Three case studies for monitoring water quality trends in Iowa

A report for "Movement Infrastructure for Clean Water in Iowa", funded in 2023 by the Water Solutions Fund in collaboration with Mosaic

By Dan Haug, Prairie Rivers of Iowa, November 2024

Partners: The Izaak Walton League of America, Iowa Environmental Council, Partners of Scott County Watersheds, Northeast Iowa RC&D, Pathfinders RC&D, Polk County Conservation, Drake University

Background

Prairie Rivers of Iowa was the recipient of a 2023 Movement Infrastructure Grant from Mosaic, funded through a partnership with the Water Solutions Fund. The goal of these grants was to build the capacity of the environmental movement to make the most of the unprecedented opportunity presented by historic federal climate and environmental policy. So far, Iowa has been awarded $1.17 billion from water-related programs in the the Inflation Reduction Act (IRA) and Infrastructure Investment and Jobs Act (IIJA). To ensure that those investments result in cleaner water in Iowa's polluted rivers, we need more robust and collaborative approaches to water monitoring.

The primary goal of the project was to build relationships and facilitate information-sharing across organizations that monitor water quality in Iowa, culminating in an Iowa Water Summit on October 8, 2024. A second goal of the project was to develop tools and case studies for interpreting water quality data. This set of case studies illustrates what we see as the main obstacle to using water quality data to track the progress of conservation efforts, and a potential solution.

Data Sources and Methods

The Ambient Stream Monitoring Network is a set of 60 sites monitored monthly by the Iowa Department of Natural Resources for a wide range of water quality parameters. 48 of these sites have been monitored for at least 20 years. Site names may be truncated in the graphs that follow, but a lookup table is provided at the end.

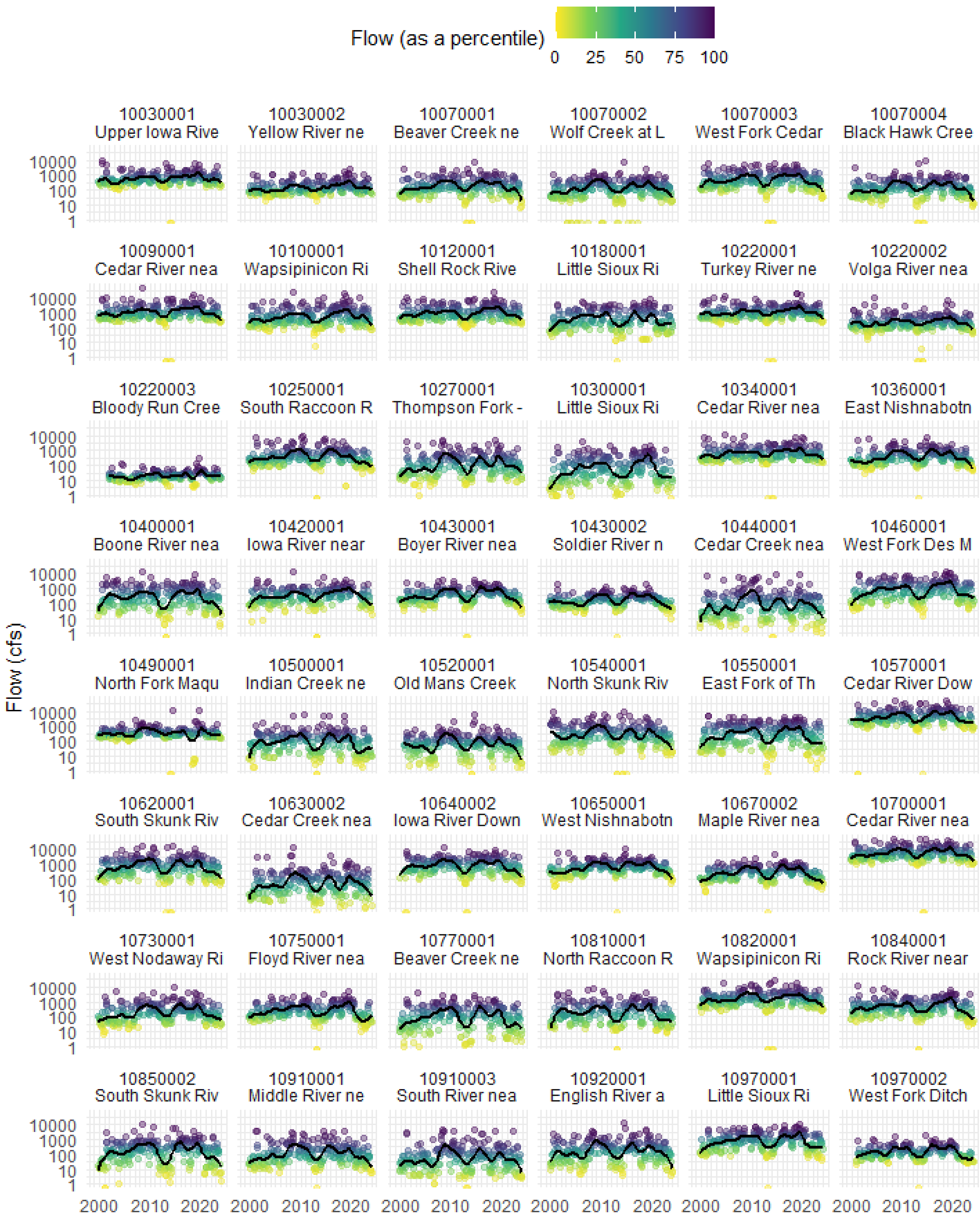
For each site, we downloaded the following data from the AQuIA database for the period from January 2000-December 2023, and that had been tagged with the "AMBIENT" or "CITIES" project codes.

- Nitrate + nitrite
- Total phosphorus
- *E. coli* bacteria
- Turbidity
- Dissolved oxygen
- Streamflow (measured at the nearest gage on the same day as monthly water quality sampling)

We also delineated a watershed for each site and overlaid a geodatabase of NPDES permit holders in the watershed, to calculate the total design flow of all sewage treatment plants and industrial facilities upstream of the sampling location.

Figure 1 shows streamflow measurements for all 48 sites on the same day that water quality samples were collected, with the black line showing a 3-year moving average. Expressing streamflow either a percentile or exceedance probability allows large and small streams to be plotted or color-coded on the same scale, and water quality measurements collected during wetter than average or drier than average conditions to be compared. Percentiles were computed for each site using the flow data available in the AQuIA database—generally 20-23 years of monthly measurements. The color-coding scheme introduced here is consistent across all graphs in this report.

Figure 1: Streamflow during monthly sampling, 2000-2023, for 48 sites with 20+ years of data



Case Study 1: Streams affected by point and non-point source pollution have opposite trends in phosphorus

Are water quality problems in a river mostly driven by point source pollution, which might be addressed by improved wastewater treatment funded by the IIJA, or by non-point source pollution, which might be addressed by agricultural conservation programs funded by the IRA? One way to find out is by plotting water quality against streamflow.

