Greater Elkhart Stormwater Partnership Surface Water Monitoring Report: Long-term trends in water quality (2010 – 2021)

Top photo: Summer stormwater runoff. Bottom photo: Rock Run Creek @ Indiana Ave.
Photo credit: Jason Kauffman, City of Goshen Stormwater Department.

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Introduction

Monitoring the health of our region's surface waters is essential for identifying the current state of water resources that provide a multitude of ecosystem services, including drinking water, agricultural drainage, wildlife habitat, and recreation. A critical component involved in plans to protect and improve the quality of surface waters for various designated uses is long-term monitoring of key water quality variables, which gives stakeholders the ability to identify areas of concern and use available data to determine appropriate management strategies to mitigate current water quality issues and prevent future deterioration to water resources.

The Greater Elkhart County Stormwater Partnership (GECSP) is a cooperative effort among the Town of Bristol, City of Elkhart, City of Goshen, and Elkhart County. The partnership has a Stormwater Quality Management Plan that outlines programs to improve the quality of stormwater that runs off the land and into rivers, lakes, and streams. Beginning in 2005, the Elkhart County Health Department, as part of the GECSP, has collected data on chemical and physical characteristics of selected surface waters throughout Elkhart County (see map, Figure 1) during the spring and summer months (April – September) of each sampling year.

This report provides an initial interpretation of water quality data collected by the Partnership for the years 2010 to 2021. The analysis focuses on graphical and statistical analyses of annual and regional trends in water quality for 10 major waterways that are sampled by the partnership. The goal of the report is to provide stakeholders with temporal and spatial analyses of trends in key water quality variables (see next section) so that they may make decisions informed by available data on the management of these waterbodies in the future.

Project Scope and Purpose

Water monitoring involves measuring any combination of chemical, physical (water temperature, pH, stream flow, discharge, stream stage), and biological (benthic macroinvertebrates, fish) attributes. Each of these broad categories can be used in different ways to inform stakeholders on the health and functioning of a water body. The GECSP assesses surface water quality by measuring chemical and physical attributes that relate to stormwater quality standards. These include the physical parameters Temperature (degrees Celsius), Dissolved Oxygen (DO, mg/L), pH, Total Suspended Solids (TSS, mg/L), and the chemical attributes Specific Conductance (SPC, µS/cm), Chlorides (mg/L), Nitrates (mg/L), Total Phosphorus (mg/L), and *E. coli* (Colony-forming units, CFU, per 100 ml).

A brief narrative of the importance of each water parameter that appears in this report is provided below:

Temperature: Measured in degrees Celsius in this report, this is a fundamental physical feature of surface waters that affects how much dissolved oxygen is available to wildlife. Temperature influences aquatic organism survival as all organisms have optimal temperatures. Temperature can be affected by many factors, including stream velocity, sunlight, water depth, turbidity (the cloudiness of the water), and seasonal changes in weather. Measuring temperature over time and at different sites can allow for the identification of fluctuations and anomalies (such as during drought and flood years).

Dissolved Oxygen (DO): Measured in milligrams per liter (mg/L), oxygen is another physical characteristic of all aquatic systems, as it is vital to fish, macroinvertebrates, and many smaller microorganisms. Dissolved oxygen measures how much oxygen is available to aquatic life. IDEM has recommended that DO levels in Indiana waterbodies should be at least 4 mg/L and at most 12 mg/L; waterbodies with levels outside of this range indicate impairment.

pH: This is a physical measure of the activity of hydrogen ions in a solution, which gives a measure of the acidity or alkalinity of a waterbody. pH ranges between 0 and 14, with 7 being neutral, and below 7 being acidic, and above 7 being basic/alkaline. It is a unitless metric. pH affects many chemical and biological processes. Most aquatic life thrives at a pH range of 6.5 – 8.0, and values outside this range can have negative impacts on aquatic life. Too acidic or basic waters can be harmful to aquatic life by altering the availability of dissolved nutrients in water to aquatic life.

Total Suspended Solids (TSS): Reported in units of mg/L, this is a physical characteristic that measures the levels of particles that are larger than 2 microns that are found in the water column. Particles of this size include anything drifting or floating in the water, from sediment, silt, sand, to plankton and algae. High TSS levels increase the cloudiness of the water and can limit light availability in the water column, which affects photosynthesis in plants and reproduction in fish. These particles can also settle out of the water and ruin habitat suitability for fish and macroinvertebrates. Pollutants and contaminants can adsorb to particles in the water. Indiana waterbodies should not exceed 30 mg/L TSS as an IDEM TMDL target.

Specific Conductance (Conductivity, abbreviated as SPC): This measures how well water can conduct an electrical current. SPC increases with increasing amount and mobility of ions such as salts. It is measured and reported as micro-Siemens (µS) per centimeter (µS/cm).

Chlorides: Measured in mg/L, this measures the level of salts in water. Salts can occur as sodium (NaCl), potassium (KCl), and calcium ($CaCl_2$). Chlorides can enter surface waters from a variety of sources. Sodium chloride is widely used in the production of industrial chemicals, and many different salts are used extensively in snow and ice control. Potassium chloride is used in the production of fertilizers. High chloride levels in surface waters can pose risks to aquatic life and humans. According to the EPA, chloride levels that exceed 230 mg/L in freshwater pose significant adverse risks to aquatic life, while chloride levels in exceedance of 250 mg/L pose health risks to humans.

Nitrates: Measured and reported in mg/L, nitrates are a common form of nitrogen applied to lawns, gardens, and crop fields as fertilizer, and these can enter waterbodies as runoff. The EPA standard for nitrate in waterbodies is 10 mg/L; excess nitrate loads can contribute to eutrophication of waterbodies and harmful algal blooms.

Phosphorus: Measured and reported in mg/L, phosphorus is a limiting nutrient that stimulates algal growth in freshwater systems. Phosphorus can contribute to eutrophication when algal blooms decay and result in a drop in dissolved oxygen levels, which can lead to fish kills. There are several water quality standards for phosphorus in surface waters, and the target levels depend on the type of surface water in question. In this report, we use 0.3 mg/L based on IDEM's TMDL standard for phosphorus.

Escherichia coli (E. coli) is a bacterium that, when present in waterbodies at certain levels, is indicative of fecal contamination from human and non-human sources. It can cause illness, skin infections, and rashes if not controlled. *E. coli* is measured and reported in Colony Forming Units per 100 milliliters (CFU per 100 ml). Indiana observes EPA standards for *E. coli*: waterbodies should not exceed 235 CFU per 100 ml.

Weather conditions: The sampling protocol indicates whether samples are considered wet or dry at the time of collection. A wet weather event is defined as a rain event with precipitation greater than 0.1 inches of rain within a twenty-four-hour period prior to collection. A dry weather even is defined as a sampling event with no precipitation twenty-four hours prior to collection. Monitoring during wet and dry conditions provides a representative sample that may help to identify how differences in land use impact water quality.

Field & Lab Methodology

The Environmental Health Division of the Elkhart County Health Department conducts surface water testing throughout Elkhart County on ditches, small tributaries, and the Elkhart and St. Joseph Rivers (see map, Figure 1 on page 4). More than 60 sites are included in the sampling program. Each year, a subset of these sites is sampled; a multi-year sampling rotation determines the sampling schedule for each site, while some sites are sampled every year (see Supplement S1 for details on annual sampling schedule). The sites are selected by stormwater representatives from the Partnership which includes the cities of Elkhart and Goshen, the Town of Bristol, and Elkhart County agencies. Representatives meet annually to determine if changes need to be made to the monitoring locations.

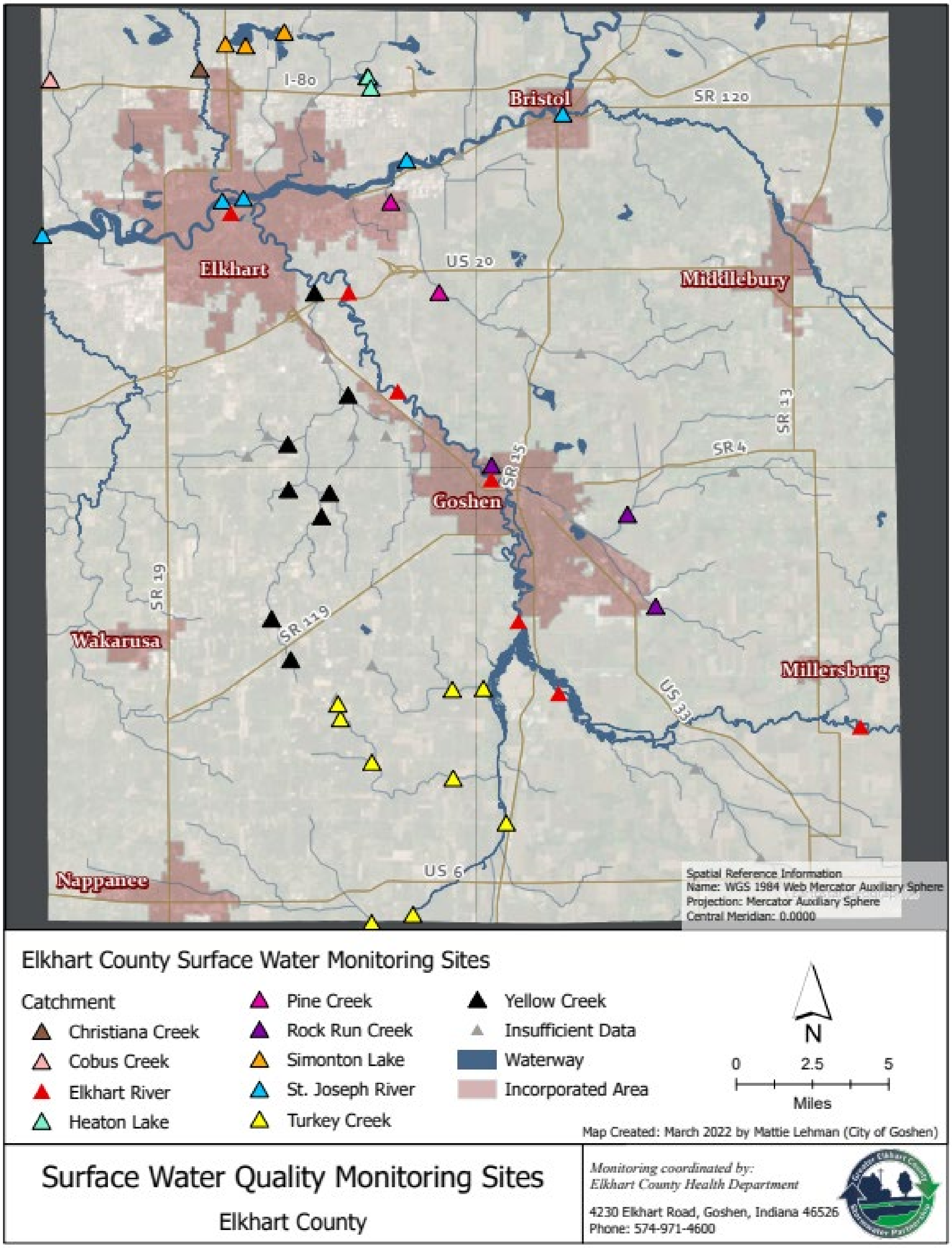

Figure 1. Surface water quality monitoring sites of Greater Elkhart County Stormwater Partnership. Map created by Mattie Lehman, City of Goshen Stormwater Department.

Timeframe of sampling

Sites are sampled on a weekly basis beginning in April/May and continuing until the last week of September of each year – in a year, a maximum of 24 samples per site are collected. However, difficulty in site access, inclement weather, or general safety concerns result in instances in which not all sites were sampled each week throughout the entire duration of the sampling schedule. Consequently, there is uneven sampling intensity for sites within and across years.

Sample collection & processing

Detailed descriptions of the field and laboratory methods used to measure the above water quality parameters can be found in the annual surface water monitoring reports prepared by the Elkhart County Health Department (https://goshenindiana.org/water-sampling-data).

Data analysis methods

Data preparation

Prior to analysis, variables with missing values were denoted in a consistent fashion (i.e., empty cells or cells with text were replaced with "NA"). Sites with less than three years of monitoring data were excluded from this report because at least three years of chemical data are necessary to establish baseline conditions and interpret temporal trends. Occasionally, extreme values were removed to facilitate readability of graphs.

Analysis of all pairs of sites for site-by-site comparisons would have resulted in nearly 2,000 unique combinations to statistically analyze. To reduce the dimensionality of the analysis and facilitate the comparison of general water quality trends over time and space, all the study sites were categorized according to the major stream or river they were on or flowed into (denoted as "major surface waters" or "regions" in the Results section of the report). The water regions were identified as follows: Elkhart River, St. Joseph River, Christiana Creek, Cobus Creek, Heaton Lake, Simonton Lake, Pine Creek, Rock Run Creek, Turkey Creek, and Yellow Creek. Table 1 below shows which sites are included in each of the water regions.

Table 1. Monitoring sites and associated water region groupings. These groupings reflect only those sites included in the present report that have at least 3 years of monitoring data.

Christiana Creek
Christiana Creek - CR 4
Cobus Creek
Cobus Creek - CR 10
Elkhart River
Elkhart River - Baintertown
Elkhart River - CR 18
Elkhart River - CR 40
Elkhart River - CR 43
Elkhart River - Indiana Ave. (Goshen)
Elkhart River - Jackson Blvd.
Elkhart River - Old CR 17
Heaton Lake
Heaton Lake - 22880 Lake Shore

Heaton Lake - 22892 Lake Shore
Heaton Lake - Ideal Beach
Pine Creek
Pine Creek - CR 18
Pine Creek - Wyland & Roske Dr.
Rock Run Creek
Horn Ditch - CR 31
Rock Run Creek - CR 21
Rock Run Creek - CR 34
Simonton Lake
Simonton Lake - 25919 Lake Dr.
Simonton Lake - 51093 Beach Dr.
Simonton Lake - 51330 SR 19
St. Joseph River
St. Joseph River - Ash Road
St. Joseph River - Bristol Boat Launch
St. Joseph River - CR 17
St. Joseph River - Johnson St.
St. Joseph River - Main St.
Turkey Creek
Berlin Ct. Ditch - CR 15
Dausman Ditch - CR 15
Dausman Ditch - CR 19
Swoveland Ditch - CR 19
Swoveland Ditch - CR 21
Turkey Creek - CR 17
Turkey Creek - CR 50
Weaver Ditch - CR 13
Weaver Ditch - CR 44
Yellow Creek
Hoke Ditch - CR 11
Little Yellow Creek - CR 13
Owl Creek - CR 11
Shaffer Ditch - CR 113
Yellow Creek - Concord High Bridge
Yellow Creek - CR 11
Yellow Creek - CR 138
Yellow Creek - CR 18
Yellow Creek - CR 32

Data analysis

Data analysis focused on graphical and statistical interpretations of the long-term water quality attributes measured from 2010 to 2021. All graphs and statistical analyses were generated in the open-source software program R (R version 4.0.4 (2021-02-15)).

We first visualized water quality trends using boxplots for each parameter in each of the 10 water regions over years and months (see Figure 2, below). Boxplots demonstrate two key aspects of a measured variable: first, the bolded horizontal line within the shaded box represents the median, or center of the data, and the length of the box and the reach of both whiskers attached to the box shows the spread, or variability, of the data. Both the central tendency and variability of data are key elements in assessing whether one site differs from another in a significant way, or if the value of a parameter is changing in one direction over time.

