approved program for certification through the Texas Stream Team. The evolution started in a classroom setting (Phase I), was refined for wider use in the field (Phase II), and was then scaled for statewide implementation by CCS volunteers through a state-approved protocol (Phase III).

PHASE I

To reach a wide audience and test the accessibility of OB monitoring, initial efforts were piloted in classrooms by Dr. Albus at the University of North Texas and through statewide educational programming administered through Texas A&M AgriLife and TWRI, using standards-aligned curriculum and educator workshops for grades 6–12 and undergraduate classrooms. Workshops included educational materials as well as toolkits and methods training so classrooms could conduct OB sampling using tampons, which quickly became known as "Tampling." The workshops trained teachers and students to illuminate (positive) tampons under ultraviolet fluorescence to indicate the presence of human wastewater contamination in surface waters (Cao et al. 2009; Hartel et al. 2007b). Students and teachers then collected data using Esri™ public data collection interfaces (ArcGIS® Online web-based mapping, Survey123, StoryMaps, and Hub) and completed feedback surveys.

To concurrently test and scale accessibility of the OB monitoring method, the ACCESS program included a comprehensive Texas Essential Knowledge and Skills (TEKS)-aligned educator toolkit, an online CCS framework, and statewide educator workshops to effectively bridge classroom learning with real-world challenges. Program components included:

- Goals: To deliver accessible watershed and water quality education that integrated CCS principles to improve learning gains and inspire adoption of BMPs for watershed health. Hands-on training served to build social and professional support for participants and communities through the CCS OB monitoring program as an early warning system for untreated wastewater leaks.
- Curriculum and workshops: TEKS-aligned curricular modules and professional development workshops for educators (grades 6–12 and undergraduate) in or near target Texas watersheds (Figure 3). Workshops included OB monitoring toolkits and hands-on training for OB sampling using tampons (the OB Tampling method) and utilizing public platforms for resource sharing and data collection.
- Data collection and interface: Participants collected data using Esri™ public geospatial tools (ArcGIS® Online, Survey123, StoryMaps, Hub) and submitted feedback on the workshop and tools via surveys.

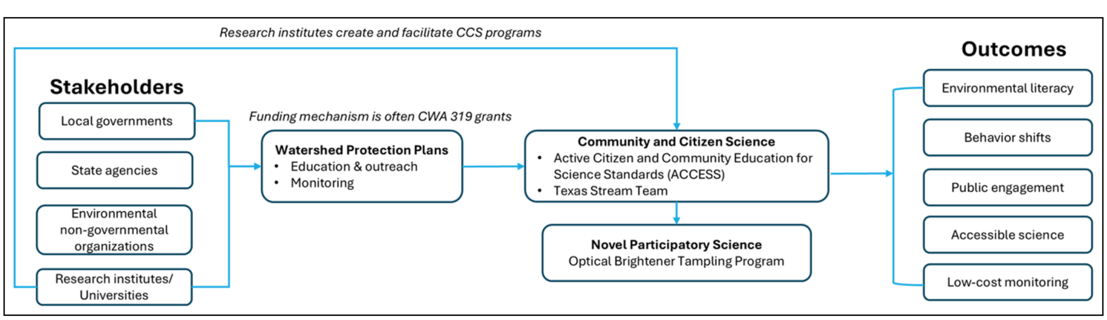

Figure 2 Stakeholder to outcome pathways in watershed management.

