Prepared in cooperation with Upper Yampa River Watershed Group, Upper Yampa Water Conservancy District, Colorado Water Conservation Board, Yampa White Green Basin Roundtable, Mount Werner Water and Sanitation District, Routt County, and the City of Steamboat Springs

Assessment of Streamflow and Water Quality in the Upper Yampa River Basin, 1992 to 2018

By Natalie K. Day

Acknowledgments

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
	Flow rate	
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year (m^3/yr)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Mass	
ounce, avoirdupois (oz)	28.35	gram (g)
pound, avoirdupois (lb)	0.4536	kilogram (kg)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows: °F = (1.8 × °C) + 32.

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows: °C = (°F – 32) / 1.8.

Datum

Vertical coordinate information is referenced to the World Geodetic System of 1984.

Horizontal coordinate information is referenced to World Geodetic System of 1984

Elevation, as used in this report, refers to distance above the vertical datum.

Supplemental Information

Concentrations of chemical constituents in water are given in milligrams per liter (mg/L)

Streamflow is given in cubic feet per second (ft^3/sec)

Abbreviations

ft^3/s	cubic feet per second
µg/L	micrograms per liter
mg/m^2	milligrams per square meter
mg/L	milligrams per liter
CDPHE	Colorado Department of Public Health and Environment
CY	Climate Year
EPA	U.S. Environmental Protection Agency
EGRET	Estimation of Graphics for RivER Trends
M&I	Municipal and Industrial
NWIS	National Water Information System
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey

UYRB	Upper Yampa River Basin
WHO	World Health Organization
WRTDS	Weighted Regressions on Time, Discharge, and Season
WY	Water Year

Abstract

The U.S. Geological Survey (USGS), in cooperation with local stakeholders in the Upper Yampa River Basin (UYRB) water community, initiated a study to characterize streamflow and surface-water quality at select areas in the UYRB study area, in northwestern Colorado. This report identifies changes in streamflow and characterizes select water-quality constituents in the UYRB, makes comparisons to regulatory standards, and provides a synthesis of these results to facilitate resource management decisions regarding water supply and algal-sourced toxicity concerns. The results presented in this study can be used by the UYRB water community to identify constituents and land areas as they relate to regulatory and toxicity concerns and to help provide a better understanding of how major factors, including land use and geology may contribute to changes in streamflow and water-quality.

Streamflow trends examined across a longer time period, from 1910–2018, at Yampa River at Steamboat Springs, Colo. correspond to observed changes in streamflow documented across western North America and the Colorado River Basin. Decreasing trends were found during spring and summer months and annually for maximum and mean streamflows. Significant decreases in mean daily streamflows of 2 percent per decade or 25 percent across the 109-year period of analysis were found in April. A fairly significant decreasing trend in the deviation from

mean peak streamflow date was found, indicating that date of peak streamflow is occurring earlier at Yampa River at Steamboat Springs, Colo.

Since the completion and first fill of Stagecoach Reservoir in 1992, through 2018, all mainstem sites had significant decreasing trends in one or more streamflow statistics during winter months. Decreasing trends were found across most months at Yampa River above Stagecoach Reservoir, Colo., with significant decreases in January or February in mean and 7-day minimum streamflow statistics. Annual decreases in 7-day minimum streamflows of 14 percent per decade or 39 percent over the 27-year period of analysis was also observed. At the site directly below Stagecoach Reservoir, decreases in all three streamflow statistics were found from September through February, ranging from 13 to 20 percent per decade or 35 to 54 percent overall. Decreases in streamflow at Yampa River at Steamboat Springs, Colo., Yampa River above Elkhead Creek, Colo., and Yampa River below Craig, Colo., had similar magnitudes over the same time period.

Trends in streamflow at tributary sites likely correspond to changes in reservoir management and at sites with no upstream flow impoundments, changes due to water use and climate. Mean and 7-day minimum streamflows decreased by 35 percent per decade or 95 percent overall during July at Fish Creek near Steamboat Springs, Colo. Significant increases in 7-day minimum streamflows occurred in August, September, and October, resulting in an overall annual increase of 43 percent per decade or 116 percent overall. These changes likely correspond to changes in water use at Fish Creek Reservoir, the primary source of municipal water supplies for Steamboat Springs. Elkhead Creek near Hayden is above Elkhead Reservoir, thus trends at this site may be more indicative of changes in climate factors or changes in water management, including diversion for irrigation. Though not significant based on 90-percent confidence intervals, decreasing trends in streamflow were found in summer months at Elk River near Milner and may become more likely if current conditions continue. Like the mainstem sites, Elkhead Creek near Hayden also had significant decreases in all three streamflow statistics during winter months, November through February, ranging from 18 to 47 percent per decade or 49 to 127 percent overall.

Median concentrations of Kjeldahl nitrogen and total phosphorus were below Colorado Department of Public Health and Environment (CDPHE) standards at all sites. At sites downstream from Stagecoach Reservoir, estimated daily concentrations of suspended sediment, Kjeldahl nitrogen, and total phosphorus concentrations were typically highest in spring (March, April, and May). Highest concentrations occurred slightly later at Yampa River above Stagecoach Reservoir, Colo., than other sites, in May, June, and July, suggesting that different factors control nutrient inputs at this site. Yampa River at Milner, Colo., had an earlier peak of total phosphorus concentrations in February and March, corresponding with higher discrete concentrations of orthophosphate, indicating that this site may have different sources of phosphorus, including the wastewater treatment plant (WWTP) discharge for the city of Steamboat Springs.

Yampa River at Milner, Colo., and Yampa River above Elkhead Creek, Colo., had the highest net yields based on a normalized hydrograph of suspended sediment, Kjeldahl nitrogen, and total phosphorus in the UYRB. Both of these basins are underlain by highly erodible Cretaceous shales and Yampa River at Milner, Colo., has urban influence from the city of Steamboat Springs.

A highly likely upward trend in the streamflow-normalized Kjeldahl nitrogen concentration and load from 1999–2018 was indicated at Yampa River at Steamboat Springs, Colo. The Kjeldahl nitrogen concentration likely increased by 10 percent or 0.035 milligrams per liter (mg/L) and load also likely increased by 22 percent or 26 tons across the time period. Total phosphorus concentration likely increased by 1.1 percent per year and 20 percent or 0.0081 mg/L and loads also likely increased by 2.1 percent per year and 41 percent or 6.2 tons across the time period. No other trends were detected in the basin. Decreases in streamflow and increased influence from urban development may contribute to these trends.

Factors like variation in climate, natural processes, and land use in the watershed can affect hydrologic and chemical characteristics of reservoirs, and indirectly affect the biological community. Excessive algal growth reduces water clarity, inhibits growth of other plants, and can lead to extensive oxygen depletion, accumulation of unsightly and decaying organic matter, unpleasant odors, and fish kills. Cyanobacteria, a type of photosynthetic bacteria that is also known as blue-green algae, can proliferate in reservoirs that exhibit eutrophic conditions and hydrologic alterations. Cyanotoxins, produced by cyanobacteria, include liver, nerve, and skin toxins, that can affect human and animal health. On multiple sampling events at Stagecoach Reservoir, the physical and chemical factors indicated conditions conducive to cyanobacterial blooms. Surface-water temperatures exceeded 20 degrees Celsius on multiple sampling days. Total phosphorus concentrations in surface waters exceeded the interim CDPHE water-quality standard of 0.025 mg/L in August and September of 2017 and 2018, whereas total nitrogen exceeded the interim standard of 0.426 mg/L on every sampling date. TN:TP ratios in samples collected at 3 feet ranged from 15 to 31.

Cyanobacteria had the highest cell densities compared to other planktonic algae from samples collected in Stagecoach Reservoir. Total cyanobacterial cell densities ranged from 75 to 1,380,000 cells per milliliter (cells/mL) and exceeded the World Health Organization's guideline values for a moderate probability of adverse health effects (100,000 cells/mL) in July and August of 2017. The cyanotoxin microcystin was detected in Stagecoach Reservoir in September 2018, but the total microsystin concentration of 0.26 µg/L was much less than the Environmental Protection Agency's recreational advisory level of 4 µg/L for microcystins. Concentration of total microcystins was below the detection limit of 0.10 µg/L on all other dates sampled. Two other types of cyanotoxins, total saxitoxins and total cylindrospermopsins, were also measured and were below detection limits on all dates.

The dominant land cover in the UYRB in 2016 was forest, which accounted for 49 percent of total land area. Other prominent land covers included shrub/scrub (39 percent, herbaceous (about 4 percent), and hay/pasture (3 percent). Development, including open space, only accounted for approximately 1.5 percent of land area in the UYRB. Developed land was greatest in the Yampa River at Steamboat Springs subbasin, where approximately 3 percent of the subbasin was developed. From 2001–2016, evergreen forest cover decreased by 26 square miles, representing 1.2 percent of the total basin area. Subbasins with the highest evergreen forest loss include Elk River near Milner (21 miles or 4.6 percent of the relative area of the subbasin), and Yampa River below Oak Creek (4.2 miles or 1.6 percent of relative area of the subbasin). Developed land area, which includes high-, medium-, and low-density land development, increased by 0.79 square miles across the UYRB, with the largest increase of 0.39 square miles in the Yampa River at Steamboat Springs subbasin.

Several information needs were identified that would aid in understanding water quality in the UYRB. Most of the suspended sediment and nutrient data used in this report are collected quarterly. Increased frequency of sampling or more targeted sampling to capture urban runoff during storm events, WWTP discharge, and groundwater sources may help to improve understanding of sources of these constituents. Land-use and land-cover data reflecting subbasin scale changes would assist in a better understanding of how changes in these factors contribute to streamflow and water-quality trends.

Introduction

The Yampa River, in northwestern Colorado, is the largest, mostly free-flowing river to the Colorado River system in the Upper Colorado River Basin. Because of limited reservoir storage, the river is known for its largely unaltered natural condition, biological diversity, and generally "good" water quality and is a valued multi-use resource in the Upper Yampa River Basin (UYRB). The Upper Yampa River Basin (UYRB), as defined in this report, is the watershed of the Yampa River from its headwaters near the Flat Top Mountains to near Craig, Colo. (fig. 1).

Figure 1. Location of Upper Yampa River Basin, Colorado, with select U.S. Geological Survey water-quality sampling sites and water year 2018 streamgage stations.

In 2012, the U.S. Geological Survey (USGS) published an analysis of water-quality data in the UYRB for 1975–2009 that documented water-quality conditions and determined that water in rivers and streams of the UYRB was generally of “very-good” quality (Bauch and others, 2012). Bauch and others (2012) identified additional streamflow data were needed to assess the effects of land use and geology on observed water quality in the basin. The USGS and local stakeholders established a comprehensive water-quality monitoring program for the UYRB in October 2010, which continues to the present day (2020). Sites in the monitoring program were selected to represent different geologic and land-use types throughout the UYRB.

In recent years, local stakeholders’ interests in understanding the interaction of water supply, nutrient conditions, Colorado Department of Public Health and Environment (CDPHE) interim concentrations for water-quality standards (Regulation #31; CDPHE, 2017), and algae blooms in Stagecoach Reservoir have grown (Halliday, 2016). Nuisance algae blooms in Stagecoach Reservoir have been observed with increasing frequency in the past several years (2015–18) and to some extent, as reported anecdotally by residents and land managers, in the mainstem of the Yampa River below Stagecoach Reservoir, drawing additional interest from stakeholders. Direct and indirect effects of land use, hydrology, and climate change can exacerbate conditions that favor bloom-forming algae, some of which can produce toxins that are harmful to human and animals, leading to impacts to water supplies.

In 2017, the USGS, in cooperation with the Upper Yampa River Watershed Group, initiated a study to evaluate temporal and spatial trends in streamflow and water-quality data through the analysis of available streamflow, suspended sediment, and nutrients data in the basin. A cooperative agreement with the USGS to perform the study was made possible through additional outside funding from the Colorado Water Conservation Board via the Yampa-White-Green Basin Roundtable, supplemented by local contributions from the Upper Yampa Water Conservancy District, Routt County, City of Steamboat Springs, and Mount Werner Water.This analysis provides a more specific understanding of water resources for the region and highlights potential impairments to water supply and the ecological health of the watershed.

Purpose and Scope

This report identifies changes in streamflow and characterizes select water-quality constituents in the UYRB, makes comparisons to regulatory standards, and provides a synthesis of these results to facilitate resource management decisions regarding water supply and algal-sourced toxicity concerns. The time periods of analysis and site selection were done to provide a better understanding of how major factors, including land use and geology may contribute to changes in streamflow and water quality in the UYRB study area.

Previous Studies

Several studies have investigated streamflow and water quality in the UYRB. Tobin (1996) assessed the initial effects of the construction and filling of Stagecoach Reservoir on the hydrology of the Upper Yampa River. The study examined physical, chemical, and biological data from sites upstream, downstream, and in the reservoir from 1988–91. Cyanobacteria blooms of *Aphanizomenon* and *Aphanocapsa* were measured in the reservoir during 1990–92.

The USGS has studied the water quantity, quality, and aquatic ecology of the Upper Yampa River Watershed (Bauch and others, 2012). The study summarized available water-quality, water-quantity and aquatic-ecology data collected from 1975–2009 by various agencies for streams, lakes, reservoirs, and groundwater. Bauch and others (2012) found a statistically significant upward trend in total phosphorus concentration at Yampa River at Steamboat Springs, CO (USGS site number 09239500), and suggested that population growth and land-use changes may have contributed to the trend.

The Upper Yampa River Watershed Plan (Halliday, 2016) was initiated by the Upper Yampa Watershed Group in 2013. The purpose of the plan is to increase local partnerships and their capacity to protect and enhance water quality, promote water conservation, and sustain and improve the present health of the watershed.

Description of the Study Area

The UYRB drains approximately 2,100 square miles of the Yampa River watershed west of the Continental Divide in northwestern Colorado (fig. 1). The boundaries of the watershed extend from the Williams Fork and Flat Top Mountains in the southwestern and southern portions of the watershed, respectively, to the Gore and Park Ranges and the Continental Divide to the east and to the Elk River and Fortification Creek drainages to the north and west, respectively. Elevations in the watershed range from more than 12,000 feet (ft) in the Flat Top Mountains and Park Range to 6,100 ft near the confluence of the Yampa River with Fortification Creek south of the city of Craig, Colo. The majority of the UYRB is within Routt County, with small portions in Grand, Garfield, Jackson, Moffat, and Rio Blanco Counties.

The population of Routt County during 2018 was estimated to be 25,733 (U.S. Census Bureau, 2018). The population of the county grew by more than 9.5 percent from 2010 through 2018. The largest municipality in the UYRB is Steamboat Springs (13,212 residents), the next largest is Craig (8,888 residents).

For the greater part of the past century, ranching, including hay and wheat production, and mining were the economic base of the Yampa River Valley. More recently, recreation-based tourism, including skiing, fishing, hunting, rafting, and camping, and second-home development became economic drivers. Tourism accounted for approximately 37 percent of the total jobs in Routt County during 2018, while mining and agriculture accounted for only about 7 percent of the total jobs during the same year. (State Demography Office, 2018). During 2018, tourism accounted for only 8 percent of the total jobs in Moffat County, while mining and agriculture accounted for 25 percent of the total jobs (State Demography Office, 2018).

The range of air temperature and precipitation in the UYRB is typical of that found in other mountainous and semiarid regions of Colorado. Annual temperatures in the cities of Steamboat Springs and Craig range from an average minimum temperature of 3.8 and 2.7-degrees Fahrenheit (°F), respectively, during January to an average maximum temperature of 83.3 and 88.9 °F, respectively, during July (High Plains Regional Climate Center, 2020). On average, almost 25 inches per year (in/yr) of precipitation falls in Steamboat Springs, and 14 in/yr falls in Craig. Much of the precipitation is snow during winter months. Snowfall averages 181 in/yr in Steamboat Springs and 66 in/yr in Craig (High Plains Regional Climate Center, 2020).

Much of the UYRB is underlain by sedimentary rocks of Cretaceous age, including sandstones, shales, and major coal beds (fig. 2). Less resistant shales in the form of broad valleys and small rounded hills are found in the western two thirds of the watershed with more resistant sandstones.

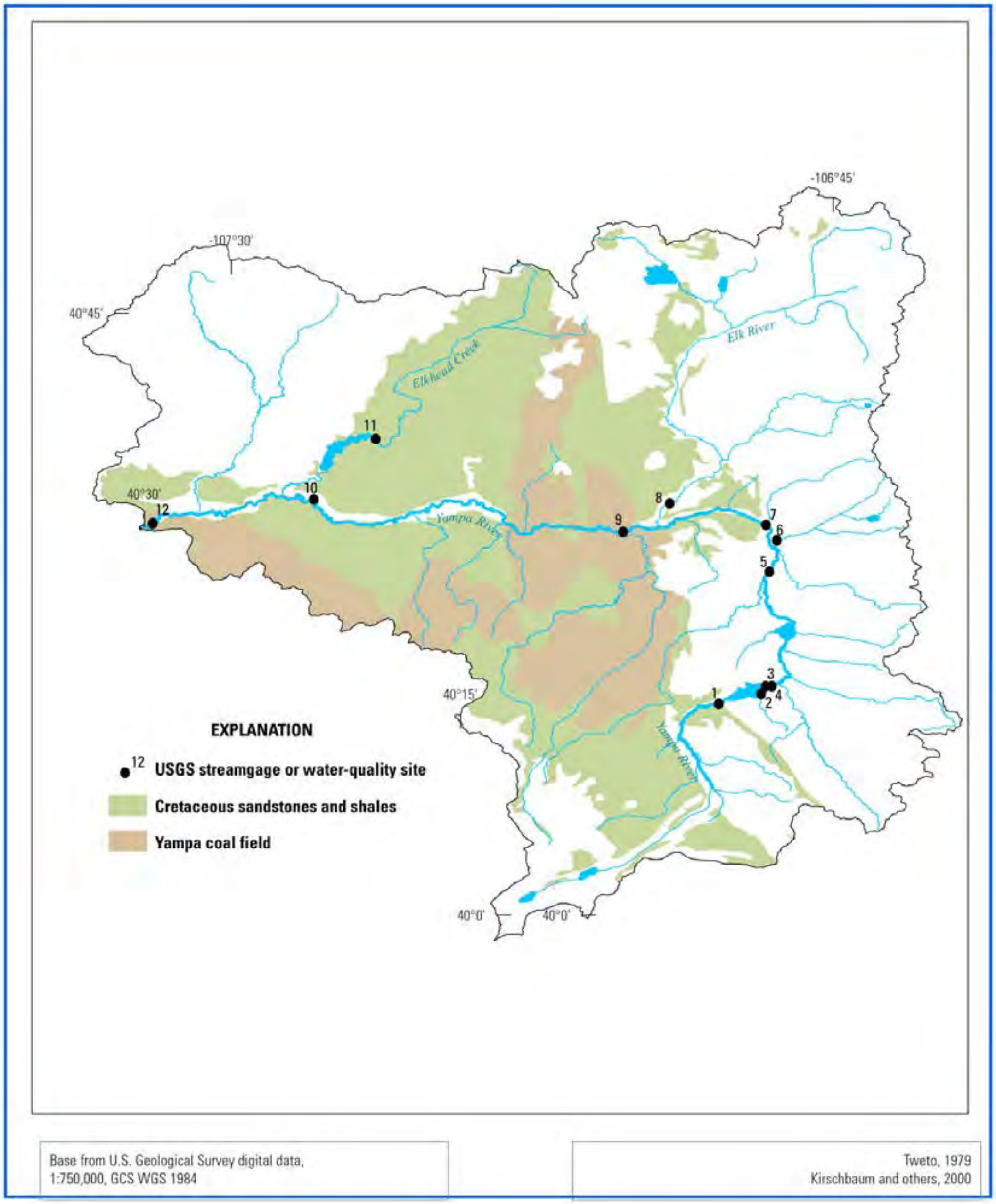


Figure 2. Map showing Cretaceous-aged sandstones, shales, and major coal beds of the Upper Yampa River Basin, Colorado.

Hydrology and Water Use

The Yampa River originates in the Flat Top Mountains as the Bear River, flows northward to the town of Yampa, Colo., and becomes the Yampa River where Phillips Creek converges with the Bear River (fig. 1). Major tributaries to the Yampa River include Oak Creek, upstream from Steamboat Springs; the Elk River, downstream from Steamboat Springs; and Elkhead Creek, downstream from Hayden, Colo. Minor tributaries include Fish Creek east of Steamboat Springs, Trout Creek, Sage Creek, and Fortification Creek.

Streamflow in the UYRB is dominated by snowmelt, with increasing flows in April, peaking in May and June, and decreasing flows in July (National Water Information System, NWIS; https://waterdata.usgs.gov/nwis). Streamflow from August through March is often dominated by base flow from groundwater discharge and supplementation from reservoirs. Mean monthly streamflow for 2013 through 2018 for two sites on the Yampa River and one site on the Elk River show seasonal patterns of streamflow (fig. 3).

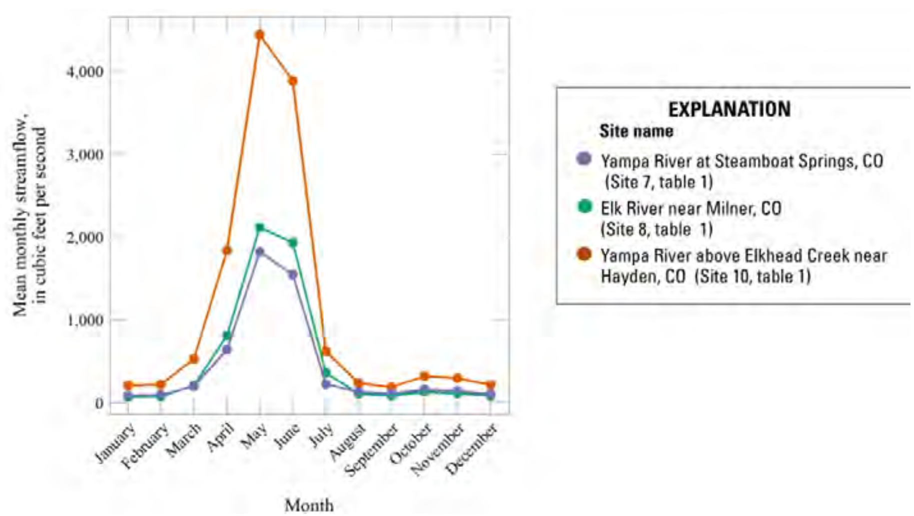


Figure 3. Mean monthly streamflow at select streamgage stations in the Upper Yampa River Basin, Colorado, water years 2013–18.

Multiple uses of surface water occur throughout the UYRB. The principal use of water is for irrigation, with irrigation ditches diverting water from the Yampa River and tributary streams throughout the basin. The ditch water is used primarily to irrigate hay and alfalfa crops and pasture lands. Total surface-water withdrawals for irrigation purposes in Routt and Moffat counties were 171 and 121 million gallons per day in 2015, respectively (Dieter and others, 2018). Combined surface water diversion rights of up to 43 cubic feet per second (ft^3/s) (86 acre-feet per day), are diverted from the UYRB into the Colorado River Basin through two small ditches in the headwater of the Yampa River during irrigation season (Colorado Water Conservation Board, 2009). These surface water diversions combined with stored water diversions through the same ditches totaled to approximately 2200 AF of total diversions to the Colorado Basin in 2019 (UYWCD records). The Steamboat Springs Ski Resort diverts an average of 275 acre-feet of water per season from an alluvial well, recharged from the Yampa River, near the Yampa River just upstream from Steamboat Springs for making artificial snow, typically from October through January (Colorado Water Conservation Board, 2009). An estimated 20 percent of the artificial snowpack is consumptively used during winter and spring through the processes of sublimation and evaporation, and the remaining portion returns to the watershed during spring snowmelt (Colorado Water Conservation Board, 2009).

The city of Steamboat Springs and the Mount Werner Water and Sanitation District divert most of their municipal water supplies directly from Fish Creek east of Steamboat Springs (Colorado Water Conservation Board, 2009). Water can be released from Fish Creek Reservoir for augmentation when flow in the creek is insufficient for supply (Colorado Water Conservation Board, 2009). The two municipal water suppliers can also withdraw water from alluvial wells adjacent to the Yampa River. The city of Craig diverts most of its municipal water from the

Yampa River upstream from Fortification Creek. Surface water is the primary water source for the towns of Hayden and Oak Creek, whereas groundwater is the primary water source for Phippsburg and the town of Yampa and part of the source for Hayden (Topper and others, 2003).

Nine major reservoirs in the UYRB, each with storage capacity greater than 4,000 acre-feet, are used for irrigation, recreational, and municipal purposes (Colorado Water Conservation Board, 2009). Stillwater Reservoir No. 1, Allen Basin Reservoir, and Yamcolo Reservoir store water primarily for irrigation; Lake Catamount, Pearl Lake, and Steamboat Lake are predominantly used for recreation and fishing; Fish Creek Reservoir stores water for municipal use; and Stagecoach Reservoir and Elkhead Reservoir store water for multiple purposes, including municipal, industrial, irrigation, and recreation. Stagecoach Reservoir, upstream from Steamboat Springs on the Yampa River, is the largest storage facility in the UYRB with a total capacity of approximately 36,500 acre-feet. Allocation of water from the Stagecoach Reservoir includes recreation and dead-pool storage volume, as well as water stored for industrial, municipal, agricultural, and augmentation uses. The dam at Stagecoach Reservoir supports a hydroelectric power station and the dam and reservoir are owned and operated by the Upper Yampa Water Conservancy District. There are no mainstem reservoirs downstream from Steamboat Springs.