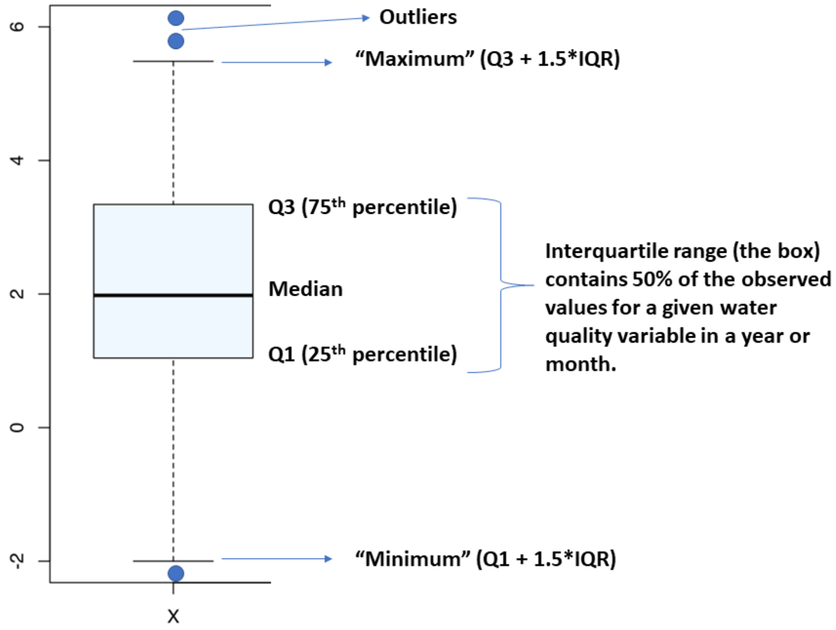

Figure 2. A generalized boxplot diagram. Within the shaded box, the center thickened black line represents the median value for a given water quality parameter in a year, month, or site. The median is a measure of central tendency of the data and is preferred over the average or mean because it is less sensitive to outliers as it represents the true middle value of the data. The top and bottom of the box are quartile 3 and quartile 1, respectively, and they correspond to the upper and lower bounds for 50% of the data, also known as the interquartile range. The horizontal notches at the end of the upper and lower whisker are the maximum and minimum values, and the closed circles that occur outside of the box and the whiskers are outliers or extreme values.

To complement the visualizations provided by the boxplots, a series of Kruskal-Wallis tests were conducted to examine how median values of each variable changed by year, month, site, and weather conditions (wet vs. dry). The Kruskal-Wallis test is used to determine if the median value of a variable is significantly different between two or more groups (i.e., do nitrates vary significantly over years, months, and sites?).

Spearman correlation coefficients and associated p-values denoting the significance of each correlation were computed to show how each of the water quality variables are associated with each other. Spearman correlation coefficients range between -1 and 1, with -1 indicating a strong inverse relationship between two variables (one variable increasing while the other decreases), and 1 indicating a strong positive association (both variables increasing or decreasing in the same direction). The purpose of the correlation analysis is to provide an exploratory overview of potential relationships among variables that could carry management implications (i.e., do two or more variables change in the same way, and as a specific example, more specifically, if nitrates are controlled, how does this affect phosphorus?).

In addition to describing overall and site-specific trends in the raw values of each water quality variable, statistical analyses, and associated visualizations of the proportion of sampling events in each year and region that exceeded water quality targets for *E. coli*, Dissolved Oxygen, TSS, Phosphorus, and Nitrates were performed. The percent exceedance of each of the above variables was plotted using line and bar plots to show annual time series of exceedances for each variable and how percent exceedance of one variable compared to the others.

Results

1. Overall trends in water quality

This section presents the annual and region-specific trends for the following water quality parameters: Temperature, Dissolved Oxygen, pH, TSS (Total Suspended Solids), SPC (Conductivity), Chlorides, Nitrates, Phosphorus, and *E. coli*.

Temperature

Surface water temperatures measured throughout the period of this study ranged between 2.4 and 34.1°C, with a median value of 18.6 °C. Heaton and Simonton Lakes and the Elkhart and St. Joseph Rivers were warmer on average than the smaller tributaries. Of all the regions characterized, Rock Run Creek and Pine Creek had significantly lower water temperatures than the other waterbodies. Temperature varied over years, and most sites exhibited a moderate warming trend (Figure 3). Temperature was moderately influenced by wet weather (moderately warmer under wet weather compared to dry), but differences over years, months, and sites were more pronounced (see Supplemental File S2 – Kruskal-Wallis tests). Seasonal changes in temperature occurred at all sites and followed a classic pattern observed in temperate waters characteristic of the region, with the highest temperatures observed in July and August (Figure 4).

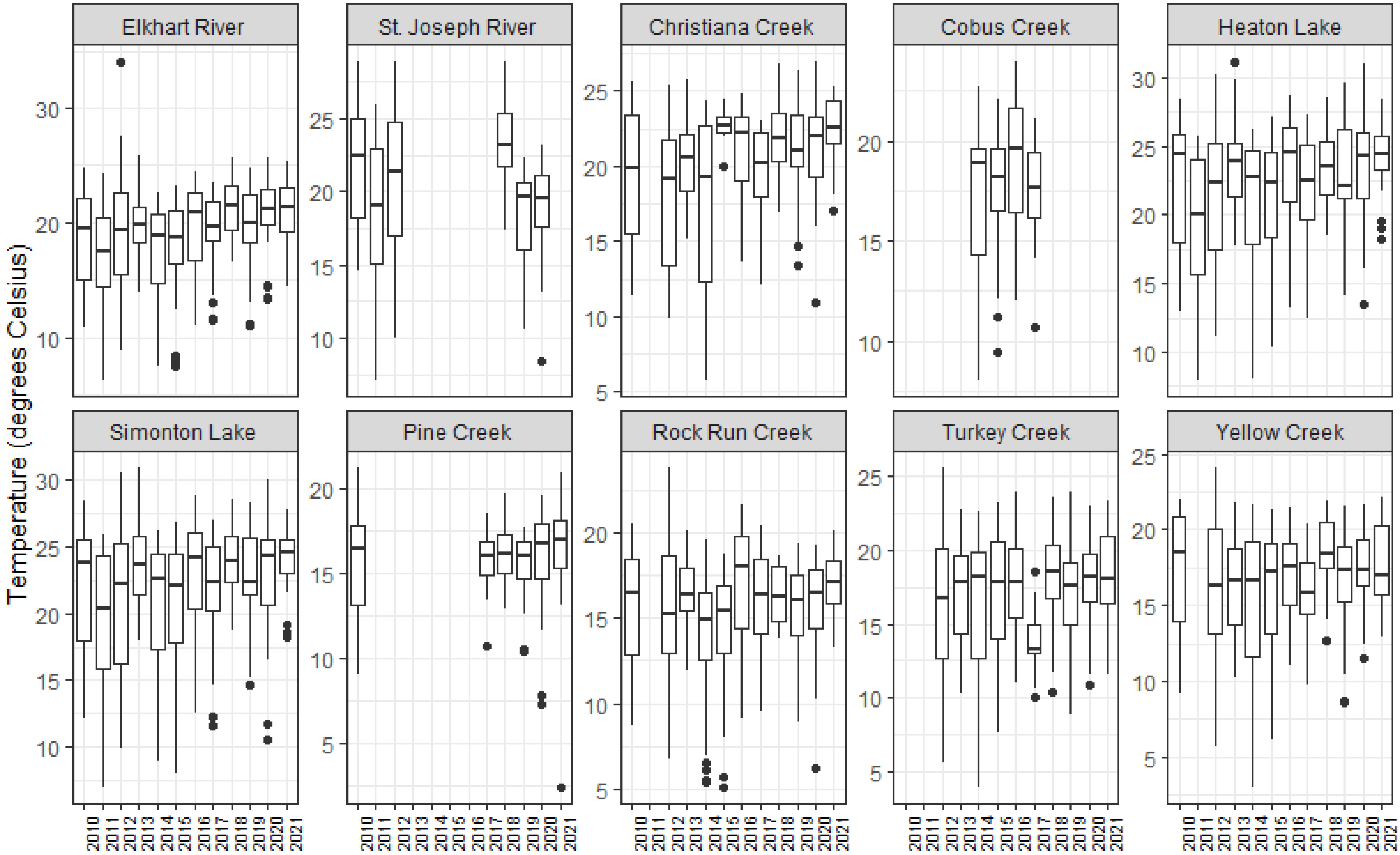

Figure 3. Boxplots depicting annual median temperatures (in degrees Celsius) for the 10 major surface waters (tick marks for each year are slightly offset to the left of the corresponding year). Note that the y-axis scales differ for each region (panel) to facilitate the interpretation of annual trends within each region.

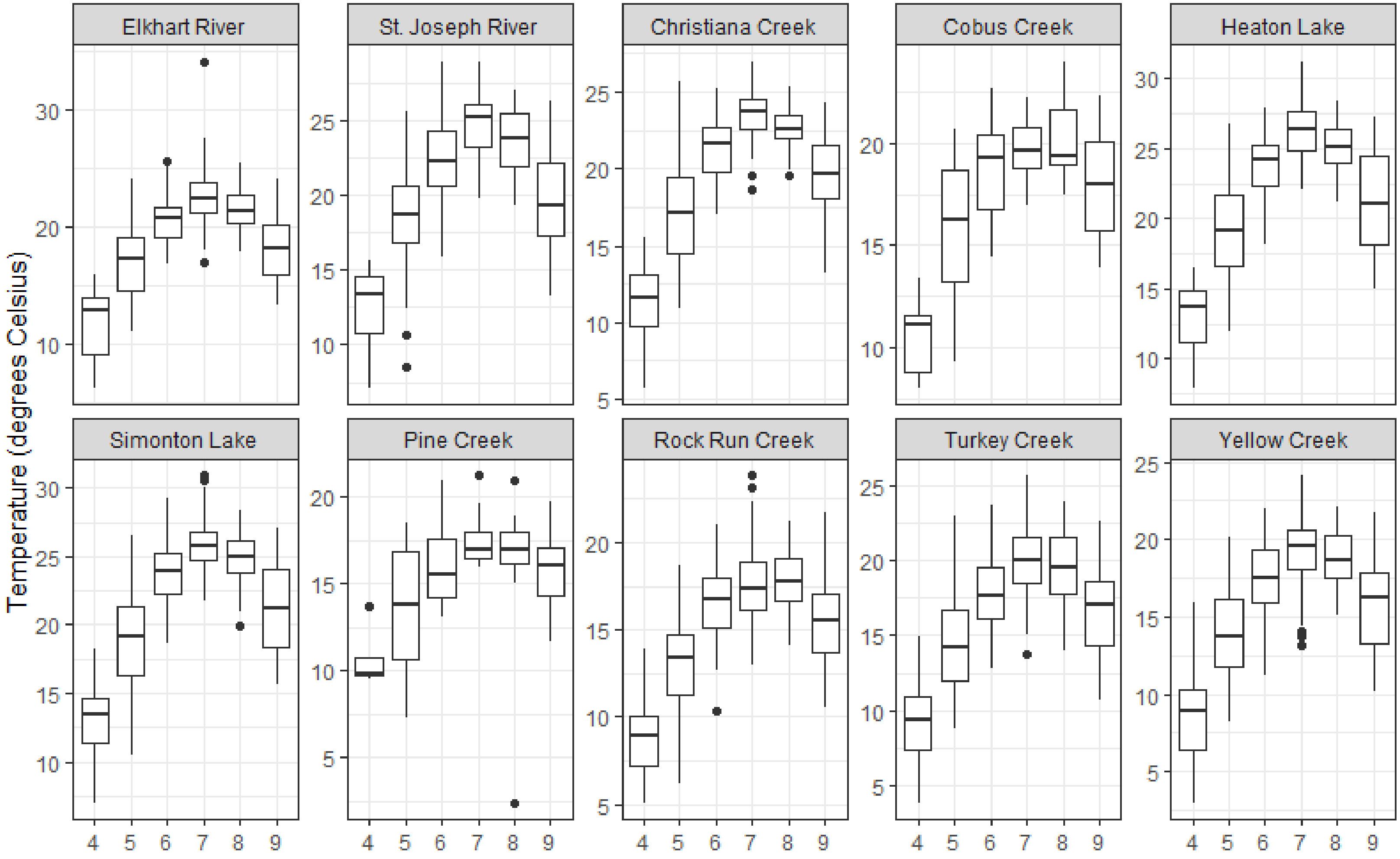

Figure 4. Boxplots depicting monthly median temperatures (in degrees Celsius) for the 10 major surface waters. Note that for this graph and for the rest of the monthly graphs for all water quality variables, the numbers on the x-axis correspond with calendar months: April – 4, May – 5, June – 6, July – 7, August – 8, and September – 9.

Dissolved Oxygen

Dissolved oxygen values ranged between 0.008 and 22.83 mg/L and had a median value of 6.5 mg/L. Dissolved oxygen levels varied among years, regions, and wet weather, with no clear trend emerging for most of these factors (Figure 5). However, dissolved oxygen tended to follow a consistent seasonal pattern for all regions: the highest dissolved oxygen levels tended to occur in April, followed by a steady decrease during the mid-summer months, and finally a slight increase in late summer (Figure 6; see Supplement S2). This seasonal pattern is likely due to a combination of factors, including higher summer temperatures and higher respiration rates in the summer compared to spring. Dissolved oxygen levels tended to be slightly lower under wet weather compared to dry (5.86 and 6.33 mg/L, respectively). Turkey Creek and Yellow Creek had median dissolved oxygen levels on the lower end of the desired range, while other regions had higher levels.

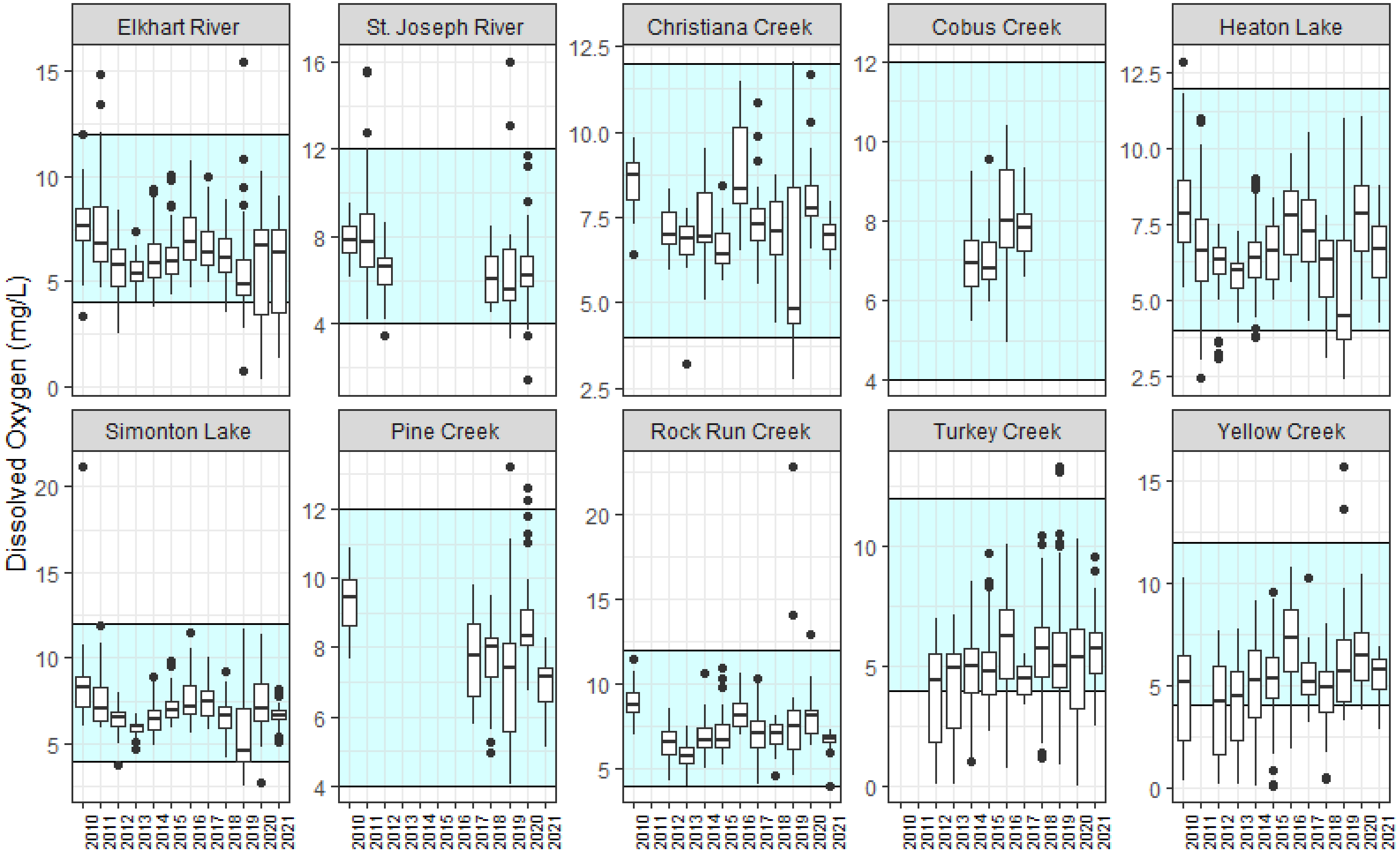

Figure 5. Boxplots of annual median dissolved oxygen levels (in milligrams per liter, mg/L) for the 10 major surface waters. The blue shaded region represents the desired measured range of DO concentrations, between 4 and 12 mg/L, for waterbodies as designated by the Indiana Administrative Code. Note that the scale for the vertical axis is different for each region to facilitate improved visualization of annual trends for each region.