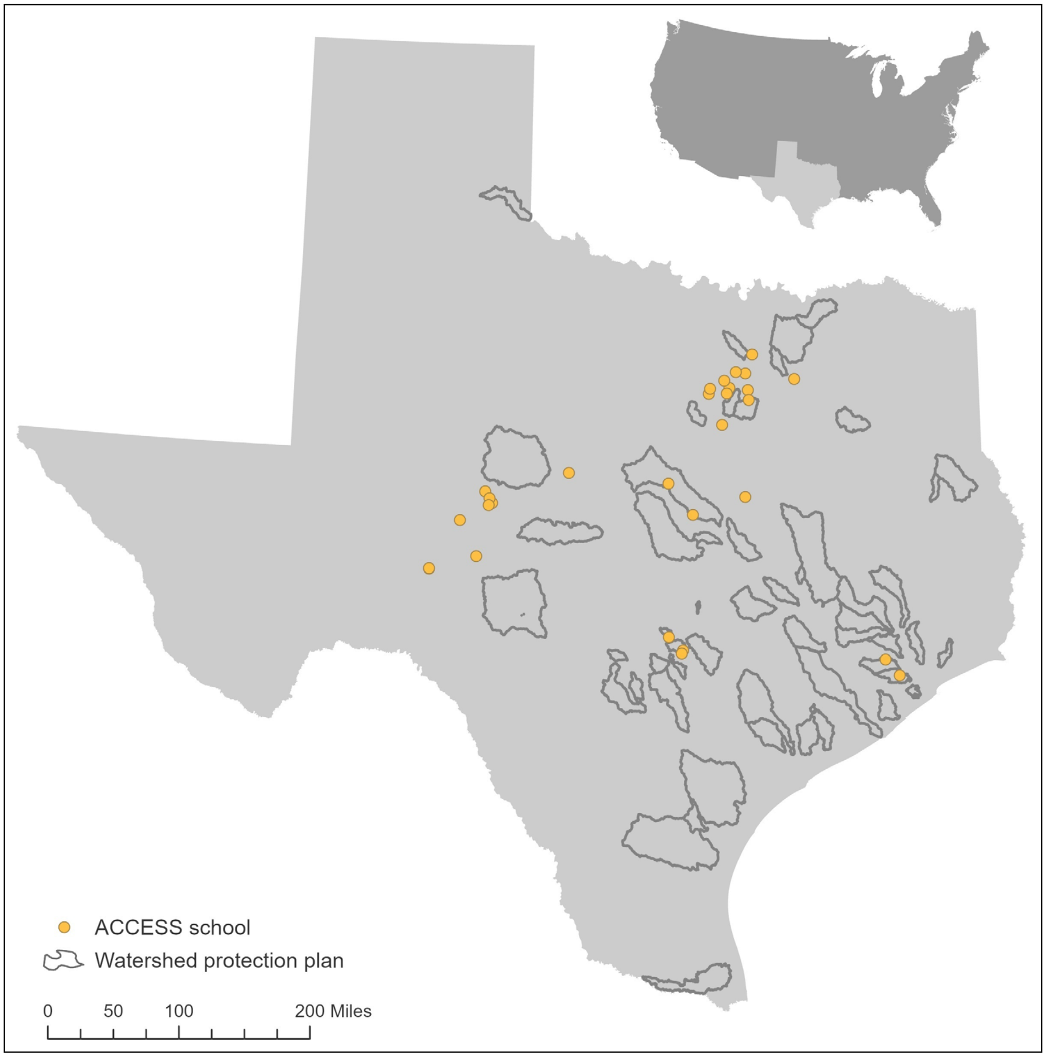

Figure 3 The Active Citizen and Community Education for Science Standards (ACCESS) program water workshop locations in relation to watershed protection plans (WPPs).

- Community feedback and co-development of OB monitoring protocol: Initially, the project team reviewed existing watershed/water quality education materials and conducted informal email surveys with water education providers through statewide networks to identify education gaps, especially related to NPS pollution. They then developed TEKS-aligned materials for target watersheds. Materials were tailored for each watershed, highlighting local impairments for greater engagement and impact, and shared in teacher workshops via a train-the-trainer OB monitoring method. Teachers were encouraged to use the method in their classrooms.
- Participant feedback: Post-workshop discussions indicated that participants appreciated the simplified nature of the OB Tampling method, which in combination with its applicability in watersheds impaired for bacteria, made it a successful program with positive teacher feedback. The ACCESS team also conducted community events with other organizations to promote the program, and iteratively refined resources with input from teachers, students, and community stakeholders throughout.

The Active Citizen and Community Education for Science Standards (ACCESS) program outcomes

Between October 2021 and July 2023, the project team hosted or participated in 45 events, reaching nearly 9,400 people directly, including 64 educators who collectively reach an estimated 6,000–12,000 students each year. The educator workshops (both in-person and virtual) built momentum for long-term engagement by equipping teachers with practical, low-cost tools for water quality education, including the OB monitoring method. These workshops catalyzed local networks of teachers, volunteers, and community partners who integrated CCS data collection and outdoor investigations into classrooms across the state.