Approach and Methods

The approach of this study was to identify and characterize changes in streamflow and selected water-quality constituents in the UYRB. These constituents of interest were selected for analysis in consultation with local stakeholders. The nature and extent of changes in streamflow were examined. Statistical models were used to estimate concentrations and loads for suspended sediment, nitrogen, and phosphorus. Nitrogen and phosphorus concentrations were compared to State of Colorado interim water-quality standards. Streamflow-normalized loads and yields were used to compare water quality across sites and identify source areas of loading. Trends in concentration and load were examined. Select physical, chemical, and biological characteristics of Stagecoach Reservoir were assessed. Changes in land use in the UYRB were assessed using data from multiple sources, including spatial and census data. All data analysis was performed in R (R Core Team, 2020).

Data Compilation and Quality Assurance

Streamflow and water-quality data used in this report were collected by the USGS and analyzed to assess streamflow and water-quality conditions in the UYRB. Quality assurance checks were applied to data and the resulting data were used in regression models, compared to CDPHE interim water-quality standards, and analyzed for temporal trends. The following discussion describes the methods used to retrieve, evaluate, and analyze streamflow and water-quality data for the UYRB.

Streamflow data and data for nitrogen (total nitrogen, Kjeldahl nitrogen) and phosphorus (total phosphorus, orthophosphate) were retrieved in an electronic format from the USGS National Water Information System (NWIS; https://waterdata.usgs.gov/nwis). Streamflow data and water-quality data were accessed from 7 mainstem Yampa River sites, 4 tributary sites, and 1 reservoir site for select periods from 1992–2018 and from one mainstem Yampa River site, Yampa River above Steamboat Springs, Colo. (USGS streamgage number 09239500), herein referred to as “Yampa River above Steamboat Springs” from the full period of record, 1910–-

2018 (table 1). Algae and toxin data were retrieved in an electronic format from the USGS National Water Information System (https://waterdata.usgs.gov/nwis) and a USGS data release (Solberg, 2020) from one reservoir site (table 1) from July–September 2017 and 2018. Data for most water-quality constituents for streams were collected quarterly to capture seasonal changes in concentrations related to changes in streamflow (for example, spring runoff, summer base flow).

Periods of analysis and water-quality constituents were chosen to capture the effects of reservoir construction, maximize comparability among sites, and limit the use of censored data. The year 1992 was chosen as the starting year for streamflow trend analysis because construction of a major reservoir, Stagecoach Reservoir, was completed and filled to spillway capacity by this time (Tobin, 1996). The period of analysis for water-quality data for five stream sites began in April 2010 when the UYRB Monitoring Program was initiated. The period of record at two sites, Yampa River at Steamboat Springs and Yampa River below Craig, Colo. (USGS streamgage number 09247600), herein referred to as "Yampa River below Craig", began in WY 1999 to avoid using excessive censored data in regression analyses. Data for water-quality constituents are reported as filtered (through a 0.45-micron filter, dissolved) or unfiltered. Data can also be reported as total; for example, total nitrogen includes all chemical species of nitrogen. Total nitrogen represents all inorganic and organic species of nitrogen present in a stream and is a calculated value that comprises separate measures of inorganic and organic chemical species. At the sites considered in this study, total nitrogen was calculated as the sum of unfiltered nitrite plus nitrate and unfiltered Kjeldahl nitrogen (organic nitrogen plus ammonia), herein referred to as "Kjeldahl nitrogen." At multiple sites in this study, greater than 50 percent of total nitrogen values were censored, meaning that either one or both of the constituents used to calculate total nitrogen were reported as “less than” a particular laboratory detection level or reporting level. Most regression techniques require less than 50 percent of data to be censored. Therefore, Kjeldahl nitrogen was used as a surrogate for total nitrogen in regression models and trend analysis. Use of Kjeldahl nitrogen will preclude detection of trends in inorganic nitrogen. Due to the large amounts of censored inorganic nitrogen species, only discrete values were assessed in this study. All USGS discrete water-quality and continuous streamflow data are reviewed and approved on a regular interval by qualified USGS personnel. All USGS data used in this report have been approved, quality assurance procedures are described later in the report.

Table 1. Summary of water year 2018 U.S. Geological Survey water-quality and stream gage stations in the Upper Yampa River Basin, Colorado.

[USGS, U.S. Geological Survey; UYRB, Upper Yampa River Basin; X, indicates that column header applies to this site; -, indicates column header does not apply to this site. USGS information from the USGS National Water Information System (NWIS, https://waterdata.ugs.gov/nwis). Streamflow period of analysis refers to climate years. A climate year is defined as a 12-month period beginning April 1 and ending March 31 of the following year. A climate year is designated as the year in which it begins. Water-quality period of analysis refers to water years. A water year is defined as a 12-month period beginning October 1 and ending September 30 of the following year. A water year is designated as the year in which it ends.]

Site number (fig.1)	USGS station identifier	USGS station name	UYRB monitoring program	Streamgage	Streamflow period of analysis	Water-quality period of analysis
1	09237450	Yampa River above Stagecoach Reservoir, CO	X	X	1992–2018	2010–18[a]
2	401634106502200	Little Morrison Creek near Stagecoach, CO	-	-	-	2012–14, 2017–18[b]
3	401707106495800	Stagecoach Reservoir at Dam, CO	-	-	-	2017–18[b]
4	09237500	Yampa River below Stagecoach, CO	-	X	1992–2018	2010–18[a]
5	402544106493600	Yampa River below Oak Creek near Steamboat Springs, CO[c]	X	-	-	2010–18[a]
6	09239000	Fish Creek near	-	X	1992–2018	-

		Steamboat Springs, CO				
7	09239500	Yampa River at Steamboat Springs, CO	X	X	1992–2018, 1910–2018	1999–2018 [a]
8	09242500	Elk River near Milner, CO[d]	X	X	1992–2018	2010–18 [a]
9	402840107004200	Yampa River at Milner, CO[c]	X	-	-	2010–18 [a]
10	09244490	Yampa River above Elkhead Creek near Hayden, CO	X	X	1992–2018	2010–18 [a]
11	09246200	Elkhead Creek above Long Gulch near Hayden, CO	-	X	1996–2018	-
12	09247600	Yampa River below Craig, CO	-	X	1992–2018	1999–2018 [a]

[a]Continuous water-quality analysis, including regression and trend analysis.

[b]Discrete water-quality analysis.

[c]Site is missing continuous streamflow data, and an interpolated hydrograph was created, limitations are discussed in “Extension of Streamflow Record” section.

[d]Site is missing streamflow data from January 1–April 31 during water years 2008–12, and an interpolated hydrograph was created, limitations are discussed in “Extension of Streamflow Record” section.

Extension of Streamflow Record

The Maintenance of Variance Extension Type 2 (MOVE.2) regression technique was used to estimate daily streamflow at sites with only a partial record by using the correlation between streamflow at the site of partial record and concurrent streamflow at a nearby gage (Hirsch, 1979), herein referred to as “estimated hydrograph.” If data between sites with partial streamflow records and sites with complete streamflow records are correlated, the coefficients produced from a linear regression can be used to predict missing streamflows at the site with a partial record. Sites with partial daily streamflow record requiring a MOVE.2 regression technique to estimate missing records include Elk River near Milner, Colo. (USGS streamgage number 09242500)), herein referred to as “Elk River near Milner,” Yampa River below Oak Creek near Steamboat Springs, Colo. (USGS streamgage number 402544106493600), herein referred to as “Yampa River below Oak Creek,” and Yampa River at Milner, Colo. (USGS streamgage number 402840107004200), herein referred to as “Yampa River at Milner.”

Streamflow data missing at Elk River near Milner from January 1–April 31 during water years (WYs) 2008–12 were estimated using continuous streamflow at Yampa River at Steamboat Springs. A water year is defined as a 12-month period beginning October 1 and ending September 30 of the following year and is designated as the year in which it ends. For Yampa River below Oak Creek and Yampa River at Milner, only discrete values of streamflow measured during collection of water-quality samples were available. A continuous streamflow record was estimated at Yampa River below Oak Creek using the relationship between discrete streamflows at that site and the continuous streamflow at Yampa River at Steamboat Springs minus the streamflow from Fish Creek near Steamboat Springs, Colo. (USGS streamgage number 09239000), herein referred to as "Fish Creek near Steamboat Springs." Likewise, a continuous streamflow record was estimated at Yampa River at Milner using the relationship between discrete streamflow at that site and the cumulative continuous streamflow at Yampa River at Steamboat Springs and Elk River near Milner. All model fits (R^2) were greater than 0.95 and meet the assumptions of the MOVE.2 analysis. Due to the large proportion of streamflow data estimated, Yampa River at Milner and Yampa River below Oak Creek were not included in the streamflow trend analysis. These sites were used in regression equations to estimate concentrations and loads; however, interpretation of these results should be assessed with a higher degree of caution. Errors in the estimated hydrograph will be propagated into concentration and load calculations.

Streamflow Trend Analysis

To explore the nature and extent of changes in streamflow in the UYRB, temporal changes in daily streamflow statistics were explored on an annual and monthly time period at 5 mainstem Yampa River sites and 3 tributary sites. The time period of analysis for assessing trends in streamflow extended from climate year (CY) 1992–2018, following the completion of Stagecoach Reservoir. A climate year is defined as a 12-month period beginning April 1 and ending March 31 of the following year and is designated as the year in which it begins. Climatic years are used in streamflow trend analysis to avoid breaking a long-low flow period into two segments, in each of the two adjacent years. Elkhead Creek above Long Gulch, near Hayden, Colo. (USGS streamgage number 09246200), herein referred to as "Elkhead Creek above Long Gulch," had a slightly shorter time period of analysis from CY 1996–2018. Streamflow trends were also examined across a longer time scale at Yampa River at Steamboat Springs from CY 1910–2018 to examine long-term trends in streamflow. Streamflow statistics included 1-day maximum, mean, and 7-day minimum and were assessed using the R package EGRET (Estimation of Graphics for RivER Trends; Hirsch and De Cicco, 2015). Trend slopes were calculated using the Thiel-Sen slope estimator (Thiel, 1950; Sen, 1968) and expressed as percentage changes per decade (Hirsch and De Cicco, 2015). The statistical strength of the trends was assessed using the Mann-Kendall trend test and 90-percent confidence intervals were used to determine significance.

Changes in timing of peak streamflow were also assessed at Yampa River at Steamboat Springs from 1910–2018. The mean date of peak streamflow was obtained by averaging dates of peak streamflow obtained from NWIS (https://waterdata.usgs.gov/nwis) across the period of analysis. Deviation from the mean peak streamflow date was calculated as the difference in peak streamflow date each year from the mean peak streamflow date for the period of analysis. Linear regression was used to look for trends in deviation of peak streamflow date from the long-term mean, where a decreasing slope would correspond to an earlier peak streamflow date.

Concentration and Load Estimates

Regression techniques were used to estimate concentrations and loads of suspended sediment and nutrient constituents at sites that met selection criteria. Selection criteria, including sample period of record, sample density, and percentage of data censoring, were applied to the data for analysis of concentrations and loads by multilinear regression. Seven sites met the criteria of having a minimum of 8 years of water-quality data with at least 20 observations (Runkel and others, 2004). Regression models define the relation between the concentration of a selected water-quality constituent and explanatory variables such as daily mean streamflow, seasonality, and time (Cohn, 2005; Helsel and others, 2020). Each explanatory variable explains part of the variation in the response variable. The regression model used to calculate daily concentrations and loads was developed through the R-LOADEST program (Lorenz and others, 2015), which is an R-based version of the USGS statistical program LOADEST (LOAD ESTimator; Runkel and others, 2004). R-LOADEST uses up to six explanatory variables to build a regression model that defines the relation of a constituent to streamflow, time, and season. The general form of the multiple linear regression model is as follows:

$$\ln C = b_0 + b_1(lnQ - lnQ^*) + b_2(t - t^*) + b_3(\sin(2\pi T)) + b_4(\cos(2\pi T) + e$$

where

ln natural log;

C is the constituent concentration, in milligrams per liter;

b_0 is the regression equation intercept;

b_n is the coefficient on the n^{th} regression variable, where n is 1 through 4;

Q is a streamflow term, in cubic feet per second;

*Q** is the streamflow centering value, in cubic feet per second;

t is time, in decimal years;

*t** is time centering value from the calibration dataset, in decimal years;

sin is the sine function;

π 3.14159;

T is the decimal portion of the year starting January 1;

cos is the cosine function; and

e is the error associated with the regression equation.

Loads are calculated by multiplying sample concentrations or regression estimates with daily-mean streamflow and a unit conversion constant. Concentration and streamflow values were log transformed to meet the assumptions of normality and constant variance (Hirsch and others, 1991). Streamflow and decimal time were centered to reduce the likelihood of multicollinearity and to ensure orthogonality in the streamflow and decimal time variables (Cohn and others, 1992). A Fourier series was used to account for differences in seasonal load (Runkel and others, 2004; Cohn, 2005). Fourier series use sine and cosine functions to describe continual change over the seasonal period. Model coefficients were estimated using adjusted maximum likelihood estimation, which is designed to correct for bias caused by the inclusion of censored data (Runkel and others, 2004).

The final model equations were selected by comparing Akaike Information Criteria (AIC; Runkel and others, 2004) scores, diagnostic plots, and statistics used to indicate whether the model fit met the assumptions of multilinear regression (Helsel and others, 2020). A consistent model form was used among sites where Fourier series and decimal time were retained at an alpha of 0.05 and the streamflow variable was always included to facilitate comparison among sites. The adjusted coefficient of determination, R^2, indicated how much variance in the response variable was explained by the regression model (Helsel and others, 2020). Values of adjusted R^2 closer to 1.0 indicated that more of the variance was being explained by the model compared to values closer to 0.0 that indicated less of the variance was being explained by the model. For two sites, continuous streamflow records and water-quality data were analyzed for WY 1999–2018 (table 1). For five sites, continuous streamflow records or estimated streamflow records and water-quality data were analyzed for WY 2010–18 (table 1).

Comparison to Water-Quality Standards

Estimated daily concentrations of nitrogen and phosphorus as well as annual median concentrations calculated from estimated daily concentrations were compared to State of Colorado interim concentrations for nitrogen and phosphorus water-quality standards. In-stream water-quality standards for surface water in Colorado have been established by the Colorado Department of Public Health and Environment (CDPHE) to protect the beneficial uses of surface water, which include aquatic life, domestic water supply, agriculture, and recreation (CDPHE, 2017). In 2012, Regulation #31 (the Basic Standards and Methodologies for Surface Waters) was revised to include interim concentrations for total nitrogen, total phosphorus, and chlorophyll *a* for rivers and streams and lakes and reservoirs (table 2). Estimated daily and median concentrations for 7 stream sites and discrete concentrations at 1 stream site and 1 reservoir site in the UYRB were compared to CDPHE interim concentrations for nitrogen and phosphorus for cold water.

Table 2. Colorado Department of Public Health and Environment (CDPHE) interim concentrations for total nitrogen, total phosphorus, and chlorophyll *a* water-quality standards for surface water in the Upper Yampa River Basin, Colorado.

[mg/L, milligrams per liter; mg/m^2, milligrams per square meter; ug/L, micrograms per liter. Interim concentrations for water-quality standards are from CDPHE (2017)]

Constituent	Cold rivers and streams	Cold lakes and reservoirs
Total nitrogen	1.25 mg/L[a]	0.426 mg/L[b]
Total phosphorus	0.11 mg/L[a]	0.025 mg/L[b]
Chlorophyll *a*	0.15 mg/m^2[c]	8.0 ug/L^2[b]

[a] Annual median, allowable exceedance frequency 1-in-5 years.

[b] Summer (July 1—September 30) average in the mixed layer of the lakes (median of multiple depths), allowable exceedance frequency 1-in-5 years.

[c]Summer (July 1—September 30) maximum attached algae, not to exceed.

Normalized Mean Daily Streamflows, Loads, and Yields

Normalized mean daily streamflow, loads, and yields were estimated for 7 sites in the UYRB (table 1). Daily mean streamflow values for a site were averaged to produce a mean daily streamflow (Q_n) for each day of the calendar year over the period of analysis for the site. An averaging function available on the National Water Information System website (https://waterdata.usgs.gov/co/nwis/dvstat/) was used to calculate the normalized mean daily streamflow. At sites with interpolated streamflow, the averaging was performed in R. For example, the mean daily streamflow for January 1, 2010–18, at Elk River near Milner was calculated from each January 1 value from the beginning of the analysis period through the end of the analysis period (2010–18). Calculating a Q_n for every day of the year removes differences in the year-to-year fluctuations in daily streamflow and allows estimates of annual load for water-quality constituents (Helsel and others, 2020). Regression models using the mean daily streamflows were used to predict annual loads at each of the seven sites.

Relative yields were calculated for seven sites by dividing the regression-based estimates of annual load at each site by the total area contributing to that site, after excluding all upstream load and basin area. This analysis provides an additional approach to compare water-quality loads among sites without the influence of year-to-year fluctuation in daily streamflow and basin area. The normalized loads and yields can be used to assess the influence of land-use activities, population, and water consumption on water quality.

Concentration and Load Trend Analysis

Characterizing long-term changes (trends) in water-quality constituents can provide insight regarding changes in land-use and climate. Trends can be compared among sites across a common time period. A trend is often presented as a percent change per year or change in concentration (milligrams per liter) or load (tons) per year and is described by the direction of change, either upward or downward. Two different methods were used to assess trends in water quality as a function of data availability. Trends in concentrations and loads of suspended sediment, nitrogen, and phosphorus were assessed using multiple linear regression models at seven sites. An additional method for assessing trends, using a weighted regression technique, was applied at two sites that met the requirements for such analysis.

Multiple Linear Regression Trend Analysis

Multiple linear regression techniques can be used to estimate long-term changes in average concentrations and loads of water-quality constituents across a designated time scale. The coefficients of a regression model describe the size and direction of the relationship between a predictor and the response variable. Thus, the presence of a significant time coefficient was interpreted to indicate a temporal trend (either upward or downward) in concentration and load. A significance level (α) of 0.1 was applied to the time coefficient for inclusion in the regression model.

Weighted Regression Trend Analysis

The Weighted Regressions on Time, Discharge, and Season (WRTDS) method (Hirsch and others, 2010) was used to assess trends in nitrogen and phosphorus concentrations and loads at Yampa River at Steamboat Springs and Yampa River below Craig. Only data for these two sites met the recommended criteria for using WRTDS of a minimum of 60 observations with sampling sufficiently representing seasonal variation in concentration and streamflow (for example, quarterly sampling; Hirsch and De Cicco, 2015). Concentration is modeled in WRTDS using the same equation used in LOADEST (eq. 1). Estimates of daily load are made by multiplying estimates of daily concentration by the respective daily mean streamflow. The fitted coefficients in most modeling approaches, including LOADEST, are constants, estimated to produce the best fit to the entire sample of measured concentrations. In contrast, the WRTDS model estimates a unique set of coefficients for every combination of Q and t in the period of record. The coefficients are fit by weighted regression, wherein the coefficients are based more heavily on observations collected under conditions that are similar to those on the day for which an estimate is required. The degree of similarity and, thus, weight on each observation is based on the distance in time, streamflow, and season. The variable-parameter weighted-regression approach allows WRTDS to represent complex relations between concentration and streamflow at a site, as well as complex trends over time.

Because estimates of daily concentration and load are strongly influenced by random variations in streamflow, WRTDS also produces flow-normalized estimates of daily concentration and load for a site. The flow-normalized estimates remove the variation in concentration or load due to random streamflow variations but not the variation due to nonrandom seasonal streamflow variation. See Hirsch and De Cicco (2015) for more details.

Confidence intervals on trend analysis were obtained using the WRTDS Bootstrap Test (WBT), which is a block bootstrap approach that is evaluated using a set of Monte Carlo simulations to estimate Type I error probability (the probability of detecting a trend when a trend was not present) (Hirsch and others, 2015). The WBT output includes (1) hypothesis tests for trend flow-normalized concentration and flow-normalized load (reject or do not reject the null hypothesis at alpha = 0.1), (2) p-values for those tests, (3) 90-percent confidence intervals for the magnitude of the trend in flow-normalized concentration and flow-normalized load, and (4) likelihood statements (in numerical form and as descriptive statements) about trends in flow-normalized concentration and flow-normalized flux. Likelihood designations are computed from the two sided attained p-value and follow the pattern described in Hirsch and others (2015) where a range of likelihood values from 0.95 to 1.0 is considered “highly likely,” 0.90 to <0.95 is “very likely,” 0.67 to <0.90 is “likely,” and 0.50 to <0.67 is “uncertain.”

Stagecoach Reservoir

Select water-quality data collected by the USGS during WY 1989–93 and 2012–18 at two mainstem sites bracketing Stagecoach Reservoir, Yampa River above Stagecoach Reservoir, Colo. (USGS site number 09237450), herein referred to as “Yampa River above Stagecoach Reservoir,” and Yampa River below Stagecoach Reservoir, Colo. (USGS site number

09237500), herein referred to as “Yampa River below Stagecoach Reservoir,” were compared. Data from 1989–93 were collected during reservoir construction and filling and are described in detail in Tobin (1996). Data were reviewed to ensure comparisons between older and more recent data were valid, in consideration of differences in detection limits and sample size and were found to be comparable. Permutation tests of independence (Helsel and others, 2020) were used to determine if there were differences in concentrations and loads of suspended sediment, Kjeldahl nitrogen, and total phosphorus between the two time periods at each site using an α value of 0.05.

Changes in Land Use

Multiple sources were used to characterize land use in the UYRB and assess recent changes in dominant land-cover classes. Data from the National Land Cover Database (NLCD; MRLC, 2016) were used to (1) characterize land cover in 2016 for each land-cover class and (2) assess changes in land cover from 2001–16 for the forest and development land-cover classes. Zonal statistics in ArcGIS (ESRI, 2018) were used to calculate the proportion of each land-cover class on basin (UYRB) and subbasin scales for each year NLCD data were compiled, including 2001, 2004, 2006, 2008, 2011, 2013, and 2016. Changes in land cover were calculated as the cumulative change in land-cover class from 2001–16.

Classification errors exist with these types of spectrally derived datasets. It is important to understand the accuracy of data in the study area to form reasonable conclusions about land-use change. For example, Danielson and others (2016) found that the error associated with cultivated cropland classification is greatest in areas where cultivated cropland is not the most dominant land-cover class, and the majority of misclassification occurred with low intensity developed classes, such as herbaceous and shrub classes.

To address suspected error associated with cultivated cropland classification, data from the U.S. Department of Agriculture (USDA; USDA, 2019) agricultural census were used to assess land area associated with agricultural activities as well as changes in area and specifics of practices over time. The USDA agricultural census collects, reviews, and combines data from farmers and ranchers to provide information on the characteristics of farm operations and farm production at the county level. Census data for Routt and Moffat Counties are presented in this report. Although most of the land area of the UYRB is within Routt County, the subbasin with the most agriculture is within Moffat County.

Assessment of Streamflow and Water Quality

Streamflow and surface-water quality are affected by watershed characteristics, including geology, land cover, and climate. The combined effects of changes in land use, land management, and climate, including but not limited to changes in agricultural management practices, factors related to urbanization, and changes in precipitation and temperature, can complicate tracking and assessing changes in hydrology, including streamflow and water quality. Data gaps and limitations that may inhibit the analysis from conveying specific conclusions are discussed.

Streamflow Trends

Changes in precipitation and temperature, land cover and land use, and water management can influence different aspects of streamflow. Changes may include low, moderate, or high portions of the streamflow-frequency distribution and these trends can be further restricted to certain seasons or months. Examining trends across different streamflow conditions and seasons can provide insight into what natural and anthropogenic related factors may influence trends and help inform water management decisions. Comparing trends among sites with different levels of influence from agricultural, urban, and dam related factors can also improve understanding of what factors may be causing changes in the watershed. Likewise, examining trends across different time periods can help clarify the contribution of shorter term changes from more persistent hydroclimatic changes, including changes in precipitation and temperature. Trends in daily discharge statistics for monthly and annual time frames of 1-day maximum, mean, and 7-day minimum streamflows are presented graphically for eight sites from 1992–2018. Trends in the same statistics as well as a trend in deviation from peak streamflow is assessed across a longer time period from 1910–2018 at one site and displayed graphically.

Since the completion of Stagecoach Reservoir in 1992, through 2018, trends in streamflow at mainstem Yampa River sites indicate some regionally consistent patterns (fig. 4). All mainstem sites had significant decreasing trends in one or more streamflow statistics during winter months. Decreasing trends were found across most months at Yampa River above Stagecoach, with significant decreases in January or February in mean and 7-day minimum streamflow statistics. Annual decreases in 7-day minimum streamflows of 14 percent per decade or 39 percent over the 27-year period of analysis were also observed. Changes in reservoir management at one of three reservoirs above this site (fig. 1), changes in water use, or climate-related changes in the basin may be influencing these trends. It is likely that the decreases in streamflow at Yampa River above Stagecoach Reservoir and subsequent changes in reservoir management, including dam-related storage of winter and spring runoff and augmentation of summer water supplies contribute to decreases seen at sites below Stagecoach Reservoir. At the site directly below Stagecoach Reservoir, decreases in all three streamflow statistics were found from September through February, ranging from 13 to 20 percent per decade or 35 to 54 percent overall. Decreases in streamflow at Yampa River at Steamboat Springs, Yampa River above Elkhead Creek, and Yampa River below Craig had similar magnitudes over the same time period. Though not significant based on 90-percent confidence intervals, all mainstem sites had decreasing trends in July and at some sites, extending through August, suggesting that if current conditions continue, decreasing trends during these months may become more likely in the future.