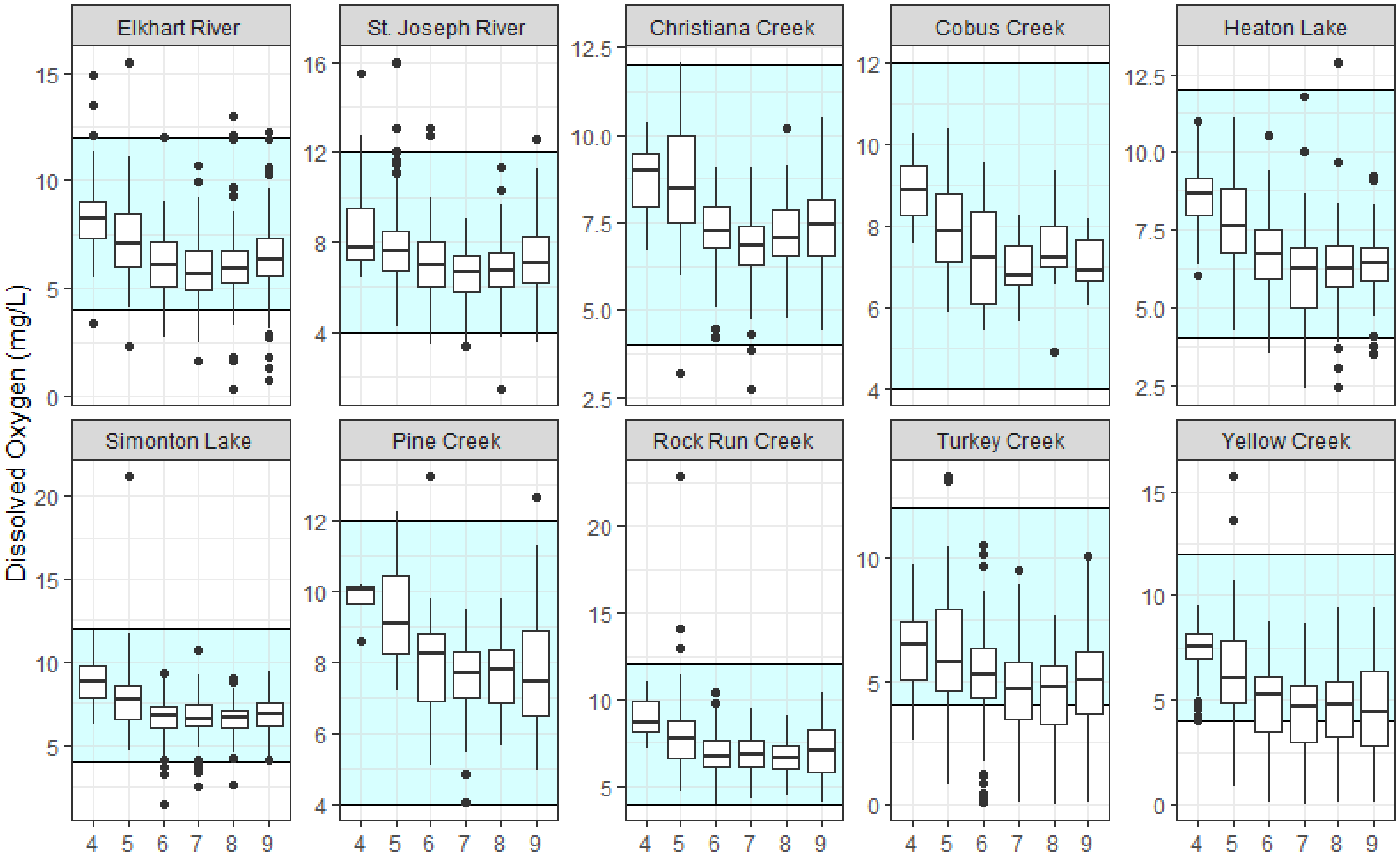

Figure 6. Boxplots of monthly median dissolved oxygen levels (in milligrams per liter, mg/L) for the 10 major surface waters. The blue shaded region represents the desired measured range of DO concentrations, between 4 and 12 mg/L, for waterbodies as designated by the Indiana Administrative Code. Note that the scale for the vertical axis is different for each region to facilitate improved visualization of annual trends for each region.

pH

pH ranged between 4.86 and 13.35, with a median of 8. pH differed significantly across years, months, regions, sites, and weather conditions, although no clear trends emerged spatially or annually (Figure 7; Supplemental File S2). Although pH was significantly different over months, it appeared to change within a narrow range for each of the study regions, suggesting pH remains stable across a range of temperatures observed (Figure 8). pH tended to be higher under dry weather compared to wet weather. One observation that stands out is that overall higher pH values were observed for most sites assessed in 2012, a drought year. Following the drought year, most sites exhibited low pH values in 2013.

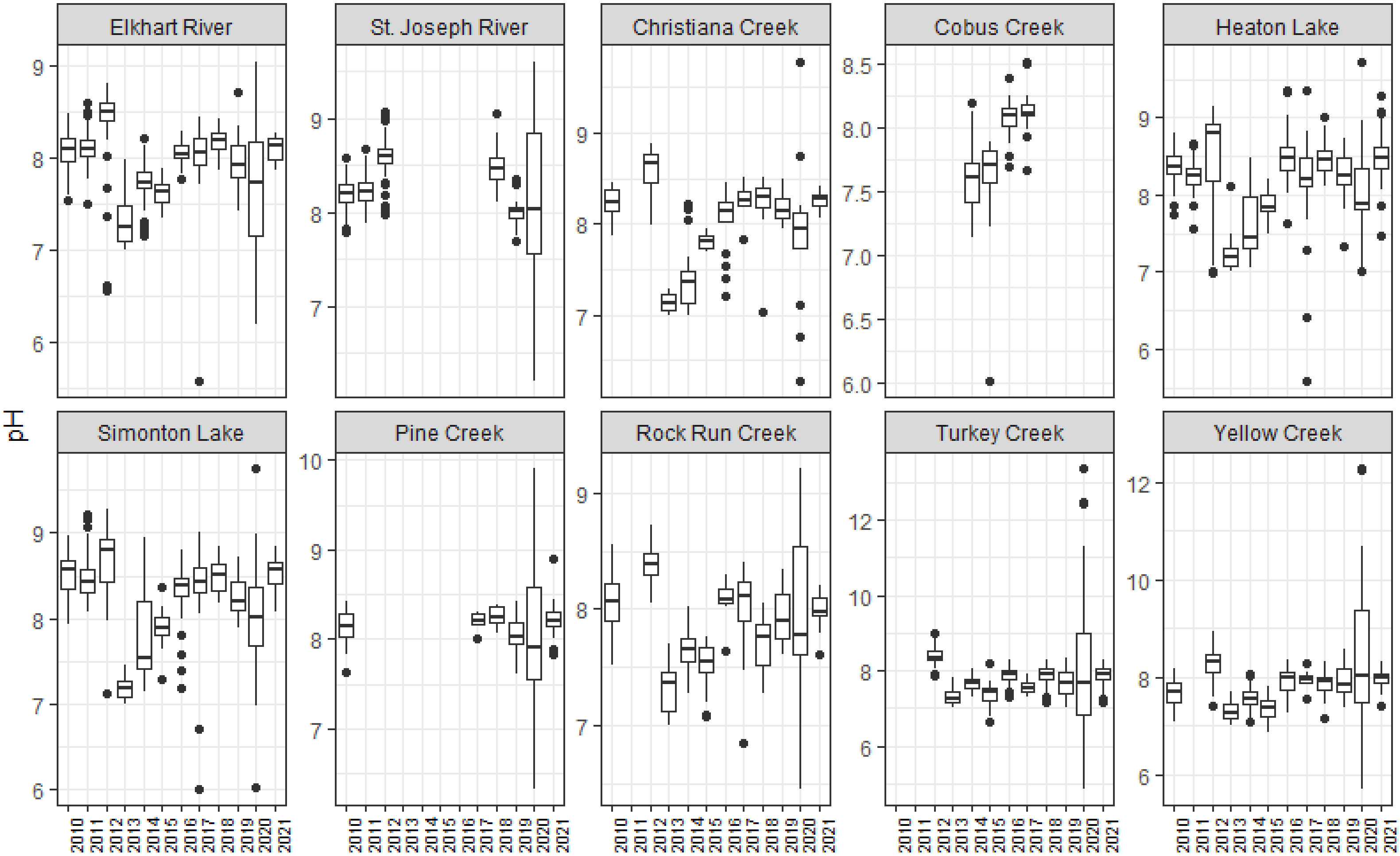

Figure 7. Boxplots of annual median pH for the 10 major surface waters. Note that the scale for the vertical axis is different for each region to facilitate improved visualization of annual trends for each region.

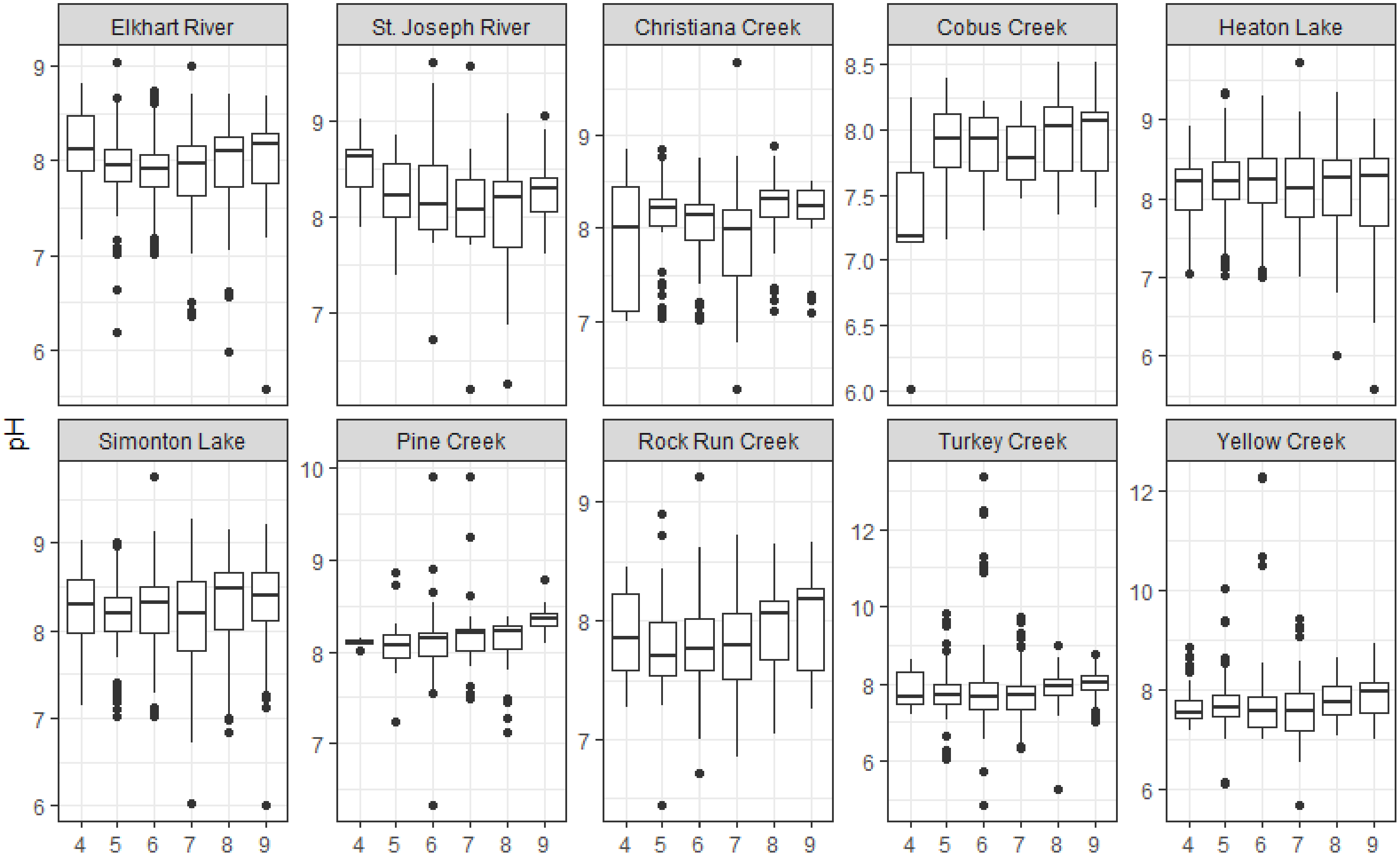

Figure 8. Boxplots of monthly median pH for the 10 major surface waters. Note that the scale for the vertical axis is different for each region to facilitate improved visualization of annual trends for each region.

TSS

Over the course of the study, TSS had a median value of 7.3 mg/L and ranged between 0 and 9,630 mg/L. TSS levels varied by region, years, wet weather, and months (Supplemental File S2). In general, sites in the northern portion of Elkhart County had the lowest overall TSS values (i.e., Christiana and Cobus Creeks), while Turkey and Yellow Creeks, in the southern and western portions of the county, had the highest TSS levels (Figure 9). Seasonal depictions of TSS for each of the regions showed no clear trends, except for the St. Joseph River, Christiana Creek, and Cobus Creek, which exhibited an increase in TSS from April to June, followed by a decline in TSS over the summer (Figure 10). Finally, TSS was significantly higher under wet conditions than dry conditions (12 and 7 mg/L, respectively).