A core goal of ACCESS was to make participation easier and more equitable by lowering the barriers that often limit who can take part in scientific research. The tools and workflows were intentionally inexpensive, portable, and adaptable to a wide range of school contexts, including under-resourced classrooms that may not have access to specialized lab equipment. This supports greater inclusivity not just by reducing cost and technical hurdles, but by positioning educators and students as contributors to locally relevant environmental research.

The use of familiar, everyday material, particularly one that can be stigmatized, can challenge perceptions of what scientific tools are supposed to look like, and invite discussion and speculation about what can be repurposed for science, who can do science, and how familiarity with materials can reduce intimidation around data collection and field methods. We anticipated that issues around the use of menstrual products with students could surface in some settings, and the team proactively shared reframing language and strategies for management in open discussions with educators. We are aware of one early instance in which a parent in a district raised concerns about the use of tampons with middle school students after the method had been used during field trip activities without reported problems. Following that, the activity was removed from the field trip site's middle school options, although teachers were still able to do the project in their own classrooms. This early experience provided a foundation for these discussions and reinforced the value of explicitly framing the item as a sampling medium (e.g., "cotton on a string") while maintaining the integrity of the protocol.

Implementation of OB monitoring methods through educator workshops and across a broader geographic range created an opportunity to pilot the approach for large-scale volunteer adoption. The ACCESS program provided critical early testing and feedback that informed the launch of the Public OB Tampling CCS Hub in 2023, in partnership with Texas State University via Texas Stream Team. In 2024, Tampling was further expanded through inclusion on SciStarter, a public CCS database and interactive platform (Project Page), to expand OB data collection beyond state lines and understand the scale of its presence and effectiveness. Additional materials and project resources can be found in the Supplemental Materials section (Supplemental file 1: ACCESS Program Final Report; Supplemental file 2: Technical Report of Phase II Study).

PHASE II

Beyond the public SciStarter platform, Dr. Albus simultaneously collaborated with Texas Stream Team to explore its potential for higher-level scientific application through wider use in CCS monitoring to enhance the value on the state agency side. With its extensive experience developing state-approved CCS protocols, Texas Stream Team provided a framework to refine and evaluate the method. The collaboration's goal was assessing key factors for state agency adoption, while including clarity, ease of use, practicality of implementation, and cost of supplies.

To expand the Tampling method, Texas Stream Team sought to test the protocol in areas with known contamination. Texas Stream Team's decade-long engagement in the Cypress Creek watershed in Hays County, Texas, collecting both CCS and professional (state-accepted) water quality data, made it an ideal testing location. Since the early 2000s, Cypress Creek (TCEQ Segment 1815) has been included in the Texas Integrated Report 303(d) list of impaired waterways. Concerned stakeholders launched a multi-year project in 2008 to develop a community-driven WPP to manage water resources within the watershed (The Meadows Center 2014). The Meadows Center and Texas Stream Team serve as water quality monitoring partners within the WPP. Guided by community interests, the WPP addresses both point and nonpoint sources of *E. coli* bacteria and other pollutants through routine monitoring, data analysis, and BMP implementation to improve Cypress Creek's water quality and restore its approval for contact recreation activities.

In the Cypress Creek watershed, both volunteers and professionals monitor water quality regularly. Texas Stream Team plays a central role in supporting the volunteer monitoring. Efforts include routine monitoring of key sites, establishing new monitoring locations, and training local residents, including waterfront property owners and new volunteers, in data collection protocols. Data collection in the region started in early 2006 and continues today, with brief gap periods throughout.