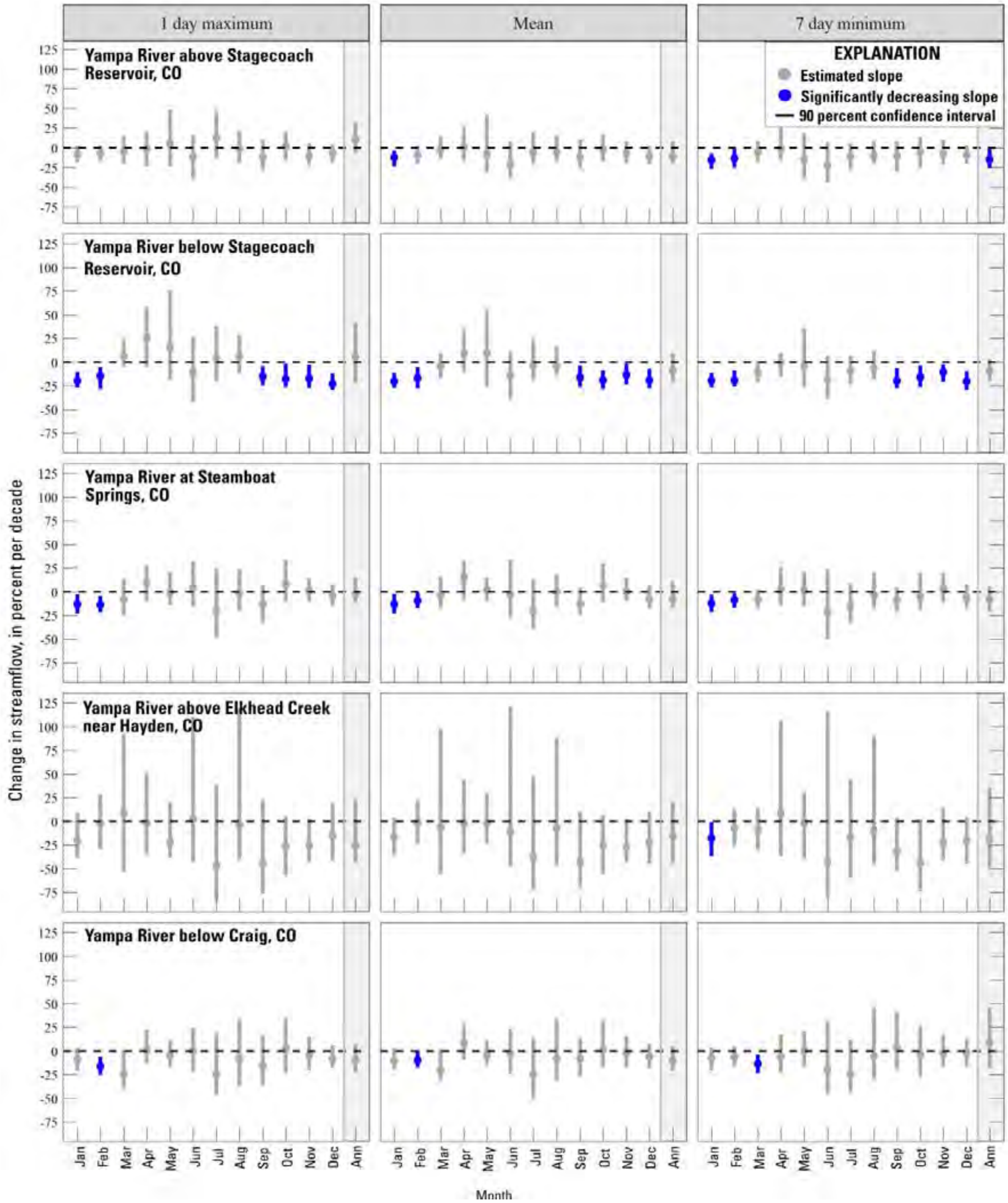


Figure 4. Changes in 1-day maximum, mean, and 7-day minimum streamflow statistics at five mainstem Yampa River sites in the Upper Yampa River Basin from 1992–2018. [CO, Colorado]

Trends in streamflow at tributary sites likely correspond to changes in reservoir management and at sites with no upstream flow impoundments, changes due to irrigation diversions and climate change related factors. Mean and 7-day minimum streamflows decreased by 35 percent per decade or 95 percent overall during July at Fish Creek near Steamboat Springs. Significant increases in 7-day minimum streamflows occurred in August, September, and October, resulting in an overall annual increase of 43 percent per decade or 116 percent overall. These changes likely correspond to changes in water use at Fish Creek Reservoir, the primary source of municipal water supplies for the city of Steamboat Springs. Releases from Fish Creek Reservoir primarily start in late July (Alfone F., oral communication). Elkhead Creek near Hayden is above Elkhead Reservoir, thus trends at this site may be more indicative of changes in climate factors or changes in water management, including diversion for irrigation. Though not significant based on 90-percent confidence intervals, decreasing trends in streamflow were found in summer months at Elk River near Milner and may become more likely if current conditions continue. Like the mainstem sites, Elkhead Creek near Hayden also had significant decreases in all three streamflow statistics during winter months, November through February, ranging from 18 to 47 percent per decade or 49 to 127 percent overall.

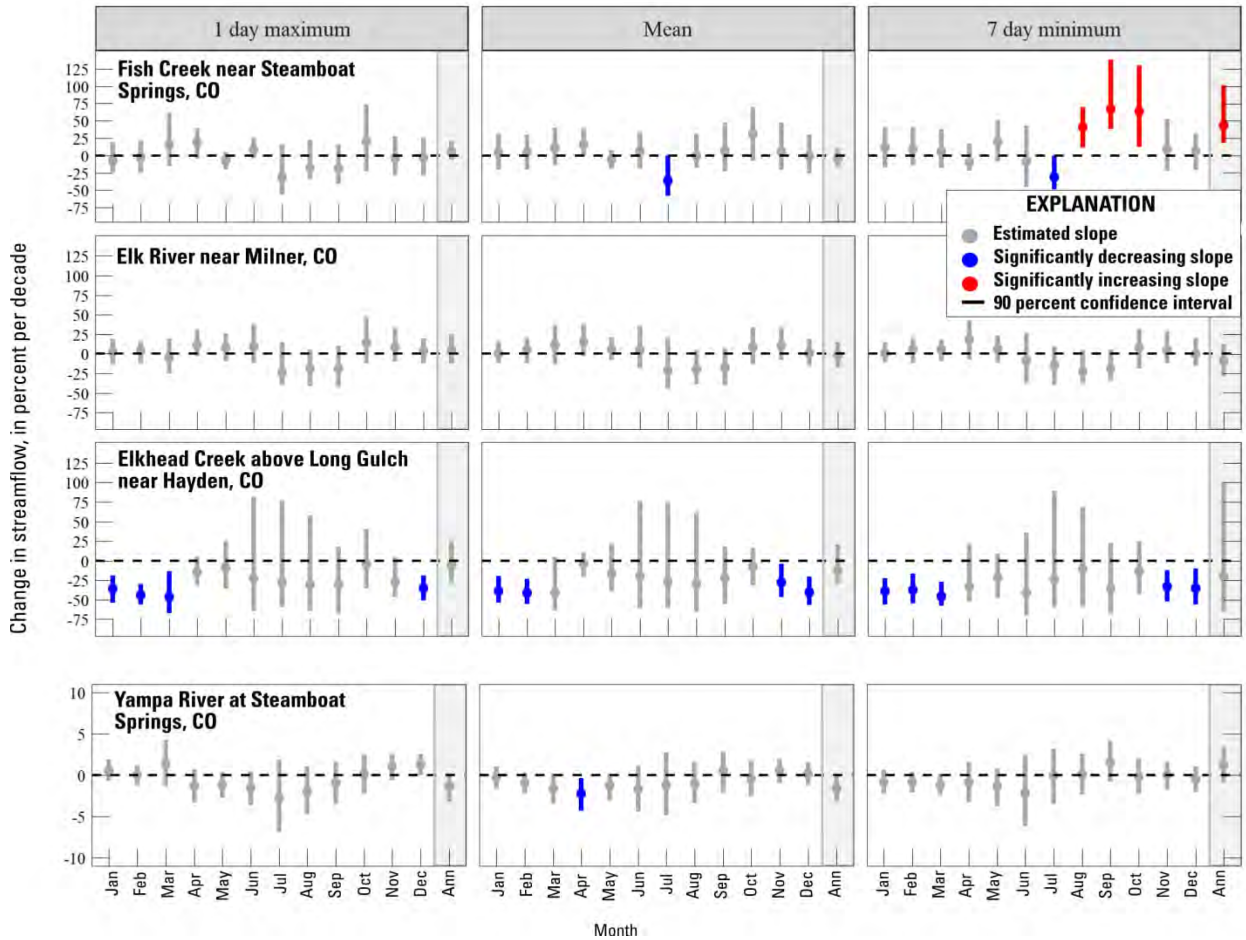


Figure 5. Changes in 1-day maximum, mean, and 7-day minimum streamflow statistics at three tributary sites in the Upper Yampa River Basin from 1992–2018 and 1 mainstem site from 1910–2018. Time period of analysis at Elkhead Creek above Long Gulch, near Hayden, Colo. was 1996–2018. [CO, Colorado]

Streamflow trends examined across a longer time period, from 1910–2018, at Yampa River at Steamboat Springs, correspond to observed changes in streamflow documented across western North America and the Colorado River Basin. Decreasing trends were found during spring and summer months and annually for maximum and mean streamflows. Significant decreases in mean daily streamflows of 2 percent per decade or 25 percent across the 109-year period of analysis were found in April (fig. 5). A fairly significant (p-value = 0.06) decreasing trend in the deviation from mean peak streamflow date was found, indicating that date of peak streamflow is occurring earlier at Yampa River at Steamboat Springs (fig. 6). The significant decreases in winter streamflows found since the completion of Stagecoach Reservoir were not present across a longer time period of analysis, supporting the idea that reservoir management and shorter term climate-related factors likely play a role in decreasing winter trends. Decreases in annual streamflows and a shift toward earlier season snowmelt runoff have been found across western North America and the Colorado River Basin and are predominately attributed to strong changes in snowmelt that accounts for a large proportion of the annual water budget (Miller and Piechota, 2008; Clow, 2010; Bennett and others, 2015).

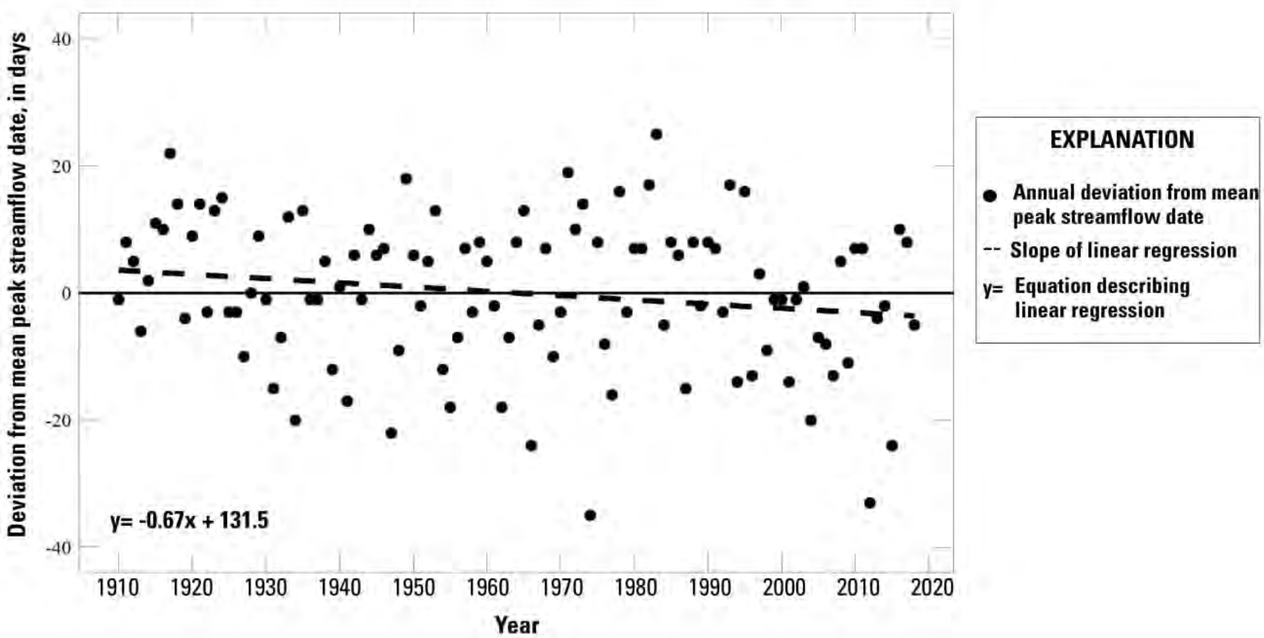


Figure 6. Temporal deviation from the mean peak streamflow date at Yampa River at Steamboat Springs, CO, water years 1910–2018.

Concentration Estimation and Comparison to Interim Water-Quality Standards

Suspended sediments are particles suspended in water ranging in size from sand to clay and are derived from instream sources such as the breakdown of terrestrial and aquatic biota and from external sources such as storm and urban runoff and wastes from industry and water treatment plants. Higher velocities, channel incision, and loss of vegetation along streambanks can be a large source of suspended sediments in watersheds. One of the major anthropogenic sources of suspended sediment is irrigation of agricultural land, particularly those derived from sedimentary rocks (Kenney and others, 2009).The amount of sediment generated and transported to streams and rivers is affected by the intensity and duration of precipitation and runoff, and by the erodibility of material over which runoff flows. High suspended sediment concentrations interfere with water-treatment processes and recreational uses of streams (Lorenz and others, 2009).

Nutrients in surface water provide essential food for plants and animals. However, high concentrations of nutrients in surface water can cause excessive growth of algae and other nuisance aquatic plants, which can cause a wide range of problems including a reduction in levels of dissolved oxygen, decrease in habitat quality, decrease in water clarity, and enhancement of the growth of toxic algae (Lopez and others, 2008). Nutrients occur naturally from the weathering and erosion of rocks and soils, breakdown of organic material, and atmospheric deposition but can also result from human activities, including application of fertilizers, runoff from agricultural and urban areas, soil erosion, wastewater treatment and septic tank effluent, detergents, animal waste, and combustion of fuels.

Nutrients occur in several chemical species or forms, including total nitrogen, nitrate, ammonia, total phosphorus, and orthophosphate. Total nitrogen includes nitrogen in its inorganic and organic forms. Organic forms of nitrogen are derived from plant material or organic contaminants and are generally unavailable to living organisms until they are converted to an inorganic form, including nitrite, nitrate, and ammonia. Nitrite typically is present in low concentrations in streams because it is unstable in oxygenated water, and high levels of nitrite generally indicate contamination though disposal of sewage or organic waste (Hem, 1992). Nitrate is a more stable than nitrite in the presence of oxygen and is generally present in low concentrations in streams and lakes because it is readily consumed by aquatic plants. Ammonia occurs in water as ammonium (NH_4^+), the form used by living organisms, or as un-ionized ammonia (NH_3), the form that can be toxic to fish in excessive concentrations. Kjeldahl nitrogen is a direct measure of ammonia plus organic nitrogen and is used in this report to discuss nitrogen concentration and loads in the UYRB. Total phosphorus is typically bound to sediment and includes dissolved phosphates and particulate organic phosphorus. Orthophosphate constitutes dominant form of dissolved phosphorus in natural water and can be readily assimilated by plants. The presence of phosphorus in surface water can indicate that erosion and sediment transport are occurring (Mueller and others, 1995).

This section is focused on concentrations of suspended sediment, Kjeldahl nitrogen, total nitrogen, total phosphorus, and orthophosphate for eight sites. Regression model coefficients and the overall fit of models for suspended sediment, Kjeldahl nitrogen, and total phosphorus concentrations are discussed. For two sites, constituent concentrations were analyzed for WY 1999–2018 and for five sites, constituent concentrations were analyzed for WY 2010–18 (table 1). Estimated annual median concentrations of these constituents were summarized for WY

2010–18 and are discussed and shown in tabular form. Time series and monthly boxplots of discrete and estimated daily concentrations of suspended sediment, Kjeldahl nitrogen, and total phosphorus are discussed and shown graphically. Discrete concentrations are also shown for Little Morrison Creek, near Stagecoach, Colo. (USGS streamgage number 401634106502200), herein referred to as "Little Morrison Creek," a minor inflow on the southern edge of Stagecoach Reservoir for water-quality data collected in 2012–14 and 2017–18. Discrete and estimated concentrations of Kjeldahl nitrogen, total nitrogen, total phosphorus, and orthophosphate are compared to CDPHE interim water-quality standards for total nitrogen and total phosphorus.

Suspended Sediment

Regression models for suspended sediment concentrations were created at five of seven sites (appendix 1). All adjusted R^2 values for suspended sediment were greater than 0.7 except at Yampa River above Stagecoach Reservoir which had an adjusted R^2 value of 0.17. Suspended sediment data at Yampa River below Craig and Yampa River at Steamboat Springs were only available prior to 1992.

Estimated annual median concentrations of suspended sediment for 2010–18 were highest at Yampa River above Stagecoach (14 milligrams per liter [mg/L]) and were almost double the next highest concentration at Yampa River above Elkhead Creek (7.4 mg/L, table 3). Given the relatively poor model fit at Yampa River above Stagecoach, annual median concentrations of discrete values were also calculated and verify regression model results. Concentrations at Yampa River above Stagecoach Reservoir were nearly double that of any other site. Generally, the estimated concentrations were highest during spring runoff events (figs. 7, 8).

Table 3. Estimated annual median concentrations of suspended sediment, Kjeldahl nitrogen, and total phosphorus at eight stream sites in the Upper Yampa River Basin, Colorado, water years 2010–18.

[USGS, U.S. Geological Survey; CO, Colorado; WY, water year, defined as the 12-month period from October 1 through September 30 and designated by the year in which it ends. Estimated annual median concentrations were calculated using linear regression techniques]

USGS site name	WY 2010	WY 2011	WY 2012	WY 2013	WY 2014	WY 2015	WY 2016	WY 2017	WY 2018	WY 2010–18
Estimated annual median suspended sediment concentration, in milligrams per liter										
Yampa River above Stagecoach Reservoir, CO	19	19	14	12	16	18	15	12	11	14
Yampa River below Oak Creek, CO[a]	5.5	4	4	4.1	4.1	4	4	4.1	4.1	4.1
Elk River near Milner, CO[a]	8	6	4.9	3.5	5.6	5	4.2	5.1	4.2	4.9
Yampa River at Milner, CO[a]	6.2	4.4	3.6	3.3	4.2	4.1	3.5	3.4	3.4	3.8
Yampa River above Elkhead Creek, CO	24	9.7	6.4	4.1	10	9.9	5.4	6.5	5.9	7.4
Estimated annual median Kjeldahl nitrogen concentration, in milligrams per liter										
Yampa River above Stagecoach Reservoir, CO	0.55	0.32	0.3	0.31	0.31	0.31	0.3	0.31	0.29	0.32
Yampa River below Oak Creek, CO[a]	0.42	0.41	0.48	0.46	0.42	0.42	0.44	0.45	0.47	0.45
Yampa River at Steamboat Springs, CO	0.37	0.35	0.38	0.37	0.35	0.35	0.36	0.38	0.38	0.36
Elk River near Milner, CO[a]	0.21	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
Yampa River at Milner, CO[a]	0.32	0.32	0.36	0.35	0.31	0.33	0.33	0.34	0.35	0.34
Yampa River above Elkhead Creek, CO	0.44	0.39	0.37	0.35	0.39	0.39	0.36	0.37	0.37	0.38
Yampa River below Craig, CO	0.38	0.37	0.39	0.39	0.38	0.38	0.38	0.38	0.39	0.38
Estimated annual median total phosphorus concentration, in milligrams per liter										
Yampa River above Stagecoach Reservoir, CO	0.088	0.059	0.05	0.05	0.056	0.054	0.049	0.051	0.043	0.054
Yampa River below Oak Creek, CO[a]	0.055	0.049	0.061	0.058	0.05	0.056	0.058	0.058	0.063	0.057
Yampa River at Steamboat Springs, CO	0.046	0.043	0.048	0.047	0.044	0.044	0.045	0.046	0.047	0.046
Elk River near Milner, CO[a]	0.022	0.016	0.016	0.015	0.016	0.016	0.015	0.016	0.016	0.016
Yampa River at Milner, CO[a]	0.048	0.046	0.063	0.061	0.05	0.054	0.057	0.056	0.064	0.056
Yampa River above Elkhead Creek, CO	0.059	0.056	0.046	0.044	0.053	0.054	0.049	0.052	0.045	0.05
Yampa River below Craig, CO	0.042	0.047	0.039	0.04	0.044	0.042	0.04	0.042	0.039	0.042

[a]Estimated hydrograph used in linear regression model, limitations are discussed in "Extension of Streamflow Record" section.

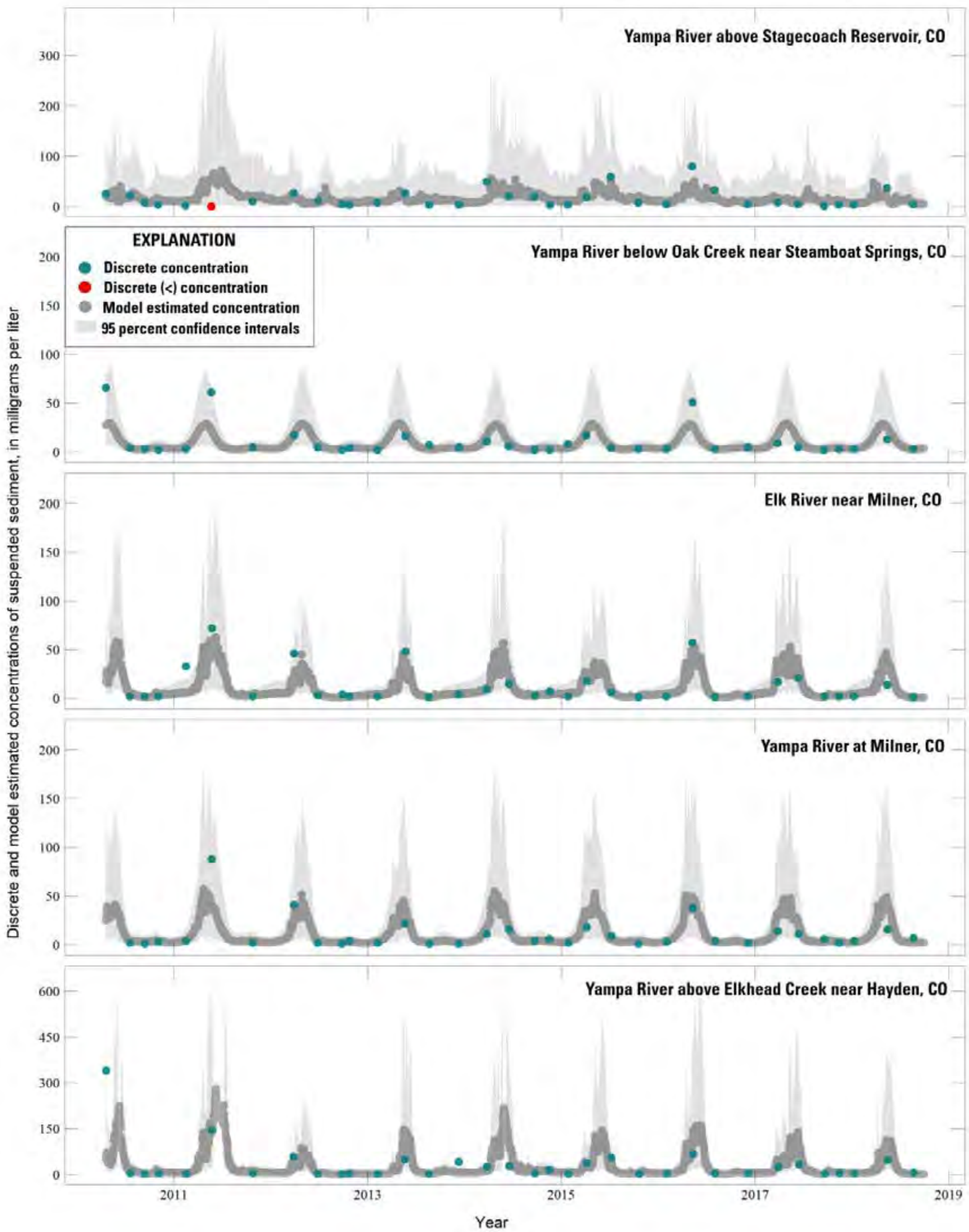
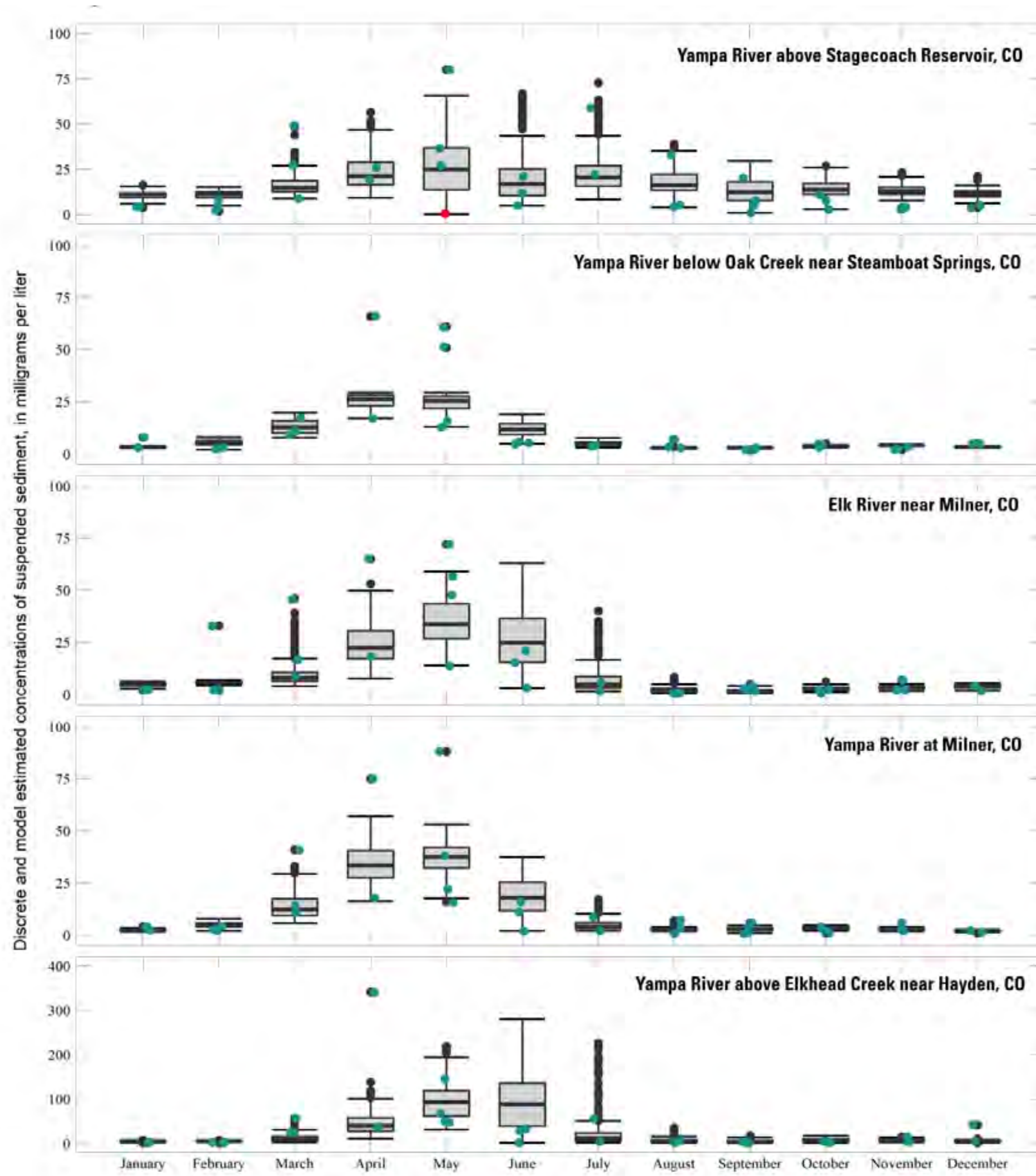