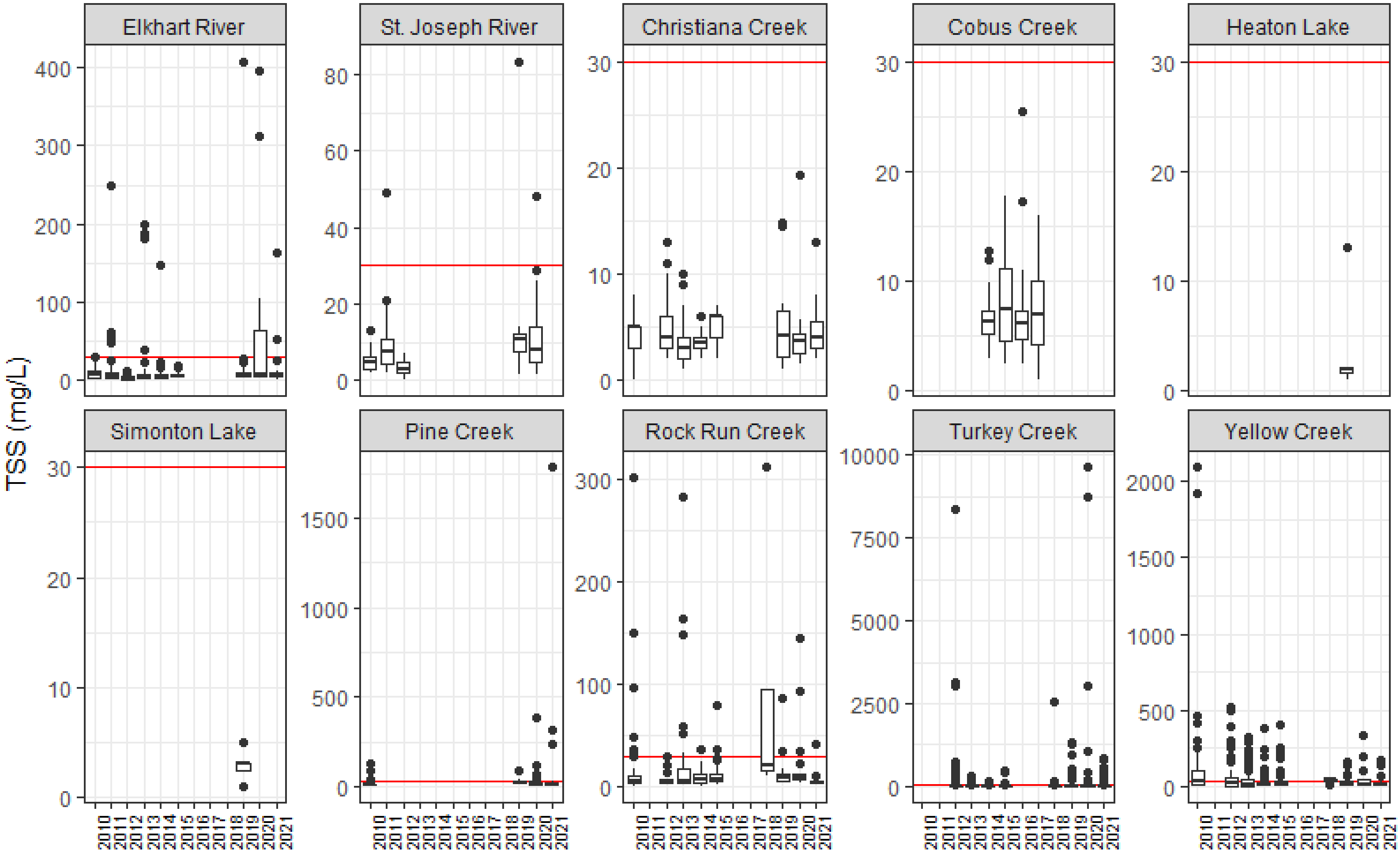

Figure 9. Boxplots of annual median TSS levels (in milligrams per liter, mg/L) for the 10 surface waters. The red horizontal line in each panel represents the TMDL target of 30 mg/L for Indiana waterbodies as designated by the Indiana Administrative Code. Note that the scale for the vertical axis is different for each region to facilitate improved visualization of annual trends for each region.

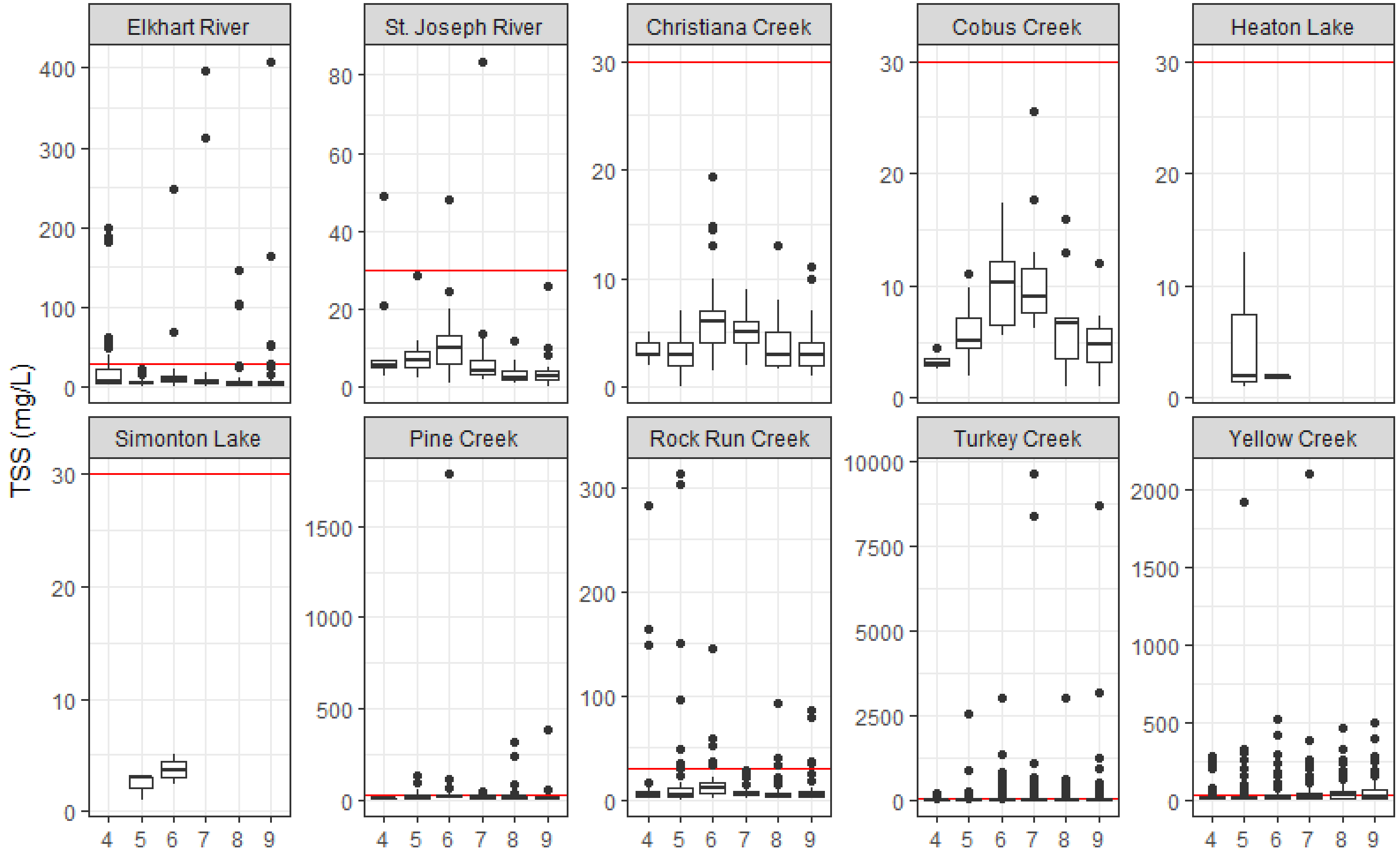

Figure 10. Boxplots of monthly median TSS levels (in milligrams per liter, mg/L) for the 10 surface waters. The red horizontal line in each panel represents the TMDL target of 30 mg/L for Indiana waterbodies as designated by the Indiana Administrative Code. Note that the scale for the vertical axis is different for each region to facilitate improved visualization of seasonal trends for each region.

SPC

Conductivity was highly variable among years and regions (Figure 11) and was significantly different across years, months, major water bodies, and weather (Supplement S2). Across all regions, years, and months, conductivity levels were lower during wet weather conditions compared to dry. Conductivity had a median value of 571 us/cm and ranged between 2 and 3102 us/cm. Turkey Creek, Yellow Creek, and Rock Run Creek had the highest median SPC levels, while Cobus Creek and Heaton Lake had the lowest values. Seasonal trends in conductivity were specific to each region, with some areas exhibiting increases or decreases in conductivity from April to September (Figure 12).

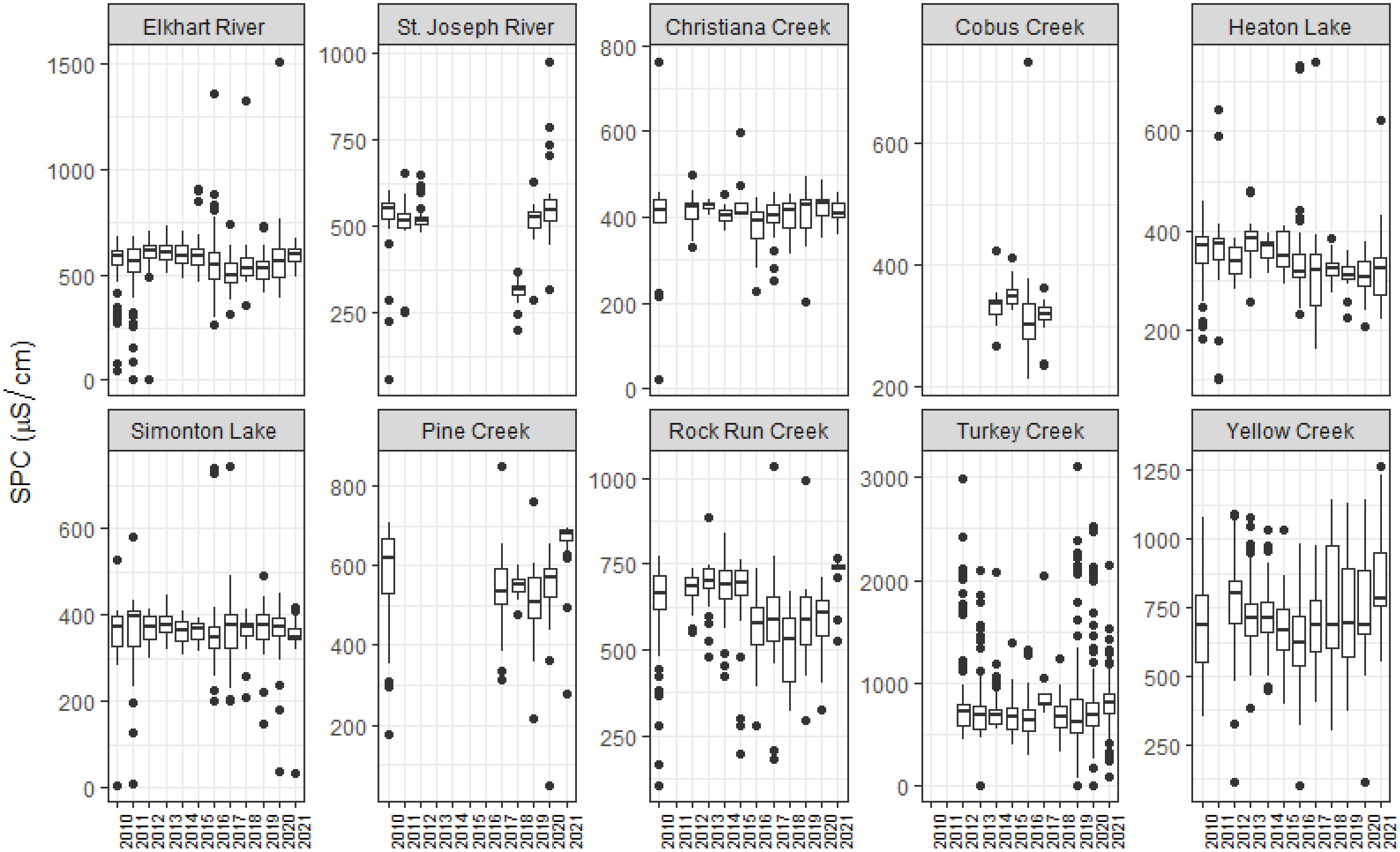

Figure 11. Boxplots of annual median SPC (in micro-Siemens per centimeter, µS/cm) for the 10 surface waters. Note that the scale for the vertical axis is different for each region to facilitate improved visualization of annual trends for each region.

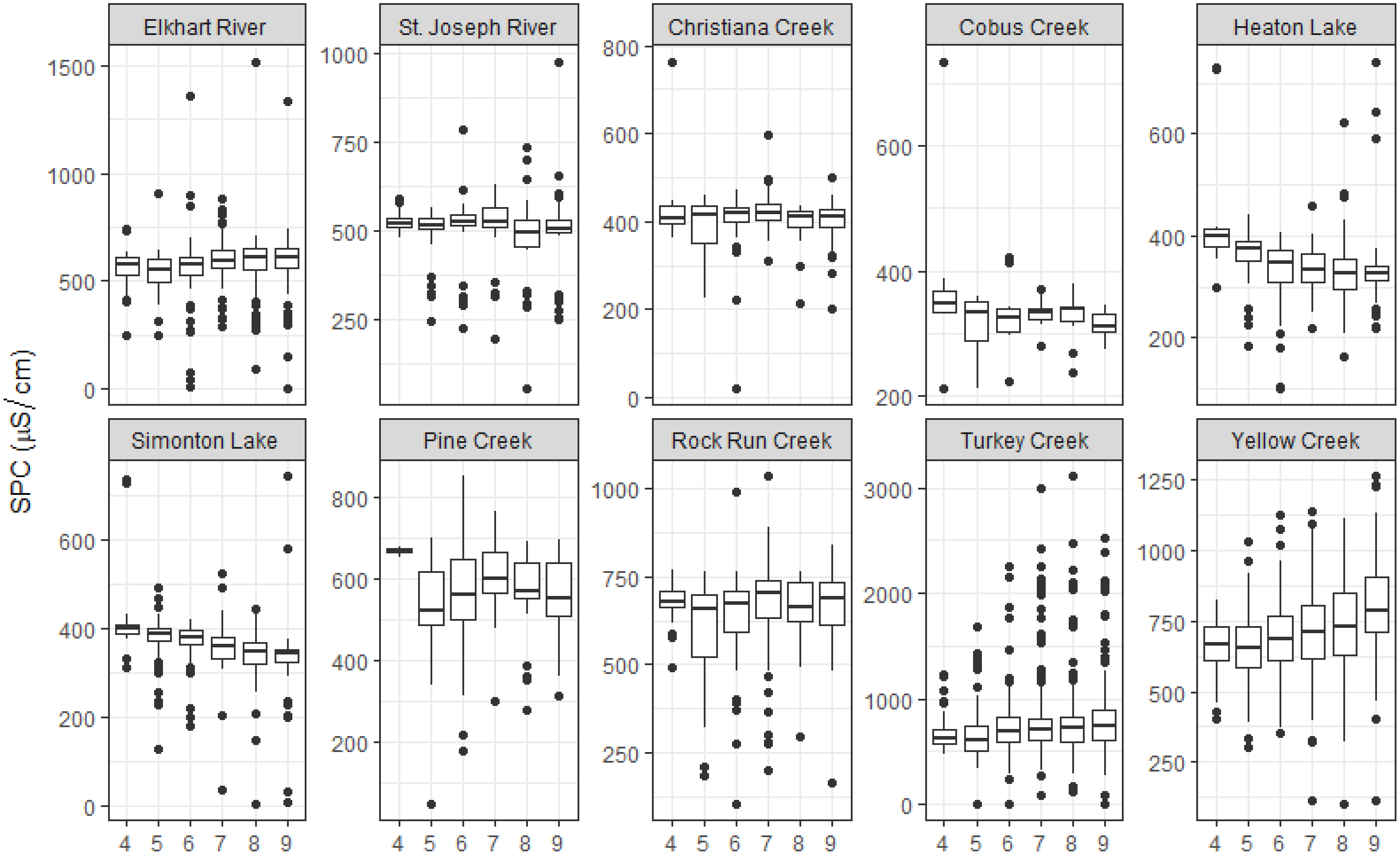

Figure 12. Boxplots of monthly median SPC (in micro-Siemens per centimeter, µS/cm) for the 10 surface waters. Note that the scale for the vertical axis is different for each region to facilitate improved visualization of annual trends for each region.