Since 2016, The Meadows Center, in collaboration with The Watershed Association—a local nonprofit organization working to keep Cypress Creek flowing—has funded quarterly professional water quality monitoring, including *E. coli* testing, as part of TCEQ's Clean Rivers Program (CRP) on Cypress Creek (TCEQ 2024b; TCEQ 2024c). CRP monitoring occurs in the Cypress Creek watershed from the headwaters at Jacob's Well to the confluence with the Blanco River, spanning a rural-urban gradient. Quarterly CRP monitoring results have been used in the Texas Integrated Report to determine whether water quality meets state standards. This history of degradation in the watershed raised concerns among local communities given the considerable number of recreational activities on Cypress Creek along with the crucial role ecotourism plays in the area's economy. In response, stakeholders at WPP meetings requested that The Meadows Center develop a monitoring plan to identify potential bacteria sources. Notably, one resident contributed personal funds to support this research.

The community's need to identify pollution sources in Cypress Creek aligned with Dr. Albus's goal to field test a potential higher-level CCS pollution screening tool, creating a unique opportunity to combine both efforts into one study. Given Texas Stream Team's history with the Cypress Creek WPP, established partners, and proximity to the research lab, the lower reach of Cypress Creek (length = ~1 mi) was chosen as the Phase II study area located within the Austin-San Antiono corridor (Figure 1).

The project team's first objective was to determine which existing monitoring locations could incorporate the Tampling method and whether new sites needed to be established to ensure a representative mix ranging from no to high contamination. We established a total of nine sampling locations along the lower reach of Cypress Creek based on historical CRP monitoring data, private and public property accessibility, and points of interest or concern.

Monitoring began in summer 2021 when samples were collected biweekly to detect OBs associated with potential wastewater contamination from laundry activities. This schedule also allowed the integration of the Tampling CCS method into the monthly professional CRP water quality monitoring activities from June to September 2021 (Supplemental file 3: 2021 Pilot Field Guide).

Our second objective was to conduct OB monitoring with slight modifications to field test the protocol for potential use by CCS. Through field work, we narrowed down three main target goals:

1) testing different tampon deployment durations,
2) understanding contamination risk, and
3) configuring a monitoring apparatus using inexpensive supplies.

These target goals were able to be successfully refined, mostly utilizing accessible, low-cost materials to ensure quality results can be achieved in the field.

Texas Stream Team successfully deployed more than 100 tampons for OB analysis across nine monitoring sites and determined the modified Tampling protocol could likely be utilized in CCS monitoring to detect human wastewater contamination as a source of bacterial contamination.

PHASE III

Based on results from Phases I and II, Texas Stream Team further refined the method for development and launch of state-approved procedures and standardizations, a Quality Assurance Project Plan (QAPP) for statewide volunteer monitoring data collection, and integration into a certified CCS collection database for monthly monitoring in conjunction with other early warning parameters.

After successfully refining the protocol based on the findings of the initial technique study, Texas Stream Team focused on a larger goal: creating a training program that could support statewide CCS monitoring of OBs. Achieving this requires not only technical development, but also careful coordination with long-time collaborator and partial funder TCEQ.

From the outset, the team saw that scaling the program would hinge on two factors: 1) ensuring methodological consistency across hundreds of volunteers; and 2) creating a system of data entry and validation that upheld quality standards required for regulatory use. Designing the training became a process of balancing technical rigor with practical usability. Our first step was to refine the program's name to align with Texas Stream Team's established naming conventions, ensuring the target parameter appeared in the title. As a result, the Optical Brightener Community Science Training was established.

To ensure consistency, we developed a suite of standardized resources that CCS and trainers could use to maximize transparency and minimize user error (Table 1).

Resources were first tested internally and then piloted with non-affiliated staff and community partners who had no prior OB monitoring experience. Their questions and the challenges they shared were invaluable, highlighting language that needed to be clarified, instructions that were too technical, and tools that could be streamlined for field use. Each pilot session became a feedback loop, and we revised the materials until volunteers with little background could carry out the method with confidence.

Equally important was designing a data entry system that regulators could trust. The monitoring form went through multiple iterations before the final version captured not only results, but also the often-overlooked process details that determine accuracy. For example, having a space for volunteers to record quality control steps (e.g., "Did you check the tampon for OB contamination prior to your monitoring event?") directly on the datasheet proved essential. A built-in quality control checklist ensures data reviewers can confirm procedures that are not otherwise evident in the results. These adjustments, though small, address the types of uncertainties that can make CCS-generated data difficult to translate into policy discussions.