Figure 7. Time series of discrete and model estimated daily concentrations of suspended sediment at five sites in the Upper Yampa River Basin, Colorado, various water years–2018. Discrete (<) concentration refers to concentration less than (<) the method detection limit. [CO, Colorado]



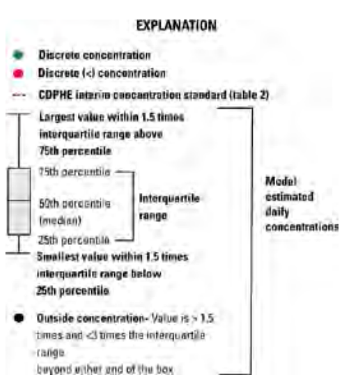


Figure 8. Boxplots of discrete and model estimated concentrations concentrations of suspended sediment at five sites in the Upper Yampa River Basin, Colorado. Discrete (<) concentration refers to concentration less than (<) the method detection limit. [CO, Colorado]

Nitrogen

In regression models for concentrations, Kjeldahl nitrogen was used as a surrogate for total nitrogen. Regression model coefficients and statistical diagnostics for Kjeldahl nitrogen concentrations, are presented in appendix 1. Values of adjusted R^2 for three of seven stream sites were less than 0.5, including Yampa River below Oak Creek, Yampa River at Steamboat Springs, and Yampa River above Elkhead Creek. This indicates that additional variables are needed to improve predictions of variation in Kjeldahl nitrogen concentrations. Kjeldahl nitrogen is unfiltered but does not capture the particulate forms of nitrogen present in the water column, which are likely influenced by high-flow periods when suspended sediment load is the greatest. The lack of particulate nitrogen, either in the form of particulate nitrogen suspended in the water or the unfiltered form of nitrate, could contribute to the lack of model fit at these sites. It is also possible that changes in stream nutrient concentrations caused by rain or snowmelt events are not characterized by quarterly sampling. Also, point-source inputs of nitrogen that are not necessarily related to streamflow, can affect the accuracy of the regression models.

The estimated annual median concentration of Kjeldahl nitrogen for 2010–18 was highest at Yampa River below Oak Creek (0.45 mg/L) and lowest at Elk River near Milner (0.19 mg/L) (table 3). Estimated daily concentrations at Yampa River above Stagecoach were highest during early summer (figs. 9, 10). At most sites downstream from Stagecoach Reservoir, estimated daily concentrations tended to be highest during early spring and lowest during summer and winter months (figs. 9, 10).

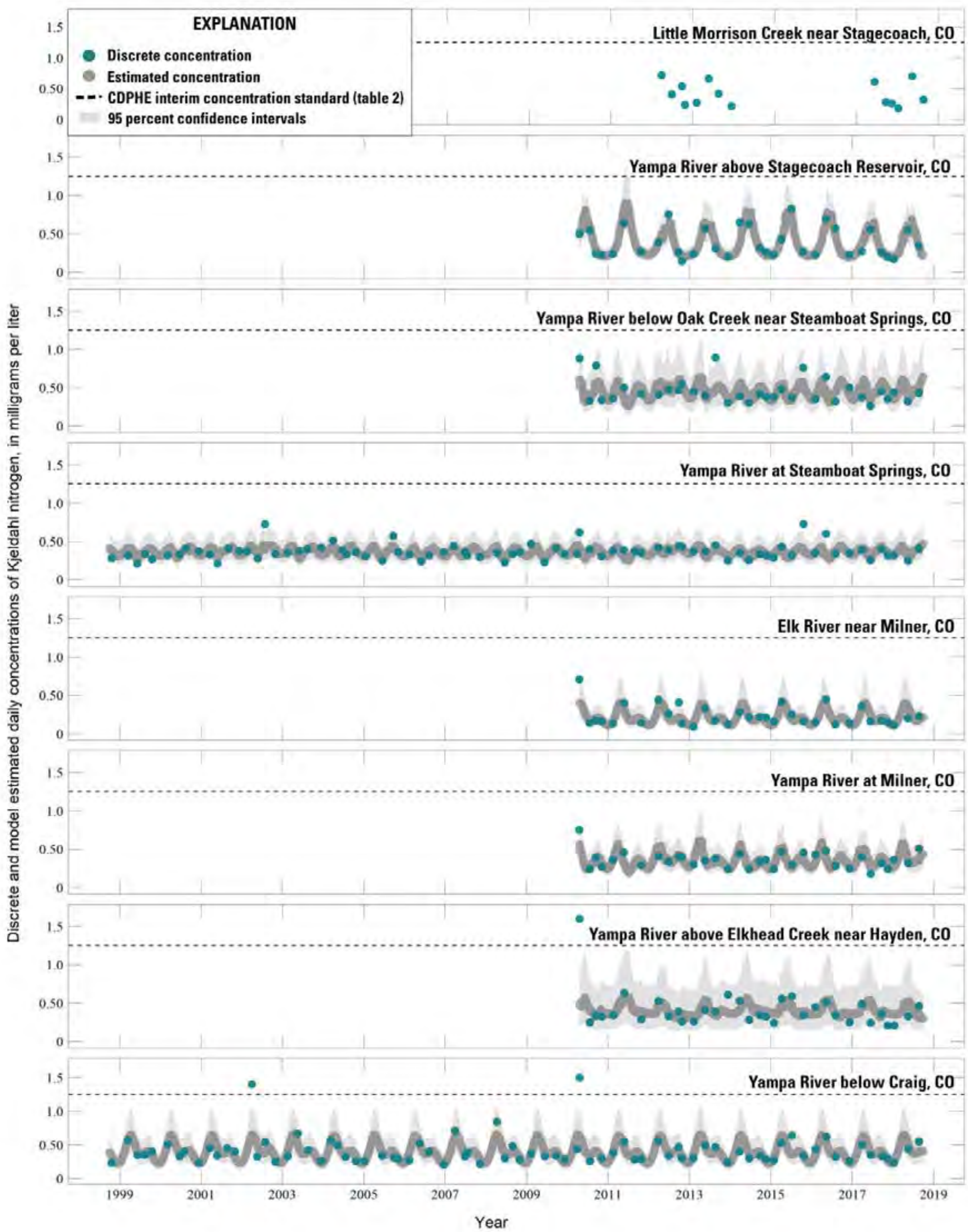
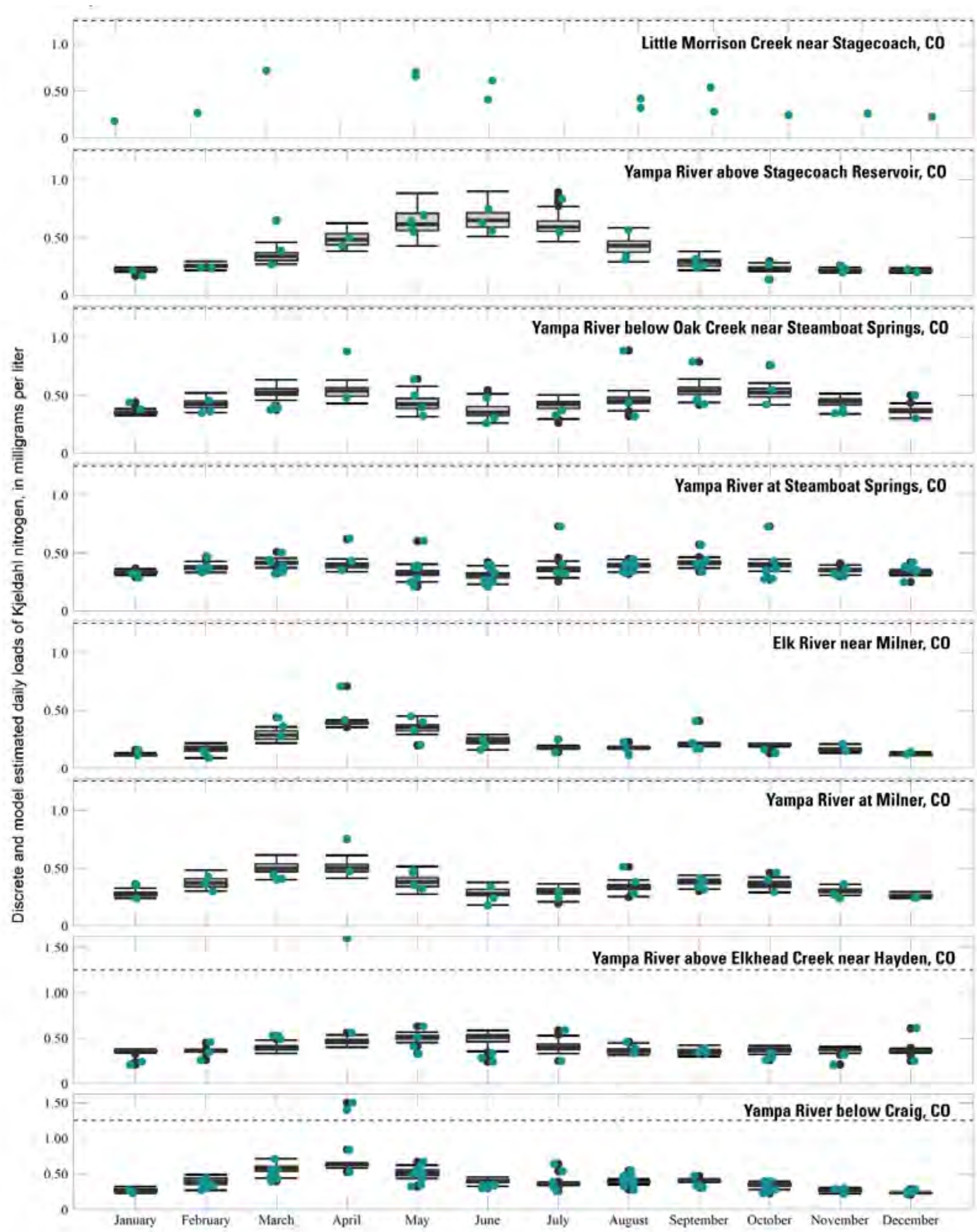


Figure 9. Time series of discrete and model estimated daily concentrations of Kjeldahl nitrogen at eight sites in the Upper Yampa River Basin, Colorado, various water years–2018. [CDPHE, Colorado Department of Public Health and Environment; CO, Colorado]



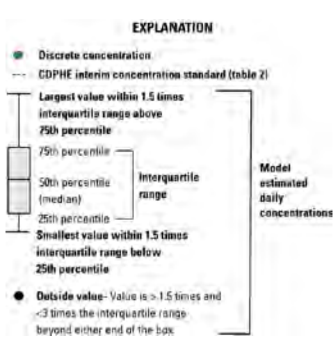


Figure 10. Boxplots of discrete and model estimated concentrations concentrations of Kjeldahl nitrogen at eight sites in the Upper Yampa River Basin, Colorado. [CDPHE, Colorado Department of Public Health and Environment; CO, Colorado]

Kjeldahl nitrogen was also used as a surrogate for total nitrogen in comparisons to the CDPHE interim water-quality standard. Estimated annual median concentrations of Kjeldahl nitrogen at the seven sites for 2010–18 were less than the interim standard of 1.25 mg/L (table 3). Discrete Kjeldahl nitrogen concentrations exceeded the interim nitrogen standard (1.25 mg/L) only three times, once at Yampa River above Elkhead Creek and twice at Yampa River below Craig (figs. 9, 10). Each exceedance occurred in April, the onset of early spring runoff events, during WY 2002 or 2011. Discrete concentrations of total nitrogen were also compared to the interim standard (fig. 11). Concentrations exceeded the interim standard on five sample days at Yampa River below Craig, and on one sample day at Yampa River above Elkhead Creek. Each exceedance occurred during spring runoff or first flush events in March and April.

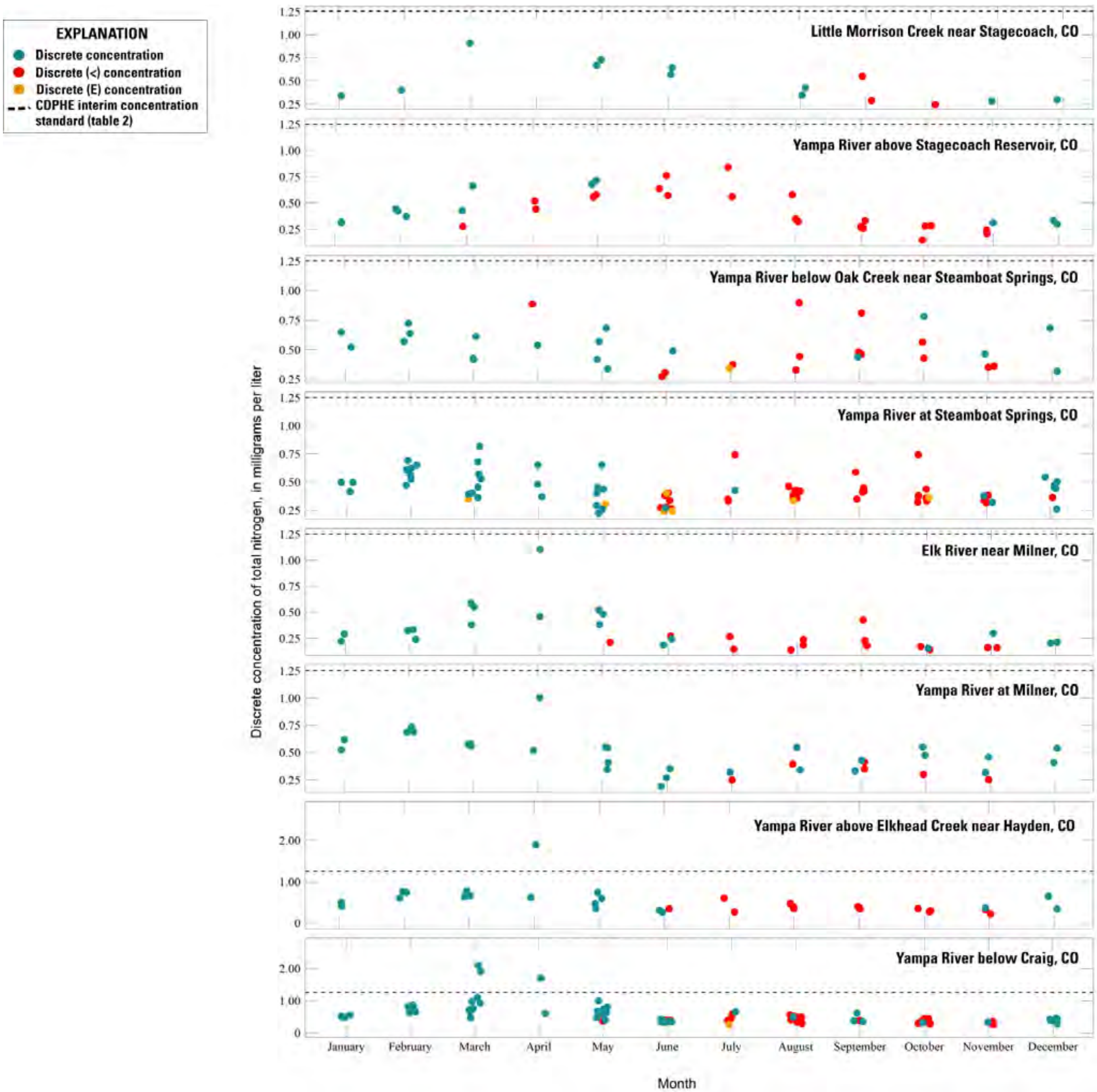


Figure 11. Discrete concentrations of total nitrogen at eight sites in the Upper Yampa River Basin, Colorado. Discrete (<) value refers to values less than (<) the method detection limit. Discrete (E) values refers to values between the laboratory reporting limit and the method detection limit. [CDPHE, Colorado Department of Public Health and Environment; CO, Colorado]

Phosphorus

The concentration of total phosphorus is a direct measurement rather than a calculation, and few censored values were present in the data used for the regression analysis. In general, the adjusted R^2 values of total phosphorus models were higher than the R^2 values of Kjeldahl nitrogen models (appendix 1). However, three of seven sites had adjusted R^2 values for total phosphorus less than 0.5, including Yampa River below Oak Creek, Yampa River at Steamboat Springs, and Yampa River at Milner. Like Kjeldahl nitrogen, additional surrogates could improve the ability to predict variation in concentrations of total phosphorus. Visual inspection of total phosphorus and suspended sediment concentrations indicated fairly strong relationships between the two constituents at five sites (fig. 12), suggesting that including a continuous surrogate for suspended sediment, such as turbidity, might improve future total phosphorus models (Jones and others, 2011; Lessels and Bishop, 2013).

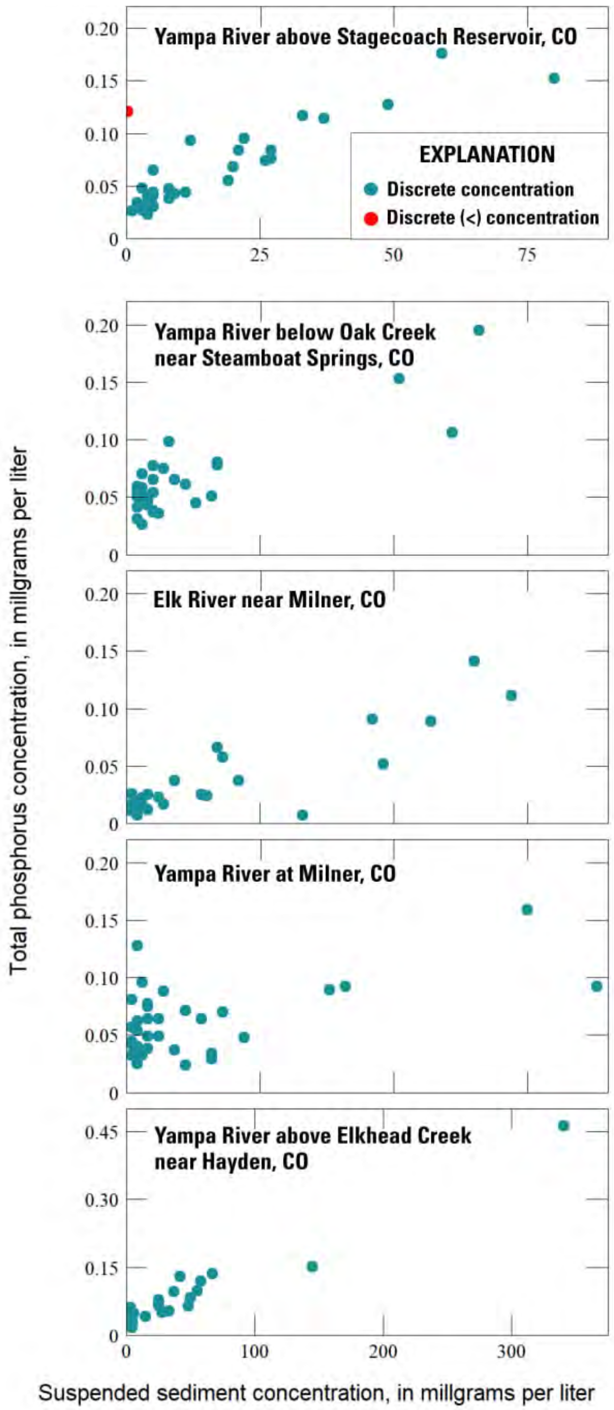


Figure 12. Discrete concentrations of suspended sediment and total phosphorus at five sites in the Upper Yampa River Basin, Colorado. Discrete (<) concentration refers to concentration less than (<) the method detection limit.

The estimated annual median concentration of total phosphorus for 2010–18 was highest at Yampa River below Oak Creek (0.57 mg/L), and lowest at Elk River near Milner (0.016 mg/L) (table 3). The concentrations for Yampa River above Stagecoach Reservoir were highest during late spring and early summer (fig. 13,14). Most sites downstream from Stagecoach Reservoir had the highest estimated daily concentrations during early spring (figs. 13, 14). Little seasonal variation was observed at Yampa River at Steamboat Springs. The regression model at this site explained only 27 percent of the variance in total phosphorus concentrations; thus, the model is limited in its ability to predict variation in concentrations and additional surrogates could strengthen the relationship. The concentrations for Yampa River at Milner were highest during late winter and early spring.