Chlorides

Chloride concentrations were highly variable across years, months, and wet weather (Supplement S2). Across all sites and years, chlorides had a median value of 27.1 mg/L and ranged between 0 and 1351.9 mg/L. For all regions, chlorides showed an annual trend in which levels increased dramatically between 2015 and 2018, followed by a sharp decline (Figure 13). However, there was some variability in the degree of increase observed for chlorides in each region, as Heaton Lake showed a modest increase in chlorides during this time. Monthly trends in chlorides for each region showed a general pattern of increase from the spring to the summer (Figure 14). Finally, median chloride levels reported during wet weather were nearly double those collected during dry weather (Supplement S2). The method for measuring chlorides changed in 2015, which may have contributed to the sharp increase in chloride levels that was observed in that same year (Elise Pfaff, personal communication).

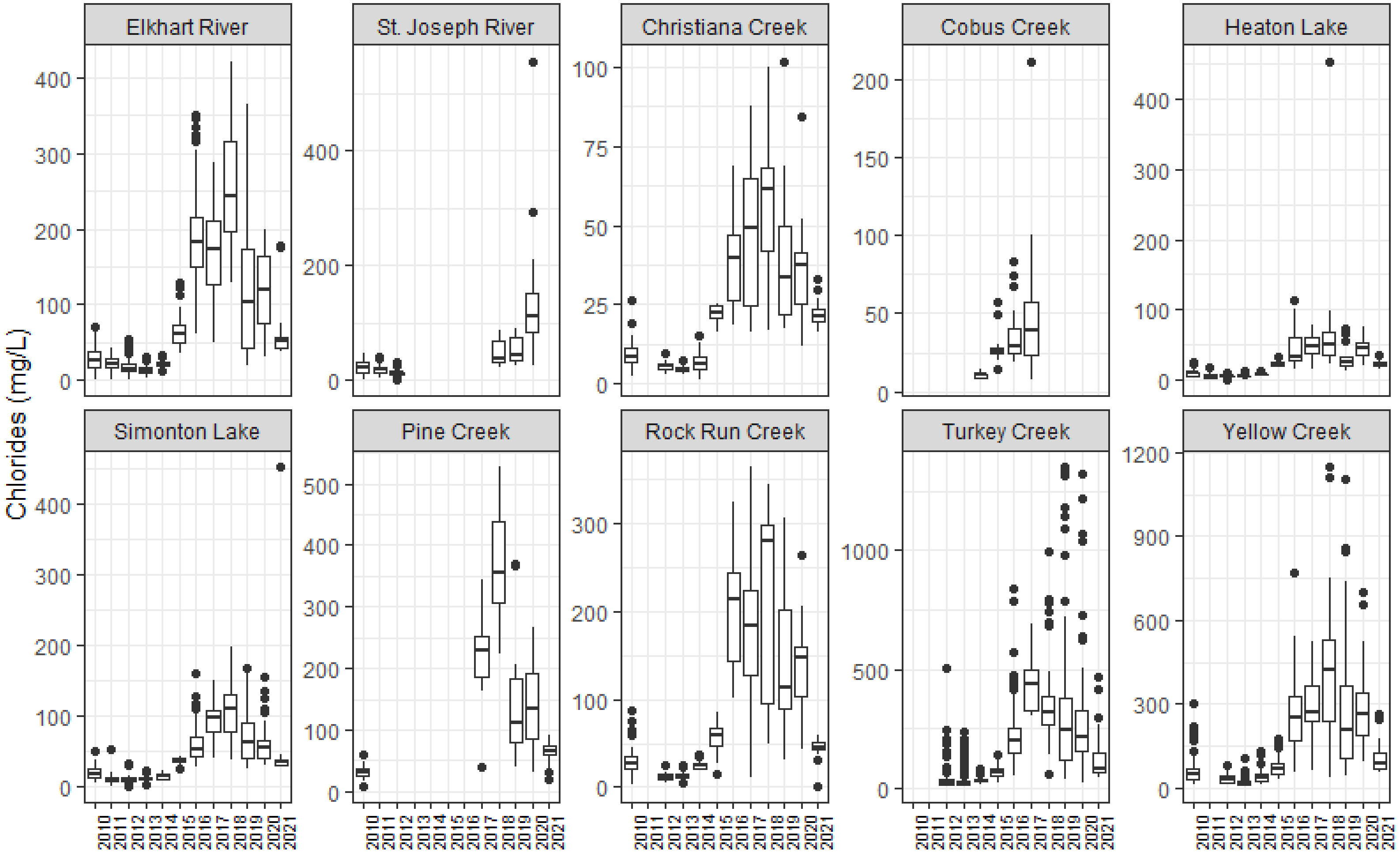

Figure 13. Boxplots of annual chloride levels (in milligrams per liter, mg/L) for the 10 major waterways. Note that the scale for the vertical axis differs among panels to facilitate improved visualization of annual trends for each region.

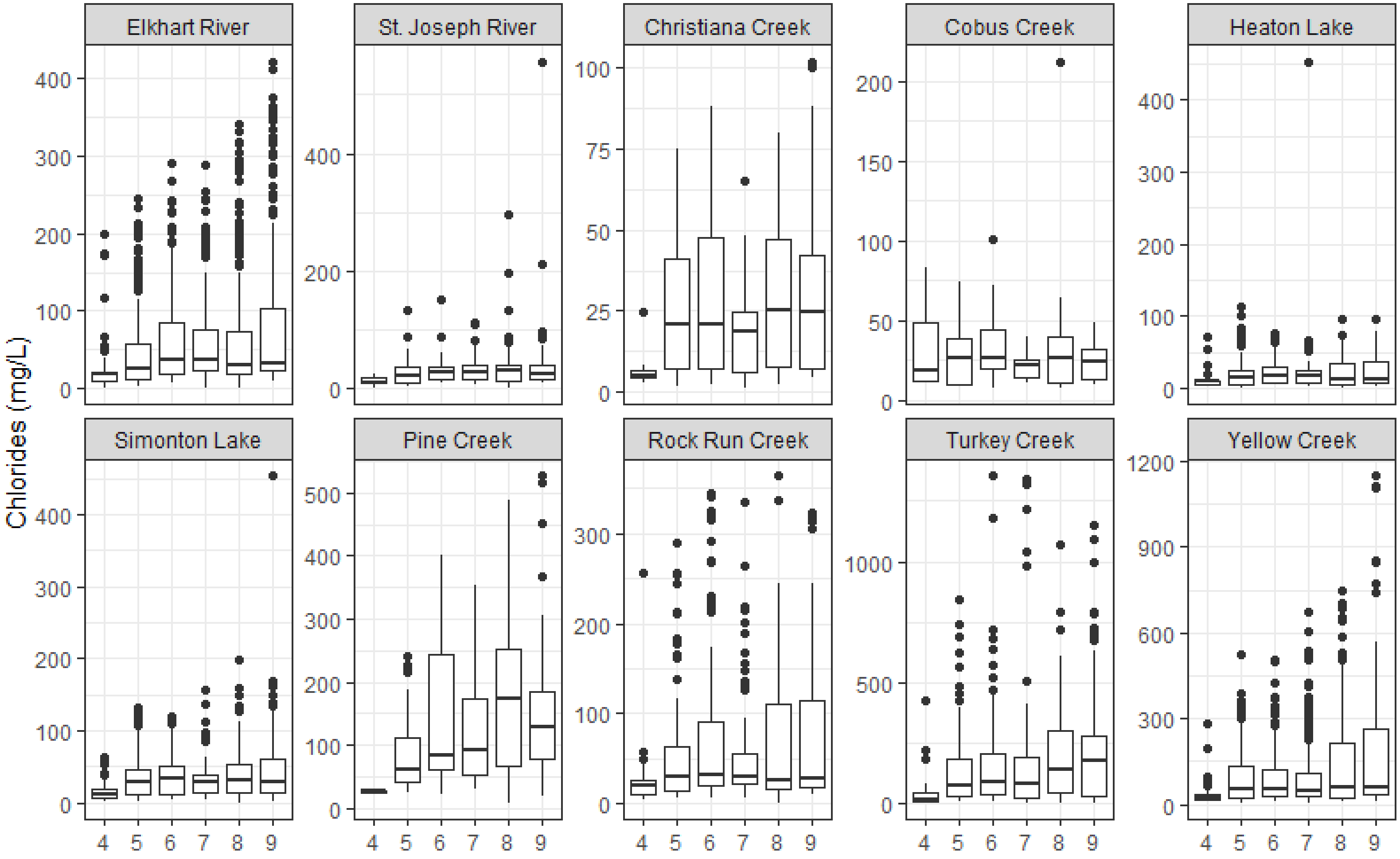

Figure 14. Boxplots of monthly median chloride levels (in milligrams per liter, mg/L) for the major surface waters. Note that the scale for the vertical axis varies for each region to facilitate improved visualization of annual trends for each region.

Nitrates

Nitrate concentrations had a median value of 1.54 mg/L and ranged between 0 and 26.3 mg/L. Nitrates varied across years, regions, months, and wet weather (Supplement S2). Annual variability in nitrates showed no consistent pattern (some regions had consistent nitrate levels across years, while Rock Run appears to have increasing nitrate levels). Differences in nitrate levels across regions were more apparent. Turkey Creek, Yellow Creek, and Rock Run Creek had the highest overall nitrate concentrations of all the regions (Figure 15). High seasonal variability in nitrate levels for the 10 regions was also observed; in general, nitrate concentrations increased from spring to summer (Figure 16). Finally, nitrate concentrations during wet weather were 1.5 times higher than those reported under dry conditions (Supplement S2).

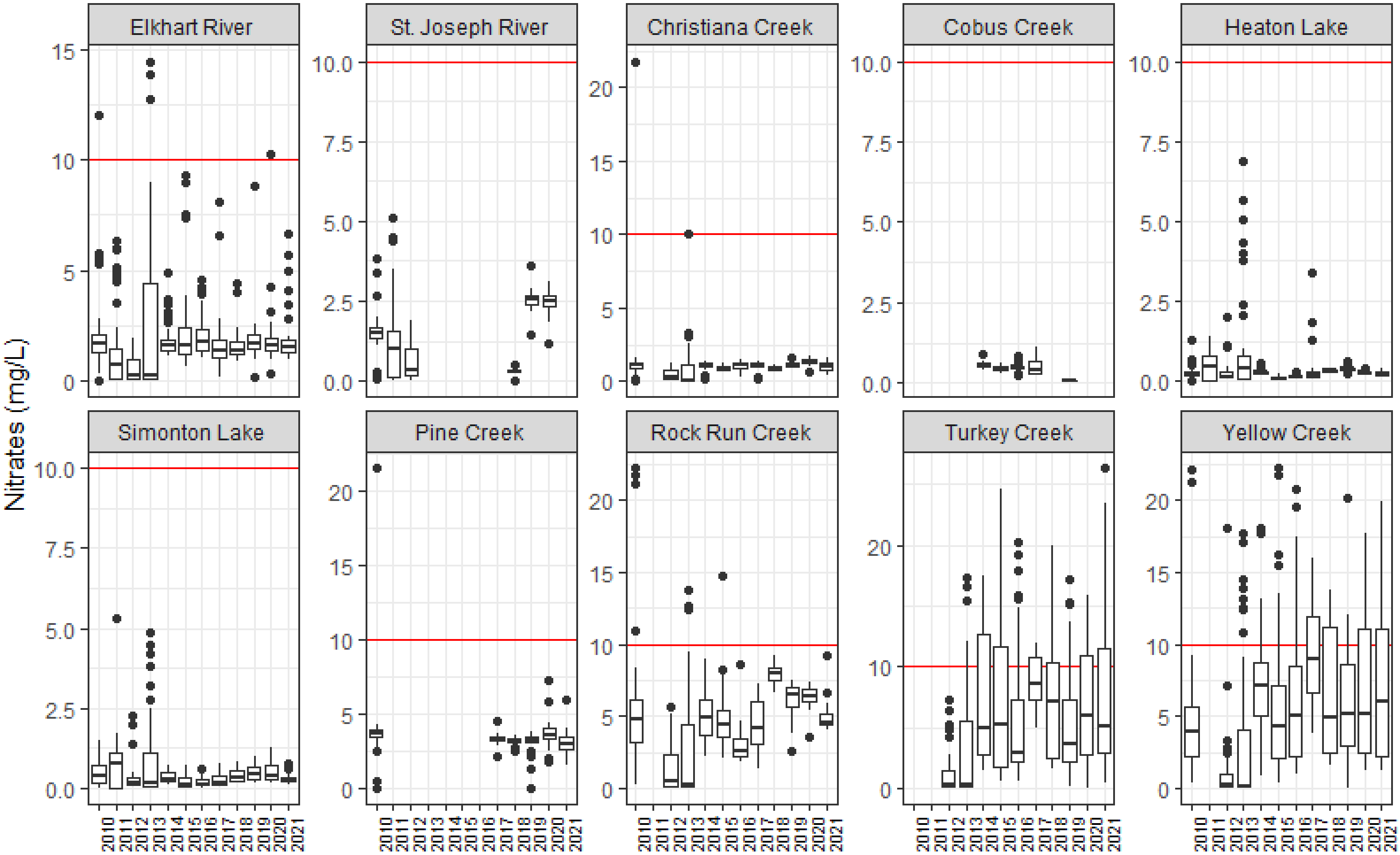

Figure 15. Boxplots of annual median nitrate levels (in milligrams per liter, mg/L) in each of the 10 surface water regions. The red horizontal line represents the maximum water quality target value of 10 mg/L for Indiana waterbodies as an IDEM TMDL target. Note that the scale for the vertical axis varies for each region to facilitate improved visualization of annual trends for each region.

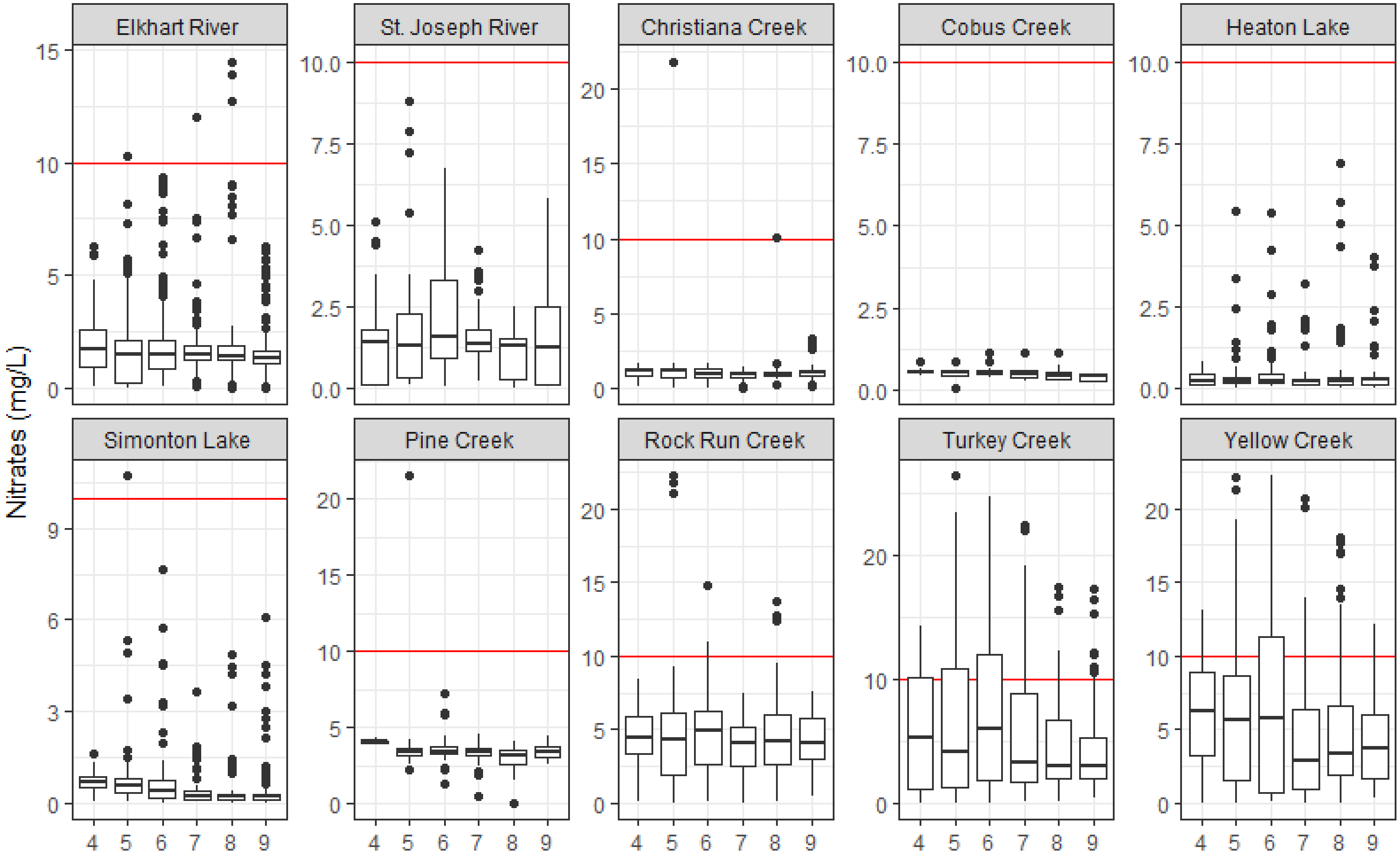

Figure 16. Boxplots of monthly nitrate levels (in milligrams per liter, mg/L) in each of the 10 regions. The red horizontal line represents the maximum water quality target value of 10 mg/L for Indiana waterbodies as an IDEM TMDL target. Note that the scale for the vertical axis varies for each region to facilitate improved visualization of annual trends for each region.

