What to Expect
From Water Quality Monitoring

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Why monitoring matters – and why it's harder than it looks

Water quality monitoring is often built into watershed projects with the hope that data will document progress, confirm that conservation practices work, and provide a clear story for funders, landowners, and community leaders. Because watershed projects are locally driven efforts, they can empower communities to engage in holistic planning and implementation that aligns with local opportunities, barriers, and goals. Monitoring plays important roles: establishing baseline conditions, identifying where problems occur, and showing how implementation aligns with water quality goals. It can also help build trust among farmers and local partners who want to see how their land management decisions affect nearby waterways.

Yet despite these benefits, monitoring rarely produces a straightforward picture of improvement. Detecting measurable change at the watershed scale is intrinsically challenging because the landscape itself is complex and highly variable. Storms, droughts, crop rotations, and land use shifts exert strong influences on water quality, often much stronger than the effects of any single project. As a result, even well-designed projects with strong local participation may not show statistically significant changes during a typical 3- to 5-year funding cycle.

Setting realistic expectations is essential. Monitoring is valuable, but it may not tell the entire story within the timeframes and budgets available.

Kyla Souza

What Science Tells Us About Detecting Change

For a watershed project to show water quality improvement, two things must happen: The impacts of project implementation must be large enough to influence watershed pollutant loads, and the monitoring program must be robust enough to detect that change amid natural variability.

Many watershed projects implement practices, but the scale of adoption may simply be too small relative to the size of the watershed and the magnitude of existing nutrient and sediment sources. For example, if a practice that reduces nitrogen loss by 30 percent is implemented on 10 percent of the cropped area, the watershed reduction would likely only be 3 percent. In addition, *legacy nutrients* stored in soils and groundwater may continue to leak into streams for years or decades, impeding water quality improvement even if current practices improve. Practices implemented may not be the most effective for the watershed's specific issues, or they may be implemented in locations where they provide only modest benefit. Larger, more impactful practices—such as wetlands, floodplain reconnection, or major drainage modifications—often require multiple landowners to work together, navigate permitting and regulatory hurdles, or commit significant acreage, all of which take time to plan and execute.

There are also many reasons that monitoring could fail to show improvement even for an effective project. Improvements can be hard to detect because water quality is highly variable from season to season and year to year—heavy storms, droughts, crop rotations, and land use changes can all influence pollutant levels more strongly than any single project can. This low "signal-to-noise ratio" makes detection of change with statistical significance less likely. Project impacts that are diluted when measured downstream further reduce the likelihood of detecting change. In addition, monitoring programs sometimes lack long-term consistency, adequate sampling frequency, or enough sites to capture subtle trends. In many watersheds, the amount of nutrients or sediment already stored in soils, groundwater, and streambeds is so large that it continues to wash into streams for years or even decades after practices are put in place. As a result, even when conservation practices reduce runoff and improve soil health locally, the monitoring data may not show a clear or statistically significant improvement in the stream, especially within the typical 3- to 5-year project window.

Change detection through watershed monitoring is more likely to be effective when a paired watershed monitoring design is used (Clausen and Spooner, 1993). This method controls for natural variability, particularly weather, which often overwhelms water quality signals at the watershed scale. By comparing a treated watershed to a similar untreated control, and establishing their relationship during a calibration period, researchers can detect changes attributable to management rather than background noise. This makes it more reliable than simple before–after comparisons for evaluating conservation practices.

Case Example: Water Quality Monitoring of Two Wabash River Tributaries

A long-term project in Indiana illustrates both the value and the difficulty of watershed monitoring. The Wabash River Enhancement Corporation (WREC), supported by the EPA 319 program, implemented a wide range of conservation practices beginning in 2013, including cover crops, buffer strips, nutrient management, and conservation tillage. Purdue University researchers monitored two nearby tributaries over more than 9 years to see how the streams responded (Figure 1).