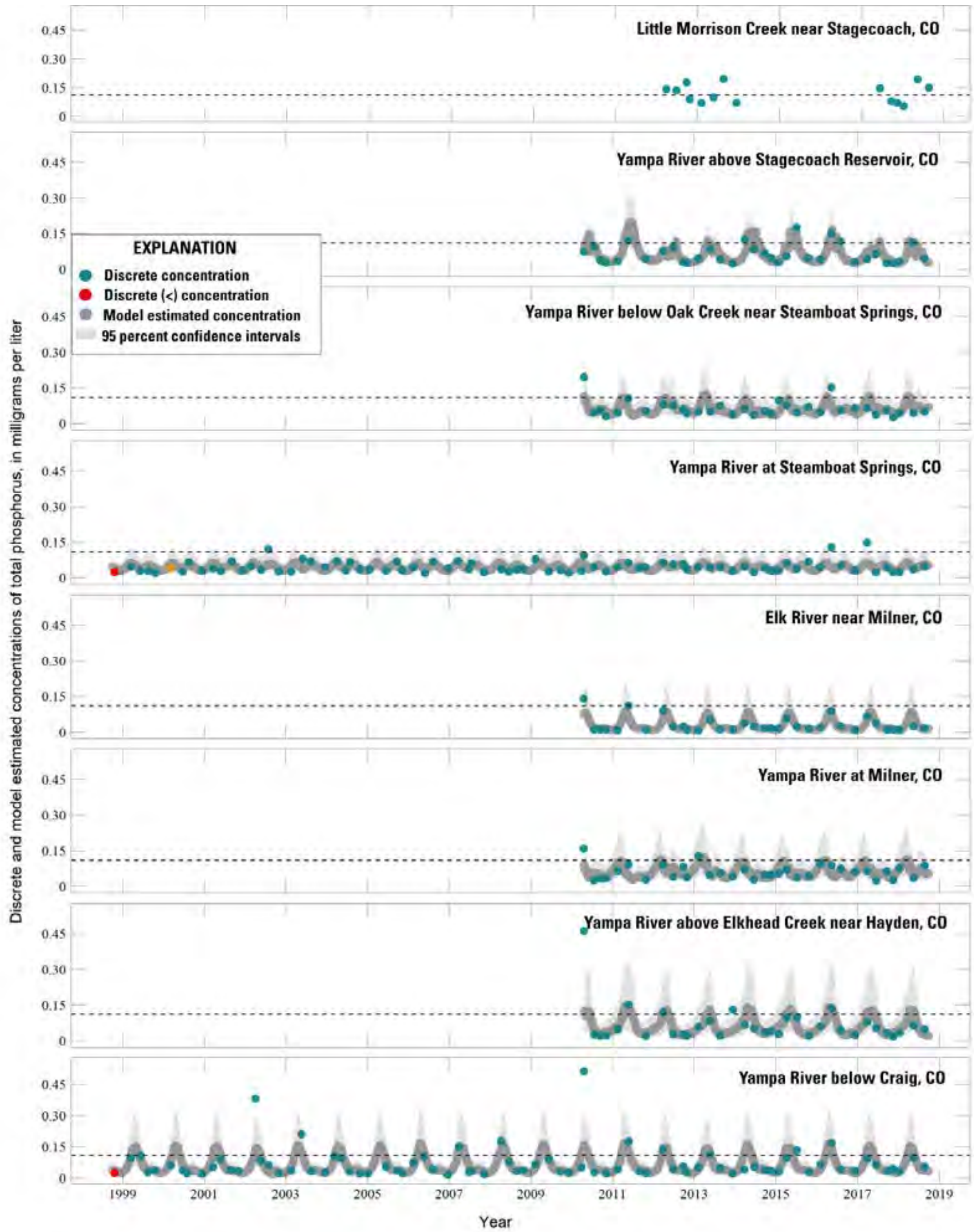
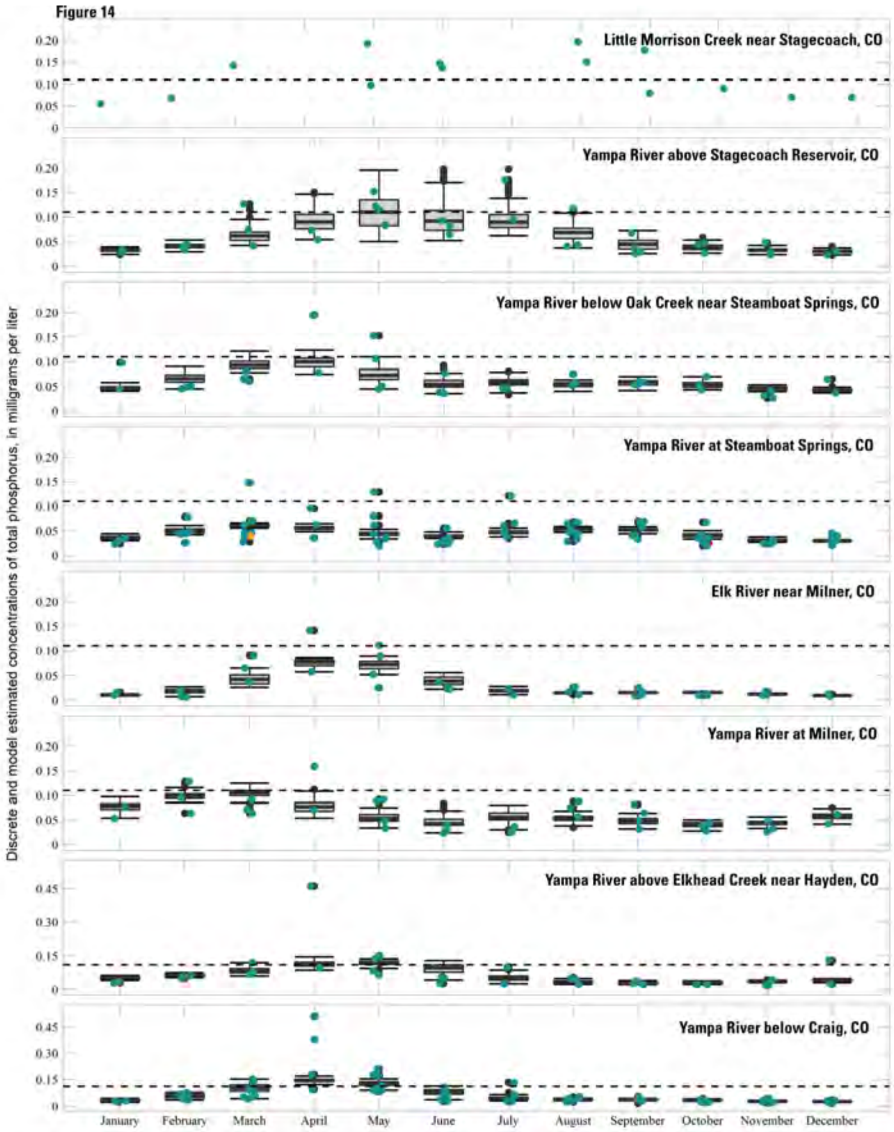


Figure 13. Time series of discrete and model estimated daily concentrations of total phosphorus at eight sites in the Upper Yampa River Basin, Colorado, various water years–2018. Discrete (<) concentration refers to concentration less than (<) the method detection limit. Discrete (E) concentration refers to concentrations between the laboratory reporting limit and the method detection. [CDPHE, Colorado Department of Public Health and Environment; CO, Colorado]



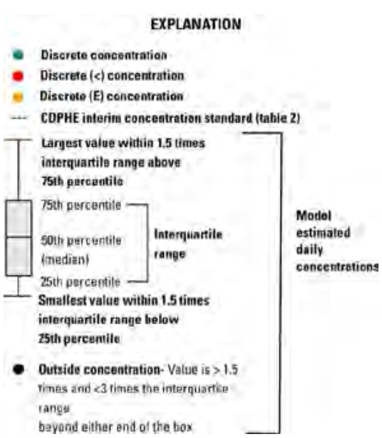


Figure 14. Boxplots of discrete and model estimated concentrations of total phosphorus at eight sites in the Upper Yampa River Basin, Colorado (CDPHE, Colorado Department of Public Health and Environment). Discrete (<) concentration refers to concentration less than (<) the method detection limit. Discrete (E) concentration refers to concentrations between the laboratory reporting limit and the method detection. [CDPHE, Colorado

Department of Public Health and Environment; CO, Colorado]

Estimated annual median concentrations of total phosphorus at the seven sites for 2010–18 were less than the CDPHE interim standard of 0.11 mg/L (table 3). Discrete concentrations of total phosphorus exceeded the CDPHE interim standard at least twice at each site (figs. 13, 14). Estimated daily concentrations exceeded the interim standard at each site during select spring and summer months (fig. 14). A limited amount of water-quality data and lack of a streamflow record prevented regression modeling of total phosphorus concentrations at Little Morrison Creek near Stagecoach. However, concentrations in one-half of discrete samples collected at the site exceed the interim standard (figs. 13, 14).

Seasonal variation in phosphorus concentrations differed among sites. Sites less affected by reservoir processes, including Yampa River above Stagecoach Reservoir and Little Morrison Creek, had longer peak durations of total phosphorus, with highest concentrations occurring later in the summer than sites downstream of the reservoir (fig. 14). Orthophosphate concentrations were also highest during summer months at these two sites. Concentrations at Elk River near Milner were highest in March, April and May, during spring runoff, while concentrations at Yampa River at Milner and Yampa River above Elkhead Creek were highest in February and lowest during summer months (fig. 15).

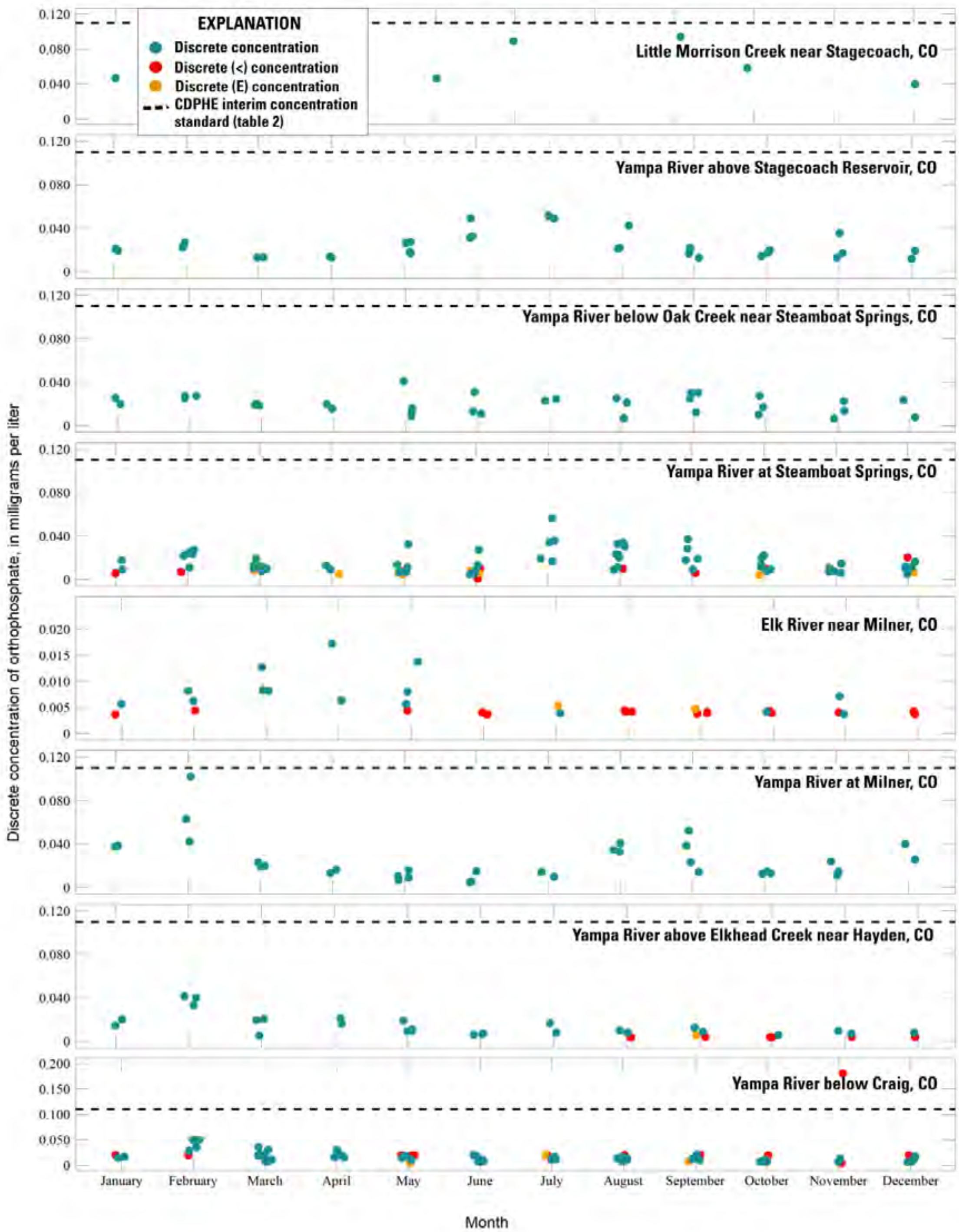


Figure 15. Discrete concentrations of orthophosphate at eight sites in the Upper Yampa River Basin, Colorado. Discrete (<) concentration refers to concentration less than (<) the method detection limit.

[CDPHE, Colorado Department of Public Health and Environment; CO, Colorado]

Load Estimation and Streamflow-Normalized Load and Yield Analysis

Management of water quality in receiving waters is complicated because sources of nutrients vary by type, magnitude, and location and are distributed over large areas. Load calculations are useful for estimating source areas for a given water-quality constituent. Comparisons of loads among sites allows the user to determine what reaches of a river are the largest contributors of a given constituents. Recognizing increases or decreases in load along a stream reach can assist land managers in identifying point or non-point sources. Identifying areas with higher yields of a given constituent can help land managers to target load-reduction strategies to specific areas.

This section is focused on loads and yields of suspended sediment, Kjeldahl nitrogen, and total phosphorus for seven sites. Regression model coefficients and the overall fit of models for suspended sediment, Kjeldahl nitrogen, and total phosphorus loads are discussed. For two sites, constituent loads were analyzed for WY 1999–2018 and for five sites, constituent loads were analyzed for WY 2010–18 (table 1). Time series of discrete and estimated daily loads of suspended sediment, Kjeldahl nitrogen, and total phosphorus are discussed and shown graphically. Streamflow normalized monthly loads and net annual yields of these constituents were summarized for WY 2010–18 and are discussed and shown in tabular form. Annual loads and net yields based on a normalized hydrograph of suspended sediment, Kjeldahl nitrogen, and total phosphorus, and orthophosphate are discussed and shown graphically. As discussed in the methods section, streamflow normalized loads and yields represent total loads under average streamflow conditions during the time period of analysis.

Suspended Sediment

Each of the five sites analyzed for suspended sediment loads had adjusted R^2 values greater than 0.91, except Yampa River above Stagecoach Reservoir, which had an adjusted R^2 value of 0.51 (appendix 1). Annual suspended sediment loads increased in a downstream direction (table 4, fig. 16). Loads were highest during spring runoff in May and June and lowest during the base flow from September through February (table 4). The largest change in load occurred between Yampa River at Milner and Yampa River above Elkhead Creek (table 4, fig. 16; 61,200-ton increase). The largest yields of suspended sediment occurred at Yampa River at Elkhead Creek (table 4, fig. 16; 130 tons per square mile [t/mi^2]).

Table 4. Estimated loads and yields of suspended sediment, Kjeldahl nitrogen, and total phosphorus based on a normalized hydrograph, for seven stream sites in the Upper Yampa River Basin, Colorado, and changes in monthly and annual loads and yields at Yampa River sites.

[USGS, U.S. Geological Survey; CO, Colorado; Jan, January; Feb, February; Mar, March; Apr, April; Jun, June; Jul, July; Aug, August; Sept, September; Oct, October; Nov, November; Dec, December, -, not applicable. Change is difference in load from the upstream Yampa River site.]

		Load, in tons														Yield, in tons per square mile
USGS site name	**Basin area, in square miles**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Annual**	**Change**	**Annual**
Suspended sediment																
Yampa River above Stagecoach Reservoir, CO	208	34	33	96	230	330	200	252	120	52	71	56	40	1,500	-	7.3
Yampa River below Oak Creek, CO	258	24	36	150	820	1,200	900	86	25	21	34	35	26	4,100	2,600	10
Elk River near Milner, CO	460	32	34	220	1,700	6,500	5,600	490	28	12	32	34	30	15,000	-	32
Yampa River at Milner, CO	85	46	83	600	4,300	12,000	7,400	620	83	59	100	75	44	25,000	6,100	72
Yampa River above Elkhead Creek, CO	456	91	89	740	7,600	36,000	38,000	3,100	180	72	210	180	100	86,000	61,000	130
Kjeldahl nitrogen																

Yampa River above Stagecoach Reservoir, CO	208	0.71	0.76	1.9	4.6	7.6	6.0	6.2	2.8	1.1	1.1	0.89	0.74	35	-	0.17
Yampa River below Oak Creek, CO[a]	258	2.5	2.8	5.9	16	34	24	6.4	4.0	3.9	4.7	3.9	2.8	111	77	0.30
Yampa River at Steamboat Springs, CO	102	2.8	3.0	6.3	18	44	36	8.6	4.3	3.7	4.5	4.0	3.0	138	27	0.26
Elk River near Milner, CO[a]	460	0.77	1.0	5.3	26	62	47	9.2	1.9	1.4	2.3	1.6	0.89	160	-	0.35
Yampa River at Milner, CO[a]	85	5.0	6.2	18	58	113	92	25	9.1	7.5	10	7.6	5.3	357	59	0.69
Yampa River above Elkhead Creek, CO	456	6.5	6.1	19	75	184	186	44	9.0	5.5	10	9.3	6.9	562	205	0.45
Yampa River below Craig, CO	561	5.0	7.1	31	117	209	135	27	7.6	6.4	8.9	6.3	4.3	566	4.2	0.01
Total phosphorus																
Yampa River above Stagecoach Reservoir, CO	208	0.11	0.12	0.37	0.90	1.4	0.94	1.0	0.46	0.19	0.19	0.14	0.11	5.9	-	0.03
Yampa River below Oak Creek, CO[a]	258	0.33	0.44	1.1	3.0	5.8	3.7	0.90	0.48	0.42	0.48	0.41	0.32	17	11	0.04
Yampa River at Steamboat Springs, CO	102	0.31	0.40	0.93	2.6	5.9	4.7	1.1	0.59	0.47	0.48	0.36	0.27	18	0.87	0.01
Elk River near Milner, CO[a]	460	0.067	0.11	0.84	5.2	13	8.0	1.1	0.16	0.10	0.17	0.12	0.07	29	-	0.06
Yampa River at Milner, CO[a]	85	1.4	1.6	3.5	8.7	16	14	4.4	1.5	0.92	1.1	1.1	1.2	56	8.8	0.10
Yampa River above Elkhead Creek, CO	456	0.93	1.1	4.3	18	43	36	6.0	0.85	0.43	0.85	0.86	0.78	113	58	0.13
Yampa River below Craig, CO	561	0.61	1.0	6.0	28	52	29	3.9	0.78	0.61	0.93	0.69	0.48	124	11	0.02

[a]Estimated hydrograph used in linear regression model, limitations are discussed in “Extension of Streamflow Record” section.

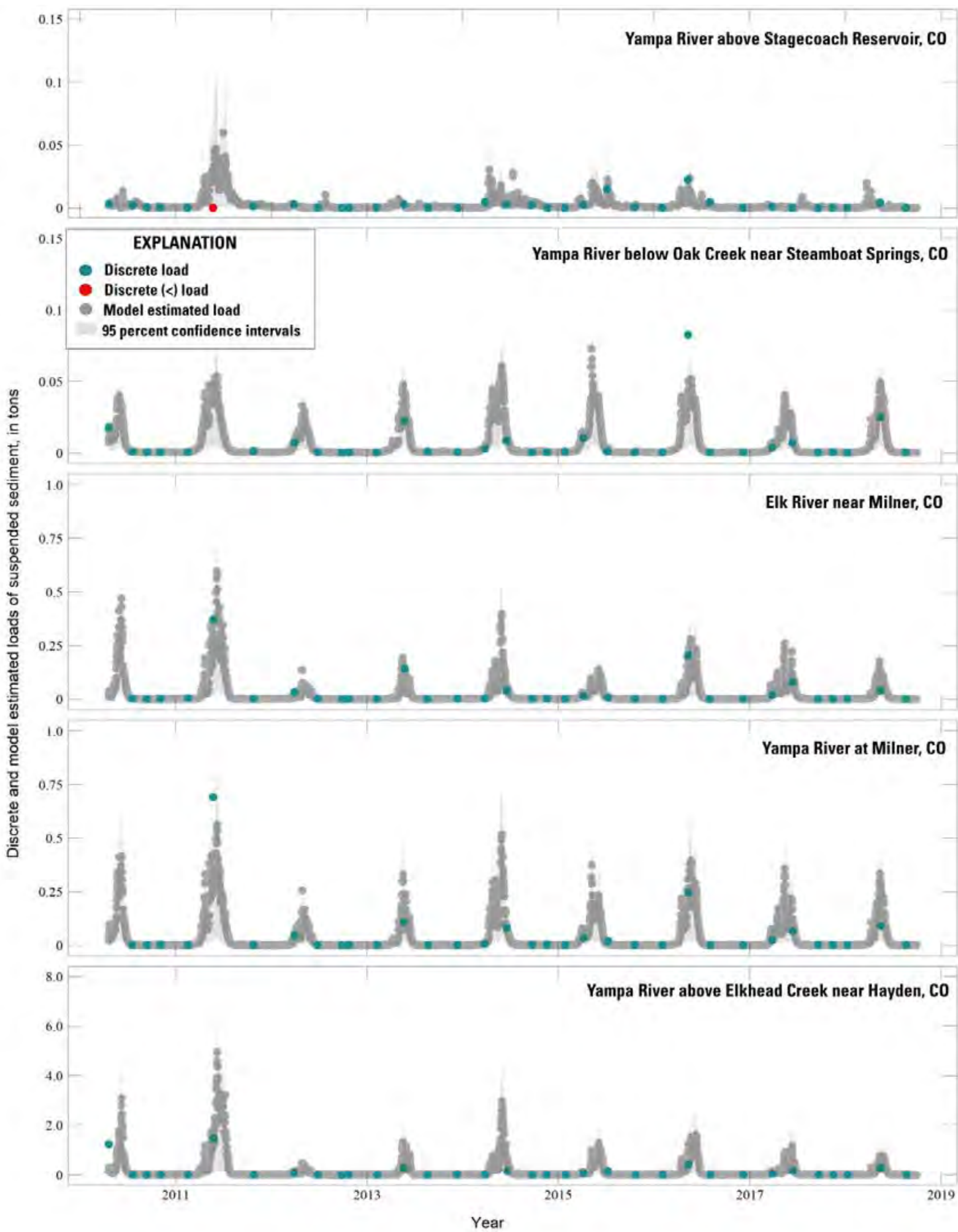


Figure 16. Time series of discrete and model estimated daily loads of suspended sediment at five sites in the Upper Yampa River Basin, Colorado, various water years–2018. Discrete (<) concentration refers to concentration less than (<) the method detection limit. [CO, Colorado]

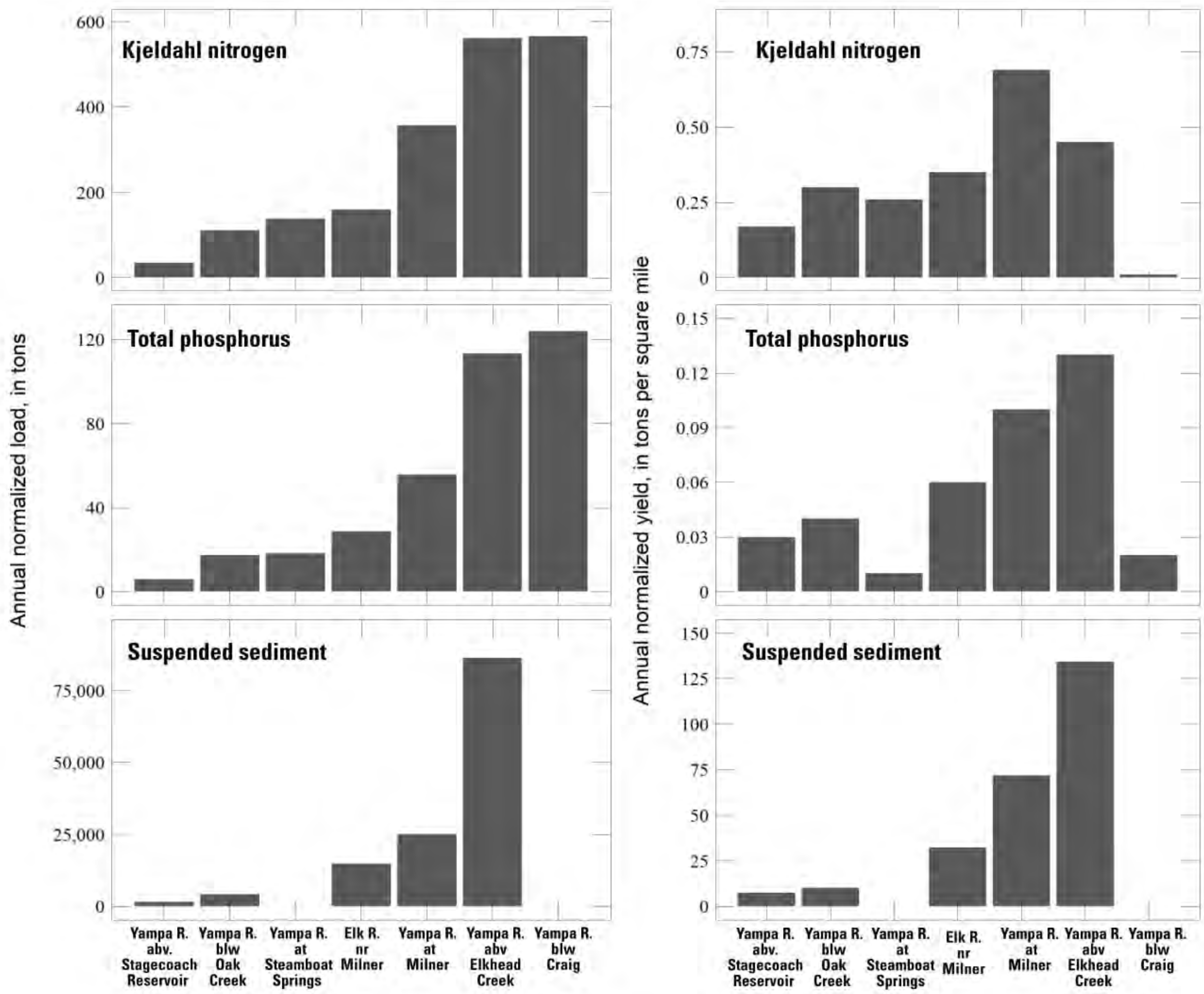


Figure 17. Annual loads and net yields of suspended sediment, Kjeldahl nitrogen, and total phosphorus, based on a normalized hydrograph at select sites in the Upper Yampa River Basin, Colorado. [Yampa R. abv Stagecoach Reservoir, Yampa River above Stagecoach Reservoir, Colo.; Yampa R. blw Oak Creek, Yampa River below Oak Creek near Steamboat Springs, Colo.; Elk R. nr Milner, Elk River near Milner, Colo.; Yampa R. at Milner, Yampa River at Milner, Colo.; Yampa R. abv Elkhead Creek, Yampa River above Elkhead Creek near Hayden, Colo.; Yampa R. blw Craig, Yampa River below Craig, Colo.]

Nitrogen

All seven sites had adjusted R^2 values for loads greater than or equal to 0.93 (appendix 1). Annual Kjeldahl nitrogen loads in the Yampa River generally increased in a downstream direction (table 4, figs. 17, 18). Loads were highest during spring runoff in May and June and lowest during the base flow from September through February (table 4). The largest change in the Kjeldahl nitrogen annual load occurred between Yampa River at Milner and Yampa River above Elkhead Creek (table 4; 205-ton increase). The largest yield of Kjeldahl nitrogen occurred at Yampa River at Milner (table 4, fig. 16; 0.69 t/mi^2).