Phosphorus

Phosphorus concentrations exhibited a median value of 0.27 mg/L and ranged between 0 and 35 mg/L. There were significant differences in phosphorus levels across years, months, regions, and weather conditions (Supplement S2). Each of the surface water regions exhibited high variability in phosphorus levels over years (Figure 17). Turkey Creek, Yellow Creek, and the Elkhart River had the highest overall phosphorus concentrations in each year they were sampled (Figure 17). No clear seasonal or monthly trends in phosphorus levels were observed within each study region (Figure 18). Finally, phosphorus concentrations during wet weather were 1.4 times higher than those reported under dry conditions (Supplement S2).

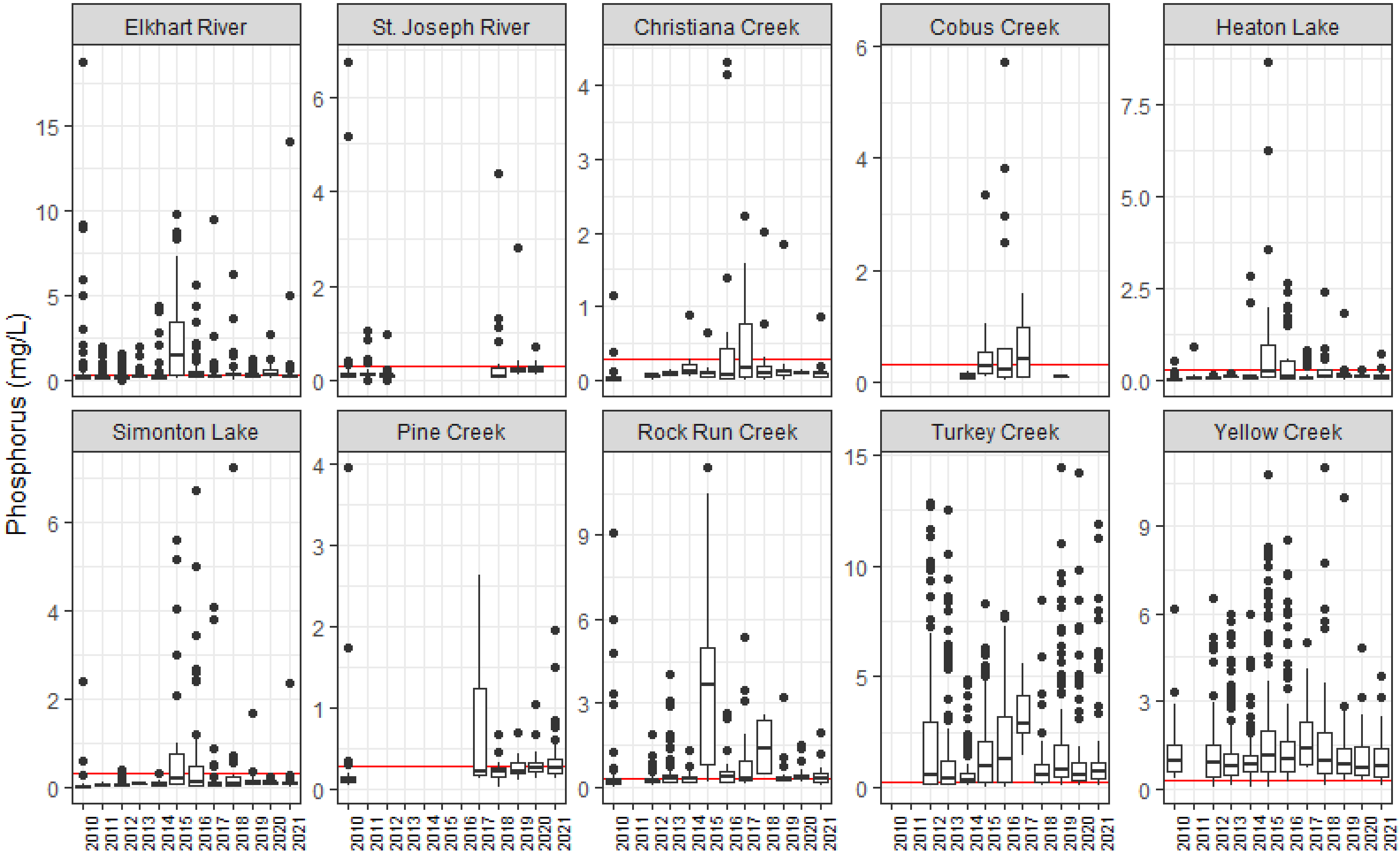

Figure 17. Boxplots of annual median phosphorus (in milligrams per liter, mg/L) levels in each of the major surface waters. The red horizontal line represents the maximum water quality target value of 0.3 mg/L for Indiana waterbodies as an IDEM TMDL target. Note that the scale for the vertical axis varies for each region to facilitate improved visualization of annual trends for each region.

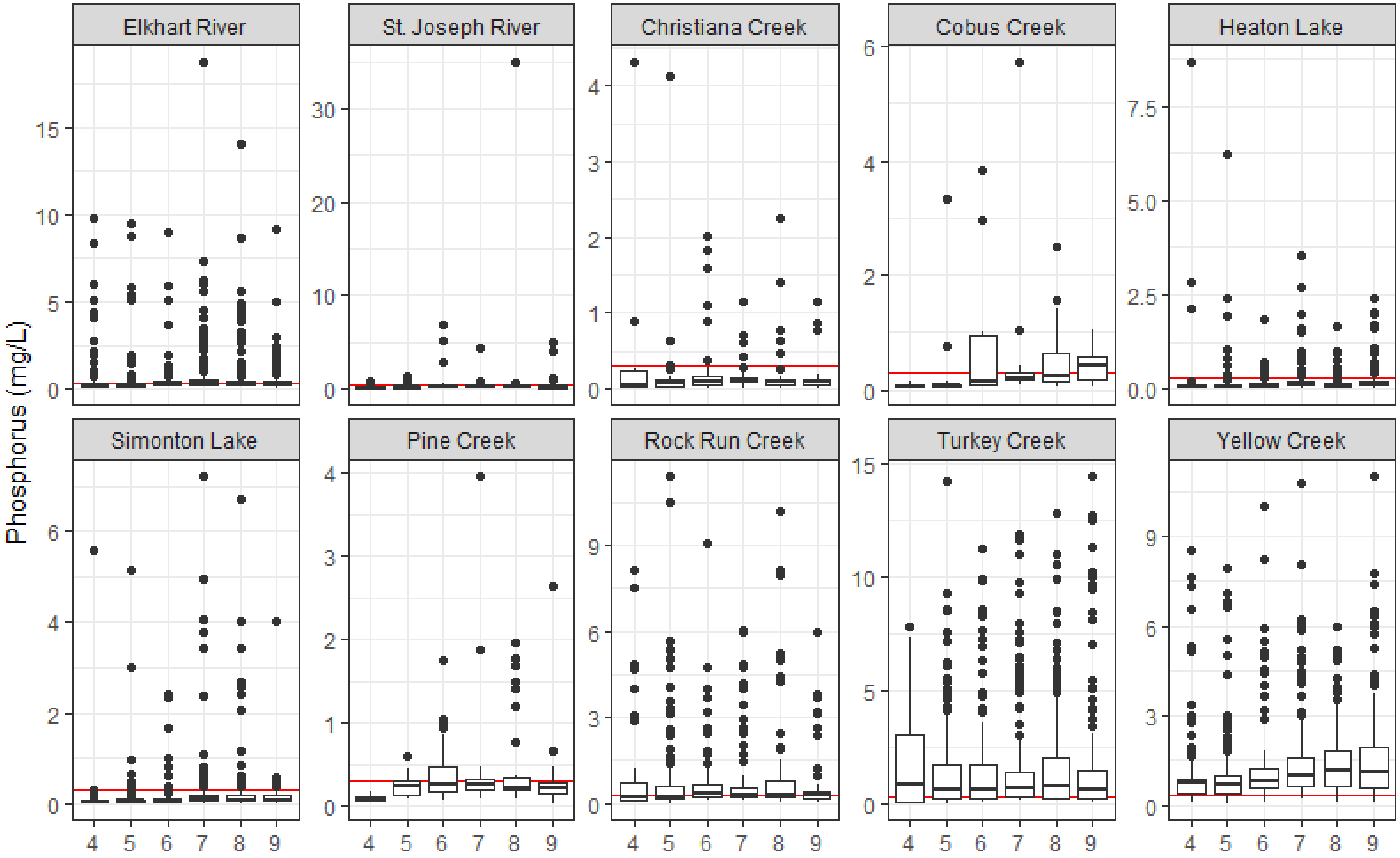

Figure 18. Boxplots of monthly median phosphorus (in milligrams per liter, mg/L) levels in each surface water region. The red horizontal line represents the maximum water quality target value of 0.3 mg/L for Indiana waterbodies as an IDEM TMDL target. Note that the scale for the vertical axis varies for each region to facilitate improved visualization of annual trends for each region.

E. coli

E.coli had a median value of 250 CFU per 100 ml and ranged between 0 and 3,465,800 CFU per 100 ml. *E. coli* varied significantly over years, months, sites, and weather conditions (Supplement S2). High variability in *E. coli* counts across years was observed for all regions (Figure 19). The highest *E. coli* levels were observed in Turkey Creek, Yellow Creek, Pine Creek, and Rock Run Creek, while the St. Joseph and Elkhart Rivers and Simonton and Heaton Lakes had the lowest levels (Figure 19). *E. coli* varied seasonally, with a general increasing trend from spring to summer observed for most regions (Figure 20). Finally, under wet weather conditions, *E. coli* counts were nearly four times higher than those measured under dry conditions (Supplement S2).

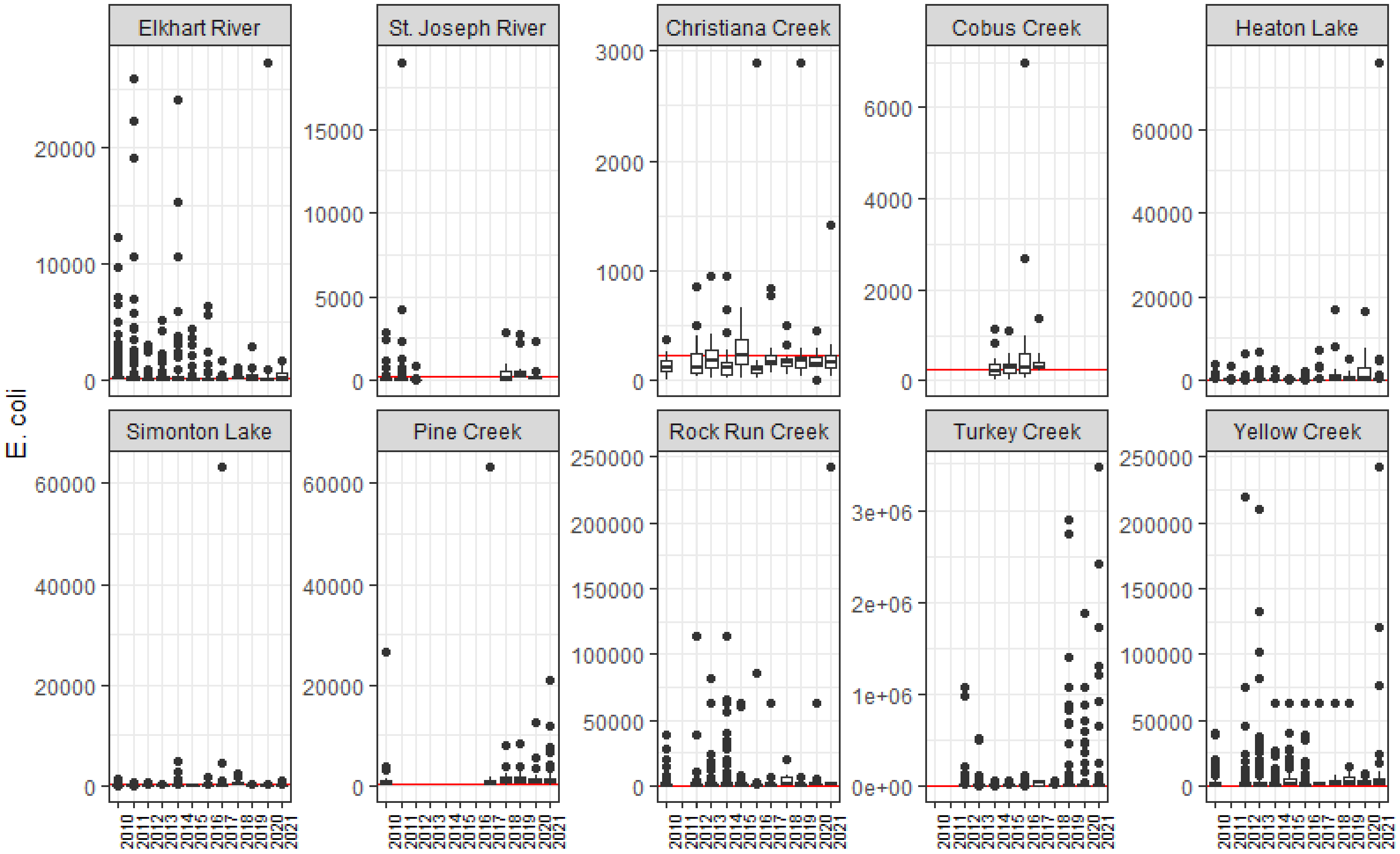

Figure 19. Boxplots of annual median *E. coli* levels (Colony forming units per 100 ml sample; CFU per 100 ml) in each of the 10 surface waters. The red horizontal line represents the maximum water quality target value of 235 CFU per 100 ml for Indiana waterbodies as an IDEM TMDL target. Note that the scale for the vertical axis varies for each region to facilitate improved visualization of annual trends for each region, as Turkey Creek *E. coli* levels are one to three orders of magnitude higher than all other waterways.