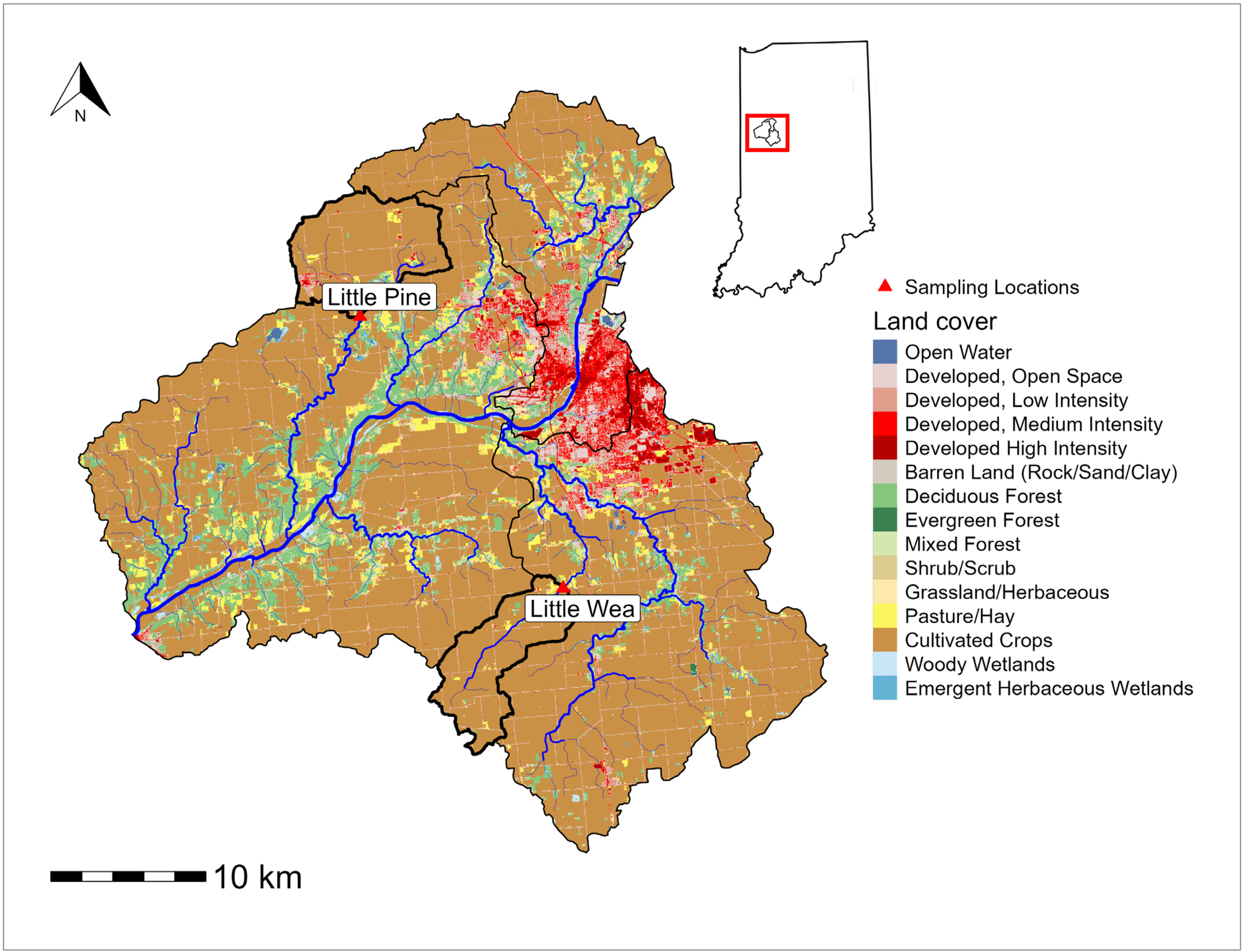

Figure 1: Two small Wabash tributary watersheds in West Central Indiana that were monitored over 9 years.

Monitoring Design

The monitoring used a paired watershed approach, in which one watershed received the majority of conservation practices while the other served as a reference. Both watersheds had similar soils, land use, and climate, making them suitable for comparison. Baseline data were collected from 2009 to 2012, followed by post-implementation monitoring from 2013 to 2015 and again from 2021 to 2024.

Parameters monitored in the two streams included discharge, nitrate + nitrite, soluble reactive phosphorus, and total suspended solids. For discharge, the U.S. Geological Survey installed and maintained gaging stations in both watersheds from March 2009 to October 2017. From 2021 to 2024, researchers monitored stream stage every 15 minutes using an

ISCO 720 bubbler flow monitor and converted stage to discharge using a rating curve. For the water chemistry parameters, researchers collected weekly grab samples from 2009 to 2017, and in 2021 they installed ISCO automatic samplers to obtain higher-frequency data.

