UPPER WHITE RIVER WATERSHED ASSESSMENT

Nov 21, 2017

REPORT

Prepared for:

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Executive Summary

Elk Creek Ranch and its owners contracted HydroSolutions of Helena, Montana to investigate the Upper White River nuisance algae problem through review of existing data and assessment of nutrient sources. HydroSolutions prepared this report for Elk Creek Ranch and its owners. The Upper White River Watershed is that portion upstream of Meeker, CO, with a focus on the White River Watershed above Coal Creek. The assessment focuses on analysis of existing data, solely within the upper portions of the Upper White River watershed. HydroSolutions collaborated with Dr. Kyle Flynn, P.E., on portions of the watershed assessment through a subcontract with KF2 Consulting.

Since 2014, nuisance benthic filamentous algae identified as C*ladophora glomerata* have been observed in the North Fork and mainstem of the White River upstream of Meeker, CO. The recent dominance of *Cladophpora* appear to represent an assemblage shift from desirable to less desirable of algal species (e.g., diatom biofilm to filamentous green algae), and widespread accumulations are likely a result of a number of complex contributing factors, many of which are detailed throughout this report. While numerous considerations exist in the proliferation of benthic algae, important contributors to algal accumulation typically include the following:

- Increased nutrient availability (nitrogen or phosphorus) that affect algal growth rate
- Diminished streamflow velocity or scouring runoff that enables greater accumulation of algal biomass over the growing season
- Changes in mean daily water temperature that translate into higher growth rate
- Changes in incident light or photosynthetically active radiation that cause increases in photosynthetic rate

The above factors are all evaluated herein and are influenced by human (anthropogenic) activities such as land disturbance, nutrient management of fertilizers, animal manure, septic systems, fish feeding, municipal or industrial discharge; or they may be beyond human control. Natural and man-made changes in river streamflow magnitude, duration, frequency, or timing, and associated hydraulics, can impact nutrient cycling and algal proliferation. Finally, alteration in streamflow magnitude, duration, and frequency, whether natural or human caused, can influence algal dynamics.

The Upper White River Watershed Assessment began with a review of previous published works. It was found that baseline water quality samples collected in the Upper White River by the United States Geological Survey (USGS) in the 1980s and 1990s contained elevated concentrations of nutrients that were considered sufficient to produce nuisance algae growth in the White River. Additionally, a more recent USGS study identified the Upper White River was as being a major source of nitrate and orthophosphate, even to the lower parts of the river. Recent work by Colorado Parks and Wildlife have also recorded large algal biomass accumulations throughout much of the upper watershed in the form of filamentous algae, and have also identified through nutrient diffusing substrate experiments that the watershed is currently not at saturating levels for nutrients.

A review and compilation of existing water quality data was completed and found only a few USGS gage sites have sufficient data upstream of Meeker, CO to support robust analysis. Water quality data review and analysis was completed and provided numerous findings:

- The median concentrations of total phosphorus (TP) and total nitrogen (TN) data, are far below the interim numeric Colorado nutrient standard making it unlikely from a regulatory perspective that these would be considered contributors to nuisance algal conditions. However, this report provides supporting information that the standards are likely too high.
- No indication of dissolved oxygen (DO) impairment exists relative to the spawning standard of 7 mg/L (15th percentile of all data). As such, water column and inter-gravel oxygen concentrations are currently supporting fish and aquatic life uses.
- pH at sample sites for most sites is within the required range of 6.5–9.0 S.U. (maximum and minimum criteria). The exception is CORIVWCH_WQX-531 5th Street Bridge, which demonstrated exceedances over the maximum allowable pH of 9.0. Alkaline conditions can negatively affect fish mucous membranes such as gills and eyes.
- Dissolved organic carbon (DOC) has only been sampled at one location in the White River downstream of Meeker. The result far exceeds the water quality standard of 3.0 mg/L.
- Measurements of benthic algal biomass made in the Upper White River Watershed by Colorado Parks and Wildlife (CPW) suggest that nuisance algal biomass responses are occurring at numerous locations in the watershed. Chlorophyll a data collected by CPW exceed the Colorado chlorophyll a water-quality standard by a large margin.

Additionally, we examined factors that directly influence algal growth rate such as water temperature, light, and nutrients. The following was concluded:

- Changes in water temperature are believed to have little influence on recent nuisance algal conditions in the White River. Instantaneous temperature data indicate that a small spatial difference in water temperature exists between the North and South Fork White River relative to the White River above Coal Creek. No apparent change in mean daily water temperature from the period 1978 to 1984 and 2007 through current was detected in the White River upstream of Meeker, CO.
- Suspended sediment data downstream of Meeker, CO (i.e., no current data upstream) indicates there has likely been an increase in the percentage of surface photosynthetically active radiation (PAR) reaching the bottom of the channel at a depth of one meter. Such changes are believed to result in only a minor change in growth rate (<5%) for *Cladophora*.
- Examination of flow normalized nutrient concentration and mass loadings in the Upper White River show that both total and dissolved nitrogen is decreasing while phosphorus is increasing. As such algae are nitrogen limited, and the watershed has shifted from being phosphorus-limited in the early 1990s to nitrogen-limited currently. Modeling seems to indicate a change occurred in 2005 altering the trajectory of all nutrient species of interest. However, no correlating or anecdotal information for which to attribute this

shift was found. The North Fork White River (North Fork) currently has the highest concentration of TN followed by the White River above Coal Creek, and then the South Fork White River (South Fork).

Based on the understanding above, nitrogen reductions in the watershed should be the firstmost priority followed by phosphorus to reduce algal biomasses provided other factors (e.g., light, temperature, and scour) are not more controlling.

The water quality data review also identified a number of data gaps. Existing data is insufficient to fully assess the chemical and biological condition of the Upper White River. Data collection could be improved upon by the following: ensuring adequate laboratory method detection resolution and reporting limits, developing a synoptic monitoring program and spatial coverage of monitoring sites throughout the watershed to assess nutrient source contributions and loads, diurnal monitoring of field parameters DO and pH during peak algal growth, collection of algal/periphyton samples (chlorophyll-a, ash free dry mass, and algal nutrient tissue content) throughout the watershed with co-located water-quality (nutrient) monitoring, suspended solids and PAR monitoring, and characterization of bed substrate (particle counts) and river transects to form a better understanding of river hydraulic conditions. Finally, re-establishment of USGS gaging activities in the North and South Fork White River for the purpose of daily flow monitoring is needed to fully assess nutrient loading from those tributaries. These data deficiencies should be considered for future planning purposes.

A limited amount diurnal water quality data was aslo collected for several days in late August 2017 as part of this investigation through deployment of three multiparameter water quality sondes in the Upper White River, North Fork, and South Fork tributaries to evaluate instream conditions and diurnal changes in water quality. This effort found a distinct day-night variation in DO and pH at all sites. At the White River above Elk Creek, pH levels peaked mid-day and exceeded the protective maximum pH standard of 9.0 S.U., presumably due to algal photosynthesis. At this same site DO levels dropped below 7.0 mg/L on two days in the early morning likely from algal respiration, which is the minimum standard required during the spawning season. A greater day-night variation in both DO and pH is evident in the mainstem and the North Fork when compared with the South Fork site, coinciding with a greater presence of algal biomass in the mainstem and North Fork, compared to the South Fork White River.

Hydrologic and streamflow data was analyzed and found there were likely multiple factors relating to watershed hydrology that contributed to nuisance algal blooms during previous years including: lack of sustained scouring flows leading to channel bed disturbance and channel bed stability that may provide armoring in places and increase the likelihood that algal communities persist from year to year; timing of runoff and length of growing season; occurrence and frequency of low flows; and known climatic changes inducing reductions in streamflow in the upper Colorado River Basin.

A watershed nutrient source assessment was subsequently completed to better understand the potential contributions of nutrient sources in the project area, and to make estimates of mass loading on an average annual basis and for a summer-month. Nutrient sources in the project area are nonpoint sources or dispersed contaminant sources. The assessment found that there are few readily controllable sources of nutrients in the watershed study area. Forested and grasslands represent the largest land covers and contribute to 85% to 91% of the annual TN and TP loads, respectively. This is not unusual for predominately forested watersheds, but identifying sources and implementing management practices is more difficult, and implementing effective management practices may not be as practical.

In examining the controllable nutrient inputs, the combined contribution in the watershed from septic system inputs, fish feeding, and agricultural use (includes hay/forage production and livestock grazing) on an annual basis is 11% and 8% for TN and TP, respectively, most of which is from agricultural use. During a typical low flow summer-month, critical to algal growth, the combined contribution from septic system inputs, fish feeding, and agricultural use increases to 23% and 17% from TN and TP, respectively. Nutrient inputs from urban or developed land use represent 5% of the summer-month TN load and 1% of the TP for the watershed (½–3% of the annual load, respectively). Controlling nutrient inputs from urban or developed land use, septic systems, and agricultural practices are typically accomplished through maintenance and implementation of best management practices, and may require additional investigation and planning. Nutrient inputs from fish feeding during summer-months can be directly mitigated through curtailment of the practice.

This report also provides recommendations in mitigating and controlling nuisance algae in the Upper White River. Of critical importance is the development of a watershed approach in the management of future actions. We understand the White River & Douglas Creek Conservation District (CD) has been identified as the lead agency to coordinate watershed activities and stakeholders in working on the nuisance algae problem for the White River. Further organization of a formalized management board or council of key stakeholders should be accomplished to direct the work and set priorities of the CD. Key tasks of this board would be to define management goals and objectives, identify the most pressing issues, develop comprehensive management strategies, and oversee a watershed-wide monitoring program. Additionally, a technical advisory committee should be formed to advise and inform the watershed board on technical issues or to undertake specific watershed efforts or tasks. One such committee could be a water quality monitoring committee responsible for organizing, reviewing, and reporting on water quality issues in the watershed.

The development of a comprehensive watershed-wide monitoring program overseen by a single organization is recommended to support sound, scientifically-based water management decisions, and to gage achievement of management goals. The program should be limited in scope by identification of a watershed area of interest and the development of specific monitoring objectives set by the watershed board. The monitoring program must include a quality assurance project plan (QAPP) with data validation controls to ensure collected data is defensible and can be used for its intended purpose. Water quality sampling and other activities must be completed under a sampling and analysis plan (SAP) to ensure sampling protocols are consistent and defensible. The water quality monitoring program should address the identified data deficiencies noted previously.

Nutrient source reduction management strategies and practices should be implemented to address all practical nutrient sources to limit algal accumulation in the watershed, beginning with nitrogen sources followed by phosphorus. Nutrient source reduction opportunities should also be identified and pursued through onsite surveys and condition assessments, stakeholder questionaires and collaboration, and through regular water quality monitoring. Many management strategies have already been identified in the Meeker Source Water Protection Plan. A critical component of implementing nutrient source reductions is through the engagement and education of watershed stakeholders.

A number of more specific recommendations include to: identify and creating and inventory of conditions of agricultural areas used for hay/forage production for grazing areas through GIS analysis and site surveys; develop and implement best management practices for agricultural uses including fertilizer application, sediment management, and grazing practices; inventory spring and seeps that discharge to tributary streams and install grazing exclosures; implement alternative stock watering, create buffer zones between cattle and streams, and support stable stream bank practices.

Additionally, related to reducing septic system inputs, Rio Blanco County should: compile septic system information within the County into a GIS spatial database, beginning with new construction and then expanding to include older systems; complete a septic system vulnerability analysis to identify key areas to address; implement a public education program to provide information on proper use and maintenance of their septic systems; begin or continue to implement the County’s optional septic system inspection program; ensure proper permitting and approval for new septic systems.

Fish feeding may be the easiest nutrient source in the watershed to control and curtail. Stakeholders that currently feed fish should consider curtailing the practice during the summer months or altogether.

While some of the abovementioned factors are outside of human control at the local level (e.g., changes in climate and streamflow are a more widespread issue and may unfortunately be the new status quo), effective management strategies to reduce algal blooms in the White River must focus on tangible activities that address factors related to algal growth rate. From a practical perspective, the remaining toolbox is limited, primary to nutrient management. Activities should include development of a board or council of watershed stakeholders to guide and direct watershed management and monitoring activities; formation of a technical advisory committee to advise the board; development of a defensible watershed-wide water quality monitoring program; and implementation of nutrient source reduction activities and practices, with a focus on reducing nitrogen sources.

Finally, in the spirit of collaboration, this report went a long way in framing the problem, identifying and interpreting available data, and making recommendations. However, we see this report only a beginning. The full understanding of *Cladophora* as a nuisance in the White River will not be solved overnight nor in a single study. Collective watershed solutions will also likely not be an easy endeavor. Conclusions herein may even be refined or reinterpreted. However, by adding to the collective body of knowledge incrementally, strengthening analysis and filling data gaps, and even strengthening relationships in the watershed, a collective and collaborative approach between stakeholders, researchers, and agency personal will go a long way to providing a lasting understanding and solution to the nuisance algae problem in the Upper White River.

1 Background and Introduction

Elk Creek Ranch and its owners contracted HydroSolutions of Helena, Montana to investigate the Upper White River nuisance algae problem through review of existing data and assessment of nutrient sources. HydroSolutions prepared this report for Elk Creek Ranch and its owners. The Upper White River Watershed is that portion upstream of Meeker, CO, with a focus on the White River Watershed above Coal Creek. The assessment focuses on analysis of existing data, solely within the upper portions of the Upper White River watershed. HydroSolutions collaborated with Dr. Kyle Flynn, P.E. on portions of the watershed assessment through a subcontract with KF2 Consulting.

1.1 Problem Statement

Since 2014, nuisance benthic filamentous algae have been observed in the North Fork White River (North Fork) and mainstem White River upstream of Meeker, The Colorado Parks and Wildlife (CPW) has identified this algae as C*ladophora glomerata*, one of the most conspicuous and pervasive nuisance aquatic algae species world-wide. The impact of its filaments have been documented in alkaline lakes and rivers across the United States (U.S.), interfering with swimming and fouling of fishing lines, clogging of irrigation intakes, and harm to fish and aquatic life through oxygen depletion at night, high daytime pH, or increased ammonium toxicity. *Cladophora* often thrives in phosphorus-enriched shallow clear waters with stable substrate. Like other benthic algae, *Cladophora* is highly patchy in spatial and temporal distribution.

Recent algal accumulations in the Upper White River are likely a result of a number of complex contributing factors, which are detailed throughout this report. While numerous considerations affect the proliferation of benthic algae, some of the most common contributors include the following:

- Increased nutrient availability (nitrogen or phosphorus) that affect algal growth rate
- Diminished streamflow velocity or scouring runoff that enables greater accumulation of algal biomass over the growing season
- Changes in mean daily water temperature that translate into higher growth rate
- Changes in incident light or photosynthetically active radiation that cause increases in photosynthetic rate

The above factors can be influenced by human (anthropogenic) activities such as land disturbance, nutrient management of fertilizers, animal manure, septic systems, fish feeding, or municipal or industrial discharges, or may also be outside our control. Natural and man-made changes in hydraulics can impact nutrient cycling and algal proliferation. Finally, shifts in streamflow magnitude, duration, and frequency, whether natural or human caused, can influence algal dynamics.

1.2 Impacts of Nuisance Algae

Elevated algal levels, in particular nuisance algae (Welch, Jacoby, et al. 1988, Dodds, Smith and Zander 1997, Suplee, Watson, et al. 2009), are believed to be the current concern in the

White River. They are primarily an aesthetic and recreational nuisance at this time based on our current understanding. However, the negative effects of large algal biomasses can be far more reaching if altered diurnal dissolved oxygen (DO) and pH variation occurs (Walling and Webb 1992). If significant enough (i.e., fluctuations too severe), DO and pH variations can cause fish kills (Welch, Quinn and Hickey 1992). Likewise, aquatic insect or macroinvertebrate populations can also be affected. Taxa shifts are most frequently reported in response to increasing enrichment. Sensitive macroinvertebrates such as mayflys (*Ephemeroptera*), stoneflys (*Plecoptera*), and caddisflys (*Trichoptera*) tend to prefer clean water with low nutrient concentrations (i.e., without extreme daily DO oscillations) while midge species (chironomids) tend to be abundant in heavy polluted water (Hilsenhoff 1987, Hynes 1966, Lenat and Penrose 1996). Finally, in such systems, macroinvertebrate density and biomass tend to increase in relation to enrichment, yet sensitive species diminish (Gücker, Brauns and Pusch 2006). An aerial photograph of the White River near Elk Creek Ranch is shown in **Photograph 1**. The photograph was taken on July 26, 2017 and shows the presence of extensive bright green filaments in the stream.

Photograph 1. White River near Elk Creek Ranch, taken on July 26, 2017

1.3 Project Purpose

This report is intended to facilitate a common understanding of the problem, compile and review relevant water quality indicators that can be analyzed, and to characterize existing water quality data and trends as well as hydrologic or hydraulic changes that may contribute to the algal proliferation in the watershed. Additionally, it is structured to assess nutrient loading and known primary nutrient contributors in the watershed, and lastly address deficiencies and limitations in the current state of understanding in the watershed. Finally, it provides recommendations for future work. The report is written to reach a broad audience. As such, most of supporting technical documentation and method descriptions are provided at the end of this document.

This report was prepared for Elk Creek Ranch and its owners. Distribution of the report is at the discretion of Elk Creek Ranch. The focus of this report are those areas and components that most affect Elk Creek Ranch and their interests. This report is not intended to be a comprehensive assessment of all activities and potential impacts to the watershed. The analysis focuses solely on the upper portions of the White River watershed.

1.4 Study Area & Regional Characteristics

The White River Basin drains approximately 3,770 square miles and encompasses almost all of Rio Blanco County (Williams 2008). The area assessed by this investigation includes the White River upstream of Meeker, CO, with a focus on the White River above Coal Creek (project study area). The study area is show in **Figure 1**.

The White River watershed above Meeker, CO is characterized as a Southern Rockies ecological region at its headwaters, and transitions into a Colorado Plateau ecological region just east of the town of Meeker. The upper reaches of the White River watershed include high elevation, steep, rugged mountains with areas covered by coniferous forests. Vegetation, soil, and land use change with elevation. Middle elevations are grazed with vegetation coverage which includes Douglas-fir, ponderosa pine, aspen, and juniper-oak woodlands. The lowest elevations of this ecological region are covered by grass and shrubs that are grazed by cattle and sheep (Chapman, et al. 2006). The characterization of this area primarily as a southern Rockies ecological region serves as the framework used for this assessment.

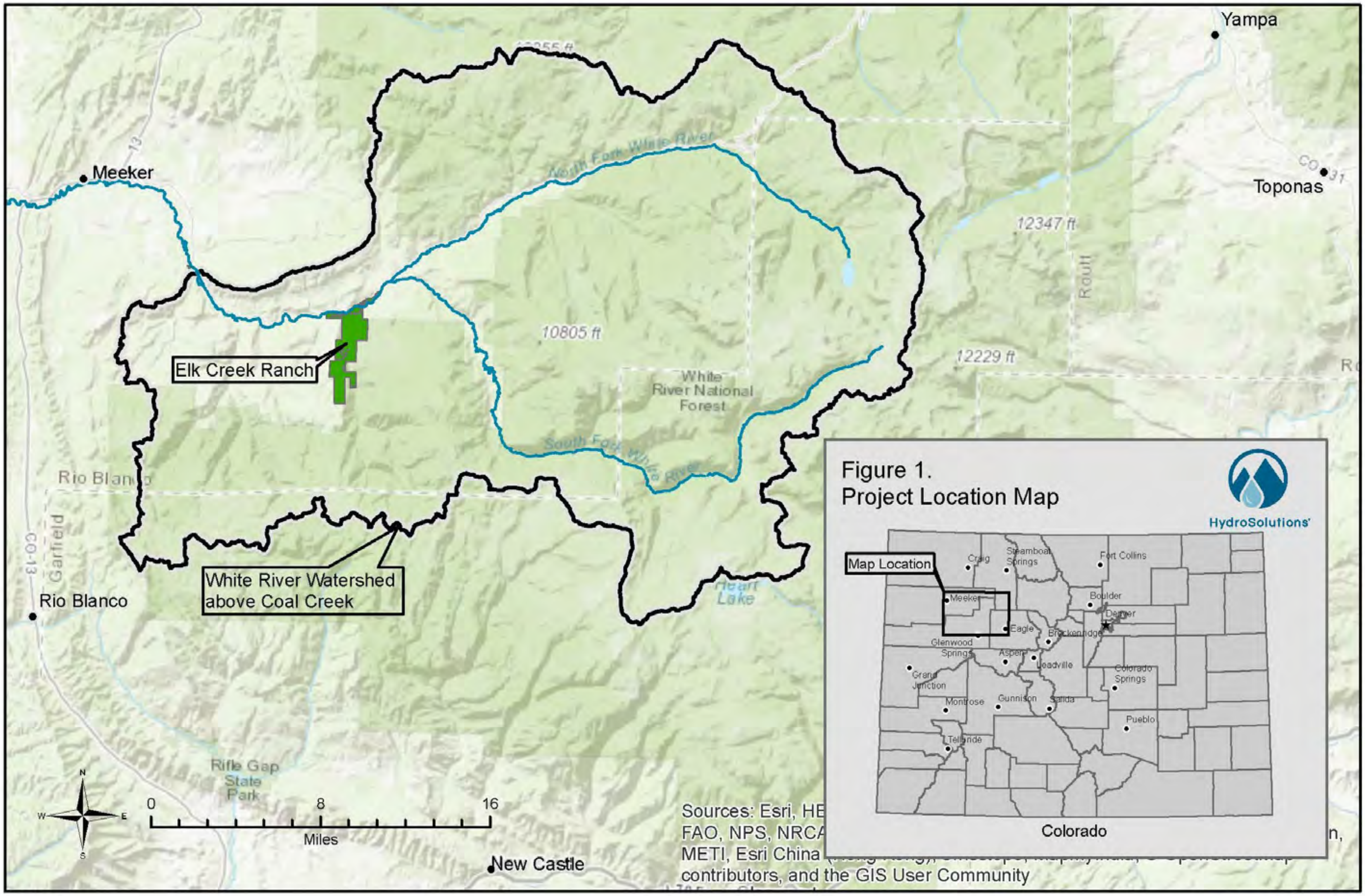

Figure 1. Upper White River watershed assessment project location map

1.5 Summary of Methods

The focus of the Upper White River watershed assessment was to investigate existing water quality data and to develop an understanding the factors leading to and affecting recent algal blooms in the Upper White River. This watershed assessment primarily focused on the review of existing data, although limited data was collected for the project. Specific methods used in this watershed assessment are detailed in respective sections. The general work methodologies completed as part of this assessment included:

- Summary of water quality indicators and applicable water quality standards relating to understanding recent nuisance algal growth
- Literature review of State of Colorado water quality assessment report, published works, and other reports relating to water quality indicators, both in general, and also specifically relating to the project area and potential for algal growth
- Review of recent investigations of water quality and benthic algae data collected by CPW in the upper White River
- Compilation existing water quality data for project area using the Water Quality Portal (WQP) to identify water quality conditions and data gaps, and to make recommendations
- Identification sites with sufficient data to evaluate water quality, to compile and analyze comparable records, and evaluate data against standards.
- Characterizing trends in concentrations and loads for factors that directly influence algal growth rate such as water temperature, suspended sediment concentration, and nutrients to provide a better indicator of environmental conditions contributing to nuisance algae in the watershed.
- Considering data deficiencies for future planning purposes
- Conducting a site visit of the watershed and deploying multiparameter water quality sondes at three locations in the Upper White River and tributaries to evaluate instream conditions and diurnal changes in water quality for about a week in late August-early September 2017.
- Analyzing hydrologic and streamflow data available from USGS to identify potential scouring flows, and for apparent changes in the hydrologic regime that could potentially be contributing to recent algal blooms
- Completing a watershed nutrient source assessment to better understand the potential contributions of nutrient sources in the project area, and made estimates of mass loading for annual loading and summer-month loading
- Preparing a summary of findings and recommendations of strategies to manage and reduce the occurrence of algal blooms in the Upper White River.

1.6 Water Quality Indicators and Applicable Water Quality Standards

Numeric water quality standards in Colorado have been adopted in Regulation No. 31 and Regulation No. 37, which provide a way to assess whether designated uses are being supported (CDPHE 2017a, CDPHE 2017b). Table 1 identifies water quality criteria for DO, pH, interim total nitrogen (N) and phosphorus (P) concentrations (collectively N and P, or nutrient), benthic chlorophyll-a (chl *a*), and dissolved organic carbon (DOC) for the White River. The latter has been included per Regulation No. 31 to limit disinfection by-products (DBPs) from organic material produced by algae.

Table 1. Numeric standards for Lower Colorado River Basin including the Upper White River study reach by Colorado Department of Public Health and Environment (CDPHE) Water Quality Division (CDPHE 2017a, CDPHE 2017b)

Assessment Unit Identifier (AUID)	Classifications	Standard						
		Total Nitrogen (mg/L)[a]	Total Phosphorus (mg/L)[a]	DO (mg/L)		pH (S.U.)	Chla (mg/m²)[b]	DOC (mg/L) [c]
				Spawning	Rest of Year			
COLCWH03	Agriculture, Aquatic life Cold 1, Recreation E, Water Supply	1.25	0.110	7.0	6.0	6.5 to 9.0	150	3.0
COLCWH06	Agriculture, Aquatic life Cold 1, Recreation E, Water Supply							
COLCWH07	Agriculture, Aquatic life Cold 1, Recreation E & P, Water Supply							

[a] Annual median, allowable exceedance frequency 1-in-5 years.
[b] Summer (July 1 – September 30) maximum attached algae, not to exceed.
[c] DOC threshold was linked to algal abundance using a ratio of DOC to chlorophyll from lakes in which DOC is predominantly from algae. It is applied to streams cautiously here.
mg/L – milligrams per liter
mg/m² – milligrams per square meter

Beneficial use attainment is judged by attainment of numeric standards. Procedures to evaluate attainment are described in CDPHE (2017) as referenced below. Specifically, in streams and rivers a comparison is made between the standard and the 85th percentile of the ranked data for chronic water quality conditions. DO is evaluated at the 15th percentile for streams and must be compared to the both the annual and spawning season criteria[1]. pH maxima is evaluated against the 85th percentile. Finally, the annual median of either total nitrogen (TN; µg/L) or total

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[1] Attainment of the spawning season DO standard is evaluated through a two-step process. An initial screening is performed by comparison of the 15th percentile DO value to the 7.0 mg/L spawning season based standard. In instances where the 15th percentile value for the entire dataset is less than the 7.0 mg/L seasonal standard, the dataset is subdivided into spawning/non-spawning values and the 15th percentile value for the spawning season data is compared to the spawning season criterion.

phosphorus (TP; µg/L) is compared for the site, with an allowed exceedance frequency 1-in-5 years [2].

Based on the aquatic life and recreational use tiers reported in Table 1, along with spatial information on the location of the waterbody in the Upper Colorado River, several water quality indicators should be used to evaluate support of designated uses in the White River. These indicators include:

- Nutrient concentrations in various forms, a potential indicator of eutrophication and for which bioavailable forms stimulate algal growth
- DO; which is a measure of the oxygen concentration of the water column, necessary for respiration of aquatic life
- pH, which is the negative log of the hydrogen ion activity, which can influence mucus cells in gill filaments and skin epithelium, and the eye lens/cornea of fish
- Chlorophyll-a biomass, which is a measure of the amount of algae attached to the stream or river bottom. Elevated levels are indicative of nuisance algal conditions
- DOC, that if elevated from algal growth can cause DBPs during the chlorination process at water treatment facilities

In addition to the constituents identified above, there are also other water-quality variables that can indirectly influence algal growth rate. These variables include:

- Water temperature, which has a direct influence on metabolic algal growth rate and thus is a fundamental forcing function of biological kinetics
- Total Suspended Solids (TSS), which if elevated may reduce light penetration and reduce algal growth, impact visual hunters such as trout, or smother benthic algae, macroinvertebrates, and fish eggs

Water quality standards, such as those listed in Table 1 are designed to protect beneficial uses including agriculture, aquatic life, and recreation. Standards are the regulatory basis for assessing the condition of waterbody as well as for controlling loading limits on point source discharges.

2 Literature Review and Water Quality Data Sources

A review of existing literature was conducted to understand and compile prevailing water quality and hydrologic conditions for the White River in the vicinity of Elk Creek Ranch. This section provides a summary of information reviewed relating to water quality indicators, both in general, and also specifically relating to the project area and its potential for algal growth. This section also summarizes the data compilation of water quality data from Water Quality Portal. The

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[2] It should be noted that the authors of this report believe the proposed interim numeric nutrient standards are too high to limit nuisance algal biomass. This is elaborated on throughout the document, but the median annual value has little relevance to conditions experienced during algal accumulation and requires knowledge about the underlying data distribution to ascertain its utility.

purpose of the data compilation was to identify water quality conditions in the White River project area and to identify data gaps and make recommendations for future data gathering as well as to guide subsequent analysis in this document. Finally, this section includes review of ongoing data collection efforts conducted by CPW in the project area.

2.1 White River Water Quality Status

All segments within the White River study area have been previously assessed by the Colorado Department of Public Health and Environment (CDPHE) Water Quality Division as part of their 2016 Integrated Report (CDPHE 2016). This is a biannual publication required by Section 305(b) of the Federal Clean Water Act requiring states to evaluate whether U.S. waters meet established water quality standards.

Review of the 2016 Integrated Report indicates three Assessment Unit Identifiers (AUID) occur within the White River project site. These correspond to the mainstem and North Fork and South Fork White River (South Fork). Each AUID has been characterized as fully supporting agricultural, aquatic life, recreational, and water supply beneficial uses; with the exception of the lowermost AUID (COLCWH07) which extends from Miller Creek to below Meeker and is affected by the town of Meeker, CO municipal discharge. This assessment and characterization from the most recent listing cycle is in contrast to observations by stakeholders in the watershed.

2.2 Published Works

The following is a summary of principal literature reviewed relating to the project area either in water quality or factors affecting algal growth. Included is the title of the report or document and a summary of information pertinent to the project area. It is recognized that there are whole literary bodies on topics such as algal-nutrient relationships, velocity-periphyton interactions, photosynthesis-irradiance response, septic system nutrient contributions, agricultural management practices, fish-feeding, etc. In the spirit of brevity, this report cites these sources in the relevant sections instead of here.

1. Town of Meeker Source Water Protection Plan (Williams 2008)

- Describes the setting of the White River alluvial aquifer, which is the Town of Meeker’s municipal water supply source. Also describes the water quality setting including hydrology, water quality standards, and drinking water supply operations.
- Lists the agencies, stakeholders, and personnel participating public planning process to develop the plan.
- Delineates the protected source water area, and inventories and assesses contaminant sources.
- Discusses groundwater contaminant concerns including septic systems, private water wells, transportation, growth and development, agricultural practices, livestock grazing, gravel mining, public land use, oil and gas development.
- Provides recommended management practices to protect and enhance water quality of the water source, and provides a comprehensive action plan in case of an emergency that threatens the water supply.

2. **Quantity and Quality of Streamflow in the White River Basin, Colorado and Utah** (USGS 1984)
    - Provides historical water quality and hydrologic data collected by the U.S. Geological Survey (USGS) to provide baseline data to serve as a measure for the effects of future development.
    - Concluded that water quality and quantity in the White River was adequate for its present use, but could be affected by future development.
    - Notes effects of the Meeker dome on hydrologic patterns and water quality on the White River just above Meeker. These effects include sharp increases in specific conductance total dissolved solids, dissolved nitrogen and phosphorus concentrations; and decreases in water temperature and dissolved oxygen level.
    - Notes elevated algal growth potential and concludes that the White River was enriched with nitrogen, but contained smaller concentrations of phosphorus.
    - Benthic invertebrate levels were analyzed. The eastern (headwaters) part of the White River exhibited healthy counts, while a slight deterioration of invertebrate levels were reported downstream of the confluence of the North and South Forks of the White River.

3. Sediment Transport and Water-Quality Characteristics and Loads, White River, Northwestern Colorado, Water Years 1975-88 (Tobin 1993)

- Provided analysis of stream flow, sediment and water quality. Report quantifies annual sediment loads and defines sediment size characteristics, and relates changes in sediment characteristics with differences in basin hydrology; also quantifies dissolved solids loads and water quality characteristics.
- Describes basin characteristics including structural geologic elements. Surface geology of the basin is mostly sedimentary rocks ranging in age from the Paleozoic Era to the Cenozoic Era. Paleozoic and Mesozoic Era sedimentary rocks are most common in the eastern third of the basin (i.e. the project area).
- Combined stream discharges of the North Fork and South Fork accounted for 78 percent of the total stream discharge of the White River at a site between Meeker and Rangely. Most of the water enters the basin as snowmelt containing small quantities of suspended sediment and dissolved solids. This snowmelt runoff that occurs in spring and early summer dilutes and transports the large concentrations of suspended sediment and dissolved solids that enter the White River from the central parts of the basin.
- Describes a decrease in water quality below Meeker attributed to large quantities of fluvial sediment from semiarid tributary basins, large concentrations of dissolved solids from groundwater sources, and concentrations of nitrogen and phosphorus in irrigation return flow.
- Nutrient water quality samples showed that the combined concentrations of dissolved nitrogen and phosphorus often exceeded 0.3 mg/L as nitrogen and 0.01 mg/L phosphorus, which were considered levels sufficient to produce nuisance algae growths.

4. Ecological Responses to Nutrients in Streams and Rivers of the Colorado Mountains and Foothills (Lewis and McCutchan 2010)

- Studied 74 mountain streams in Colorado, ranging in elevation of about 4,900 to 9,800 feet above mean sea level. The streams were considered unenriched to mildly enriched with nutrients, nitrogen and phosphorus. (Note highly enriched waters were defined as phosphorus concentrations greater than 500 µg/l and nitrogen greater than 2,000 µg/l.)
- Study streams were similar to the White River in that they had predominantly natural vegetation with little anthropogenic nutrient sources. Half of the study streams had small nutrient sources including low-density housing (septic systems) or livestock grazing. The other half had no anthropogenic nutrient sources in their basins.
- Channel beds of the study streams contained gravel to small boulders and some exposed bed rocks. All of the study streams were shallow at base flow, which the authors define as less than one meter deep.
- The study showed:
  - No meaningful relationship between periphyton biomass accumulation and concentrations of total or dissolved forms of nitrogen or phosphorus.
  - A strong positive relationship between macroinvertebrate communities and periphyton abundance.
  - Variation in abundance of periphyton biomass was mostly attributed to 1) the initial amount of biomass at the start of the growing season, 2) length of the growing season, and 3) water temperature.
- Acknowledges that substantial nutrient pollution, within a large range of increasing nutrient concentrations, enhances periphyton biomass accumulation in streams with a stable bed and adequate radiant light reaching the bed.
- Suggests that the nutrient response in periphyton biomass is suppressed by other controlling factors at lower nutrient concentrations, and becomes a quantitatively significant response only in excess of a threshold beyond which nutrients become dominant over other controlling factors. The study also notes that suppression of periphyton growth rates across all elevations is yet unexplained.

5. The Influence of Channel Bed Disturbance on Algal Biomass in a Colorado Mountain Stream (Segura, et al. 2010)

- Conducted on the Williams Fork River (tributary to Colorado River in Grand County, Colorado), near the project area, and found that stream locations with higher bed disturbance showed slower accrual rates of algal biomass than locations with lower disturbance. The study showed that the rate of accumulation during the growing season had a quantitative relationship to channel bed disturbance over the growing season.
- Bed disturbance varies spatially over the full range of flows, and locally due to the channel geomorphology (e.g., shape, slope, etc.). The amount of bed disturbed increases with flow until the entire bed is in motion, and the movement of the bed at a given location is linked to diminished accumulation of biomass at that location.

- Concluded that channel bed disturbance sets back the average biomass accumulation spatially within a stream, and the rate of increase of biomass where disturbance is not occurring is established by another set of factors, called growth rate control factors.
- Growth rate control factors serve to check the biomass accumulation rate, and include:
    - Low concentrations of potentially limiting nutrients
    - Grazing associated with benthic macroinvertebrates
    - Moderate impairment of photosynthesis by tree canopy shading
    - Consistently low temperature, which the authors note is most important (mean water temperature of the three sites studied on the Williams Fork over two years ranged from 7.6 to 9.8 degrees Celsius)
- Growth rate factors together, diminished biomass accumulation over the reach scale at the study sites even when most of the bed was stable, i.e. not disturbed.

6. Characterization and Data-Gap Analysis of Surface-Water Quality in the Piceance Study Area, Western Colorado, 1959–2009 (Thomas, et al. 2013)

- Evaluated a large area of Western Colorado, including a portion of the White River at USGS 09304200 White River above Coal Creek, near Meeker, CO within the project area (shown in Figure 1**)**.
- Trend analysis and loading estimates of certain constituents were made. Monotonic trends were determined using a seasonal Kendall test with parabolic trends being identified by LOADEST (statistical model). The following water quality variables were considered in the analysis, which is current through 2009 (associated conclusions are shown in parenthesis):
    - Water temperature (1990–2009, no trend)
    - Dissolved oxygen (1990–2009, no trend)
    - pH (1990–2009, upward trend)
    - Ammonia (1990–2009, downward trend)
    - Nitrate (1990–2002, upward trend; 2002–2009, downward trend)
    - Orthophosphate (1990–2009, downward trend)
    - Phosphorus (1991–2009, upward trend)
    - Suspended Sediment (1990–2001, no trend)
- Loads were calculated using LOADEST for the 1996 water year. Those relevant to this work were 48.2 tons for nitrate and 27.3 tons for orthophosphate at the White River above Coal Creek. The upper White River was identified as being a major source of nitrate and orthophosphate even to the lower parts of the river.

2.3 Water Quality Data Compilation

A data compilation was initiated to identify water quality sites in the White River project area, to evaluate data, and identify data gaps and make recommendations. The initial compilation was done using the Water Quality Portal (WQP; www.waterqualitydata.us), which was recently developed as a cooperative service by USGS, the Environmental Protection Agency (EPA), and the National Water Quality Monitoring Council (NWQMC) to aggregate and standardize data using webservices. Details regarding this compilation are found in **Appendix A**. Through these queries, it was determined that USGS gages sites are the primary locations that have sufficient data upstream of Meeker, CO to support analysis. These sites are identified in Section 3.

2.4 Colorado Parks and Wildlife (CPW) Ongoing Monitoring Efforts

2.4.1 Description of Work

In the summer of 2015, Colorado Parks and Wildlife (CPW) initiated a preliminary investigation of nutrients and benthic algae in the Upper White River. This included the collection of water quality samples from 10 identified sites of interest on the North Fork and the mainstem White River above Meeker. Water quality samples were analyzed for total suspended solids, chloride, sulfate, total nutrients, and nitrate plus nitrite (NO_{3+2}) by Colorado River Watch Laboratory. Macroinvertebrates were also collected at six of the sample sites and scored using Colorado's Multi-Metric Index (MMI). CPW presents their preliminary findings and analytical results in a report available upon request (CPW 2016).

In 2016, CPW expanded their investigation into the cause and conditions of the algae blooms in the White River and sampled 15 locations in the White River and some of its tributaries, shown on **Figure 2**. Monthly water quality samples were collected from March through October and analyzed for nutrients, major ions, and suspended solids. Samples were analyzed for chloride, sulfate, TSS, NO_{3+2}, and TP by Colorado River Watch Laboratory (River Watch). Additional samples, collected as duplicates via a side-by-side method were analyzed for NO_{3+2}, total Kjeldahl nitrogen (TKN), TN, and TP by Metro Wastewater Reclamation District (Metro) Laboratory. Field parameters (DO, pH, conductivity, and turbidity) were recorded for each monthly collection event. During the July sampling event, additional samples were collected on the White River at Wakara for periphyton identification and samples were collected at five locations for chlorophyll a. During the September sampling event, macroinvertebrates were collected at nine of the sample sites and scored using Colorado's MMI. CPW also conducted a nutrient addition experiment at various sampling locations in 2016 to assess the nutrient cycling process.

CPW published a summary report of the data and findings from their 2016 sampling and investigation activities (CPW 2017). Additionally, a PowerPoint presentation was developed and presented by Mindi May of CPW in April 2017 that included the results of the 2016 sampling activities and nutrient addition experiment. This summary report and presentation is available through CPW. Table B-1, included in **Appendix B** provides a summary of the sampling activities completed by CPW in 2015 and 2016 as well as the key findings presented in their 2015 and 2016 reports.

CPW continues its efforts of data collection along the White River and tributaries in 2017. Water quality sampling has decreased frequency to every-other-month extended duration for the entire year. Samples to be analyzed for chlorophyll a and periphyton identification were collected in July 2017 at the same locations used in 2016. Macroinvertebrate sampling was completed in September 2017. No analytical results from 2017 sampling activities are available at the time of this report.

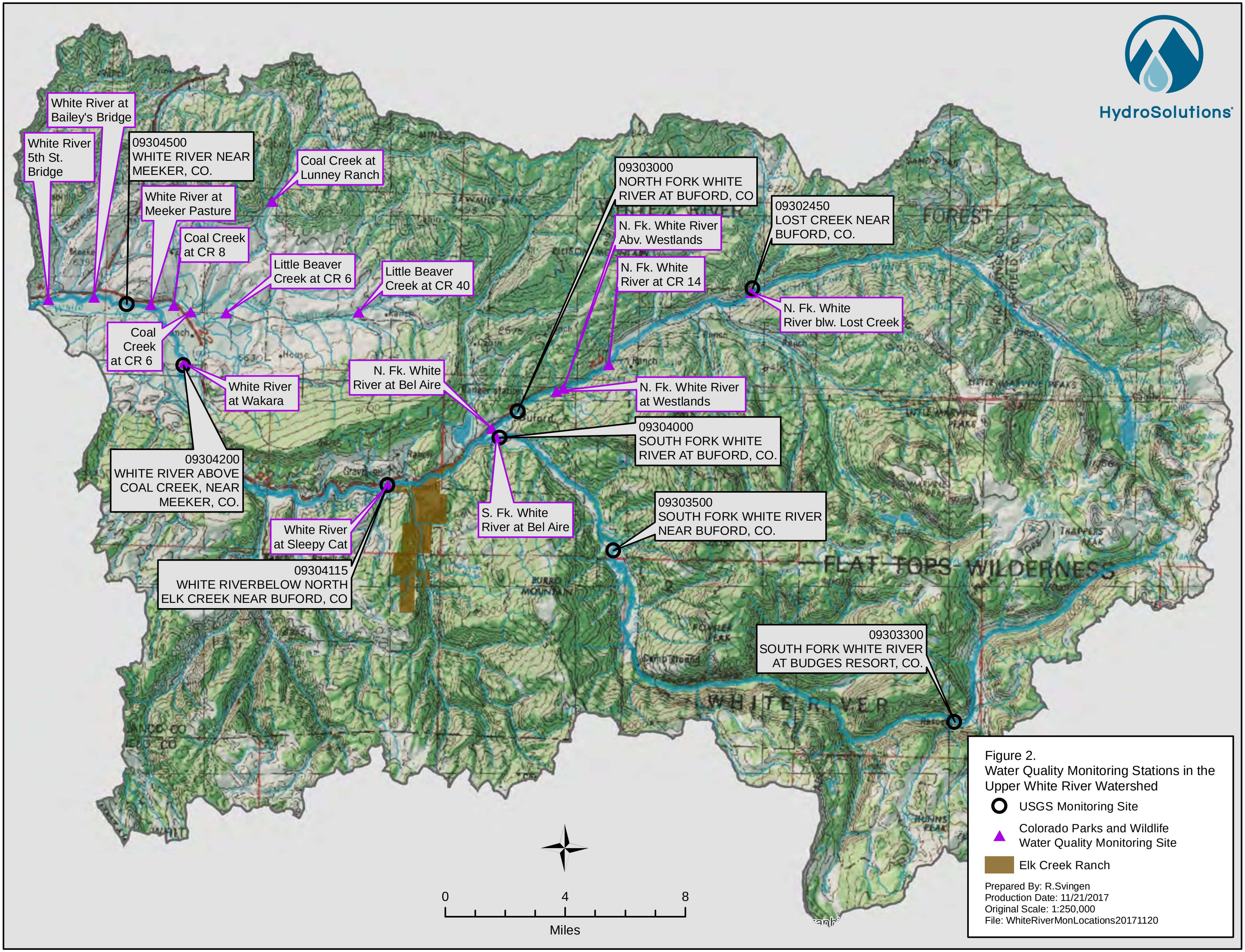

Figure 2.
Water Quality Monitoring Stations in the Upper White River Watershed

Prepared By: R.Svingen
Production Date: 11/21/2017
Original Scale: 1:250,000
File: WhiteRiverMonLocations20171120

2.4.2 Review of Synoptic Monitoring Analytical Results and Protocols

The analytical results of CPW's 2015 and 2016 synoptic sampling were reviewed as part of this report.

Box and whisker plots were prepared for CPW's 2016 analytical results to display the distribution of the dataset for each analyte or measured parameter, according to sampling location. These charts are included as Figure B-1 in **Appendix B**. Separate charts were developed for each laboratory in those cases where side-by-side samples were sent to both Metro and River Watch laboratories for analysis. For more effective scaling and comparison, a chart was developed to include only the analytical results from samples collected on the mainstem, North Fork, and South Fork White River. Charts were also developed to include results from samples collected from tributaries, as seen in Figure B-1.

The River Watch analytical results reported for conductivity, chloride, sulfate, and nitrate were also plotted for each individual sampling event completed by CPW from 2015 to 2016. This comparison is presented as Figures B-2 through B-5 in **Appendix B**.

While the data collection efforts of Colorado Parks and Wildlife offer a valuable synoptic analysis of recent river conditions in the Upper White River watershed, the analytical results must be interpreted with caution due to the following reasons:

- Reported analytical values for NO_{3+2} and total phosphorous are inconsistent between the two analyzing laboratories from duplicate (side-by-side) samples collected in 2016. This issue is illustrated by the box and whisker plots included in Figure B-1.
- Numerous unexplained outliers exist in the analytical results. This may be partially explained or exacerbated by variations or inconsistencies in laboratory reporting limits, which may not be optimal for this application.
- Quality assurance and control (QA/QC) samples (trip blanks, field blanks, field duplicates, and equipment blanks) were not collected as part of these sampling activities which makes it difficult to assess the field handling and collection methods used to collect and transport the samples. In the absence of QA/QC samples, precision, accuracy, representativeness, comparativeness and completeness of the data cannot be accurately evaluated.
- Samples were not analyzed for soluble reactive phosphorous (SRP), which is a measure of orthophosphate the fraction of phosphorus most readily directly taken up by benthic algae.
- No governing quality assurance/quality control (QA/QC) guidance has been implemented for the collection or validation of the data collected as part of CPW's sampling activities. As such, a review of this data lacks established criteria and documentation by which it can be evaluated as usable for its intended purpose.
- The sampling and analysis plan (SAP) used to collect the data provides generalized guidance for sample parameters and locations but lacks specific directives to maximize sampling efforts. Sampling activities, collection, documentation, and handling methods presumably follow standard operating procedures (SOP) and industry standards, but these are not explicitly specified.

The existing limitations of this data support the development of a formalized sampling program to better optimize data collection efforts in support of a common goal.

3 Water Quality

3.1 Introduction

Extant water-quality data were evaluated in the Upper White River to identify sites having sufficient data and comparable records to evaluate data against water-quality standards (e.g., Table 1 nutrients, DO, pH, chlorophyll a, etc.). This section also characterizes trends in concentrations or loads of factors that directly influence algal growth rate such as water temperature, suspended sediment concentration, and nutrients to provide an indicator of environmental conditions contributing to nuisance algae in the watershed. Lastly, data deficiencies are identified for future planning purposes.

3.2 Sites and Available Data

In examining available sites and data, data from the WQP was first queried as described in **Appendix A** to identify sites of interest. Based on the identified sites and number of samples the analysis was further refined. Lastly empirical models were used to characterize changes in concentrations or loads as described in **Appendix C**. Based on this compilation, few sites in the Upper White River have sufficient data to meet the credible evidence requirements of the Colorado Department of Public Health & Environment (2017). A summary of available data and associated constituents is presented in **Table 2**. A brief discussion whether the data are attaining water-quality standards then follows. Only locations with a sample size of $n \geq 25$, were included, where n is the number of uncensored samples[3]. USGS samples sites in the Upper White River are shown in **Figure 2**.

3.2.1 Nutrients (Nitrogen and Phosphorus)

Total nitrogen (TN) and total phosphorus (TP) data are available at numerous sites in the Upper White River and include sites both the North and South Fork (**Figure A-2, Figure A-3; Appendix A**). However, only a handful of sites have a sufficiently long period of record for examination. In review of this data, the median TN and TP is far below the proposed numeric nutrient standard at all sites making it highly unlikely that either exceeds the proposed interim Colorado numeric nutrient criterion[4]. It should be noted that the authors believe the interim nutrient criteria proposed by the CDPHE is far too high to prevent nuisance algal accumulation and we elaborate on this later in the document.

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[3] An uncensored sample is a sample that contains an analyte of interest above the lower reporting limit (LRL), meaning the laboratory instrumentation was able to provide meaningful quantification of the result. Censored samples are those samples that are above <LRL and therefore are not quantifiable. The sample size of $n \geq 25$ is intended by the authors to provide an initial approximation for screening, but is not definitive as no specific sample size is given in CDPHE (2017).

[4] Figures in **Appendix A** currently excludes censored data from plotting such that the actual median would be lower than shown.

3.2.2 Dissolved Oxygen (DO)

DO data are present throughout the upper White River at both USGS gage sites and STORET monitoring sites (**Figure A-4; Appendix A**). No indication of DO impairment exists relative to the spawning standard of 7 mg/L (15th percentile of all data). As such, water column and inter-gravel oxygen concentrations support fish and aquatic life uses. However, it should be noted that DO minima typically occur prior to sunrise thus it is possible that insufficient diurnal (day and night cycle) data have been collected to fully characterize daily DO conditions. Please see later presentation of sonde data to fill this data gap.

Table 2. Number of uncensored observations at select sites in the Upper White River Watershed over the period of record in the Water Quality Portal (WQP; see Appendix A)

Site ID and Name	Total[a] Nitrogen	Total Phosphorus	Dissolved Oxygen	pH	Chla	DOC
USGS 09303000; North Fork White River at Buford, CO	*n* = 66	*n* = 114	*n* = 161	*n* = 205	---	---
USGS 09304000; South Fork White River at Buford, CO	*n* = 61	*n* = 109	*n* = 156	*n* = 207	---	---
USGS 395650107435600; White River above Dry Creek, near Meeker, CO	*n* = 60	*n* = 96	*n* = 96	*n* = 104	---	---
USGS 09304200; White River above Coal Creek near Meeker, CO	*n* = 60	*n* = 87	*n* = 160	*n* = 670	---	---
USGS 09304600; White River at Meeker, CO	---	---	---	*n* = 469	---	---
USGS 09304800; White River below Meeker, CO	*n* = 134	*n* = 190	*n* = 224	*n* = 691	*n* = 6	*n* = 100
USGS 09306224; White River above Crooked Wash near White River City, CO	---	---	*n* = 44	*n* = 84	---	---
21COL001_WQX-000043; White River at Meeker	---	---	*n* = 103	*n* = 136	---	---
21COL001-000117; White River below Piceance Creek	---	---	*n* = 101	*n* = 132	---	---
CORIVWCH_WQX-531; 5th Street Bridge	---	---	*n* = 196	*n* = 189	---	---

[a] Note that many censored observations exist for total nitrogen (TN) and total phosphorus (TP); these are not included in the count above.

3.2.3 pH

Samples of pH are found at the same locations where nutrients and DO were collected (**Figure A-5; Appendix A**). Examination of these data indicate pH meets both the maximum and minimum criteria. The exception is CORIVWCH_WQX-531 5th Street Bridge, which exceeds the Colorado pH criteria with the 85th percentile of the entire dataset being equal to 9.1 S.U. (maximum allowable pH is 9.0 S.U.). The latter is considered a water quality exceedance, noting that alkaline conditions can negatively affect fish mucous membranes such as gills and eyes. Since pH maxima typically occur during daytime hours, it is likely that samples have already been collected during periods of peak pH. Diurnal pH data collected in 2017 are later evaluated to confirm this assertion.

3.2.4 Chlorophyll a

Very few benthic chlorophyll a data exist in the upper White River watershed. A site downstream of Meeker, CO exists (**Figure A-6; Appendix A**) and biomass samples from this site are very low and are from the late 1970s. No other sites were identified. We later describe efforts by CPW in this section as these data are not currently in the WQP.

3.2.5 Dissolved Organic Carbon (DOC)

DOC has only been sampled at one location in the upper White River downstream of Meeker, CO (**Figure A-7; Appendix A**). The site far exceeds the water quality standard of 3.0 mg/L. We note the City of Meeker municipal wastewater effluent discharge is immediately upstream of this site and is likely a major source of DOC to the lower watershed. Since the focus of this investigation is nuisance algae the Upper White River (upstream of Meeker), the effects of the municipal wastewater effluent discharge are not discussed further here. DOC excursions in the lower river should be considered in future evaluations of the White River.

3.3 Physical and Environmental Factors that Affect Algal Growth

Physical factors affecting the growth of algae are detailed here with respect to data in the White River. Included is a discussion of:

- water temperature, which directly governs algal growth rate (roughly a doubling in growth rate for a 10°C increase in water temperature as a rough rule of thumb),
- the effect of suspended sediment concentration (SSC) on photosynthetically active radiation (PAR), which is the amount of light in the 400-700 nanometer (nm) wavelength reaching the river bottom that is converted into chemical energy through photosynthesis, and
- finally available nutrients which are required to synthesize algal proteins/amino acids (nitrogen) and nucleic acids/phospholipids/adenosine triphosphate (ATP) (phosphorus).

3.3.1 Water Temperature

Water temperature was examined due to its influence on algal growth rate. Data are available at numerous locations (**Figure A-9; Appendix A**) and include both instantaneous samples as well as continuous data. Instantaneous data indicate that a small spatial difference in water temperature exists between the North and South Fork White River relative to the White River above Coal Creek (**Figure 3a**). During the critical flow period of August (**Figure 3b**), the North Fork White River (USGS 0903000) median is about 1°C cooler than the South Fork, which is about 1°C cooler than the White River above Coal Creek.