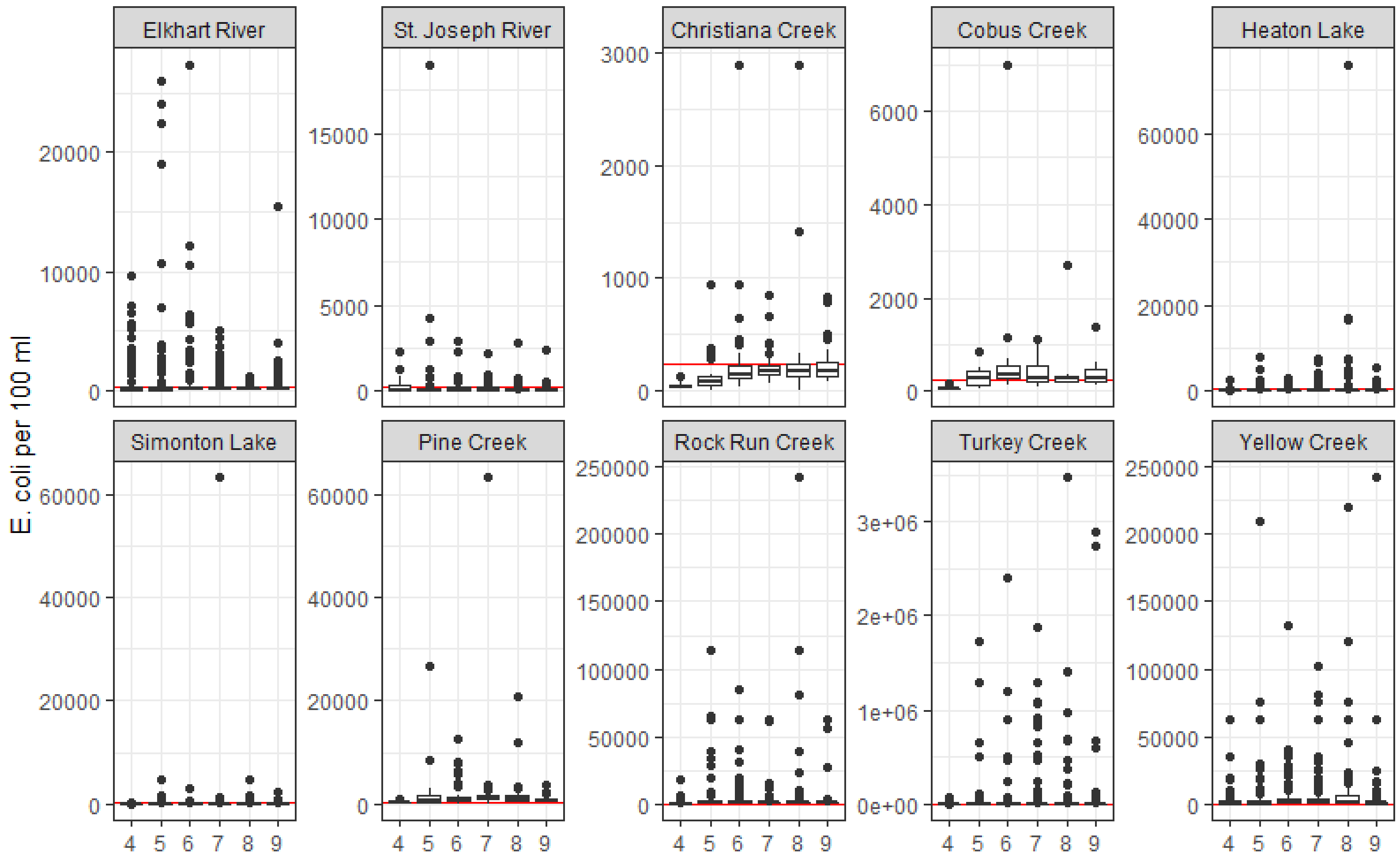

Figure 20. Boxplots of monthly median *E. coli* levels (Colony forming units per 100 ml sample; CFU per 100 ml) in each of the 10 surface waters. Note that the scale for the vertical axis varies for each region to facilitate improved visualization of annual trends for each region, as Turkey Creek *E. coli* levels span an order of magnitude higher than all other waterways.

Summary of general water quality trends

The above graphs of measured water quality parameters show the inherent variable nature of the chemical and physical characteristics of surface waters across years, months, and regions. Despite the high temporal and spatial variability, some general trends can be summarized. Of note is a positive observation that in most years and months, nearly all sites meet the water quality standard for dissolved oxygen, as levels of this parameter consistently fall within the desired range that supports aquatic life. Second, the regional analysis of water quality variables over years and months revealed some interesting spatial relationships. Surface waters to the south and west of Goshen, particularly Turkey and Yellow Creeks, with consistently higher levels of chlorides, nitrates, phosphorus, and *E. coli*, stand out as areas of concern. Third, the degree to which annual and seasonal changes in the values of the different water quality parameters changed seasonally and annually varied depending on the region examined, which suggests the need to analyze further how local land uses, land cover types (forest, row crop, urban, etc.), soils, and wetland loss in the catchments for specific sites, affect water quality dynamics.

2. Correlation analysis

Many pairs of variables had significant correlations (Table 2). A positive correlation indicates that a directional change in one variable is associated with a corresponding change in the same direction (positive or negative) in the other. A negative correlation shows that a reduction in the value of one variable is associated with an increase in the value of another – an inverse relationship. To maintain a narrow focus, we discuss below the management implications of correlations between variable pairs with a correlation coefficient greater than +0.3 or less than -0.3.

Positive correlations

SPC & Nitrates, SPC & Chlorides, Nitrates & Chlorides, Nitrates & Phosphorus, SPC & Phosphorus, Phosphorus & TSS, Phosphorus & Chlorides, *E. coli* & Nitrates, *E. coli* & Phosphorus, *E. coli* & TSS, *E. coli* & Chlorides, and *E. coli* & SPC had moderately strong positive correlations (range: 0.33 to 0.54; Table 2). These positive relationships between the above sets of variables do not necessarily point toward a cause-and-effect relationship, and they do not indicate the sources of pollutants in surface waters. However, this initial analysis may carry management implications. For instance, the strong positive association between nitrates & phosphorus may suggest a common pathway or source to a waterbody. Additionally, the strong correlations between *E. coli* and several physical and chemical water constituents may suggest important linkages and pathways of introduction of *E. coli* into surface waters from the landscape. For example, the strong positive relationship between *E. coli* and TSS, Phosphorus, Nitrates, and SPC is suggestive that multiple sources (e.g., agricultural runoff, illicit discharges, CSOs) are contributing to high *E. coli* levels.

Negative correlations

DO & SPC, DO & Phosphorus, DO & TSS, pH & Phosphorus, pH & *E. coli*, pH & Nitrates, and SPC & Temperature all had moderate negative correlations (range: -0.36 to -0.31; Table 2). While these associations are weaker than the positive relationships reported above, they do raise questions regarding the interactions among physical and chemical components that may be considered in future management decisions affecting surface waters. For instance, the negative relationship observed between pH and phosphorus & nitrates may suggest that the bioavailability of nutrients is dependent on pH. The effects of pH on phosphorus availability are variable and have been reported in many aquatic ecosystems (Fisher and Wood 2004, Seitzinger 1991, Wu et al. 2015).

Table 2. Spearman correlation coefficients and associated p-values for water quality variables measured in this study. Bolded sets of variables indicate significant associations (> 0.3, for both positive and negative).

Variable 1	**Variable 2**	**Correlation**
CHLORIDES	TEMP	-0.08
CHLORIDES	TSS	0.29
CHLORIDES	**ECOLI**	0.33
DO	**PHOSPHORUS**	-0.33
DO	**SPC**	-0.32
DO	**TSS**	-0.32
DO	ECOLI	-0.27
DO	TEMP	-0.23
DO	CHLORIDES	-0.06
DO	NITRATES	-0.01
DO	PH	0.23
NITRATES	TEMP	-0.29
NITRATES	TSS	0.26
NITRATES	**CHLORIDES**	0.48
NITRATES	**PHOSPHORUS**	0.48
NITRATES	**ECOLI**	0.49
PH	**PHOSPHORUS**	-0.37
PH	**ECOLI**	-0.31
PH	**NITRATES**	-0.31
PH	TSS	-0.25
PH	CHLORIDES	-0.05
PH	TEMP	0.16
PHOSPHORUS	TEMP	-0.20
PHOSPHORUS	**CHLORIDES**	0.45
PHOSPHORUS	**TSS**	0.49
PHOSPHORUS	**ECOLI**	0.54
SPC	**TEMP**	-0.35
SPC	PH	-0.26
SPC	TSS	0.11
SPC	**CHLORIDES**	0.31
SPC	**ECOLI**	0.47
SPC	**NITRATES**	0.48
SPC	**PHOSPHORUS**	0.51
TEMP	ECOLI	-0.28
TSS	TEMP	-0.02
TSS	**ECOLI**	0.53

Effects of wet weather on strength of correlations

A new set of correlations was computed for all variable pairs under dry and wet weather conditions. When dry and wet conditions are considered separately, the same general associations noted above and in Table 1 still hold. However, it is interesting to note that the strength of the correlations for most variable pairs increases during wet weather (Table 3). Two relationships stand out as especially significant. First, the positive correlation between Nitrates & Phosphorus increased from 0.43 under dry conditions to 0.60 under wet conditions (Table 3). This suggests that wet conditions increase runoff of these nutrients into surface waters. Secondly, the positive relationship between TSS, nitrates, and phosphorus & *E. coli* increased markedly when only wet conditions are analyzed (Table 3), which supports a long-speculative hypothesis that *E. coli* levels increase during precipitation, and it may be cooccurring with sediment loading.

Table 3. Spearman correlation coefficients for water quality variables measured under dry and wet conditions. Bolded sets of variables indicate significant associations (> 0.3, for both positive and negative) that are stronger under wet conditions relative to dry.

Variable 1	**Variable 2**	**DRY**	**WET**
CHLORIDES	TSS	0.27	0.26
CHLORIDES	TEMP	-0.05	-0.19
CHLORIDES	ECOLI	0.32	0.20
DO	**SPC**	-0.31	-0.38
DO	PH	0.21	0.21
DO	NITRATES	0.02	-0.15
DO	PHOSPHORUS	-0.33	-0.33
DO	CHLORIDES	0.01	0.03
DO	TSS	-0.34	-0.20
DO	**TEMP**	-0.24	-0.36
DO	ECOLI	-0.20	-0.26
NITRATES	**PHOSPHORUS**	0.43	0.60
NITRATES	CHLORIDES	0.48	0.35
NITRATES	**TSS**	0.17	0.36
NITRATES	**TEMP**	-0.30	-0.41
NITRATES	**ECOLI**	0.45	0.62
PH	**NITRATES**	-0.20	-0.55
PH	**PHOSPHORUS**	-0.29	-0.41
PH	CHLORIDES	0.06	-0.01
PH	**TSS**	-0.18	-0.36
PH	TEMP	0.16	0.24
PH	**ECOLI**	-0.23	-0.45
PHOSPHORUS	CHLORIDES	0.43	0.34
PHOSPHORUS	TSS	0.49	0.48
PHOSPHORUS	TEMP	-0.25	-0.17
PHOSPHORUS	**ECOLI**	0.51	0.60
SPC	PH	-0.20	-0.30

SPC	**NITRATES**	0.48	0.54
SPC	PHOSPHORUS	0.52	0.48
SPC	**CHLORIDES**	0.28	0.31
SPC	TSS	0.14	0.08
SPC	TEMP	-0.38	-0.23
SPC	ECOLI	0.51	0.41
TEMP	ECOLI	-0.30	-0.29
TSS	TEMP	0.00	-0.08
TSS	**ECOLI**	0.50	0.60

3. Analysis of exceedances

Understanding the percent of water samples exceeding water quality standards is another important way to identify areas of concern and to track progress towards improved water quality. This section provides graphical interpretations of annual and regional trends in the percentage of samples collected in each region and year that exceeded water quality targets for dissolved oxygen, nitrates, phosphorus, TSS, and *E. coli*.

Annual trends in exceedances

Figure 21 presents annual trends in the percentage of all samples in each year that exceeded the water quality standard for *E. coli*, nitrates, phosphorus, DO, and TSS. We see an increasing trend in the number of samples that exceeded the water quality targets for phosphorus and *E. coli* in each year (Figure 21). Furthermore, the annual pattern observed for the percentage of sites that exceeded the water quality target for *E. coli* is similar to the trend observed for phosphorus exceedances. This pattern aligns with the strong positive correlation between *E. coli* and phosphorus (Table 2). The percentage of sites exceeding the water quality standard for DO and TSS was much lower compared to *E. coli* and phosphorus exceedances. Annual trends in DO exceedances resembled the pattern of TSS exceedances, which is consistent with the negative correlation between these variables, in which higher TSS levels are associated with lower DO levels (Table 2).

Figure 22 further details the annual trends in water quality exceedances and assists with the comparison of the relationship among the exceedances of each water quality variable in each year. Sites exceeded water quality standards for *E. coli* and phosphorus much more frequently than the other variables (Figure 22). In general, in each year, most sites exceed the water quality target for *E. coli* and phosphorus, while 25% or fewer exceed the standards for DO, TSS, and Nitrates (Figure 22).

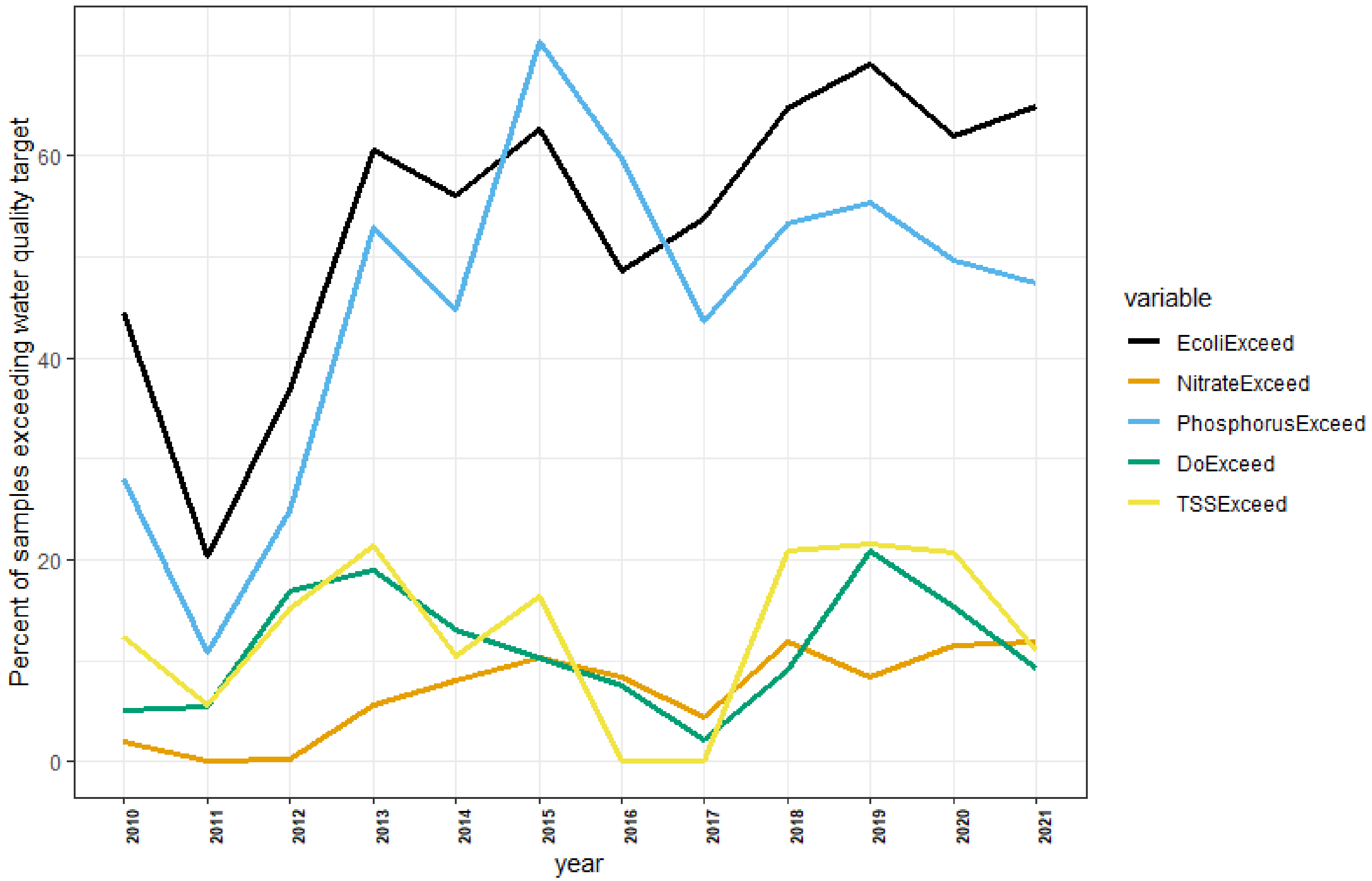

Figure 21. Time series of percent exceedances of water quality targets for Dissolved Oxygen (green line), *E. coli* (black line), Nitrates (orange line), Phosphorus (blue line), and TSS (yellow line). Note that this figure depicts exceedance percentages as the number of total samples collected and analyzed in each year across all samples collected in a year.