In the North Raccoon River near Lake View (site #10810001), total phosphorus decreases with streamflow, with concentrations greater than 3 mg/L observed when streamflow is less than the 15th percentile (see Figure 2). This is consistent with a steady flow of phosphorus from point sources, which would be diluted by tile drainage and runoff in wetter periods. This site is downstream of a meatpacking plant and a large sewage treatment plant in Storm Lake, as well as several smaller facilities. Both major facilities have been required to investigate the feasibility of new technology to reduce phosphorus concentrations, but these upgrades have not yet been completed.

In the South Raccoon River near Redfield (site #10250001), phosphorus tends to increase with streamflow, with concentrations greater than 3 mg/L observed when streamflow is greater than the 95th percentile (See Figure 3). This is consistent with phosphorus bound to sediment being eroded from fields in the watershed or from streambanks during wetter periods. The South Raccoon River watershed is located in a hillier part of Iowa than the North Raccoon River watershed.

Figure 2: Phosphorus vs flow, 2000-2023
North Raccoon River near Lake View

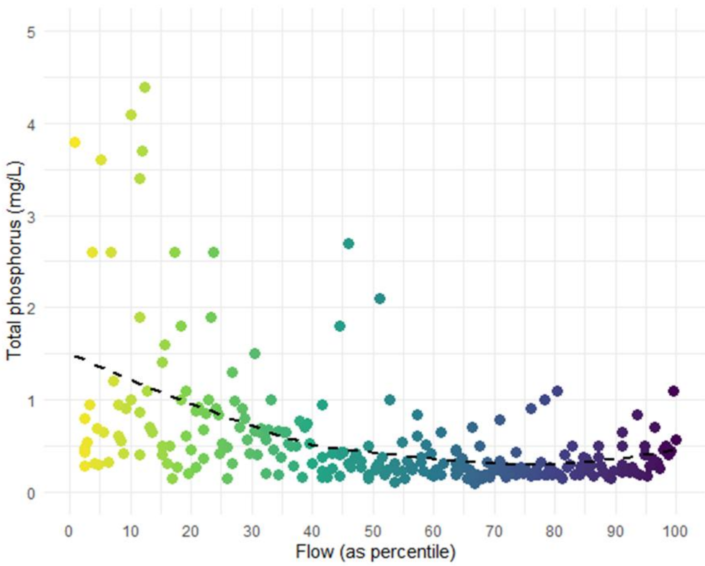


Figure 3: Phosphorus vs flow, 2000-2023
South Raccoon River near Redfield

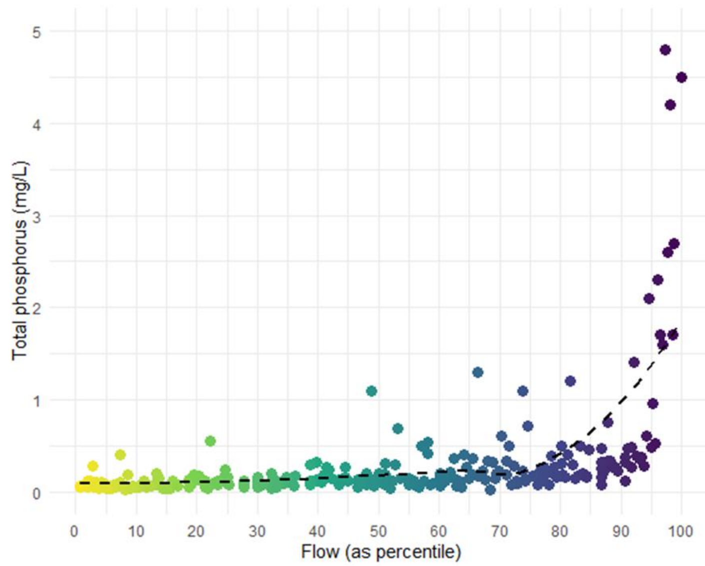
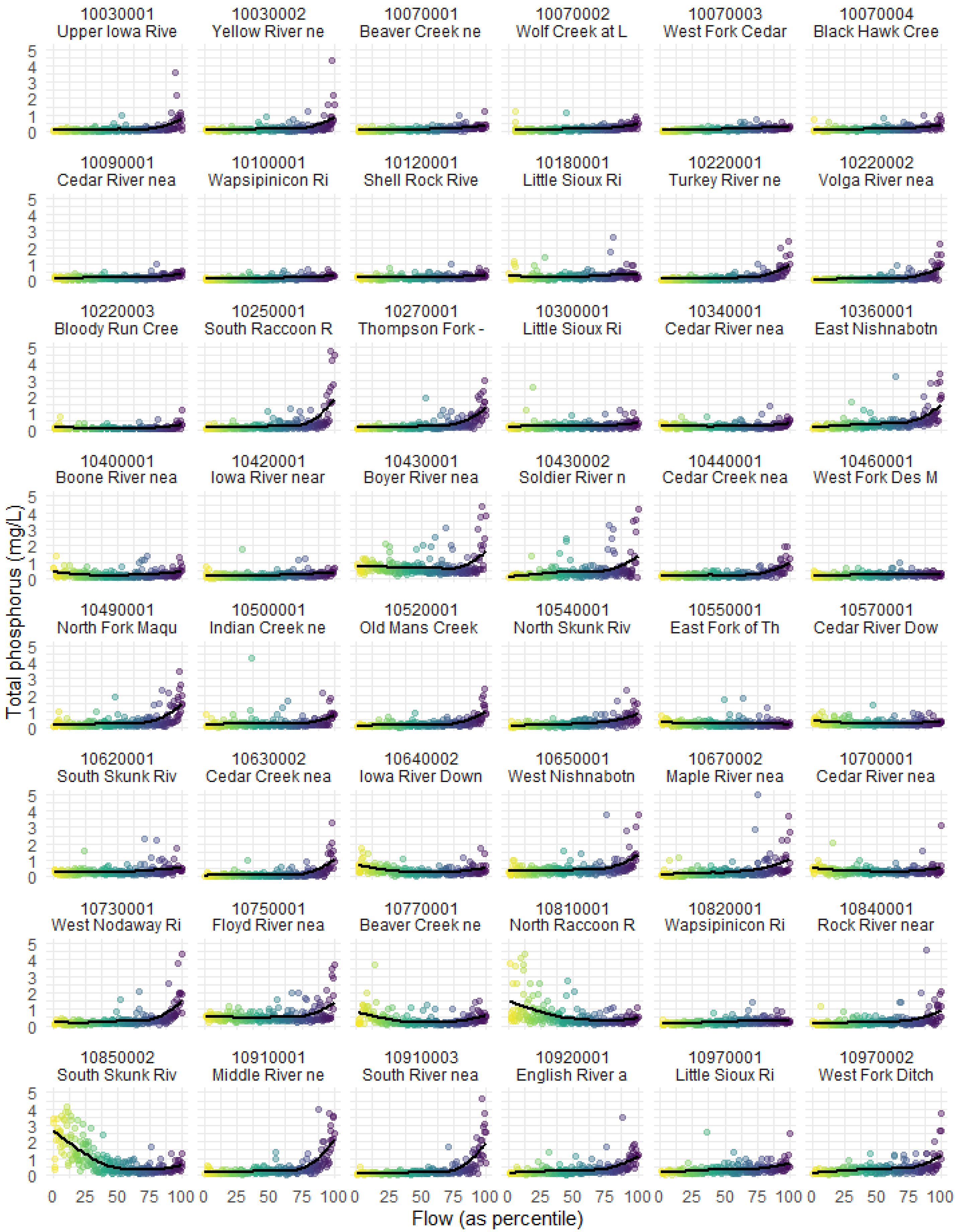


Figure 4 shows the relationships between phosphorus and streamflow for all 48 sites. Many sites in southern, western, and northeastern Iowa have patterns similar to the South Raccoon River, with phosphorus increasing sharply at the highest flows. A pattern similar to the North Raccoon River can be observed at sites downstream of wastewater treatment plants in Ames (10850002), Webster City (10400001), Grimes (10770001), and Marshalltown (10640002).