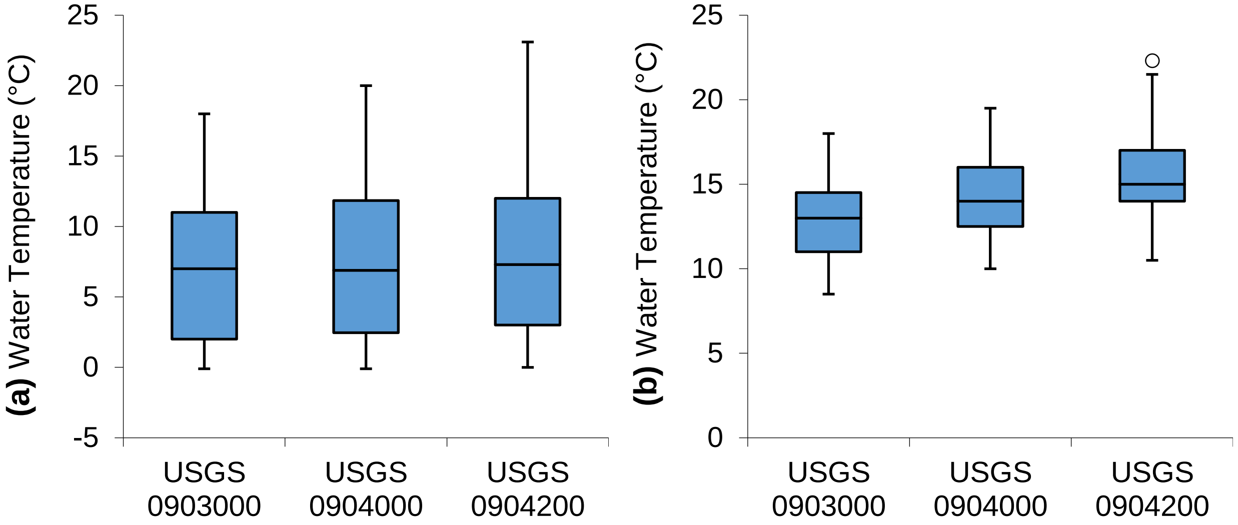

Figure 3. Instantaneous water temperatures in the Upper White River from (a) all samples irrespective of time of year and (b) August samples

Daily water temperatures (minimum, maximum, average) have also been recorded at USGS 09304200 White River above Coal Creek near Meeker, CO from 1978–1984 and 2007–current on a seasonal basis (5/1 through 9/30). Examination of this data show no apparent trend or change in mean daily water temperature (**Figure 4a**). Daily water temperatures range from just under 5 to just over 19°C over the monitoring period. Review of Thomas et al. (2013) confirm that there is no trend in water temperature over the period of 1990–2009 and mean annual data for each August are shown in **Figure 4b**. While there appears to be a slight increase in August water temperature between the 1970s and 1980s and now, the trendline slope is not significant (p=0.28) and thus no significant trend exists (deviation across all years was within 3°C, 13.5–16.5°C).

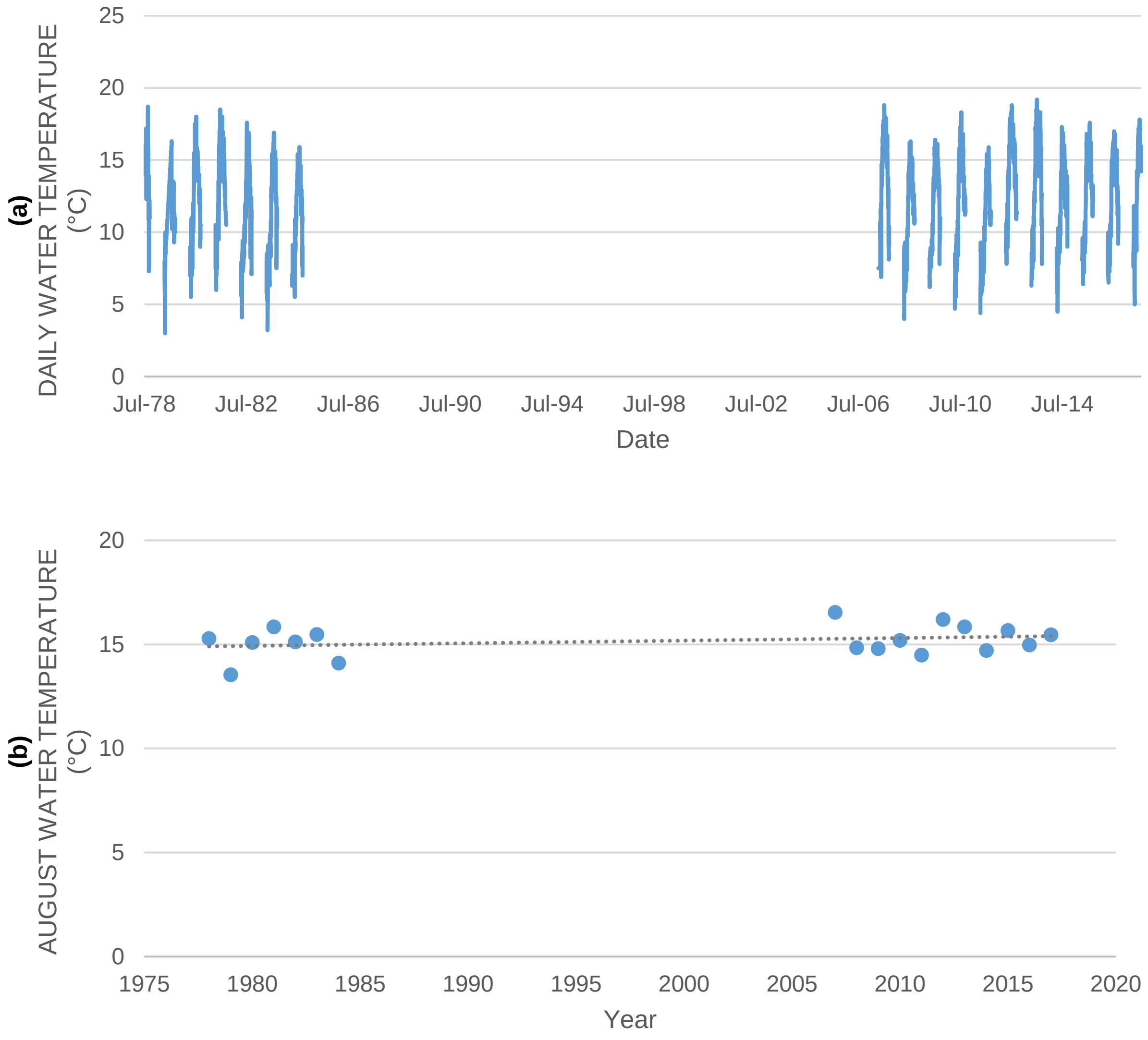

Figure 4. (a) Mean daily water temperature for the White River above Coal Creek near Meeker, CO (USGS Station 09304200). (b) Mean annual August water temperature for the same location

Based on the review above, changes in water temperature are believed to have little influence on recent nuisance algal conditions in the White River. As noted previously, there is insufficient spatial variation to explain nuisance algae deviations at any point in the river and temporal trends (such as from climate change) also appear to be insignificant. Furthermore, evaluating data in accordance with growth literature on *Cladophora* provides a strong indication that changes in water temperature are not biologically significant. According to *Cladophora* growth curves published by Tomlinson et al. (2010) (**Figure 5**), small deviations in temperature provide very little effective change in growth rate. Additionally, maximum daily temperatures (not shown) are well below the limiting threshold of 25-30°C for *Cladophora* (Dodds and Gudder 1992, Whitton 1970).

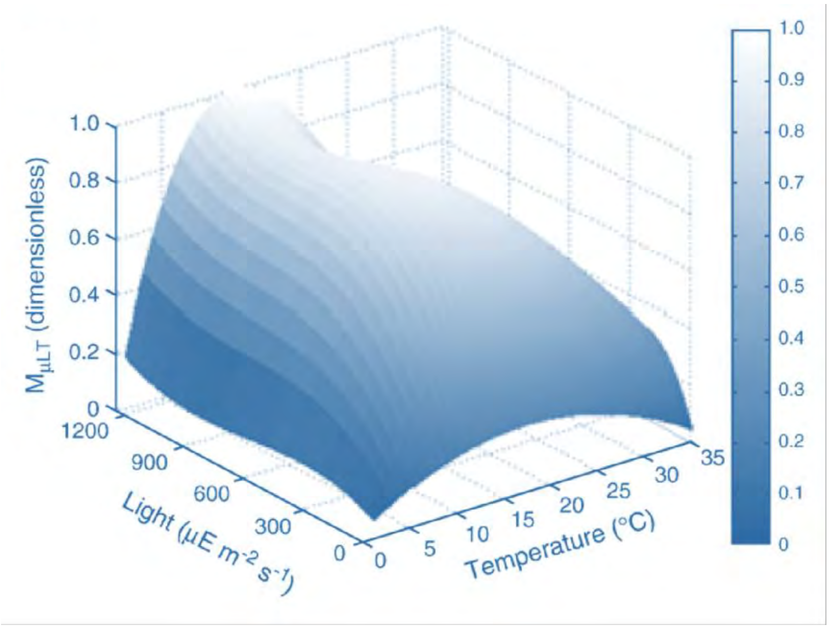

Figure 5. Dimensionless growth rate of *Cladophora* as a function of water temperature and incident photosynthetically active light (400-700 nm) taken from Tomlinson et al. (2010)

3.3.2 Suspended Sediment

Suspended sediment data was also examined due to the influence of suspended particles on absorption and scattering of light in aquatic systems, which has concomitant changes in photosynthetic activity (Kirk 1994). Data are available throughout the study area (**Figure A-8; Appendix A**). However, the only monitoring site with current data is well downstream of the study area: USGS 09304800 White River downstream of Meeker, CO. We rely on those observations for characterization of conditions in the upper White River, noting that it is unclear whether this location is fully representative of water quality upstream of Meeker.

Suspended material influences both absorbance and scattering properties of the water and the amount of solar radiation reaching the bottom of the channel. Inorganic suspended sediment is responsible for scattering of light whereas detritus absorbs and scatters light and phytoplankton primarily absorb light. Thomas et al. (2013) did not characterize a trend in suspended sediment concentration for the gage referenced above from 1990–2009 due to issues in fitting the LOADEST model. In our examination of the data; however, there is statistically significant ($p=0.0003$) downward monotonic trend in both annual and August suspended sediment concentration (**Figure 6**; note logarithmic scale). This plausibly influences the light environment and perhaps the photosynthesis-irradiance (PI) response.

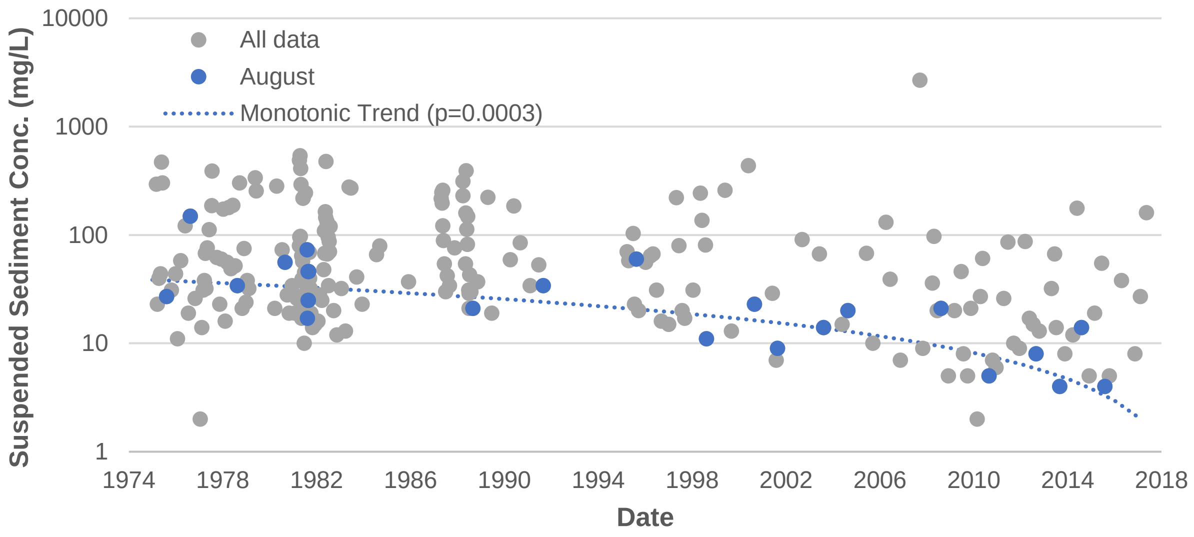

Figure 6. Suspended sediment concentration at USGS 09304800 White River below Meeker, CO along with August monotonic trendline

The effect of suspended sediment concentration on downwelling photosynthetically active radiation (PAR) can be approximated using Beer-Lambert law (Chapra 2008)

$$\mathrm{PAR}(\mathrm{z}) = PAR(O)\mathrm{e}^{-k_e \mathrm{z}} \qquad \text{(Equation 1)}$$

where PAR(0) is the photosynthetically active radiation (PAR) at the water surface (µE/m^2/s), k_e is the light extinction coefficient (/m), z is the depth of water (m), and PAR(z) is the impinging radiation at the stream bottom. For the purpose of this evaluation, water depth is assumed to be one meter, although we realize there are substantial variations in depth.

The light extinction coefficient referenced above can be approximated as the sum of partial extinction coefficients reliant on the concentrations of particles in suspension and their optical attributes (Di Toro 1978, Kirk 1994, Van Duin, et al. 2001). Ignoring detrital and phytoplankton contributions, the extinction coefficient can be simplified to

$$k_e = k_e + \alpha_i m_i \qquad \text{(Equation 2)}$$

where k_{eb} reflects the extinction due to colloidal color and water (/m; assumed to be 0.1 /m), α_i is a coefficient unique to inorganic solids (m^2/g), and m_i is the concentration of inorganic solids (g/m^3). We use the α_i reported from Di Toro (1978) here (α_i=0.052), which is widely used in water-quality modeling.

Using the above assumptions, it appears that increase in the percentage of surface PAR reaching the bottom of the channel due to declining sediment concentrations at a depth of one meter is considerable (**Figure 7**). However, applying such changes to the daily average PAR and the P-I response curve from Tomlinson et al. (2010) results only in a minor change in growth rate (<5%) since *Cladophora* saturates at relatively low irradiances (approximately 400 µE/m2/s) relative to the mean daily PAR. More detailed modeling studies should be conducted to evaluate the full importance of this effect on summer algal accumulation. Confirmation sampling should also be initiated to ensure the above conclusions are valid and applicable to the upper watershed.

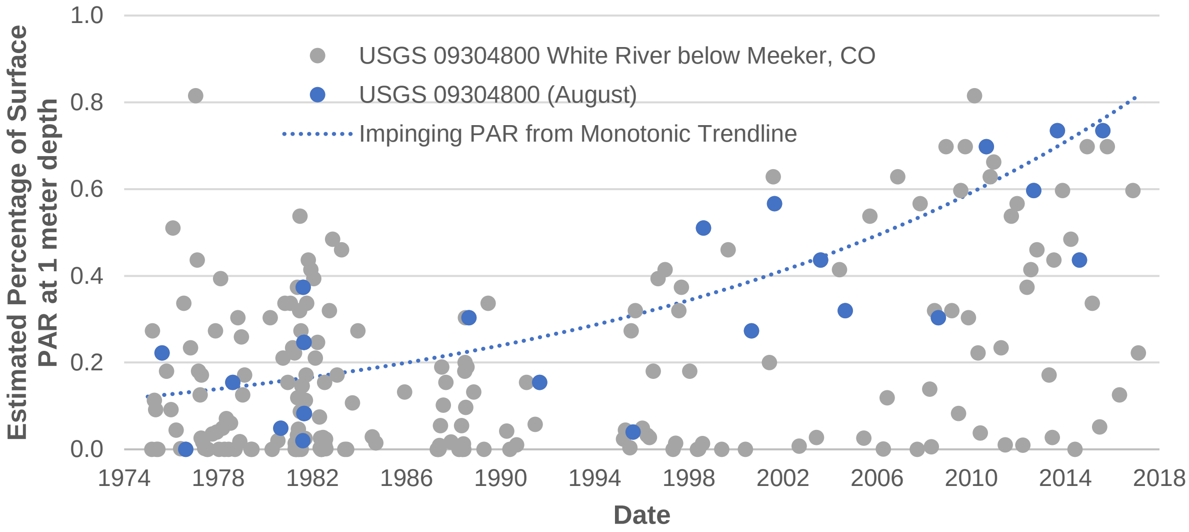

Figure 7. Estimated percentage of surface PAR reaching a depth of one meter during August using Beer-Lambert law and associated changes in suspended sediment concentrations at USGS 09304800 White River below Meeker, CO

3.3.3 Nutrients

Ambient nutrient concentrations influence algal growth rate and are the primary macronutrients needed to synthesize algal protoplasm (Stumm and Morgan 1996). Because of this, total nitrogen (pCode 00600), total phosphorus (pCode 00665), nitrate plus nitrate (pCode 00631), and orthophosphate (pCode 00671) were evaluated to better understand how these may influence algal accumulation in the watershed. Sites considered were USGS 09303000 North Fork White River at Buford, CO, USGS 09303000 South Fork at Buford, CO, and USGS 09304200 White River above Coal Creek near Meeker, CO. Both total and dissolved nutrients are discussed.

Raw data for each site by year are shown in **Figure 8**, with censored data estimated as ½ of the reporting limit. Any data 1.5 times outside the interquartile range is shown as an outlier (black dots). General trends are consistent across all sites. Over the 1991-current period of record, total nitrogen (TN) has declined at all sites. The North Fork has the highest concentration of TN followed by the White River above Coal Creek, and then the South Fork. Nitrate plus nitrite (NO_{3+2}) exhibits a similar declining trend and spatial distribution. Total phosphorus (TP) has the opposite trend with a temporal increase and a similar distribution of concentration amongst the sites. Lastly, orthophosphate is more difficult to assess due to detection limit issues in the early 1990s.

To better understand the relationship between the point measurements above, a statistical modeling approach was used as described in **Appendix C** to estimate flow normalized trends in both concentrations and loads. Summaries of those results are found here and additional details are included in **Appendix C**[5].

Flow normalized nutrient concentration estimates are shown in **Figure 9** and summarized in **Table 3** (note: flow normalization removes the influence of discharge on concentration and therefore normalizes each year to an average discharge condition). Both total nitrogen and NO_{3+2} are trending downward with a slope change in 2005. Conversely, total phosphorus is increasing, with a similar shift in time. Finally, orthophosphate (ortho-P) appears to have declined from 1991-2005 and has been increasing thereafter.

Table 3. Summary of flow normalized nitrogen and phosphorus concentrations for the White River for both average annual (Avg) and August (Aug) periods for water years 2013–2017

Constituent	Discharge [cms][a]		White River FN Concentration		North Fork FN Concentration		South Fork FN Concentration	
			[µg/L]	[µg/L]	[µg/L]	[µg/L]	[µg/L]	[µg/L]
	Avg	Aug	Avg	Aug	Aug	Aug	Avg	Aug
Total Nitrogen (pCode 00600)	14.7	6.2	188	138	195	93	157	87
Nitrate plus Nitrite (pCode 00631)			25	7	40	5	26	4
Total phosphorus (pCode 00665)			32	28	40	29	33	21
Orthophosphate (pCode 00671)			8	9	13	12	11	10

[a] Flow at USGS White River above Coal Creek

Flow normalized loads are shown in **Figure 10** and are summarized in **Table 4**. The most recent 5-year average flow normalized total nitrogen load in the White River above Coal Creek gage is approximately 138,000 kg/yr (152 tons/yr) whereas the annual total phosphorus load for the White River above Coal Creek is 28,000 kg/yr (30.8 tons/yr). The flow normalized annual nitrate load is 23,100 kg/yr (25.5 tons/yr) and the orthophosphate load is 4,030 kg/yr (4.44 tons/yr). Flow normalized loads for the North and South Fork were also calculated, but are based on estimated flow and thus are approximations only (actual measurements were used in fitting the model). The North Fork comprises roughly 50% and the South Fork 40% of the annual load, excluding orthophosphate which has an unusual result. Loads for August during the critical flow period are also provided, which will later be used to put sources in the White River Watershed into context under both annual and critical periods.

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[5] This includes, but is not limited to, use of existing flow and chemistry data (with no re-censoring of non-detects), using daily streamflow estimates for both the North and South Fork White River since daily discharge data have not been recorded since the early 2000s, constraining the data to a common period of record of 1991-current, and interpretation of results.

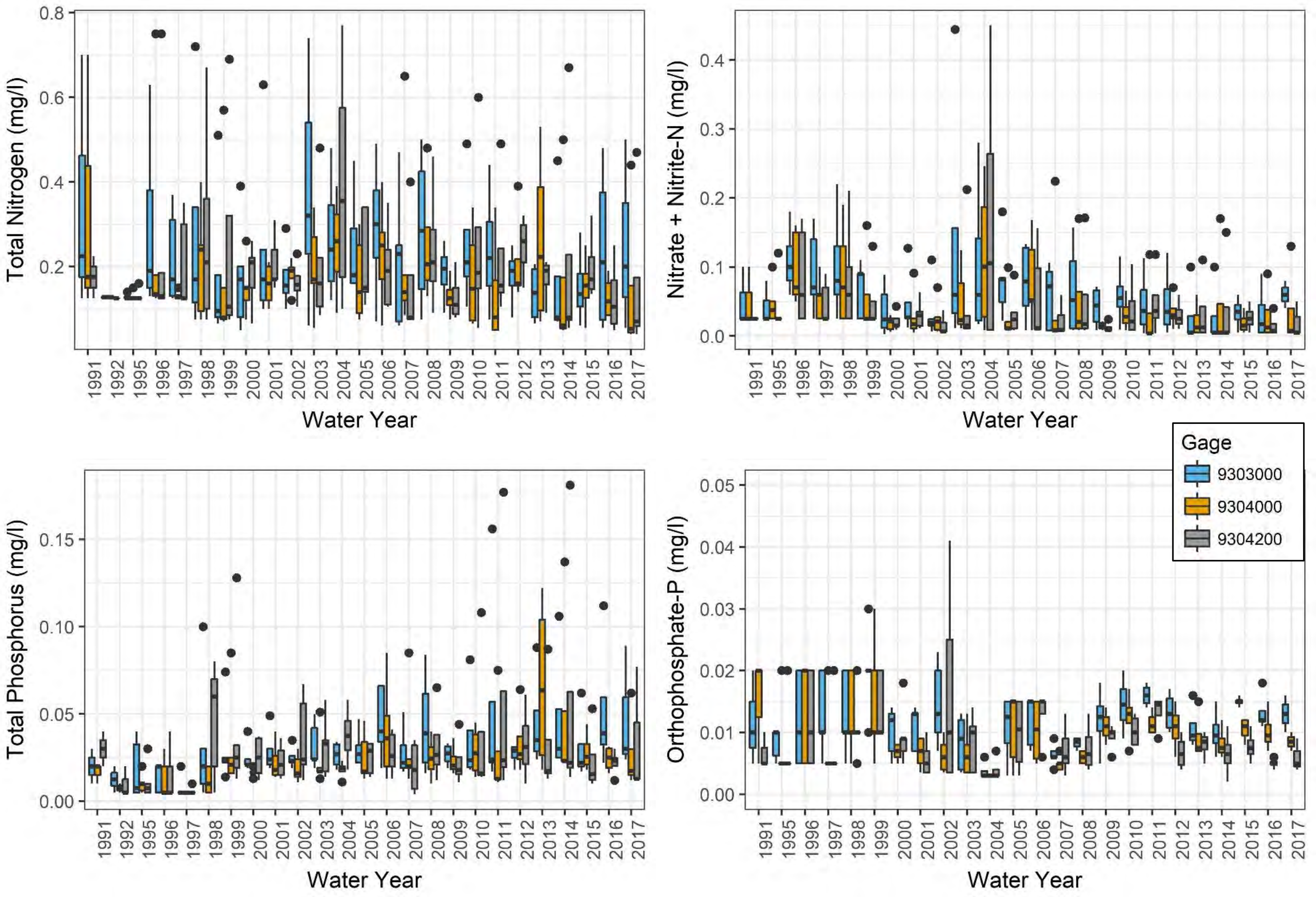

Figure 8. Nitrogen and phosphorus concentrations for gages in the Upper White River over the 1991-current period

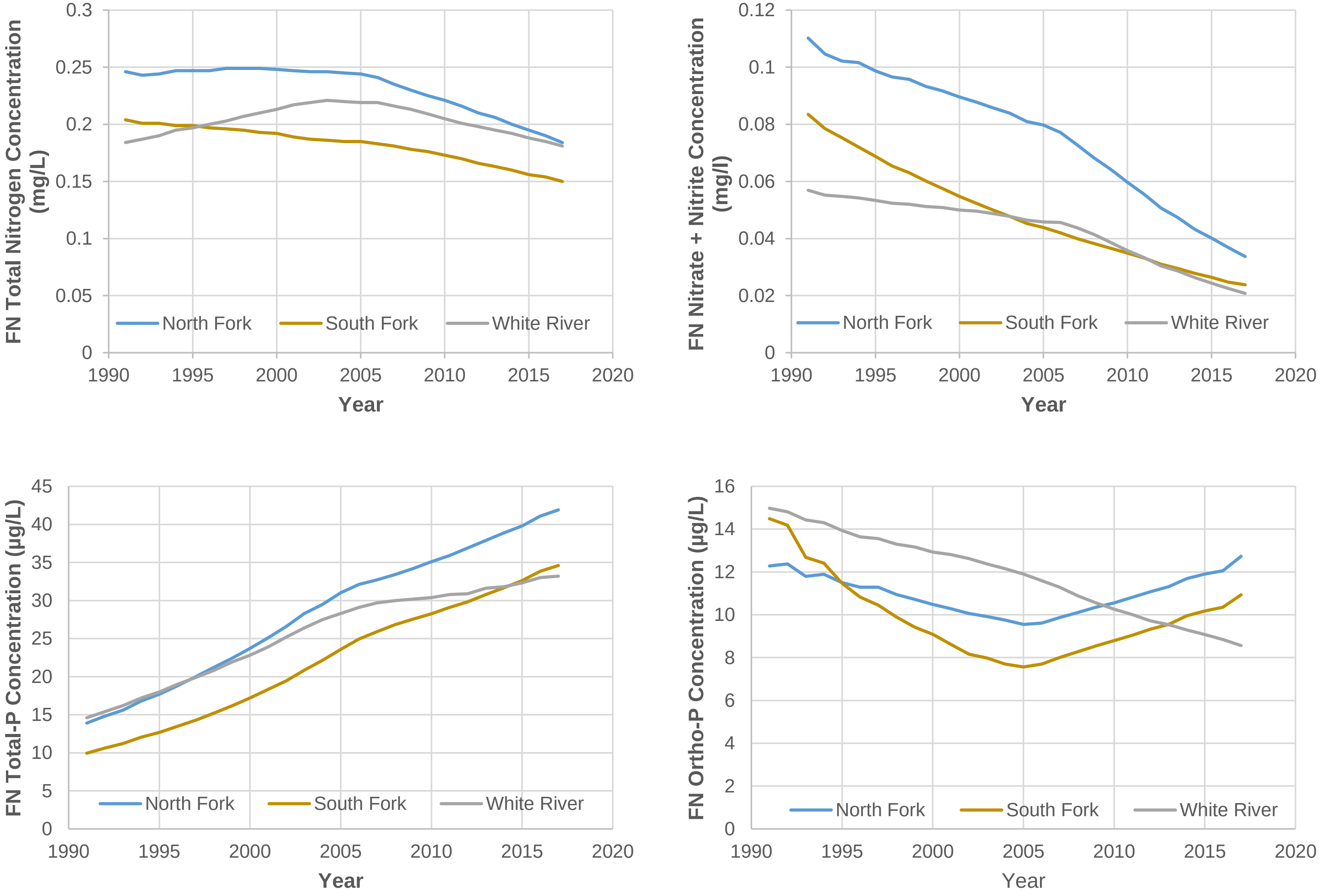

Figure 9. Flow normalized annual nitrogen and phosphorus concentration estimates for gages in the Upper White River

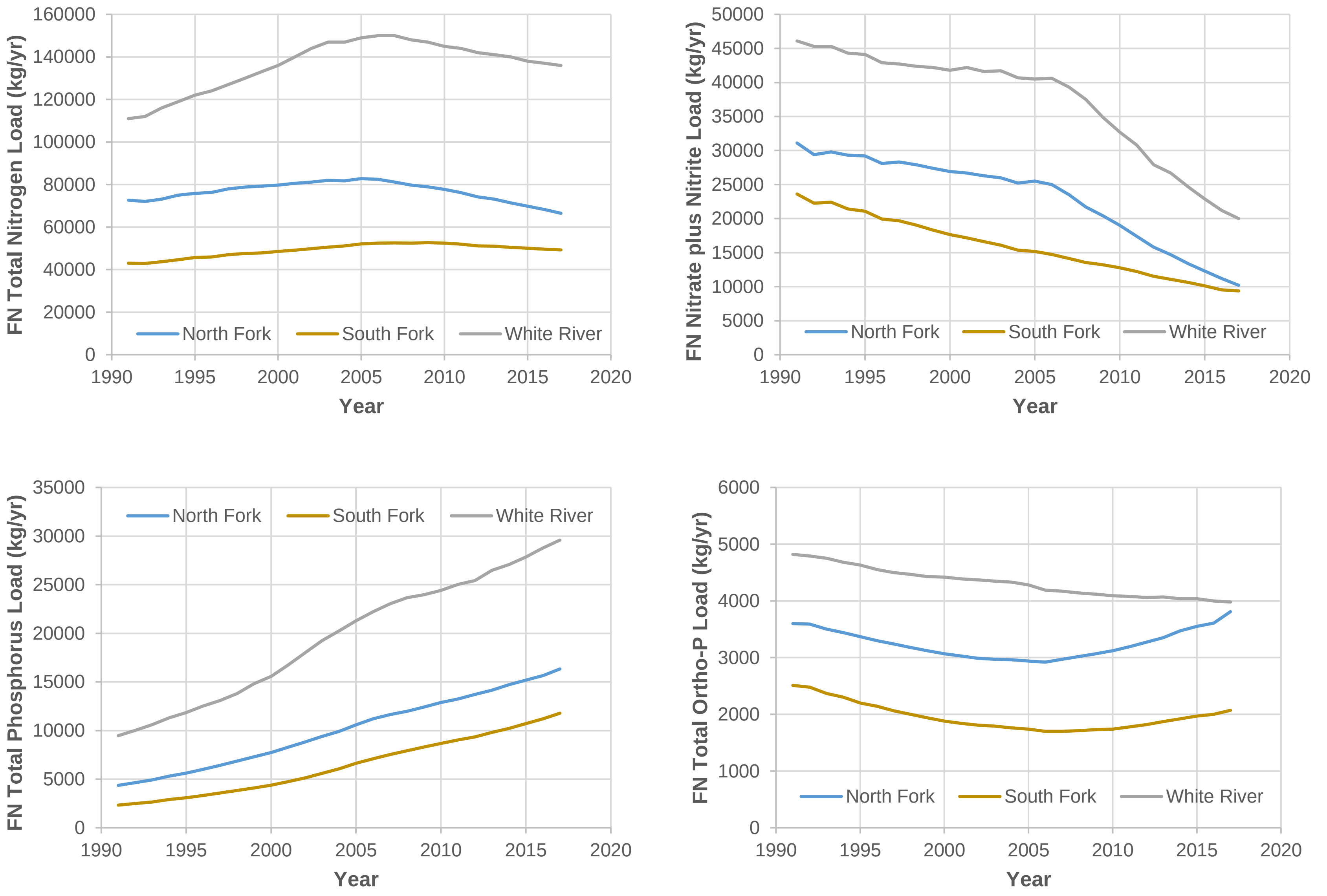

Figure 10. Flow normalized nitrogen and phosphorus annual load estimates for gages in the Upper White River

Table 4. Summary of nitrogen and phosphorus loads for USGS 09304200 White River above Coal Creek near Meeker, CO for both average annual (Avg) and August (Aug) periods for water years 2013–2017

Constituent	Discharge [cms][a]		White River FN Load		North Fork FN Load		South Fork FN Load	
			10^3 [kg/yr]	**[kg/d]**	**10^3 [kg/yr]**	**[kg/d]**	**10^3 [kg/yr]**	**[kg/d]**
	Avg	**Aug**	**Avg**	**Aug**	**Avg**	**Aug**	**Avg**	**Aug**
Total phosphorus (pCode 00665)	14.7	6.2	28.0	17.0	15.2	16.0	10.7	7.89
Orthophosphate (pCode 00671)			4.03	5.19	3.56	6.31	1.97	3.24
Total Nitrogen (pCode 00600)			138	89.5	69.8	55.6	50.1	32.6
Nitrate + Nitrite (pCode 00631)			23.1	5.80	12.4	3.22	10.1	1.90

[a] Flow at USGS White River above Coal Creek. Note: daily flow for the North Fork and South Fork White River were synthesized to estimate loadings in these locations.

Based on the information presented previously, nitrogen is decreasing in the watershed while phosphorus is increasing. All models indicate a shift in 2005; changing the trajectory of all nutrient species of interest. We have no correlating or anecdotal information for which to attribute this shift. However, the consideration should be investigated when evaluating management changes on concentrations and loads in the watershed. It also can be seen that nitrogen is the limiting nutrient since phosphorus is in excess (see **Section 3.5.2** for a robust discussion on limiting nutrient). Concentrations also likely do not limit algal growth rate annually, but most likely to some extent during the summer growing season (see **Section 3.5.3**). Finally, in general nutrient concentrations in the White River are comparable or higher than the median nutrient concentrations of the 74 Colorado streams studied by Lewis and McCutchan (2010). Total nitrogen concentrations in the White River appear to be slightly less than the median total nitrogen concentrations of the study streams. Total and soluble reactive phosphorus concentrations in the White River appear to be higher than the median corresponding concentrations of the 74 study streams, but are within the overall range of concentrations.

3.4 Biological Responses

Few measurements of benthic algal biomass have been made in the White River watershed and those that are of relevance have been made by CPW (2017) in accordance with Colorado Water Quality Control Division Standard Operating Procedures (Colorado Water Quality Control Division 2016). For reference, algal biomass is typically measured in units of chlorophyll a per square meter, where chlorophyll *a* is the light harvesting pigment found in algae. Alternatively, biomass can be measured as either dry mass or ash free dry mass. Observed benthic biomass in the range of 100-150 mg chlorophyll *a* (mg/m^2) has been suggested as an unacceptable aesthetic impediment to river recreation (Welch, Jacoby, et al. 1988, Suplee, Watson, et al. 2009) and 150 mg/m^2 is the recommended water quality standard for the State of Colorado (CDPHE 2017a).

Examination of White River samples collected by CPW (2017) are shown in **Figure 11**. All sites sampled except one (below Lost Creek) exceed the chlorophyll a standard for Colorado by a considerable percentage. This suggests that nuisance algal biomass responses are occurring at numerous locations in the watershed, and these are not isolated to one particular location. They occur both in the North Fork and South Fork White River, as well as the mainstem river. Future sampling should be completed to confirm these results.

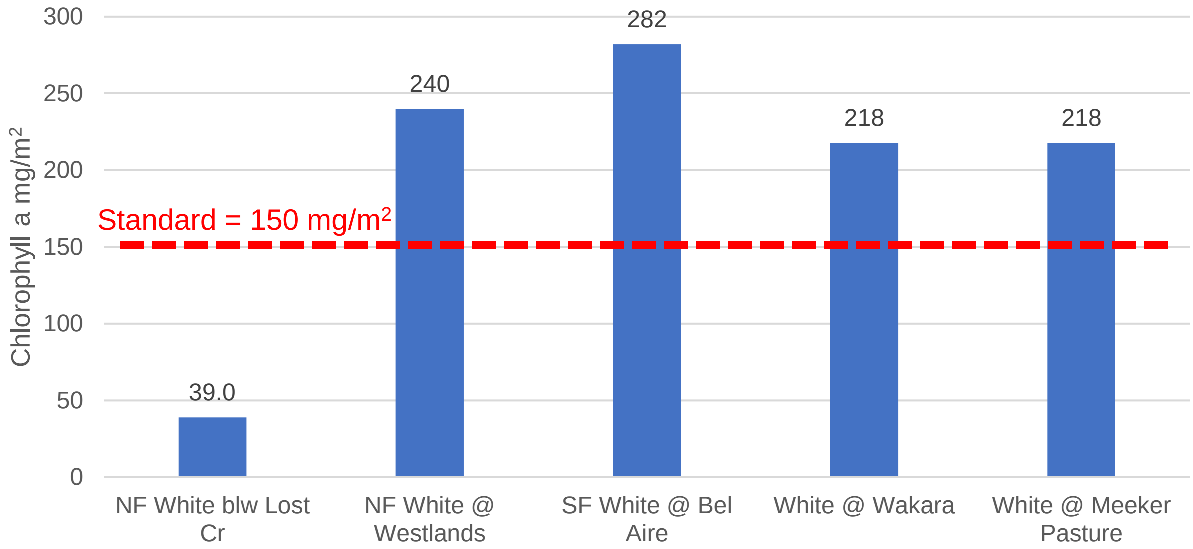

Figure 11. Periphyton biomass as observed and recorded by CPW (2017) as part of a 2016 investigation

Variation in abundance of periphyton biomass can be attributed to 1) the initial amount of biomass at the start of the growing season, 2) length of the growing season, and 3) water temperature (Lewis and McCutchan 2010). The length and peak of the growing season for periphyton communities in Colorado mountain streams is largely dependent upon elevation. Lewis and McCutchan (2010) describes the median peak growing season dates of instream periphyton for different elevation categories for Colorado mountain streams:

- Alpine (>2,700 meters or 8,858 feet) late August
- Montane (2,100 to 2,700 meters or 6,890 to 8,858 feet) late September
- Foothills (<2,100 meters or 6,890 feet) late October

Based on these elevation categories, the project area is considered “foothills” from Meeker to just above Elk Creek Ranch, “montane” above Elk Creek Ranch to just below Trappers Lake, and “alpine” above Trappers Lake. Based on observations during a site visit and from personnel at Elk Creek Ranch, peak periphyton biomass accumulation appeared to have passed in the mainstem White River below Elk Creek by late August 2017. Additionally, observations from indicate that periphyton levels began to suppress first, lower in the White River and later at higher elevations in the North Fork White River. The factors affecting senescence of algae in the White River should be evaluated.

3.5 Summary and Discussion

Based on the previous data, a number of conclusions can be made about the White River watershed upstream of Meeker, CO. These are detailed in the following sections.

3.5.1 Algal Biomass in Excess of Nuisance Algae

The CPW data presented previously provides convincing evidence that benthic algal biomass in the Upper White River is a nuisance and exceeds the Colorado chlorophyll a water-quality standard by a large margin. Recreational uses are therefore not being supported. Furthermore, it is not uncommon in rivers with these types of elevated biomasses to see other aquatic life impacts related to the photosynthesis and respiration of the algae. These manifest as either daytime pH maxima excursions or nighttime DO minima. Additional benthic biomass data at different spatial locations in the watershed should be collected to further understand the extent of nuisance conditions in the river. An aerial photograph of the White River at the confluence of the North and South Fork White River is shown in **Photograph 2**. The photograph was taken on July 26, 2017 and shows the presence of extensive bright green filaments in the North Fork (stream coming in on top of the photograph), and little visible algae in the South Fork.

Photograph 2. White River at North Fork-South Fork White River Confluence, taken on July 26, 2017

3.5.2 Nitrogen as the Limiting Nutrient in the Upper White River

As shown previously and described subseueqntly, nitrogen is the limiting nutrient in the White River. A number of formulations have been proposed to define nutrient limitation. For the present, we apply “Liebig’s law of the minimum” (Liebig 1847, Hooker 1917) where a single nutrient (i.e., the one in shortest supply) will limit plant growth at any given time. This concept was popularized for agriculture in the 19th century and subsequently has been adopted for algae (Droop 1973). By evaluating the stoichiometric ratio of nitrogen and phosphorus, either in algal tissue preferably, or alternatively in the water column, a determination of which nutrient is in shortest supply and thus is limiting can be made.

As shown in **Figure 12a**, both uncensored TN:TP observations (dots) and flow normalized TN:TP mass ratio from the statistical model suggest the ratio of nitrogen to phosphorus in the White River has been declining since 1991. Early in the 1990s, the White River had a TN:TP ratio of approximately 10–20:1 (by mass), indicative of phosphorus limitation. The ratio is currently approaching 5:1. For reference, optimal stoichiometry is defined by the Redfield ratio at 7:1 by mass (Redfield 1958), which has been found applicable to benthic algae (Kahlert 1998, Hillebrand and Sommer 1999). In this regard, the watershed has moved from being phosphorus to nitrogen limited over time, due in large part due to increases in phosphorus loads and subesequent declines in nitrogen.

Another potentially useful indicator is the ratio of dissolved nutrients (**Figure 12b**). This constitutes the fraction of nutrients in the water column readily available for algal uptake and assimilation. Although such an approach must be used cautiously due to the arguments presented in Dodds (2003), results for the White River confirm the previous result. Convincingly, the ratio of soluble inorganic nitrogen to phosphorus was farily stationary throughout the period of 1990–2005 (at or near Redfield ratio), but then began declining thereafter. Currently, soluble N:P ratios are approximately 3:1 (note log scale), suggesting strong nitrogen limitation. It is unclear what change occurred in 2005 to cause this shift.

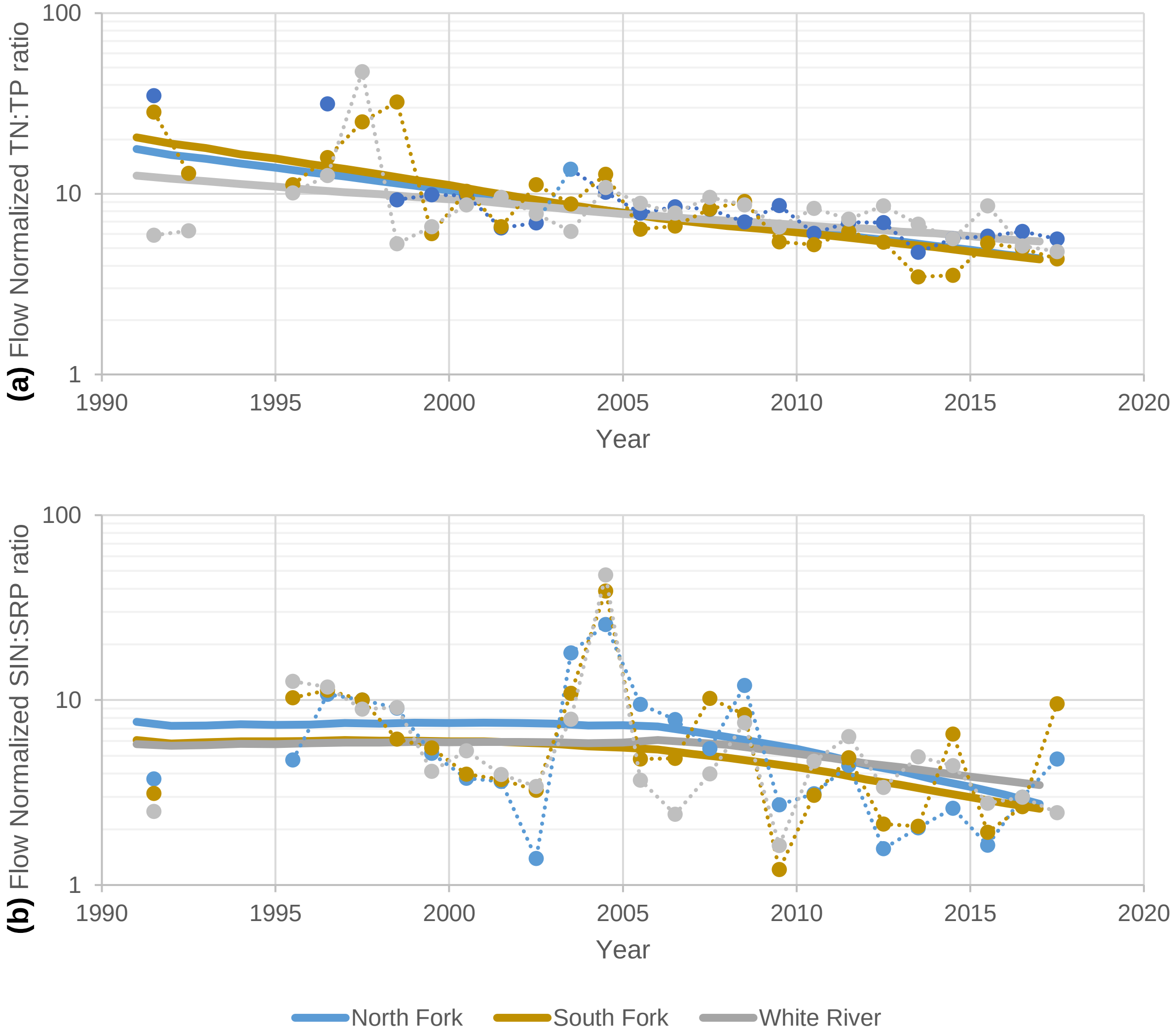

Figure 12. Observed annual average (dots and dashed lines) and simulated (solid lines) nitrogen to phosphorus ratios in the White River. (a) TN:TP ratios. (b) nitrate to orthophosphate ratios by mass

The limiting nutrient conclusion above is supported by other lines of evidence. In particular, the nutrient diffusing substrate experiments conducted by CPW show similar results where the highest responses of total periphyton over the control both above and below the glass fiber disk were in either the N alone, or N plus P additions (CPW 2017). This is consistent with nitrogen being in shortest supply, or co-limitation of nitrogen and phosphorus. The authors note that a distinction should be made between two nutrients being simultaneously near growth-limiting conditions, and co-limitation. The latter can occur in an algal community but not an individual species (Borchardt 1996).

The above conclusions, while compelling, do have limitations. Most notably it is recommended that future work examine tissue cocentrations as opposed to water column concentrations to conclusively ascertain the most limiting nutrient. Algal tissue monitoring is the most accurate method of understanding internal algal nutrition and certainly should be incorporated into future monitoing campaigns. Furthermore based on the understanding above, if nutrient reductions are to be pursued to limit algal accumulation in the watershed, nitrogen sources should be the firstmost priority followed by phosphorus.

3.5.3 Nutrition Requirements to Limit Nuisance *Cladophora* Growth

In examination the nutrient status of the upper White River, it is important to note that nutrient thresholds required to limit *Cladophora* growth have been suggested in the literature. Most frequently these are reported as algal tissue concentrations, but water column concentrations are also sometimes used. The former is the commonly accepted means of nutrient limitation of algal growth established by Droop (1973), but we discuss both here in an attempt to reconcile results noted previously with growth limiting thresholds.

Phosphorus limitation in *Cladophora* has been studied extensively due to its preference for phosphorus enriched waters. Wong and Clark (1976), found a strong empirical relationship between phosphorus tissue content and water column total phosphorus concentration in examination of six rivers in Quebec. Concentrations greater than 60 µg/L TP in the water column (0.16% tissue content) sustained maximum growth, meaning water column concentrations must be kept well below those levels to avoid excessive accumulation. Using their data, water column concentration must be less than 20–25 µg/L TP to keep *Cladophora* photosynthetic rates at half of their maximum [i.e., to constrain plant tissue concentrations somewhere between the minimum cell quota of 0.04–0.06% P and 0.16% P, where no limitation occurs at all (Auer and Canale 1982, Gerloff and Fitzgerald 1976)][6].

This TP threshold is consistent with work by Stevenson (2014) who indicate water column total phosphorus concentration should be less than 23 and 27 µg TP/L to limit *Cladophora* algal cover to less than 10% streambed cover. Similarly, Chételat et al. (1999) indicate a shift in dominance to green algal taxa such as *Cladophora* above 20 µg TP/L. Finally, Freeman (1986) in the Manawatu River in New Zealand found no growth limitation at dissolved reactive phosphorus concentrations (DRP) of 9 µgP/L whereas at 4–5 µgDRP/L *Cladophora* abundance was greatly reduced.

As such it is reasonable to expect that <25 µg/L of total phosphorus or <5 µg/L of dissolved phosphorus will reduce *Cladophora* growth rates to levels that would restrict nuisance conditions. Concentrations in the White River (**Table 3**) exceed those values substantially and large scale phosphorus reductions would be required to achieve any sort of limitation of growth by phosphorus.

Fewer studies have characterized nitrogen limitation. Gerloff and Fitzgerald (1976) report the minimum cell concentration of nitrogen that permits maximum yield in *Cladophora* as approximately 1.1% tissue content. Likewise, Wong and Clark (1976) found reductions in daily

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[6] Early studies by Gerloff and Fitzgerald (1976) report the minimum cell concentration for P in *Cladophora* that permits maximum yield (critical cell concentration) in laboratory culture at approximately 0.06% P tissue and has a very steep rate of increase in biomass yield. Work by Auer and Canale (1982) through photosynthetic studies suggest 0.06% P is the minimum cell quota (where growth ceases).

relative photosynthetic rate between 1.2–1.5% nitrogen tissue content. We are unaware of any direct field relationship between nitrogen water column concentration and nitrogen tissue content in the literature (for example, none was reported in any of the studies above).

However, by examining data from Gordon et al. (1981), Lohman and Priscu (1992), and Flynn (2014), a two-step correlation can be made. First, regressing soluble inorganic nitrogen (SIN; NO_{3+2} plus ammonia) in the water column with tissue concentrations from nitrogen limited *Cladophora* above, it is believed that approximately 12–17 µgN/L of soluble inorganic nitrogen will constrain tissue concentrations to 1.1–1.5%. This is equivalent to approximately 150–200 µg/L of total nitrogen based on the low SIN:TN ratio observed in the White River. As such, there is reasonable evidence that nitrogen is providing some limitation on *Cladophora* growth, especially during August when concentrations are already at or below these levels. Nitrogen reductions in the watershed could therefore be a viable means of reducing algal biomasses provided other factors (e.g., light, temperature, and scour) are not more controlling.

It is strongly recommended that sampling of both tissue concentration and water column concentration be made over a spatial gradient both with and without abundant *Cladophora*, and a range of water column nutrient concentrations to confirm the above literature estimates (for both nitrogen and phosphorus). Finally, hardness and grazing can also affect *Cladophora* establishment and filament extension (Whitton, 1970; Dodds and Gudder, 1992) although in this instance we do not think these are important considerations.

3.6 Data Gaps and Conclusions from Initial Screening of Data Against Water Quality Standards

Insufficient data exist in the WQP to fully assess the chemical and biological condition of the upper White River. The following is noted:

- Nutrient data are widely available, and are well below the proposed interim nutrient criterion for Colorado. Dissolved nutrients are in excess of limiting levels during non-growing season period indicative of a supply of dissolved nutrients not being used biologically and during the growing season (July-September) at levels that reduce algal growth rate relative to saturation but not enough to control nuisance algae accumulation. Nitrogen appears to be the limiting nutrient throughout the watershed. The North Fork has elevated concentrations relative to South Fork.
- DO achieves relevant standards at all locations in the watershed, but diurnal data has not been collected. Diurnal data will help better evaluate attainment of water quality standards and to identify if there are diurnal impacts to fish or aquatic life. These data were collected as part of this effort and are described in **Section 4**.
- One pH excursion was identified at the 5th Street Bridge in Meeker, CO (i.e., 85th percentile of pH data above 9.0 S.U.), but the rest of the watershed appears to have pH conditions that are not harmful to fish or aquatic life. More diurnal data should be collected to better evaluate attainment of pH standards.
- Insufficient benthic chlorophyll a and DOC data exist throughout much the watershed to make a determination about conditions in the upper White River. Of the samples that

were collected by CPW, chlorophyll a greatly exceeded the Colorado standard upstream of meeker and DOC data in the WQP exceeded the standard downstream of Meeker.

A large-scale effort should be initiated to address the data gaps above to provide a greater understanding of conditions in the watershed. The information could then be used to either directly address nuisance algae in the river, or potentially pursue funding mechanisms from available agencies for restoration or planning activities.

4 Data Collection

4.1 Field Activities

Multiparameter water quality sondes were deployed in the White River and tributaries to evaluate instream conditions and diurnal changes in water quality. YSI EXO2 multiparameter sondes were deployed in three stream locations from August 28 to September 4, 2017. The sondes were deployed into the North Fork White River at former Bel Aire fish rearing station (near Buford), the South Fork White River, and the mainstem of the White River just above Elk Creek. The South Fork White River site was at a ranch bridge approximately 3.5 miles upstream from confluence with North Fork. The sondes continuously logged data at 15-minute increments throughout the deployment. Sonde deployment was conducted by Elk Creek Ranch and overseen by HydroSolutions. A sampling and analysis plan (SAP) was prepared to direct the deployment and data collection activities.

Relevant physical parameters that were measured and recorded for this data collection activity included:

- Temperature (degrees Celsius)
- Conductivity and specific conductivity (micro-Siemens per centimeter, µS/cm)
- Total dissolved solids (milligrams per liter, mg/L)
- pH
- Oxidation Reduction Potential (millivolts, mV)
- Turbidity
- Dissolved Oxygen (percent saturation, % sat and miligrams per liter, mg/L)

Field observations were made during deployment of water quality sondes and in the subsequent days observing these and other sites of interest in Upper White River watershed with Elk Creek Ranch personnel. The North Fork White River appeared to contain both bright green attached algae and dead and dying algae dried onto rocks. The North Fork appeared to support more attached bright green algae, indicating that it was still growing and healthy compared to the other sites. Downstream at the White River about Elk Creek site, algae were visible, but they appeared dull and more had become detached from rocks and were floating downstream. Filamentous attached algae were not visible at the South Fork White River site. A photograph of attached algae in the North Fork White River near Buford is shown below in **Photograph 3**.

Photograph 3. North Fork White River near Buford, Colorado, photograph taken on August 28, 2017

4.2 Results

Diurnal variation in pH and dissolved oxygen (DO) generate a useful comparison of the actual stream conditions to the numeric standards established by the state of Colorado for the White River, as presented in **Table 1** and more so indicate whether fish and aquatic life might be harmed by the algal accumulation in the watershed. Exceedances of the Colorado water quality standards for pH and DO were recorded on the mainstem site above Elk Creek, where the maximum pH standard of 9.0, was exceeded every day and DO levels dropped below 7.0 mg/L (the minimum standard for spawning) on two days. **Figure 13** below illustrates the pH and DO values measured in the mainstem of the White River.

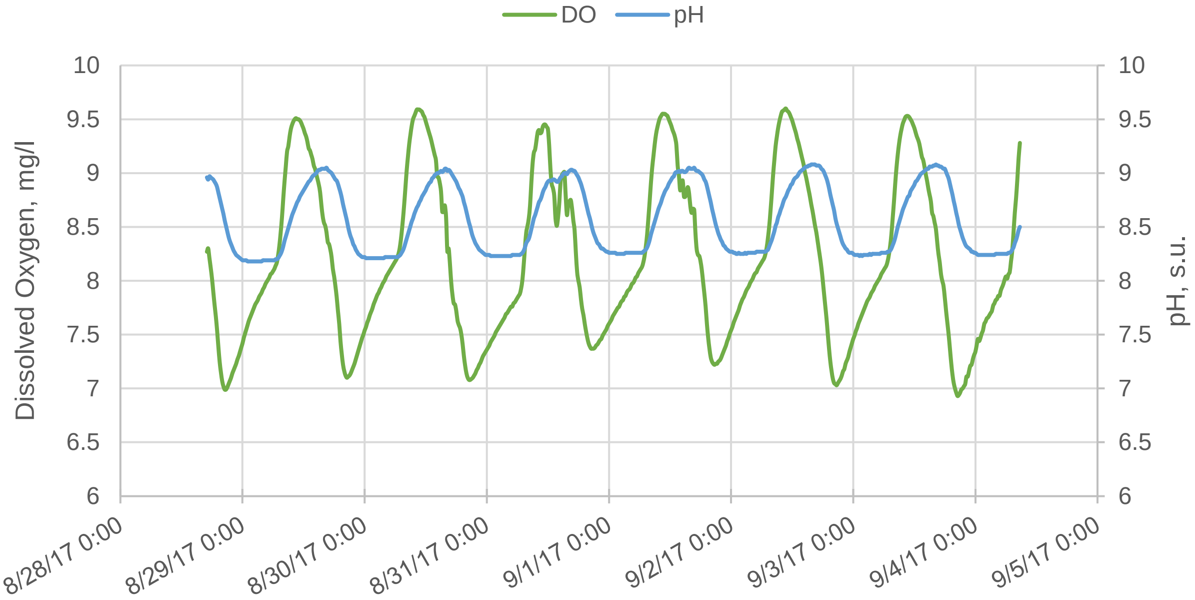


Figure 13. Diurnal variations in temperature and pH recorded by a multiparameter sonde deployed in the mainstem of the White River above Elk Creek from August 28 – September 4, 2017

A distinct day-night (diurnal) variation in DO and pH is evident in the data collected at all sites. However, diurnal cycling is more evident in the mainstem and the North Fork when compared with the South Fork site. Measurements coincided with the observed presence of greater biomass in the mainstem and North Fork, compared to the South Fork. DO levels at all sites were measured above the protective minimum DO standard of 6 mg/L, and pH levels recorded on the North Fork and South Fork locations were within established numeric water quality standards. Comparative diurnal trends in DO, pH, and temperature for the three sample locations are presented in **Figure 14**. A complete tabulated data set of all field parameters measured at all stream locations is on file with HydroSolutions and can be made available upon request and per the authorization of Elk Creek Ranch.