Throughout this development phase, we kept TCEQ closely involved. Quarterly check-ins with their staff, along with annual hybrid meetings with statewide trainers,

RESOURCE	LOCATION	PRIMARY PURPOSE	FORMAT
Manual	Supplemental file 4: Manual	Provides background information, protocols, supply lists, and detailed instructions	Comprehensive written document (PDF/print)
Final Field Guide	Supplemental file 5: Final Field Guide	Step-by-step instructions for in-field use, condensed from the manual	One-page, double-sided quick reference sheet (PDF/print)
Monitoring Form	Supplemental file 6: Monitoring Form	Standardized data collection tool; includes critical steps and quality control checks	Data sheet for field use (print/digital entry)
Prerequisite Module	Supplemental file 7: Prerequisite Module	Pre-training module to build baseline knowledge	Online module
PowerPoint Slides	Supplemental file 8: PowerPoint Slides	Day-of training presentation	Slide deck (digital)
Equipment List	Supplemental file 9: Equipment List	Cost estimates and purchasing information for required materials	Webpage
Instructional Videos	https://www.youtube.com/txstreamteam	Demonstrate OB protocols and field techniques visually	YouTube videos, linked and shareable
Trainer Checklist	Supplemental file 10: Trainer Checklist	Ensures trainers cover consistent topics during each session	One-page checklist (PDF/print)
Training Participant Packet	Supplemental file 11: Training Participant Packet	Day-of training packet for trainees to complete throughout the training and keep (includes the Monitoring Form and Field Guide)	Printed packet (PDF/print)

Table 1 Standardized training resources for citizen science and community science optical brightener (CCS OB) monitoring.

created an open line of communication for feedback and timeline planning with the state regulatory authority. The entire training development process took approximately six months. Importantly, it was timed so the new resources could be incorporated into the recertification of our QAPP. Because OB is not a parameter typically monitored by state regulators, there were several rounds of review with TCEQ's Quality Assurance staff to ensure the procedures and standardizations met their expectations. In the end, steady dialogue and methodical adjustments paid off: The integration of OB monitoring into the QAPP provided the formal recognition the program needed to scale to a statewide level.

Together, we reached the consensus that, ideally, OB monitoring should be paired with *E. coli* bacteria sampling. This pairing allowed OB data to serve as a flag for potential human contamination, while *E. coli* results helped distinguish between true contamination and false positives. This marks a critical difference between a) the OB monitoring protocol and certification for Texas Stream Team volunteers under a QAPP, and b) the public OB Tampling program created by Dr. Albus. The OB Tampling program is designed to be accessible for untrained students and volunteers and will continue to be available for non-certified participants, providing publicly mapped OB monitoring data without accompanying *E. coli* bacteria sampling.

LIMITATIONS AND FUTURE RESEARCH NEEDS

Our findings confirm that OB monitoring is an accessible and effective addition to community-based water quality programs, but they also highlight limitations and future needs. Qualitative OB data (presence/absence) are easy for volunteers to obtain but the data lacks the quantitative precision needed to pinpoint pollution severity. A fluorescing (positive) tampon indicates potential wastewater contamination, but without measured intensity or concentration, it remains challenging to target specific sources for mitigation. Moreover, OB presence alone suggests human wastewater but does not speak to the overall health of the waterway. Therefore, OB monitoring is best used as a screening tool alongside traditional indicators, particularly fecal bacteria, to build a more complete picture of water quality. Incorporating conventional water quality parameters or combining OB monitoring with dye testing and infrastructure maps could improve source confirmation, making a positive OB result actionable within a larger water quality assessment toolkit (Chandler and Lerner 2015; Muller and Muller 2022). Researchers working with OBs should explore combining qualitative and quantitative results for more comprehensive assessments and develop accessible methods to identify background florescence interference.