Figure 4 : Total phosphorus vs. streamflow for 48 sites with 20+ years of data, y-axis cropped



When there is a strong relationship between water quality and streamflow, a weather-related trend in streamflow will also result in a water quality trend. Streamflow in the North Raccoon River and the South Raccoon River have decreased in recent years due to a multi-year drought. In the North Raccoon River, this results in an increasing trend in total phosphorus over the past decade (see Figure 5). In the South Raccoon River, this results in a slight decreasing trend in total phosphorus over the past decade (see Figure 6). These weather-related water quality trends pose a challenge for evaluating the progress of conservation projects.

Figure 5: Phosphorus trends, 2015-2023
North Raccoon River near Lake View

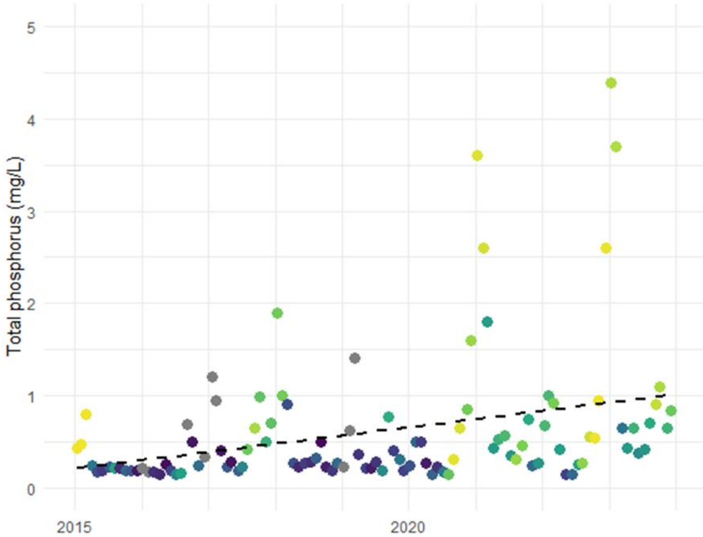
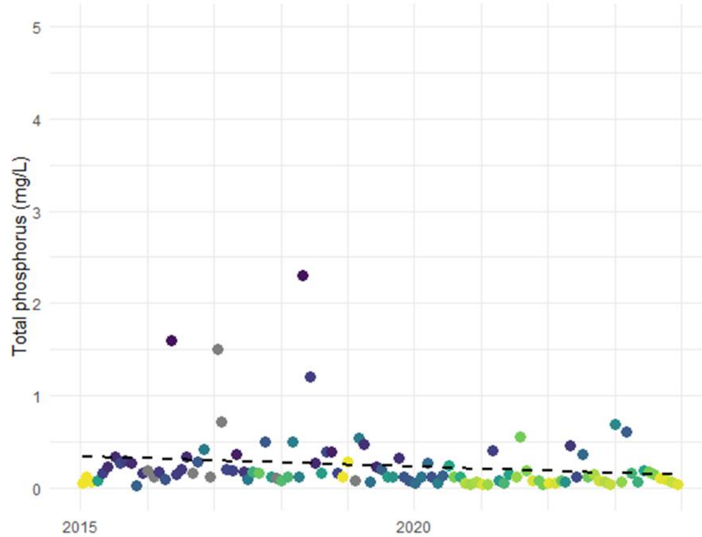


Figure 6: Phosphorus trends, 2015-2023
South Raccoon River near Redfield



However, both trends disappear if we exclude samples collected when flows were drier than average. This approach is a simple way to check whether streamflow is driving observed water quality trends.

Figure 7: Phosphorus trends, 2015-2023
Samples when flow > 50th percentile
North Raccoon River near Lake View

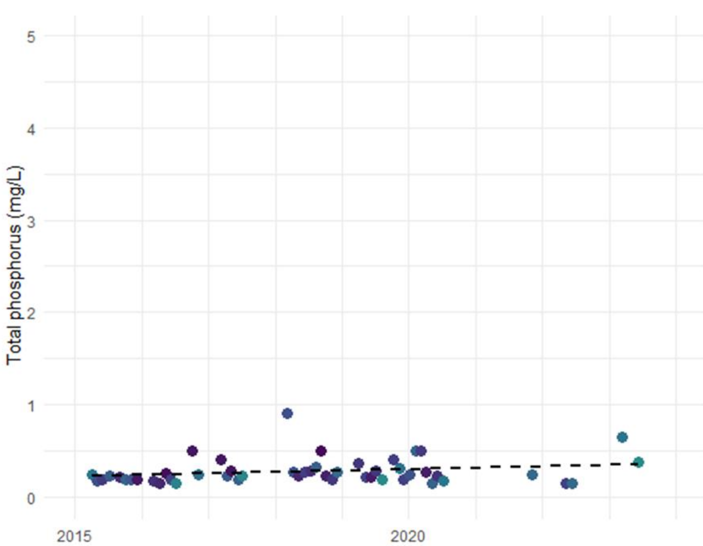
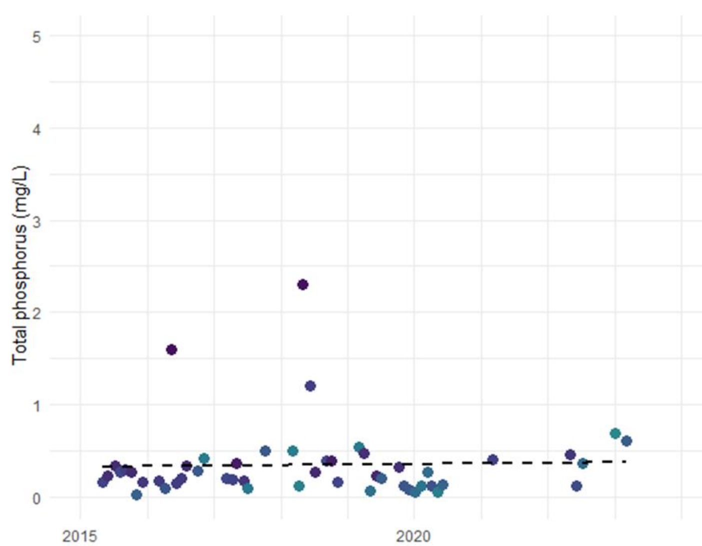