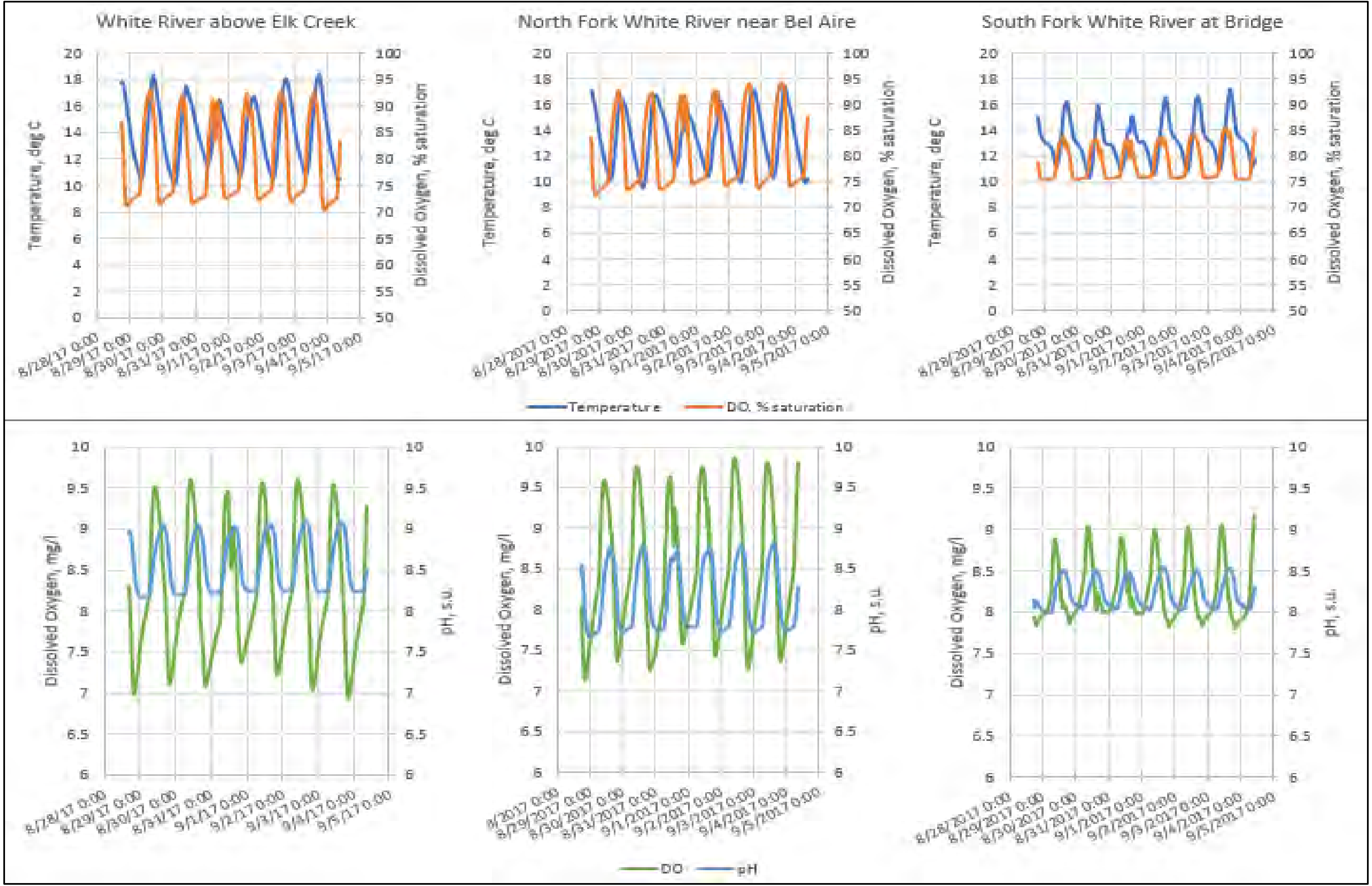


Figure 14. Temperature, dissolved oxygen, and pH measurements collected at three locations by a multiparameter sonde from August 28 – September 4, 2017.

4.3 Discussion

Diurnal pH and DO cycling is normal in shallow rivers with periphyton (benthic algae). Provided the magnitude of these cycles are not in excess, diurnal variation is not problematic. The relationship between the demand for carbon dioxide, nitrogen, phosphorus, water by algae, and the use of sunlight to produce algal protoplasm by photosynthesis is represented below (Stumm and Morgan 1996)

$$\underset{\text{carbon dioxide}}{106\mathrm{CO_2}} + \underset{\text{nitrate}}{16\mathrm{NO_3^-}} + \underset{\text{orthophosphate}}{\mathrm{HPO_4^{2-}}} + \underset{\text{water}}{122\mathrm{H_2O}} + \underset{\text{hydrogen ion}}{18\mathrm{H^+}} \xrightarrow{\text{sunlight}} \underset{\text{algal protoplasm}}{\mathrm{C_{106}H_{263}O_{110}N_{16}P}} + \underset{\text{oxygen}}{138\mathrm{O_2}}$$

where reactants are shown to the left of the arrow and products are to the right.

During the daytime, chlorophyll a (light harvesting pigment within the algal cells) captures sunlight such that photosynthesis or gross primary production of the system is dominant. Carbon dioxide (CO_2), nitrate, orthophosphate, water, and hydrogen ions are removed from the water to create algal material along with DO. The decrease in CO_2 and hydrogen ion in solution increase waterbody pH; liberation of oxygen from the reactants creates DO. At night, there is no solar radiation and the net reaction proceeds to the left due to respiration. Oxygen is consumed and hydrogen ion released causing low oxygen and pH. As such, both DO and pH are highest during the daytime hours when the sun is overhead and photosynthesis is at its maximum. Correspondingly they are lowest at night just prior to sunrise.

In examination of the magnitude of the DO and pH cycles in **Figure 14**, it is believed the mainstem and North Fork White River are more productive than the South Fork White River. Because magnitude of the cycle is largely a function of the amount of periphyton on the river bottom (including both *Cladophora* and biofilm) and the relative ratio of the areal extent of algae to river water volume, it is inferred that more biomass is accumulated in those two areas than the South Fork. Examination of concomitant nutrient levels support this assertion and there is likely a greater mass of biological material photosynthesizing and respiring.

It is noted that diurnal pH values measured in the mainstem of the White River are in excess of the Colorado water quality standard (>9.0 s.u.) and have potential to harm aquatic life. Likewise, DO concentrations at this same location slightly exceed the Colorado standard for salmonid spawning (<7 mg/L). Field observations were made after the peak algae in the White River, during its senescent phase (sloughing and decaying). As such, even greater day-night variations in DO and pH might be expected earlier in the growing season, which is even more concerning. A more timely effort should be made in the future to evaluate diurnal cycling in late July or early August, prior to algal senescence.

Research has shown trout are negatively impacted at pH levels greater than 9.0 due to alkaline conditions, and eventual death if alkaline enough (Bozeman 2014). The standard's upper limit of 9.0 is believed to protect fish against a greater prevalence of hydroxide ions which cause hypertrophy of mucus cells in gill filaments and skin epithelium, and additional detrimental effects on the eye lens and cornea (Suplee, Flynn and Chapra 2015). Generally DO levels above 8 mg/l are desirable for trout and at levels below 6 mg/l, trout and other coldwater fish begin to experience decreased growth, activity, fitness, and survival rates. Adult coldwater fish are more tolerant of low DO levels than embryos or juveniles (Bozeman 2014).

Finally, other conditions were not assessed, primarily seasonal dynamics. For instance, when large amounts of filamentous biomass accumulate in rivers, these algae eventually slough, die, and decompose on either the shoreline or in pools of the river. The oxidation of carbon results in biochemical oxygen demand (BOD), which in turn decreases the DO in the stream. Very low localized oxygen concentrations have been observed in pools and runs of river where decaying algae have accumulated in late summer and early fall (unpublished data). Such locations serve as the primary cold-water refugia for fish during this time of the year and may contribute to additional impacts not investigated here.

5 Hydrology

Like most mountain watersheds in Colorado and the western United States, the hydrology of the White River watershed is driven by snowmelt runoff (USGS 1984). Watershed hydrology is an important component in the physical disturbance mechanism regulating algae in rivers. It also controls how loads manifest as concentrations in the river. During runoff, increased streamflow and streamflow velocity and provide a mechanism where algal material is scoured and transported downstream. In the case of *Cladophora*, bedload movement also serves to detach *Cladophora* holdfasts thereby setting back their accumulation. Conversely, in years with diminished runoff detachment or bedload movement is minimal. In addition, decreased baseflow in the summertime months increases both water temperature and ambient nutrient concentrations the algae are exposed to.

5.1 Gaging Stations

Streamflow data available from USGS was reviewed to identify potential scouring flows, and for apparent changes in the hydrologic regime that could potentially be contributing to recent algal blooms in the White River. **Table 5** summarizes active and inactive USGS stream gaging stations upstream of Meeker, CO.

White River near Meeker, Colorado (USGS Station 09304500) was selected for this analysis since it is an active gage with the longest period of record (greater than 100 years of data) and incorporates the largest drainage area above Meeker. While there are many other historical and inactive USGS stream gage and water quality monitoring locations in the basin, this is the best candidate site. This evaluation included review of the magnitude, timing, and duration of flows, examination of peak flows, and a comparison of recent summer time stream flows to historical average summer time stream flows.

Table 5. Summary of USGS stream gaging stations in the White River and select tributaries above Meeker, Rio Blanco County, Colorado

Name	Station Number	Drainage Area (Sq. Miles)	Period of Record
White River near Meeker, CO	USGS 09304500	760	1901-2017
White River above Coal Creek nr Meeker, CO	USGS 09304200	648	1961-2017
White River below North Elk Creek nr Buford, CO	USGS 09304115	530	2003-2017
North Fork White River at Buford, CO	USGS 09303000	259	1910—2001
North Fork White River nr Buford, CO	USGS 09302800	220	1903-1973
NF White R above Ripple Cr nr Trappers Lake, CO	USGS 09302420	62.5	1965-1973
South Fork White River at Buford, CO	USGS 09304000	177	1919-1997
South Fork White River nr Buford, CO	USGS 09303500	152	1093-1992
South Fork White River nr Budges Resort, CO	USGS 09303400	128	1976-1995
South Fork White River at Budges Resort, CO	USGS 09303300	52	1975-1995

5.2 Flood Frequency & Peak Flows

Flood flow magnitude and frequency for the White River above Meeker (USGS 09304200), the North Fork White River (USGS 09303000) and South Fork White River (USGS 09304000) are listed in **Table 6**. As is noted, the peak flow contribution from the North Fork and South Fork roughly sum to the White River near Meeker, and thus much of the streamflow during annual peak flow is accounted for by those two forks of the river.

Table 6. Flood flow magnitude in ft^3/s and recurrence interval (frequency) for the North Fork, South Fork and Mainstem White River above Meeker, Colorado (USGS 2000)

	Recurrence Interval							
Station	2-Year	5-Year	10-Year	25-Year	50-Year	100-Year	200-Year	500-Year
White River nr Meeker USGS 09304500	3,170	4,210	4,840	5,600	6,140	6,650	7,150	7,780
North Fork White River at Buford USGS 09303000	1,380	1,890	2,230	2,640	2,940	3,240	3,540	3,930
South Fork White River at Buford USGS 09304000	1,800	2,310	2,600	2,920	3,140	3,340	3,530	3,760
Reference: (USGS 2000) Analysis of the Magnitude and Frequency of Floods in Colorado, Water Resources Investigations Report 99-4190. Denver, CO: United States Geological Survey.								

Annual peak flows for the White River near Meeker from 2007 to 2017 are summarized in **Table 7**. The frequency distribution and cumulative frequency distribution for the period of record is shown in **Figure 15**. Accordingly, the annual peak flows of the three most recent years (2015 to 2017) have ranged from the 21–32% percentile; all less than the 2-year flood flow. The year 2014 ranked 66 percentile for the period of record and was between the 2- and 5- year flood flow. Annual peak flow in 2012 and 2013 ranked 2 and 12 percentile, again less than the 2-year flood flow. Peak flow in 2011 was greater than 97 percent of all flows of the period of record at this gage at 5,930 cfs, and was between a 25 and 50 flood flow. Peak flow in 2008 to 2010 was similar to 2014, ranking 66-67% each year for the period of record at this gage, 2- to 5-year flood flows.

Table 7. Annual peak flow values at USGS 09304500 for 2010 to 2017, their percentile rank, and flood recurrence interval

Date	Peak Discharge (ft^3/s)	Percentile Rank of Annual Peak Discharge Values for Period of Record	Flood Flow Recurrence Interval
5/16/2007	1,920	11%	< 2-Year
5/21/2008	3,690	67%	2- to 5-Year
5/25/2009	3,670	66%	2- to 5-Year
6/8/2010	3,670	66%	2- to 5-Year
6/7/2011	5,930	97%	25- to 50-Year
4/27/2012	1,160	2%	< 2-Year
5/27/2013	1,930	12%	< 2-Year
6/1/2014	3,650	66%	2- to 5-Year
6/4/2015	2,680	32%	< 2-Year
6/6/2016	2,580	28%	< 2-Year
6/11/2017	2,300	21%	< 2-Year
Median Annual Peak Flow	3,214	50%	~2-Year

Percentile values found using linear interpolation of cumulative frequency distribution of annual peak flows at White River near Meeker, Colorado (USGS 09304500) for period of record, 1901-2017.

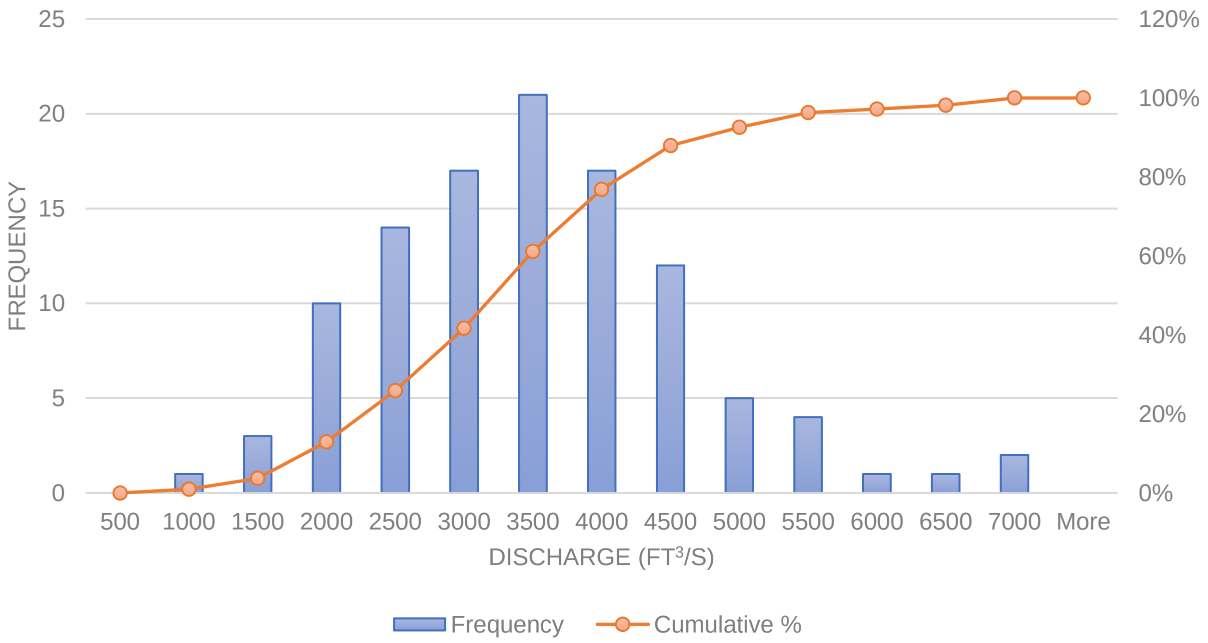


Figure 15. Frequency distribution and cumulative percent of peak flows in White River near Meeker, CO (USGS Station 09304500)

As can be seen in **Table 7**, a majority of the recent annual peak flows (after 2011) in the White River are characteristic of flood magnitudes less than the 2-year flood flow. The 2-year flood flow deserves special attention, as it is the discharge typically associated with the channel forming or bankfull flow (1.5-year flow). At discharges greater than the bankfull flow, bedload movement is most prevalent and thus scouring would be a dominant process expected to significantly reduce *Cladophora* accumulation. Of the period 2007–2017, five years have experienced peak flow less than the 2-year event, and three of these (the most recent) have been reported to have nuisance algae.

As shown in **Table 8**, about three quarters of the 109 annual peak flows between 1901 and 2017 were 4,000 ft^3/s or less, with over half of all of the annual peak flows between 3,000 and 4,000 ft^3/s. Since 2011, annual peak flow has exceeded 4,000 ft^3/s one time (2011), and has exceeded 3,000 ft^3/s twice (2011 and 2014). The 3,000 ft^3/s and 4,000 ft^3/s benchmarks approximate the 2-year and 5-year flood events. The 2-year flood event approximates the bankfull flow in which a scouring flow may be likely to occur. The frequency of these events, historically and in recent years, were reviewed to understand the occurrence and frequency of scouring flows in the Upper White River watershed. In the sixty years from 1931 to 1990 peak annual flows of 3,000 ft^3/s or greater occurred every 1.67 years. In the current decade there have been only 2 peak annual flows greater than 3,000 ft^3/s, coming roughly every 3.5 years. At least in the short term, this appears to indicate a lack of scouring flow events in the Upper White River.

Table 8. Number of occurrences of annual peak flow exceeding 3,000 ft^3/s and 4,000 ft^3/s at White River near Meeker, CO (USGS Station 09304500)

Period	Number Years	No. Years Peak Flow >3,000 ft^3/s	No. Years Peak Flow >4,000 ft^3/s	Notes
1901-2017	109	64	26	Period of Record (peak discharge not measured 1902-1909)
1901-1930	22	13	6	Peak flow for this period occurred on June 30, 1957 at 5,220 ft^3/s (peak discharge not measured 1902-1909)
1931-1960	30	18	7	Peak flow for this period occurred on June 16, 1921 at 6,370 ft^3/s
1961-1990	30	18	9	Peak flow of period of record occurred on May 25, 1984 at 6,950 ft^3/s (near 200-Year Flood)
1991-2017	27	15	4	Peak flow for this period occurred on June 7, 2011 at 5,930 ft^3/s
2011-2017	7	2	1	Peak flow for this period occurred on June 7, 2011 at 5,930 ft^3/s (near 50-Year Flood)

5.3 Duration of Peak Flow

The duration of peak flow for any given year is also important. Sustained flows provide time needed to scour stream substrate. We reviewed the number of days average daily discharge in the White River near Meeker exceeded the 2-year flood flow of 3,170 ft^3/s for each decade from 1901 to 2017 (**Table 9**). **Figure 16** shows the number of days per year over that same period that average daily discharge exceeded the 2-year flood flow.

The decade from 1981 to 1990 had the largest number of days (89 days) with flows greater than the 2-year flood flow, while the decade from 1931 to 1940 had the least (2 days). The current decade had 41 days where average daily discharge exceeded the 2-year flood flow. Most (40) of those days came in 2011. The year 2011 also has the highest number of day where average daily discharge exceeded the 2-year flood flow. The last three years of nuisance algal accumulation had zero days of the estimated bankfull flow.

Table 9. Number of days per decade that average daily discharge was greater than the 2-year flood flow (3,170 ft^3/s) in White River near Meeker, CO (USGS Station 09304500)

Period	No. Days Average Daily Discharge > 2-Year Flood Flow	Period	No. Days Average Daily Discharge > 2-Year Flood Flow
1901-1910	11	1961-1970	17
1911-1920	64	1971-1980	37
1921-1930	62	1981-1990	89
1931-1940	2	1991-2000	44
1941-1950	31	2001-2010	10
1951-1960	68	2011-2017	41

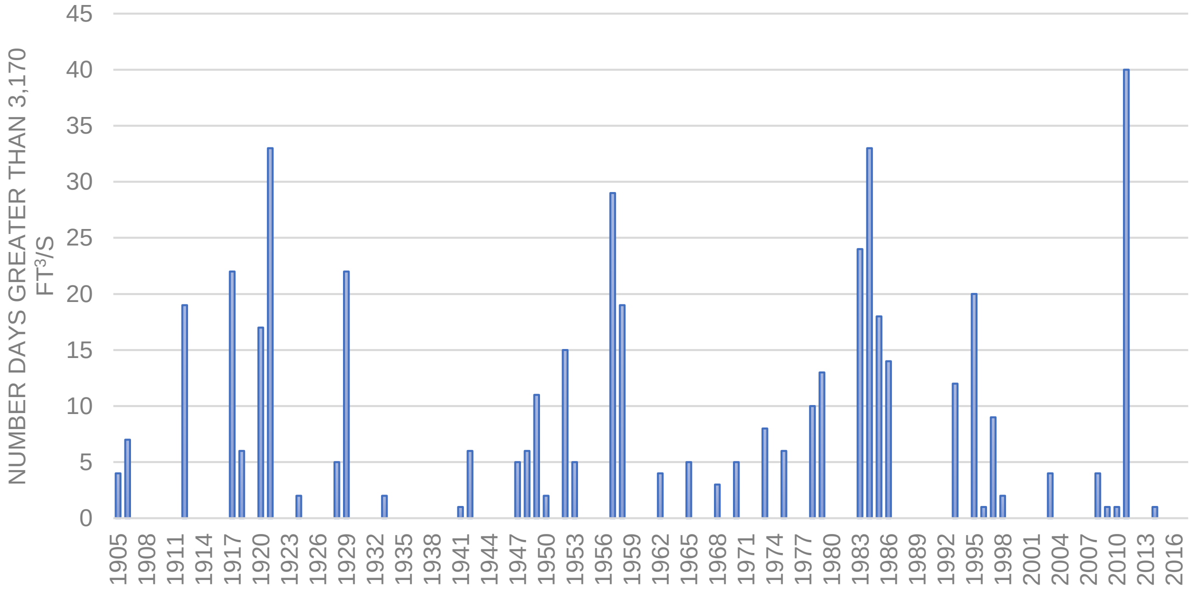


Figure 16. Number of days per year that the average daily discharge was greater than the 2-year flood flow (3,170 ft^3/s) in White River near Meeker, CO (USGS Station 09304500)

The flow duration curve for White River near Meeker is shown in **Figure 17**. **Table 10** summarizes the flow duration curve for this location, listing the percent of time discharges are exceeded 95, 90, 75 70, 50, 25, and 10 percent of the time. Two periods are shown, 1) the period of record 1901 to 2017, and 2) 2012 to 2017. The latter is shown to represent current conditions without potential bias from the water year of 2011.

As indicted, the current (2012 to 2017) period is general characteristic of lower peak flow and lower baseflow flow than for the period of record. Flows have been of lower magnitude with shorter duration than they have been historically, and low flows have been for a longer duration than historically. In this way, current conditions have been hydrologically different than over the period of record.

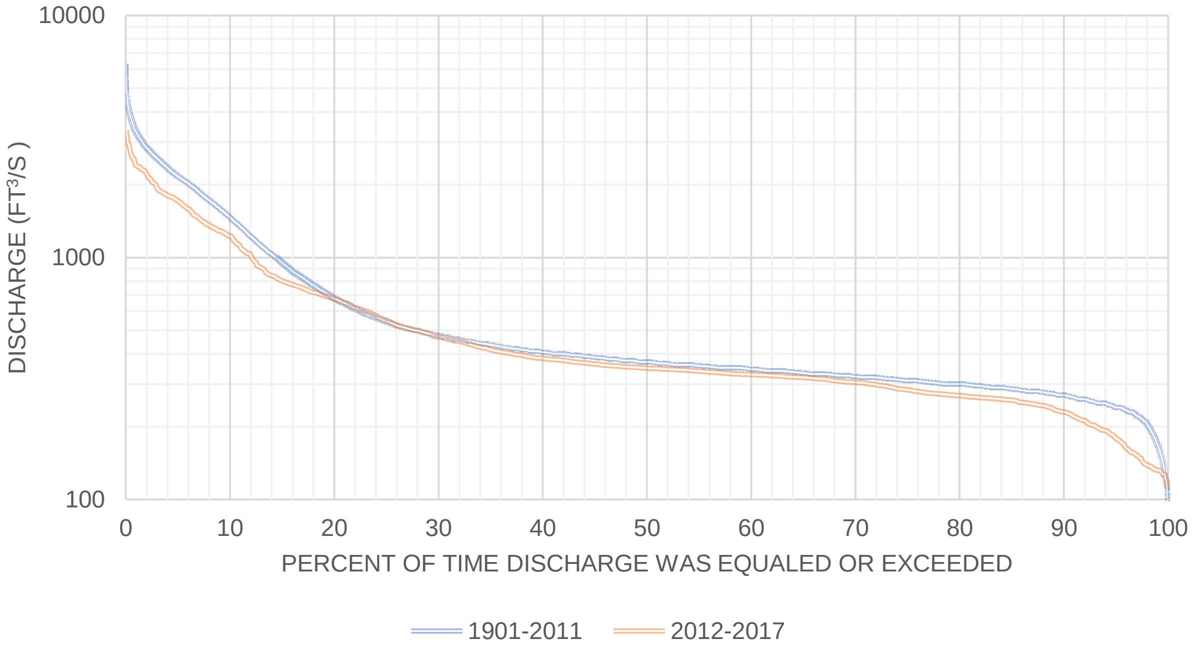


Figure 17. Flow duration curve for White River near Meeker, CO (USGS Station 09304500)

Table 10. Flow duration at White River near Meeker, CO, USGS Station 09304500 for period of record and 2012 to 2017

Period	**Percent of Time Discharge, in cubic feet per second, equaled or exceeded**						
	95	90	75	70	50	25	10
1901-2011	240	270	310	322	370	542	1470
2012-2017	178	230	284	305	349	550	1230

5.4 Timing of Peak Flow

Historically peak runoff in the White River above Meeker occurs at the end of May as noted in the annual hydrograph for USGS Station 09304500 (**Figure 18**). The period of 2014 to 2017 is also shown for reference. As observed in the figure, daily discharge from 2014 to 2017 is similar in timing to the median daily discharge for the period of record. Runoff in 2014 and 2015 began slightly sooner and August flows in 2015 and 2016 were lower than the statistic.

Median peak flow and peak flow day of year and date by decade, 1910 to 2017, are shown in **Table 11**. Over the period of record the median and average date for the annual peak flow occurs on May 29, with a standard deviation of 13 days. Peak flow dates 2010 to 2017 were within this standard deviation of the median peak flow date for all years, except for 2012, which occurred on April 27 of that year, over one month early. Note, the 2012 peak flow was the earliest recorded annual peak discharge recorded at USGS Station 09304500. Recent peak flow dates, 2014 through 2017, have occurred near-to, or after the median peak flow date for the period of record.

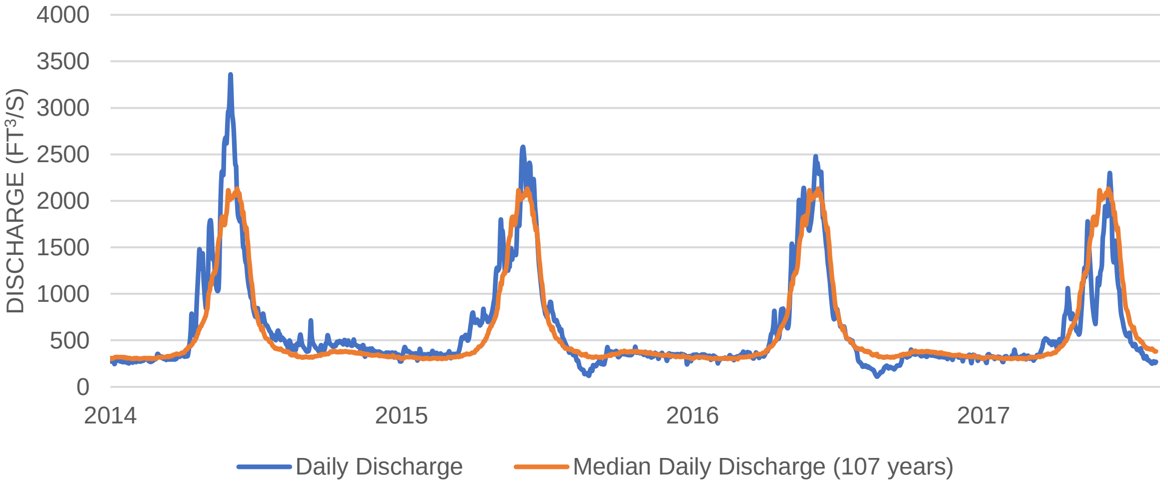


Figure 18. Daily discharge 2014-2017 White River near Meeker, CO (USGS Station 09304500)

Table 11. Median peak flow values and date that occurred each decade from 1910 to 2017 for White River near Meeker, CO, USGS Station 09304500

Period	Median Peak (ft^3/s)	Median Peak Day of Year	Median Date
1910-1920	3,490	160	8-Jun
1921-1930	3,035	153	1-Jun
1931-1940	2,885	139	18-May
1941-1950	3,485	150	29-May
1951-1960	3,140	159	7-Jun
1961-1970	2,950	145	24-May
1971-1980	3,310	156	4-Jun
1981-1990	2,790	155	3-Jun
1991-2000	3,420	152	31-May
2001-2010	3,300	143	22-May
2011-2017	2,580	155	3-Jun
Period of Record	**3,145**	**150**	**29-May**

Table 11 shows that there were three decades in which the median peak flow date of the decade was earlier than the median peak flow date for the period of record: 1931 to 1940, 1961 to 1970, and 2001 to 2010. The median peak flow date 2001 to 2010 was about a week earlier than the median peak date of the period of record, however, the median peak date for the current decade is 5 days later than the median of the period of record.

Review of regression analysis of annual peak flow dates 1950 to present at USGS Station 09304500 show that annual peak flows are coming about 11 days earlier over the period analyzed (personal communication, Bob Dorsett, 11/2/2017). Regression coefficients were significant at the 95% confidence level.

Figure 19 shows the mean monthly discharge 2014 to 2017 for the White River near Meeker (USGS Station 09304500) compared to the average monthly discharge over the period of record. In general, mean monthly discharge values 2014 to 2017 are comparable to the period of record, although 2017 has some months that differ appreciably. In 2017 mean monthly discharge in March and April 2017 were similar to slightly greater, while May through August were less than the average monthly discharge for the period of record. Also, mean flows in August 2015 to 2017 were about half of the average monthly discharge for the period of record. In comparing mean monthly flow for April, the period from 1984 to 2016 is 21 percent higher (mean flow for the period is 613 ft^3/s), than the period 1950 to 1983 (mean flow for the period is 508 cfs). This indicates that higher flow may be occurring earlier in the season.

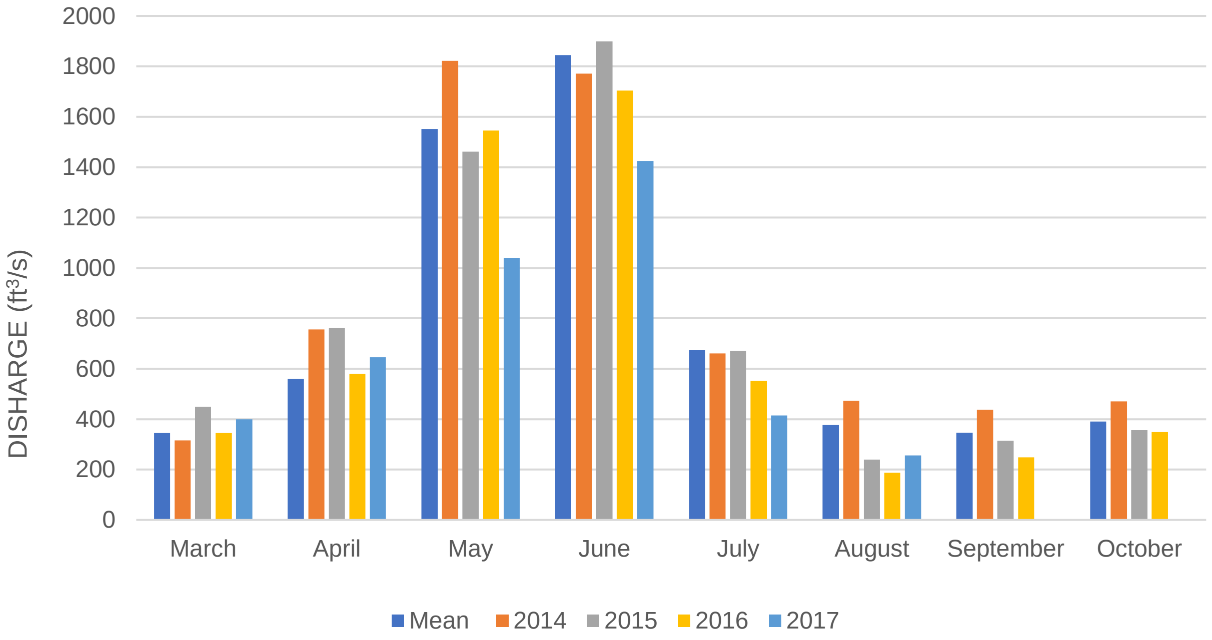


Figure 19. Monthly mean discharge 2014 to 2017 and mean monthly discharge for period of record (1910 to 2017), White River near Meeker, CO (USGS Station 09304500)

5.5 Low Flow

Low-flow characteristics are commonly used to evaluate the adequacy of a stream to assimilate industrial or municipal wastes, or to fulfill water-supply requirements (USGS 1984). Like a flood recurrence interval, a low-flow statistic used to evaluate toxicity or other water-quality impacts. The 7-day low flow that occurs on average once every 20 years (i.e., 7Q20) is the most widely used national low-flow statistic. The USGS assembles annual Water-Year reports that include the 7-day low-flow for a given year (used in computation of extreme value statistics) and we compared data from the White River near Meeker from 2010 to 2016 with the published 7Q20 for that gage. This low-flow information is summarized in **Table 12**.

As indicated in the table and shown in **Figure 20**, each of the last 7 years (2010 to 2016) have had a 7-day low-flow period less than the published 2-year low-flow value of 270 cfs at the White River near Meeker. Four, nearly 5, of the last 7 years have seen 7-day low flow periods below the 7-day 20-year low flow value of 169 cfs.

Table 12. Summary of annual mean discharge and 7-day low-flow values for White River near Meeker, CO (USGS Station 09304500) from 2010 to 2016

Water Year	Annual Mean Discharge (ft^3/s) [1]	7-Day Low Flow (ft^3/s) [1]	Low Flow Date [1]
2010	530	170	9/17/2010
2011	975	246	2/2/2011
2012	403	133	9/13/2012
2013	392	133	9/2/2013
2014	649	232	12/4/2014
2015	645	135	8/20/2015
2016	569	128	8/20/2016
Mean Annual 1910-2016 [1]	618	-	-
7-day, 2-Year Low Flow [2]	-	270	-
7-day, 20-Year Low Flow [2]	-	169	-

1 USGS Annual Water Year Report for 09304500 https://waterdata.usgs.gov/nwis/wys_rpt
2 USGS Stream Stats from Basin Characteristics File https://streamstatsags.cr.usgs.gov/gagepages/html/09304500.htm#31

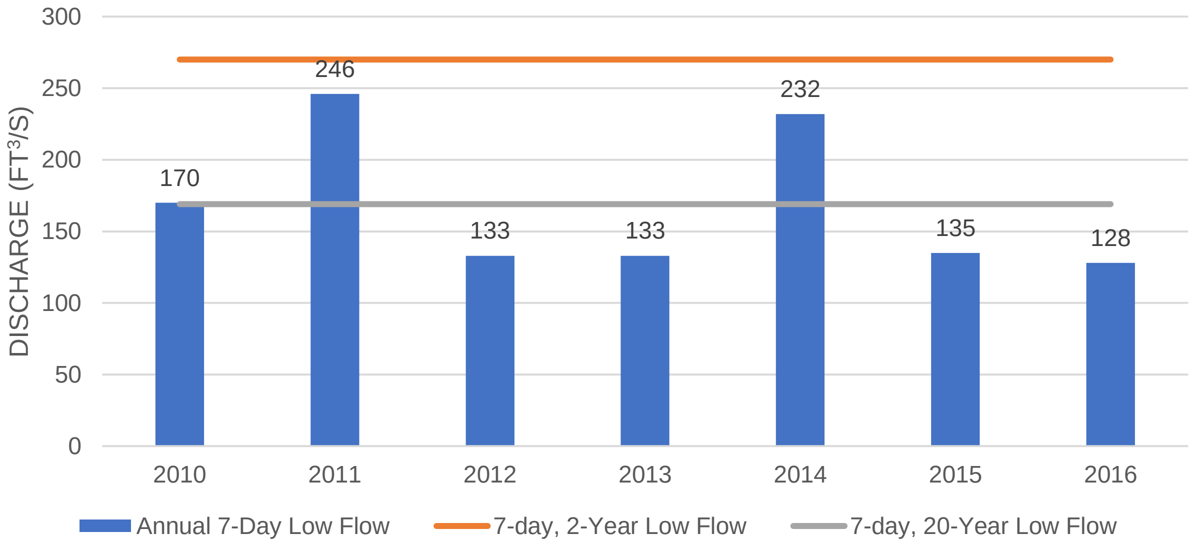


Figure 20. Annual 7-day low flow values 2010 to 2016 compared to 7-day, 2-year and 7-day, 20-year low flow recurrence values, White River near Meeker, CO (USGS Station 09304500)

5.6 Annual Discharge

The annual mean discharge is the measured daily discharge averaged over the year and indicates the total amount of water conveyed through the system. The annual mean discharge of the White River near Meeker (USGS Station 09304500) for recent years was reviewed and compared with the long-term average annual discharge, and is shown in **Table 13**.

Table 13. Annual Mean Discharge from 2010 to 2016 for White River near Meeker, CO (USGS Station 09304500), compared with long-term annual discharge

Water Year	Annual Mean Discharge (ft^3/s)
2016	569
2015	645
2014	650
2013	392
2012	403
2011	975
2010	529
Mean 1910-2016	618

Table 13 shows that since 2010 there have been four years that the annual mean discharge was less than the long-term average (2010, 2012, 2013, and 2016), and three years (2011, 2014, and 2015) that the annual mean discharge was greater than the long-term average. Note that the average annual discharge in both 2012 and 2013 was among the lowest recorded at USGS Station 09304500. Of the 107 years of record, there were only 6 years that had less average annual discharge, and only 2 of those years occurred before 1980 (1934 and 1977). These years (2012 and 2013) immediately preceded the start of the White River nuisance algal blooms.

5.7 Summary & Discussion

Streamflow is an important factor governing the algal mass balance and is also important in expressing nutrient loads on a concentration basis. Channel bed disturbance by floods is generally understood to be one of the fundamental controls of temporal and spatial patterns in stream periphyton (Biggs, Smith and Duncan 1999) and days of accrual and scour are both important factors governing algal accumulation in streams and rivers (B. Biggs 2000, Uehlinger, Bührer and Reichert 1996). Many studies confirm that movement of large portions of the channel bed suppress periphyton biomass (Segura, et al. 2010). Additionally, the length of the growing season and the days of accrual following a bed-load moving event have been found to be a very good predictor of algal biomass. For example, Lewis and McCutchan (2010) found that the length of the growing season (along with water temperature) is a “master variable” in controlling algal growth rate in unpolluted or minimally polluted Colorado montane streams.

There were likely multiple hydrologic factors that contributed to nuisance algal blooms beginning in 2014. The primary factor is the lack of sustained scouring flows leading to channel bed disturbance in the Upper White River. A scouring flow has probably not occurred since 2011. Recent peak flows have been of lower magnitude and short duration and the last large-scale scouring flow event in the study area likely occurred in 2011, which was a 25-year to 50-year flood event. During 2011 there were 40 days with flows greater than the 2-year flood flow. Since

2011, stream flow has peaked only 1 day (in 2014) greater than the 2-year flood flow. All other peak flow events since 2011 have been less than the 2-year flood flow.

Geomorphic characteristics of the streambed may also contribute to the proliferation of algal biomass. While a study detailing the geomorphology of the White River was not found, onsite observations indicate that the stream bed substrate containing attached algal tended to be large cobbles (7 to 10 inches). This substrate appeared stable and may even provide stream bed armoring in places, which could increase the likelihood that algal communities persist year to year without a scouring flow to wash them away. *Cladophora* have been shown to have an affinity for large and more stable substrate sizes (W. Dodds 1991) that are less prone to mobilization during runoff.

The timing of peak flow events may also be an important factor contributing to algal proliferation. Earlier peak flows can increase the days of accrual for instream algal communities, or influence the length of runoff. In 2012 peak flow was the earliest annual peak discharge recorded at USGS Station 09304500, occuring over a month earlier than the long-term median peak flow date. Recent peak flow dates, 2014 through 2017, are more aligned with historical conditions. Regression analysis of peak flow dates (1950 to present) show a significant trend at the 95% confidence level that peak flows are coming earlier. Additional analysis of this could be completed in evaluating center of mass runoff because peak date alone may not fully describe the runoff.

The extended occurrence of low flow may be another factor contributing to the proliferation of nuisance algae in the White River. Lower flows increase nutrient concentrations as a result of less dilution capacity as well as a greater proportion of the streamflow being contributed by groundwater. While this investigation did not compile and examine groundwater data, it typically contains high dissolved nitrogen constituents in agricultural areas. Each of the last 7 years (2010 to 2016) has had a 7-day low-flow period less than the published 2-year low-flow value of 270 ft^3/s at the White River near Meeker. Four, nearly 5, of the last 7 years have seen 7-day low flow periods below the 7-day 20-year low flow value of 169 ft^3/s. Thus, for a given nutrient load, ambient concentrations would increase.

Changes in hydrology in this region are not totally unexpected. McCabe et al. (2017) indicate increasing air temperature from climate change has been contributing to a substantial reduction in runoff efficiency in the Upper Colorado River Basin (White River included). Reductions in flow are the largest documented since record keeping began, and warm season (April through September) temperature has a larger effect on variability in water-year stream flow in the basin than cool season, suggesting that evaporation or snow melt have driven recent reductions (McCabe, et al. 2017). The authors also indicate that as warming continues, the negative effects of temperature on water-year stream flow in the Upper Colorado River Basin will continue. These changes are outside of the control of local watershed groups, but it is certainly possible they are at least a component of the recent algal proliferation in the White River.

6 Nutrient Source Assessment

The availability of nutrients is a key environmental component affecting algal growth rates as described previously in **Section 3**. They are also one of the few components that can be managed in unregulated hydrologic systems. An important step in the mitigation of impairment in any given water body is determination of pollutant sources and amount (White, et al. 2015). Therefore, an assessment of nutrient sources was completed to better understand the potential contributions of nutrient sources in the project area. Information on sources and their potential relative contributions can assist planners in making decisions on management actions or in developing a monitoring plan.

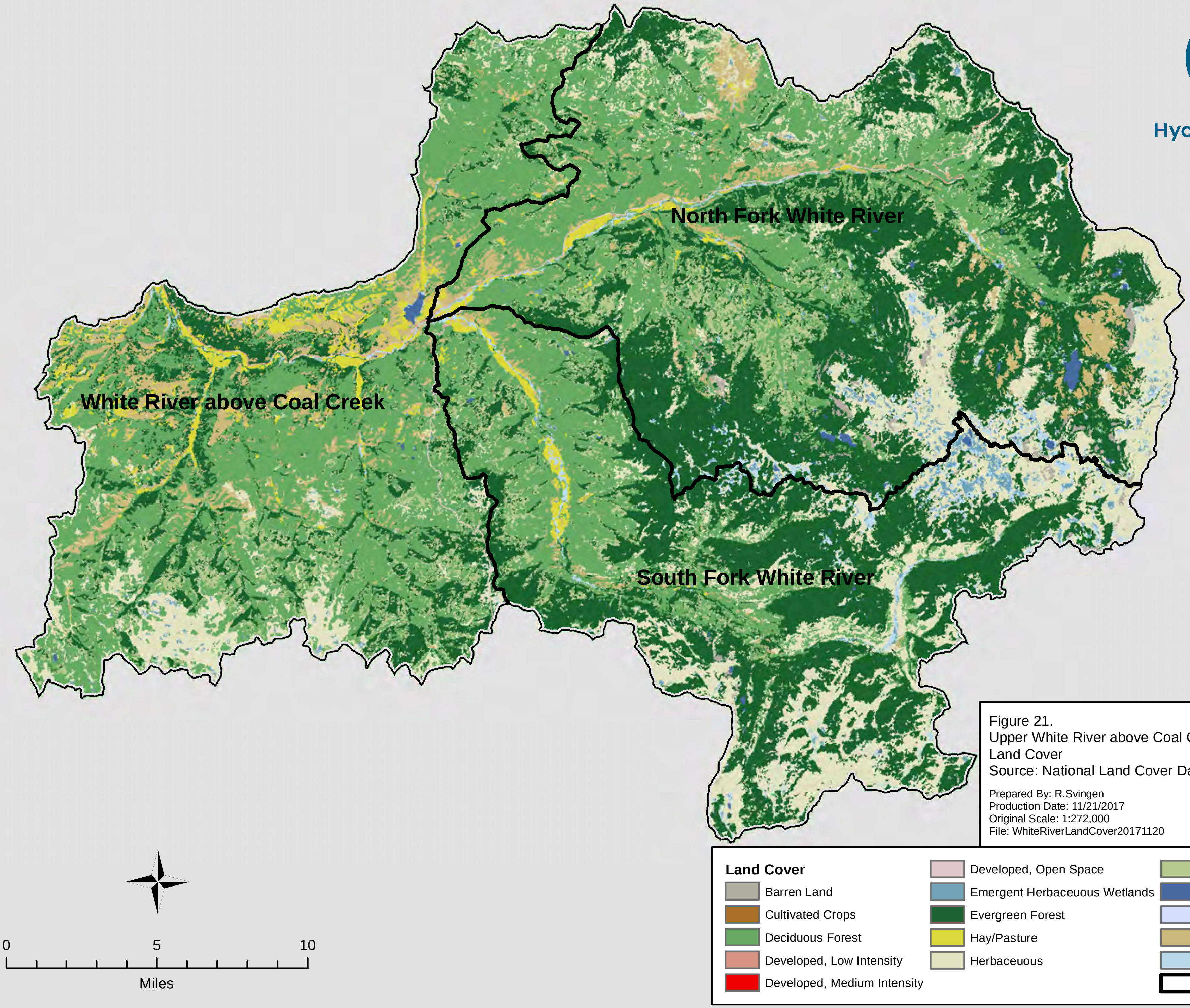
6.1 Methods

The simplest method to estimate nutrient contributions is the export coefficient (EC) approach. An EC is the mass of a pollutant contributed per unit land area per unit time (lb/acre/year). Since nutrient losses or contaminant contributions are strongly linked to land use, the total nutrient load to a water body can be inferred from watershed composition or its land use coverage (White, et al. 2015). The EC concept is not intended to accurately represent the load from a single field but is utilized in a broader sense to generalize the typical load from a particular land use (White, et al. 2015).

A procedure for calculating nutrient loads using the EC approach is presented by the EPA (Reckhow, Beaulac and Simpson 1980). This document, along with other publications, were reviewed to select representative EC values (Lin 2004). Where ever possible, source-specific data was used to estimate nutrient contributions. ECs used in this nutrient assessment are discussed in a subsequent section.

6.1.1 Land Cover

A Geographic Information System (GIS) analysis was used to estimate land cover in the White River Basin above Meeker for the purpose of the source assessment. Land cover for the Upper White River above Coal Creek from the 2011 National Land Cover Database (NLCD) (Homer, et al. 2015) is shown in **Figure 21**. Land cover was delineated above USGS Station 09304200, White River above Coal Creek for the purpose of calibrating to the estimated annual and August loads presented in **Table 4**, and also both the North Fork and South Fork to better understand the spatial distribution of sources in the watershed. GIS analysis found a total watershed area of 640 square miles above USGS Station 09304200, which compared well with 648 square miles of drainage area reported by the USGS for this gage. The sub-watersheds of the North Fork (261 sq. mi), South Fork (180 sq. mi), and White River above Coal Creek (199 sq. mi) are also shown. A summary of land cover for each sub-watershed is shown in **Table 14**.



HydroSolutions

Figure 21.
Upper White River above Coal Creek
Land Cover
Source: National Land Cover Database 2011

Prepared By: R.Svingen
Production Date: 11/21/2017
Original Scale: 1:272,000
File: WhiteRiverLandCover20171120

Table 14. Land cover in percent and acres, White River above Coal Creek and tributaries

Land Cover	Watershed Total		South Fork White River		North Fork White River		White River above Coal Creek	
Urban [1]	0.32%	1,298	0.04%	51	0.38%	635	0.48%	612
Undisturbed Forest [2]	72.48%	297,011	68.46%	78,979	73.30%	122,289	75.05%	95,742
Grassland [3]	21.72%	89,017	25.38%	29,275	21.01%	35,059	19.35%	24,683
Pasture/Hay	1.93%	7,918	1.23%	1,419	0.80%	1,330	4.05%	5,169
Open Water (atmospheric input)	0.35%	1,435	0.26%	301	0.51%	854	0.22%	280
Cultivated Crops	0.00%	0	0.00%	0	0.00%	0	0.00%	0
Wetlands	2.47%	10,115	4.06%	4,683	2.67%	4,457	0.76%	974
Barren Land	0.73%	2,985	0.57%	660	1.33%	2,214	0.09%	110
Total	100.00%	409,778	100.00%	115,368	100.00%	166,839	100.00%	127,571

Notes:

[1] Includes developed open space, and developed low, medium, and high intensity

[2] Includes deciduous, evergreen, and mixed forest

[3] Includes shrub/scrub and grasslands/herbaceous

Land use coverage was converted to hectares (ha; 1 ha = 2.47 acres) to complete the nutrient source assessment.

6.1.2 Export Coefficients

Published nutrient ECs were evaluated for their applicability and use. An accurate EC for a watershed needs to consider land use, topography, climate, management, level of conservation adoption, and soils. Site or region-specific EC were reviewed and used where available. White et al. (2015) provides ECs by ecological regions of the United States for a variety of land uses including: cultivated crops, grassland, undisturbed forest, and urban. This includes the Southern Rockies ecological region, of which the Upper White River is a part of. Other sources including Harmel, et al (2006), Lin (2004), and Reckhow, Beaulac and Simpson (1980) were also reviewed, and for reference provide a comparison of the range of published ECs for a variety of land uses. A summary of ECs considered for this nutrient assessment is included in **Appendix D**. ECs used in this nutrient assessment are shown in **Table 15**.

Table 15. Summary of nutrient export coefficients used for annual and summer-month nutrient load estimates

Land Use	Annual Load		Summer Month	
	TN	TP	TN	TP
Urban	8.14 [1]	0.285 [1]	3.01	0.112
Undisturbed Forest [2]	0.772	0.205	0.14	0.038
Grassland (all types) [1]	0.669 [1]	0.022 [1]	0.13 [2]	0.01 [2]
Pasture/Hay	4.09 [3]	0.64 [3]	1.52 [4]	0.25 [4]
Open Water/Atmospheric [5]	3.07	0.26	3.07	0.26

[1] (White, et al 2015) ECs for Southern Rockies Ecological Region, median values

[2] (White, et al 2015) ECs for Southern Rockies Ecological Region, between 10th and 90th percentile values

[3] (Reckhow 1980) Table 8 Nutrient Export from Non-Row Crop, Hay (Morris, MN; 572 mm precip/yr, loam soil) 6-year mean

[4] (Reckhow 1980) Table 9 Nutrient Export from Grazed and Pastured Watershed (Eastern SD; 584 mm precip/yr, sandy clay loam soil)

[5] TN value based on EPA CASTNET, Total N Deposition at Gothic, CO (GTH161), 2015 (wet and dry); TP value based on (Reckhow 1980), Table 13a Forest Atmospheric Inputs (wetfall only)

Note summer-month ECs for land use (forest, grassland, pasture/hay, and urban land use) used in the nutrient assessment decreased 55% to 84% from ECs used for annual loading estimate. This accounts for the decrease in runoff during the summer months, while other source inputs are averaged over the year.

6.1.3 Nutrient Loading

The method for the nutrient loading calculations in this assessment, modified from Reckhow (1980), is shown below:

$$\text{White River Nutrient Load } = \sum_{i=1}^{n}(EC_i \times Area_i) + S + F + PS \quad \text{(Equation 3)}$$

where

- EC_i is the export coefficient (kg/ha/year) for a land cover/use
- $Area_i$ is the area of the land cover/use, i, in the basin in ha
- S is the septic load in kg/year
- F is the fish feeding load in kg/year
- PS are point source inputs in kg/year

Note: there are not any known point source inputs in study area to be included in this assessment and we assume that loads in the North Fork, South Fork, and White River above Coal Creek are cumulative to the total watershed load.

Nutrient loads for the land cover/uses were estimated with the ECs shown above in **Table 15** for the annual and summer-month load estimates. The summer-month load is the total mass loading for one month during the summer season, based on a 31-day month. The total load for the watershed above Coal Creek was assumed to be the load modeled in **Section 3.4.6**, i.e., average annual load is 28,000 kg TP and 138,000 kg TN per year and the average summer-month load is 17.0 kg/day TP and 89.5 kg/day TN. Since the forest land cover is the largest area in the basin, that EC was optimized within the eco-region limits (10th to 90th percentile values) provided by White (2015) to arrive at the modeled annual and summer-month nutrient load estimate above. For summer-month load estimates, land cover/uses for grassland, pasture/hay, and urban/developed land use were also reduced as shown in **Table 15**. Nutrient load estimates for atmospheric, septic, and fish feeding are described below.