Phosphorus

All seven sites had adjusted R^2 values greater than or equal to 0.90 (appendix 1). Annual total phosphorus loads increased in a downstream order (fig. 17, 19). Loads at Yampa River sites were highest during high streamflow during May and June (table 4). Like Kjeldahl nitrogen, the largest change in annual load occurred between Yampa River at Milner and Yampa River above Elkhead Creek (table 4; fig. 17; 58-ton increase). The largest yields of total phosphorus occurred at Yampa River at Milner and Yampa River at Elkhead Creek (table 4, fig. 17; 0.1 and 0.13 t/mi^2, respectively).

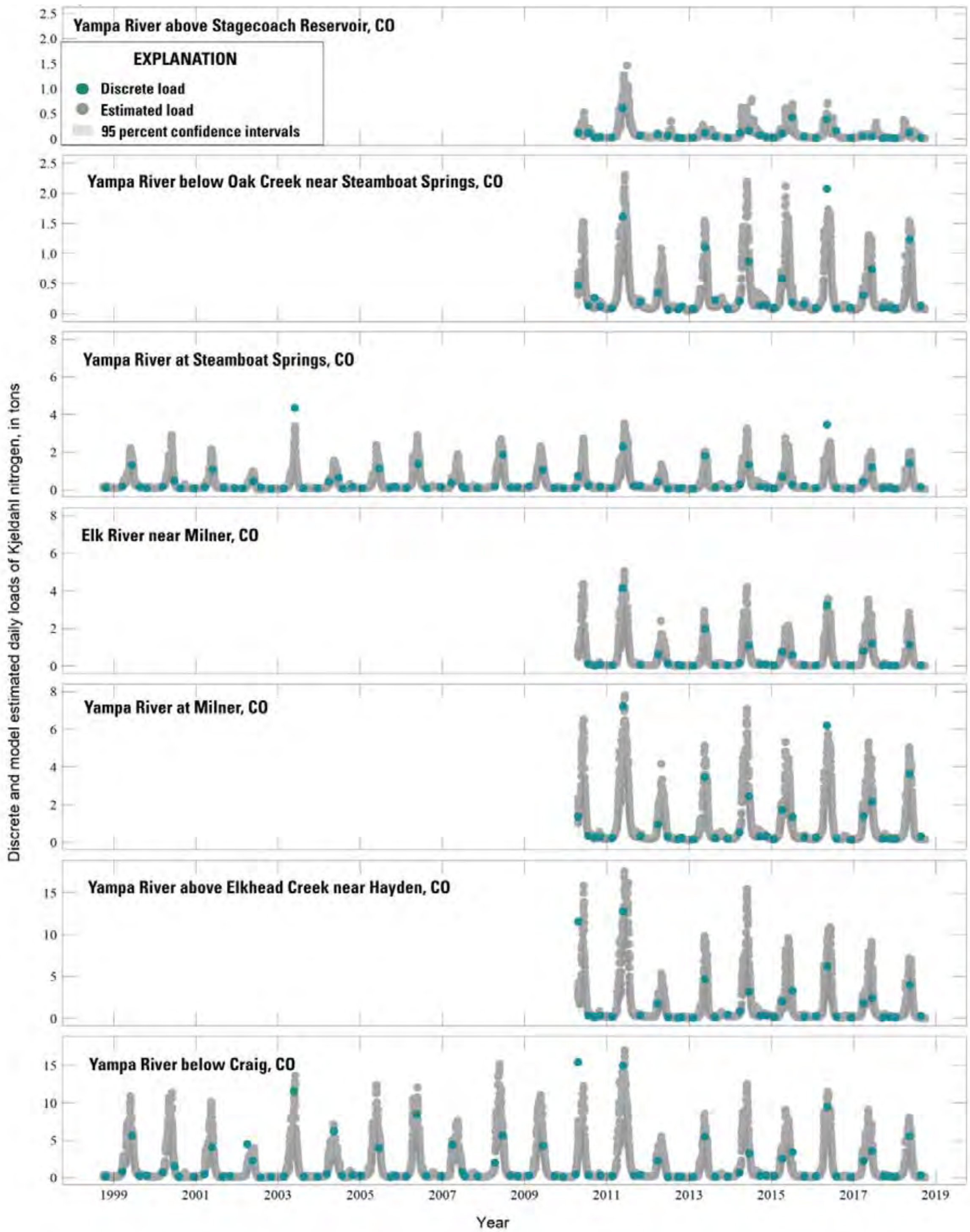


Figure 18. Time series of discrete and model estimated daily loads of Kjeldahl nitrogen at seven sites in the Upper Yampa River Basin, Colorado, various water years–2018. [CO, Colorado]

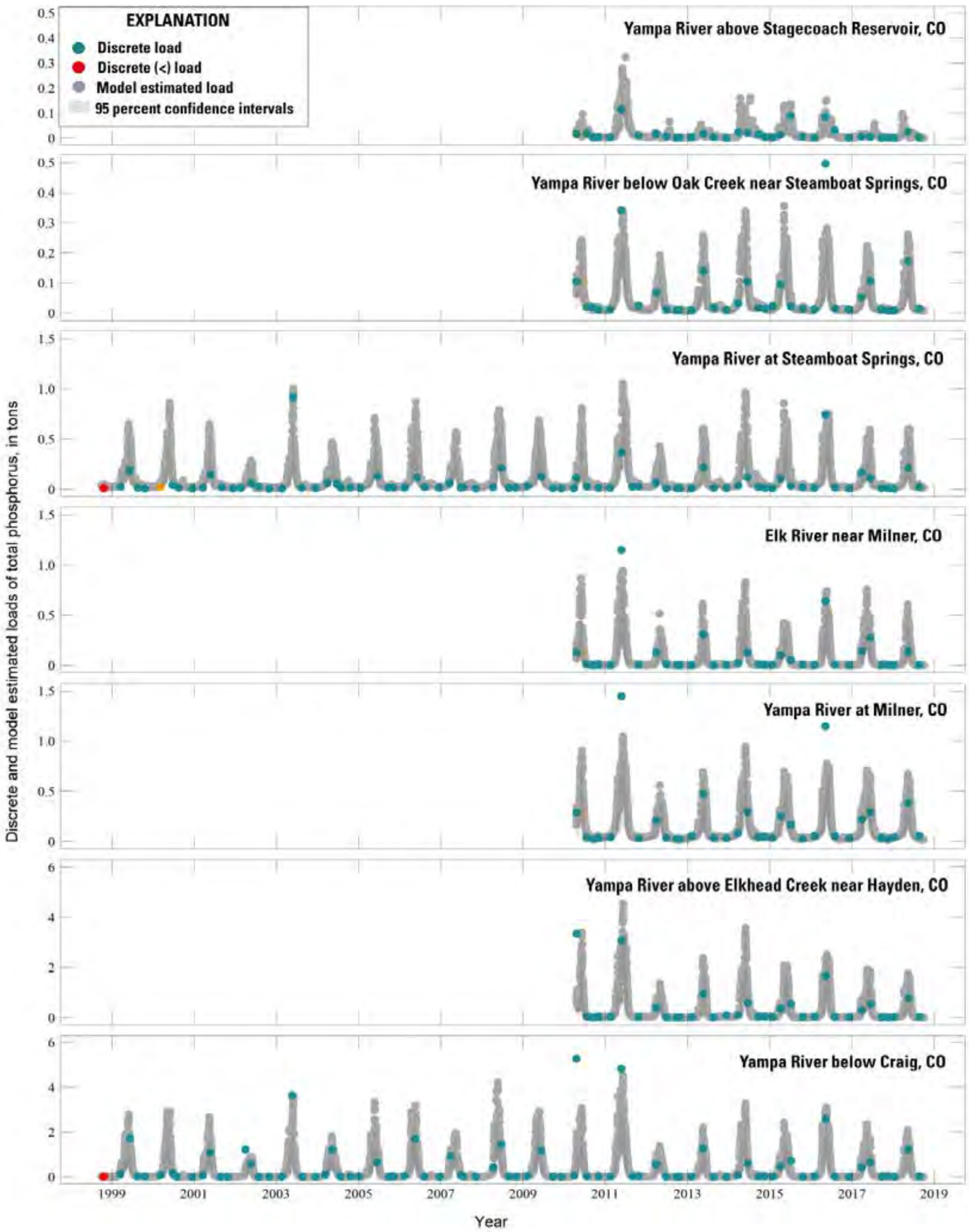


Figure 19. Time series of discrete and model estimated daily loads of total phosphorus at seven sites in the Upper Yampa River Basin, Colorado, various water years–2018. Discrete (<) value refers to values less than (<) the method detection limit. Discrete (E) values refers to values between the laboratory reporting limit and the method detection limit. [CO, Colorado]

Concentration and Load Trend Analysis

Tracking the trends of nutrient concentrations and loads across a watershed is necessary to address knowledge gaps related to nutrient source area identification and patterns of change across the region in nutrient transport and delivery. Trends in concentrations and loads can be caused by changes in land management, land use, and climate or a combination of these factors. Two methods were used to assess trends in water-quality as a function of data availability. Trends in concentrations and loads of suspended sediment, nitrogen, and phosphorus were assessed using multiple linear regression models at seven sites and model coefficients for time are discussed. An additional method for assessing trends, using a weighted regression technique, was applied at two sites, Yampa River at Steamboat Springs and Yampa River below Craig, that met the recommended criteria for using WRTDS of a minimum of 60 observations with sampling sufficiently representing seasonal variation in concentration and streamflow. The strengths of this method compared to the multiple linear regression method include the ability to identify non-monotonic trend patterns and the ability to differentiate between trends in concentration versus trends in load. The likelihood designations used to describe trends follow the pattern used by Hirsch and others (2015) and are described in the "Weighted Regression Trend Analysis" section. The weighted regression model coefficients and statistical diagnostics are presented in tabular form. Estimated annual concentrations and loads and associated slopes are shown in graphical form and are discussed.

Suspended Sediment

In linear regression models for suspended sediment, the time coefficient (time, time*) was not statistically significant (p-value > 0.1) for each of the five sites evaluated, indicating trends in suspended sediment concentrations and loads were not identified (appendix 1). The weighted regression technique could not be used at Yampa River at Steamboat Springs or Yampa River below Craig because suspended sediment data were only available prior to 1992.

Nitrogen

The time coefficient was not statistically significant (p-value > 0.1) for each of the seven stream sites evaluated, indicating that trends in Kjeldahl nitrogen concentrations and loads were not identified (appendix 1). A highly likely upward trend in the streamflow-normalized Kjeldahl nitrogen concentration and load from 1999–2018 was indicated at Yampa River at Steamboat Springs (table 5) using the weighted-regression trend analysis. The Kjeldahl nitrogen concentration likely increased by 10 percent or 0.035 mg/L for the time period (fig. 20, table 5). The Kjeldahl nitrogen load also likely increased by 22 percent or 26 tons from 1999 to 2018. No trends were identified for Kjeldahl nitrogen concentrations and loads at Yampa River below Craig, CO, for WY 1999–2018 (table 5).

Table 5. Results of weighted-regression trend-analysis and regression statistics for annual streamflow-normalized concentrations and loads at Yampa River at Steamboat, CO, and Yampa River below Craig, CO, water years 1999–2018.

[USGS, U.S. Geological Survey; No, number of samples included in analysis; p-value is significance statistic; Likelihood, likelihood that the sign of the true slope is the same as the sign of the estimated slope]

USGS site name	Parameter	Load bias	No. of samples	Trend slope, units	Trend slope, units per year	Percent change, total	Percent change, per year	p-value	Likelihood	Trend direction
Concentration, in milligrams per liter										
Yampa River at Steamboat Springs, CO	Kjeldahl nitrogen	-0.039	80	0.035	0.0018	10	0.5	0.15	0.93	Very likely upwards
Yampa River at Steamboat Springs, CO	Total phosphorus	0.12	80	0.0081	0.00043	20	1.1	0.10	0.94	Very likely upwards
Yampa River below Craig, CO	Kjeldahl nitrogen	-0.017	80	0	0	0	0	0.79	0.61	Likely as not upwards
Yampa River below Craig, CO	Total phosphorus	-0.027	80	0.0045	0.00024	7.1	0.37	0.67	0.66	Likely as not upwards
Load, in tons										
Yampa River at Steamboat Springs, CO	Kjeldahl nitrogen	-0.039	80	26	1.4	22	1.2	0.13	0.94	Very likely upwards
Yampa River at Steamboat Springs, CO	Total phosphorus	0.12	80	6.2	0.33	41	2.1	0.17	0.92	Very likely upwards
Yampa River below Craig, CO	Kjeldahl nitrogen	-0.017	80	24	1.3	4.2	0.22	0.83	0.57	Likely as not upwards
Yampa River below Craig, CO	Total phosphorus	-0.027	80	0.51	0.027	0.36	0.019	0.99	0.48	Likely as not upwards

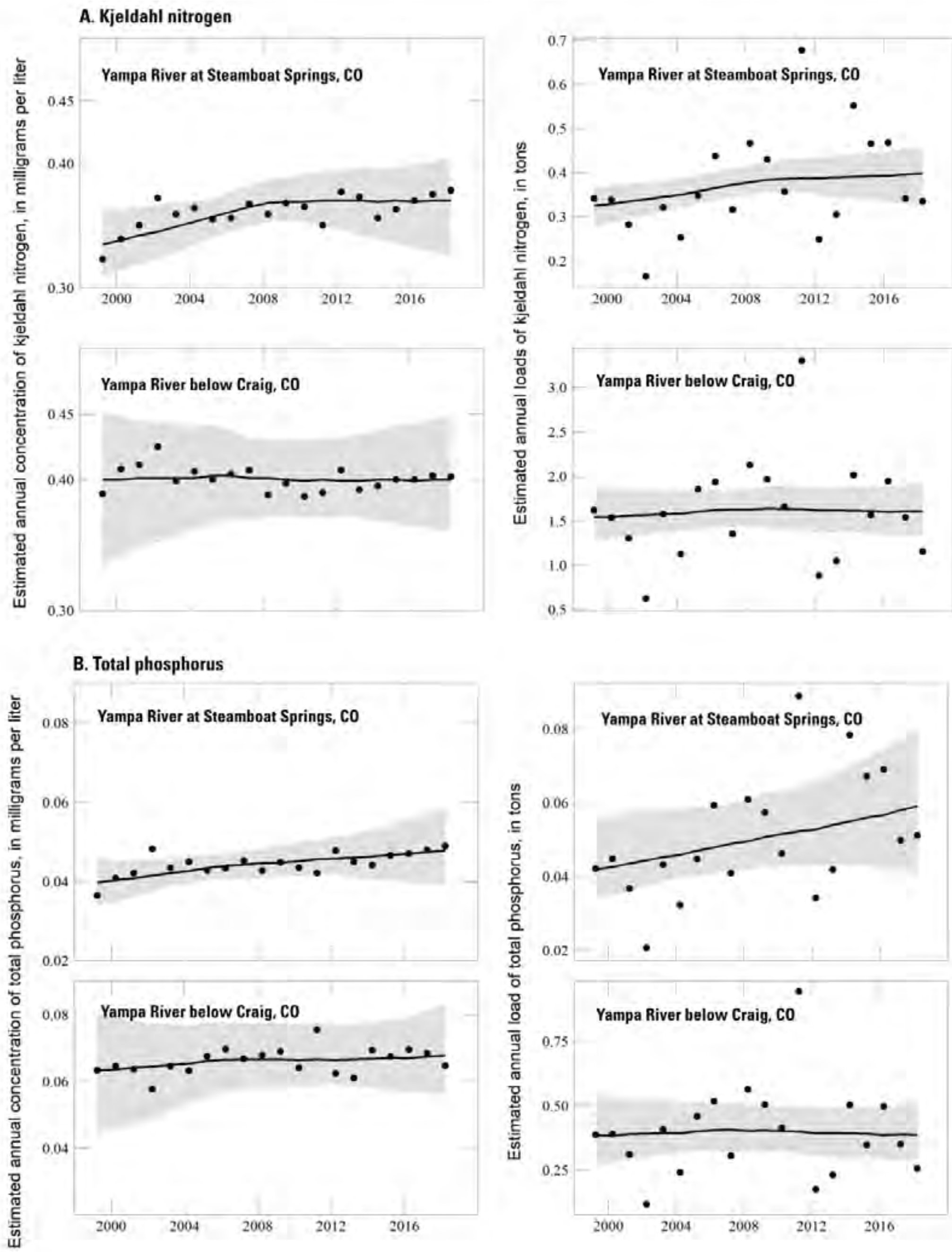


Figure 20. Estimated annual concentrations and loads of (*A*) Kjeldahl nitrogen and (*B*) total phosphorus using weighted regression trend analysis at Yampa River at Steamboat Springs, Colo., and Yampa River at Craig, Colo., in the Upper Yampa River Basin, Colorado, water years 1999–2018. [CO, Colorado].

Phosphorus

The time coefficient for total phosphorus was not statistically significant (p-value > 0.1) for each of the seven sites evaluated, indicating that trends in total phosphorus concentrations and loads were not identified (appendix 1). However, the weighted regression technique indicated a highly likely upward trend in streamflow-normalized concentration and load for WY 1999–2018 at Yampa River at Steamboat Springs (table 5). Total phosphorus concentration likely increased by 1.1 percent per year and 20 percent or 0.0081 milligrams per liter across the time period (fig. 20, table 5). Bauch and others (2012) reported a statistically significant upward trend in phosphorus concentration from 1997 to 2008 at Yampa River at Steamboat Springs, with an estimated rate of change of 3.1 percent per year or 0.001 mg/L per year. The report suggested that the upward trend may have reflected population growth and related land-use changes that occurred upstream from the site. Loads also likely increased by 2.1 percent per year and 41 percent or 6.2 tons across the time period (table 5). Trends were not indicated for total phosphorus concentrations and loads at Yampa River below Craig for WY 1999–2018 (table 5).

Stagecoach Reservoir Water Quality and Algae

Factors like variation in climate, natural processes, and land use in the watershed can affect hydrologic and chemical characteristics of reservoirs, and indirectly affect the biological community. Among the most common factors affecting reservoir water quality is eutrophication, the enrichment of reservoir water with nutrients, organic matter, and silt. Eutrophic conditions can lead to extensive and rapid growth of planktonic algae. Excessive algal growth reduces water clarity, inhibits growth of other plants, and can lead to extensive oxygen depletion, accumulation of unsightly and decaying organic matter, unpleasant odors, and fish kills. Cyanobacteria, a type of photosynthetic bacteria that is also known as blue-green algae, can proliferate in reservoirs that exhibit eutrophic conditions and hydrologic alterations, as demonstrated by the increasingly frequent and highly visible harmful cyanobacterial blooms or CyanoHABs in lakes and reservoirs around the world (Paerl and Otten, 2013). Cyanotoxins, produced by cyanobacteria, include liver, nerve, and skin toxins, that can affect human and animal health. Potential exposure routes to cyanotoxins include contact, ingestion or inhalation during recreational activities, contaminated drinking water, and crops irrigated by contaminated water (Chorus and Bartram, 1999; Corbel and others, 2013).

Selected physical and chemical characteristics of water samples collected at two depths once a month from July–September 2017 and 2018 at one location in Stagecoach Reservoir are presented graphically and discussed. Cell densities of planktonic algae and cyanotoxin concentrations from samples collected on same dates are compared to guideline values to evaluate potential human recreational risks.

On multiple sampling events at Stagecoach Reservoir, the physical and chemical factors indicate conditions conducive to cyanobacterial blooms. Nutrient-enriched waterbodies are especially prone to CyanoHABs if they also have long residence times, water temperatures periodically exceeding 20 degrees Celsius, calm surface waters, and persistent vertical stratification (Paerl, 1988). In Stagecoach Reservoir, surface-water temperatures exceeded 20 degrees Celsius on sampling dates in July of 2017 and 2018 (fig. 21). Anoxic conditions, defined as dissolved-oxygen concentrations less than 0.5 mg/L, were measured at all samples collected at a depth of 114–120 feet (fig. 21). Loss of oxygen is primarily due to oxygen consumption at the sediment-water interface, where bacterial decomposition of sediment organic matter is highest, and the use of oxygen by aquatic organisms in the water column (Wetzel, 1983). Phosphorus enrichment, especially relative to nitrogen enrichment, may favor the development of CyanoHABs, particularly those with nitrogen-fixing cyanobacteria (Smith and Schindler, 2009). These cyanobacteria can supply their own nitrogen by converting atmospheric nitrogen (N_2) to biologically available ammonia (Downing and others, 2001). Nitrogen-rich aquatic ecosystems can also have CyanoHABs, especially non-N_2-fixing genera (Paerl and Fulton, 2006). Most of the watershed that drains into Stagecoach Reservoir overlies sedimentary rocks, which contribute dissolved materials to surface water (Terziotti and others, 2010). Total phosphorus concentrations in surface waters exceeded the interim CDPHE water-quality standard of 0.025 mg/L (table 2) in August and September of 2017 and 2018, whereas total nitrogen exceeded the interim standard of 0.426 mg/L (table 2) on every sampling date (fig. 21).

Total nitrogen to total phosphorus ratios (TN:TP) can be indicators of nutrient limitation in a body of water (Forsberg, 1979) and bloom-forming cyanobacteria tend to dominate in lakes where the TN:TP ratio is less than 30 (Smith, 1983). TN:TP ratios in samples collected at 3 feet ranged from 15 to 31 (fig. 21). One or more of the nitrogen constituents were less than the detection limit or estimated, resulting in multiple censored total nitrogen values and N:P ratios. Although many of the species constituting blooms in the reservoir are capable of nitrogen fixation, insufficient data exist to directly correlate nutrient limitation to species composition in blooms in Stagecoach Reservoir. Chlorophyll *a* concentration exceeded the CDPHE limit of 8.0 micrograms per liter (µg/L) (table 2) on multiple sampling days (fig. 21).

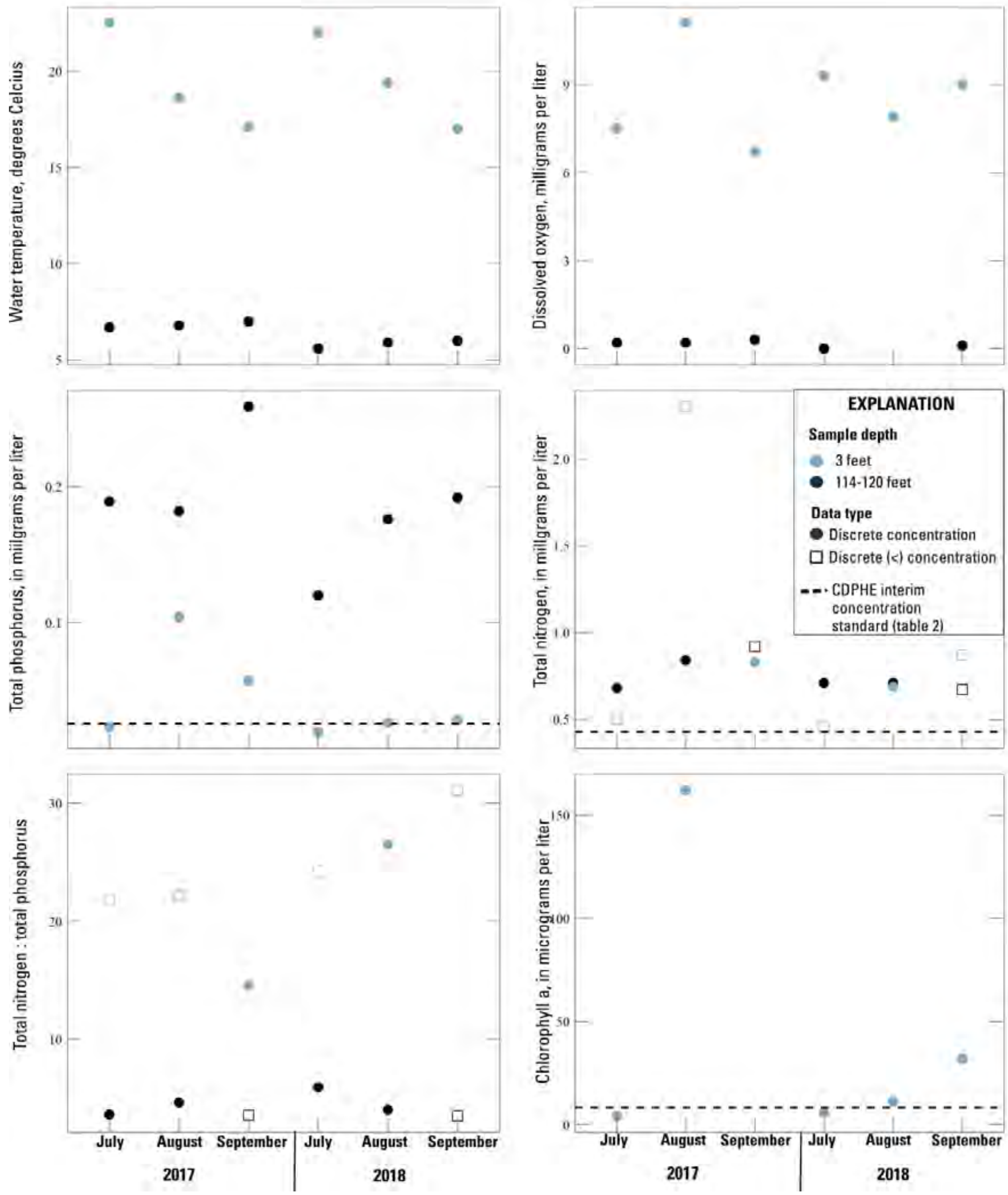


Figure 21. Water temperature; concentrations of dissolved oxygen, total phosphorus, and total nitrogen, ratio of total nitrogen to total phosphorus, and chlorophyll *a* concentration at two depths at the site Stagecoach Reservoir at Dam, Colorado, July–September 2017 and 2018 (CDPHE, Colorado Department of Public Health and Environment).