Figure 8: Phosphorus trends, 2015-2023
Samples when flow > 50th percentile
South Raccoon River near Redfield

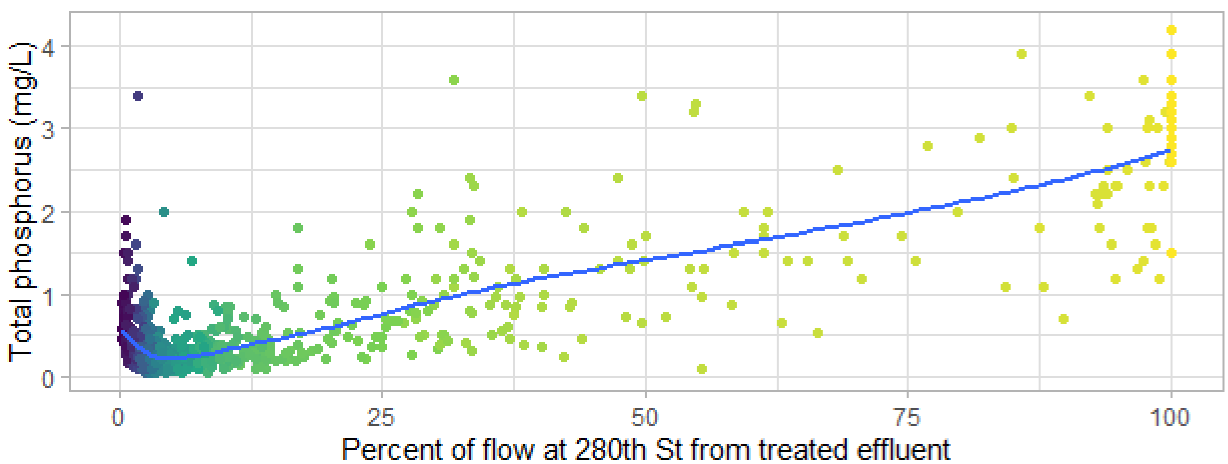


Case Study 2: The water quality benefits of wastewater treatment upgrades are most apparent during dry weather

For decades, wastewater treatment plants have been required to remove solids and oxygen-depleting substances, but effluent limits for *E. coli*, chloride, nitrogen, and phosphorus are more recent and in some cases are still being phased in. Communities in Iowa have received an additional $83.7M in Clean Water State Revolving Fund grants and loans from the Bipartisan Infrastructure Law to upgrade and replace deteriorating wastewater infrastructure. The impact of these investments on water quality will be greatest in times and places where effluent makes up a large fraction of the water in the stream. Below, we introduce a method to screen for these locations.

Where frequent measurements of effluent flow are available, the fraction of streamflow from treated effluent can be calculated directly. The Ames Water Pollution Control Facility provided a long-term daily record of effluent flows (2003-2021) for a previous study. We compared this to streamflow at a USGS gage (#05471000) located on the South Skunk River several miles upstream of the outfall (see Figure 9). Total phosphorus was tested weekly at a site 0.2 miles downstream of outfall during the same period. As the South Skunk River dries up and effluent becomes a larger fraction of the water, total phosphorus levels approach the levels found in the treated effluent, which average 3.8 mg/L.

Figure 9: Total phosphorus concentration in the South Skunk River below the Ames Water Pollution Control Facility vs the fraction of water in the river from treated effluent from the Ames Water Pollution Control Facility.



We used the “sf” and “nhdplusTools” packages for R to delineate a watershed for each of the 48 sites and identify all the wastewater treatment plants with outfalls located in each watershed. Effluent flow data is not readily available, but design flow is listed for each facility. For municipal wastewater treatment plants in Minnesota, the design flow listed is the average wet weather flow. For industrial wastewater treatment plants, this is the maximum wet weather flow. For consistency, we used the same metrics for Iowa facilities. Comparing the total design flow of point sources in a watershed to streamflow at a gage located near the sampling site can put an upper limit for the percentage of the water in the stream that is coming from effluent, and thus an upper limit for the reduction in pollutant load that is possible across different conditions.

As shown in figure 10, the actual flow of effluent from the Ames WPCF is smaller than the design flow. Because of infiltration and inflow of rainwater into storm sewers, the effluent flow is not constant across weather conditions, but increases along with streamflow. However, the variation in effluent flow is much smaller than the variation in streamflow, so the overall pattern still holds. Effluent can be a large fraction of the water in a stream during low flow conditions and becomes diluted as streamflow increases.

Figure 10: Effluent from the Ames Water Pollution Control Facility as a fraction of streamflow in the South Skunk River, 2003-2021. ***Purple line: based on facility design flow (average wet weather flow, as of 2023). Colored dots: based on daily measurements of effluent flow.***