6.2 Nutrient Sources

Nutrient sources in the project area are predominantly nonpoint sources or dispersed contaminant sources. The EPA defines nonpoint sources as (EPA 2017):

> *Nonpoint source pollution generally results from land runoff, precipitation, atmospheric deposition, drainage, seepage or hydrologic modification. Nonpoint source (NPS) pollution, unlike pollution from industrial and sewage treatment plants, comes from many diffuse sources. NPS pollution is caused by rainfall or snowmelt moving over and through the ground. As the runoff moves, it picks up and carries away natural and human-made pollutants, finally depositing them into lakes, rivers, wetlands, coastal waters and ground waters.*

The EPA notes that nonpoint source pollution is the leading unmitigated cause of water quality problems, and the nonpoint source pollutants have harmful effects on drinking water supplies, recreation, fisheries, and wildlife. Nonpoint source pollution can include (EPA 2017):

- Fertilizers, herbicides and insecticides from agricultural lands and residential areas
- Oil, grease, and toxic chemicals from urban runoff and energy production
- Sediment from improperly managed construction sites, crop and forest land, and eroding streambanks
- Salt from irrigation practices and acid drainage from abandoned mines
- Bacteria and nutrients from livestock, pet wastes and faulty septic systems
- Atmospheric deposition

There are no known nutrient point sources in the project area.

The Meeker Source Water Protection Plan (Williams 2008) includes the Upper White River Watershed within its Secondary Protection Area. The Upper White River Watershed is upstream of the Primary Protection Area (Meeker wellfield area) to the headwaters of the White River. The Source Water Protection plan identified the following areas of concern regarding potential sources of contamination:

- Agricultural practices (including irrigated fields and livestock grazing)
- Oil and gas development
- Septic systems (individual sewage disposal systems, or ISDS)
- Transportation on roads
- Land uses/growth/development
- Private water wells
- Residential practices

- Gravel and uranium mining
- Forest lands

These sources as incorporated in land use coverage in the watershed, along with specific sources, such as fish feeding and fertilizer application which are described later.

6.2.1 Forest and Grasslands

Forested area and grasslands represent the largest areas in the watershed, over 120,000 acres, 188 square miles, or about 95% of the watershed. Of that, the forested area includes deciduous (33%), evergreen (33%), and mixed forests (6%) that accounts for about 72% of the watershed. A similar proportion exists for the sub-watersheds (North Fork, South Fork, and White River above Coal Creek).

For forested areas, eco-region specific ECs for TN range from 0.026 to 1.27 kg/ha/year (10th to 90th percentile values), with a median value of 0.297 based on over 400,000 samples (White, et al. 2015). The EC used for the annual load estimate was 0.77 kg/ha/year, which is higher than the median value. The EC used for summer-month load estimate was 0.14 kg/ha/year, which is lower than the median value. Eco-region specific ECs for TP in forested areas range from 0 to 0.41 kg/ha/year (10th to 90th percentile values), with a median value of 0.002 based on over 400,000 samples (White, et al. 2015). The EC used for annual load estimate was 0.21 kg/ha/year. The EC used for summer-month load estimate was 0.04 kg/ha/year. Both the annual and summer-month EC for TP was higher than the median value for the eco-region.

For grasslands, eco-region specific ECs for TN range from 0.064 to 5.07 kg/ha/year (10th to 90th percentile values), with a median value of 0.669, based on over 200,000 samples (White, et al. 2015). The median eco-region specific EC value was used for annual load estimate. The EC used for summer-month load estimate was 0.13 kg/ha/year, which is lower than the median value. Eco-region specific ECs for TP in grasslands range from 0 to 0.404 kg/ha/year (10th to 90th percentile values), with a median value of 0.022, based on over 200,000 samples (White, et al. 2015). The median eco-region specific EC value was used for annual load estimate. The EC used for summer-month load estimate was 0.01 kg/ha/year, which is lower than the median.

There are a number of factors that have potential to affect the nutrient losses from forested areas and grasslands including: tree and plant species type, soil type and bedrock parent material, vegetation age, climate, and amount of disturbance. Applicable components in the White River are detailed below:

Studies have demonstrated that pine and coniferous softwoods have a higher rainfall interception capacity and evapotranspiration rates than hardwoods (considering leaf-off periods of the year), and therefore, higher nutrient loads develop from tributaries draining hardwoods (Reckhow, Beaulac and Simpson 1980). Deciduous forest makes up about 33% of the total watershed study area, about 21% of the South Fork drainage, 27% of the North Fork drainage, and 50% of the White River above Coal Creek drainage.

Wildlife and livestock grazing may have an impact on parts of the forest in the White River watershed. An example of this is in Lost Park, which is the headwaters of Lost Creek, a tributary to the North Fork. This Park experiences intensive grazing by elk and at times produces sediment laden runoff (personal communication, Clay Ramey, White River National Forest Fisheries Biologist, 8/30/2017). White River Forest personnel also indicated that the lower reaches of Lost Creek is also home to beaver, which may help reduce nutrient impacts by trapping sediment. During a site visit on August 29, 2017 (see **Photograph 4**), Lost Creek near its outlet to North Fork White River was observed to have little streamflow with stagnant to slow moving water. The water appeared turbid and contained some algal growth.

The surface geology in the White River Basin is mostly sedimentary rocks ranging from the Paleozoic Era to the Cenozoic Era (Tobin 1993). These are most common in the eastern/headwaters portion of the watershed and project study area. Sedimentary rocks can result in high background concentrations of nutrients and also form the parent material of the soils in the headwaters area of the basin. Reckhow (1980) notes that forested watersheds with loam soils overlying sedimentary formations have phosphorus losses twice as high as those with sandy soils overlying granitic igneous formations. This is due to higher nutrient content and erodibility and leachability of loam soils than sands and gravels, and may cause shifts toward the higher end of the phosphorus export range (Reckhow, Beaulac and Simpson 1980).

Photograph 4. Lost Creek, tributary to North Fork White River, August 29, 2017

The amount of disturbance (typically harvest and fire) within a forested watershed also affects nutrient losses to the watershed. Deforestation due to ongoing timber harvest can lead to higher nutrient losses caused by 1) removal of the nutrient uptake pathway (e.g., vegetation), 2) increase in forest floor temperature, 3) increase in weathering (wetting and drying) of forest soils, 4) increase in microbial activity, and increase of the nutrient pool due to dead organic material (Reckhow, Beaulac and Simpson 1980). While widespread timber harvest or other disturbances are not known to exist in the project study area and do not appear to be a factor contributing to excessive nutrient loading in the White River watershed, the Big Fish is noted and is discussed subsequently.

Forest fires increase nutrient losses in comparison to undisturbed forests, depending on the severity and extent of the burn and the type of fire (Reckhow, Beaulac and Simpson 1980). The Big Fish Fire of 2002 burned 22,000 acres at the headwaters of the North Fork White River around Trapper's Lake. This represents about 13% of that watershed and certainly immediately after the fire there could be some temporary impacts to hydrology and nutrient losses due to this fire (although none are specifically noted in **Figure 8**). Even if they did occur then, such effects would presumably have mitigated through revegetation that has occurred over the past 15 years.

As such, we believe that forest disturbance due to fire is likely not a factor contributing to excessive nutrient loading in the White River watershed.A limited number of sites within forested areas of the Upper White River watershed were observed during a site visit on August 29, 2017. Minor impacts that are typical from livestock grazing were noted near a road crossing on Marvine Creek above the campground. Impacts include loss of vegetation, exposed soil, and disturbed channel bank and bed, as shown in **Photograph 5**. No visual impacts to the clarity of the stream were observed.

Photograph 5. Channel bank by livestock grazing in Marvine Creek above campground on August 29, 2017

6.2.2 Agriculture, Pasture/Hay

Agricultural land use is represented by the Pasture/Hay category shown in **Table 14** and comprise almost 8,000 acres of pasture/hay in the White River watershed above the Coal Creek gage, accounting for about 2% of the overall area. No cultivated crops were classified in the NLCD within the study area. The majority of the pasture/hay area is in the White River above Coal Creek drainage (over 5,000 acres). The South Fork and North Fork White River have about equal areas of pasture/hay, 1,419 acres and 1,330 acres, respectively. Nutrient contributions from this land use include both hay/forage (pasture grass) production and livestock grazing. The pasture/hay areas are almost entirely in the valley bottoms near the rivers. Observed pasture/hay typical of the Upper White River are shown in **Photograph 6**.

Site specific or eco-region specific EC data were not available for this land class. Available studies (Harmel, et al. 2006, Lin 2004, Reckhow, Beaulac and Simpson 1980) do not include study sites in the Rocky Mountains. The EC used for annual TN and TP load estimates were 4.09 and 0.64 kg/ha/year, respectively based on an EC for hay (non-row crops) from a study from Morris, Minnesota (Reckhow, Beaulac and Simpson 1980). The EC used for the summer-month TN and TP load estimates were 1.52 and 0.25 kg/ha/year, respectively based on an EC for pasture from a study from eastern South Dakota (Reckhow, Beaulac and Simpson 1980).

Photograph 6. Pasture/hay area in North Fork White River watershed

The magnitude of nutrient losses from agricultural land use is influenced on the soil types and the length of time and extent that the soils are exposed to runoff. Nutrient losses from organic and clay soils is higher than sandy/gravel soils. Nutrient losses are also influenced by farming practices and methods. Conventional tillage methods, leading to high erosion of soils, is a prime cause of higher nutrients losses (Reckhow, Beaulac and Simpson 1980) and it is not believed this practice is done extensively in the Upper White River.

Nutrient loss from pasture due to grazing largely depends on management practices employed (Reckhow, Beaulac and Simpson 1980). Rotational grazing, which allows for regrowth of vegetation, tends to reduce runoff and associated nutrient losses. Continuous grazing is associated with higher nutrient losses due to soil compaction, reduced vegetation, and increased wasted from livestock. Animal density is also a factor in nutrient losses. Nutrient losses increase with increased density. As shown in **Appendix D** nutrient ECs for animal feedlots or manure storage are orders of magnitude higher than other land uses. Large animal feedlots or concentrated animal feeding operations are not known to exist in the watershed.

The nutrient ECs used are intended to incorporate the net contribution from fertilizer application (i.e. the difference between the amount applied and the amount taken up and used by the plant). In general, the type of fertilizer is not as important as the timing of the application (Reckhow, Beaulac and Simpson 1980). Fertilizer applied on frozen soils in winter or early spring tend to increase nutrient losses from snowmelt and runoff events, while fertilizer application followed by soil incorporation tends to reduce nutrient losses. Also applying fertilizer in amounts exceeding recommended rates will increase nutrient losses. Specific fertilizer types and amounts used in the project area are discussed below. Because efficiencies of the fertilizer application are unknown, the analysis provided below is for informational purposes, are not directly included in the nutrient source assessment.

6.2.3 Fertilizer Application

Fertilizers are used to enhance the growth of plants by providing nitrogen, phosphorous, and potassium, as well as secondary nutrients and mineral catalysts. Application of fertilizers are managed in order to optimize plant uptake and growth and minimize runoff of excess nutrients. In mountain meadow areas, like the Upper White River watershed, nitrogen is typically the most limiting nutrient followed by phosphorous (Brummer and Davis 1996). While nitrogen is applied primarily on the basis of yield potential, economic increases in production are typically obtained for organic soils at applications between 60 to 100 pounds of nitrogen per acre in mountain meadow areas (Brummer and Davis 1996). Phosphate application rates, on the other hand, should be determined on the basis of soil test results. A phosphate application of 10 to 20 pounds per acre is suggested in mountain meadow organic soils for established stands with low to medium levels of extractable phosphorous based on AB-DTPA and sodium bicarbonate soil tests (Brummer and Davis 1996). The main potassium fertilizer is potash, but most Colorado soils are naturally high in extractable potassium and additional application of this nutrient it not necessary in mountain meadow pastures.

Fertilizers that provide the three main macronutrients of nitrogen, phosphorous, and potassium are classified with a numeric rating system to identify the elemental composition of each. The first number represents the percentage of nitrogen, the second number indicates the percentage of phosphate (P_2O_5), and the last number provides the amount of potassium oxide (K_2O). By molecular weight, a phosphate molecule is 43.6% phosphorous and 56.4% oxygen. In this way, the amount of phosphorous applied is calculated as 43.6% of the total phosphate in the fertilizer.

Pasture grass is grown in the Upper White River watershed for the purpose of stock grazing. Since 2002, Meeker Fertilizer LLC has been the sole fertilizer supplier to the upper pastures of the White River above Meeker. Fertilizers in this area are typically applied in early May. Over the last decade, fertilizer use in this area has reportedly decreased due to a reduction in the number of cattle and sheep grazing in the area and recent initiatives to reduce nutrient runoff to the White River (Marc Etchart, personal communication 8/28/17). Marc Etchart of Meeker Fertilizer provided the total acres fertilized and the overall amount and types of fertilizer applied for the years 2002, 2012, and 2017 from Elk Creek/Sleepy Cat Bridge up to the highest pastures. Mr. Etchart noted that he made a transition from pelletized fertilizer to liquid fertilizer in 2007. Before 2007, a pelletized fertilizer was used which consisted of no more than 20% monoammonium phosphate (11-52-0) mixed with 80% ammonium nitrate (34-00-00). In 2007, Mr. Etchart switched to a liquid fertilizer product consisting of 15–20% Ammonium Polyphosphate (10-34-0), 80% Urea Ammonium Nitrate, and 3% to 5% Ammonium Sulfate. **Table 16** summarizes the fertilizer products used by Meeker Fertilizer LLC in the years before and after 2007.

Table 16. Type of fertilizer applied to pasture grass from Elk Creek/Sleepy Cat Bridge to the highest pastures before and after 2007

Fertilizer Used	After 2007 (Liquid)		Before 2007 (Pelletized)	
	Ammonium Polyphosphate 10-34-0	Urea Ammonium Nitrate 32-0-0	Monoammonium Phosphate 11-52-0	Ammonium Nitrate 34-0-0
Percent Product in Mixture	20%	80%	20%	80%
Percent Nitrogen	10%	32%	11%	34%
Percent Phosphate	34%	0%	52%	0%

The data supplied by Mr. Echart, and the corresponding fertilizer product specification sheets were used to calculate estimates of nitrogen, phosphate, and phosphorous applications on a per acre basis. **Table 17** summarizes these results.

Table 17. Acres fertilized, tons of fertilizer applied, and phosphate, phosphorous, and nitrogen application for pasture grass above Elk Creek/Sleepy Cat Bridge for years 2002, 2012, and 2017

Component	2017	2012	2002
South Fork, acres	268	264	-
North Fork, acres	594	764	-
Total Area, acres	862	1028	1150
Total Fertilizer applied, tons	89	116	144
Total Phosphate, lbs (kg)	12,104 (5,490)	15,776 (7,156)	29,952 (13,586)
Total Phosphorous, lbs (kg)	5,277 (2,394)	6,878 (3,120)	13,059 (5,923)
Total Nitrogen, lbs (kg)	49,128 (22,284)	64,032 (29,044)	84,672 (38,407)
Phosphate Application, lb/acre (kg/ha)	14.0 (15.7)	15.3 (17.1)	26.0 (29.1)
Phosphorous Application, lb/acre (kg/ha)	6.1 (6.7)	6.7 (7.5)	11.4 (12.8)
Nitrogen Application, lb/acre (kg/ha)	57.0 (63.9)	62.3 (69.8)	73.6 (82.5)

As shown in **Table 17**, the amount (by weight) of phosphorous and nitrogen applied to the pasture grass from Elk Creek/Sleepy Cat Bridge to the highest pastures has declined on an overall and per acre basis since 2002. Based on the information provided by Mr. Echart, current fertilizer application in the Upper White River (14 pounds per acre phosphate and 57 pounds per acre nitrogen) is consistent with Mountain Meadows fertilizing recommendations (60 to 100 pounds per acre nitrogen and 10 to 20 pounds per acre phosphate) (Brummer and Davis 1996).

6.2.4 Septic Systems

Nutrient loading contributions from septic systems in the watershed study area were estimated following the method provided by Reckhow (1980).

$$\text{Septic System Loading, } S = EC_{st} \times \#\text{capita\_years} \times (1 - SR) \qquad \text{(Equation 4)}$$

Where,

- EC_{st} is the export coefficient (kg/capita-year/year) from septic systems
- #capita_years is the number of capita-year in the watershed serviced by septic systems/ISDS
- SR is the soil retention coefficient

Septic system ECs were based on wastewater characteristics in the EPA Onsite Wastewater Treatment Systems Manual (2002) and EC provided by Reckhow (1980). The ECs used were 4.75 kg/capita-year for TN, and 0.58 kg/capita-year for TP.

GIS analysis was used to estimate the number of residences in the study area. Rio Blanco County provided a database showing the spatial distribution of residential addresses-driveways in the County. Those addresses within the study area were distributed into sub-watersheds: South Fork (18), North Fork (80), and White River above Coal Creek (106). Variables used in the septic system loading estimate are provided in **Table 18**.

Table 18. Summary of variables used in Upper White River septic system loading assessment

Area	# Residences [1]	Seasonal (estimated) [2]	Permanent Residences	Seasonal Residences	Permanent Capita-Years [3]	Seasonal Capita-Years [3, 4]	Total Capita-Years
South Fork	18	85%	2.7	15.3	6.7	6.2	12.9
North Fork	80	50%	40	40	99.2	16.3	115.5
White River above Coal Creek	106	30%	74.2	31.8	184.0	13.0	197.0

[1] GIS analysis from data file from Rio Blanco County

[2] Seasonal estimates provided by Elk Creek Ranch

[3] Based on 2.48 persons per residence/household (U.S. Census Bureau: https://www.census.gov/quickfacts/fact/table/rioblancocountycolorado/PST045216)

[4] Seasonal estimate assumes 60 days spent per year

The nutrient load assessment for septic system loading makes a number of assumptions:

- Each residential driveway (outside of incorporated limits) identified in GIS analysis from Rio Blanco County database, has, and uses a septic system for wastewater treatment and disposal.
- All septic systems are sufficiently close to surface water to impact the receiving water.
- The number of seasonal residence was estimated as follows (Colton Brown, personal communication, 10/4/2017): South Fork (85%), North Fork (50%), and White River above Coal Creek (30%).
- Seasonal use is 60 days per year, seasonal use is concentrated during the summer months (i.e. all residences are occupied).
- Each household has on average 2.48 people (online census data for Rio Blanco County, CO: https://www.census.gov/quickfacts/fact/table/rioblancocountycolorado/PST045216); note this estimate may be low for seasonal use
- A soil retention coefficient of 0.5 was used for TP loading for all watershed areas. This assumes that 50% of the TP load is retained within the soil, while the other 50% contributes to nutrient loading.
- A soil retention coefficient of 0.1 was used for TN loading for all watershed areas. This assumes that 10% of the TP load is retained within the soil, while the other 90% contributes to nutrient loading.

There are a number of factors that affect the septic system nutrient contribution to the watershed (Reckhow, Beaulac and Simpson 1980).

- Number of people using the system and the fraction of the year that the system is in use. The study area contains a number of seasonal residences as noted above. Use of septic systems in the study area likely concentrates during the summer months.
- The location of the septic drainfield in relation to the stream or a receiving water with hydrologic connection with the stream. In general, most of the development and residential homes in the watershed are in the valley areas proximate to streams or surface water.
- Depth to groundwater and groundwater movement. Soils have a lessened ability to retain nutrients the closer the groundwater table is to the septic drain field. Groundwater level data for the watershed was not reviewed.
- Soil drainage, permeability, and slope
- System age

6.2.5 Fish Feeding

Fish food and faeces from aquaculture are known contributors to nutrient enrichment of streams and rivers (Folke, Kautsky and Troell 1994, López 1997, Lazzari and Baldisserotto 2008). Kibria et al. (1997) indicate that two routes of delivery occur in such operations: (1) direct waste from feed in the form of dust and uneaten food and (2) nutrients from faecal contributions. Both should be considered in evaluating the nutrient contribution of such practices. Enrichment of the nutrient pool of the receiving water or sediment often occurs, and ultimately can stimulate algal growth (López 1997, Kibria, et al. 1997).

It is estimated that between 10–30% of total amount of fish food fed in intensive aquaculture goes uneaten (Kibria, et al. 1997, citing others). Feeding in the White River (Westlands) is approximated at 10–12 tons per year (9,072–10,886 kg annually) (CPW 2016). Hence the feeding operation results in nutrient loading. Furthermore, nitrogen and phosphorus retention efficiency in fish is quite low. Retention rates varies across studies, but are believed to be somewhere around 25% for phosphorus and 35% for nitrogen (Hernández and Roman 2016, Hernández, Satoh, et al. 2004, Kibria, et al. 1997, Lazzari and Baldisserotto 2008). A large portion of the nutrient feed therefore returns to the waterbody as either uneaten feed or faecal waste.

According to Bob Dorsett (personal communication 9/11/2017), Purina Aquamax or Purina Game Fish Chow is used to feed fish in the White River. The nutrient composition reported by the manufacturer is 32–43% protein and 0.8–1.1% phosphorus (minimum). Protein is the primary source of nitrogen and is assumed to be 16% of the overall protein content (Tacon 1987) or 5.1–6.9% nitrogen content in the feed. This fish diet approximates many of those noted in literature, containing between 5–7% nitrogen and 1–1.5% phosphorus (Olsen, Holmer and Olsen 2008, Naylor, Moccia and Durant 1999, Tacon 1987).

The information above can be used to calculate loads associated with fish feeding in the White River. The amount of non-eaten food waste is estimated as follows, which is incorporated into a modified version of the python code proposed initially by Bob Dorsett (personal communication, 09/05/2017)

$$F_{waste} = F_{total} \times (1 - f_e) \qquad \text{(Equation 5)}$$

where F_{waste} is the dry mass of the food not eaten (kg/d), F_{total} is the total dry mass of feed (kg/d), and f_e is the feeding efficiency (%) taken to be 0.80, which is approximately the midpoint of the range cited earlier for uneaten food in intensive aquaculture.

The amount of nitrogen or phosphorus mass in the uneaten food waste is the percentage of nutrient constituent in the feed

$$F_{n,p\ waste} = F_{waste} \times r_{n,p} \qquad \text{(Equation 6)}$$

where $F_{n,p\ waste}$ is the direct mass of feed waste of nitrogen or phosphorus respectively (kgN/d or kgP/d) and $r_{n,p}$ is the fraction content of either nitrogen or phosphorus in the feed (%N or %P). Values of nutrient content used for the White River analysis are r_n = 6.9% nitrogen and r_p = 1.1% phosphorus (which reflects the maximum likely loading).

Associated faecal output can be determined from the total amount of feed ingested. Ingestion is simply the difference between the total feed and the amount of feed waste

$$F_{ingest} = F_{total} - F_{waste} \qquad \text{(Equation 7)}$$

where F_{ingest} is the mass of feed ingested (kg/d).

Accounting for retention efficiency, and converting to nitrogen and phosphorus mass units, the total fecal load contribution is

$$F_{n,p\,fecal} = F_{ingest} \times r_{n,p} \times (1 - c_{n,p}) \qquad \text{(Equation 8)}$$

where $F_{n,p\ \mathrm{fecal}}$ is the nitrogen on phosphorus faecal contribution from fish feeding (kgN/d or kgP/d) and $c_{n,p}$ is the conversion or retention efficiency of nitrogen or phosphorus respectively (%). The retention efficiency is estimated to be 30% as indicated previously.

The overall daily nitrogen or phosphorus load to the waterbody therefore is the sum of the contribution from feed waste and faecal deposition

$$W_{n,p} = F_{n,p\,waste} + F_{n,p\,fecal} \qquad \text{(Equation 9)}$$

where $W_{n,p}$ is the daily nitrogen or phosphorus load (kgN/d or kgP/d). The value can be applied to any period by multiplying the load in kg/d by the number of days of feeding.

Using this approach, two loading estimates were made for the White River, one on a daily basis and one annually. These are shown in **Table 19** below along with associated assumptions. It should be noted that no efforts were made to resolve speciation of the loads that would be delivered (e.g., dissolved inorganic phosphorus or organic phosphorus). Therefore, it is most appropriate to compare them to total nutrient load fraction.

Table 19. Summary of fish feed nutrient load estimates for the White River

Nutrient	**Load**		**Assumptions**
	(kg/d)	**(kg/yr)**	
Nitrogen	1.43	523	F_{total} = 27.34 kg/d r_n = 0.069 (6.9%) f_e = 0.8 (80%) c_n = 0.3
Phosphorus	0.23	83.5	F_{total} = 27.34 kg/d r_p 0.011 (1.1%) f_e = 0.8 (80%) c_p = 0.3

6.2.6 Developed Land Use “Urban” Sources

Urban land use in the nutrient assessment included the following sub-categories in the GIS analysis: developed open space, developed low intensity, developed medium intensity, and developed high intensity. The South Fork White River drainage had the least “urban” land use including 37 acres developed open space and 13 acres developed low intensity. The North Fork White River and White River drainage below the South Fork-North Fork confluence to Coal Creek were both found to have similar amounts of “urban” land use: 483 acres and 461 acres of developed open space, and 150 acres and 149 acres of developed low intensity, respectively. Both of the drainages identified 2 acres of developed medium intensity. No developed high intensity urban land use was found in the study area.

The eco-region specific median ECs for TN and TP were used for the annual estimate from urban land use. The median eco-region ECs for urban land use are: 8.14 kg/ha/year for TN and

0.285 for TP (White, et al. 2015). Similar to forested areas, grasslands, and pasture/hay the summer-month urban land use EC was reduced to account for a reduction in load due to less runoff. Summer-month urban land use ECs used were 3.01 and 0.11 kg/ha for TN and TP, respectively.

6.2.7 Atmospheric Deposition

Atmospheric deposition is the contribution of nutrients (and other components) to the watershed from the atmosphere. Atmospheric deposition includes both components of dryfall (particles or dust transported by wind) and wetfall (components deposited by precipitation). The TN EC used in the nutrient assessment is based on data from the EPA Clean Air Status and Trends Network (CASTNET) from the monitoring site in Gothic, Gunnison County, Colorado (GTH161). Results from this site include both dryfall and wetfall TN deposition. The most recent (2015) TN deposition reported by CASTNET for GTH161 was 3.07 kg/ha. TP data was not available for this site, so a published value of 0.26 kg/ha/year was used from Reckhow (1980), and is wetfall deposition only. The atmospheric deposition contribution is tied to the open water land use category, and accounts for less than a half percent of the overall watershed study area. GIS analysis identified 301 acres in the South Fork drainage, 854 acres in the North Fork drainage, and 280 acres in the White River above Coal Creek drainage.

6.3 Estimated Nutrient Loads

6.3.1 Annual Load

Estimated annual nutrient loads are presented below in **Table 20** (nitrogen) and **Table 21** (phosphorus). The tables show the estimated load in both total mass (kg) and as a percentage in each drainage, and for each source or land use category.

Table 20. Estimated annual TN load by land use and drainage in Kg/year and percent

Source	Watershed Total		South Fork White River		North Fork White River		White River above Coal Creek	
Urban	4,277	3.1%	168	0.5%	2,092	3.9%	2,016	4.2%
Undisturbed Forest	92,821	67.3%	24,683	69.4%	38,218	70.7%	29,921	61.9%
Grassland	24,100	17.5%	7,926	22.3%	9,492	17.6%	6,683	13.8%
Pasture/Hay	13,105	9.5%	2,348	6.6%	2,201	4.1%	8,556	17.7%
Atmospheric	1,783	1.3%	374	1.1%	1,061	2.0%	348	0.7%
Septic	1,391	1.0%	55	0.2%	494	0.9%	842	1.7%
Fish Feeding	523	0.4%	-	0.0%	523	1.0%	-	0.0%
Total	138,000	100%	35,554	100%	54,080	100%	48,366	100%

Table 21. Estimated annual TP load by source and drainage in Kg/year and percent

Source	Watershed Total		South Fork White River		North Fork White River		White River above Coal Creek	
Urban	150	0.5%	6	0.1%	73	0.7%	71	0.7%
Undisturbed Forest	24,678	88.1%	6,562	90.7%	10,161	91.6%	7,955	82.3%
Grassland	793	2.8%	261	3.6%	312	2.8%	220	2.3%
Pasture/Hay	2,051	7.3%	367	5.1%	344	3.1%	1,339	13.8%
Atmospheric	151	0.5%	32	0.4%	90	0.8%	30	0.3%
Septic	94	0.3%	4	0.1%	33	0.3%	57	0.6%
Fish Feeding	84	0.3%	-	0.0%	84	0.8%	-	0.0%
Total	28,000	100%	7,232	100%	11,097	100%	9,671	100%

Due to the large land area, forested area and grasslands contribute to majority of the annual TN and TP loads in the watershed, 85% to 91% respectively at the White River above Coal Creek. Pasture/hay contributes about 9.5% and 7% of TN and TP load. All other land uses contribute less than one percent on an annual basis. In the White River above Coal Creek drainage, pasture/hay makes up almost 18% of the annual TN load and 14% of the annual TP load.

6.3.2 Summer-Month Load

Estimated summer-month nutrient loads are presented below in **Tables 22** (nitrogen) and **Table 23** (phosphorus) to better understand the proportion of nutrient sources during base flow conditions, when algal communities grow and for which sources can be controlled or managed. During base flow conditions the per-month nutrient load is reduced from the higher rate of loading that comes during runoff when stream flows are highest to non-runoff period that is a critical and productive period for algal growth. The total mass (kg) for a single summer month in each drainage, and for each source or land use category is provided.

Table 22. Estimated summer-month TN load by source and drainage in Kg/month

Source	Watershed Total		South Fork White River		North Fork White River		White River above Coal Creek	
Urban	134	5%	5	1%	66	6%	63	6%
Undisturbed Forest	1,449	52%	385	60%	597	54%	467	45%
Grassland	398	14%	131	20%	157	14%	110	11%
Pasture/Hay	414	15%	74	12%	69	6%	270	26%
Atmospheric	151	5%	32	5%	90	8%	30	3%
Septic	184	7%	16	3%	72	7%	95	9%
Fish Feeding	44.4	2%	0	0%	44	4%	0	0%
Total	2,775	100%	644	100%	1,095	100%	1,036	100%

Table 23. Estimated summer-month TP load by source and drainage in Kg/month

Source	Watershed Total		South Fork White River		North Fork White River		White River above Coal Creek	
Urban	5	1%	0	0%	2	1%	2	1%
Undisturbed Forest	391	74%	104	80%	161	78%	126	66%
Grassland	31	6%	10	8%	12	6%	8	4%
Pasture/Hay	68	13%	12	9%	11	6%	44	23%
Atmospheric	13	2%	3	2%	8	4%	3	1%
Septic	12	2%	1	1%	5	2%	6	3%
Fish Feeding	7.1	1%	0	0%	7	3%	0	0%
Total	527	100%	130	100%	207	100%	190	100%

The summer-month nutrient loads by source (in percent of total) for the White River watershed project area are presented below in **Figure 22**. As with the annual load assessment, forested areas and grasslands represent the largest nutrient source contributors. Pasture/hay areas increase their proportion of nutrient contribution in the summer-month at 13% to 15% for TP and TN, respectively in the overall watershed above Coal Creek. In the White River above Coal Creek, pasture/hay areas account for an even greater proportion, about a quarter of the summer-month nutrient load.

Nutrient losses from “urban” areas slightly increase in proportion during the summer-month period, especially for TN, accounting for 5% of the TN load in the overall watershed. Atmospheric inputs account for a greater proportion of the summer-month nutrient load, about 2% to 5% of the summer-month load in the overall watershed. With a greater area of “open water” the North Fork drainage has a slightly greater proportion of atmospheric nutrient input at 4% to 8% for TP and TN, respectively.

Septic system inputs account for 7% of the TN load in the overall watershed and in the North Fork drainage during the summer-month. Septic system inputs account for about 3% of the summer-month TN load in the South Fork and 9% in the White River above Coal Creek. Septic system inputs account for 1% to 2% of the summer-month TP load for watershed and sub-watersheds.

Fish feeding accounts for about 2% of the summer-month TN load in the watershed, but is twice that (4%) for the North Fork drainage. The summer-month TP load from fish feeding amounts to 3% in the North Fork and is about 1% in the overall watershed.

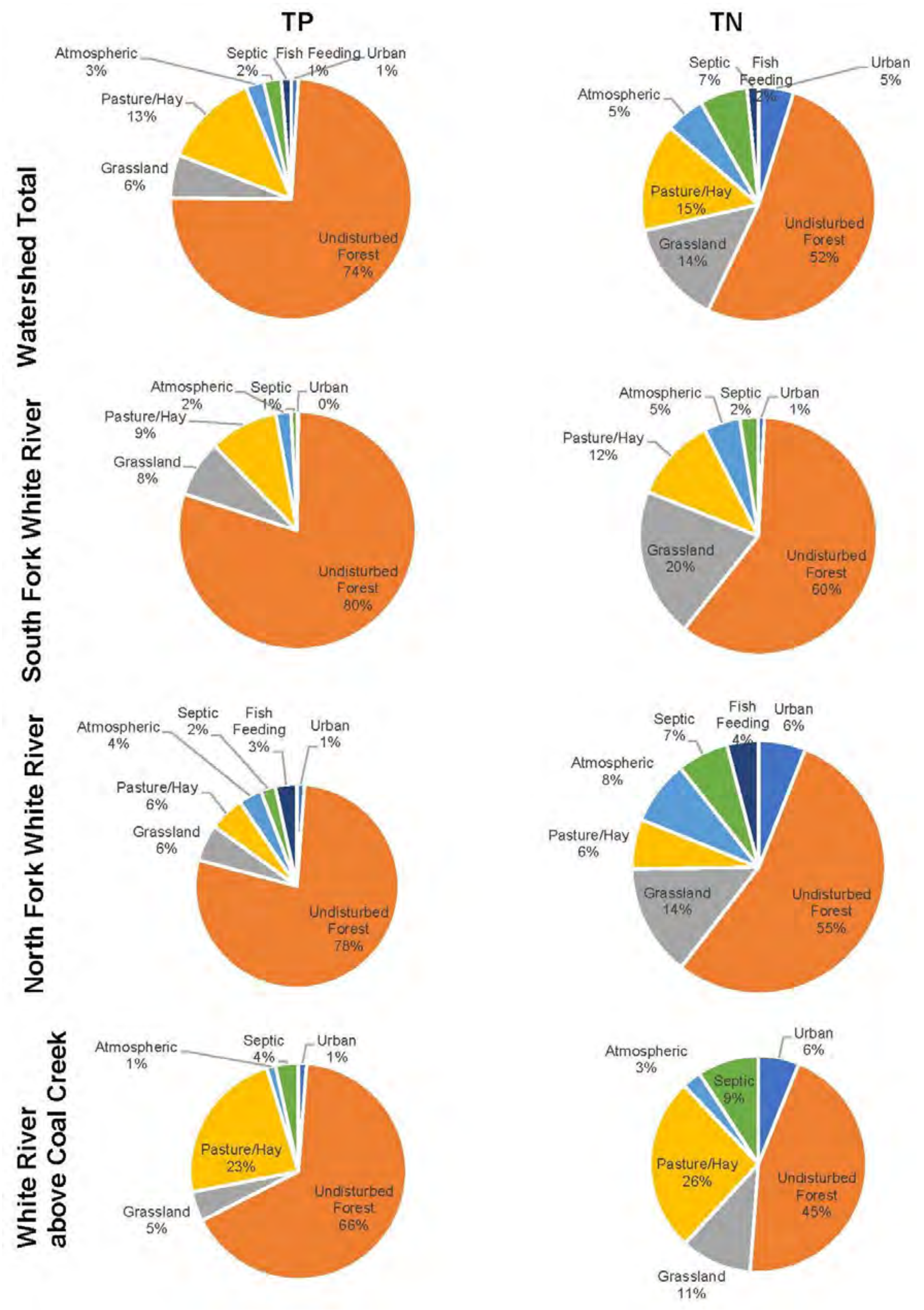


Figure 22. Estimated summer-month nutrient loading White River above Coal Creek by percent and tributaries

6.3.3 Discussion

The nutrient source assessment above demonstrates that there are very few readily controllable sources of identified nutrients in the watershed study area. Some of these are easily remedied. For example, nutrient inputs from fish feeding during summer-months can be directly mitigated through curtailment of the practice. Mitigating nutrient inputs from septic system and agricultural practices are typically accomplished through maintenance and implementation of best management practices, and may require additional investigation and planning. In looking at these relatively more controllable nutrient inputs, the combined contribution to the watershed from septic system inputs, fish feeding, and agricultural use to the annual load is 8% and 11% for TP and TN, respectively, most of which is coming from pasture/hay. During a summer-month, critical to algal growth, the combined contribution from septic system inputs, fish feeding, and agricultural use increases to 17% and 23% from TP and TN, respectively. Inputs from developed or urban uses may also be mitigated through improved management and practices. These inputs represent 1% of the summer-month TP load and 5% of the TN for the watershed (½-% to 3% of the annual load, respectively). Forested areas and grasslands contribute the greatest proportion of nutrient inputs to the watershed, but identifying sources and implementing management practices is more difficult and implementing effective management practices may not be as practical.

Nutrient inputs from sources can typically be mitigated through comprehensive planning and best management practices. Identification of specific sources within these general land use areas is critically important to mitigate nutrient inputs in the watershed. Source identification begins with understanding and compiling potential source areas and then prioritization of critical/vulnerable areas. Initial identification can be accomplished through GIS analysis, and refined through stakeholder engagement, site surveys, and monitoring. Implementation of a focused water quality monitoring program is critical to fill in data gaps, identify sources, and monitor progress. Recommendations are further presented in **Section 8**.

7 Summary of Findings

Findings from the watershed assessment are summarized below.

1. White River baseline water quality reports (USGS 1984) (Tobin 1993) document:

    - Sharp increases in specific conductance total dissolved solids, dissolved nitrogen and phosphorus concentrations; and decreases in water temperature and dissolved oxygen in the White River occur above Meeker due to effects of the Meeker Dome
    - Elevated concentrations of nutrients in water quality samples which were considered levels sufficient to produce nuisance algae growth in the White River

2. Recent studies (Lewis and McCutchan 2010) (Segura, et al. 2010) investigated factors affecting algal growth and response in mountain streams in Colorado found:

    - Most of the variation in abundance of periphyton biomass was attributed to 1) the initial amount of biomass at the start of the growing season, 2) length of the growing season, and 3) water temperature (most important)

- The nutrient response in periphyton biomass is suppressed by other controlling factors at low nutrient concentrations, and becomes a quantitatively significant response only when nutrients become dominant over other controlling factors
- The movement of the stream bed at a given location is linked to diminished accumulation of biomass at that location. Channel bed disturbance sets back the average biomass accumulation spatially within a stream
- Other growth rate control factors serve to check the biomass accumulation rate, and include: low concentrations of potentially limiting nutrients, grazing associated with benthic macroinvertebrates, and reductions in photosynthesis by tree canopy shading.

3. A USGS study (Thomas, et al. 2013) evaluated a large area of Western Colorado, including a portion of the White River at USGS 09304200 White River above Coal Creek, near Meeker. The following was noted:

   - The upper White River was identified as being a major source of nitrate and orthophosphate even to the lower parts of the river
   - No trends in water temperature, dissolved oxygen, or suspended sediment concentration; upward trends in pH and phosphorus; downward trend in ammonia, and a more complex trend in nitrate
   - Loads were calculated at 48.2 tons nitrate and 27.3 tons orthophosphate at the White River above Coal Creek.

4. Data compilation and review of CPW 2015-2016 White River water quality data indicate:

   - Benthic algal biomass in the upper White River is a nuisance and exceeds the Colorado chlorophyll a water-quality standard by a large margin
   - Nitrogen is the limiting nutrient (from nutrient diffusing substrates)
   - Data collection efforts of Colorado Parks and Wildlife offer a valuable synoptic analysis of recent river conditions in the Upper White River watershed, but due to laboratory detection limits and quality control concerns the analytical results must be interpreted with caution.

5. White River water quality data review and analysis (this report):

   - Nutrient data are available at numerous sites in the project area, however, only a handful of sites have a sufficient period of record for examination
   - The median TN and TP concentration is far below the proposed numeric nutrient standard making it highly unlikely that the annual median of either exceeds the proposed interim Colorado numeric nutrient criterion
   - No indication of DO impairment exists relative to the spawning standard of 7 mg/L (15th percentile of all data)

- pH at the 5th Street Bridge has exceeded the maximum allowable pH of 9.0, which can negatively affect fish mucous membranes such as gills and eyes
- DOC has only been sampled at one location in the upper White River downstream of Meeker. The site far exceeds the water quality standard of 3.0 mg/L and is influenced by the City of Meeker municipal wastewater effluent discharge
- Changes in water temperature are believed to have little influence on recent nuisance algal conditions in the White River. Instantaneous temperature data indicate a small spatial difference between the North and South Fork White River relative to the White River above Coal Creek. No apparent trend exists in mean daily water temperature at USGS 09304200 over the period of record
- Suspended sediment concentration appears to be declining. This likely results in additional surface PAR reaching the bottom of the channel. However, such changes are believed to result only in a minor change in growth rate (<5%) since *Cladophora* saturates at relatively low irradiances relative to daily average PAR.
- Both TN and nitrate plus nitrate concentrations and loads have declined in the watershed over the period of record. The North Fork having the highest concentration and load of TN followed by the White River above Coal Creek, and then the South Fork. TP has the opposite concentration and loading trend. Finally, orthophosphate is more difficult to assess. Modeling seems to indicate a change in occurred in 2005 that has changed the trajectory of all nutrient species of interest. We have no correlating or anecdotal information for which to attribute this shift.
- The ratio of nitrogen to phosphorus in the White River has been declining since 1991 and the watershed is currently N-limited. In this regard, the watershed has moved from being phosphorus to nitrogen limited over time, due in large part due to increases in phosphorus and subesequent declines in nitrogen.
- In review of nutrient thresholds required to limit *Cladophora* growth, phosphorus concentrations in the watershed are far too high to expect P-limitation at any location in the watershed while nitrogen appears to provide some limitation on growth rate.
- If nutrient reductions are to be pursued to limit algal accumulation in the watershed, nitrogen sources should be the firstmost priority followed by phosphorus; assuming other factors (e.g., light, temperature, and scour) are not more controlling.

6. White River and tributaries multiparameter water quality sonde deployment:

   - Exceedances of the Colorado water quality standards for pH and DO were recorded on the mainstem site above Elk Creek. The protective maximum pH standard of 9.0 was exceeded every day during the daytime and DO levels dropped below 7.0 mg/L (the minimum standard for spawning) on two days at night. A DO minima of 6.0 mg/L outside of spawning season and we did not evaluate if spawning species were present.
   - A distinct day-night variation in DO and pH is evident in the data at all sites. A greater day-night variation in both DO and pH is evident in the mainstem and the North Fork when compared with the South Fork site, indicating a greater presence of algal biomass in the mainstem and North Fork, compared to the South Fork White River.

7. Review of White River hydrology at USGS Station 09304500, White River near Meeker indicates:
   - There were likely multiple factors relating to watershed hydrology that contributed to nuisance algal blooms beginning in 2014 including:
     - Lack of sustained scouring flows leading to channel bed disturbance. A scouring flow has probably not occurred since 2011.
     - Channel bed stability (large cobbles, 7 to 10 inches) that may provide armoring in places, and could increase the likelihood that algal communities persist year to year
     - Timing of runoff and length of growing season. Regression analysis of annual peak flow dates 1950 to show that peak flows are coming about 11 days earlier over the period analyzed. Regression coefficients were significant at the 95% confidence level.
     - Occurrence of low flows: each of the last 7 years (2010 to 2016) has had a 7-day low-flow period less than the published 2-year low-flow value of 270 cfs, and 4 (nearly 5) of the last 7 years have seen 7-day low flow periods below the 7-day 20-year low flow value of 169 cfs.
   - Climatic changes inducing reductions in streamflow in the upper Colorado River Basin were also found in a recent USGS publication (McCabe, et al. 2017).
8. Upper White River nutrient source assessment found:
   - Nutrient sources in the project area are all nonpoint sources or dispersed contaminant sources. No nutrient point sources are known to exist in the project area. The surface geology in the White River Basin is mostly sedimentary rocks ranging from age from the Paleozoic Era to the Cenozoic Era (Tobin 1993). Reckhow (1980) notes that forested watersheds with loam soils overlying sedimentary formations have phosphorus losses twice as high as those with sandy soils overlying granitic igneous formations, indicating that the headwaters area of the White River watershed may be prone to higher phosphorus losses.
   - Forested and grasslands represent the largest land covers in the watershed study area and were the largest contributors of non-controllable nutrient loads in the watershed. They contribute 85% to 91% of the annual TN and TP loads, respectively. Pasture/hay areas contribute about 9% and 7% of annual TN and TP loads. In the White River above Coal Creek drainage, pasture/hay makes up almost 18% and 14% of the annual TN and TP loads.
   - Combined contribution from septic system inputs, fish feeding, and to agricultural use is 11% and 23% of the TN annual and summer month load, respectively, while the combined TP contribution of the annual and summer month load is 8% and 17%, respectively.

- Urban land use accounts for about 3% of the overall TN load, and less than 1% of overall TP load. Urban land use accounts for slightly greater percentage of the nutrient load in both the North Fork and in the White River above Coal Creek drainage.
- Widespread timber harvest or other disturbances are not known to exist in the project study area, and do not appear to be a factor contributing to excessive nutrient loading in the White River watershed.
- Forest disturbance due to fire is likely not a factor contributing to large-scale nutrient loading in the White River watershed.
- Pasture grass is grown in the Upper White River watershed for the purpose of stock grazing. Fertilizers in this area are typically applied in early May. The amount (by weight) of phosphorous and nitrogen applied to the pasture grass from Elk Creek/Sleepy Cat Bridge to the highest pastures has declined on an overall and per acre basis since 2002. Current fertilizer application in the Upper White River (14 pounds per acre phosphate and 57 pounds per acre nitrogen) is consistent with Mountain Meadows fertilizing recommendations (60 to 100 pounds per acre nitrogen and 10 to 20 pounds per acre phosphate) (Brummer and Davis 1996).
- Fish food and faeces from aquaculture are known contributors to nutrient enrichment and nutrient loads from fish feeding to White River were estimated to be 523 kg/year (1.43 kg/day) nitrogen and 83.5 kg/year (0.23 kg/day) phosphorus. This accounts for 1% and 2% of the TP and TN summer-month load, respectively. In the North Fork drainage, fish feeding accounts for a slightly greater proportion, 3% and 4% of the summer-month TP and TN load, respectively.
- Septic system inputs account for 2% and 7% of the TP and TN summer-month load, respectively. In the White River above Coal Creek drainage, septic system inputs account for a slightly greater proportion, 4% and 9% of the summer-month TP and TN load, respectively.
- The nutrient source assessment demonstrates that there are very few readily controllable sources of nutrients in the watershed study area; these are septic system inputs, fish feeding, and to some extent agricultural use.

8 Recommendations & Conclusions

8.1 Watershed Approach

In one sense, watersheds are all facing similar problems: increasing pressure on resources, increasing development, and changing climate. In another sense, watersheds are all unique in that they have a unique and diverse set of challenges, conditions, and stakeholders. Solutions to solving the unique challenges are different, but the approach can be similar.

We understand the White River & Douglas Creek Conservation District (CD) has been identified as the lead agency to coordinate watershed activities and stakeholders to work on and solve the White River nuisance algae problem. Identification of a lead agency or group is an important first step. Interested and key stakeholders should further organize under the CD to form a collaborative watershed group or council of stakeholders in the White River. The watershed group has a unique potential to take a community driven approach to manage complex land and water issues.

A White River watershed group can rely on the perspectives, experiences, and resources of other stakeholders and other local watershed groups to identify and solve the unique challenges in the watershed. Forming a watershed group is important to establish:

1. Leadership for water quality and management actions in the watershed
2. Forum for collaboration between stakeholders and engagement with the community
3. Identification of the most pressing water quality problems
4. Comprehensive management up, down, and across the watershed (within scope of established area)
5. A set of watershed management goals and objectives
6. Oversight of a focused, basin-wide, and long-term water quality monitoring program to support sound, scientifically-based water management decisions, and to gage achievement of management goals

As this group is still in its beginnings, there is additional work to be done to establish a broader White River watershed group. The watershed group could be formalized through the formation of a management board or council of key stakeholders. An important role of this board or council would be to direct the work and set priorities of the group formed under the CD. Additionally, this group may need to:

- Identify council or board members and member organizations
- Identify roles and responsibilities of members
- Development of an operating framework, agreement or understanding for the council or board
- Identify of the scope and watershed area of interest
- Development of a funding plan
- Development of Management Goals, which could include:
    - Control nuisance algae in the White River by reducing nutrient concentrations
    - Protect White River beneficial uses through reducing current rates of nutrient loading
    - Improve White River water quality through tributary non-point source controls

Additionally, we recommend a technical advisory committee(s) be formed to advise and inform the board or council on technical issues or to undertake specific watershed efforts or tasks. One such committee could be a water quality monitoring committee responsible for organizing, reviewing, and reporting on water quality issues in the watershed.

8.2 Water Quality Monitoring

Implementation of a focused water quality monitoring program is critical in filling in data gaps, identifying nutrient sources, and monitoring progress. We offer the following recommendations related to water quality monitoring in the White River based on our evaluation:

- Develop a comprehensive watershed-wide monitoring program overseen by a single organization. Note: watershed-wide would be limited in scope by identification of watershed area of interest by the established watershed group.
- Monitoring program must include a quality assurance project plan (QAPP) with data validation controls to ensure collected data is defensible and can be used for its intended purpose
- Establish data quality objectives and set project required reporting limits
- Review laboratory, laboratory methods and reporting limits to ensure adequate method detection resolution
- Develop a comprehensive basin monitoring program that includes a sampling and analysis plan (SAP) to ensure sampling protocols are consistent, and directs the collection of quality control samples (a Quality Assurance Project Plan is also recommended)
- The following constituents not already being collected should be included:
    - Diurnal monitoring of field parameters DO and pH to assess excursions from water quality standards that may be impacting fish or aquatic life; effort should be made to evaluate diurnal cycling in late July or early August, prior to algal senescence
    - Implement a robust biological monitoring program that includes collection of algal/periphyton samples (chlorophyll-a, ash free dry mass, and algal nutrient tissue content) at multiple locations in both the North Fork and South Fork and multiple locations dowstream
    - Sampling of both tissue concentration and water column concentration made over a spatial gradient both with and without abundant *Cladophora*, and a range of water column nutrient concentrations to confirm nutrient limitation for both nitrogen and phosphorus
    - Suspended solids monitoring including partitioning of inorganic susepended solids, volatile suspended solids, and phytoplankton, and water color.
    - Concomittant measurement of PAR during sampling to better understand the light climate of the White River
    - Re-establishment of USGS gaging activities in the North Fork and South Fork for the purpose of daily flow monitoring
    - Better characterization of bed substrate (particle counts) and establishment of hydraulic transects so that incipient motion calculations for bed load movement can be made
    - Collection of total and dissolved components of nitrogen and phosphorus at low-level detection limits in locations of algal tissue monitoring to establish site-specific threshold nutrient concentrations to set effective nutrient targets for limiting nuisance algal biomass
    - The inclusion of DOC (as necessary) if disinfection byproducts at downstream water treatment facilities are of concern
- Implementation of a widespread synoptic monitoring scheme to better understand spatial distribution of both concentration and load.
- Development of specific monitoring objectives. Monitoring objectives could include:

  - Evaluate time trends in nutrient concentrations in the mainstem White River and selected tributaries
  - Evaluate time trends for periphyton (algae) standing crops in the White River
  - Monitor nutrient and periphyton target levels in the White River
  - Refine nutrient loading rates to White River from point and non-point sources

8.3 Nutrient Source Reduction

Going forward, it must be understood that many changes (climatic, streamflow hydrology, water temperature) cannot be managed in unregulated watersheds. As such, a primary management mechanism is nutrient controls. In order to reduce the overall nutrient load to the watershed, a multi-focal approach should be considered to address all practical nutrient sources. Analyses of water quality data suggest strong nitrogen limitation, and if nutrient reductions are to be pursued to limit algal accumulation in the watershed, nitrogen sources should be the firstmost priority followed by phosphorus. Identification and refinement of sources would occur through implementation of a water quality monitoring program. Once sources have been identified specific actions can be developed and implemented. The following recommendations are provided for the sources identified in the nutrient source assessment as an initial approach.

8.3.1 Forest and Grassland Management

Forested areas and grasslands represent the largest land cover areas and contribute the majority of the annual and summer-month nutrient load. The majority of these lands are managed by the U.S. Forest Service (USFS) and the Bureau of Land Management (BLM). While these areas, for the most part are natural, there are management practices that can be developed or improved upon. In mitigating nutrient impacts from forested areas and grasslands we recommend:

- Collaborate with the USFS and BLM to inventory of land uses and conditions on these public lands including grazing stocking rates and rotational practices
- Identify specific sources of nutrients through regular water quality monitoring
- Develop and implement rangeland monitoring programs for all allotments per the Rio Blanco County Land & Natural Resource Plan and Policy
- Review and implement Management Approaches for Public Lands from the Meeker Source Water Protection Plan (Williams 2008) including:
  - Development of Management Plans by the BLM and USFS, review plans for source water protection concerns
  - Implementation of the National Fire Plan to reduce fuels within the National Forest lands in the watershed
  - Fire prevention and education
  - Minimize the effects of livestock grazing on the upper White River watershed. Conduct an intensive analysis to review and/or revise their allotment management plan to identify impacts and mitigate problems in order to comply with the Clean Water Act.
  - Minimize the effects of recreational activities within the watershed from both motorized and non-motorized activities. Continue to provide multiple uses while

    restricting motorized vehicles to system roads that are signed. Prevent off-highway vehicles (OHV) damage to stream banks and upland areas surrounding the upper White River and its tributaries. Restore or close areas degraded by OHV usage.
  - The USFS and BLM will be encouraged to use road maintenance best management practices to prevent sediment delivery to streams. These may include grading, culverts, sediment basins, water bars, and revegetating areas along stream banks and reservoirs.

8.3.2 Agricultural Practices

The proximity of pasture/hay areas to streams make these key areas to address in mitigating associated nutrient impacts. These nutrient impacts result from 1) agricultural practices of hay/forage production, irrigation, and fertilization practices; 2) from direct nutrient contribution from animal waste and sediment loss due to livestock impact in riparian areas. In mitigating nutrient impacts from agricultural pasture and hay areas we recommend:

- Identification and mapping of agricultural areas used for hay/forage production, and for grazing, inventory areas and conditions with GIS analysis and site surveys
- Implement water quality monitoring to identify source areas (upstream/downstream sampling) and identified locations of direct surface water contribution from these areas
- Develop and implement best management practices for agricultural uses including fertilizer application, sediment management, and grazing practices
- Engage with stakeholders and provide resources and education on best management practices
- Inventory spring and seeps that recharge to tributary streams and install grazing exclosures.
- Review and implement Management Approaches for Agricultural Uses from the Meeker Source Water Protection Plan (Williams 2008) including:
  - Public education through mailings and workshops on water quality and best management practices for handling of manure, and chemical application use and storage.
  - Information on water quality impacts of grazing and encouraging the use of best management practices on alternative stock watering, creating buffer zone between cattle and streams, and bioengineering stream bank stabilization practices.
  - Explore funding opportunities

Many resources exist describing nutrient management practices for agricultural practices and fertilizer application. Best management practices should be refined and specific to the source identified. Natural Resources Conservation Service (NRCS) Nutrient Management Conservation Practice Standard (Code 590) is included within **Appendix E** and provides specific management practices for the handling and application of fertilizers. Based on personal communication with Marc Etchart (8/28/17) fertilizer application in the upper White River is applied per recommended practices and rates for Mountain Meadows. Additionally, Colorado State University Extension Water Quality Program provides a host of resources and multiple best management practices for agricultural uses. The publications can be found at this web address: http://waterquality.colostate.edu/publications.shtml.