In addition, a "sampling blitz" engaged volunteers in collecting grab samples at nearly 200 sites within the watershed twice each year. Participation as citizen scientists led to increased engagement with the watershed, but results have not been used to show the effect of the project (Muenich et al., 2016).

Conservation Practice Adoption

Conservation practices, such as cover crops, nutrient management plans, and structural practices were implemented beginning in 2013 by both federal and state programs. Federal funding included USEPA 319, USDA Environmental Quality Incentives Program (EQIP), and USDA Conservation Stewardship Program (CSP), while the state of Indiana also funded practices through its Clean Water Indiana (CWI). An evaluation of funded contracts showed that adoption rates of cover crops were estimated to be as high as 43 percent in the Treatment watershed (Figure 2).

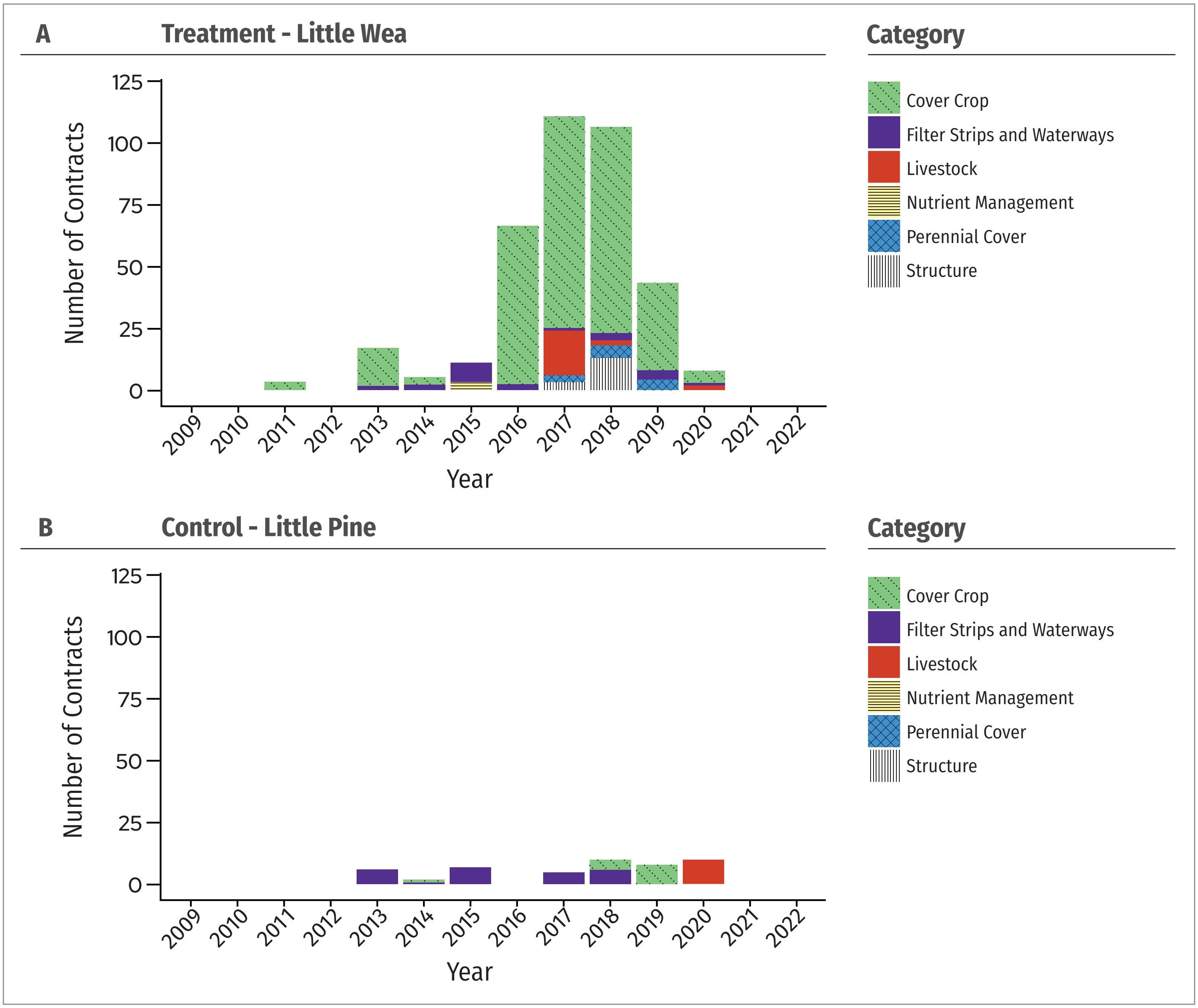

Figure 2: Funded conservation practices in the two watersheds, showing greater implementation in the Treatment watershed. Source: Rudko, 2024.

What the Data Showed

Nitrate + nitrite measured as nitrogen (referred to here as nitrate-N) was the only monitored parameter that showed a statistically significant change and is therefore the focus here. Nitrate-N concentrations were typical of agricultural streams in Indiana, with average levels ranging from 3 to 7 mg/L and occasional individual samples exceeding 20 mg/L.

Samples were divided into three periods: Baseline (2009–2012), Post-implementation 1 (2013–2015), and Post-implementation 2 (2021–2024) to better determine changes. Discharge and nitrate-N (NO3-N) concentrations during each of these periods for each watershed are shown in Figure 3, with lines showing means for that period. It is apparent that the concentrations decreased slightly in the Treatment watershed—but is the decrease significant?

Because variability is so wide due to climate and other changes, the important factor is the comparison between the two watersheds. A statistical method called Generalized Least Squares (GLS) was used with a treatment variable (to represent each monitoring period), and a correction term for correlation among samples collected in close succession. This method showed that the concentrations decrease in the Treatment watershed was statistically significant and can likely be attributed to changes in water quality to the agricultural conservation practices implemented in this watershed.