Fluorescence in surface water can result not only from OBs but also from natural organic matter, pollutants, and dyes that may cause false positives in fluorometric measurements due to background interference (Dubber and Gill 2017; Hartel et al. 2008; Hartel et al. 2007b; Hagedorn and Saluta 2005). Conversely, false negatives occur due to variability in detergent composition, as some products lack OBs (Dubber and Gill 2017; Cao et al. 2009). Differentiating OBs from other fluorescing organic compounds requires advanced techniques inaccessible to most CCS programs (Cao et al. 2009; Hartel et al. 2008; Hartel et al. 2007b). These realities complicate interpretation of OB presence/absence, and have limited the method's broader adoption. Even with the Texas Stream Team example, scaling the Tampling program may prove challenging if groups lack complementary bacterial monitoring capacity or worry about ambiguous results.

Another notable gap in the pilot phase was the limited involvement of the program's intended end-users. Although the protocol was extensively piloted in classrooms, external volunteer monitors—the target audience for the OB CCS protocol—should be more involved in continued refinement to fully meet the practical needs of community water quality monitors. To address this gap, a forthcoming feasibility study will involve Texas Stream Team volunteers directly.

CONCLUSION

Bacteria-related water pollution is a widespread concern, yet monitoring its sources often requires expensive tools or specialized expertise, making it inaccessible for many communities. To bridge this gap, we developed a low-cost OB CCS water quality monitoring program to broaden access to bacteria-monitoring tools, enabling community volunteers and educators to gather meaningful data about local water quality.

Each partner within the project team brought unique expertise. Dr. Albus contributed blended expertise in environmental science and education, ensuring the method supported community learning objectives and outcomes. Texas Stream Team added decades of experience in developing state-approved monitoring procedures for large-scale adoption by CCS volunteers that address stakeholder-identified water quality parameters. This collaboration ensured the OB CCS protocol was both educationally meaningful, aligning with state education standards and filling learning gaps (Phase I), and technically robust—capable of producing useful data on stakeholder-identified water quality issues while complementing professional monitoring efforts (Phases II–III).

Field testing confirmed that OB monitoring can be both accessible and low in cost for CCS programs. Only simple, inexpensive equipment and minimal training were required to implement the protocol, lowering barriers for volunteer participation. Additionally, because the Texas Stream Team OB monitoring protocol meets state-approved standardizations, it can lead to more timely interventions in local water management as communities are better equipped to collect data and implement actionable outcomes outside of academic institutions or government agencies (Lopez and Weaver 2021).

The journey of the Tampling CCS program highlights the powerful synergy between education and CCS. What began as a simple, low-cost, hands-on water quality testing classroom lab activity has evolved into a formally recognized monitoring method accepted by Texas' state regulatory agency, lending it scientific credibility and a rigorous framework for data collection. Integration into Texas Stream Team's network provided training and standardization for volunteers, and built legitimacy among water resource professionals. This progression from educational tool into a public CCS method into a certified statewide CCS program demonstrates how grassroots innovations and collaboration can enrich environmental monitoring practices. Ultimately, the successful development of the Tampling method and collaborative roll-out to volunteers underscores a fundamental lesson in citizen science theory and practice: Given the right tools, collaborations, and training, ordinary people armed with low-cost tools can play an extraordinary role in safeguarding water resources, from their own backyards to the global community.

DATA ACCESSIBILITY STATEMENT

Not applicable. Ancillary materials can be found in Table 1, Supplementary Files section, on the Public OB Tampling CCS Hub, and on the SciStarter Project Page. The Hub contains raw data actively being collected through the nationwide Tampling program.

SUPPLEMENTARY FILES

- **Supplemental File 1.** ACCESS Program Final Report. DOI: https://doi.org/10.5334/cstp.964.s1
- **Supplemental File 2.** Technical Report of Phase II Study. DOI: https://doi.org/10.5334/cstp.964.s2
- **Supplemental File 3.** 2021 Pilot Field Guide. First rendition of step-by-step instructions for in-field use. DOI: https://doi.org/10.5334/cstp.964.s3