A paper by Osmond et al. (2007) from North Carolina Agricultural Research Service provides a comprehensive review of literature and research on grazing practices including nonpoint source pollution, grazing management, ecosystem parameters, and economic considerations of grazing best management practices. The paper discusses the importance and efficacy in nutrient management in the use of vegetative filter strips, seasonal grazing, stocking numbers and proximity to the stream, grazing intensity, maintaining pasture vegetation to reduce runoff and soil erosion, providing alternate water sources, and the use of stream fencing.

The authors concluded and provided these recommendations (Osmond, et al. 2007):

“From this review, it is apparent that the nonpoint source pollution from pastured cattle is a function of many factors: climate, seasonality, stocking density, grass type, feeding practices, alternative water and shade availability, and fencing. Most studies documented increases in nutrients, sediments, and bacteria when cattle were allowed access to riparian areas. In some studies, however, good pasture management practices (such as alternative watering and shade) reduced nonpoint source pollution from livestock and other negative impacts on stream stability and aquatic wildlife. Based on this literature review, we recommend the following:

- Practices should be used that encourage more uniform livestock distribution over the pasture.
- Riparian areas should not be used as shade paddocks, holding areas, or feeding areas. In addition, because riparian areas are very important in maintaining water quality, rotational stocking systems should be encouraged that limit the duration of grazing in riparian areas to a maximum of 3 days and that provide an adequate nongrazing recovery period of 3 weeks.
- Access to the riparian area should not occur (a) when soils are wet or boggy, and (b) when acceptable forage is available on riparian sites within the same grazing unit.
- Consider using goats or sheep to graze riparian areas in preference to cattle or horses.
- Fencing is the most reliable way to minimize the impacts of livestock on riparian areas. If, however, this is not possible, at least fence the most vulnerable streamside corridors for complete habitat preservation, while providing strategic access to drinking water for grazing animals.”

8.3.3 Septic System Management

Once a septic system exists, its inputs are not easily controlled. Septic failures and illicit connections can happen anywhere. Addressing impacts from septic systems and prioritizing efforts begins with understanding what exists. We recommend Rio Blanco County begin compiling septic system information within the County into a GIS spatial database, beginning with new construction and then expanding to include older systems. The spatial distribution of the following factors for septic systems should be compiled:

- Housing/system age
- Building lot size
- Housing density

- Soil types
- Water table levels (seasonal and average)
- Proximity to surface water

It is also important to document location of a replacement drain field for each system, and a septic maintenance schedule. Once a database exists, GIS analysis can be used to complete a vulnerability analysis to identify key areas to address. As prescribed in the Meeker Source Water Protection Plan (Williams 2008) the County should:

1. Implement a public education program to provide information on proper use and maintenance of their septic systems and how the source water of their drinking water (and other receptors) can be impacted by an inadequate functioning septic system
2. Continue to implement their optional a septic system inspection program.
3. Ensure proper permitting and approval for new septic systems.

In addition, septic system management recommendations developed by the Tri-State Water Quality Council are provided as part of **Appendix E**. These recommendations were developed to help reduce nutrient impacts to the Clark Fork River in Montana and Idaho.

8.3.4 Fish Feeding

Fish feeding may be the easiest nutrient source in the watershed to control and curtail. The nutrient source assessment has shown that fish feeding contributes up to 4% of the nutrient load during the summer-moths in the North Fork drainage. Stakeholders that currently feed fish should consider voluntary curtailment of the practice during the summer months or altogether.

8.3.5 Developed Land Use

Developed land use does not account for much of the watershed area, but nutrient impacts from these areas can be high. In mitigating nutrient impacts from developed or “urban” areas we recommend:

- Identification and assessment of conditions of developed areas and their potential nutrient contribution through site surveys and landowner interviews
- Implement water quality monitoring to identify specific sources
- Engage with stakeholders and provide resources and education on importance of water quality protection and best management practices to mitigate impacts
- Develop and implement best management practices
- Review and implement Management Approaches for Residential Practices from the Meeker Source Water Protection Plan (Williams 2008) including public education and handling of hazardous materials and wastes.

8.4 Other Recommendations

We make the following additional recommendation to facilitate the assessment, monitoring, and mitigation of nuisance algae in the White River:

- Assess algal growing season and evaluate factors affecting suppression of algal growth rates in the White River.
- Complete a geomorphic and hydraulic evaluation of the White River and main tributaries to discern channel stability, discharge to initiate channel bed disturbance, and other

morphologic factors affecting the proliferation of nuisance algae. Geomorphic evaluation should include assessment of natural and man-made instream structures affecting river hydraulics and effect on nutrient cycling.

- Detailed modeling effort to evaluate the full importance of the influence of suspended particles on absorption and scattering of light in aquatic systems and concomitant changes in photosynthetic activity on summer algal accumulation. Confirmation sampling in the upper White River should also be initiated valid conclusions of modeling.
- Review of instream diversions and water use. Look for opportunities to leave more water instream during critical low flow periods
- Monitor and assess changes in aquatic biological indicators
- Research and evaluate transport/leaching potential of liquid vs. pelletized fertilizer
- Develop an atmospheric monitoring station to assess atmospheric deposition in the watershed.

8.5 Conclusions

Recent algal blooms in the upper White River watershed have resulted in nuisance algal biomass in excess is State of Colorado water quality standard along with related impacts to pH and dissolved oxygen. These are the result of multiple complex and intertwined factors. Those that most likely contribute to blooms in the White River include elevated nutrient concentrations; a shallow well-illuminated river, hydrologic factors including lack of annual scouring flow and decreased low-flow; an armored stream bed that prevents channel bed disturbance; and finally, climatic factors including earlier runoff and longer growing season.

While some of the abovementioned factors are outside of human control at the local level (e.g., changes in climate and streamflow are a more widespread issue and may unfortunately be the new status quo), effective management strategies to reduce algal blooms in the White River must focus on tangible activities that address factors related to algal growth rate. From a practical perspective, the remaining toolbox is limited, primary to nutrient management. Activities should include development of a board or council of watershed stakeholders to guide and direct watershed management and monitoring activities; development of a technical advisory committee to advise the board; development of a defensible watershed-wide water quality monitoring program; and implementation of nutrient source reduction activities and practices, with a focus on reducing nitrogen sources.

Finally, in the spirit of collaboration, this report went a long way in framing the problem, identifying and interpreting available data, and making recommendations. However, we see this report only a beginning. The full understanding of *Cladophora* as a nuisance in the White River will not be solved overnight nor understood in a single study, nor will collective watershed solutions be an easy endeavor. Conclusions herein may even be refined or reinterpreted. However, by adding to the collective body of knowledge incrementally, strengthening analysis and filling data gaps, and even strengthening relationships in the watershed, a collective and collaborative approach between stakeholders, researchers, and agency personal will go a long way to providing a lasting understanding and solution to the nuisance algae problem in the White River.

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Appendix A: Water Quality Data Compilation

A.1 Introduction

The water quality data compilation was completed using the Water Quality Portal (WQP; www.waterqualitydata.us) to identify sites that might be suitable for expanding analysis upon and to evaluate water-quality standards at those sites. While historically, water quality data for the nation has been housed separately by Federal agencies such as the U.S. Environmental Protection Agency (EPA) and the U.S. Geological Survey, the WQP was recently developed as a cooperative service by the United States Geological Survey (USGS), the Environmental Protection Agency (EPA), and the National Water Quality Monitoring Council (NWQMC) to aggregate and standardize data from these those sources and share then using webservices (**Figure A-1**).

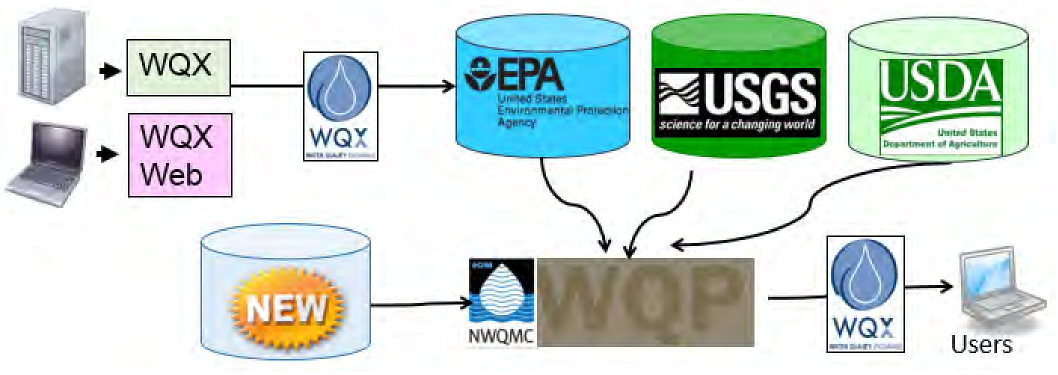


Figure A-1. Data flow for the Water Quality Portal (from STORET-WQX; at https://www.epa.gov/waterdata/storage-and-retrieval-and-water-quality-exchange). The abovementioned Federal agencies are responsible for long-term stewardship of the data.

The portal currently serves data from the USGS National Water Information System (NWIS) [USGS, 2016], U.S. Department of Agriculture (USDA) Sustaining the Earth's Watersheds—Agricultural Research Data System (STEWARDS) [Steineretal., 2009], and the USEPA STOrage and RETrieval Water Quality eXchange (STORET-WQX) [USEPA, 2016]. More than 290 million records from more than 2.7 million sites (E. K. Read, et al. 2017) are present in this database. Of these, the EPA STORET-WQX is the only database to which external data providers (i.e., non-EPA affiliated) may submit data. Web sources in the WQP as identified by Read et al. (2017) are shown in **Table A-1**.

A.2 Methods

Data from the WQP for this project were accessed via webervices for all sites in the Upper White River Hydrologic Unit Code (HUC 14050005; Upper White) using the dataRetrieval.r package from Hirsch and De Cicco (2015). This was employed from the latest version of R (R Core Team 2017), with modification for graphical and statistical analysis. The structure of the queries is shown in **Table A-2** and no efforts were made to estimate censored data for the graphical figures in this appendix. In this instance, the approach is adequate provided statistical characterization of the data is not completed (censored data are omitted for plotting purposes).

Table A-1. Water Quality Portal data holdings including groundwater, inland, and marine water observations (E. K. Read, et al. 2017).

Data Source	Number of Sites	Number of Results	URL
USGS NWIS \ USGS BioData	1,616,518	94,075,242	http://waterdata.usgs.gov/nwis https://aquatic.biodata.usgs.gov/landing.action
USDA STEWARDS	227	1,230,333	http://www.nrrig.mwa.ars.usda.gov/stewards/stewards.html
EPA STORET-WQX	740,532	202,277,135	https://www.epa.gov/waterdata/storage-and-retrieval-and-water-quality-exchange

These totals represent the holdings in the WQP at the time of Read et al. (2017), accessed 10 October 2016 from www.waterqualitydata.us. Note: the WQP is not static and is being updated continually.

Table A-2. Water Quality Portal data requests and associated structure.

Data Source	Data Type	Characteristic and Units
Initial query	All data	huc = "14050005" siteType = "Stream"
Total nitrogen (TN)	Subset	CharacteristicName = "Nitrogen, mixed forms (NH3), (NH4), organic, (NO2), (NO3)" ResultMeasure.MeasureUnitCode = "mg/l" ResultSampleFractionText = "Total"
Total phosphorus (TP)	Subset	CharacteristicName = "Phosphate-phosphorus as P" CharacteristicName = "Total Phosphorus, mixed forms" CharacteristicName = "Phosphorus" ResultMeasure.MeasureUnitCode = "mg/l" ResultMeasure.MeasureUnitCode = "mg/l as P" ResultSampleFractionText = "Total"
Dissolved oxygen	Subset	CharacteristicName = "Dissolved oxygen (DO)" CharacteristicName = "Oxygen" ResultMeasure.MeasureUnitCode = "mg/l"
pH	Subset	CharacteristicName = "pH"
Chlorophyll a	Subset	CharacteristicName = "Chlorophyll a" ResultMeasure.MeasureUnitCode = "mg/m2"
Dissolved organic carbon (DOC)	Subset	CharacteristicName = "Organic carbon" ResultSampleFractionText = "Dissolved"

A.3 Results

Data summaries for each constituent are shown graphically in **Figure A-2** through **A-9**. The size of the monitoring point reflects the number of samples at a given spatial location and the box and whisker plots show the distribution of all the data for any site having more than 25 samples. Narrative summaries of each constituent are provided subsequently, which are further elaborated upon in the report text:

- **Nutrients (Figure A-2, Figure A-3):** Only a handful of sites have a sufficient nutrient data primarily the USGS gaging network. Data from all sites is far below the proposed interim Colorado numeric nutrient standard, noting that the applicability of the interim standard to nuisance algal conditions is further discussed in the report text.
- **Dissolved oxygen (DO) (Figure A-4):** Sites show no indication of DO impairment relative to the spawning standard of 7 mg/L (15th percentile of all data). DO minima typically occur prior to sunrise, thus diurnal data should be collected for full characterization of this water-quality endpoint.
- **pH (Figure A-5):** The site CORIVWCH_WQX-531 5th Street Bridge is exceeding the pH criteria since the 85th percentile of the dataset is equal to 9.1 S.U. Diurnal variability in pH does occur, however in this case, pH maxima typically occur during daytime hours thus it is more likely that at least some samples have been collected during peak pH. Several other sites also have a handful of pH observations above 9.0.
- **Chlorophyll a (Figure A-6):** Few benthic chlorophyll a samples exist in the project site. Only one site reports data and biomass at this site is very low (from the late 1970s).
- **Dissolved Organic Carbon (DOC) (Figure A-7):** DOC has only been collected at one location in the upper White River. These data far exceed the water quality standard of 3.0 mg/L, however the site is downstream of Meeker, CO and the City of Meeker municipal wastewater effluent is likely a major source of DOC to the lower watershed.
- **Suspended Solids Concentration (SSC) (Figure A-8):** Suspended solids data are limited primarily to the USGS gage sites. No comparison was made against a water quality standard since the standard is narrative, but these data are used at several locations in the main report text.
- **Instantaneous Water Temperature** (**Figure A-9**)**:** Instantaneous water temperature measurements have been made at numerous locations and are used in the main document to assess spatial variation in temperature and the potential influence on algal growth rate.

As is evident from review of above, there are large data gaps for certain constituents. In particular these are benthic chlorophyll a, which is nearly absent for the watershed, and likewise diurnal data for both DO or pH which is the most effective way to assess these types of water-quality variables. The above data gaps are further discussed in the report text.

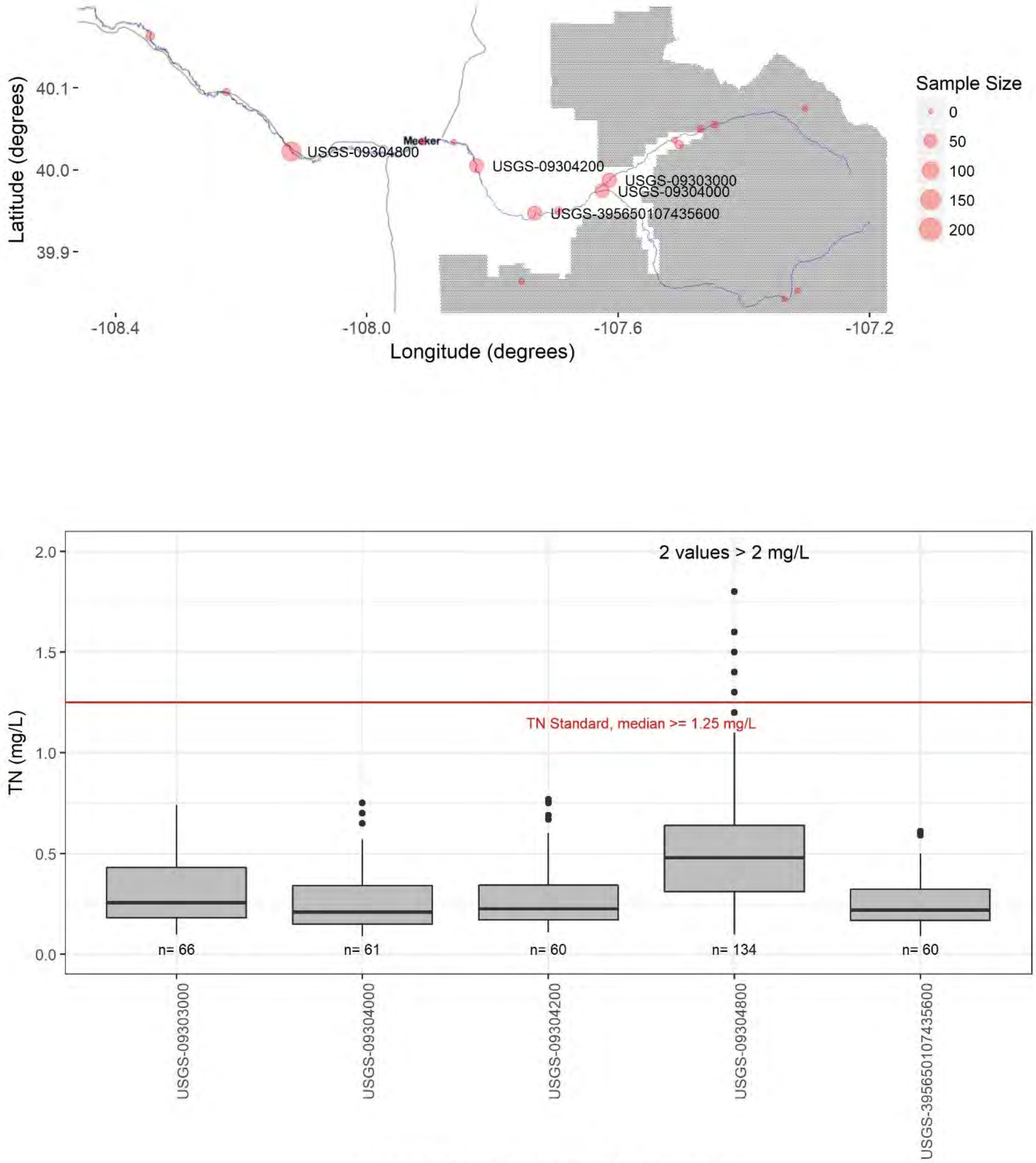
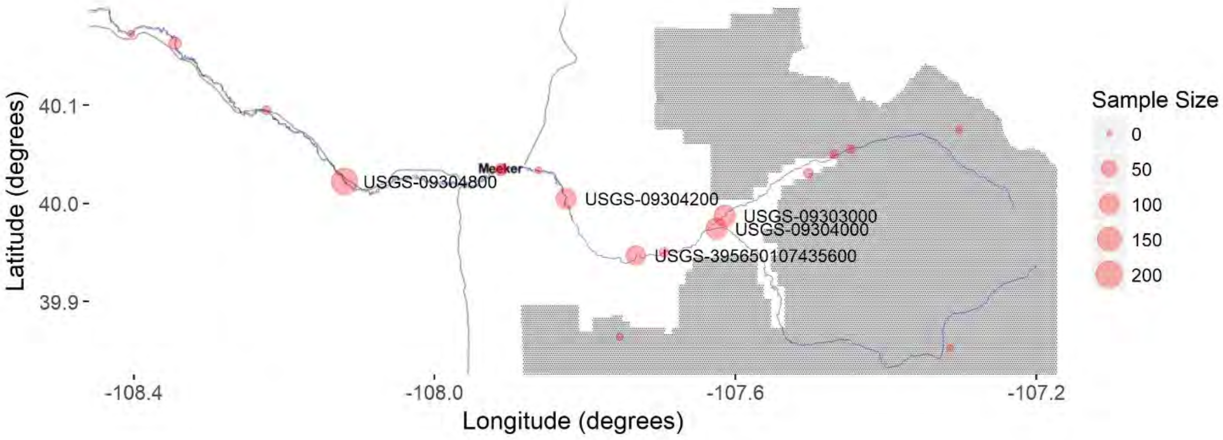


Figure A-2. Summary of total nitrogen (TN) observations in the upper White River vicinity as compared to the interim numeric TN nutrient standard.



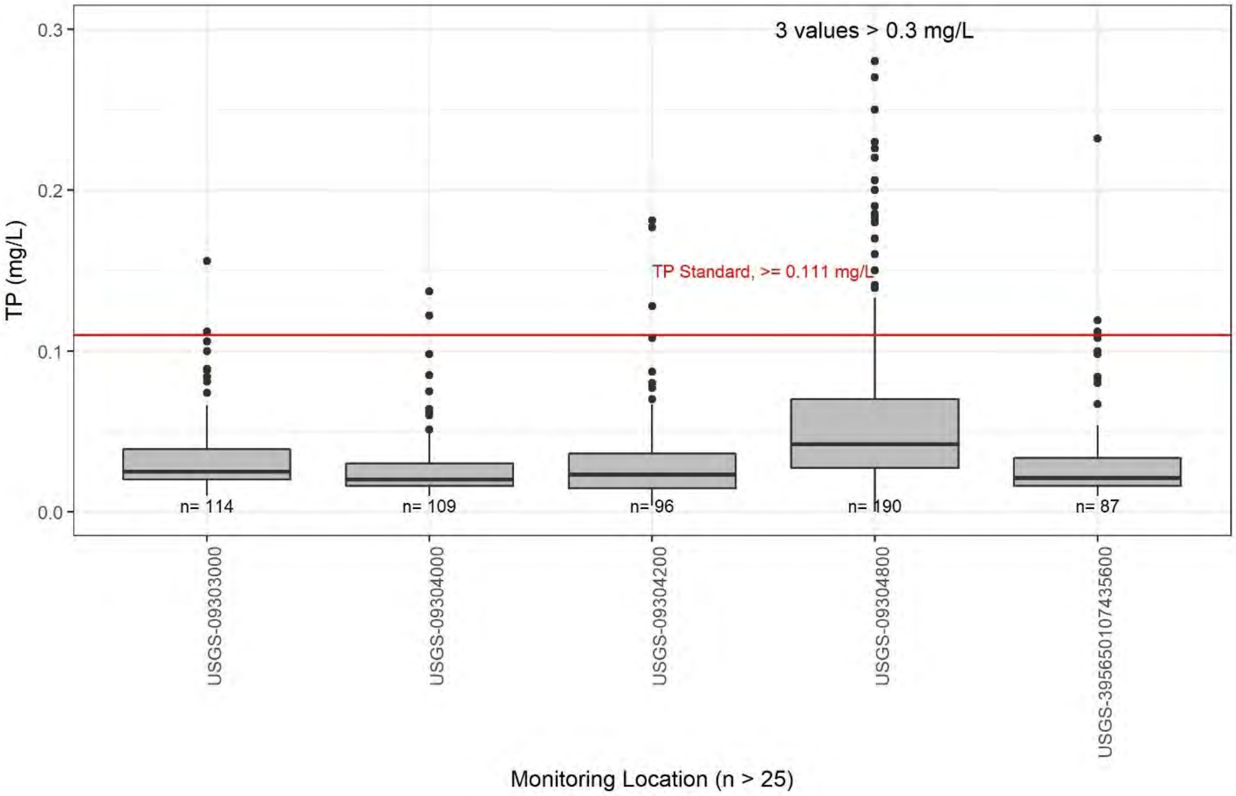


Figure A-3. Summary of total phosphorus (TP) observations in the upper White River vicinity as compared to the interim numeric TP nutrient standard.

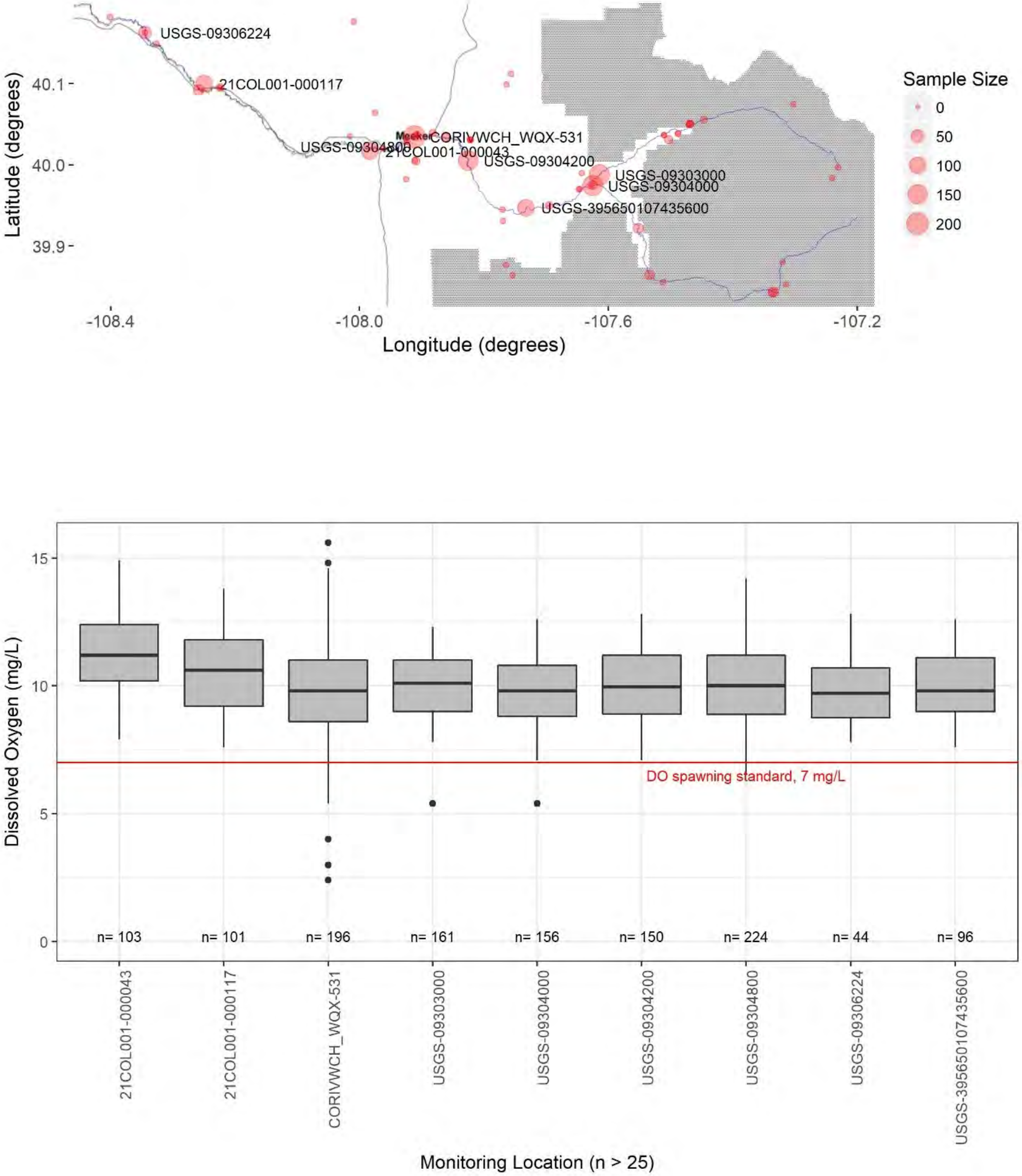


Figure A-4. Summary of dissolved oxygen (DO) observations in the upper White River vicinity as compared to the DO spawning standard.

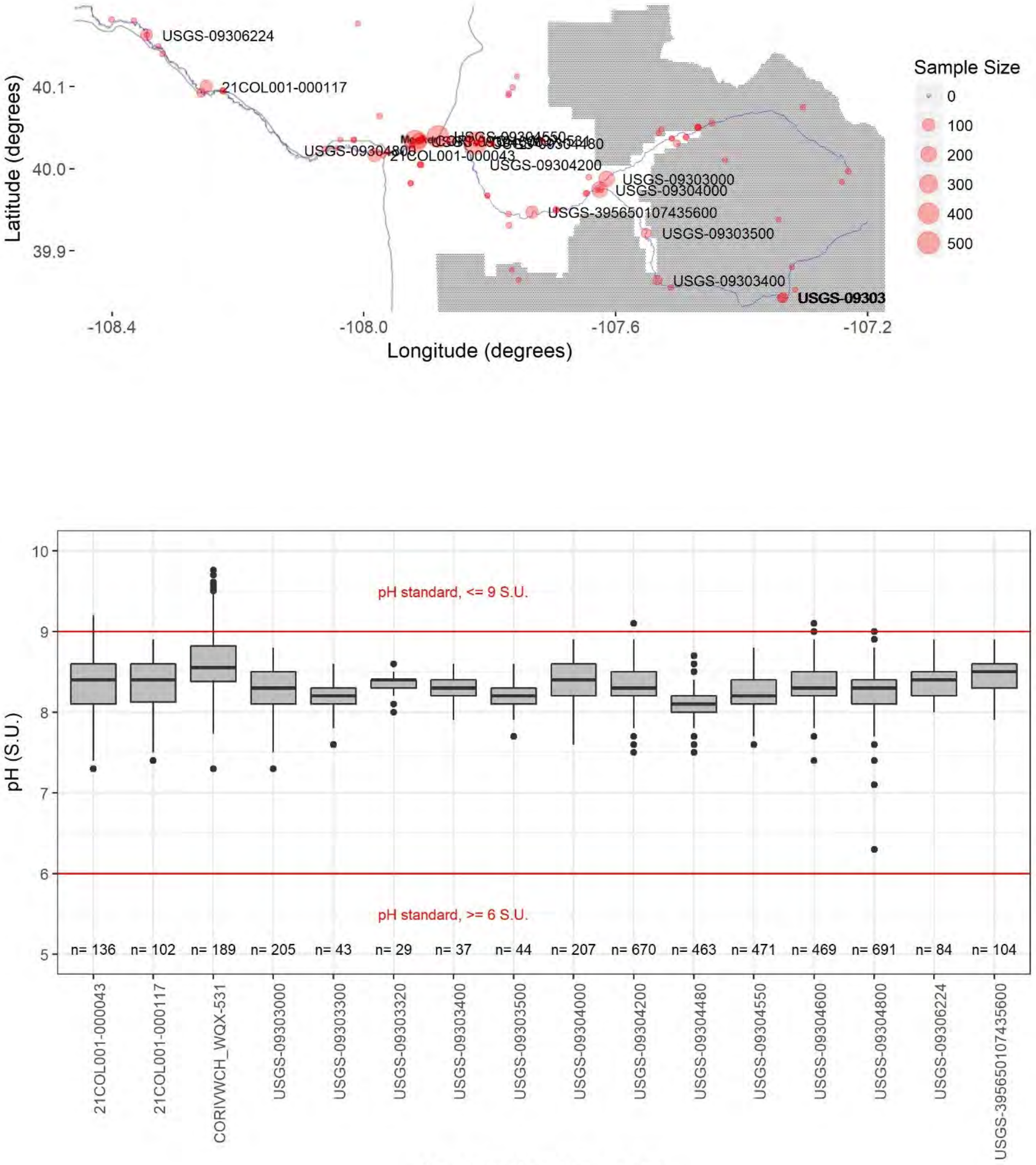
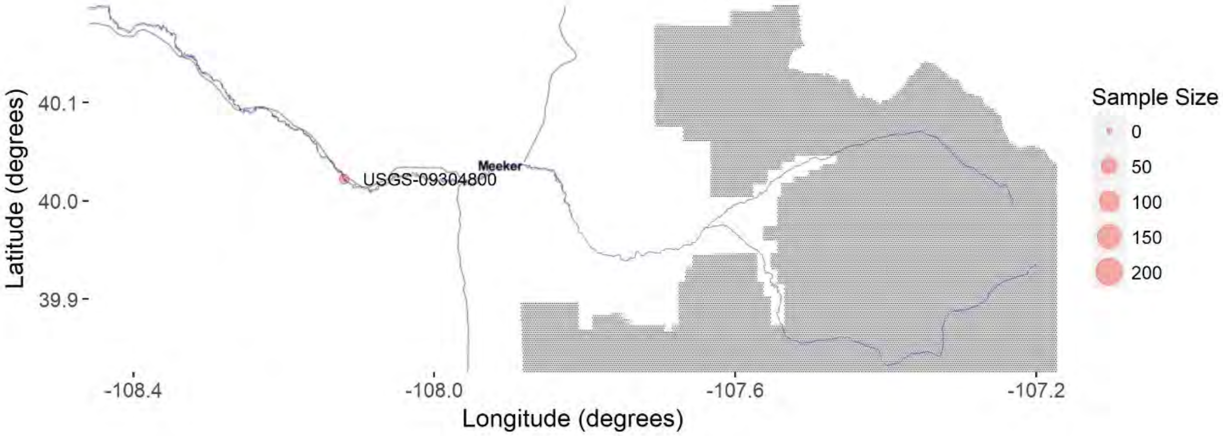


Figure A-5. Summary of pH observations in the upper White River vicinity as compared to the pH minima and maxima standard.



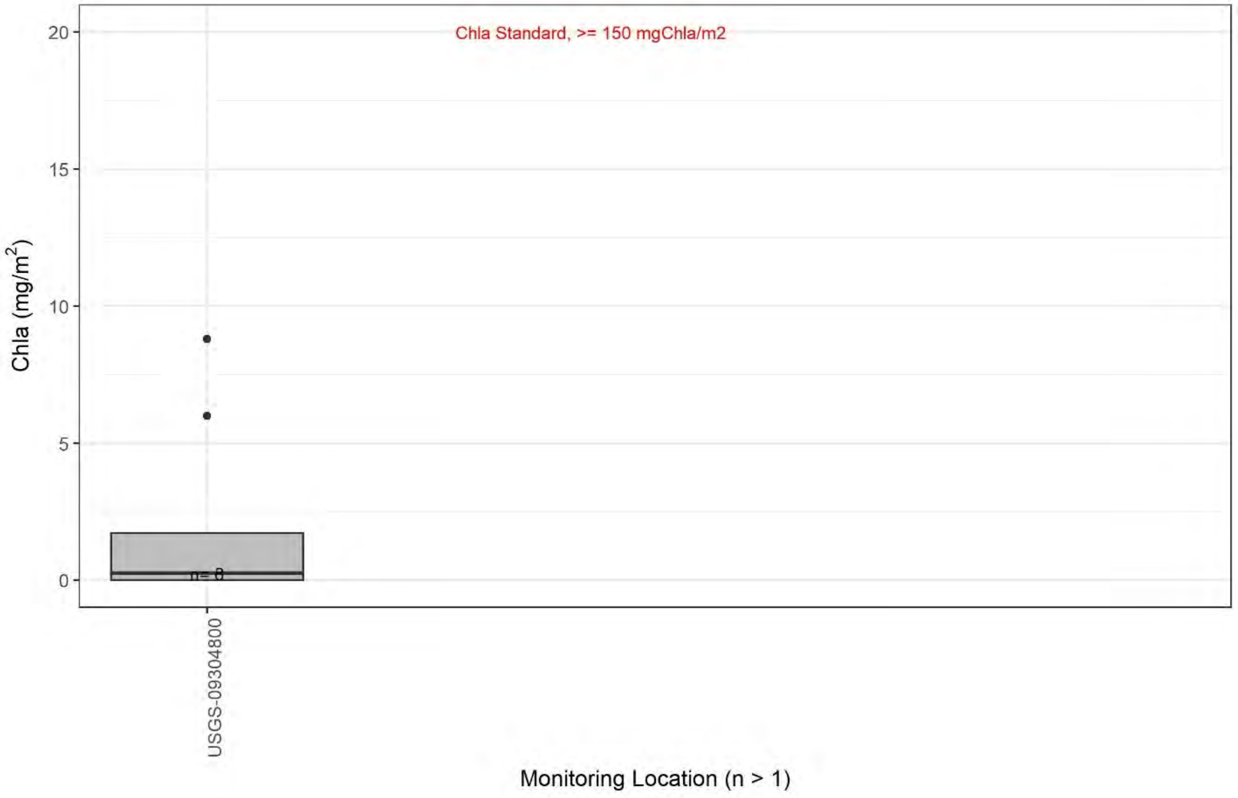
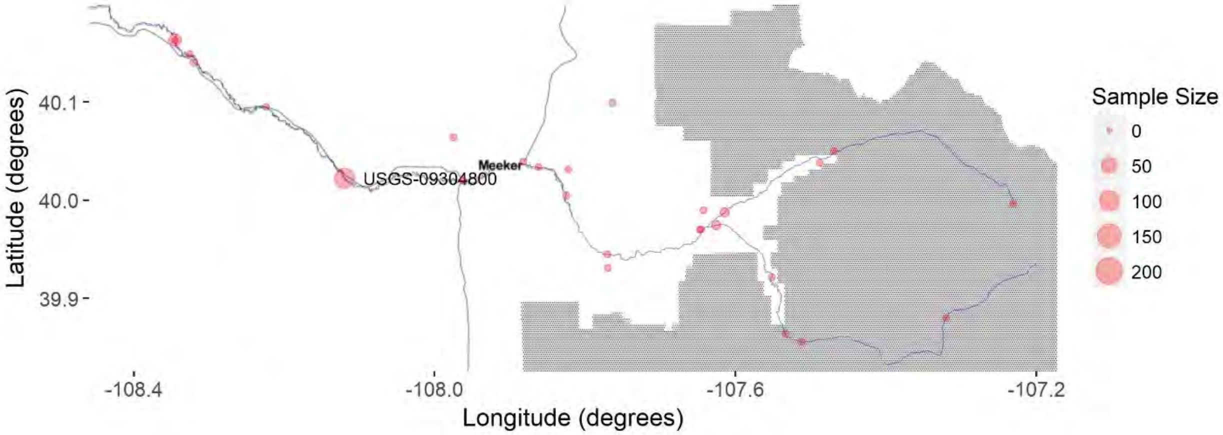


Figure A-6. Summary of benthic chlorophyll *a* observations in the upper White River vicinity compared to the standard.



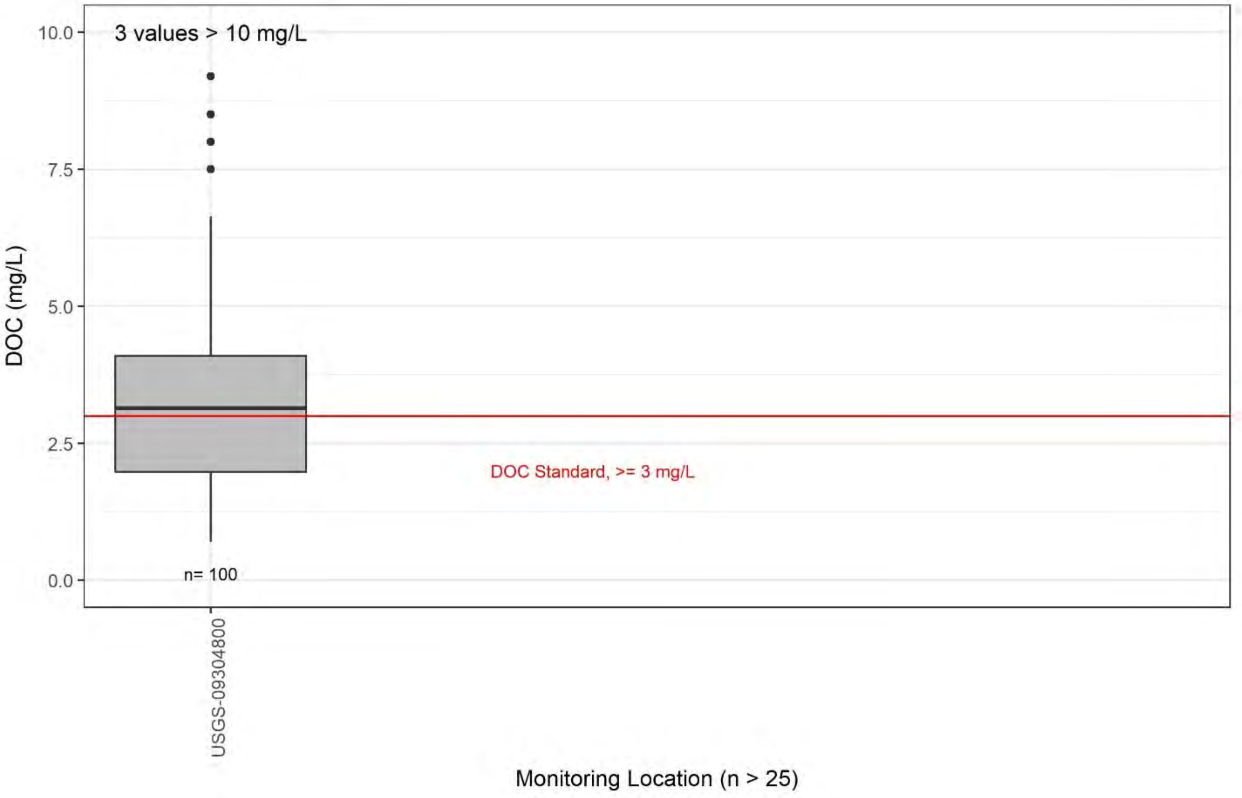


Figure A-7. Summary of dissolved organic carbon (DOC) in the upper White River vicinity compared to the DOC standard.

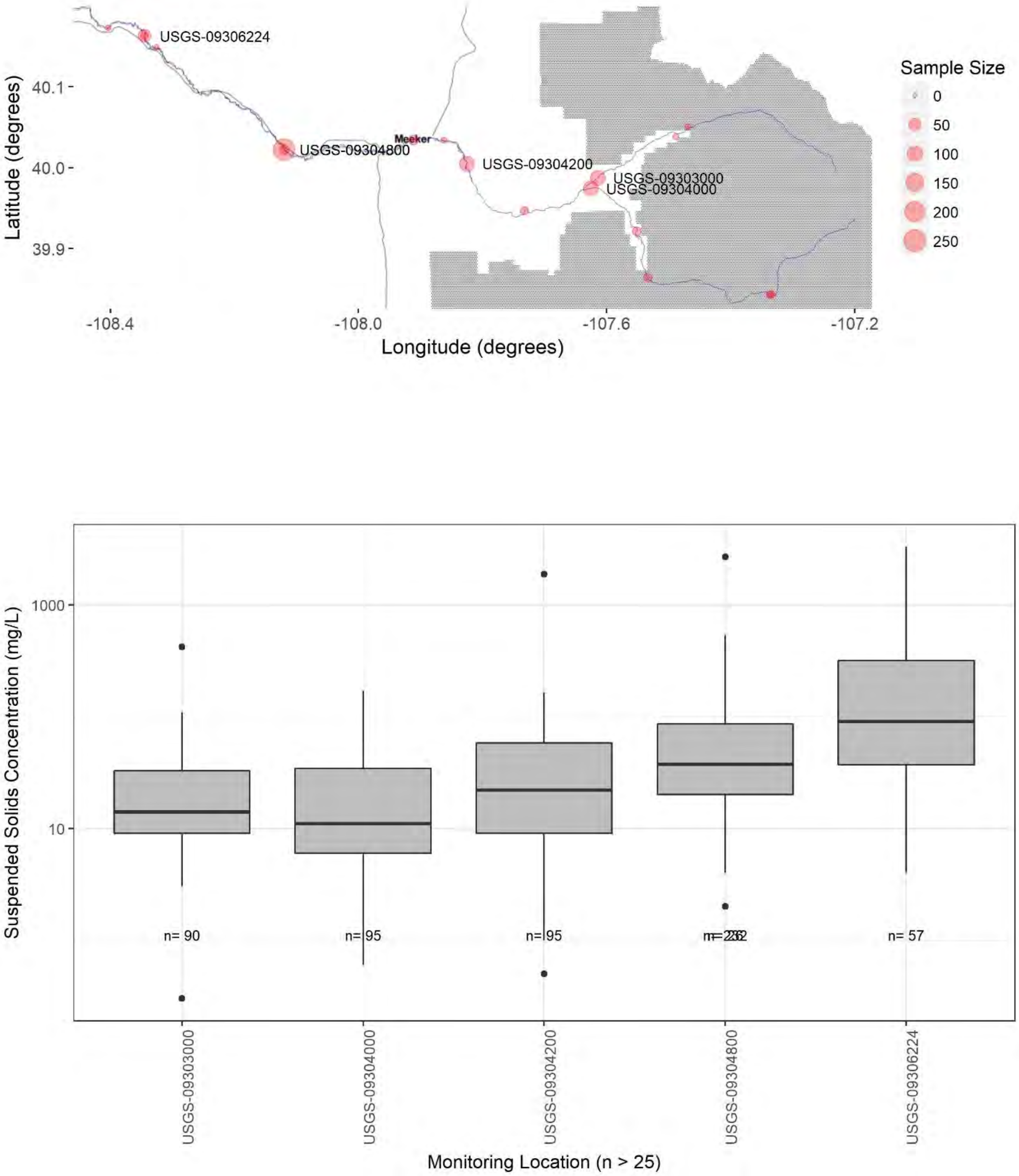


Figure A-8. Summary of suspended sediment concentration (SSC) in the upper White River vicinity.

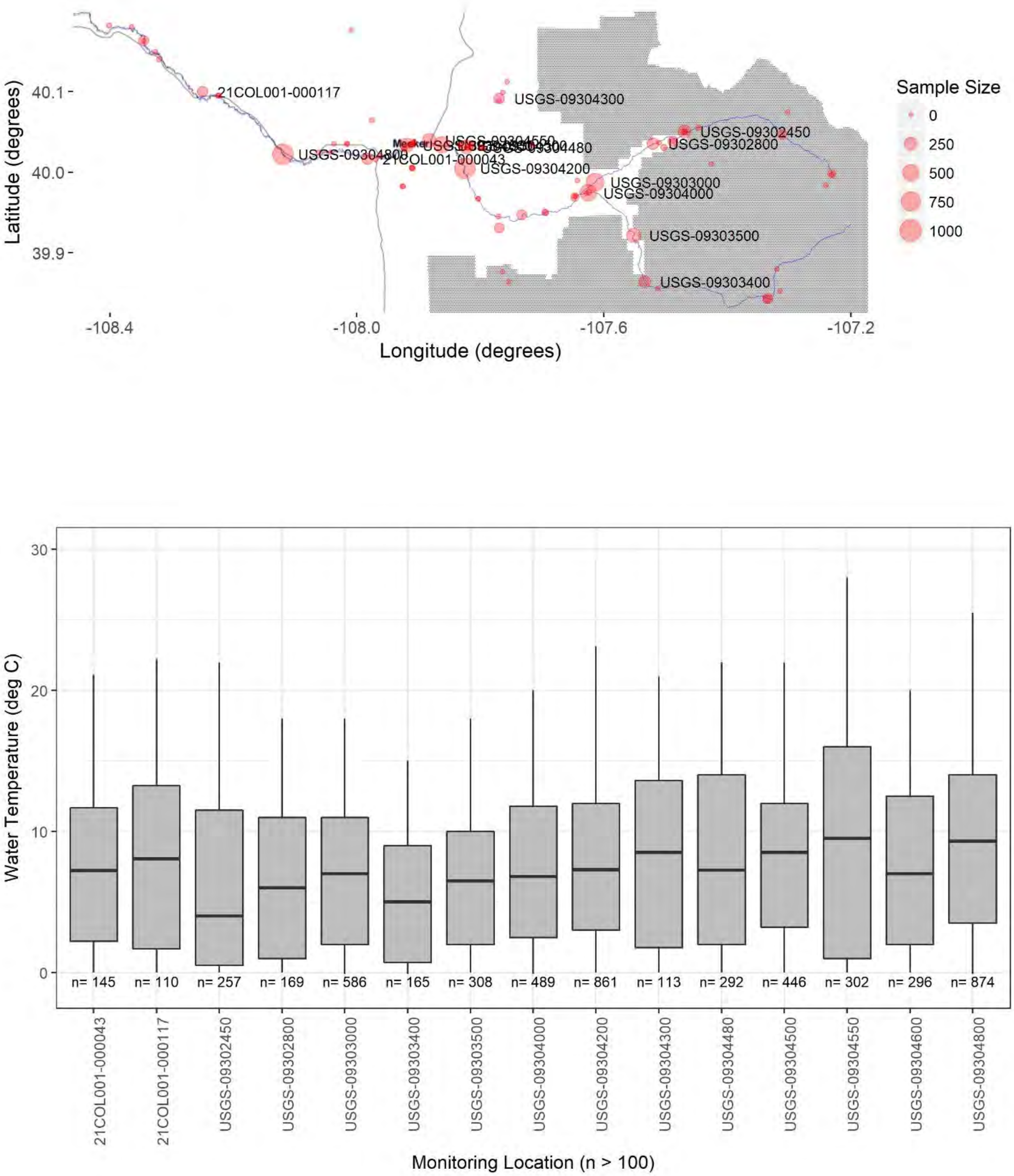


Figure A-9. Summary of water temperature in the upper White River vicinity.

Appendix B: Colorado Parks and Wildlife White River Synoptic Water Quality Monitoring

Table B-1. Colorado Parks and Wildlife sampling site list and samples collected 2015-2016

Location	2015 Water Quality[1]	2015 Macro[1]	2016 Water Quality[2]	2016 Macro[3]	2016 Chl-a[4]	2016 Algae ID[4]
North Fork White River below Lost Creek			X		X	
North Fork White River at County Road 14	X	X	X	X		
North Fork White River above Westlands	X		X			
North Fork White River at Westlands	X	X	X	X	X	
North Fork White River at Bel Aire	X	X	X	X		
South Fork White River at Bel Aire	X	X	X	X	X	
White River at Sleepy Cat	X		X			
White River at Wakara	X	X	X	X	X	X
White River at Meeker Pasture	X		X		X	
White River at Bailey's Bridge	X	X		X		
White River at 5th Street Bridge	X		X			
Coal Creek at Lunney Ranch			X			
Little Beaver Creek at County Road 40			X			
Little Beaver Creek at County Road 6			X			
Coal Creek at County Road 6			X			
Coal Creek at County Road 8			X			

[1] Samples collected on August 31, 2015.

[2] Samples collected monthly from March through October 2016.

[3] Samples collected on September 22, 2016

[4] Samples collected July 19, 2016

Macro macroinvertebrates

Chl-a Chlorophyll-a

B.1 Key findings of CPW's 2015 Investigation and Draft Report

- Low TSS at sites upstream of Wakara, increasing downstream until a peak at Meeker Pasture. All sites downstream of Wakara had TSS above 10 mg/L which may reduce the White River's primary productivity at those locations. Photosynthetically active radiation (PAR) measurements should be made to evaluate this assertion.
- Chloride was in the range of 1.0 mg/L upstream of Sleepy Cat, but increased downstream and reached a maximum of 10.9 mg/L at Bailey's Bridge. Concentrations of Chloride at the Meeker Pasture and Bailey's bridge may be under influence of groundwater from the Meeker Dome. Chloride has historically been used as a conservative tracer and is likely an indicator of groundwater influx, which can be elevated in nutrients.
- The analyzing laboratory did not have the ability to analyze samples for organic nitrogen or ammonia. As a result, only nitrate + nitrite (NO_{3+2}) was reported by the laboratory and total nitrogen (TN) concentrations were not determined for any of the samples.
- NO_{3+2} concentrations were below 0.040 mg/L at all sites, but an elevated sample of 0.143 mg/L was reported at the North Fork of the White River at Westlands Ranch.
- An increase in NO_{3+2} was also reported in the sample collected at Meeker Pasture when compared to the sampling sites upstream and downstream, suggesting a nitrogen source in this area.
- Low NO_{3+2} concentration was reported in the sample collected at the North Fork of the White River at Bel Aire, which was the sampling site most immediately downstream of Westlands Ranch. Uptake by algae was determined to be the most logical explanation for the reduction and was supported by the algae growth pattern that was observed and documented during the sampling event. This phenomenon is suggestive of a system that is nitrogen limited or co-limited by nitrogen and phosphorous.
- Concentrations of total phosphorus (TP) reported in samples collected at Meeker's Pasture and Bailey's Bridge exceeded Colorado numeric water quality standards for TP in cold water streams.
- Concentrations of TP were higher in samples obtained from the North Fork of the White River when compared to those collected from the South Fork of the White River.
- Both TP and NO_{3+2} concentrations are elevated at Meeker Pasture, suggesting a nutrient source between Wakara and Meeker Pasture or from Coal Creek. Elevated TP and NO_{3+2} concentrations correspond with heavy growth of filamentous algae observed and documented at Meeker Pasture and Bailey's Bridge during the sampling event.
- MMI scores were higher at the most upstream sampling locations. The sites sampled on the North and South Fork of the White River were in attainment of MMI thresholds, but samples on the mainstem collected at Wakara and Bailey's Bridge were below the impairment threshold.