Cyanobacteria had the highest cell densities compared to other planktonic algae from samples collected in Stagecoach Reservoir. Total cyanobacterial cell densities ranged from 75 to 1,380,000 cells per milliliter (cells/mL) and exceeded the World Health Organization's (WHO) guideline values for a moderate probability of adverse health effects (100,000 cells/mL) in July and August of 2017 (WHO, 2003, fig. 22). Cyanobacterial genera that exceeded the guideline value included *Aphanizomenon sp.* (1,380,000 cells/mL), *Cyanodictyon sp.* (238,000 cells/mL) and *Chroococcus sp.* (122,000 cells/mL). Other cyanobacterial genera included *Aphanocapsa sp., Microcystis sp., Planktolyngbya sp., Pseudanabaena sp., Rivularia sp., and Snowella sp.*; many of these can fix nitrogen. Other types of planktonic algae were present in the reservoir including *Bacillariophyta* (diatoms), *Chlorophyta*, *Cryophyte*, *Cryptophyta*, *Euglenophyta*, *Haptophyte*, and *Ochrophyta*.

The cyanotoxin microcystin was detected in Stagecoach Reservoir in September 2018, but the total microsystin concentration of 0.26 µg/L was much less than the Environmental Protection Agency's recreational advisory level of 4 µg/L for microcystins (EPA, 2016). Concentration of total microcystins was below the detection limit of 0.10 µg/L on all other dates sampled. Two other types of cyanotoxins, total saxitoxins and total cylindrospermopsins, were also measured and were below detection limits of 0.02 and 0.05 µg/L, respectively, on all dates.

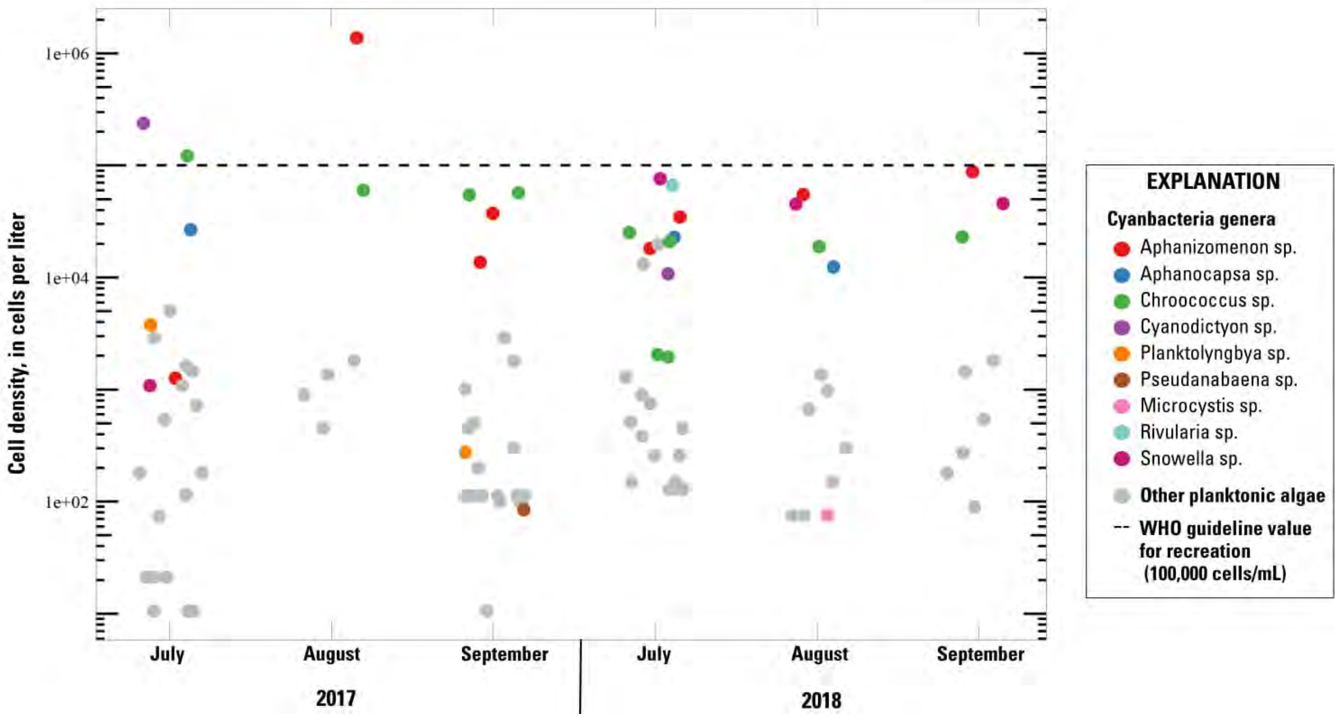


Figure 22. Planktonic algal cell densities, in cells per milliliter, in Stagecoach Reservoir, Colorado, July–September 2017 and 2018. Other includes all other planktonic algae. [sp., species, WHO, World Health Organization

Increased nutrient import into reservoirs can lead to eutrophication and algae blooms, while reservoirs have the potential to act as nutrient sinks or sources of nutrients, potentially reducing or enhancing nutrient loads downstream (Shaughnessy and others 2019). Mean concentrations of suspended sediment and Kjeldahl nitrogen, but not total phosphorus, were significantly lower in more recently collected data, WY 2012–18, compared to data collected during the construction and filling of Stagecoach Reservoir, WY 1989–93, at Yampa River above Stagecoach Reservoir. It is not clear why this decrease was observed. Mean concentrations of the two time periods differed by 109 mg/L for suspended sediment and by 0.124 mg/L for

Kjeldahl nitrogen. There were no differences in concentrations of Kjeldahl nitrogen or total phosphorus between more recently collected data and data collected during reservoir construction at Yampa River below Stagecoach Reservoir. No recent suspended sediment data exist at Yampa River below Stagecoach Reservoir. Thus, quantifying storage of sediment in Stagecoach Reservoir and the amount of sediment occurring from channel erosion downstream from the dam is not possible.

Changes in Land Use

The dominant land cover in the UYRB in 2016 was forest, which accounted for 49 percent of total land area (27.5 percent deciduous, 18.6 percent evergreen, and 2.5 percent mixed forest; figs. 23, 24). Other prominent land covers included shrub/scrub (39 percent), herbaceous (about 4 percent), and hay/pasture (3 percent). Development, including open space, only accounted for approximately 1.5 percent of land area in the UYRB. Land cover varied on a subbasin scale. In general, in 2016, the percentage of forest was greatest at higher elevations and shrub/scrub cover was greatest at lower elevations. Developed land was greatest in the Yampa River at Steamboat Springs subbasin, where approximately 3 percent of the subbasin was developed.

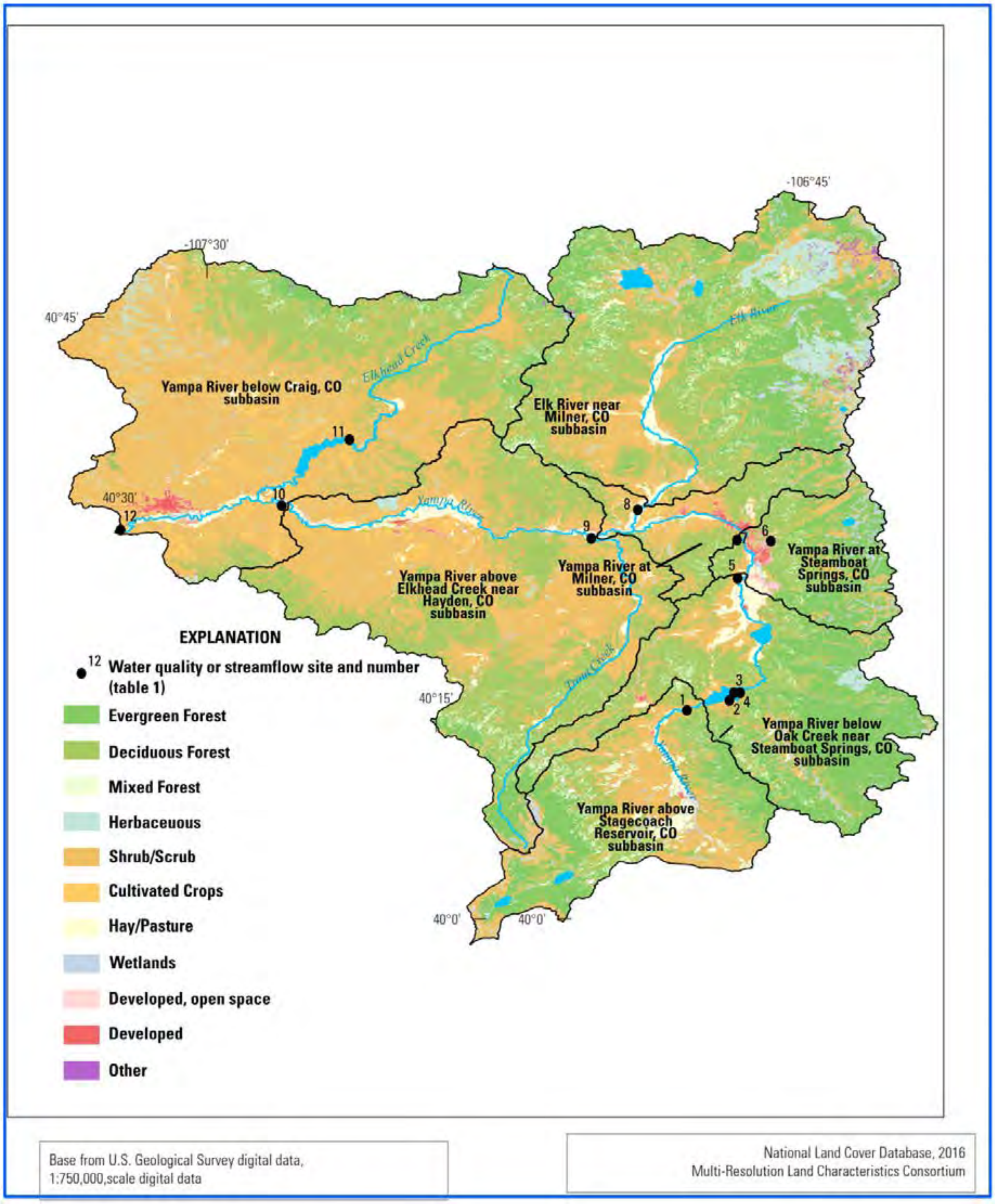


Figure 23. Land cover in the Upper Yampa River Basin, Colorado, 2016.

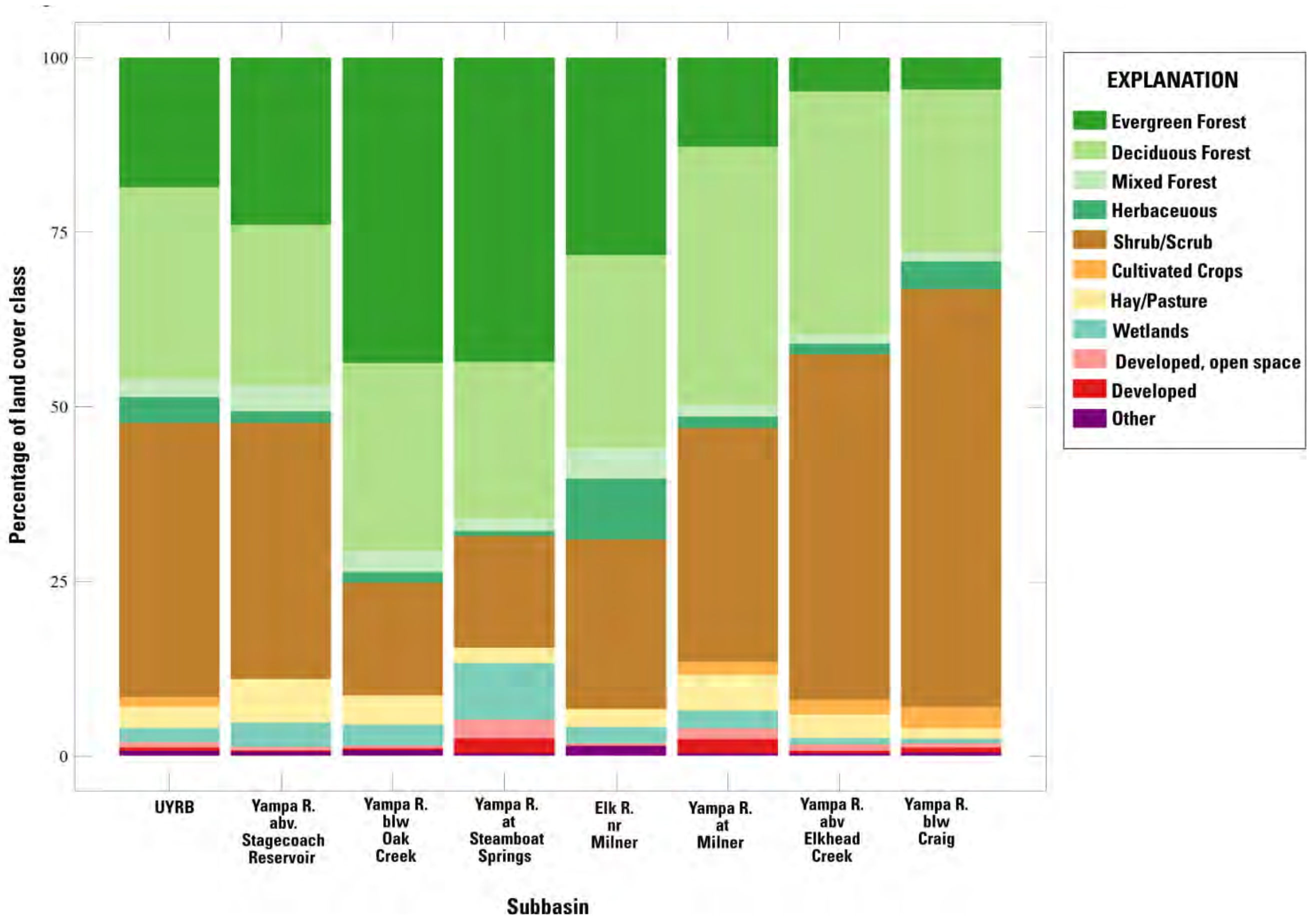


Figure 24. Percentage of land-use cover classes in the Upper Yampa River Basin and its subbasins, Colorado (National Land Cover Database, 2016). Other includes Barren, Open Water, and Snow/Ice classes. [Yampa R. abv Stagecoach Reservoir, Yampa River above Stagecoach Reservoir, Colo.; Yampa R. blw Oak Creek, Yampa River below Oak Creek near Steamboat Springs, Colo.; Elk R. nr Milner, Elk River near Milner, Colo.; Yampa R. at Milner, Yampa River at Milner, Colo.; Yampa R. abv Elkhead Creek, Yampa River above Elkhead Creek near Hayden, Colo.; Yampa R. blw Craig, Yampa River below Craig, Colo.]

Data from the NLCD were used to assess the cumulative change in forested and developed land-cover classes from 2001 to 2016 (MRLC, 2016). In the UYRB, evergreen forest cover decreased by 26 square miles, representing 1.2 percent of the total basin area (table 6). Losses of evergreen forest were reported for the five subbasins upstream from the Yampa River at Milner site. Subbasins with the highest evergreen forest loss include Elk River near Milner (21 square miles or 4.6 percent of the relative area of the subbasin), and Yampa River below Oak Creek (4.2 square miles or 1.6 percent of relative area of the subbasin). The largest proportion of these losses were between 2001 and 2004, during which time two wildland fires, the Mount Zirkel Complex and Green Creek fire, occurred in the two respective subbasins (Monitoring Trends in Burn Severity, 2020). In addition to fires, infestations of the western balsam bark beetle and spruce beetle have resulted in substantial tree mortality in many forests in the UYRB (Colorado State Forest Service, 2019, 2020).

Table 6. Change in forest- and development land-cover classes in the Upper Yampa River Basin Colorado, from 2001–16.

[UYRB, Upper Yampa River Basin; Miles^2, total change in area, in square miles; Percent, total change in area relative to subbasin area, in percent. Land-cover data from National Land Cover Database (MRLC, 2016)]

Subbasin	Total area, in square miles	Evergreen Forest		Deciduous Forest		Mixed Forest		Developed		Developed, open space	
		Miles^2	Change	Miles^2	Change	Miles^2	Percent	Miles^2	Percent	Miles^2	Percent
UYRB	2,100	-26	-1.2	-2.7	-0.13	-0.41	-0.019	0.79	0.037	0.38	0.018
Subbasin											
Yampa River above Stagecoach Reservoir, CO	210	-0.61	-0.29	-0.11	-0.052	0.11	0.053	0.00035	0.00017	0.0024	0.0012
Yampa River below Oak Creek near Steamboat Springs, CO	260	-4.2	-1.6	0.062	0.024	0.016	0.0061	0.0014	0.00054	-0.0014	-0.00054
Yampa River at Steamboat Springs, CO	100	-0.14	-0.13	-0.023	-0.022	0.00035	0.00034	0.39	0.38	0.19	0.18
Elk River near Milner, CO	460	-21	-4.6	-1.4	-0.29	-0.77	-0.17	0	0	0	0
Yampa River at Milner, CO	85	-0.15	-0.18	-0.035	-0.041	0.03	0.035	0.13	0.15	0.071	0.084

Yampa River above Elkhead Creek, CO	460	0.0052	0.0011	-0.5	-0.11	0.024	0.0053	0.066	0.015	0.07	0.015
Yampa River below Craig, CO	560	0.2	0.035	-0.73	-0.13	0.18	0.032	0.21	0.037	0.055	0.0098

Developed land area, which includes high-, medium-, and low-density land development, increased by 0.79 square miles across the UYRB, with the largest increase of 0.39 square miles in the Yampa River at Steamboat Springs subbasin. It is important to consider that the resolution of the NLCD data set is 900 square meters; thus, changes in land use less than this may not be captured using this method.

Data from the 2012 and 2017 USDA agricultural census for Routt and Moffat Counties were used to assess change in agricultural practices in the UYRB (USDA, 2019). There are several factors to consider when interpreting census data. While the USDA agricultural census is meant to include all agricultural producers in Colorado, participation is voluntary, and nonresponses are a source of bias. Further, several linguistic and environmental factors affect the interpretation of questions by respondents.

Cropland and pastureland decreased by 31 and 24 percent, respectively, in Routt County from 2012 to 2017 but increased by 3 and 6 percent, respectively, in Moffat County (table 7). Both counties documented losses in the total amount of land enrolled in conservation programs, including Conservation Reserve, Wetlands Reserve, Farmable Wetlands, and Conservation Reserve Enhancement Program. Farmers enrolling their land in the Conservation Reserve Program (CRP) have agreed, for a rental payment, to remove environmentally sensitive land from agricultural production and plant species that will improve environmental health and quality. Acres of irrigated land, which includes all land watered by any artificial or controlled means, decreased by 8 percent in Routt County and increased by 28 percent in Moffat County.

The total number of cattle and calves in Routt County decreased by 33 percent and increased by 27 percent in Moffat County. There were substantial increases in the number of sheep and lambs, 61 percent, in Routt County, with a smaller increase of 7 percent in Moffat County. Both counties experienced increases in the amount of land treated with manure, 110 percent in Routt County and 75 percent in Moffat County. Commercial fertilizers were applied to 45 percent less cropland, but 110 percent more pastureland in Routt County. Conversely, 85 percent more crop land and 43 percent less pastureland were reportedly treated with commercial fertilizer in Moffat County. While the USDA census is comprehensive, the spatial resolution of the data does not lend itself to identifying areas that may influence watershed processes.

Table 7. U.S. Department of Agriculture agricultural census data for Routt and Moffat Counties, Colorado, and percent change in agricultural practices, 2012 and 2017.

	Routt County			Moffat County		
Agricultural practices	**2012**	**2017**	**Change, in percent**	**2012**	**2017**	**Change, in percent**
Total cropland, in acres	117,000	81,000	-31	120,000	123,000	3
Total pastureland, in acres	475,000	360,000	-24	790,000	836,000	6
Land in conservation, in acres	15,200	13,400	-12	29,500	24,000	-19
Irrigated land, in acres	46,600	42,700	-8	23,500	30,100	28
Number of cattle	37,200	24,900	-33	27,300	34,700	27
Number of sheep	8,820	14,200	61	51,300	54,600	7
Area of land treaded with manure, in acres	4,130	8,660	110	5,970	10,500	75
Area of cropland treated with commercial fertilizer, in acres	14,600	8,020	-45	11,300	20,900	85
Area of pastureland treated with commercial fertilizer, in acres	4,130	8,660	110	3,990	2,280	-43

There are several factors to consider when interpreting agricultural census data. While the USDA agricultural census is meant to include all agricultural producers in Colorado, participation is voluntary, and nonresponses are a source of bias. Further, several linguistic and environmental factors affect the interpretation of questions by respondents, such as the wording of the specific question or the order in which the questions are presented. For example, the question about area of land treated with manure could be interpreted in multiple ways: (1) area of land where manure is specifically applied as a fertilizer, or (2) area of land where winter feeding of cattle occurs. While the USDA census is comprehensive, the spatial resolution of the data does not lend itself to identifying areas that may have a disproportionate effect on watershed processes. For example, increases in number of sheep along water bodies versus upland areas would likely have a larger effect on water quality.

Synthesis of Steamflow and Water-Quality Results

The assessment of streamflow and surface-water quality in this study was designed to characterize and detect changes in streamflow and selected water-quality constituents in the UYRB and to help provide a better understanding of potential drivers of change, including land-use change and long-term watershed characteristics, including geology and land cover. The primary determinants of nutrient concentrations in water bodies are geology, soil type, point-source inputs, and predominant catchment land use, which influences nonpoint-source contribution. Given that geology and soil type are relatively static, these factors can only explain baseline differences in nutrient concentrations among waterbodies. Examples of point-source nutrient contributions include discharge from industrial sources and effluent from municipal wastewater treatment plants. Nonpoint source nutrient contributions are often associated with anthropogenic activities including agriculture and urbanization. Changes in forested ecosystems, such as those caused by acidification from atmospheric deposition, wildfires, and insect infestation, can also impact nutrient inputs to receiving waterbodies.

Shorter term changes to streamflows in the UYRB likely reflect water management, while longer term changes reflect trends occurring across the Western United States, predominately associated with changes to snowmelt and temperature. The seasonality of suspended sediment, nitrogen, and phosphorus concentrations and loads across sites suggests that most of these constituents enter the rivers during spring runoff; thus, managing inputs during these events will decrease the potential for exceedances of the CDPHE standards in the future. Geology and land use were the most likely factors contributing to high concentrations and yields of suspended sediment and nutrients and increasing trends at some sites. Linking changes in streamflow and water-quality to land cover and changes in land use was limited by the lack of available data to characterize these factors on a subbasin scale.

The observed changes in streamflow at mainstem and tributary sites likely reflect the combined effect of changes in precipitation and increases in temperature related to climate change and increased water use. Variability in streamflow in the Colorado River Basin (CRB) is largely controlled by cool season precipitation and spring and summer air temperatures (Woodhouse and others, 2016). Thus, water supply in the CRB is increasingly stressed by warming temperatures that have decreased winter snowpack (Mote and others, 2018), resulting in earlier snowmelt timing (Clow, 2010), and increased evaporation losses in the basin (McCabe and others, 2017; Udall and Overpeck, 2017). In this report, the long-term trends in streamflow at Yampa River at Steamboat Springs from 1910–2018 correspond to documented changes happening in the UCRB, including reductions in annual streamflow, especially during spring and summer periods (Miller and Piechota, 2008) and changes in the timing of peak streamflow (Clow, 2010). The basin-wide comparison of trends in streamflow, from 1992–2018, showed significant decreases in streamflow during winter months across mainstem and some tributary sites. In addition to possible contributions from changes in consumptive use, and reservoir management, this time period coincides with one of the hottest drought periods in the UCRB, where annual average streamflow was 19 percent below that of the twentieth century (Udall and Overpeck, 2017). Projected hydrographs based on planning scenarios incorporating the effects expected from climate change predict 8–11 percent reductions in annual streamflow by 2030 at the Yampa River at Steamboat Springs site (State of Colorado, 2019).

Concentrations of modeled water-quality constituents exhibited similarities in seasonal variation at most sites, indicating that factors controlling delivery of constituents to streams in the UYRB may be similar across sites. At sites downstream from Stagecoach Reservoir, suspended sediment, Kjeldahl nitrogen, and total phosphorus concentrations were typically highest in spring (March, April, and May). High concentrations can occur during the leading edge of the snowmelt runoff period in constituents that bind to particulate matter, as material that is washed off the land surface drains into streams (Hirsch, 2011). Flushing of soils from groundwater discharge can also occur during early runoff periods when infiltration from melting snows increase the piezometric gradient near channels, contributing stored nutrients and increasing instream concentrations. Median concentrations of Kjeldahl nitrogen and total phosphorus were below CDPHE standards at all sites; however, managing inputs during these events will decrease the potential for exceedances of the CDPHE standards in the future. Yampa River at Milner had an earlier peak of total phosphorus concentrations in February and March (fig. 14), corresponding with higher discrete concentrations of orthophosphate (fig. 15), indicating that this site may have different sources of phosphorus, including the wastewater treatment plant (WWTP) discharge for the city of Steamboat Springs.

Yampa River at Milner and Yampa River above Elkhead Creek had the highest net yields of suspended sediment, Kjeldahl nitrogen, and total phosphorus in the UYRB and are likely influenced by urban development and local geology (fig. 17). Although the Yampa River at Milner subbasin is the smallest in the UYRB, it includes much of the Steamboat Springs area. The subbasin is also underlain by Mancos Shale (fig. 3), a late Cretaceous marine deposit that can contain nitrogen sources and is highly erodible especially following surface disturbance (Thomas and others, 2019; Fick and others, 2020). Limitations of certainty should be considered based on the use of an estimated hydrograph at Yampa River at Milner. Most of the Yampa River above Elkhead Creek subbasin is underlain by the Yampa coal field (fig. 2), which has high phosphorus content (30 times greater than the average value for Cretaceous-age coal) because of ash deposits (Affolter, 2000).