- **Supplemental File 4.** Manual. Background information, protocols, supply lists, and detailed instructions. DOI: https://doi.org/10.5334/cstp.964.s4
- **Supplemental File 5.** Final Field Guide. Step-by-step instructions for in-field use. DOI: https://doi.org/10.5334/cstp.964.s5
- **Supplemental File 6.** Monitoring Form. Standardized data collection tool. DOI: https://doi.org/10.5334/cstp.964.s6
- **Supplemental File 7.** Prerequisite Module. Pre-training module to build baseline knowledge. DOI: https://doi.org/10.5334/cstp.964.s7
- **Supplemental File 8.** PowerPoint Slides. Day-of training presentation. DOI: https://doi.org/10.5334/cstp.964.s8
- **Supplemental File 9.** Equipment List. Cost estimates and purchasing information for required materials. DOI: https://doi.org/10.5334/cstp.964.s9
- **Supplemental File 10.** Trainer Checklist. Topics trainers cover during each session. DOI: https://doi.org/10.5334/cstp.964.s10
- **Supplemental File 11.** Training Participant Packet. Day-of training packet for trainees to complete throughout the training and keep. DOI: https://doi.org/10.5334/cstp.964.s11

ACKNOWLEDGEMENTS

We are grateful to a handful of staff from The Meadows Center who assisted with initial project implementation: Sandra Arismendez for initial project management, Laura Parchman for data organization, and Jenna Walker for project supervision and original concept. We also thank students and interns who assisted in Phase II field work: Haley Busse, Kaylee Boggan, Tina Cummings, Cooper Peterson, Ally Schlandt, and Daniel Vasquez.

For ACCESS and non-certified Tampling development, we thank Pamela Simmons-Brooks for co-presenting and curricular designer, support staff at TWRI, Pamela Golcher and Bess Price, for their help with the ACCESS materials development, and the teachers, students, and volunteers that gave their time and energy to the project.

FUNDING INFORMATION

This project was funded in part by a CWA 319(h) grant via the U.S. Environmental Protection Agency through TCEQ, and by Peter Way of Wimberley, Texas. The ACCESS program was funded by a CWA 319(h) grant via the Texas State Soil and Water Conservation Board. The views expressed do not necessarily reflect the views and policies of the funders, nor do the funders endorse trade names or recommend the use of commercial products mentioned in this document.

COMPETING INTERESTS

The authors have no competing interests to declare.

AUTHOR CONTRIBUTIONS

All authors contributed feedback and helped shape the research and manuscript; KA* provided the research concept, contributed to research design, writing, editing, and grant funding; AN* contributed to research design, writing, editing, grant funding, and management of the research team efforts; DJ* was responsible for data collection (Phase II), writing, and editing; DH was responsible for the literature review and map visualizations, and contributed to writing and final review; BH was responsible for data collection (Phase I), writing, and editing; CL assisted in visualization of concepts and provided final editing; MM was responsible for OB protocol development and paper final review.

*Authors contributed equally to the contents of this paper.

AUTHOR AFFILIATIONS

Kelly Albus orcid.org/0000-0001-9642-0859
Division of Environmental Science, Texas Woman's University, US
Aspen Navarro orcid.org/0009-0005-5135-8074
The Meadows Center for Water and the Environment, Texas State University, US
Desiree Jackson orcid.org/0009-0006-3558-5514
The Meadows Center for Water and the Environment, Texas State University, US
Delaney Hankins orcid.org/0009-0008-9052-6159
The Meadows Center for Water and the Environment, Texas State University, US
Benton Hendrickson orcid.org/0009-0009-0607-2228
Department of Biological Sciences, University of North Texas, US
Christina Lopez orcid.org/0000-0002-8665-5598
The Meadows Center for Water and the Environment, Texas State University, US
Madison Mitchell orcid.org/0009-0003-3940-8724
The Meadows Center for Water and the Environment, Texas State University, US

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TO CITE THIS ARTICLE:
Albus, K., Navarro, A., Jackson, D., Hankins, D., Hendrickson, B., Lopez, C. and Mitchell, M. 2026. Illuminating Collaborative Opportunities in the Creation of a Community Science Tampling Program. *Citizen Science: Theory and Practice,* 11(1): 14, pp. 1–15. DOI: https://doi.org/10.5334/cstp.964

Submitted: 11 December 2025 **Accepted:** 01 June 2026 **Published:** 09 July 2026

Citizen Science: Theory and Practice is a peer-reviewed open access journal published by Ubiquity Press.