B.2 Key findings of CPW's 2016 Investigation and Summary Report

- Visible filamentous algae was identified as *Cladophora glomerata*
- Nitrogen was identified as the limiting nutrient
- Coal Creek is a major source of nutrients, but nutrient levels above Coal Creek are sufficient to support nuisance algae
- Nutrient sources identified included septic systems, fish food, sediment, animal waste, and fertilizers
- Reduction of both nitrogen and phosphorous was recommended

Figure B-1. **(a)** Box and Whisker Plot for Colorado Parks and Wildlife 2016 Synoptic Sampling Laboratory Analytical Results and Field Parameters for Sampling Locations on the North Fork, South Fork, Mainstem, and Tributaries of the White River

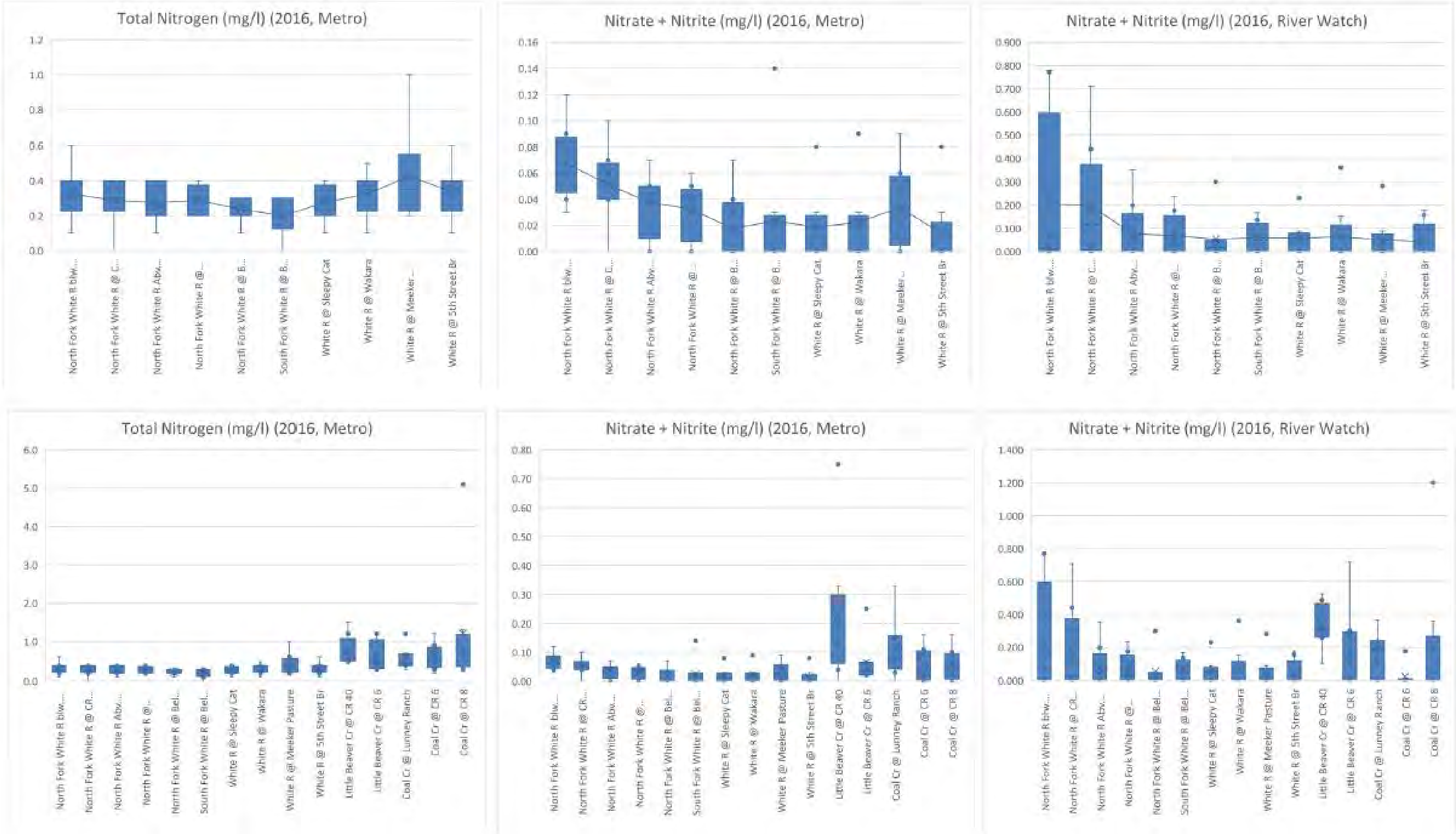


Figure B-1. **(b)** Box and Whisker Plot for Colorado Parks and Wildlife 2016 Synoptic Sampling Laboratory Analytical Results and Field Parameters for Sampling Locations on the North Fork, South Fork, Mainstem, and Tributaries of the White River

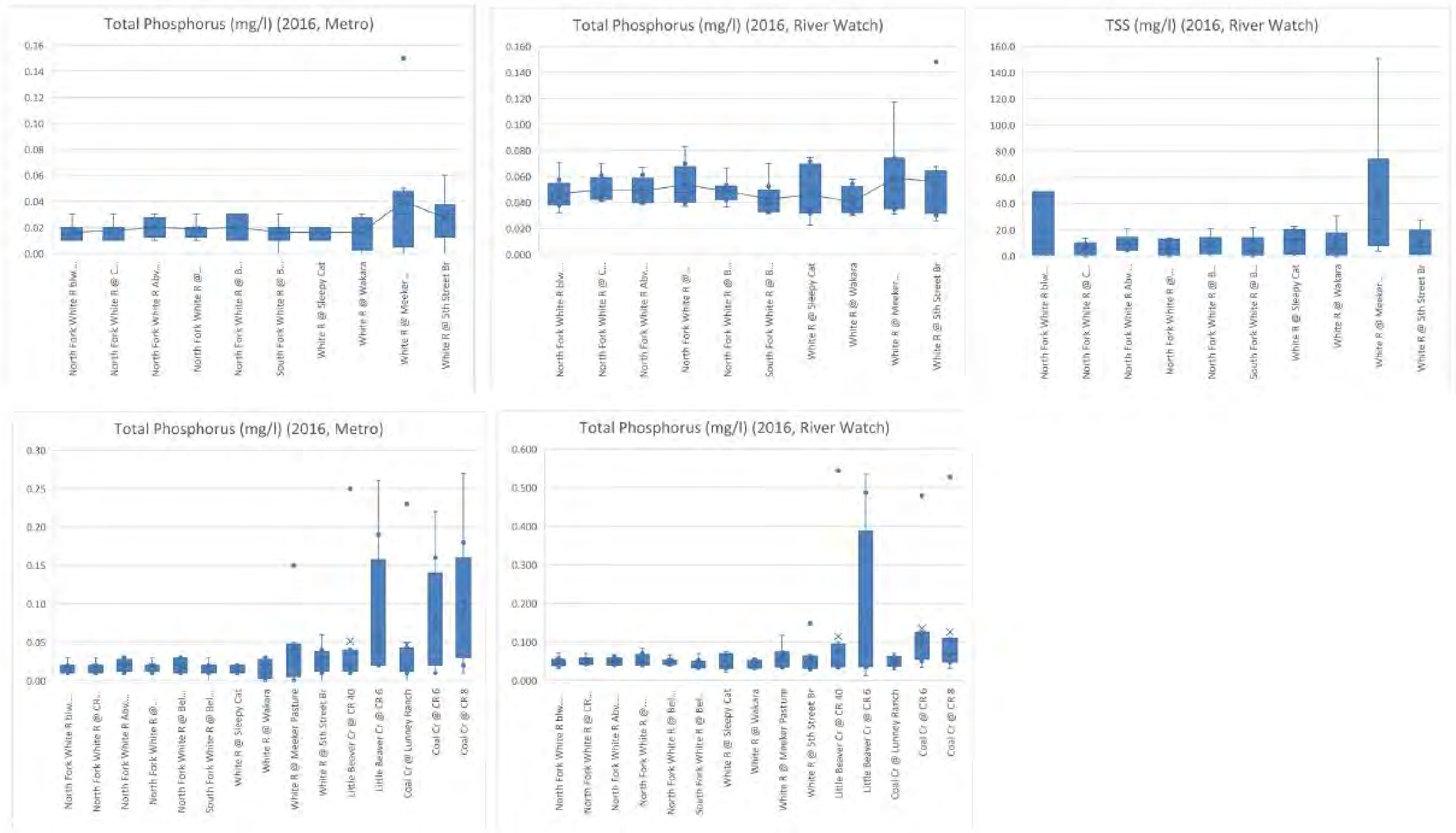


Figure B-1. **(c)** Box and Whisker Plot for Colorado Parks and Wildlife 2016 Synoptic Sampling Laboratory Analytical Results and Field Parameters for Sampling Locations on the North Fork, South Fork, Mainstem, and Tributaries of the White River

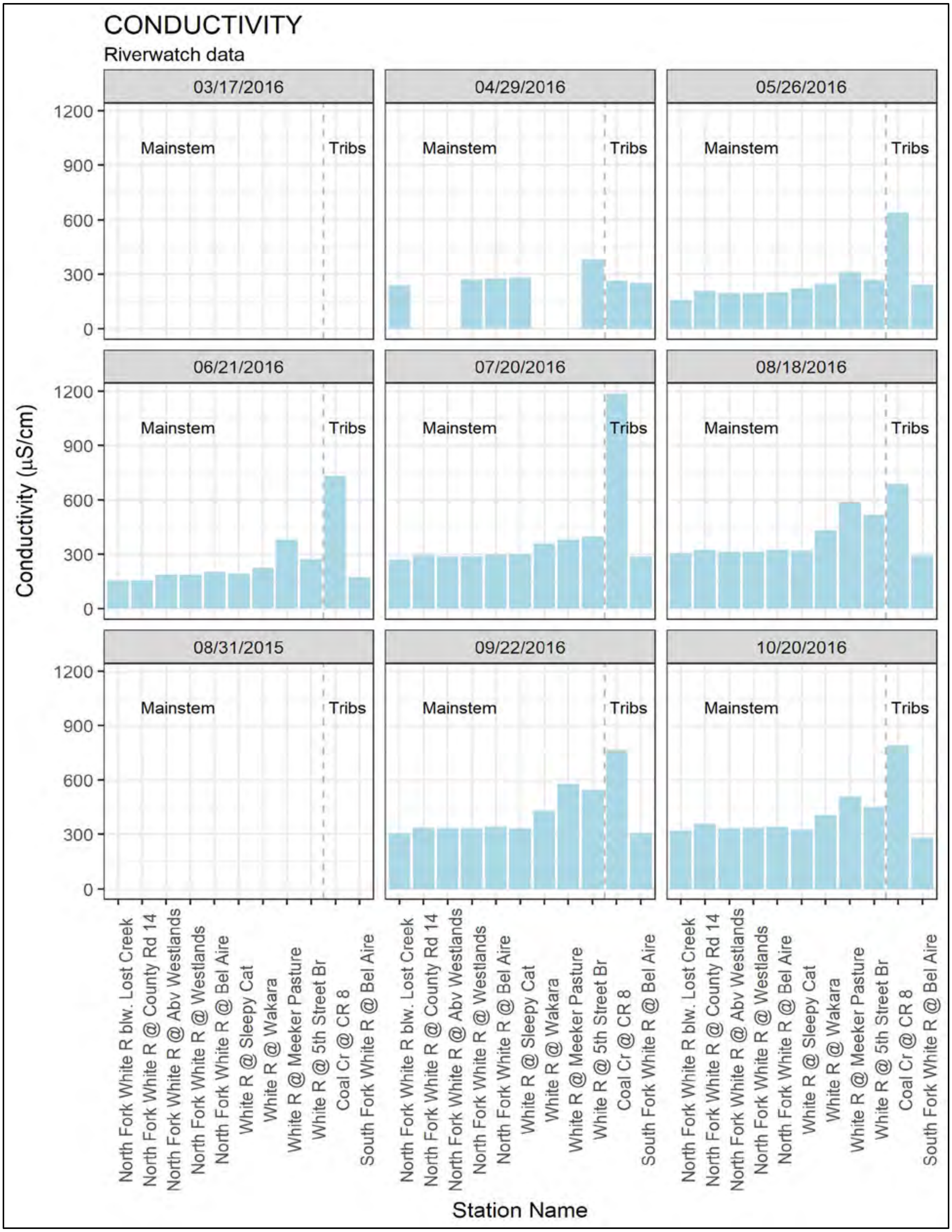


Figure B-2. Conductivity Results from Colorado Parks and Wildlife 2015-2016 Synoptic Sampling on the North Fork, South Fork, Mainstem, and Tributaries of the White River

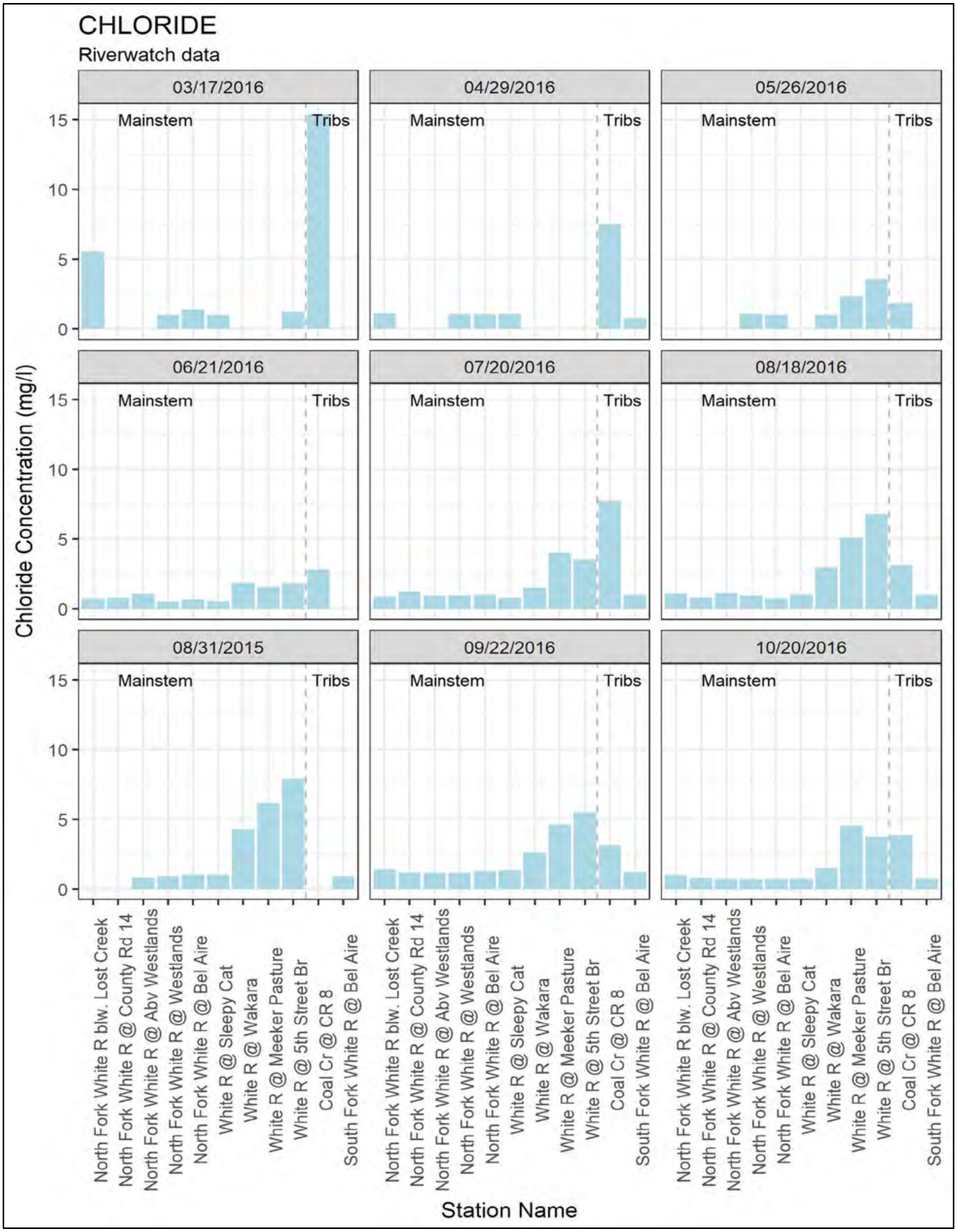


Figure B-3 Chloride Concentrations from Colorado Parks and Wildlife 2015-2016 Synoptic Sampling on the North Fork, South Fork, Mainstem, and Tributaries of the White River

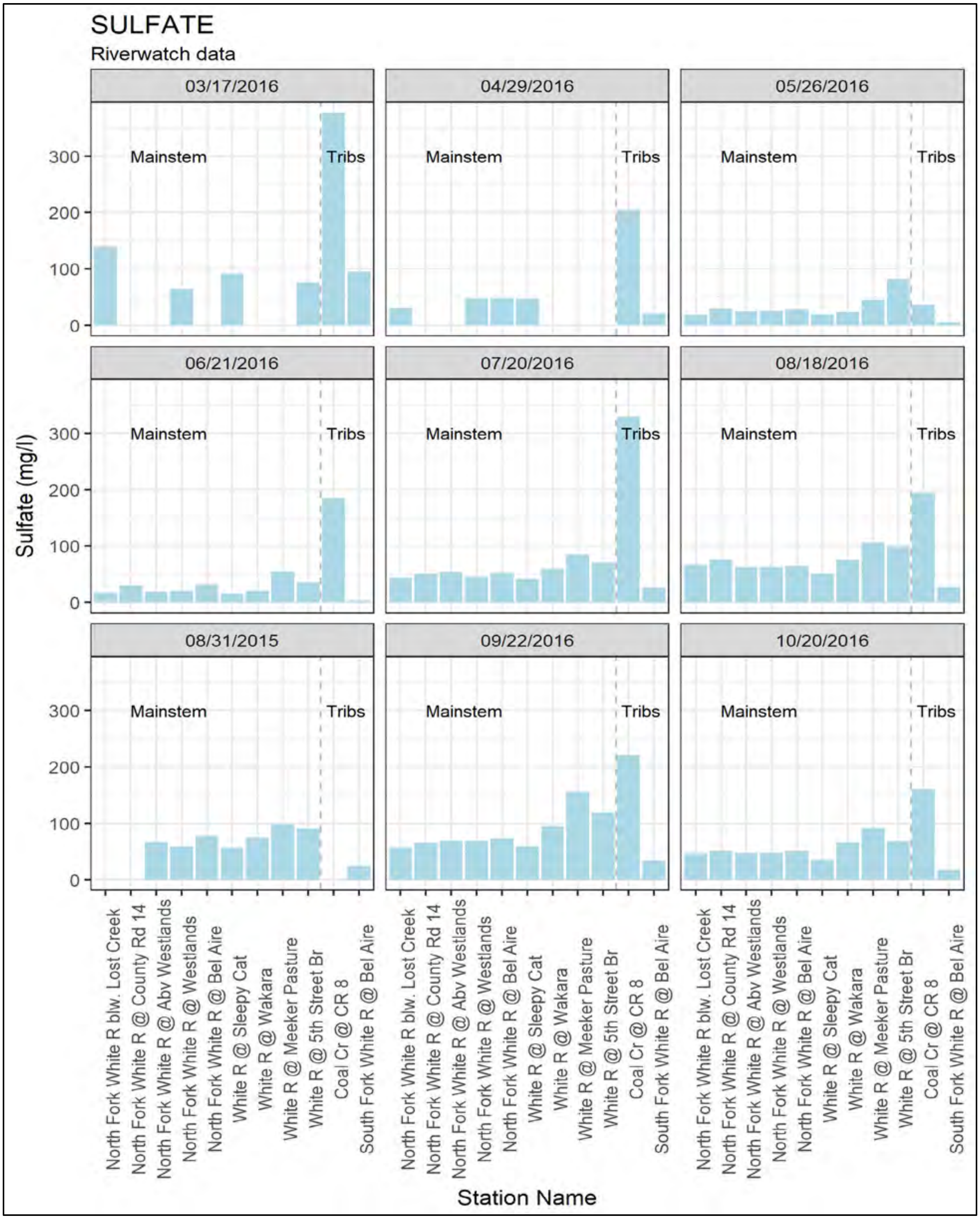


Figure B-4 Sulfate Concentrations from Colorado Parks and Wildlife 2015-2016 Synoptic Sampling on the North Fork, South Fork, Mainstem, and Tributaries of the White River

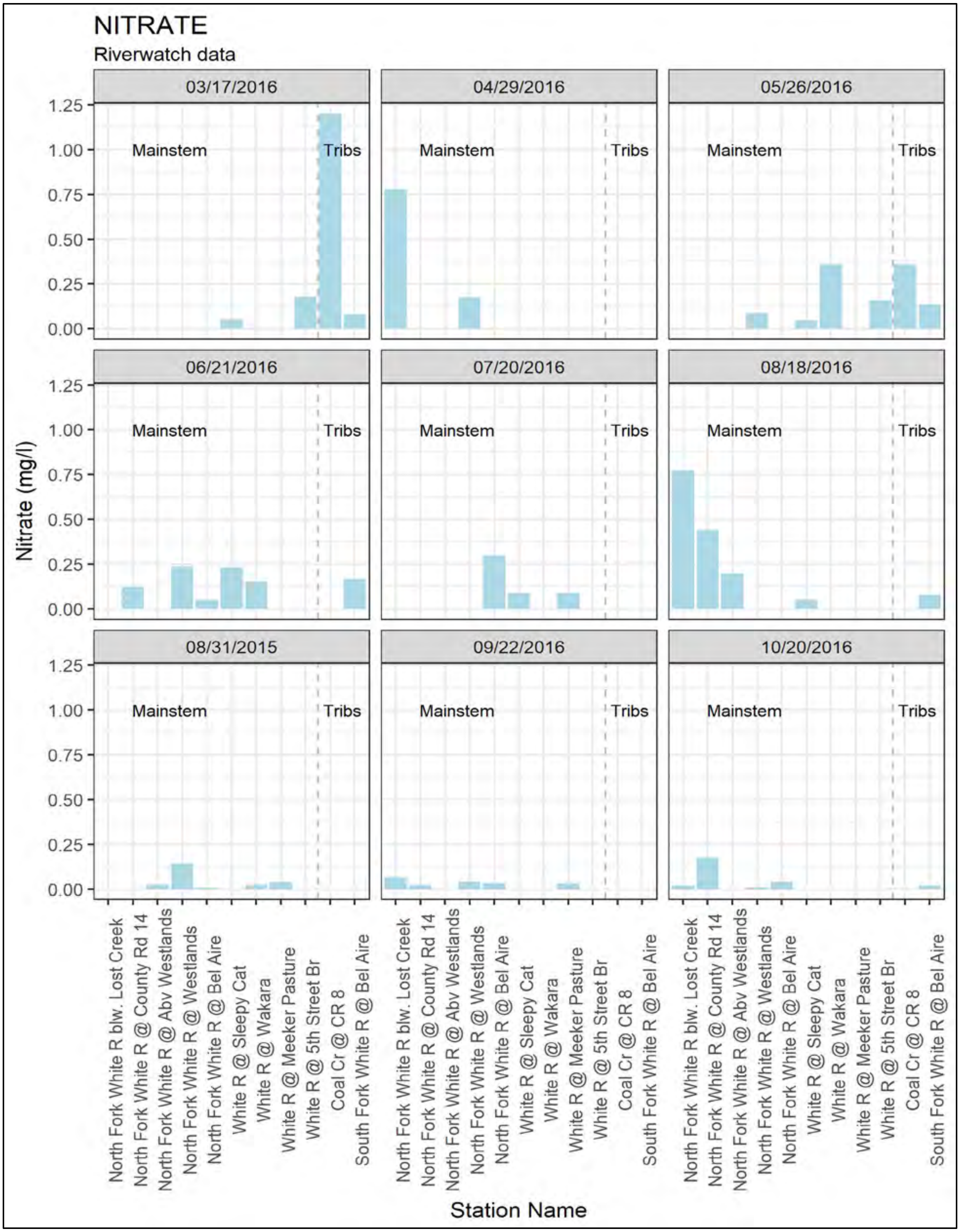


Figure B-5 Nitrate Concentrations from Colorado Parks and Wildlife 2015-2016 Synoptic Sampling on the North Fork, South Fork, Mainstem, and Tributaries of the White River

Appendix C: Trend and Load Analysis

C.1 Introduction

Trends and loads were evaluated using the Weighted Regressions on Time Discharge and Season model (WRTDS; Hirsch et al. 2010) to better understand if environmental changes have influenced nuisance algal conditions. Analysis was completed using the Exploration and Graphics for RivEr Trends software (EGRET; Hirsch and De Cicco, 2015). WRTDS is a method for analysis of water-quality data sets that can be used to characterize the status and trends in concentration or load by fitting a generalized regression model to observed data and then flow normalizing predictions to eliminate variability due to the random variation in streamflow. It is preferred over other techniques due to its ability to fit weighted regressions. For an extensive discussion of the motivations and design of the WRTDS method, see Hirsch et al. (2010).

WRTDS can be used for a variety of purposes including the following (Hirsch and De Cicco 2015), several of which are used here:

1. Estimating long-term changes (trends) in average concentrations or load;
2. Estimating mean annual concentration or loads for specific years or periods of analysis;
3. Estimating mean concentrations or load over some specified period, such as a year or decade;
4. Providing insights into the change in system behavior that may lead to a better understanding of the causative mechanism behind the trends that are observed.

C.2 Model Description

WRTDS creates a statistical representation of the expected value of concentration for every day in the period of record and then uses that representation to produce daily, monthly, or annual time series of daily concentration and load (Hirsch and De Cicco 2015). The regression is structured

$$\ln(c) = \beta_0 + \beta_1 \ln(q) + \beta_2 T + \beta_3 \sin(2\pi T) + \beta_4 \cos(2\pi T) + \varepsilon$$

where *c* is the concentration (mg/L), *q* is the mean daily discharge (cubic meter per second, m^3/s), *T* is time (decimal years), $\beta_{0,\ 1,\ 2,\ 3,\ 4}$ are regression coefficients, and ε is model error. Although the form of the equation is linear in q and T, these properties hold true only locally since coefficients vary throughout the q,T space. Additionally, the sine and cosine wave are free to change too.

The estimation method relies on weighted regressions where each observation is weighted based on the relevance of that observation to the estimation point. As indicated by Hirsh et al. (2010), this distance has three dimensions. The first is the difference between the time of each observation and the estimation point, known as the ‘‘time distance.’’ The second is measured by the difference between the time of year known as the ‘‘seasonal distance.’’ The third is the difference between the discharge and the discharge of the observation point known as the ‘‘discharge distance.’’

Following computation of the model, traditional output, diagnostics and flow-normalized values are produced from WRTDS. The latter is intended to integrate out the influence of variation in concentration from day-to-day variability in discharge and is useful in evaluating trends. Flow normalization is described mathematically for a specific day of the evaluation period as

$$c_{f,i} = \frac{c_i}{n}\sum_{1}^{n} q_n$$

where $c_{f,i}$ is the flow normalized concentration for day i under consideration (mg/L), c_i is the concentration estimate from the WRTDS model for that same day i (mg/L), q_n is the series of daily discharges for the specific day of the year in question (m^3/s), and n is the number of days in the discharge record for the given day of the year.

Hirsh et al. (2010) indicate the resulting flow-normalized annual concentration and flux histories are temporally smooth because they eliminate all the concentration or load variability due to the random variation in streamflow. Furthermore, they provide a much clearer indication of water-quality change because the flow-normalized records are more stable and are not driven by random variations in streamflow. They are appropriate to use when computing changes over time or for tracking changes in water quality, land-use practices, or point-source loading.

C.3 Model Application (Water Years 1991–2017)

Analysis was completed with WRTDS for both total and soluble nutrient fractions in the White River through September 30, 2017. Stream gages in the project site considered in the application of the model are shown in **Table C-1**. The number of data points for each constituent, censored percentage of data, and the continuous flow period of record are included. Note that while the entire period of record is shown in the table, data for the period of 1991–2017 were used in the analysis as this reflects the common period of overlap.

In examination of locations, there is only one gage in the upper watershed with requisite information to directly apply the WRTDS model through 2017; USGS 09304200 White River above Coal Creek near Meeker, CO. The other sites are either missing published daily streamflow values (e.g., USGS 09303000, USGS 09304000, and USGS 395650107435600) or have an inadequate number of water quality samples (e.g., USGS 09304500). This highlights a deficiency in the current monitoring network that should be remedied going forward. We detail a record extension procedure below to provide estimates at key locations.

A synthetic time-series of streamflow was generated for the missing period at USGS 09303000 North Fork White River and USGS 09304000 South Fork White River at Buford, CO, using the ratio of published daily value median statistic (**Figure C-2**) for each gage relative to White River above Coal Creek (overlapping period of 1962–1997). As an example, ratio of the published daily median statistic (50th percentile) discharge at USGS 09303000 North Fork of the White River at Buford, CO to the published statistic for USGS 09304200 White River above Coal Creek near Meeker, CO was multiplied by the observed USGS daily flow at 09304200 White River above Coal Creek value to fill the missing value for the day. Tabulation was done individually for both the North Fork and South Fork.

Table C-1. Data considered in application of the WRTDS model to estimate loads in the upper White River. Values shown in parentheses are the number of censored observations, where censored observations are less than the laboratory detection limit.

Site	Total Phosphorus 00665	Dissolved Orthophosphate 00671	Total Nitrogen 00600	Nitrate plus Nitrite 00631[a]	Daily Flow
USGS 09303000 North Fork White River at Buford, CO	1976–2017 *n*=125 9.5%	1981–2017 *n*=131 21%	1991–2017 *n*=109 39%	1976–2017 *n*=149 34%	1951–2001
USGS 09304000 South Fork White River at Buford, CO	1976–2017 *n*=125 13%	1981–2017 *n*=127 31%	1991–2017 *n*=109 44%	1976–2017 *n*=144 33%	1951–1997
USGS 395650107435600 White River above Dry Creek, near Meeker, CO	1997–2017 *n*=88 1.1%	1997–2017 *n*=88 23%	1997–2017 *n*=87 31%	1997–2017 *n*=88 31%	None
USGS 09304200 White River above Coal Creek near Meeker, CO	1991–2017 *n*=111 14%	1973–2017 *n*=129 30%	1991–2017 *n*=110 45%	1975–2017 *n*=130 42%	1961–2017
USGS 09304500 White River near Meeker, CO	1979–1979 *n*=1 0%	1973–1981 *n*=7 0%	1979–1979 *n*=1 0%	1973–1981 *n*=7 0%	1901–2017

[a] Ammonia plus ammonium (pCode 00608) was considered but had such a high number of censored observations that it was excluded from the analysis.

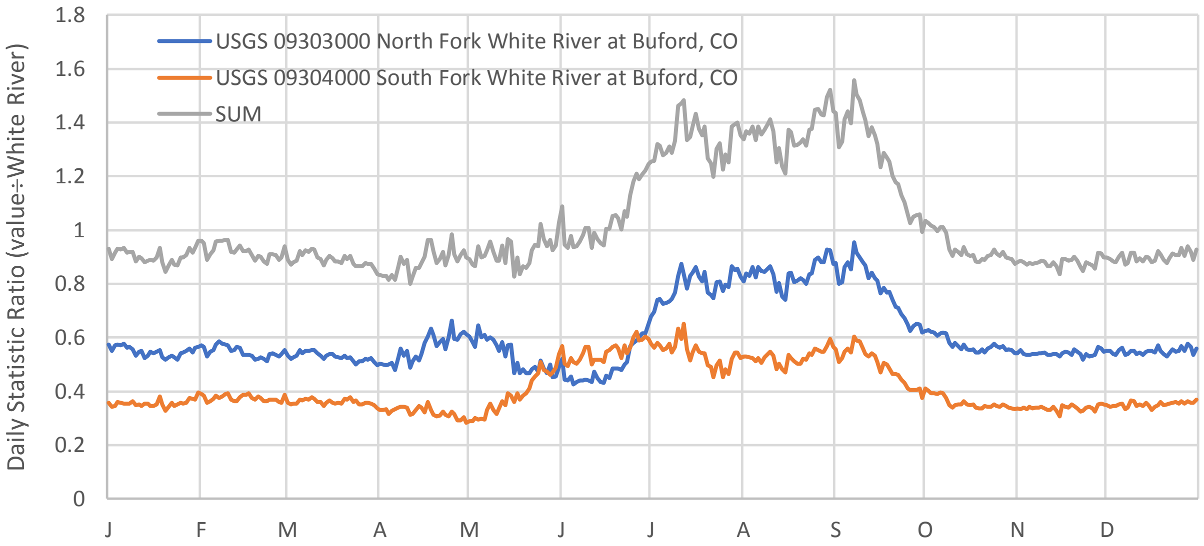
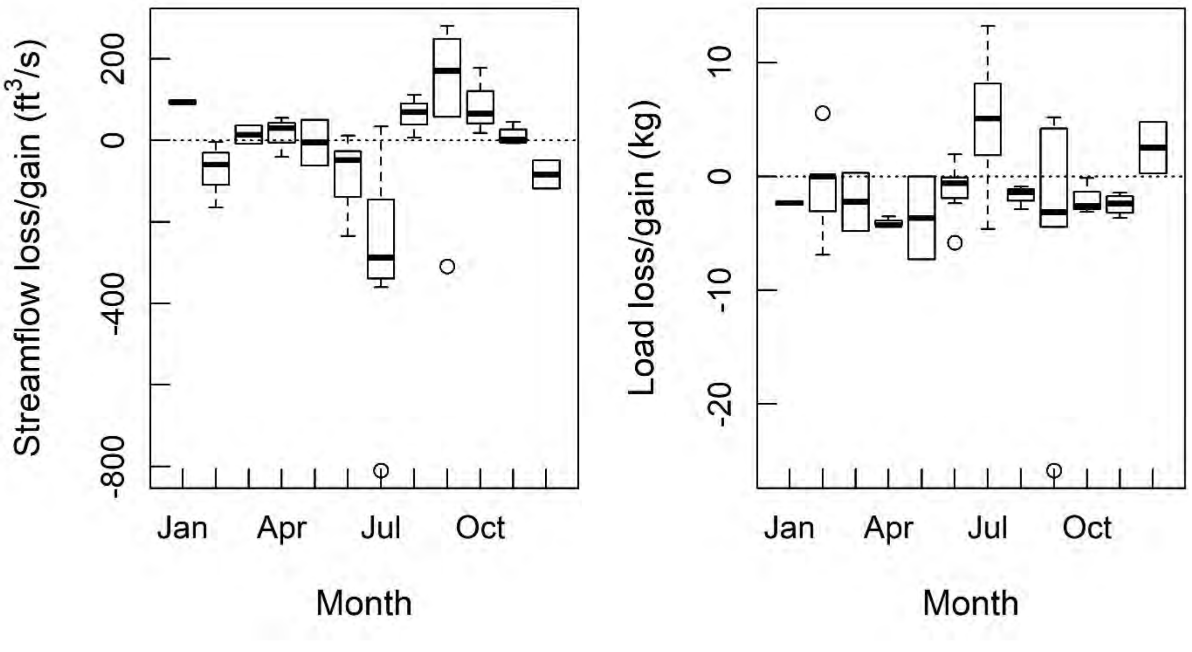


Figure C-2. Ratio of the daily statistic for USGS 09303000 North Fork of the White River at Buford, CO and USGS 09304000 South Fork of the White River at Buford, CO relative to USGS 09304200 White River above Coal Creek near Meeker, CO.

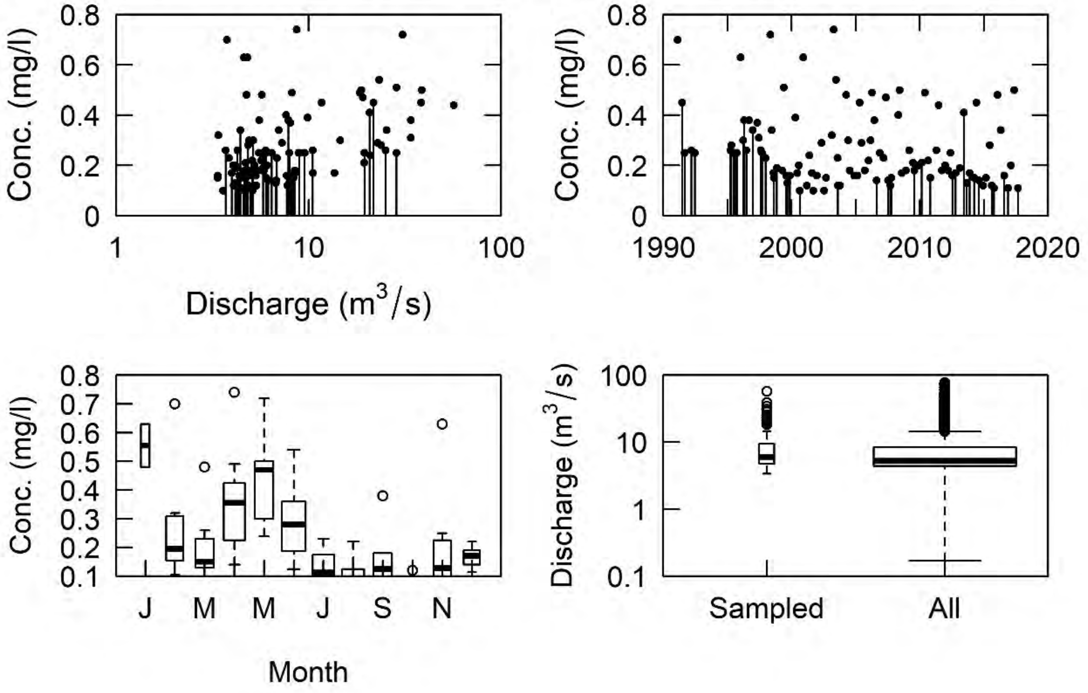
As evidenced above, the North Fork comprises roughly 50–60 percent of the flow in the White River above Coal Creek during the non-irrigation season (October through June) whereas during the irrigation season (July through September) it is nearer 80 percent. The South Fork is approximately 40 percent during the winter months and 60 percent during the irrigation season. In summing these percentages, it should be recognized nearly all of the water in the winter months can be accounted for the sum of the North and South Fork gages. However, during the summer the upper gages account for more than 100 percent of the flow, meaning there are consumptive losses (e.g., irrigation, other withdrawals) between the confluence and the White River at Coal Creek during that period.

Flow changes between combined synoptic flow and water quality samples (±1 day) were compiled at USGS 09303000 North Fork of the White River at Buford, CO and USGS 09303000 South Fork at Buford, CO to assess this occurrence. Invoking the principle of superposition and ignoring routing, these compared to USGS 09304200 White River above Coal Creek near Meeker, CO. Streamflow deviations between the sum of the contributions of the upstream and downstream gages differ at certain times of the year. Neutral or positive gains occur during fall and winter months, and losses during the irrigation season (**Figure C-3a**).



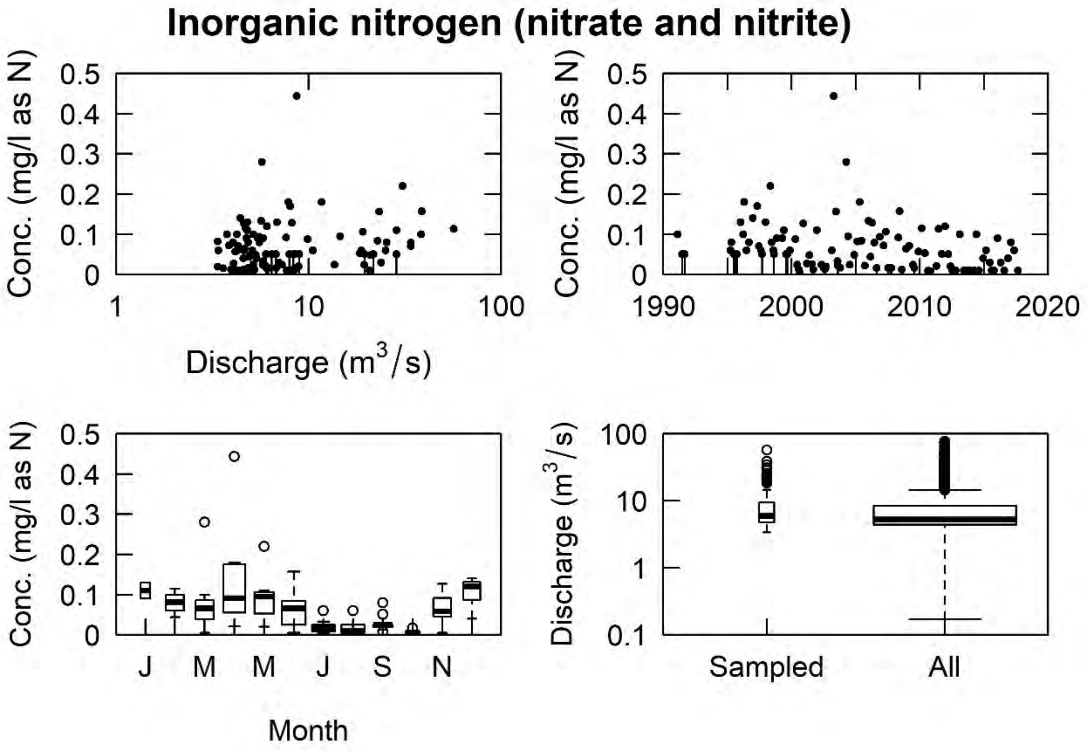
(a) **(b)**

Figure C-3. (a) Streamflow gains or losses by month between the sum of the North and South Fork of the White River at Buford, CO and the White River above Coal Creek for same day measurements. (b). Same as previous, but for loads.



NORTH FORK WHITE RIVER AT BUFORD, CO

Nitrogen, mixed forms (NH3), (NH4), organic, (NO2) and (NO3)



Inorganic nitrogen (nitrate and nitrite)

Figure C-4. Summary of nitrogen data for USGS 09303000 North Fork White River at Buford, CO from 1990-current.

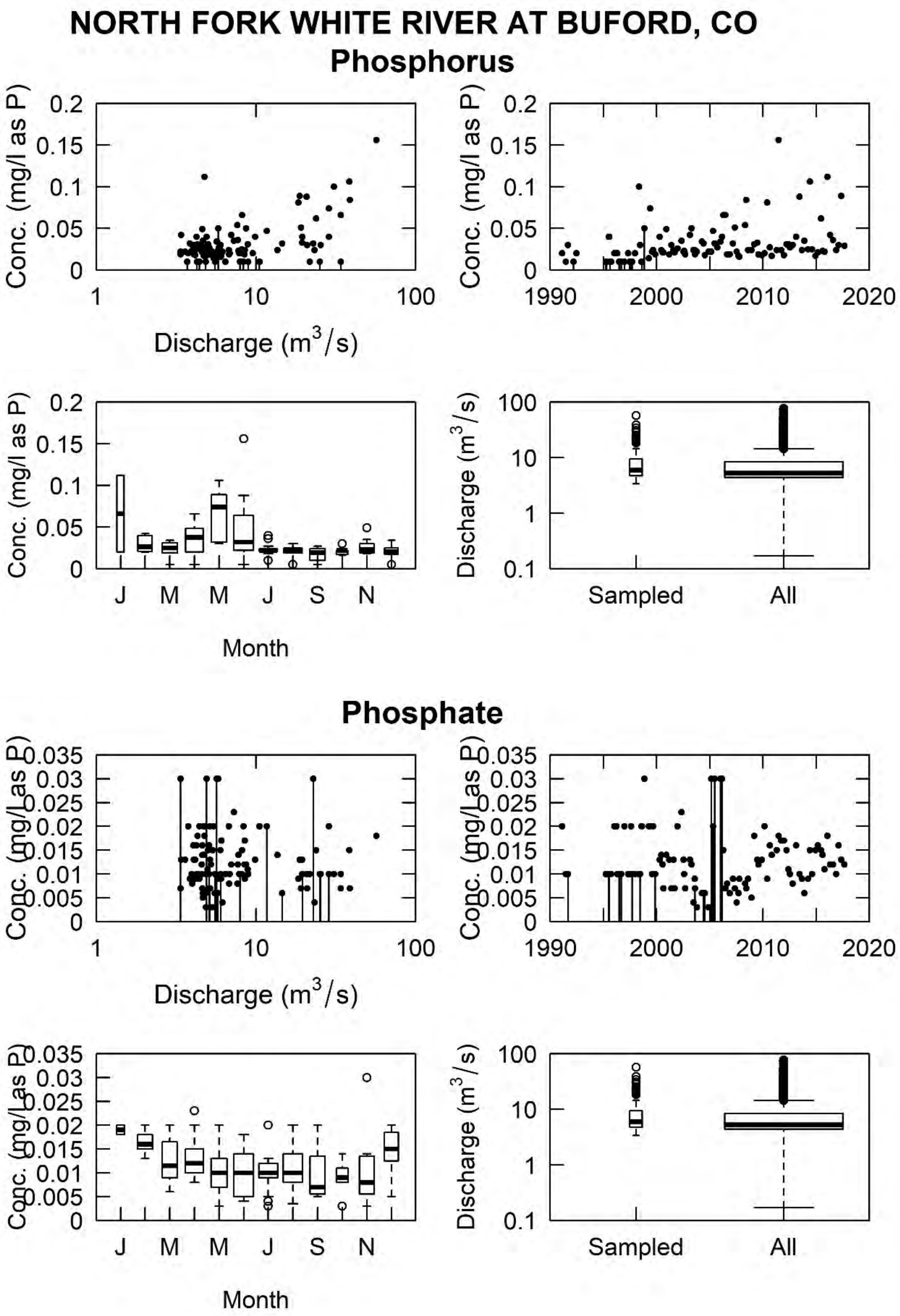
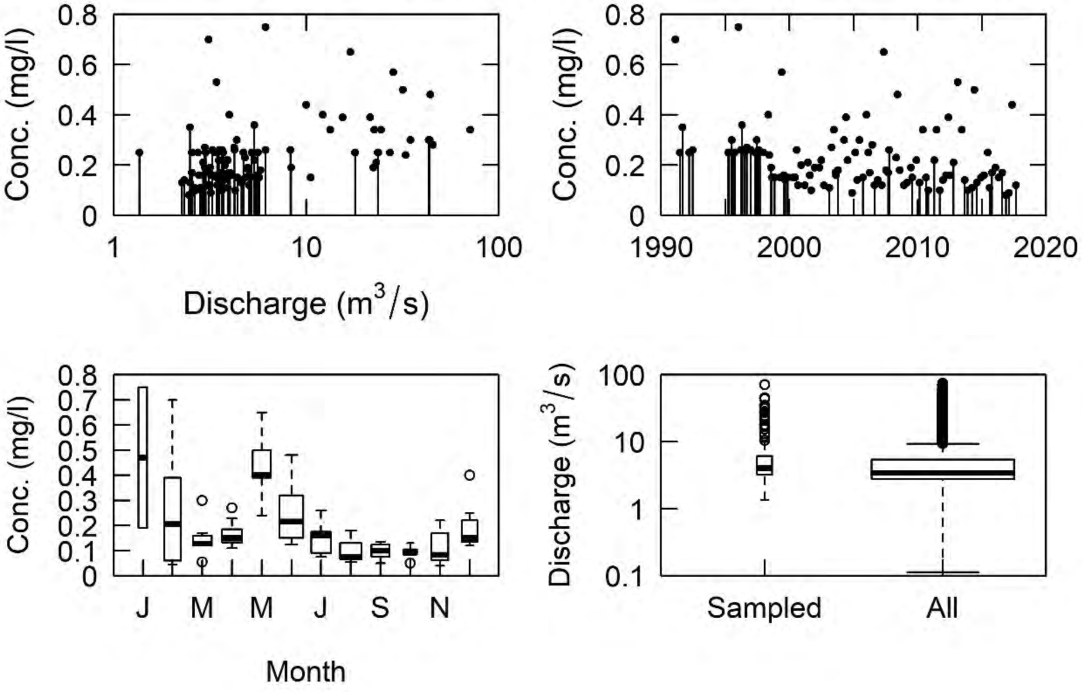


Figure C-5. Summary of phosphorus data for USGS 09303000 North Fork White River at Buford, CO from 1990-current.

SOUTH FORK WHITE RIVER AT BUFORD, CO.

Nitrogen, mixed forms (NH3), (NH4), organic, (NO2) and (NO3)



Inorganic nitrogen (nitrate and nitrite)

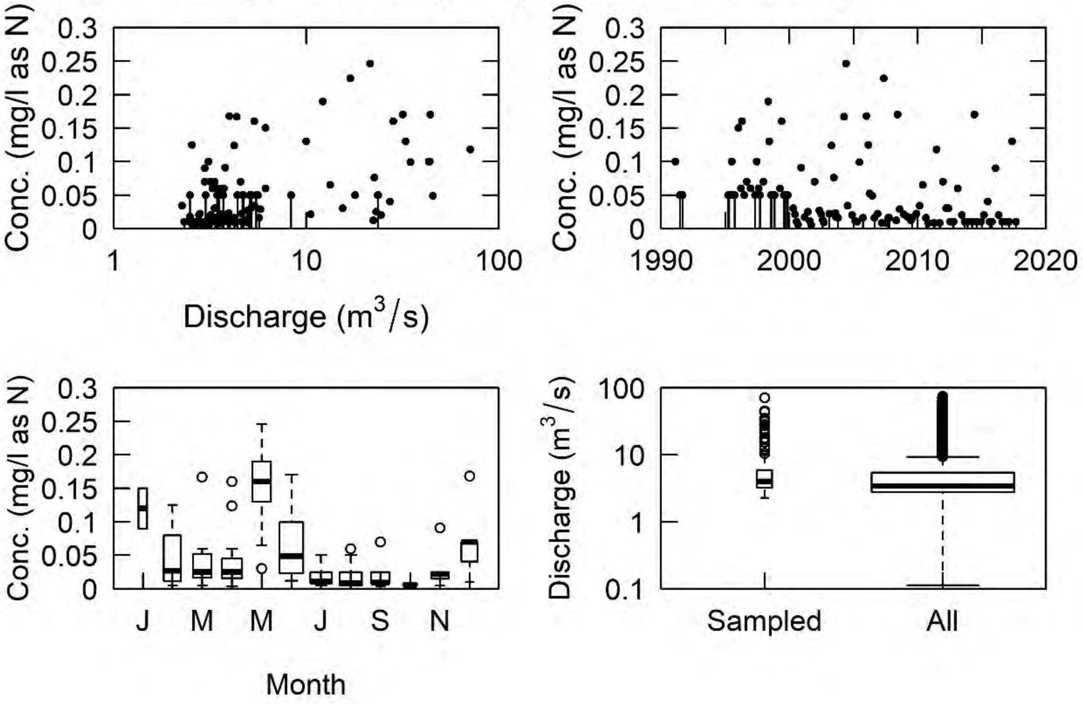


Figure C-6. Summary of nitrogen data for USGS 09304000 South Fork White River at Buford, CO from 1990-current.

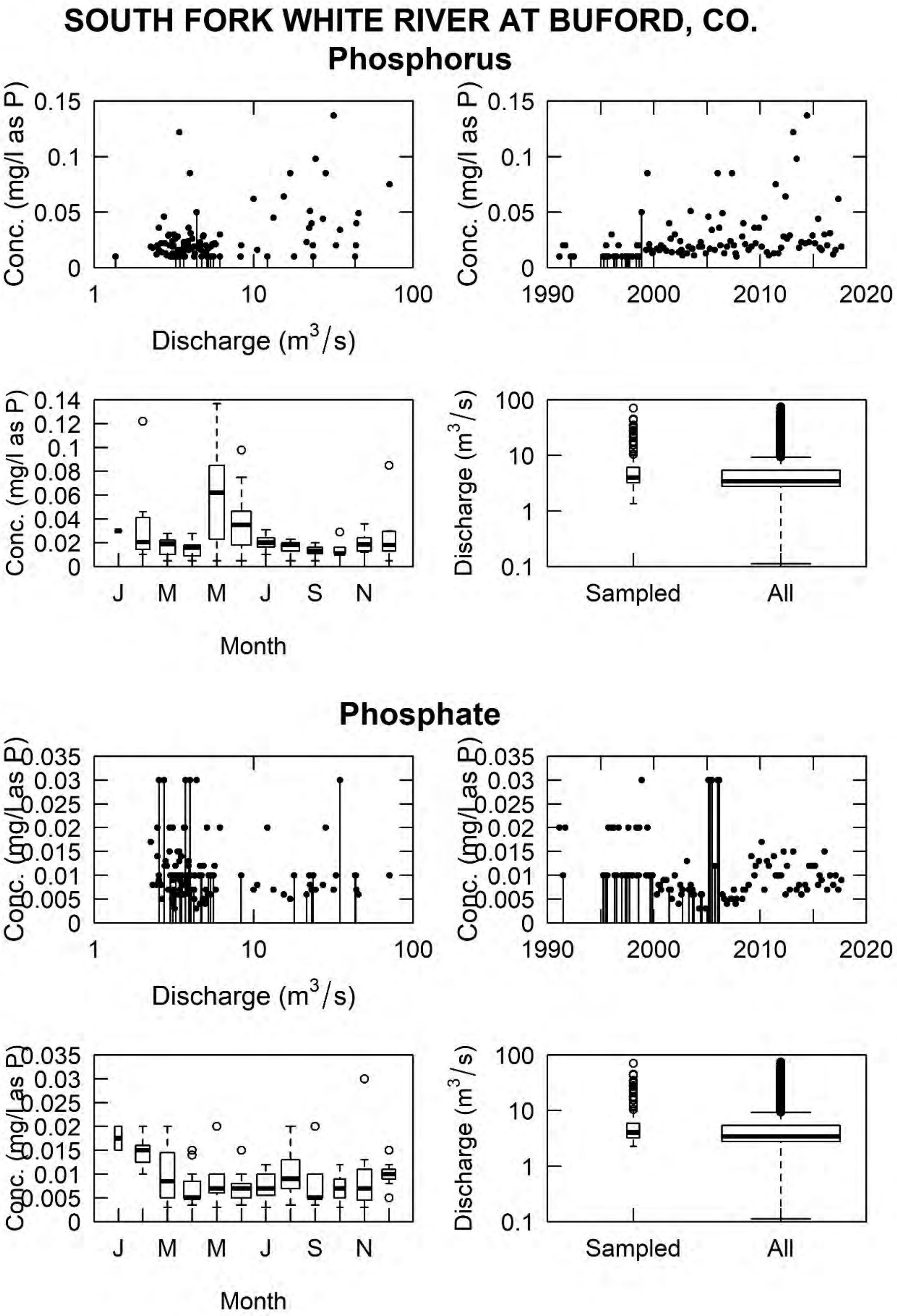
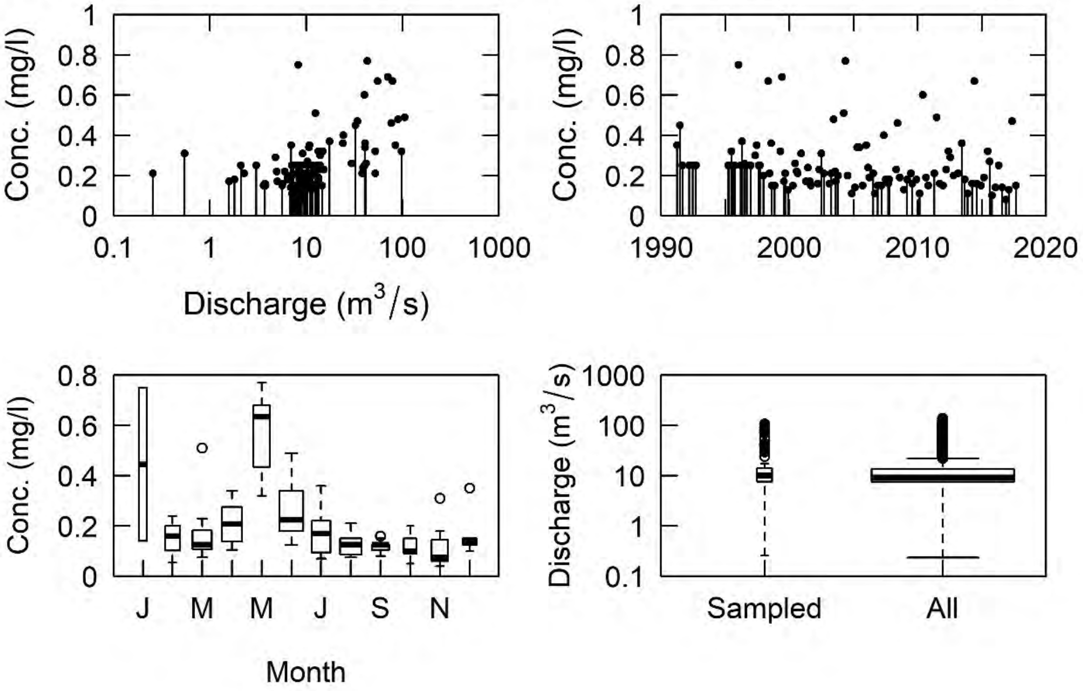


Figure C-7. Summary of phosphorus data for USGS 09304000 South Fork White River at Buford, CO from 1990-current.