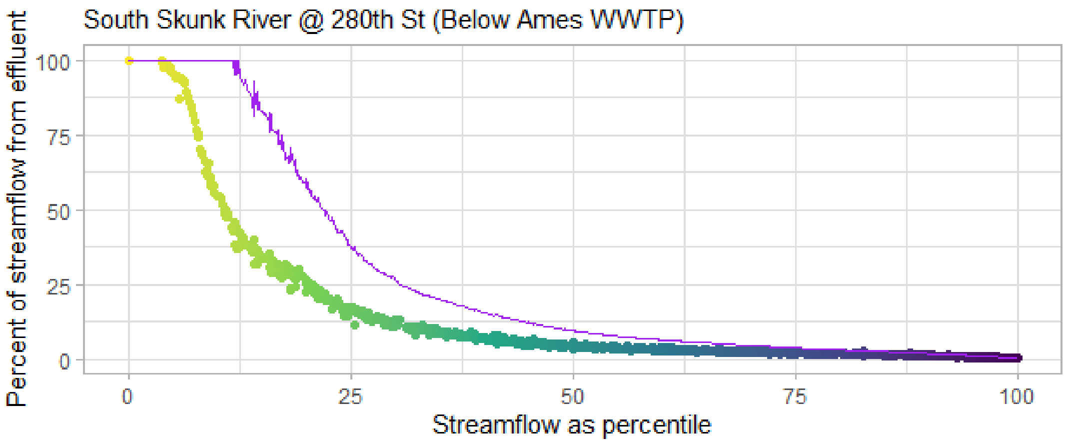
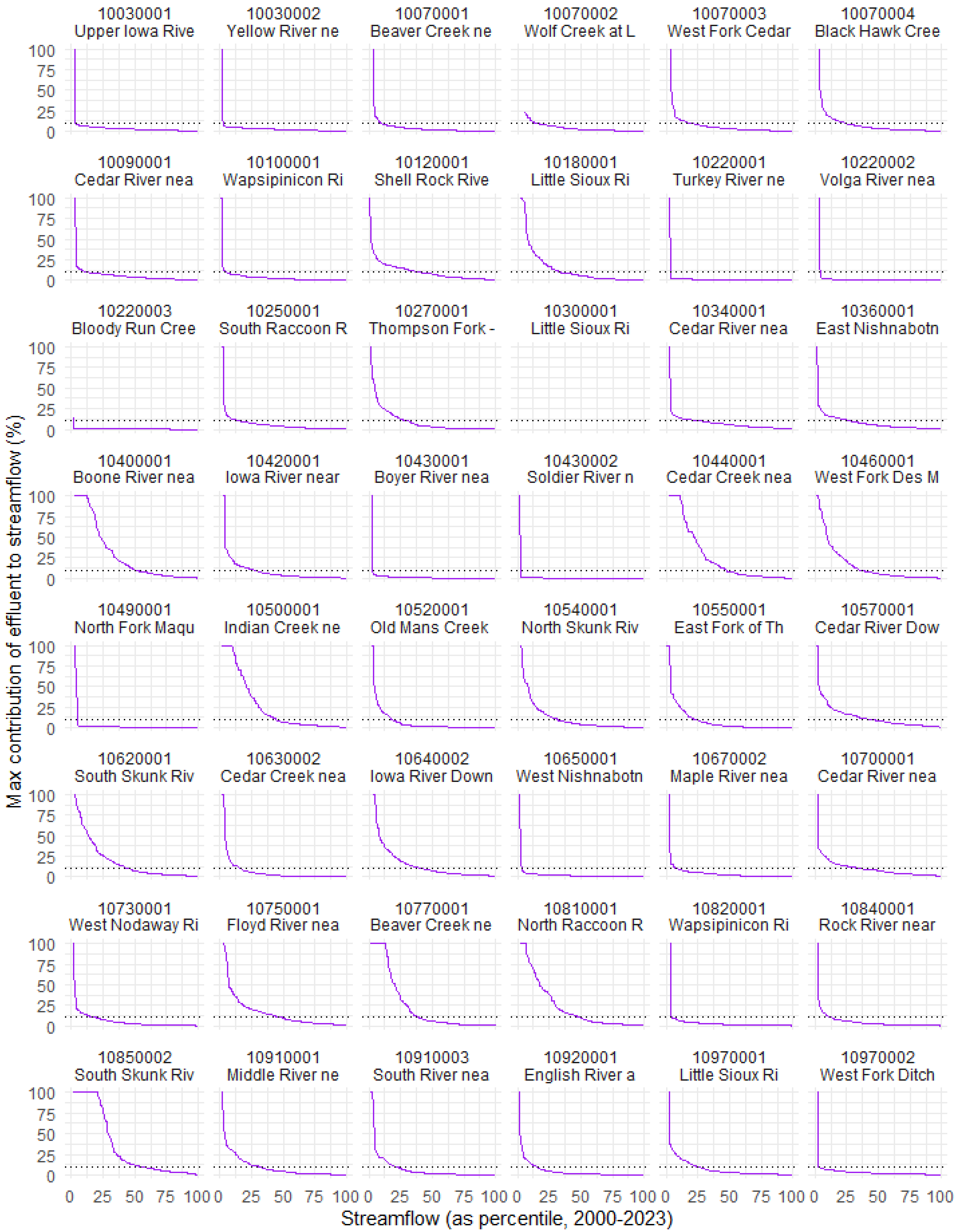


Figure 11 shows how effluent from wastewater treatment plants has the potential to influence all 48 long-term monitoring sites. As indicated by the dotted line on the graphs, effluent from upstream point sources makes up less than 10% of the water in most Iowa streams, except during conditions when the river would otherwise dry up completely. However, effluent has the potential to be make a large fraction streamflow on a regular basis in the South Skunk River downstream of Ames, the Boone River downstream of Webster City, Cedar Creek downstream of Fairfield, Indian Creek downstream of Maxwell and Nevada, Beaver Creek downstream of Grimes, and the North Raccoon River downstream of Storm Lake and Sac City.

Figure 11: Total design flow of point sources in watershed, as percentage of streamflow



The South Skunk River near Cambridge (site #10850002) is located 0.2 miles downstream of a sewage treatment plant, the Ames Water Pollution Control Facility (WPCF). The WPCF installed a UV disinfection system in 2015 in order to meet new effluent limits for *E. coli* bacteria. The system is in operation during what the statute defines as the recreational season, from March 15 to November 15. A comparison of *E. coli* vs flow relationships before and after the system was installed shows a change in the shape of the curve. Since the system was installed, *E. coli* concentrations during drier conditions (flows less than the 30th percentile) appear to have improved, while *E. coli* during wetter conditions shows little change.

Figure 12: ***E. coli*** **vs flow, recreational season, 2000-2014 South Skunk River near Cambridge**

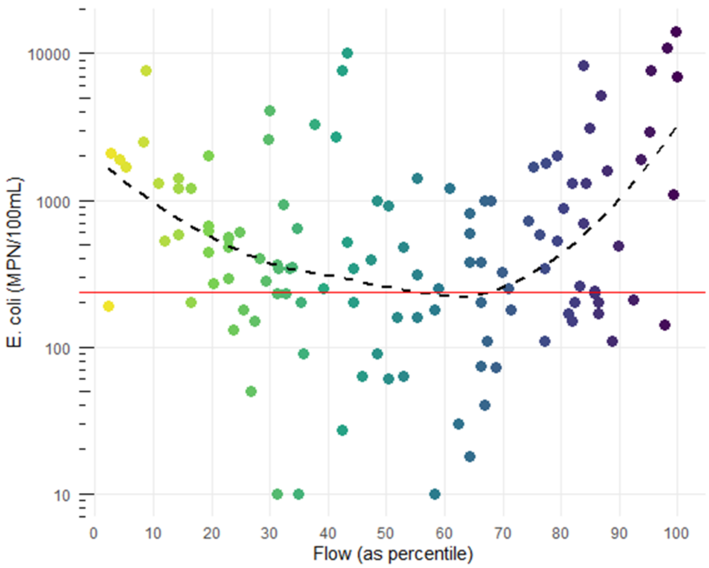
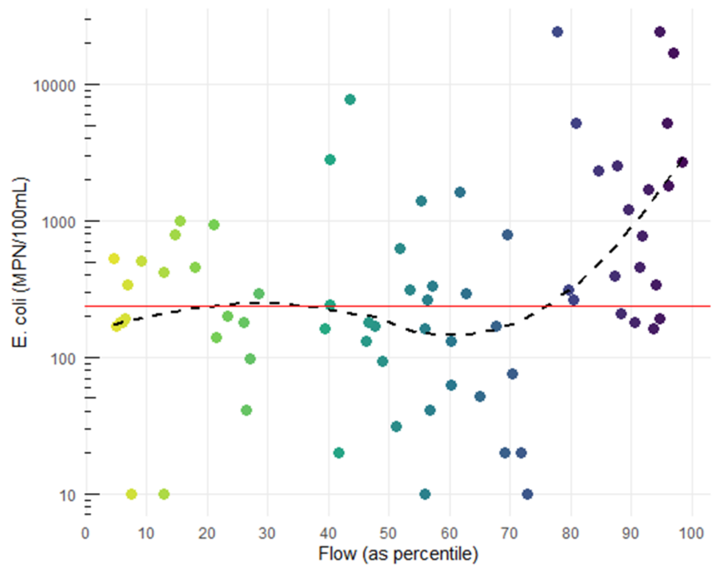


Figure 13: ***E. coli*** **vs flow, recreational season, 2015-2023 South Skunk River near Cambridge**



Many communities in Iowa are investing in improved wastewater treatment systems to meet new permit requirements. To see how these changes are benefitting Iowa's rivers, we recommend breaking out results using streamflow or some proxy to identify periods where effluent is a large fraction of streamflow.