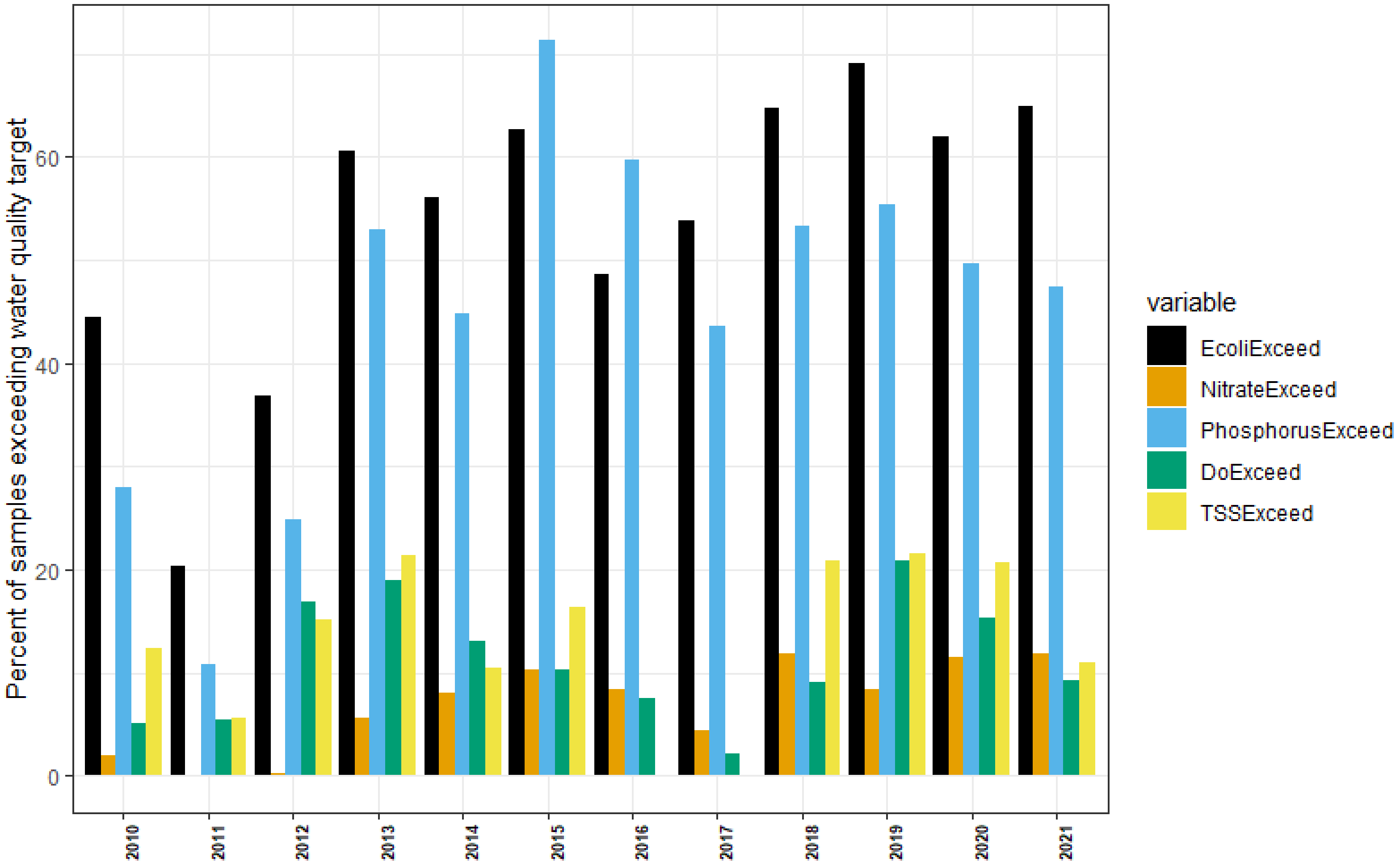

Figure 22. Bar plots depicting the percentage of sites in a year that exceeded each of the water quality targets for *E. coli*, Nitrate, Phosphorus, Dissolved Oxygen, and Total Suspended Solids.

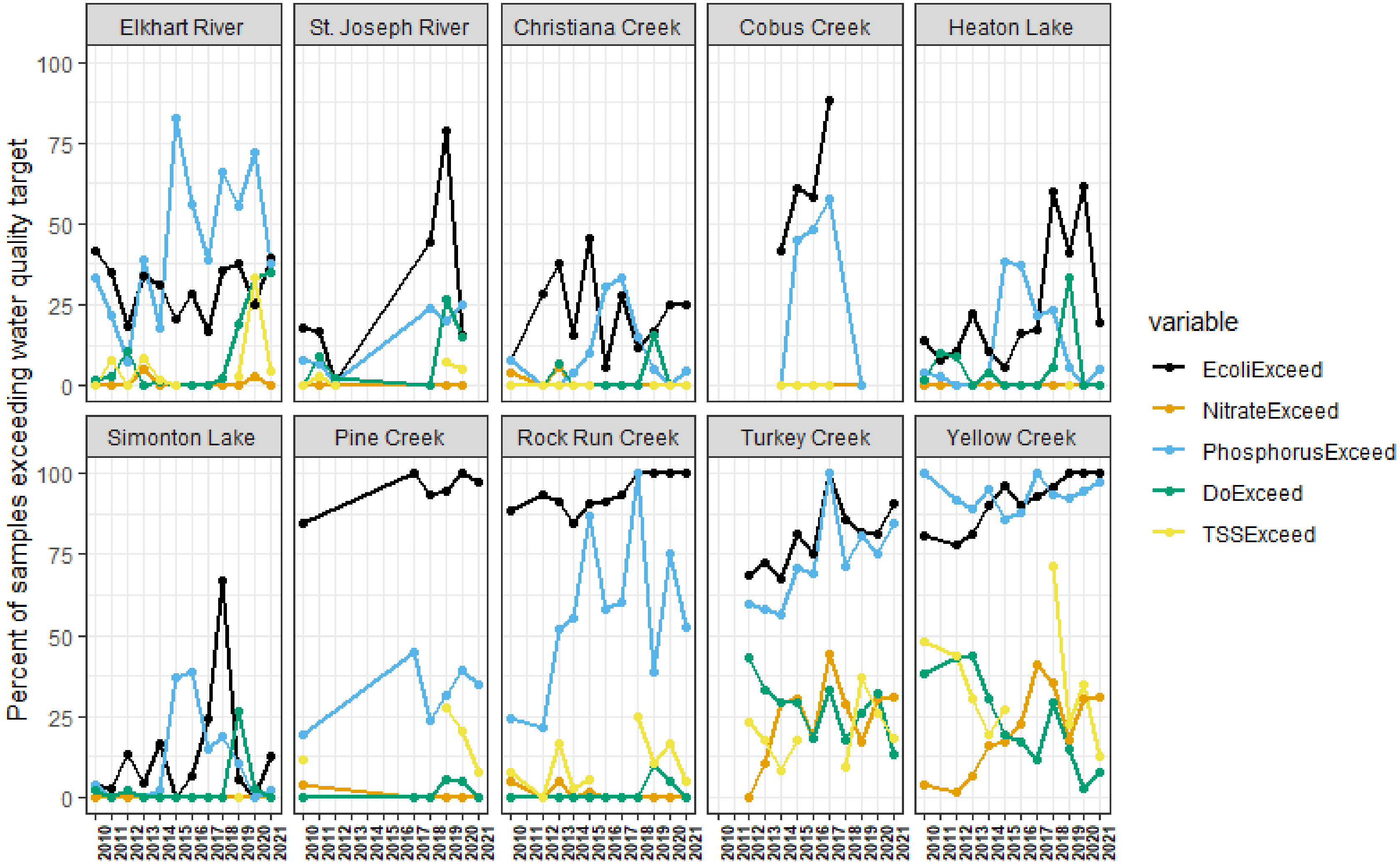

Figure 23. Annual trends of the percentage of samples collected in each of the major 10 surface waters that exceed the water quality TMDL targets for *E. coli*, Nitrates, Phosphorus, DO, and TSS. Note, solid circles indicate water quality data was collected for a given year and the absence of data collection is indicated by a solid line.

In addition to presenting county-wide annual trends in water quality exceedances, region-specific annual trends are presented (Figure 23). Several trends emerge from Figure 23. First, with the regional time-series analysis, it becomes apparent that samples collected from Turkey Creek, Yellow Creek, Rock Run Creek, and Pine Creek exceeded the water quality target for *E. coli* much more often than sites within the other regions (Figure 23). Second, trends in *E. coli* and phosphorus exceedance for each region do not always correlate with each other, as is evident in the panel for Christiana Creek, Elkhart River, and Heaton Lake. Taken together, these observations suggest region-wide differences in exceedances and the degree to which variables relate to each other, which may be indicative of local land use and coverage for these regions.

Summary of results

Since its inception, the GECSP surface water monitoring program has measured several chemical and physical attributes of many of Elkhart County's surface waters. The results presented above demonstrate the value of long-term monitoring in the identification of spatial and temporal trends in water quality, as well as identifying areas of concern. The results can be summarized as follows:

1. All the water quality variables exhibited significant annual, seasonal, and regional changes. The high variability in water quality over regions, years, and months reinforce the value of this program in establishing baseline conditions for monitoring sites. However, DO and temperature exhibit a typical seasonal pattern that is characteristic of waterbodies in the region.

2. Several variables are correlated with each other (Tables 2 and 3), and the strength of many of these relationships appears to increase under wet weather conditions.). The negative associations between DO & SPC, DO & Phosphorus, and DO & TSS are consistent with known patterns of eutrophication and subsequent reductions in oxygen availability in aquatic systems. The correlation analysis also revealed a strong positive association between TSS & *E. coli*, suggesting that both components increase in similar ways in the watershed.

3. Correlations must be interpreted with caution because not all variables were reported completely in each year and across all sites. Thus, the correlations give an overall snapshot of potential relationships among variables, but they do not prove cause-and-effect.

4. The proportion of sites exceeding the water quality targets for *E. coli* and phosphorus is trending upwards over time, while the exceedances of the water quality standards for DO, nitrates, and TSS are much lower in comparison. Collectively, Turkey Creek, Yellow Creek, Rock Run Creek, and Pine Creek exceed water quality standards much more frequently compared to the other major surface waters.

5. Analysis of long-term water quality trends across major water regions revealed striking spatial trends in TSS, nitrates, phosphorus, and *E. coli.* Presenting aggregated water quality trends for major waterways aided in identifying areas of concern and should serve as a basis for detailed analysis of specific sites.

6. It must be noted that the above trends may be influenced by the site selection process. Since different combinations of sites are sampled each year, differences in water quality over time may be due, in part, to the differences in sites sampled over years.

Conclusion

While most regions seem to be maintaining adequate dissolved oxygen levels to support aquatic life, it is concerning to see an increasing trend in the percentage of samples in each year that exceed the water quality targets for phosphorus and *E. coli*. The observed positive correlations among these variables may suggest the possibility that management of one of these parameters may assist in reducing the others. Given these initial results and interpretations, general sampling considerations and recommendations are presented below.

Sampling site recommendations: Sites on and draining to Turkey Creek, Yellow Creek, Rock Run Creek, and Pine Creek stand out as areas of concern for phosphorus, nitrates, TSS, and *E. coli*. Additional sampling sites along the tributaries or main stem of each of these waterways may yield valuable information. For Turkey Creek, it is recommended that at least one additional monitoring site be established between CR 17 and CR 50, and downstream of where Dausman Ditch enters Turkey Creek. These sites have consistently high nutrient and *E. coli* levels and adding more sites along these streams will aid in determining potential sources and pathways.

Time frame of sampling: The current time frame of sampling has revealed interesting monthly and annual trends in the different water quality parameters, especially chlorides. Recent research on Lake Michigan tributaries suggests that peak chloride levels occur during the winter (Dugan et al. 2021). Thus, it might be valuable to consider surface water monitoring outside the growing season.

Collaboration & coordination of sampling efforts: Another point of consideration is aligning site sampling schedules with the Elkhart Aquatic Community Monitoring Program so that long-term assessments of changes in biological communities can be related to changes in physical and chemical characteristics. A cursory analysis of long-term aquatic community monitoring and surface water monitoring by the partnership has revealed substantial overlap in the sites and waterbodies sampled by each program, but differences in sampling schedule prevent rigorous analysis on the relationships between water quality and biological communities. This represents a significant gap of knowledge but also an opportunity to coordinate sampling efforts of stakeholders focusing on different aspects of water monitoring throughout Elkhart County.

Incorporation of local habitat characteristics and land cover classifications: The physical and chemical attributes presented in this report are affected by a multitude of factors. Land cover characteristics and the degree of impervious surfaces likely play a role in local water quality dynamics. For instance, chloride levels in tributaries draining to Lake Michigan tend to be higher in watersheds characterized by high imperviousness and urban land cover compared to other land cover types (Dugan et al. 2021). Future surface water monitoring by the GECSP might consider conducting site characterizations, including assessments of riparian buffers, proximity to roads, road salt applications, and percent land cover and imperviousness of each monitoring site's watershed, as these could provide insight into drivers of annual and seasonal trends in water quality. In addition to site characteristics, integrating seasonal and annual weather conditions (precipitation, temperature, humidity) and USGS gage data on stream flow could further elucidate observed trends in water quality.

Site-by-site comparisons: More detailed analyses and comparisons of specific combinations of monitoring sites will aid in furthering understanding of water quality trends. Stormwater Partners are encouraged to share their suggestions for sites that should be analyzed in detail.

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References

Dugan, H. A., L. A. Rock, A. D. Kendall, and R. J. Mooney. 2021. Tributary chloride loading into Lake Michigan. Limnology and Oceanography doi: 10.1002/lol2.10228.

Fisher, L. H., and T. M. Wood. 2004. Effect of Water-Column pH on Sediment-Phosphorus Release Rates in Upper Klamath Lake, Oregon, 2001. U.S. Geological Survey Water-Resources Investigations Report 03–4271. Available at: https://pubs.usgs.gov/wri/wri034271/pdf/wri034271.pdf

Seitzinger, S. 1991. The effect of pH on the release of phosphorus from Potomac estuary sediments: Implications for blue-green algal blooms. Estuarine, Coastal, and Shelf Science 33: 409-418.

Wu, Y., Y. Wen, J. Zhou, and Y. Wu. 2013. Phosphorus release from lake sediments: Effects of pH, temperature and dissolved oxygen. KSCE Journal of Civil Engineering 18:323-329.