WHITE RIVER ABOVE COAL CREEK NEAR MEEKER, CO

Nitrogen, mixed forms (NH3), (NH4), organic, (NO2) and (NO3)



Inorganic nitrogen (nitrate and nitrite)

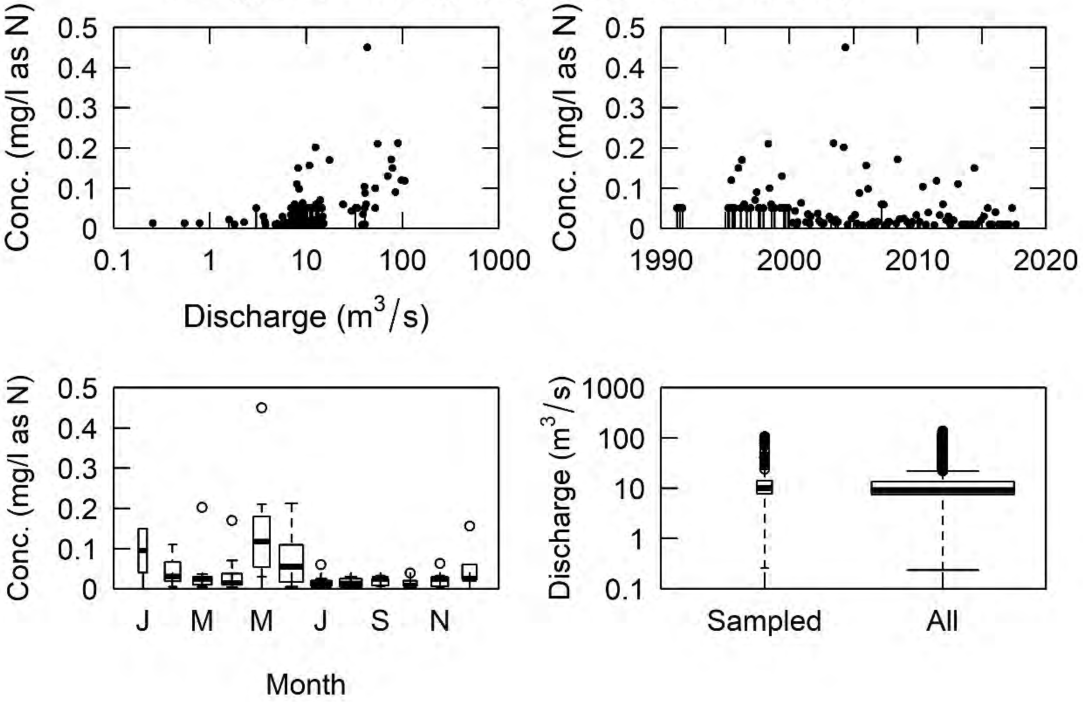


Figure C-8. Summary of nitrogen data for USGS 09304200 White River above Coal Creek at Meeker, CO from 1990-current.

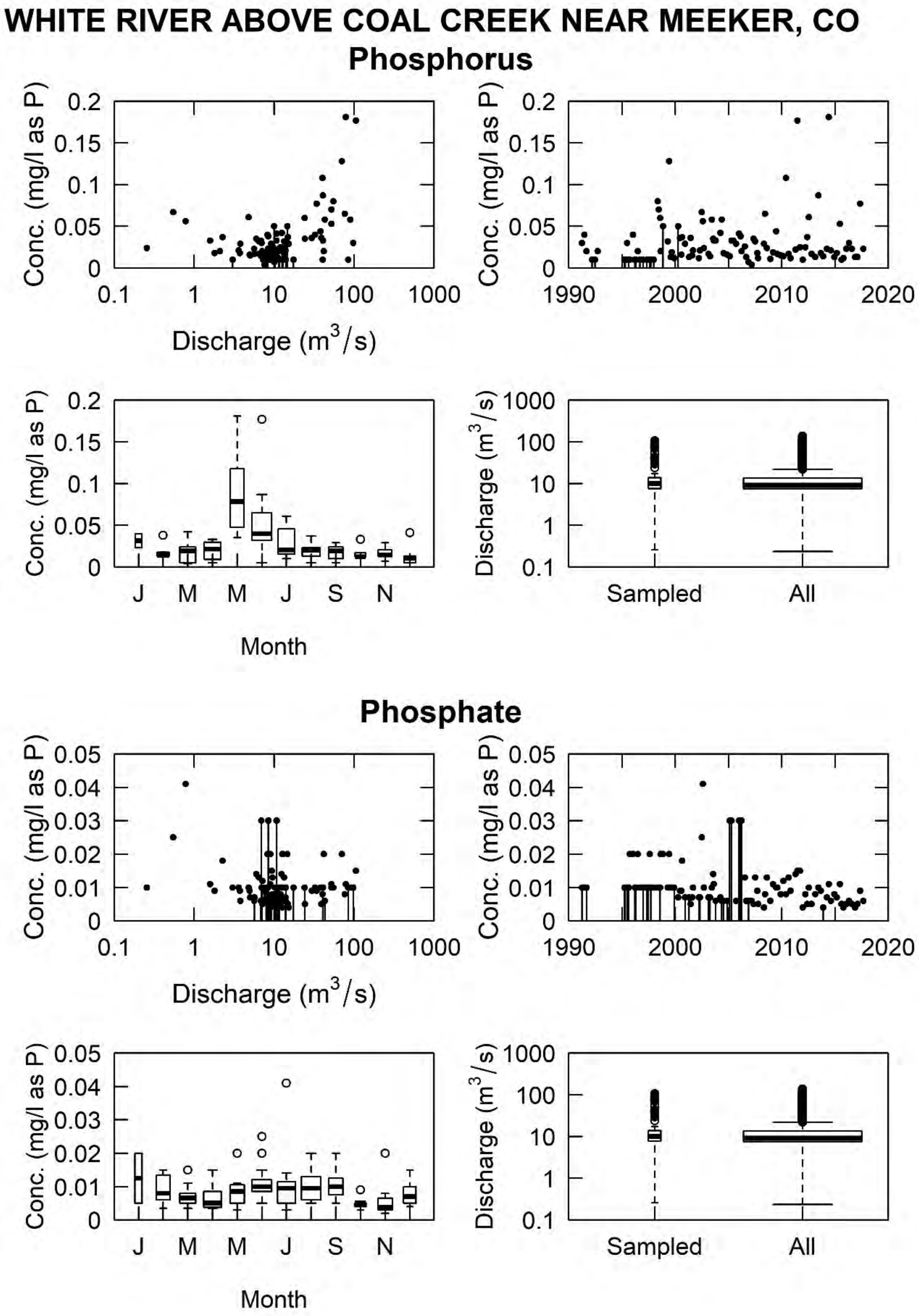


Figure C-9. Summary of phosphorus data for USGS 09304200 White River above Coal Creek at Meeker, CO from 1990-current.

C.3 Data Summary

A graphical summary of the available data at each gage location used in the analysis is shown in **Figure C-4** through **Figure C-9**. The relationship with discharge (top left panel), time (top right panel), concentration by season (bottom left panel), and the range of discharges over which samples were taken are all shown. These are elaborated upon more in the results.

C.4 Results

The WRTDS model of total phosphorus (phosphorus; pCode 00665), dissolved orthophosphate (phosphate; pCode 00671), total nitrogen (nitrogen; pCode 00600), and dissolved nitrogen (nitrate and nitrite; pCode 00631) for USGS 09304200 White River above Coal Creek near Meeker, CO is shown in **Figure C-10** and **Figure C-11** along with daily observed predicted concentrations and loads. A summary of model residuals and 1:1 predicted vs. observed plots are included. Models of the same constituents are also presented for the North Fork (**Figure C-12** and **Figure C-13**) and South Fork of the White River (**Figure C-14** and **Figure C-15**).

Overall, all of the models provide a reasonable fit over the 1991–current period with a load bias statistic ranging from between ±15%. Each model is reliant on a large number of censored observations prior to 1999 (with the exception of total phosphorus), and the orthophosphate model in particular is influenced by high method detection limits. With those caveats in mind, the WRTDS model for total phosphorus indicates an increase in both load and concentration over time whereas the orthophosphate model exhibits a declining trend from 1991–1995 and increasing concentrations thereafter. Some of the same deficiencies noted in the phosphorus model fits are also applicable for nitrogen. Early in the historical record the model is reliant on a notable percentage of censored data. After 1999, censoring is lower, albeit certainly not absent from the dataset.

In considering the fits above, it must be noted that analytical techniques used by the USGS have changed over the analysis period. Such changes are apparent in both the model and data. Over the period of 1973 through September 30, 1991, for phosphorus method I-2600/I-4600 was used (Water Quality Technical Memorandum 92.10, 1992), which changed to I-2610/I-4610 in 1991, and EPA method 365.1 effective January 1, 1999 (Water Quality Technical Memorandum 99.05, 1999). Additionally, the USGS National Water-Quality Laboratory (NWQL) used the minimum reporting level (MRL) for reporting detections prior to 1996, which is the smallest concentration of a substance that can be measured reliably using a given analytical method. In 1996 they began censoring data at the laboratory reporting level (LRL), which is generally is twice the method detection level (MDL). This change can create an artificial upward trend, especially in heavily censored datasets. We see no influence of this effect in the current data and no effort was made to re-censor values to a consistent threshold prior to analysis as a consequence.

Finally, one thing to keep in mind in appraisal of flow normalized results is that if the probability distribution of discharge for a given day of the year has changed over the period of record, the flow normalization approach may not be appropriate. Examples of such changes would include: construction of a large dam upstream of the monitoring location, or a substantial change in climate or the consumptive use of water.

WHITE RIVER ABOVE COAL CREEK NEAR MEEKER, CO

Phosphorus

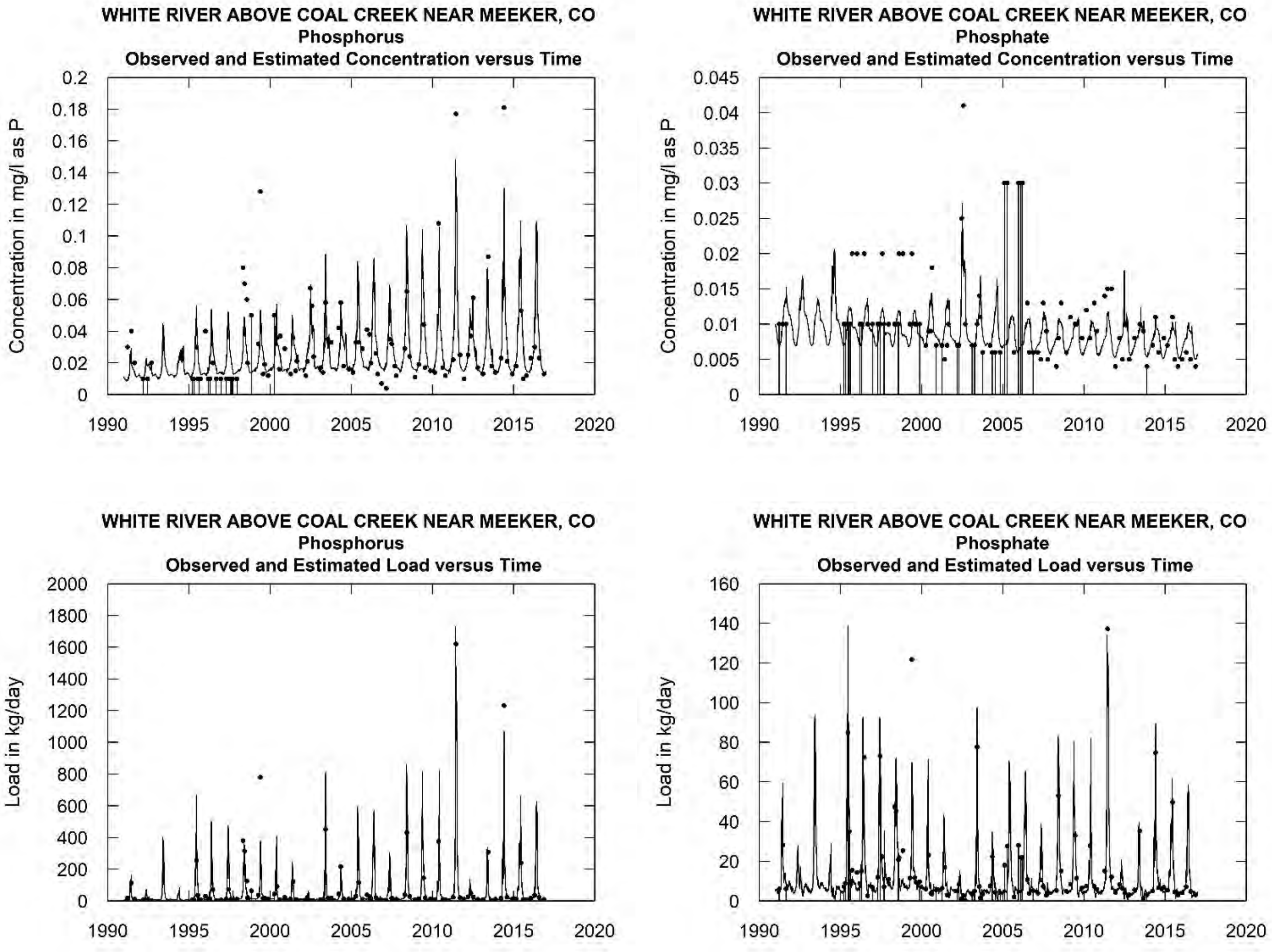
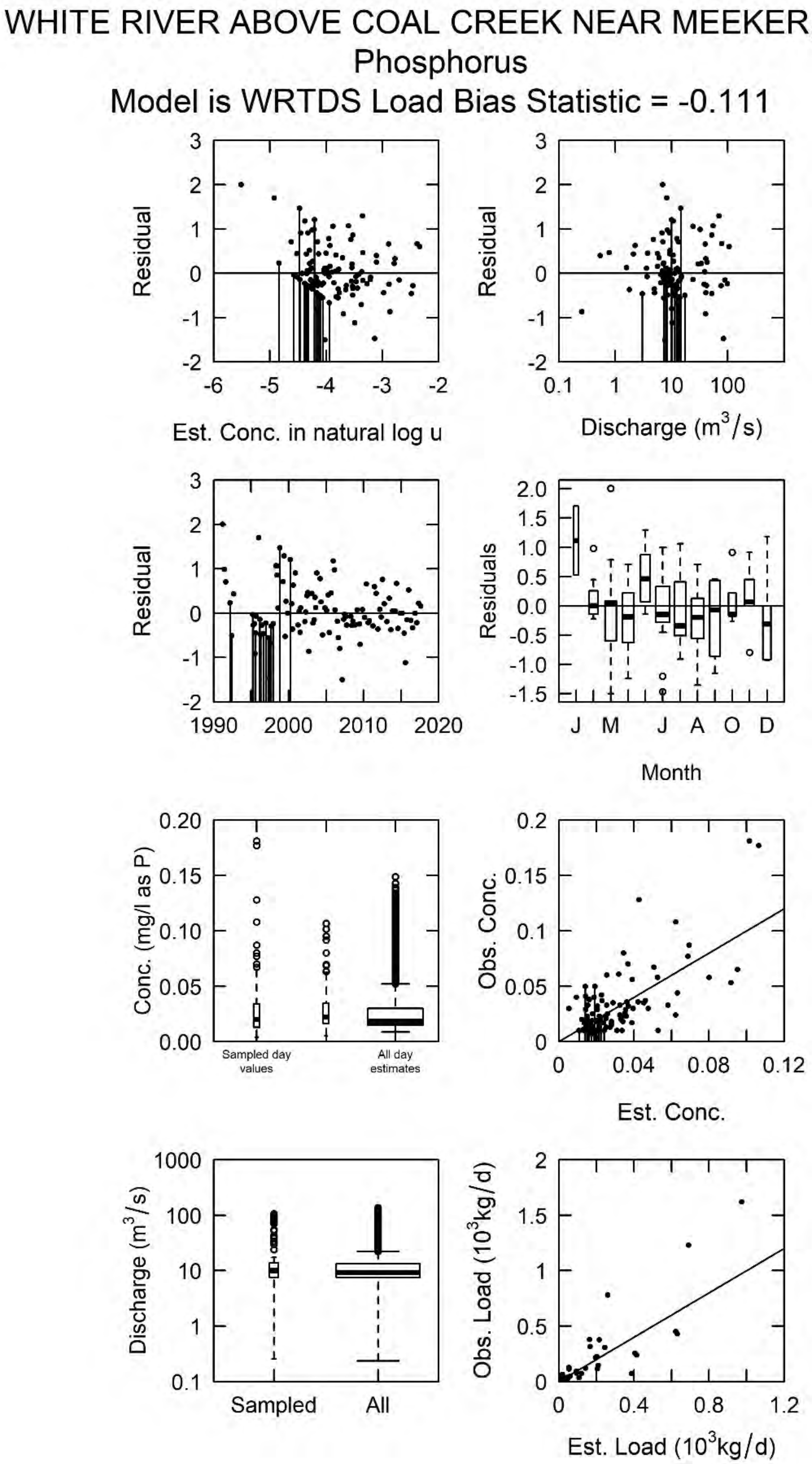


Figure C-10a. WRTDS model fits for phosphorus (00665) and phosphate (00671) at USGS 09304200 White River above Coal Creek. (lines) WRTDS daily model estimates. (circles) Instantaneous observed concentrations or loads. Vertical lines are censored data points. The pre-2000 data is called to attention by the authors and is discussed in the text.



WHITE RIVER ABOVE COAL CREEK NEAR MEEKER, CO
Phosphorus
Model is WRTDS Load Bias Statistic = -0.111

Figure C-10b. **WRTDS residuals and bias statistics for phosphorus (00665) at USGS 09304200 White River above Coal Creek.**

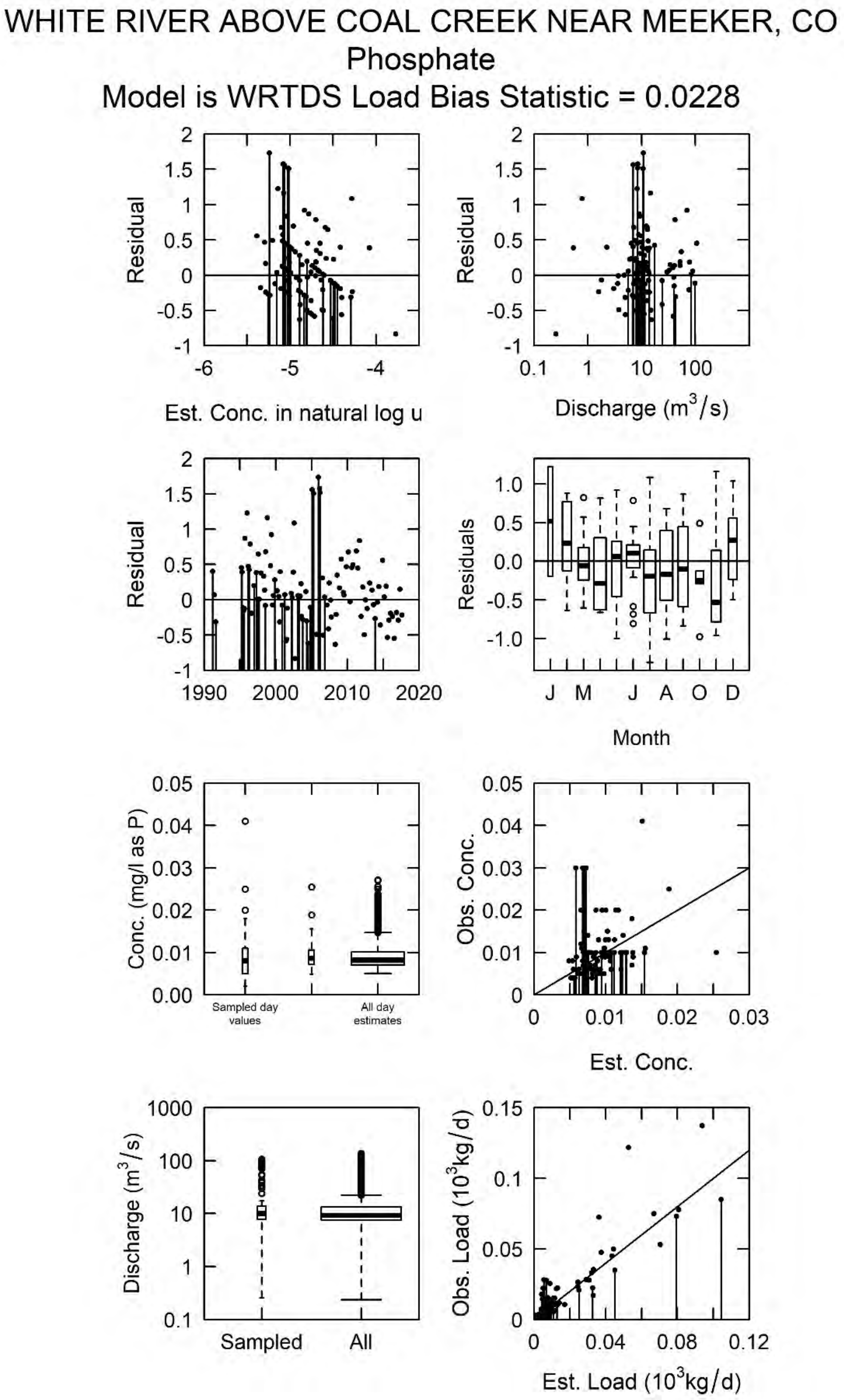


Figure C-10c. WRTDS residuals and bias statistics for phosphate (00671) at USGS 09304200 White River above Coal Creek.

WHITE RIVER ABOVE COAL CREEK NEAR MEEKER, CO
Phosphorus

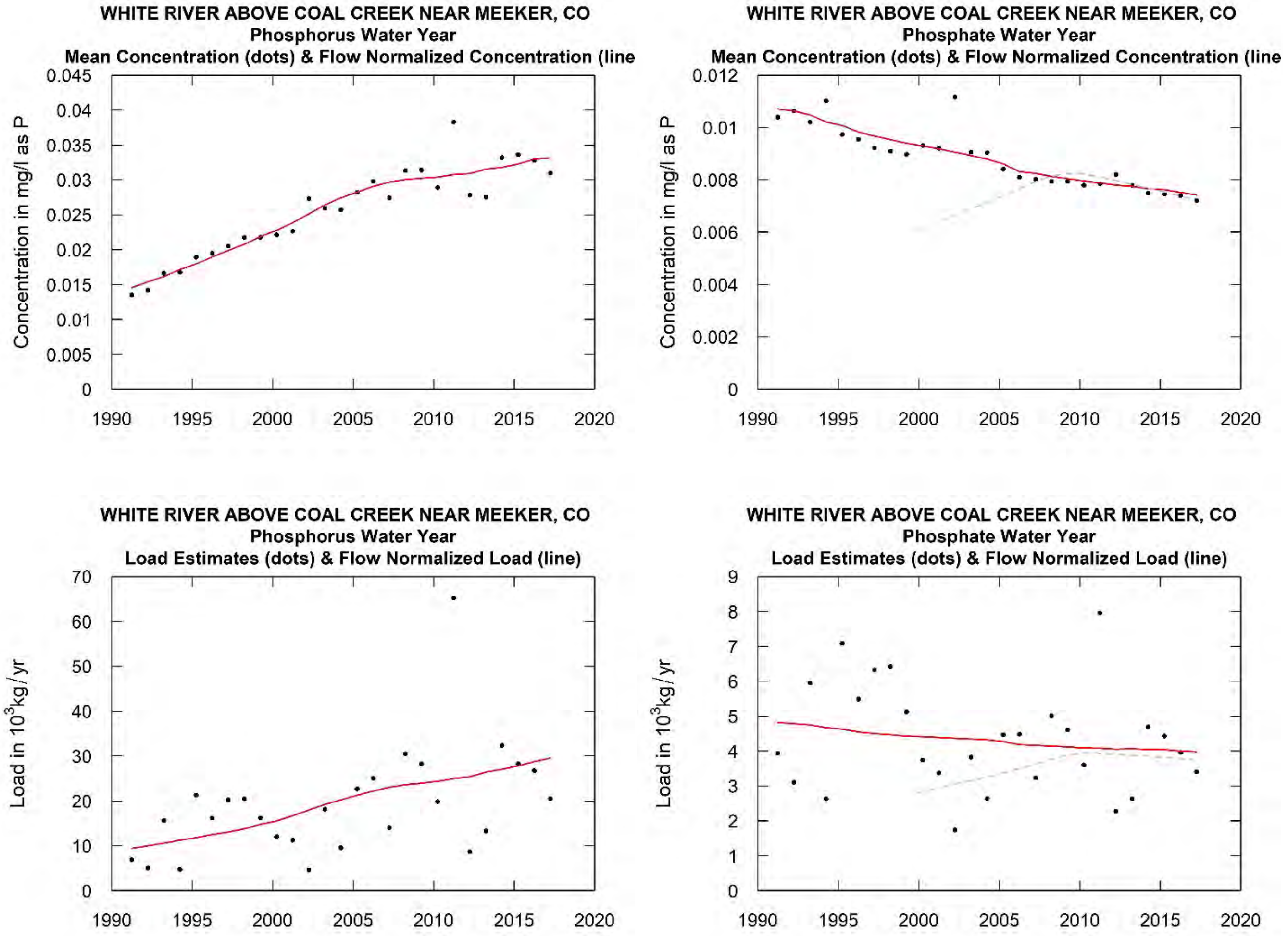


Figure C-10d. WRTDS annual estimated concentrations and loads (black dots) and flow normalized concentrations and loads (red lines) for phosphorus (00665) and phosphate (00671) at USGS 09304200 White River above Coal Creek. The grey dashed lines for phosphate show the WRTDS flow normalized estimate for the period of 1999–current, removing the influence of pre-2000 data.

WHITE RIVER ABOVE COAL CREEK NEAR MEEKER, CO
Nitrogen

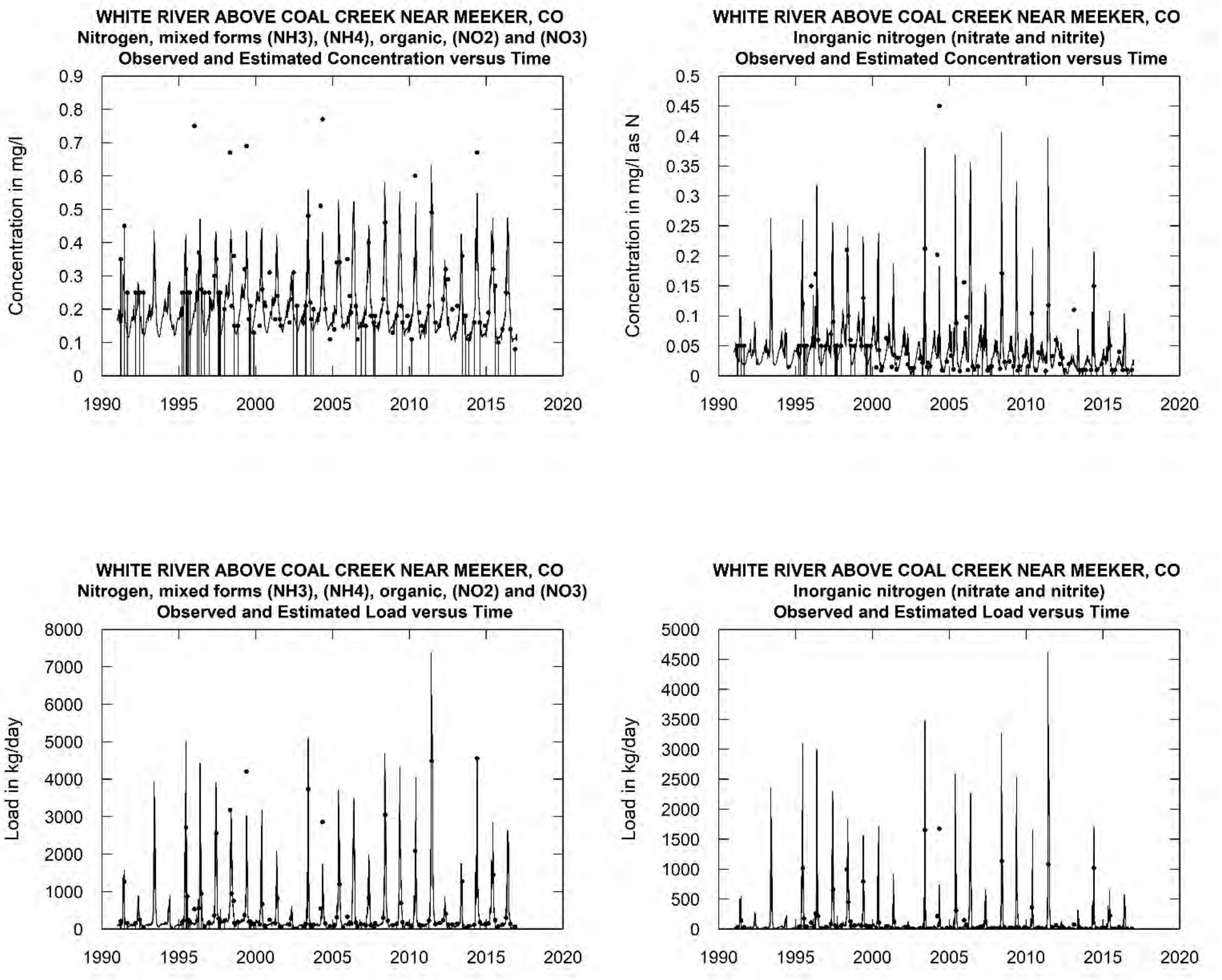


Figure C-11a. WRTDS model fits for total nitrogen (00600) and nitrate plus nitrite (00631) at USGS 09304200 White River above Coal Creek. (lines) WRTDS daily model estimates. (circles) Instantaneous observed concentrations or loads.

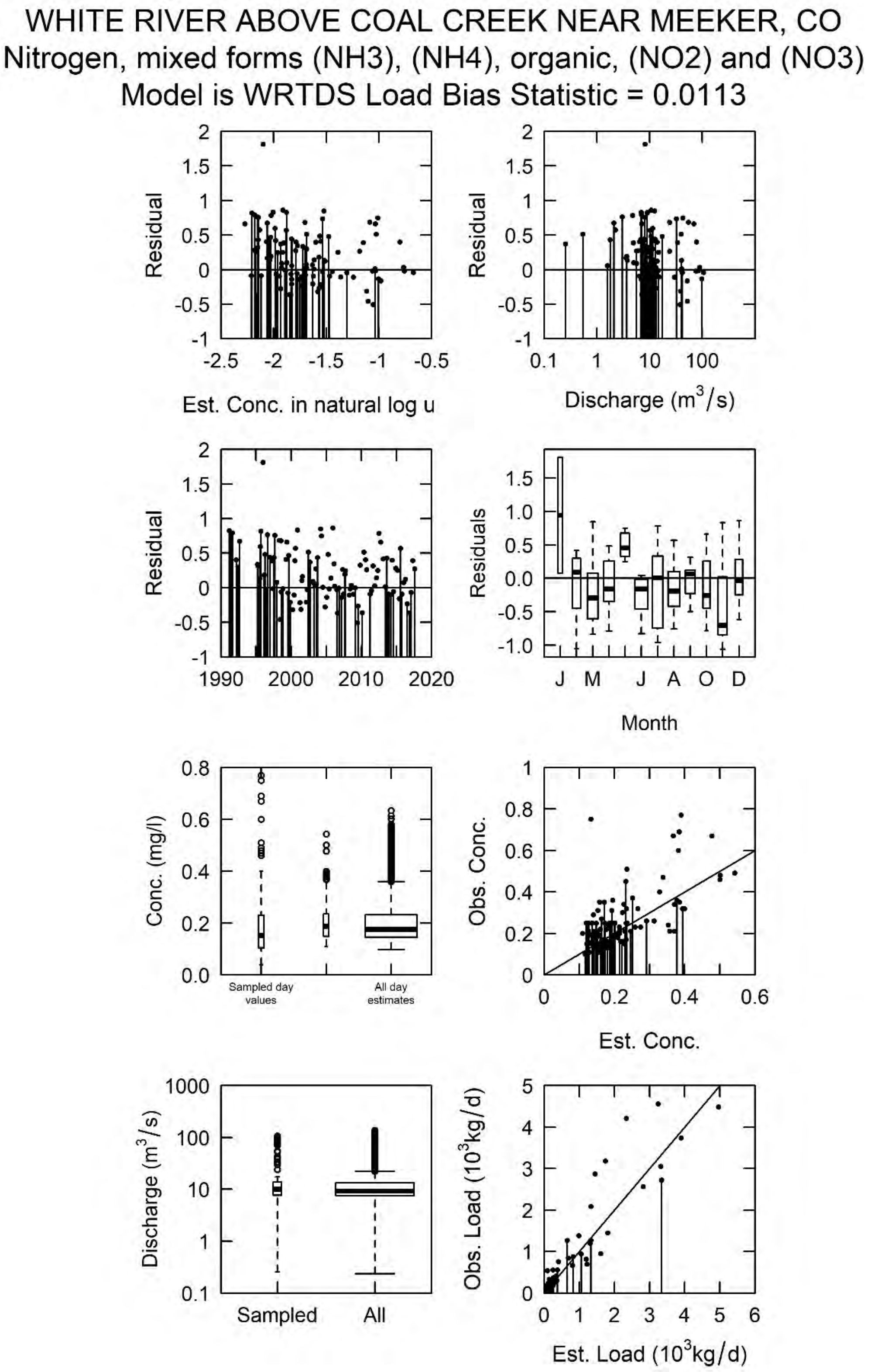


Figure C-11b. **WRTDS residuals and bias statistics for total nitrogen (00600) at USGS 09304200 White River above Coal Creek.**

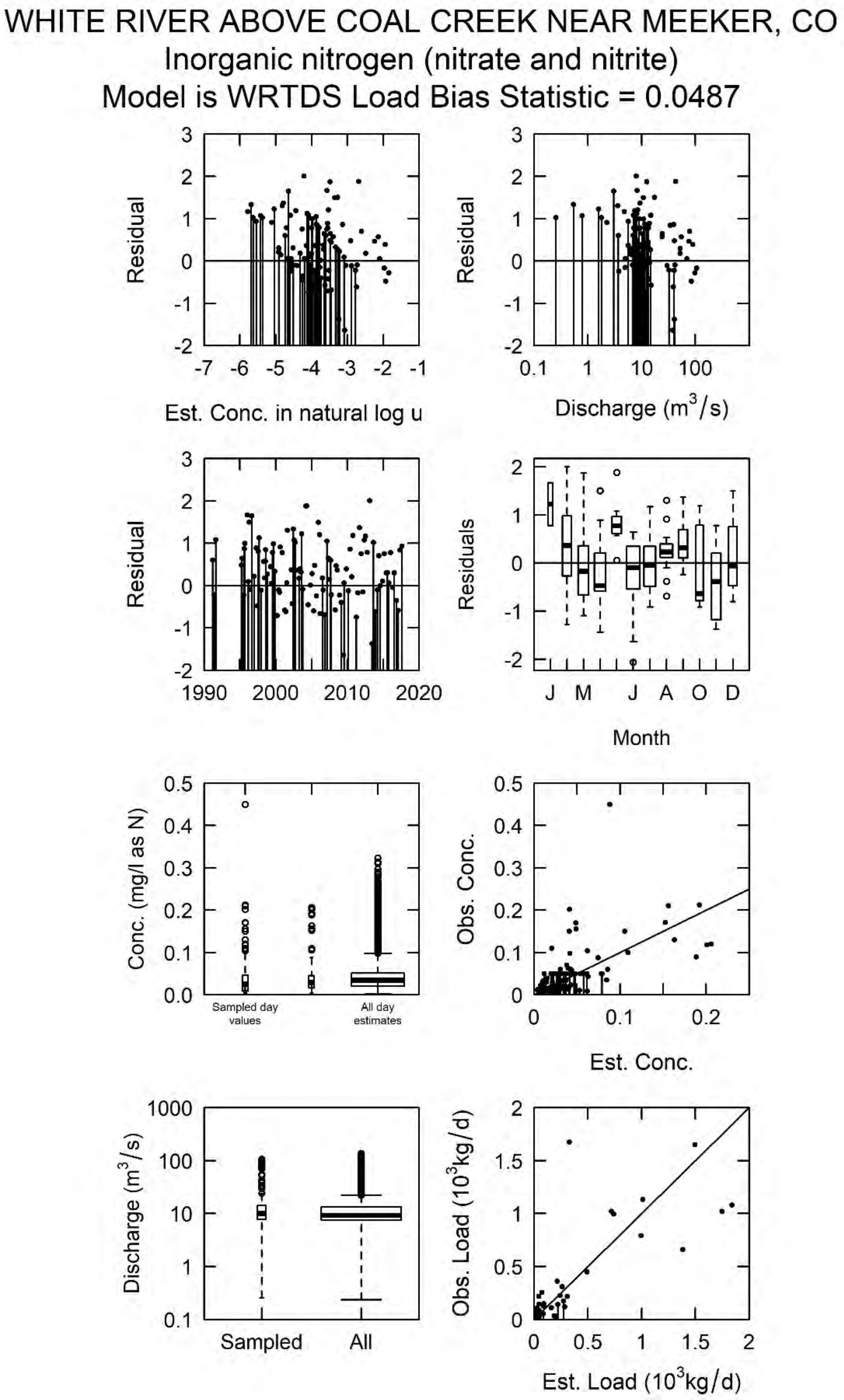
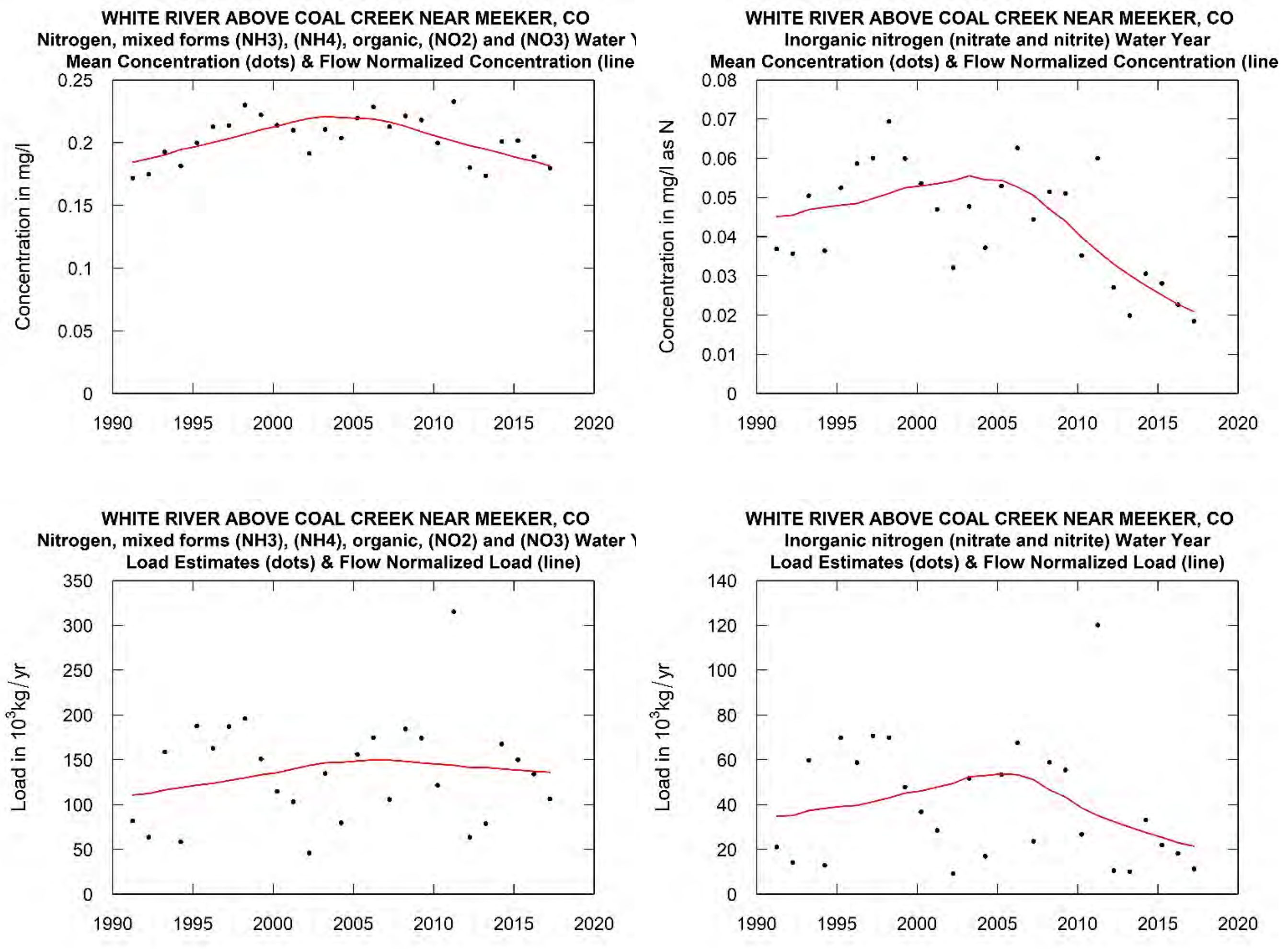


Figure C-11c. **WRTDS residuals and bias statistics for nitrate plus nitrite (00631) at USGS 09304200 White River above Coal Creek.**

WHITE RIVER ABOVE COAL CREEK NEAR MEEKER, CO
Nitrogen



WHITE RIVER ABOVE COAL CREEK NEAR MEEKER, CO
Nitrogen, mixed forms (NH3), (NH4), organic, (NO2) and (NO3) Water
Mean Concentration (dots) & Flow Normalized Concentration (line

WHITE RIVER ABOVE COAL CREEK NEAR MEEKER, CO
Inorganic nitrogen (nitrate and nitrite) Water Year
Mean Concentration (dots) & Flow Normalized Concentration (line

WHITE RIVER ABOVE COAL CREEK NEAR MEEKER, CO
Nitrogen, mixed forms (NH3), (NH4), organic, (NO2) and (NO3) Water
Load Estimates (dots) & Flow Normalized Load (line)

WHITE RIVER ABOVE COAL CREEK NEAR MEEKER, CO
Inorganic nitrogen (nitrate and nitrite) Water Year
Load Estimates (dots) & Flow Normalized Load (line)

Figure C-11d. **WRTDS annual estimated concentrations and loads (black dots) and flow normalized concentrations and loads (red lines) for total nitrogen (00600) and nitrate plus nitrite (00631) at USGS 09304200 White River above Coal Creek.**

NORTH FORK WHITE RIVER AT BUFORD, CO
Phosphorus

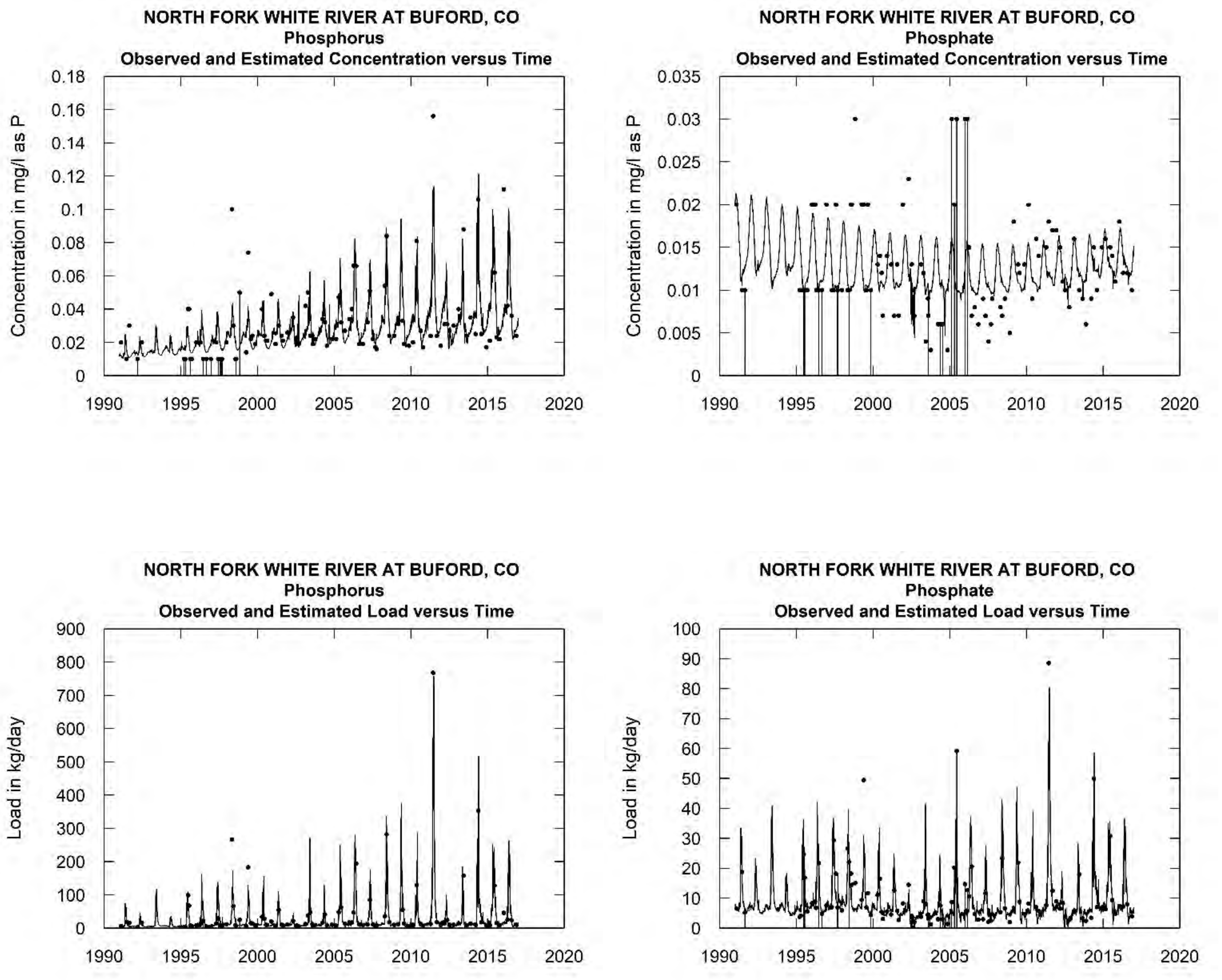


Figure C-12a. **WRTDS model fits for phosphorus (00665) and phosphate (00671) at USGS 09303000 North Fork White River at Buford, CO. (lines) WRTDS daily model estimates. (circles) Instantaneous observed concentrations or loads. Vertical lines are censored data points. The pre-2000 data is called to attention by the authors and is discussed in the text.**

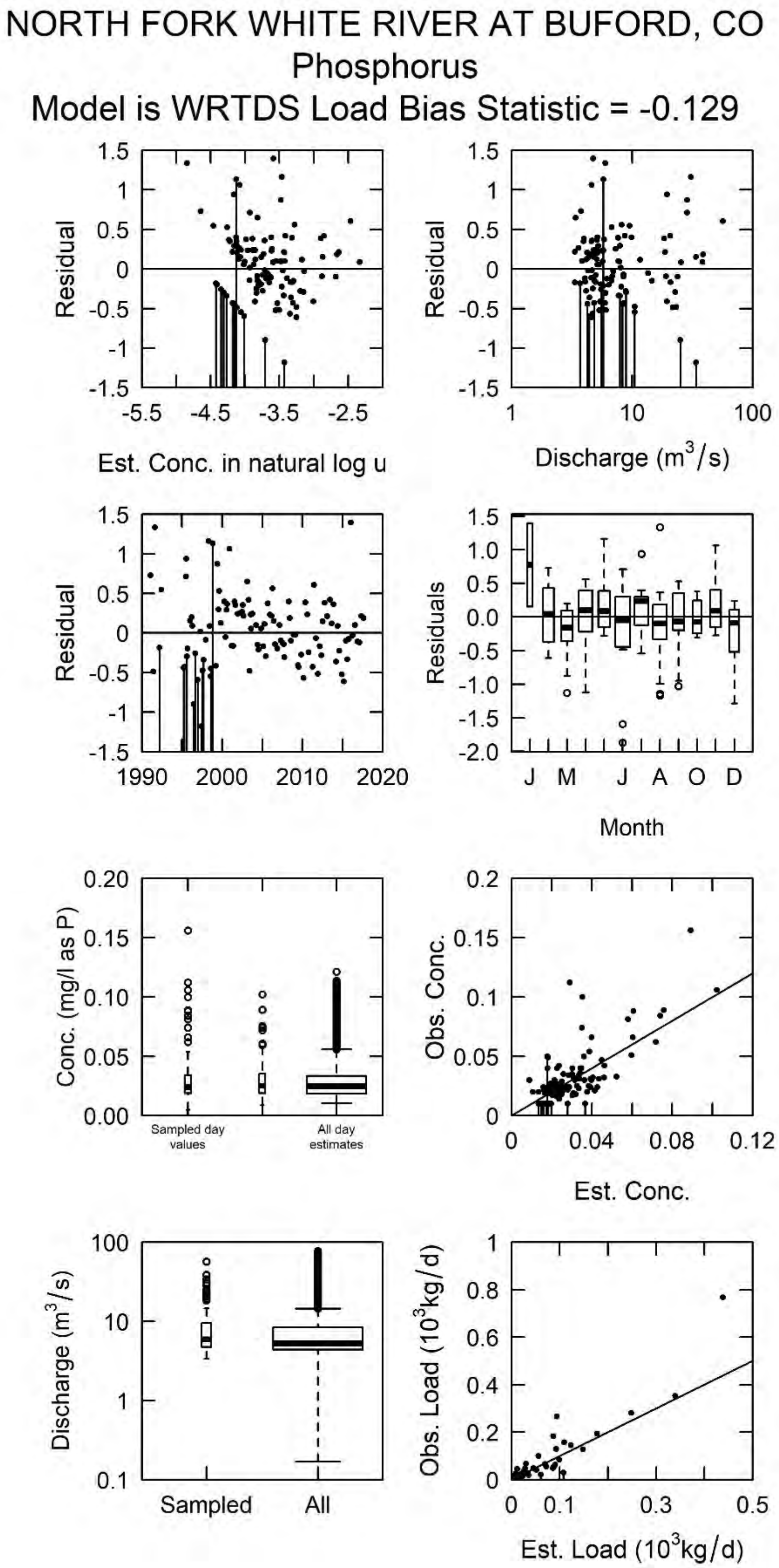


Figure C-12b. **WRTDS residuals and bias statistics for phosphorus (00665) at USGS 09303000 North Fork White River.**

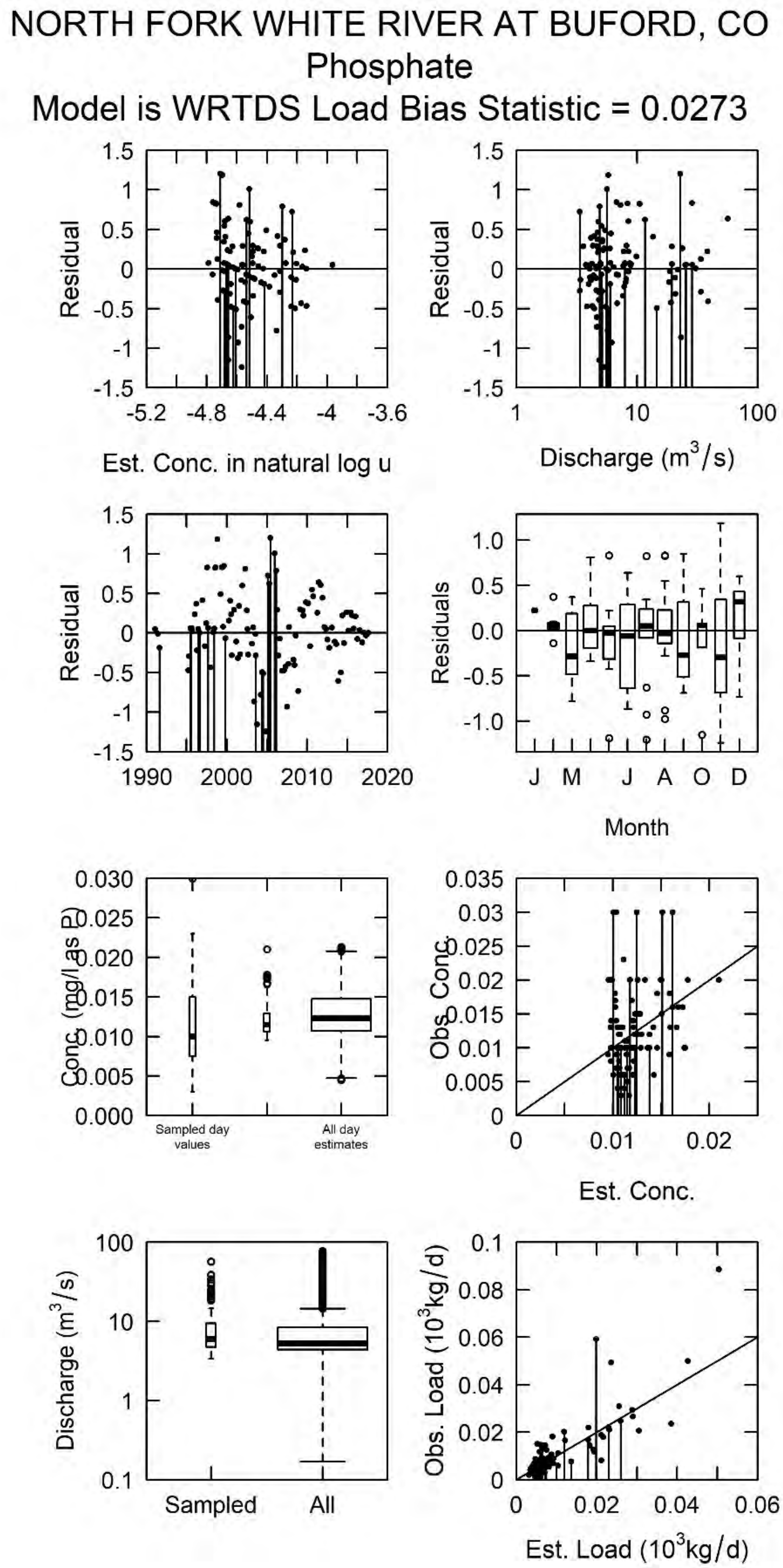
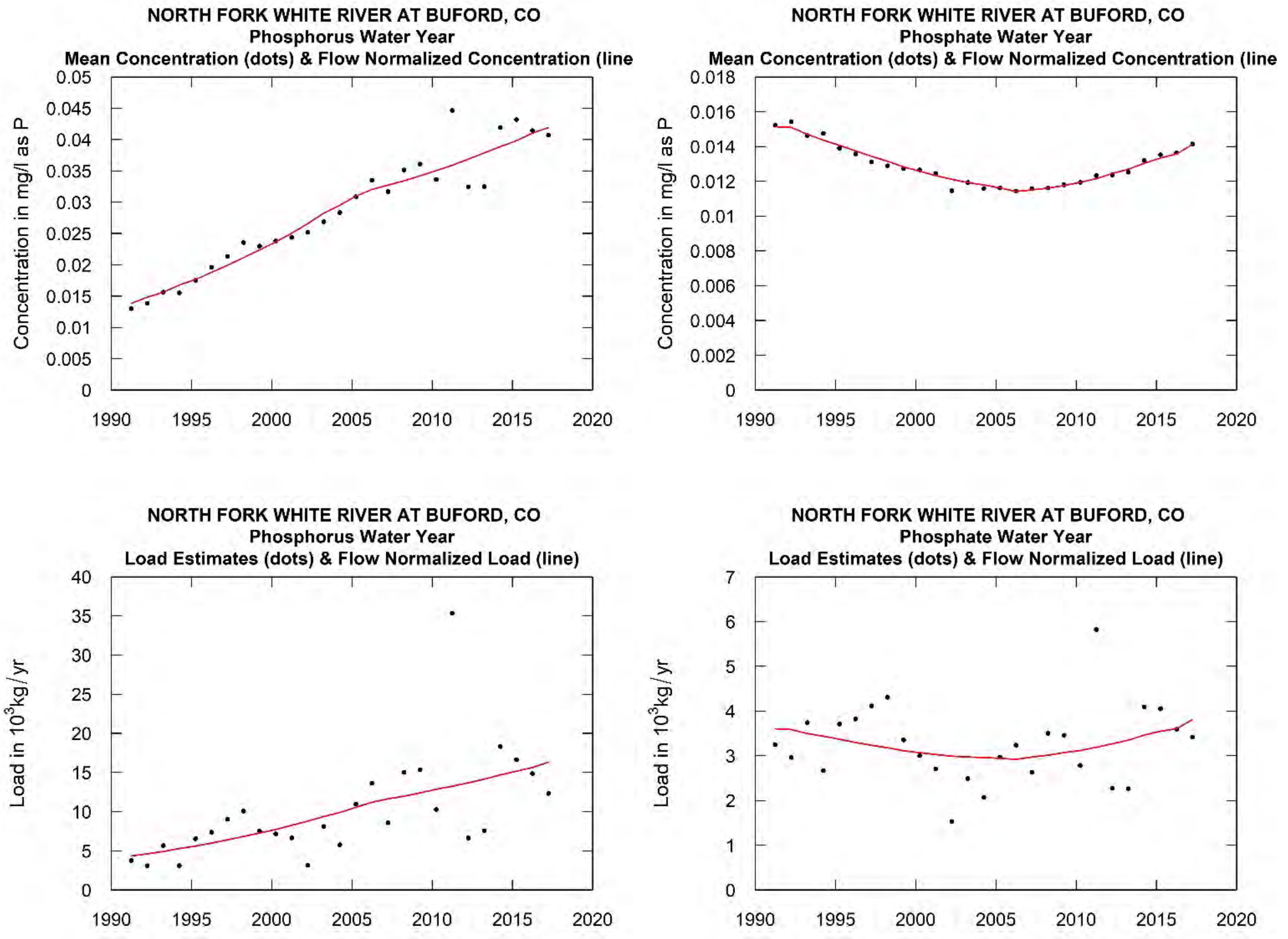