Case Study 3: Nitrate reductions due to watershed conservation projects are difficult to distinguish from weather-related trends

Average nitrate concentrations in many Iowa streams have been declining in recent years after peak in 2014 or 2015 (see figure 16). However it is unclear how much of this is due to agricultural conservation practices and how much of this is due to recent drought, which limits nitrate transport. In most streams, nitrate increases with streamflow, although patterns can be complex (see Figure 18). We had hoped the method introduced the first case study—pulling out a subset of samples collected under similar flow conditions—would be a simple way to account for the influence of weather and reveal underlying trends related to land management (Figure 17 applies this method to all sites).

To test whether this method works, we compared a pair of sites we thought would have a large contrast in land management. Black Hawk Creek is a tributary of the middle Cedar River, a priority watershed for the Iowa Nutrient Reduction Strategy. Grundy County Soil and Water Conservation District received grant funding to hire a full-time project coordinator, and their efforts seem to have been successful. By 2020, Black Hawk Creek Watershed had 21,000 acres of cover crops (10% of the watershed).

In contrast, the East Fork of the Des Moines River is not a priority watershed for the Iowa Nutrient Reduction Strategy and has never had a watershed coordinator. A large part of the watershed is in Kossuth County, which reported only 13,558 acres of cover crops (2% of the watershed) in the 2022 Ag Census.

However, the downward trend in nitrate over the past nine years is actually larger in the East Fork of the Des Moines River, even if we exclude samples collected during drought or floods (see Figure 14 and 15). Evidently there are other factors influencing nitrate trends in the rivers, beyond just cover crops and streamflow.

Figure 14: Nitrate trends, 2015-2023
During flows in 60-90th percentile
North Raccoon River near Sac City

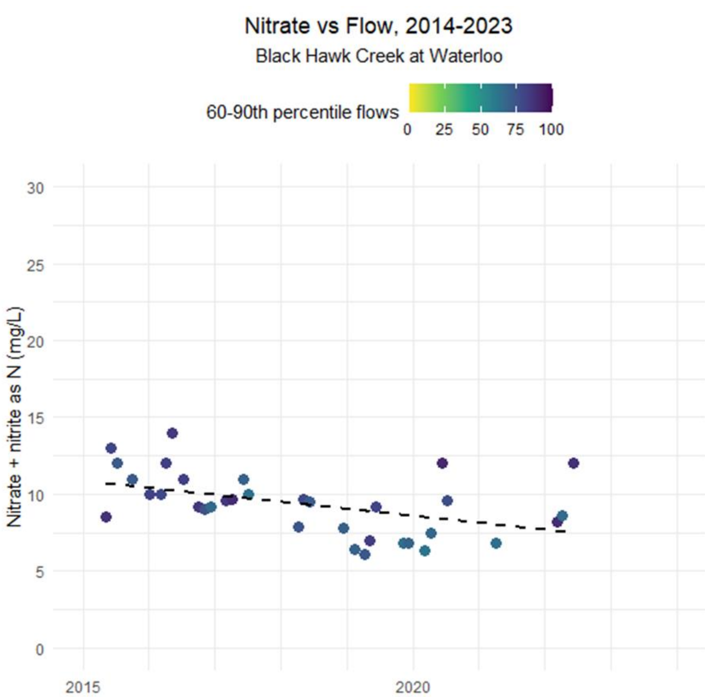
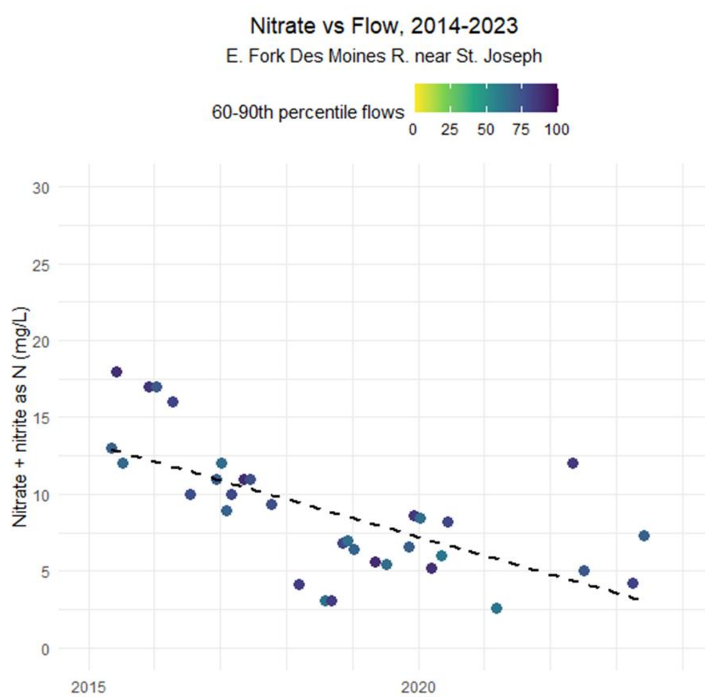


Figure 15: Nitrate trends, 2015-2023
During flows in 60-90th percentile
South Raccoon River near Redfield



This is a cautionary tale for anyone hoping to use stream monitoring to evaluate projects meant to reduce non-point source pollution. Without a better study design and more thorough inventory of influences in the watershed, we cannot confidently attribute water quality trends to conservation practices, or lack of them.