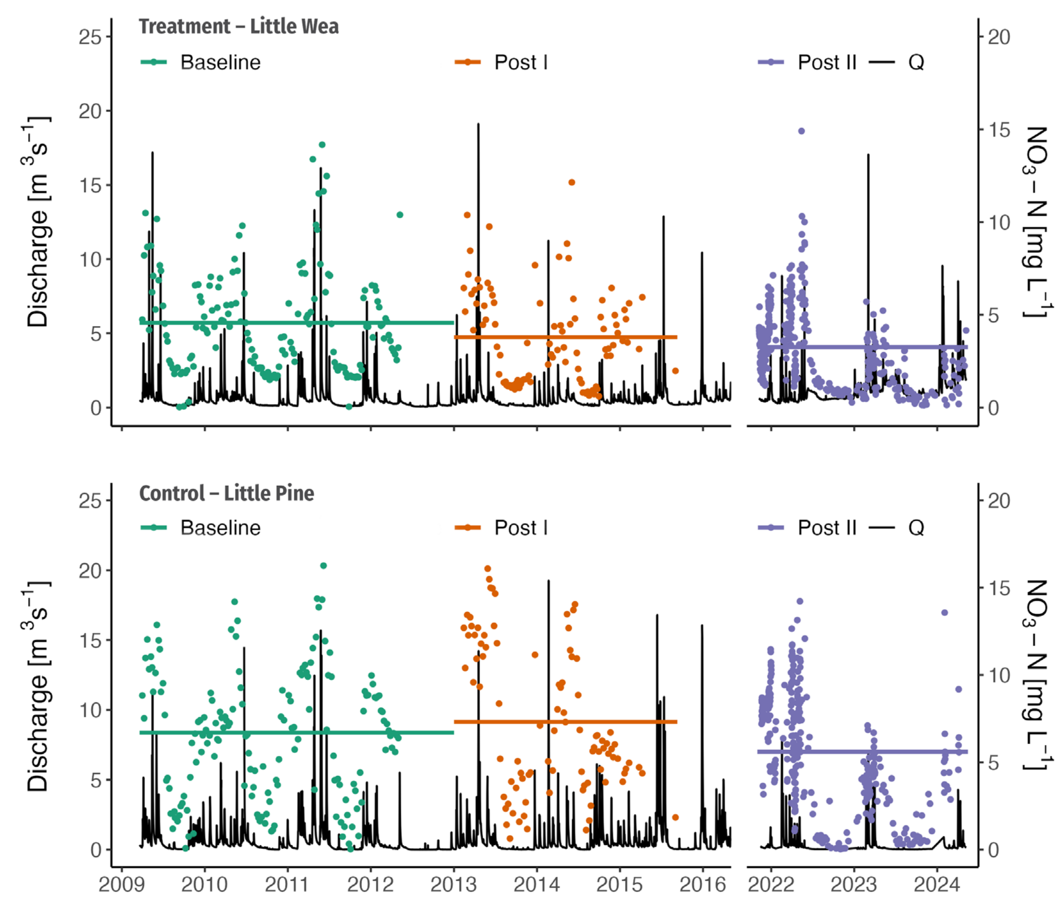

Figure 3. Time series of NO3-N concentrations during each monitoring period for the Treatment (top) and Control (bottom) watersheds. Solid horizontal lines are the simple mean concentration for that monitoring period. Source: Rudko, 2024.

The more recent monitoring, from 2021 to 2024, did not show any additional change in concentration. This suggests that farmers did not abandon practices after their implementation, and that practices have been effective in maintaining the achieved lower concentrations during the first post-implementation monitoring that occurred 10 years earlier.

Key Takeaways for Watershed Projects

Although watershed monitoring may not always show clear improvements, it remains an important component of effective watershed projects. Monitoring helps identify where to focus efforts, supports adaptive management, and builds shared understanding among farmers, agencies, and researchers. Because watershed work is an ongoing, adaptive process, monitoring offers the data needed to adjust strategies and focus resources to where they will have the greatest impact. It can also play a role in demonstrating results to funders, community members, and partner organizations, giving credibility to the project and helping build support for continued investment. In many communities, monitoring further serves as an engagement tool, bringing in volunteers, schools, and local groups and fostering hands-on learning about watershed systems. When thoughtfully designed, it generates the evidence needed to sustain and expand water quality efforts.

Several principles can guide decisions about whether and how to monitor:

- Match monitoring scale to project goals. If the goal is to evaluate specific practices, edge-of-field or plot-scale monitoring will be more responsive than watershed-scale sampling.
- If detecting statistically significant watershed-scale improvement is a project goal, design the watershed project with monitoring in mind. A paired watershed design has a higher likelihood of showing change but requires more monitoring over a longer time period, including before practices are implemented.