Disturbances to the land surface in both of these basins, including grazing, construction of urban areas and increases in mining or harvesting of timber, could exacerbate contributions of sediment and nutrients to the river. The relatively small yields of total phosphorus from the Yampa River at Steamboat Springs subbasin compared to others suggests that the influence of development may not be detected until further downstream or that land uses other than urban development may contribute more to phosphorus loading across the UYRB. Also, the underlying geology associated with the Yampa River at Steamboat subbasin is crystalline metamorphic and igneous rocks (Bauch and others, 2012) that do not contribute phosphorus to the system through rapid erosion.

The increasing trends of Kjeldahl nitrogen and total phosphorus concentrations and loads at Yampa River at Steamboat Springs may reflect changes in land use and streamflow regime. The weighted regression method used at this site allows for separate trend analysis of concentration and load, which can provide insight into when changes are occurring. As loads are more influenced by days with high flow, larger trends in loads than in concentrations can indicate that much of the change is occurring during high flow periods (Hirsch and De Cicco, 2015). Percent changes in Kjeldahl nitrogen and total phosphorus loads were double the concurrent changes in concentration (table 5). Therefore, changes in inputs of nitrogen and phosphorus entering the river during high streamflow periods likely contribute to the observed trends. The decreases in streamflow during spring months at this site (fig. 5) may lower the ability of the river to dilute nutrients, leading to increases in concentrations, a response that is commonly observed during droughts (Mosley, 2015). Change in land management is also a likely contributor to increasing trends at Yampa River at Steamboat Springs, as the subbasin has the highest percentage of developed land area in the UYRB and experienced a 38-percent increase in land area developed from 2001 to 2016 (fig. 24, table 7). To investigate causes of increases in nitrogen and phosphrous concentrations and loads, additional variables are needed to improve the predictive ability of regression models. Other factors, including climate change (Heath and Baron, 2014), atmospheric deposition (Baron and others, 2000) and canopy loss from forest fire and outbreaks of western bark beetle and spruce beetle (Mikkelson and others, 2013), may impact the amount of runoff and water-quality of receiving streams and rivers.

Geology and land use above Stagecoach Reservoir likely contribute to the increasing frequency of cyanobacterial blooms in the reservoir. Concerns of cyanobacterial blooms and elevated phosphorus concentrations have been associated with Stagecoach Reservoir since its inception (Bureau of Reclamation, 1986). Stagecoach Reservoir overlies sandstones and shales (fig. 2), which contribute dissolved materials to surface water (Terziotti and others, 2010), thus, it is likely that geology contributes to the elevated levels of phosphorus. Across all sites examined, annual median concentrations of total phosphorus were the highest at Yampa River above Stagecoach Reservoir (table 3). No trends in phosphorus were observed at this site, although existing phosphorus concentrations in combination with other changes such as increasing temperatures can further promote algae blooms (Paerl and Huisman, 2008). Land use in the Yampa River above Stagecoach Reservoir subbasin contains the highest percentage of hay and pastureland in the UYRB (fig. 24). Grazing practices may exacerbate soil erosion (Duniway and others, 2019). Fertilizer application may also contribute to dissolved phosphorus levels in the rivers in summer months when conditions are most favorable for algae blooms (Van Meter and others, 2020). Maximum concentrations of Kjeldahl nitrogen, total nitrogen, total phosphorus, and orthophosphate occur slightly later at Yampa River above Stagecoach Reservoir than other sites (in May, June, and July) suggesting that different factors control nutrient inputs at this site.

Although regression models can support a conceptual understanding of controls on constituent loading to a receiving water body, the models may generate poor estimates of concentrations and loads when limited explanatory variables are available, and when not all sources and processes are well defined by available sampling data. The utility of some of the models used to make estimates of suspended sediment, Kjeldahl nitrogen, and total phosphorus concentrations, loads, and trends were more limited at some sites due to limited sample data or explanatory variables (appendix 1). For example, phosphorus is generally transported in streams while sorbed to sediment particles and thus behaves similarly to suspended sediment. In watersheds where total nitrogen and phosphorus are primarily in the particulate form, turbidity data sets may provide improved estimates of nutrient loading than streamflow alone (Jones and others, 2011; Lessels and Bishop, 2013). Additionally, variation in nutrient concentrations may not be accurately captured by quarterly sampling. Quarterly sampling provides a snapshot of seasonal variation in water-quality constituents but does not necessarily capture the influence of other factors including storm events, groundwater interactions, and land-use related activities. At sites likely to have more urban influence, including Yampa River at Steamboat Springs and Yampa River at Milner, more targeted sampling to capture urban runoff during storm events, WWTP discharge, and groundwater sources may help to improve model estimates in the future.

The lack of trends in suspended sediment, Kjeldahl nitrogen, and total phosphorus at sites upstream from Steamboat Springs (including Yampa River at Oak Creek and Yampa River above Stagecoach Reservoir) does not necessarily exclude these sites from contributing to increasing trends observed downstream. Limitations in available data and trend analysis techniques at these upstream sites may be less sensitive to trends exhibiting seasonality or non-linear trend slopes, preventing detection of significant trends (Hirsch and De Cicco, 2014). Continued monitoring may improve the ability to detect unidentified trends in these areas in the future when available data better meets regression assumptions and requirements, allowing for additional trend assessments.

An assessment of the influence of land use on water quality and quantity could not be fully explored in this report due to limited land-use data. The accuracy of some land-cover classifications from the National Land Cover Database only permitted analysis of land-use change for development and forest classes. Further, agricultural census data from the U.S. Department of Agriculture lacked the spatial resolution needed to assess land-use change on a subbasin scale. Other studies have found changes in land management and (or) land use/cover to be the major driver of changes in water quality (see references in Murphy and Sprague, 2019). Thus, future work should incorporate data that represents characteristics which may or may not have changed over time, including land use and agricultural practices, on a finer spatial scale.

Summary

The Yampa River, in northwestern Colorado, is the largest, mostly free-flowing river to the Colorado River system in the Upper Colorado River Basin. Because of limited reservoir storage, the river is known for its largely unaltered natural condition, biological diversity, and generally “good” water quality and is a valued multi-use resource in the Upper Yampa River Basin (UYRB). In 2019, the U.S. Geological Survey (USGS), in cooperation with the Upper Yampa River Watershed Group, Upper Yampa Water Conservancy District, Colorado Water Conservation Board, Yampa-White-Green Basin Roundtable, Mount Werner Water and Sanitation District, Routt County, and the City of Steamboat Springs, initiated a study to characterize streamflow and surface-water quality at sites in the UYRB. The assessment of streamflow and surface-water quality in this study is designed to characterize changes in streamflow and select water-quality constituents in the UYRB as they relate to regulatory and toxicity concerns and to help provide a better understanding of how major factors, including land use and geology may contribute to changes in hydrology in the UYRB study area. This report (1) describes seasonal variation and temporal trends in streamflow, suspended sediment, and nutrient concentrations and loads; (2) provides comparisons of nutrient concentrations to interim State of Colorado nutrient standards; (3) identifies subbasins with higher suspended sediment and nutrient yields; (4) summarizes water-quality and algal data for Stagecoach Reservoir; (5)

assesses land-cover and land-use change in the basin; and (6) explores connections between land-use change and long-term watershed characteristics, including geology and land cover, to streamflow and water-quality characteristics.

The UYRB drains approximately 2,100 square miles of the Yampa River watershed west of the Continental Divide in northwestern Colorado. Much of the watershed is underlain by sedimentary rocks of Cretaceous age, including sandstones, shales, and major coal beds. Streamflow in the UYRB is dominated by snowmelt, with increasing flows in April, peaking in May and June, and decreasing flows in July. Stagecoach Reservoir, upstream from Steamboat Springs on the Yampa River, is the largest storage facility in the UYRB with a total capacity of approximately 36,500 acre-feet. There are no mainstem reservoirs downstream from the city of Steamboat Springs.

Streamflow and water-quality data used in this report were collected by the USGS. Water-quality data include streamflow, suspended sediment, Kjeldahl nitrogen, total nitrogen, total phosphorus, orthophosphate, temperature, dissolved oxygen, planktonic algal densities and toxins concentrations for streams and Stagecoach Reservoir. All USGS continuous streamflow data and discrete water-quality data were analyzed and approved.

Since the completion of Stagecoach Reservoir in 1992, through 2018, all mainstem sites had significant decreasing trends in one or more streamflow statistics during winter months. Decreasing trends were found across most months at Yampa River above Stagecoach Reservoir, Colo., with significant decreases in January or February in mean and 7-day minimum streamflow statistics. Annual decreases in 7-day minimum streamflows of 14 percent per decade or 39 percent over the 27-year period of analysis were also observed. At the site directly below

Stagecoach Reservoir, decreases in all three streamflow statistics were found from September through February, ranging from 13 to 20 percent per decade or 35 to 54 percent overall. Decreases in streamflow at Yampa River at Steamboat Springs, Colo., Yampa River above Elkhead Creek, Colo., and Yampa River below Craig, Colo., had similar magnitudes over the same time period.

Trends in streamflow at tributary sites likely correspond to changes in reservoir management and at sites with no upstream flow impoundments, changes due to water use and climate. Mean and 7-day minimum streamflows decreased by 35 percent per decade or 95 percent overall during July at Fish Creek near Steamboat Springs, Colo. Significant increases in 7-day minimum streamflows occurred in August, September, and October, resulting in an overall annual increase of 43 percent per decade or 116 percent overall. These changes likely correspond to changes in water use at Fish Creek Reservoir, the primary source of municipal water supplies for Steamboat Springs. Elkhead Creek near Hayden is above Elkhead Reservoir, thus trends at this site may be more indicative of changes in climate factors or changes in water management, including diversion for irrigation. Though not significant based on 90-percent confidence intervals, decreasing trends in streamflow were found in summer months at Elk River near Milner and may become more likely if current conditions continue. Like the mainstem sites, Elkhead Creek near Hayden also had significant decreases in all three streamflow statistics during winter months, November through February, ranging from 18 to 47 percent per decade or 49 to 127 percent overall.

Streamflow trends examined across a longer time period, from 1910 to 2018, at Yampa River at Steamboat Springs, Colo., correspond to observed changes in streamflow documented across western North America and the Colorado River Basin. Decreasing trends were found during spring and summer months and annually for maximum and mean streamflows. Significant decreases in mean daily streamflows of 2 percent per decade or 25 percent across the 109-year period of analysis were found in April. A fairly significant decreasing trend in the deviation from mean peak streamflow date was found, indicating that date of peak streamflow is occurring earlier at Yampa River at Steamboat Springs, Colo.

At sites downstream from Stagecoach Reservoir, estimated daily concentrations of suspended sediment, Kjeldahl nitrogen, and total phosphorus concentrations were typically highest in spring (March, April, and May). Highest concentrations occurred slightly later at Yampa River above Stagecoach Reservoir, Colo., than other sites, in May, June, and July, suggesting that different factors control nutrient inputs at this site. Yampa River at Milner, Colo., had an earlier peak of total phosphorus concentrations in February and March, corresponding with higher discrete concentrations of orthophosphate, indicating that this site may have different sources of phosphorus, including the wastewater treatment plant (WWTP) discharge for the city of Steamboat Springs. Median concentrations of Kjeldahl nitrogen and total phosphorus were below Colorado Department of Public Health and Environment (CDPHE) standards at all sites; however, managing inputs during the identified periods with highest concentrations will decrease the potential for exceedances of the CDPHE standards in the future.

Yampa River at Milner, Colo., and Yampa River above Elkhead Creek, Colo., had the highest net yields based on a normalized hydrograph of suspended sediment, Kjeldahl nitrogen, and total phosphorus in the UYRB. Both of these basins are underlain by highly erodible

Cretaceous shales and Yampa River at Milner, Colo., has urban influence from the city of Steamboat Springs.

A highly likely upward trend in the streamflow-normalized Kjeldahl nitrogen concentration and load from 1999–2018 was indicated at Yampa River at Steamboat Springs. The Kjeldahl nitrogen concentration likely increased by 10 percent or 0.035 milligrams per liter (mg/L) and load also likely increased by 22 percent or 26 tons across the time period. Total phosphorus concentration likely increased by 1.1 percent per year and 20 percent or 0.0081 mg/L and loads also likely increased by 2.1 percent per year and 41 percent or 6.2 tons across the time period. No other trends were detected in the basin. Decreases in streamflow and increased influence from urban development may contribute to these trends.

Factors like variation in climate, natural processes, and land use in the watershed can affect hydrologic and chemical characteristics of reservoirs, and indirectly affect the biological community. Excessive algal growth reduces water clarity, inhibits growth of other plants, and can lead to extensive oxygen depletion, accumulation of unsightly and decaying organic matter, unpleasant odors, and fish kills. Cyanobacteria, a type of photosynthetic bacteria that is also known as blue-green algae, can proliferate in reservoirs that exhibit eutrophic conditions and hydrologic alterations. Cyanotoxins, produced by cyanobacteria, include liver, nerve, and skin toxins, that can affect human and animal health. On multiple sampling events at Stagecoach Reservoir, the physical and chemical factors indicate conditions conducive to cyanobacterial blooms. Surface-water temperatures exceeded 20 degrees Celsius on multiple sampling days. Total phosphorus concentrations in surface waters exceeded the interim CDPHE water-quality standard of 0.025 mg/L in August and September of 2017 and 2018, whereas total nitrogen exceeded the interim standard of 0.426 mg/L on every sampling date. TN:TP ratios in samples collected at 3 feet ranged from 15 to 31.

Cyanobacteria had the highest cell densities compared to other planktonic algae from samples collected in Stagecoach Reservoir. Total cyanobacterial cell densities ranged from 75 to 1,380,000 cells per milliliter (cells/mL) and exceeded the World Health Organization's guideline values for a moderate probability of adverse health effects (100,000 cells/mL) in July and August of 2017. The cyanotoxin microcystin was detected in Stagecoach Reservoir in September 2018, but the total microsystin concentration of 0.26 µg/L was much less than the Environmental Protection Agency's recreational advisory level of 4 µg/L for microcystins. Concentration of total microcystins was below the detection limit of 0.10 µg/L on all other dates sampled. Two other types of cyanotoxins, total saxitoxins and total cylindrospermopsins, were also measured and were below detection limits on all dates.

The dominant land cover in the UYRB in 2016 was forest, which accounted for 49 percent of total land area. Other prominent land covers included shrub/scrub (39 percent), herbaceous (about 4 percent), and hay/pasture (3 percent). Development, including open space, accounted for approximately 1.5 percent of land area in the UYRB. Developed land was greatest in the Yampa River at Steamboat Springs subbasin, where approximately 3 percent of the subbasin was developed. From 2001–16, evergreen forest cover decreased by 26 square miles, representing 1.2 percent of the total basin area. Subbasins with the highest evergreen forest loss include Elk River near Milner (21 square miles or 4.6 percent of the relative area of the subbasin), and Yampa River below Oak Creek (4.2 square miles or 1.6 percent of relative area of the subbasin). Developed land area, which includes high-, medium-, and low-density land development, increased by 0.79 square miles across the UYRB, with the largest increase of 0.39 square miles in the Yampa River at Steamboat Springs subbasin.

Several information needs were identified that would aid in understanding water quality in the UYRB. Most of the suspended sediment and nutrient data used in this report are collected quarterly. Increased frequency of sampling or more targeted sampling to capture urban runoff during storm events, WWTP discharge, and groundwater sources may help to improve understanding of sources of these constituents. Land-use and land-cover data reflecting subbasin-scale changes would assist in a better understanding of how changes in these factors contribute to streamflow and water-quality trends.

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Appendix 1. Regression Equation Variable Coefficients and Statistical Diagnostics

Regression model coefficients and statistical diagnostics from models used to predict concentrations and loads of suspended sediment, Kjeldahl nitrogen, and total phosphorus at seven sites in the Upper Yampa River Basin. Table 1.1 provides regression model coefficients and statistical diagnostics for concentrations. Table 1.2 provides regression model coefficients and statistical diagnostics for loads.

Table 1.1. Regression model coefficients and statistical diagnostics for concentrations of suspended sediment, Kjeldahl nitrogen, and total phosphorus at seven sites in the Upper Yampa River Basin, Colorado.

[USGS, U.S. Geological Survey; ln, natural logarithm; Q*, centered daily streamflow in cubic feet per second (ft^3/s); Time*, centered decimal time in decimal years; sin(2πT), sine function of a Fourier Series; π, approximately 3.141593; T, decimal portion of the year starting January 1; cos(2πT), cosine function of a Fourier Series; k, is an integer; ERV, estimated residual variance; Adjusted R^2 , adjusted coefficient of determination; SCR, serial correlation of the residuals; Est., estimate coefficient; p-value, significance statistic, —, no coefficient available]

USGS site name	Y-axis intercept		ln(Q*)		Time*		sin(k*2πT) k=1		cos(k*2πT) k=1		sin(k*2πT) k=2		cos(k*2πT) k=2		ERV	Adjusted R^2	SCR
	Est.	p-value	Est.	p-value	Est.	p-value	Est.	p-value	Est.	p-value	Est.	p-value	Est.	p-value			
Suspended sediment, in milligrams per liter																	
Yampa River above Stagecoach Reservoir, CO	2.3	0.00	0.77	0.01	-	-	-	-	-	-	-	-	-	-	1.19	0.17	0.28
Yampa River below Oak Creek near Steamboat Springs, CO	1.7	0.00	-0.05	0.77	-	-	0.92	0.00	-0.45	0.02	-0.52	0.01	-0.28	0.04	0.33	0.71	0.07
Elk River near Milner, CO	2.0	0.00	0.69	0.00	-	-	0.56	0.01	0.32	0.13	-	-	-	-	0.44	0.77	-0.09
Yampa River at Milner, CO	1.9	0.00	0.44	0.07	-	-	0.78	0.00	-0.26	0.33	-0.21	0.38	-0.44	0.01	0.48	0.75	-0.27
Yampa River above Elkhead Creek near Hayden, CO	2.6	0.00	0.99	0.00	-	-	-	-	-	-	-	-	-	-	0.57	0.76	-0.14
Kjeldahl nitrogen, in milligrams per liter																	
Yampa River above Stagecoach Reservoir, CO	-1.0	0	0.16	0.01	-	-	0.20	0.00	-0.49	0	-0.04	0.37	0.09	0.05	0.03	0.88	-0.03
Yampa River below Oak Creek near Steamboat Springs, CO	-0.96	0	-0.19	0.03	-	-	0.08	0.33	-0.17	0.05	-0.11	0.20	-0.20	0	0.08	0.31	-0.26
Yampa River at Steamboat	-1.1	0	-0.11	0.01	-	-	0.05	0.24	-0.09	0.07	-0.02	0.72	-0.11	0	0.05	0.26	0.03

Springs, CO																	
Elk River near Milner, CO	-1.6	0	0	0.99	-	-	0.26	0.04	-0.30	0.03	-0.15	0.23	-0.32	0	0.09	0.62	-0.05
Yampa River at Milner, CO	-1.2	0	0.17	0.03	-	-	0.02	0	-0.20	0.03	-0.10	0.20	-0.24	0	0.05	0.51	0.04
Yampa River above Elkhead Creek near Hayden, CO	-0.94	0	0.12	0.01	-	-	-	-	-	-	-	-	-	-	0.14	0.16	-0.13
Yampa River below Craig, CO	-1.0	0	-0.03	0.56	-	-	0.27	0	-0.24	0	0.01	0.85	-0.26	0	0.06	0.57	-0.30
Total phosphorus, in milligrams per liter																	
Yampa River above Stagecoach Reservoir, CO	-2.8	0	0.37	0	-	-	0.22	0	-0.42	0	-	-	-	-	0.08	0.79	0.03
Yampa River below Oak Creek near Steamboat Springs, CO	-3.0	0	-0.25	0.03	-	-	0.4	0.01	-0.29	0.01	-0.13	0.22	-0.22	0.01	0.12	0.39	-0.04
Yampa River at Steamboat Springs, CO	-3.2	0	-0.08	0.26	-	-	0.16	0.04	-0.21	0.02	0.12	0.15	-0.19	0	0.15	0.27	0.04
Elk River near Milner, CO	-3.9	0	0.06	0.7	-	-	0.66	0	-0.47	0.02	-0.26	0.14	-0.37	0	0.21	0.75	-0.21
Yampa River at Milner, CO	-3.1	0	-0.29	0	-	-	0.51	0	-0.12	0.33	-	-	-	-	0.15	0.40	-0.33
Yampa River above Elkhead Creek near Hayden, CO	-2.9	0	0.21	0.03	-	-	0.48	0	0.01	0.94	-	-	-	-	0.25	0.59	-0.33

Yampa River below Craig, CO	-3.0	0	0.12	0.11	-	-	0.53	0	-0.27	0	-0.03	0.77	-0.29	0	0.16	0.67	-0.16

Table 1.2. Regression model coefficients and statistical diagnostics for loads of suspended sediment, Kjeldahl nitrogen, and total phosphorus at seven sites in the Upper Yampa River Basin, Colorado.

[USGS, U.S. Geological Survey; ln, natural logarithm; Q*, centered daily streamflow in cubic feet per second (ft^3/s); Time*, centered decimal time in decimal years; sin(2πT), sine function of a Fourier Series; π, approximately 3.141593; T, decimal portion of the year starting January 1; cos(2πT), cosine function of a Fourier Series; k, is an integer; ERV, estimated residual variance; R^2 , adjusted coefficient of determination; SCR, serial correlation of the residuals; Est., estimate coefficient; p-value, significance statistic, —, no coefficient available]

USGS site name	Y-axis intercept		ln(Q*)		Time*		sin(k*2πT) k=1		cos(k*2πT) k=1		sin(k*2πT) k=2		cos(k*2πT) k=2		ERV	Adjusted R^2	SCR
	Est.	p-value	Est.	p-value	Est.	p-value	Est.	p-value	Est.	p-value	Est.	p-value	Est.	p-value			
Suspended sediment, in milligrams per liter																	
Yampa River above Stagecoach Reservoir, CO	7.5	0	1.77	0	-	-	-	-	-	-	-	-	-	-	1.19	0.51	0.28
Yampa River below Oak Creek near Steamboat Springs, CO	8.2	0	0.95	0	-	-	0.92	0	-0.45	0.02	-0.52	0.01	-0.28	0.04	0.33	0.92	0.07
Elk River near Milner, CO	8.9	0	1.69	0	-	-	0.56	0.01	0.32	0.13	-	-	-	-	0.44	0.94	-0.09

Yampa River at Milner, CO	9.6	0	0.44	0	-	-	0.78	0	-0.26	0.33	-0.28	0.38	-0.44	0.01	0.48	0.92	-0.27
Yampa River above Elkhead Creek near Hayden, CO	10	0	1.99	0	-	-	-	-	-	-	-	-	-	-	0.57	0.93	-0.14
Kjeldahl nitrogen, in milligrams per liter																	
Yampa River above Stagecoach Reservoir, CO	4.2	0	1.16	0	-	-	0.20	0	-0.49	0	-0.04	0.37	0.09	0.05	0.03	0.97	-0.03
Yampa River below Oak Creek near Steamboat Springs, CO	5.6	0	0.81	0	-	-	0.08	0.33	-0.17	0.05	-0.11	0.20	-0.20	0	0.08	0.93	-0.26
Yampa River at Steamboat Springs, CO	5.8	0	0.89	0	-	-	0.05	0.24	-0.09	0.07	-0.02	0.72	-0.11	0	0.05	0.96	0.03
Elk River near Milner, CO	5.2	0	1.00	0	-	-	0.27	0.04	-0.30	0.03	-0.15	0.23	-0.32	0	0.09	0.97	-0.05
Yampa River at Milner, CO	6.5	0	0.83	0	-	-	0.24	0	-0.20	0.03	-0.10	0.20	-0.24	0	0.05	0.97	0.04
Yampa River above Elkhead Creek near Hayden, CO	6.6	0	1.12	0	-	-	-	-	-	-	-	-	-	-	0.14	0.94	-0.13
Yampa River below Craig, CO	6.6	0	0.97	0	-	-	0.27	0	-0.24	0	0.01	0.85	-0.26	0	0.06	0.97	-0.30
Total phosphorus, in milligrams per liter																	

Yampa River above Stagecoach Reservoir, CO	2.4	0	1.37	0	-	-	0.22	0	-0.42	0	-	-	-	-	0.08	0.95	0.03
Yampa River below Oak Creek near Steamboat Springs, CO	3.6	0	0.75	0	-	-	0.40	0	-0.29	0.01	-0.13	0.22	-0.22	0.01	0.12	0.92	-0.04
Yampa River at Steamboat Springs, CO	3.7	0	0.92	0	-	-	0.16	0.04	0.02	0.02	0.12	0.15	-0.19	0	0.15	0.90	0.04
Elk River near Milner, CO	3.0	0	1.06	0	-	-	0.66	0	-0.47	0.02	-0.26	0.14	-0.37	0	0.21	0.96	-0.21
Yampa River at Milner, CO	4.6	0	0.71	0	-	-	0.51	0	-0.12	0.33	-	-	-	-	0.15	0.90	-0.33
Yampa River above Elkhead Creek near Hayden, CO	4.6	0	1.21	0	-	-	0.48	0	0.01	0.94	-	-	-	-	0.25	0.94	-0.33
Yampa River below Craig, CO	4.7	0	1.12	0	-	-	0.53	0	-0.27	0	-0.03	0.77	-0.29	0	0.16	0.96	-0.16