Figure 16: Nitrate trends, 2000-2023, in 48 streams with long-term data

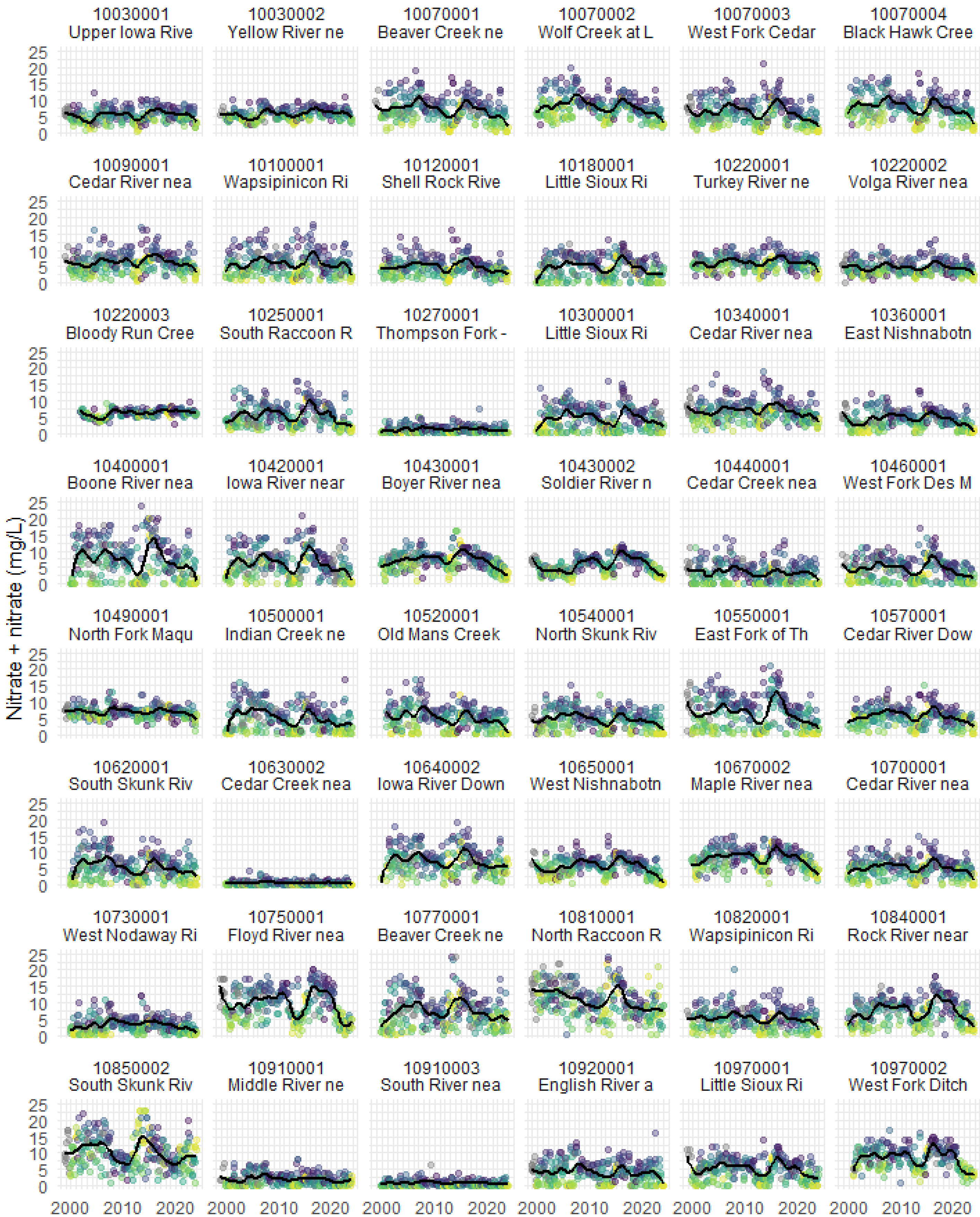


Figure 17 : Nitrate trends, 2000-2023, during flows > 50th percentile

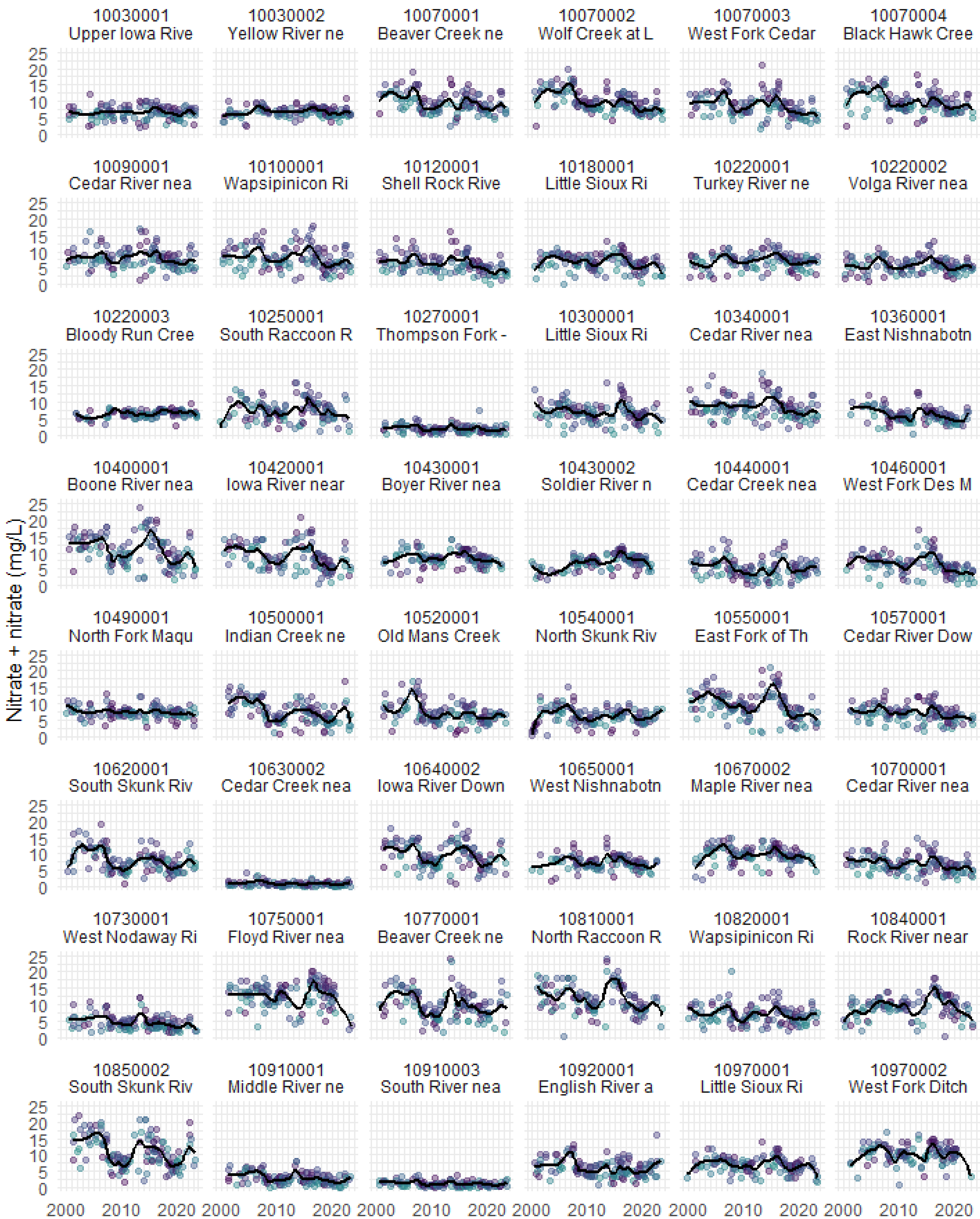
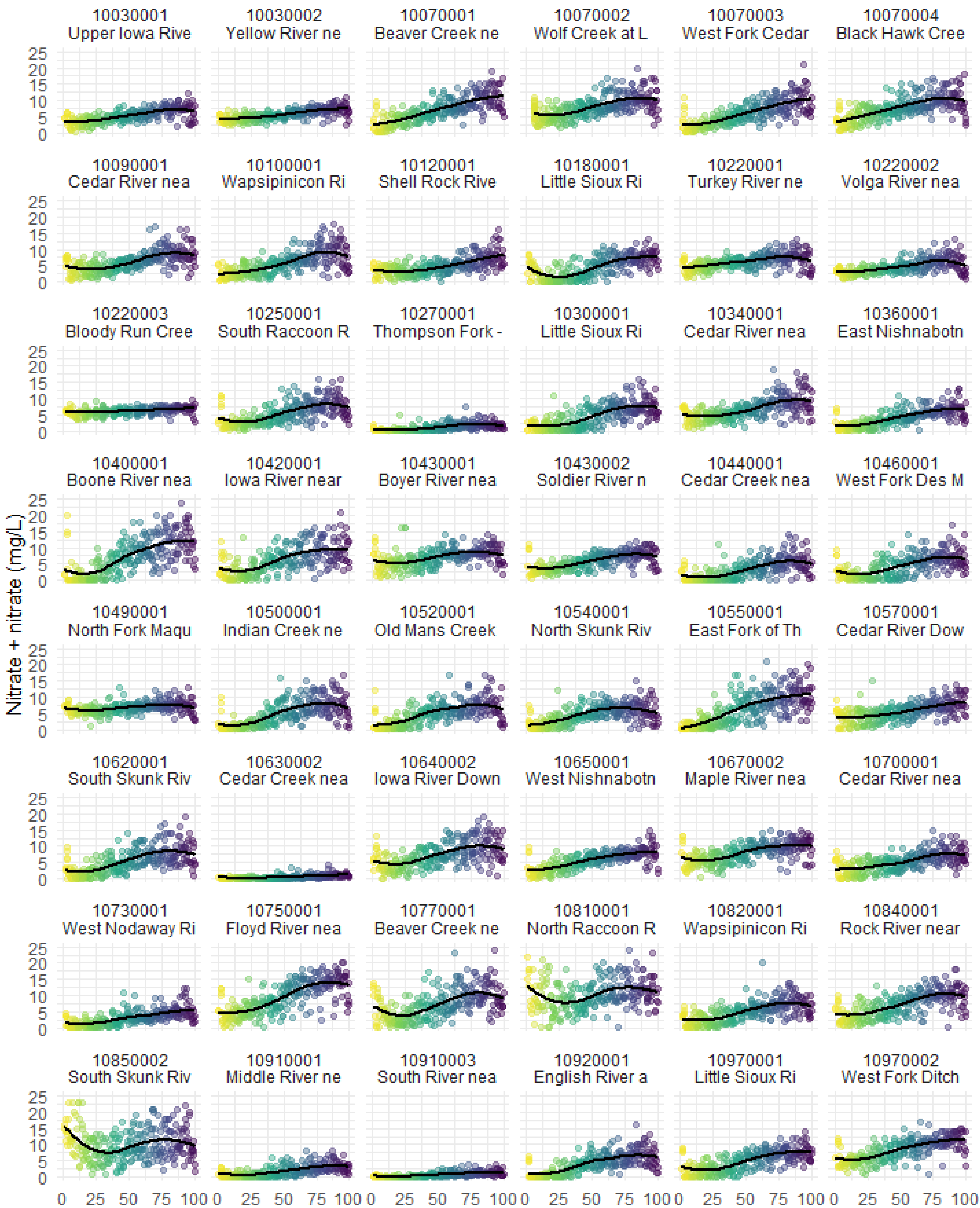