- Focus on the most meaningful parameters. Nitrate responds relatively quickly to management changes; phosphorus and sediment often require long timeframes and high sampling frequency to show trends.
- Prioritize sampling frequency and data quality over the number of sites. A few well-monitored locations are far more valuable than many inadequately sampled ones.
- Set realistic timelines. Most watershed projects will not show statistically significant change within a single grant cycle.
- Partner with researchers. Robust design and analysis increase the likelihood of detecting true changes and communicating them clearly to stakeholders.

Monitoring also has important social value. Many farmers want to understand how their practices affect nearby streams, and local data can help justify investments and strengthen trust. Even when improvements are slow to detect, monitoring provides shared evidence that supports long-term collaboration.

Monitoring is essential for understanding watershed systems, but its ability to show measurable improvement is limited by natural variability, legacy effects, and project scale. When designed intentionally and interpreted realistically, monitoring can inform decisions, support outreach and education, and provide local evidence that builds confidence in conservation strategies. The key is to view monitoring not as a quick proof of success but as part of a long-term commitment to improving water quality and supporting resilient agricultural landscapes.

References

Clausen, J. C., & Spooner, J. (1993). *Paired watershed study design* (No. PB-94-154820/XAB; EPA–841/F-93/009). Environmental Protection Agency. Washington, DC: Office of Wetlands, Oceans and Watersheds.

Muenich, R. L., Peel, S., Bowling, L. C., Haas, M. H., Turco, R. F., Frankenberger, J. R., & Chaubey, I. (2016). The Wabash Sampling Blitz: A study on the effectiveness of citizen science. *Citizen Science: Theory and Practice*, 1(1), 3. https://doi.org/10.5334/cstp.1.

Rudko, N. (2024). *The impact of agricultural conservation practices on water quality in tile-drained watersheds* [Doctoral dissertation]. Purdue University. https://doi.org/10.25394/PGS.26357689.

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