Figure 18 : Nitrate vs. flow, 2000-2023



Site list

Since October 1999, the Iowa Department of Natural Resources has maintained a network of stations to monitor ambient water quality in the state.

https://programs.iowadnr.gov/aquia/Programs/Streams

The 48 sites below have been monitored for at least 20 years, and are presented in the same order as the graphs in the report.

AQuIA Site ID	Site name (updated in 2024)	County
	Row 1	
10030001	Upper Iowa River near Dorchester	Allamakee
10030002	Yellow River at Ion	Allamakee
10070001	Beaver Creek near Cedar Falls	Black Hawk
10070002	Wolf Creek at La Porte City	Black Hawk
10070003	West Fork Cedar River at Finchford	Black Hawk
10070004	Black Hawk Creek at Waterloo	Black Hawk
	Row 2	
10090001	Cedar River at Janesville	Bremer
10100001	Wapsipinicon River near Otterville	Buchanan
10120001	Shell Rock River at Shell Rock	Butler
10180001	Little Sioux River near Larrabee	Cherokee
10220001	Turkey River near Garber	Clayton
10220002	Volga River near Elkport	Clayton
	Row 3	
10220003	Bloody Run Creek near Marquette	Clayton
10250001	South Raccoon River near Redfield	Dallas
10270001	Thompson Fork - Grand River at Davis City	Decatur
10300001	Little Sioux River near Milford	Dickinson
10340001	Cedar River at Midway	Floyd
10360001	East Nishnabotna River near Shenandoah	Page
Row 4		
10400001	Boone River near Stratford	Hamilton
10420001	Iowa River near Gifford	Hardin
10430001	Boyer River near Missouri Valley	Harrison
10430002	Soldier River at Pisgah	Harrison
10440001	Cedar Creek near Oakland Mills	Henry
10460001	West Fork Des Moines River near Humboldt	Humboldt
Row 5		
10490001	North Fork Maquoketa River near Hurstville	Jackson
10500001	Indian Creek near Mingo	Jasper
10520001	Old Mans Creek near Iowa City	Johnson
10540001	North Skunk River near Hayesville	Keokuk
10550001	East Fork Des Moines River near St. Joseph	Kossuth
10570001	Cedar River near Cedar Rapids	Linn

Row 6		
10620001	South Skunk River near Oskaloosa	Mahaska
10630002	Cedar Creek near Bussey	Marion
10640002	Iowa River near Marshalltown	Marshall
10650001	West Nishnabotna River near Malvern	Mills
10670002	Maple River at Mapleton	Monona
10700001	Cedar River near Conesville	Muscatine
Row 7		
10730001	West Nodaway River at Shambaugh	Page
10750001	Floyd River near James	Plymouth
10770001	Beaver Creek at Johnston	Polk
10810001	North Raccoon River near Lake View	Sac
10820001	Wapsipinicon River near De Witt	Scott
10840001	Rock River near Hawarden	Sioux
Row 8		
10850002	South Skunk River near Cambridge	Story
10910001	Middle River near Indianola	Warren
10910003	South River near Ackworth	Warren
10920001	English River at Riverside	Washington
10970001	Little Sioux River near Smithland	Woodbury
10970002	West Fork Ditch near Hornick	Woodbury