Figure C-12c. **WRTDS residuals and bias statistics for phosphate (00671) at USGS 09303000 North Fork White River.**

NORTH FORK WHITE RIVER AT BUFORD, CO
Phosphorus


NORTH FORK WHITE RIVER AT BUFORD, CO
Phosphorus Water Year
Mean Concentration (dots) & Flow Normalized Concentration (line

NORTH FORK WHITE RIVER AT BUFORD, CO
Phosphate Water Year
Mean Concentration (dots) & Flow Normalized Concentration (line

NORTH FORK WHITE RIVER AT BUFORD, CO
Phosphorus Water Year
Load Estimates (dots) & Flow Normalized Load (line)

NORTH FORK WHITE RIVER AT BUFORD, CO
Phosphate Water Year
Load Estimates (dots) & Flow Normalized Load (line)

Figure C-12d. **WRTDS annual estimated concentrations and loads (black dots) and flow normalized concentrations and loads (red lines) for total nitrogen (00600) and nitrate plus nitrite (00631) at USGS 09304200 White River above Coal Creek.**

NORTH FORK WHITE RIVER AT BUFORD, CO
Nitrogen

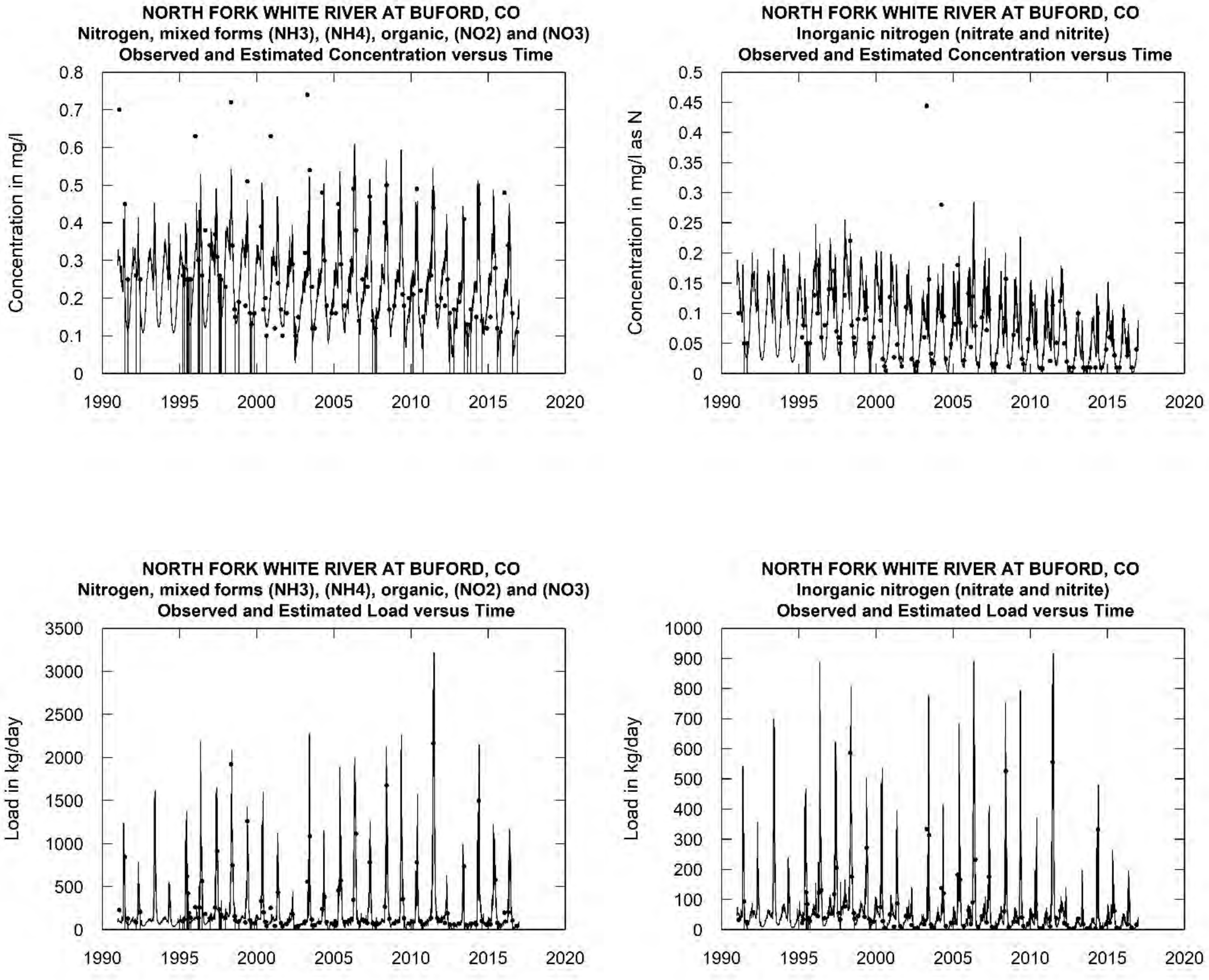
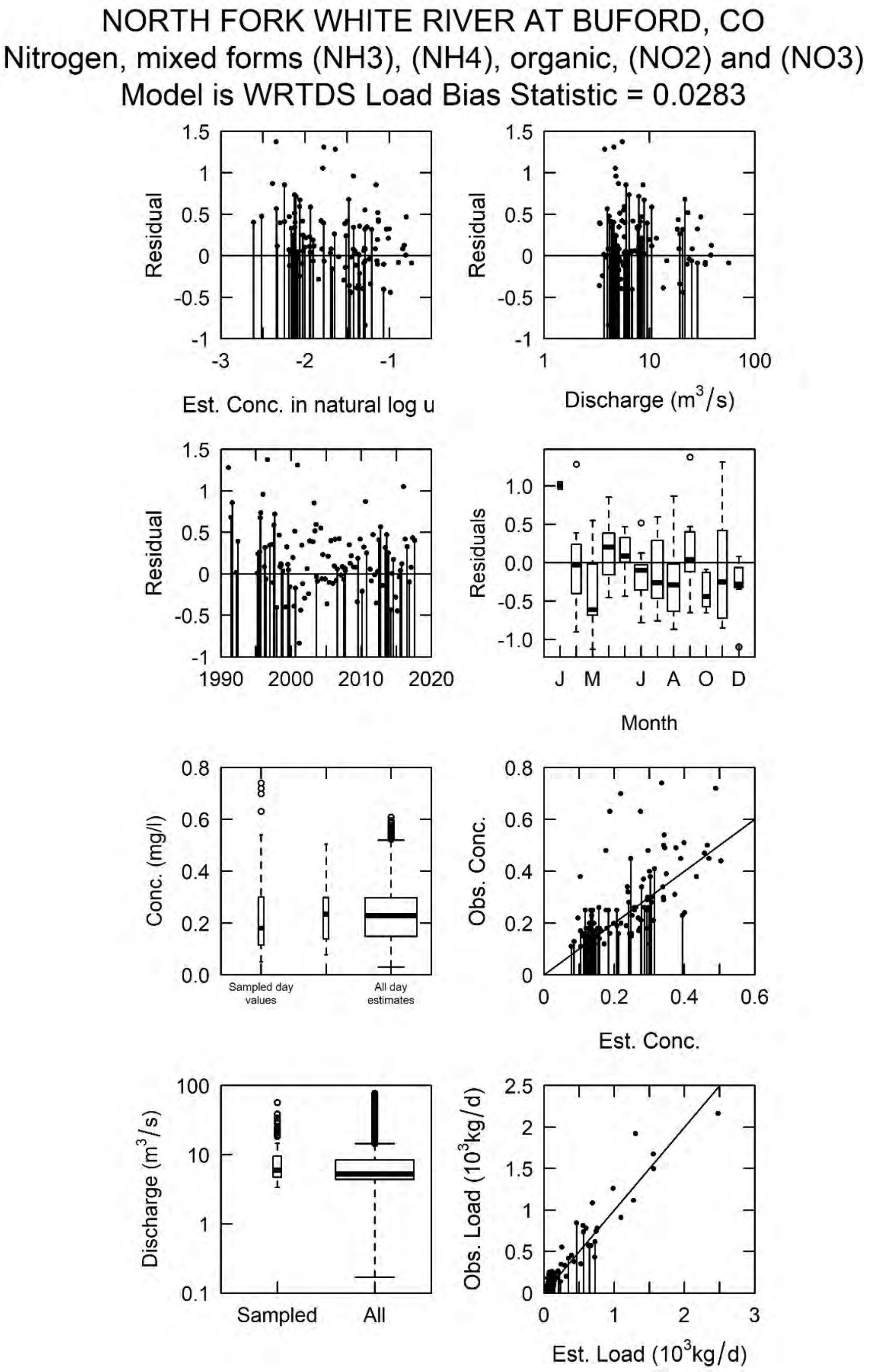


Figure C-13a. WRTDS model fits for total nitrogen (00600) and nitrate plus nitrite (00631) at USGS 09303000 North Fork White River. (lines) WRTDS daily model estimates. (circles) Instantaneous observed concentrations or loads.



NORTH FORK WHITE RIVER AT BUFORD, CO
Nitrogen, mixed forms (NH3), (NH4), organic, (NO2) and (NO3)
Model is WRTDS Load Bias Statistic = 0.0283

Figure C-13. **WRTDS residuals and bias statistics for total nitrogen (00600) at USGS 09303000 North Fork White River.**

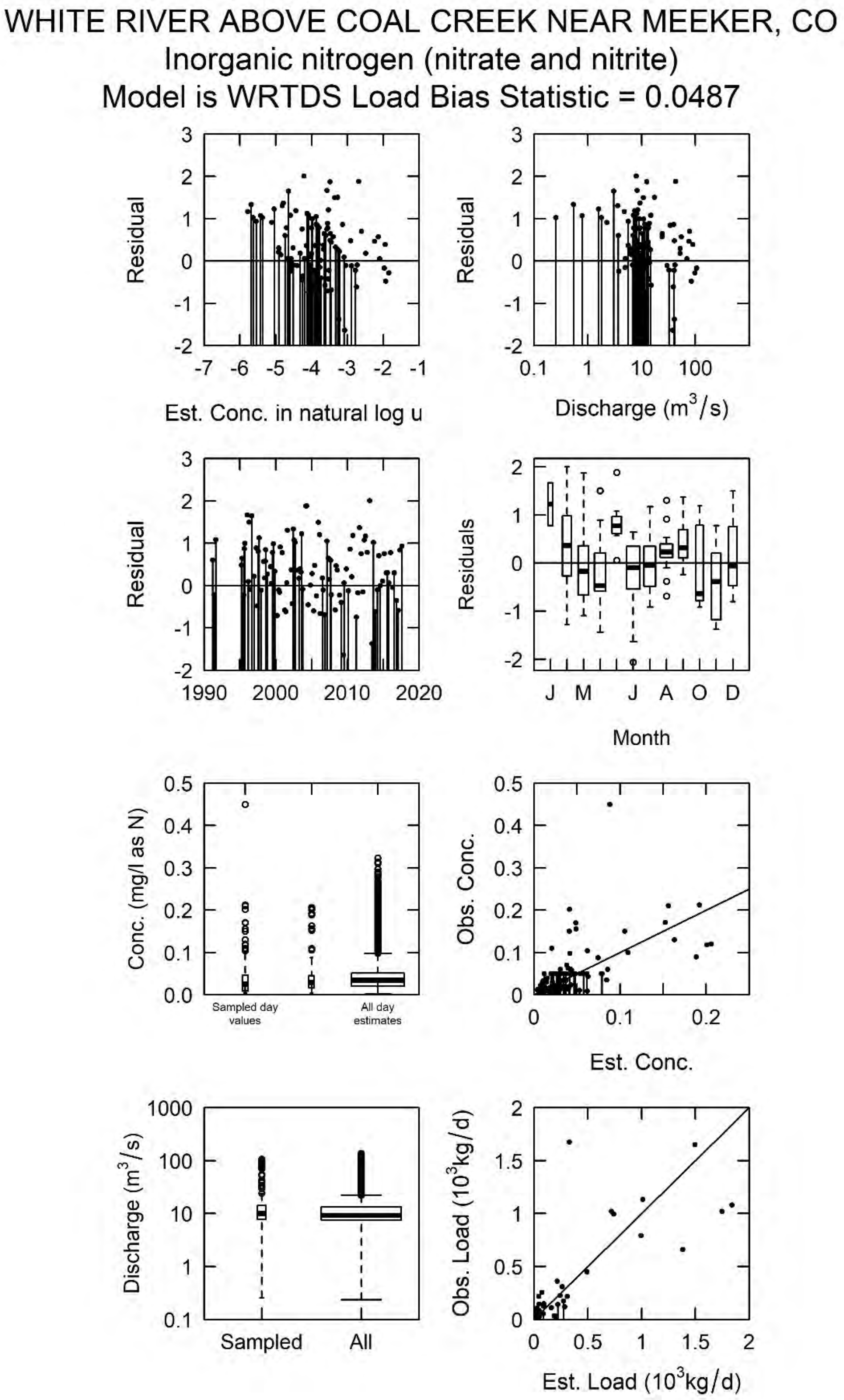


Figure C-13c. WRTDS residuals and bias statistics for nitrate plus nitrite (00631) at USGS 09303000 North Fork White River.

NORTH FORK WHITE RIVER AT BUFORD, CO
Nitrogen

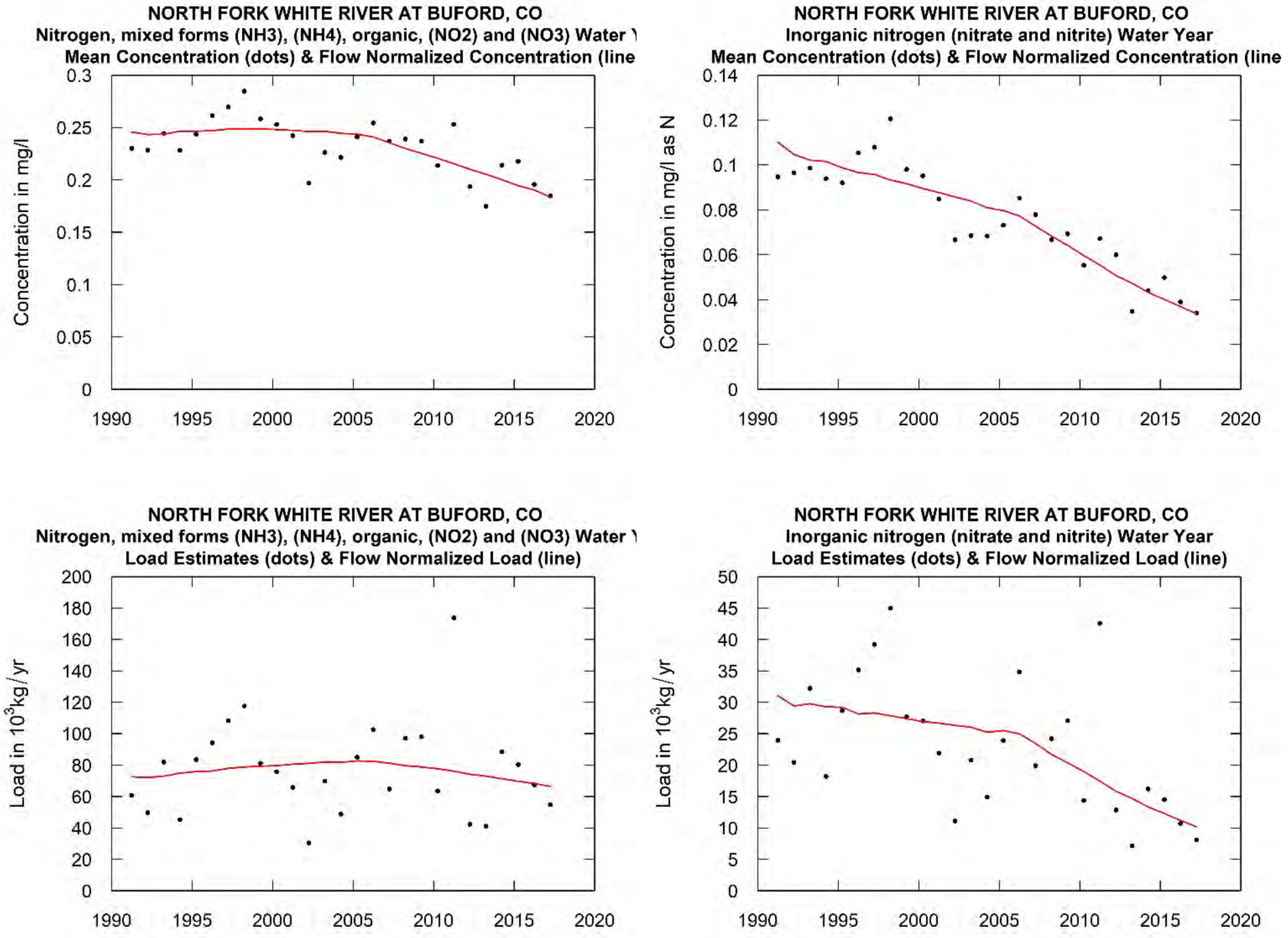


Figure C-13d. **WRTDS annual estimated concentrations and loads (black dots) and flow normalized concentrations and loads (red lines) for total nitrogen (00600) and nitrate plus nitrite (00631) at USGS 09303000 North Fork White River.**

SOUTH FORK WHITE RIVER AT BUFORD, CO
Phosphorus

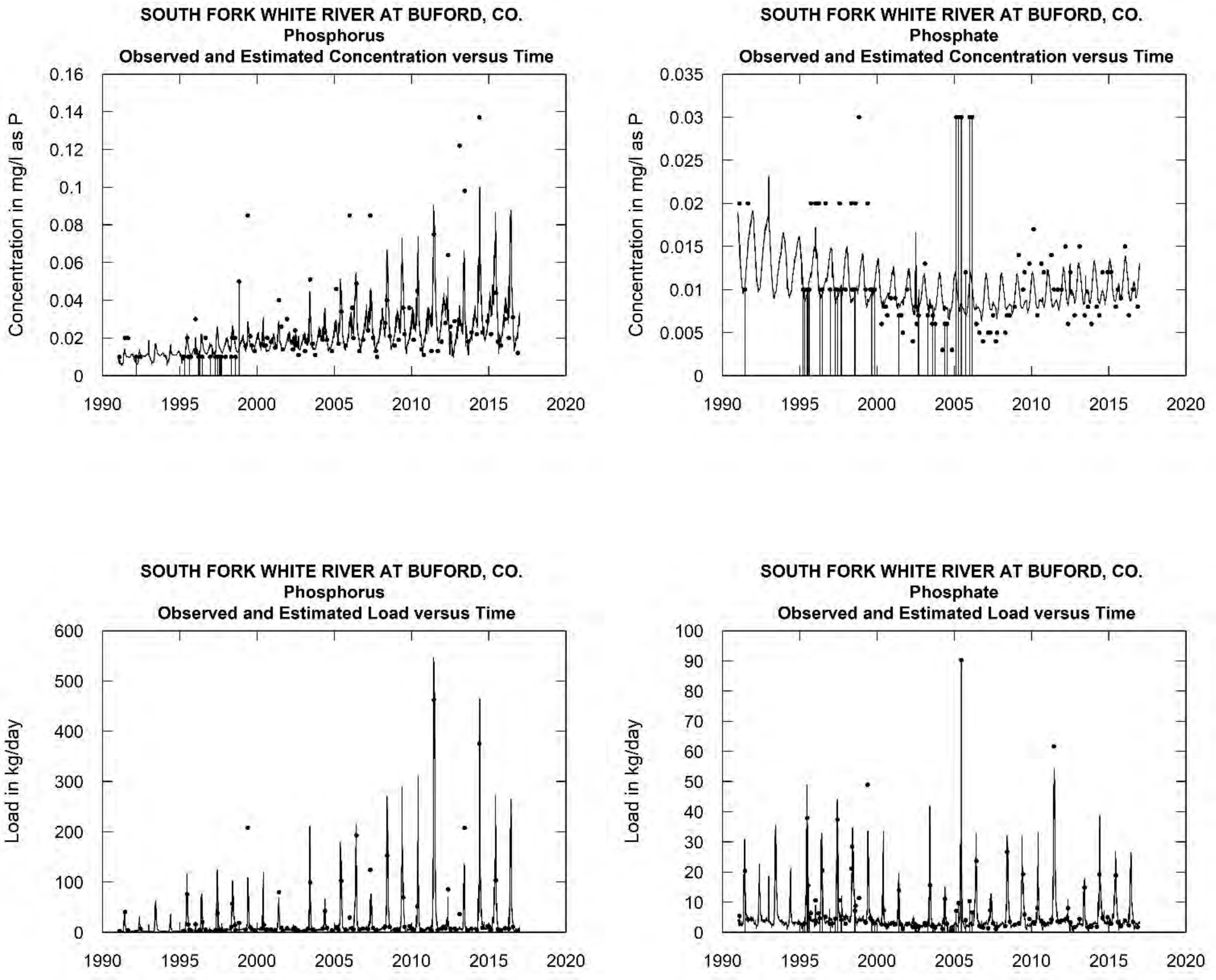


Figure C-14a. **WRTDS model fits for phosphorus (00665) and phosphate (00671) at USGS 09304000 South Fork White River at Buford, CO. (lines) WRTDS daily model estimates. (circles) Instantaneous observed concentrations or loads. Vertical lines are censored data points. The pre-2000 data is called to attention by the authors and is discussed in the text.**

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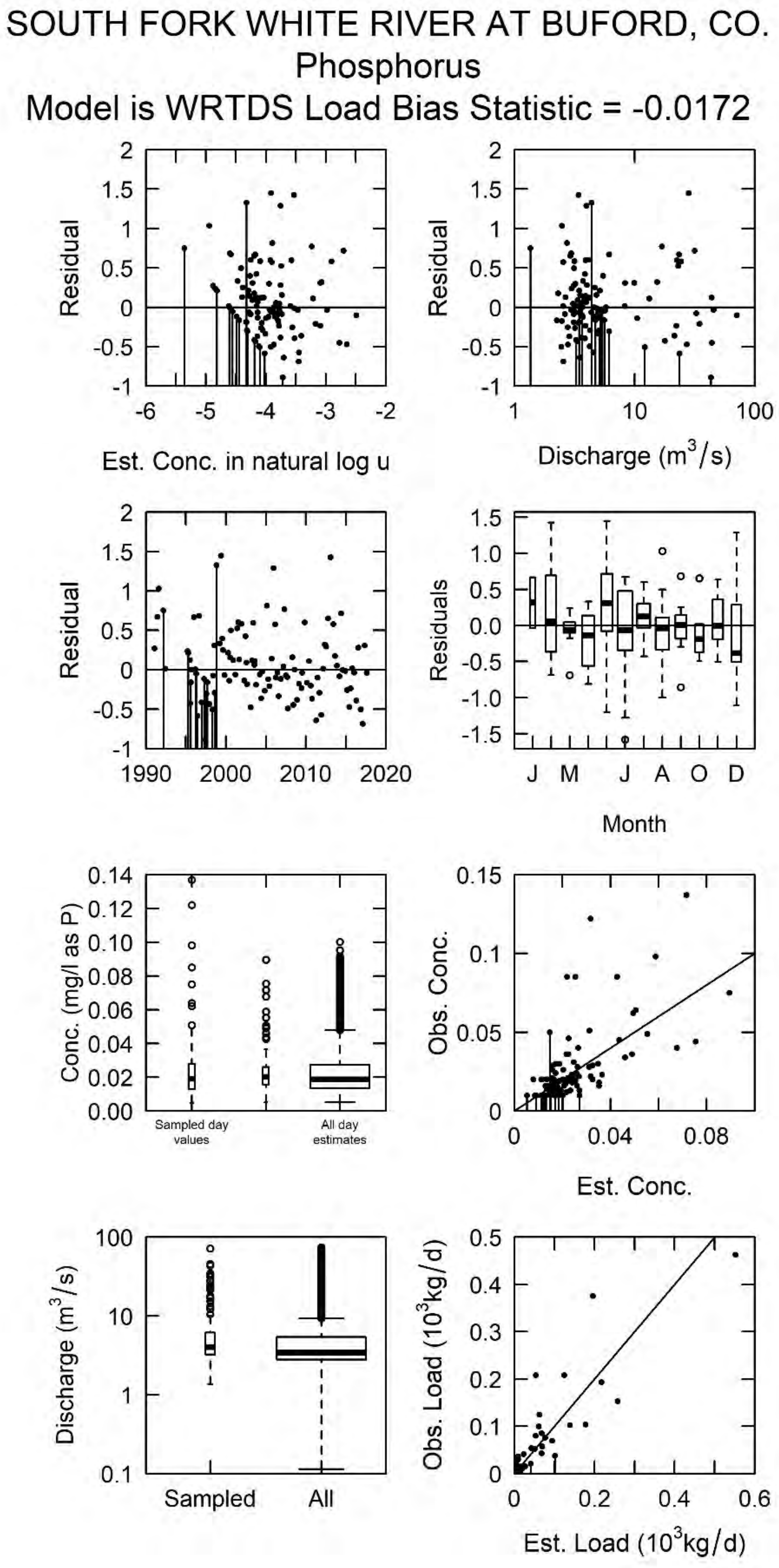

Figure C-14b. WRTDS residuals and bias statistics for phosphorus (00665) at USGS 09304000 South Fork White River.

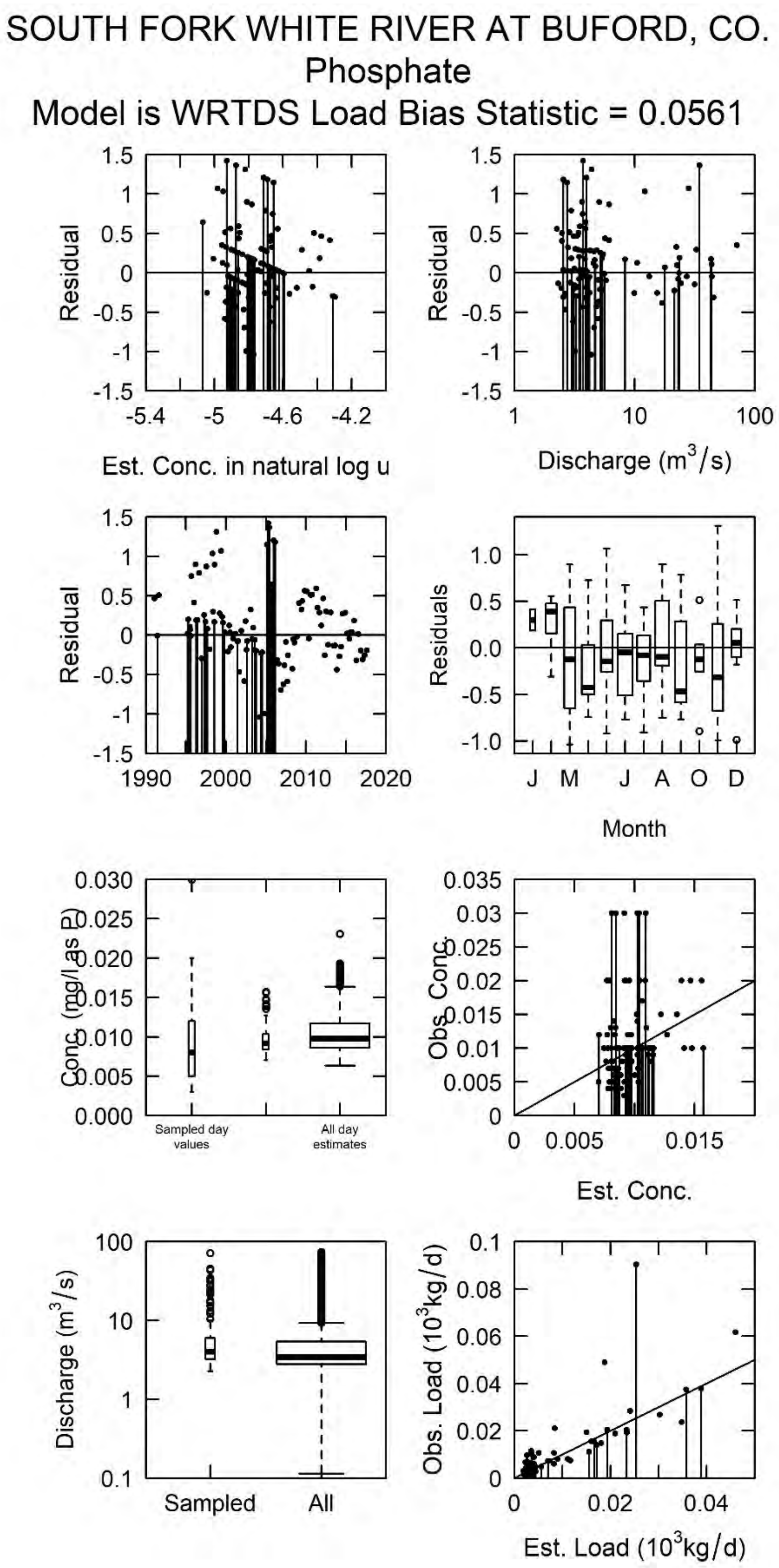

Figure C-14c. WRTDS residuals and bias statistics for phosphate (00671) at USGS 09303000 North Fork White River.

SOUTH FORK WHITE RIVER AT BUFORD, CO
Phosphorus

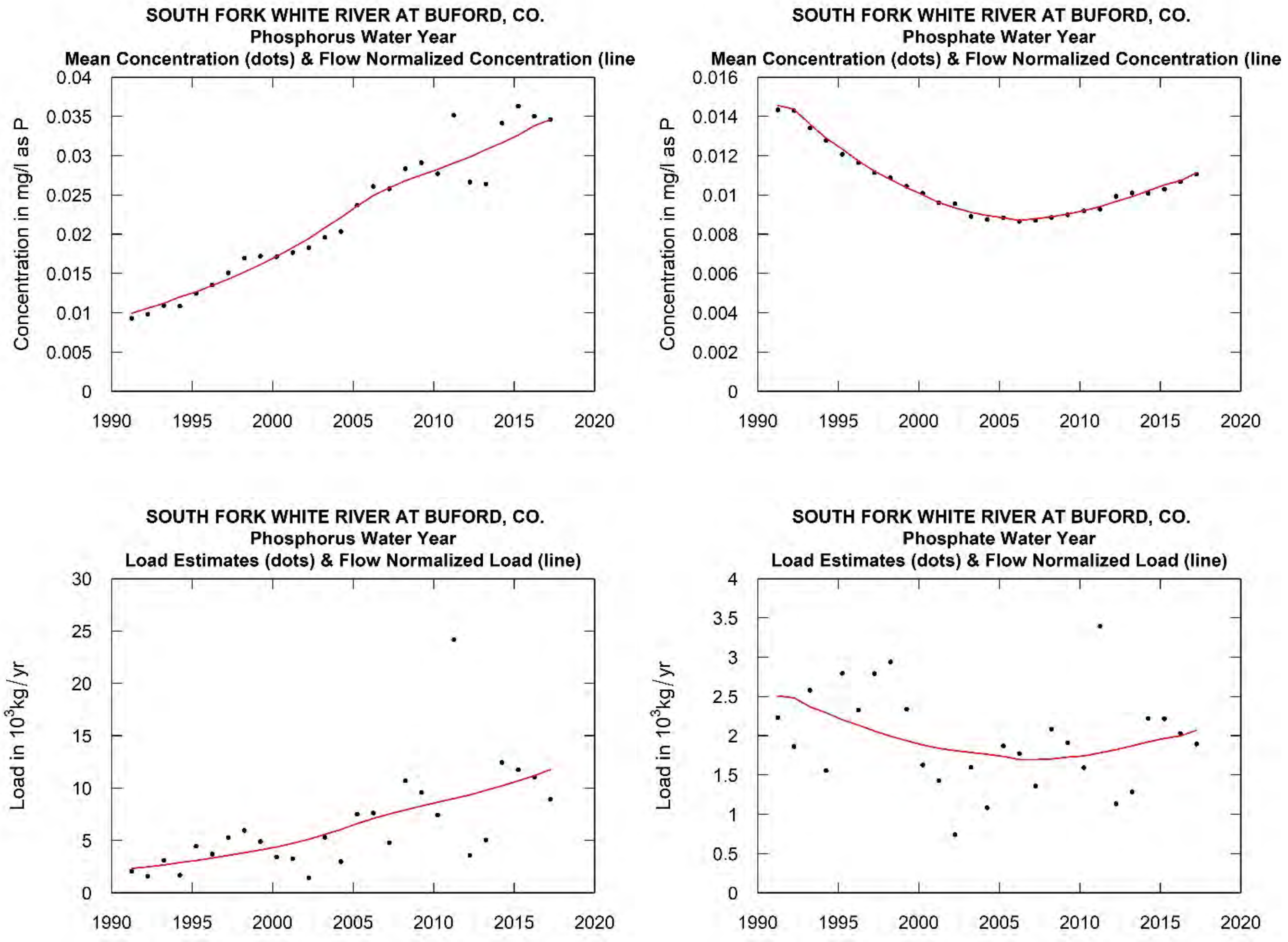

Figure C-14d. **WRTDS annual estimated concentrations and loads (black dots) and flow normalized concentrations and loads (red lines) for total nitrogen (00600) and nitrate plus nitrite (00631) at USGS 0930400 South Fork White River.**

SOUTH FORK WHITE RIVER AT BUFORD, CO
Nitrogen

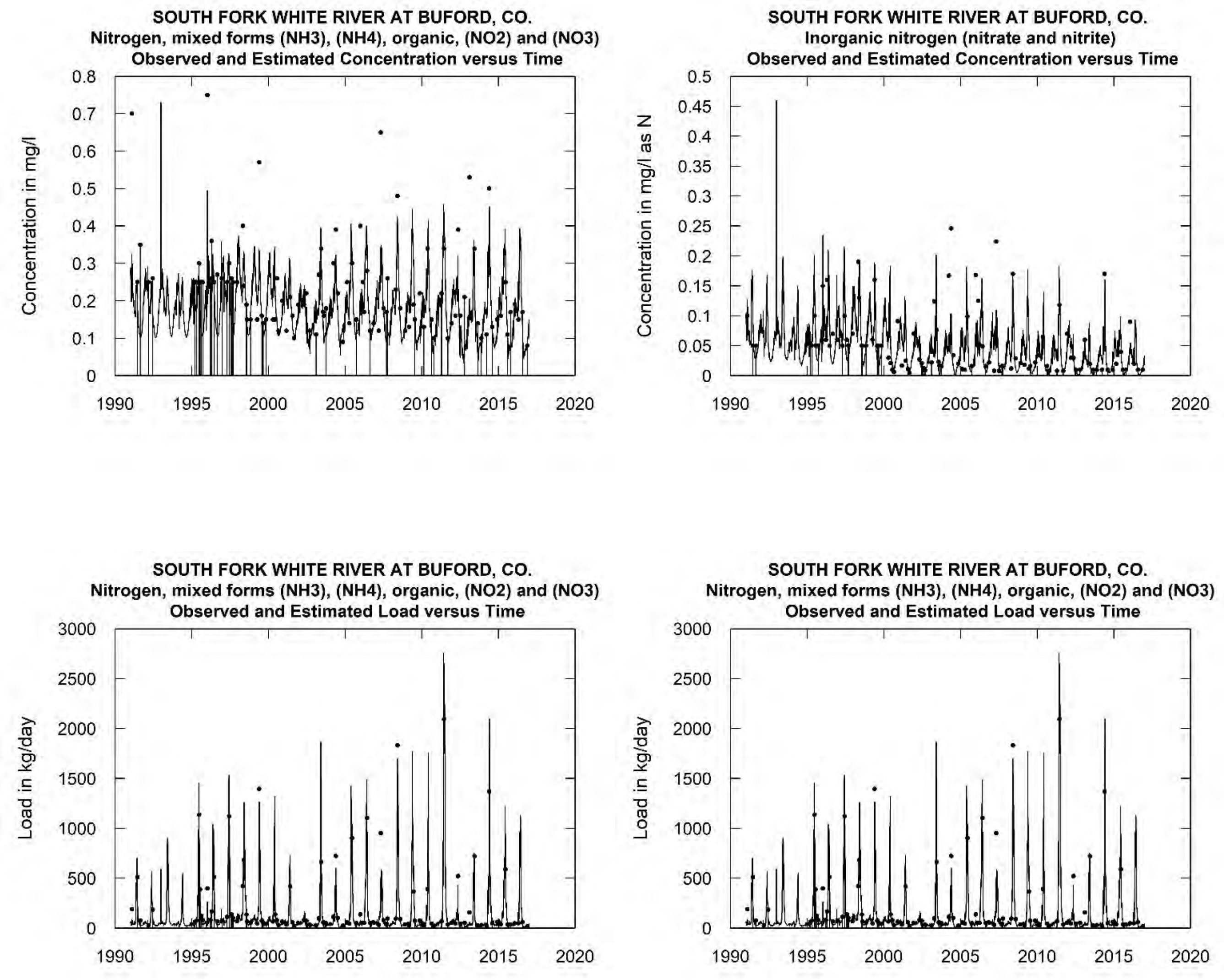

Figure C-15a. WRTDS model fits for total nitrogen (00600) and nitrate plus nitrite (00631) at USGS 09303000 North Fork White River. (lines) WRTDS daily model estimates. (circles) Instantaneous observed concentrations or loads.

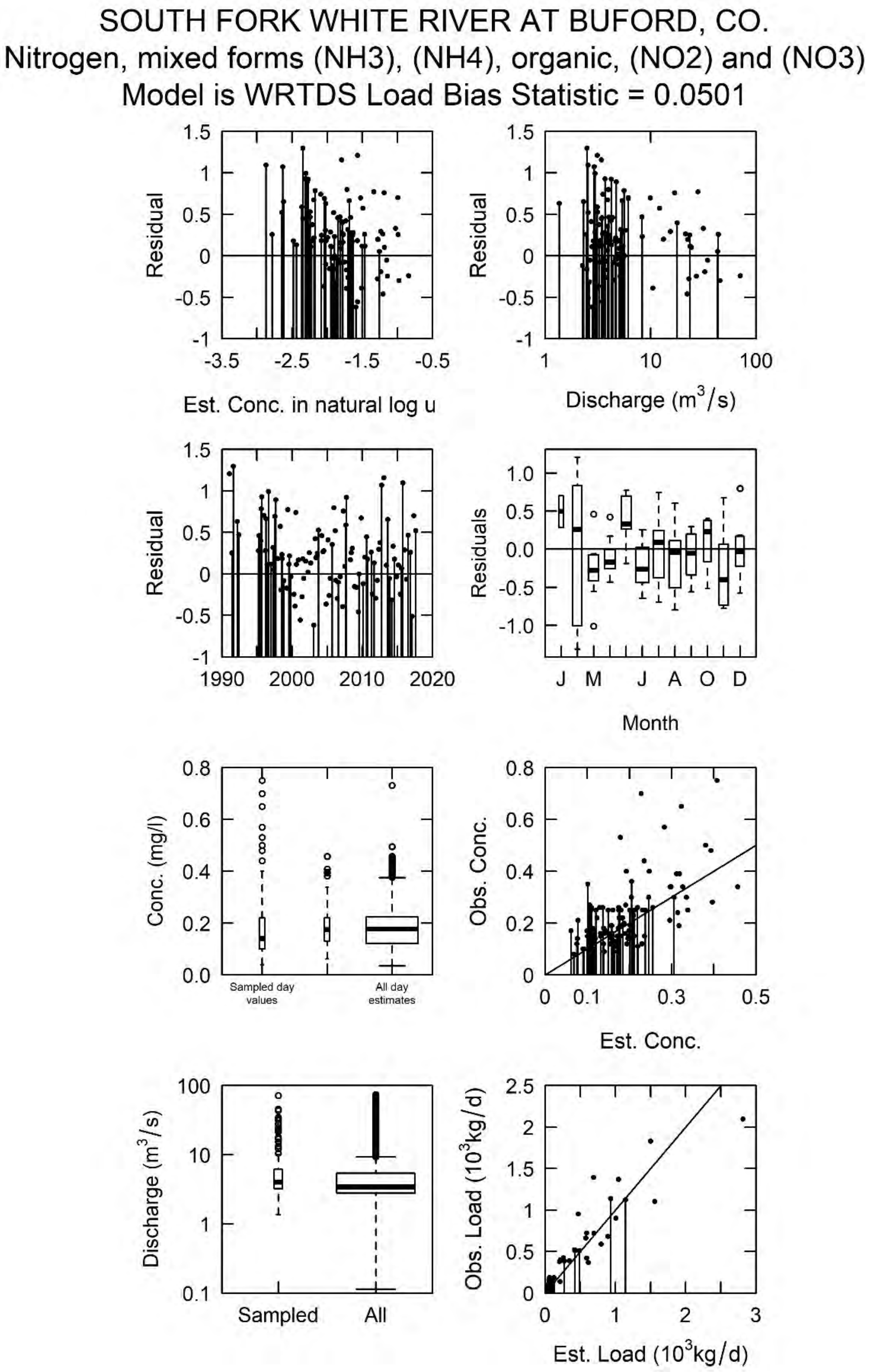

Figure C-15b. **WRTDS residuals and bias statistics for total nitrogen (00600) at USGS 09304000 South Fork White River.**

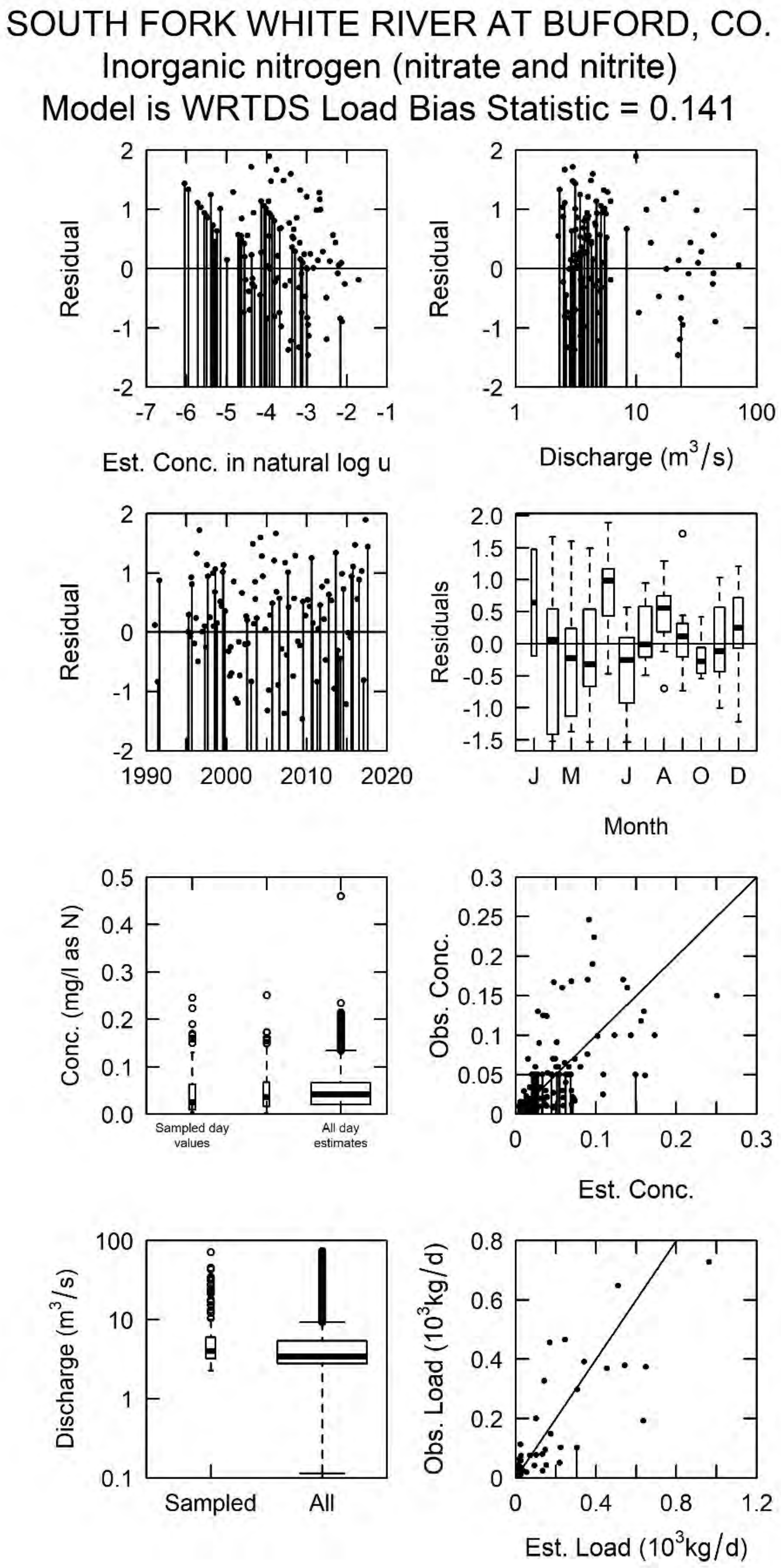

Figure C-15c. WRTDS residuals and bias statistics for nitrate plus nitrite (00631) at USGS 09304000 South Fork White River.

SOUTH FORK WHITE RIVER AT BUFORD, CO
Nitrogen

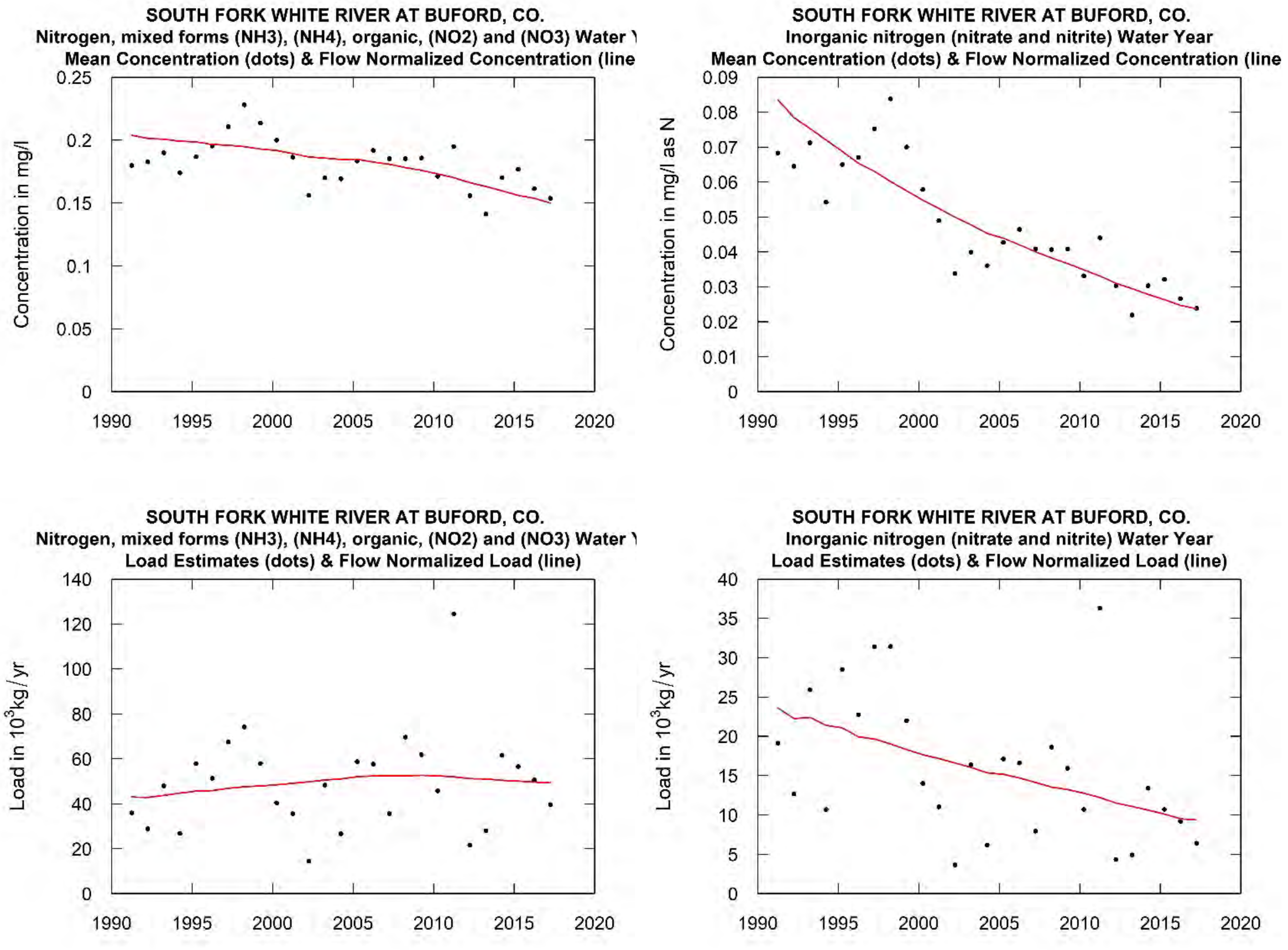

Figure C-15d. **WRTDS annual estimated concentrations and loads (black dots) and flow normalized concentrations and loads (red lines) for total nitrogen (00600) and nitrate plus nitrite (00631) at USGS 09304000 South Fork White River.**

Appendix D: Summary of Nutrient Export Coefficients

Nutrient Export Coefficients (EC) in kg/ha/yr for Southern Rockies Ecological Region (White, et al. 2015)

				10th percentile		median value		90th percentile	
Land Use	**samples**	**precip (mm/yr)**	**runoff (mm/yr)**	**TN**	**TP**	**TN**	**TP**	**TN**	**TP**
Urban	15,421	426	84.4	4.35	0.112	8.14	0.285	18.8	0.899
Undisturbed Forest	403,303	396	4.22	0.026	0	0.297	0.002	1.27	0.41
Grassland (all types)	213,036	386	21.4	0.064	0	0.669	0.022	5.07	0.404
Cultivated Cropland	4,689	388	6.16	0.033	0	0.596	0.018	6.82	0.448

Nutrient Export Coefficients (EC) in kg/ha/yr from Various Sources

Land Use	**TN**	**TP**	**Source**
Forested Watersheds	2.46	0.206	Reckhow 1980, Figures 4a (TP, n=26) and 4b (TN, n=11), Nutrient Export from Forested Land Use (Median Values)
Pasture/Hay	4.09	0.64	Reckhow 1980, Table 8 Nutrient Export from Non Row Crop (Morris, MN; 572 mm precip/yr, loam soil), 6-year mean
Pasture	1.52	0.25	Reckhow 1980, Table 9 Nutrient Export from Grazed and Pastured Watershed (Eastern SD; 584 mm precip/yr, sandy clay loam soil)
Nonrow Crops	6.08	0.76	Reckhow 1980, Figures 6a (TP, n=13) and 6b (TN, n=10), Nutrient Export from Nonrow Crops (Median Values)
Grazed and Pastured Watersheds	5.19	0.81	Reckhow 1980, Figures 7a (TP, n=14) and 7b (TN, n=13), Nutrient Export from Grazed and Pastured Watersheds (Median Values)
Mixed Agricultural Watersheds	14.3	0.91	Reckhow 1980, Figures 9a (TP, n=20) and 9b (TN, n=21), Nutrient Export from Mixed Agricultural Watersheds (Median Values)
Pasture/Range	0.97	0.22	Harmel 2006, Table 4 (Median Values)
Atmospheric	6.77	0.26	Reckhow 1980, Table 13a Forest Atmospheric Inputs, TN for New Mexico, TP for Clear Lake Ontario Canada; wetfall only
Atmospheric	3.07	NA	EPA Clean Air Status and Trends Network (CASTNET), Total N Deposition at Gothic, CO (GTH161), 2015 (wet and dry) https://www.epa.gov/castnet
Animal Feedlot and Manure Storage	2,923	224	Reckhow 1980, Figures 8a (TP, n=13) and 8b (TN, n=7), Nutrient Export from Animal Feedlot and Manure Storage (Median Values)

White, Michael, Daren Harmel, Haw Yen, Jeff Arnold, Marilyn Gambone, and Richard Haney. 2015. Development of Sediment and Nutrient Export Coefficients for U.S. EcoRegions. 51(3):758-775. DOI: 10.1111/jawr.12270, Journal of the American Water Resources Association (JAWRA).

Reckhow, Kenneth H., Michael N. Beaulac, and Johnathan T. Simpson. 1980. Modeling Phosphorus Loading and Lake Response Under Uncertainty A Manual and Compilation of Export Coefficients. Washington D.C.: U.S. Environmenal Protection Agency.

Harmel, Daren, Steve Potter, Pamela Casebolt, Ken Reckhow, Colleen Green, and Rick Haney. 2006. "Compilation of Measured Nutrient Load Data for Agricultural Land Uses in the United States." Journal of the American Water Resources Association (JAWRA) 42(5):1163-1178.

Appendix E: Suggested Nutrient Management Practices for Septic and Agriculture

List of Septic System Management Recommendations

(modified from the Clark Fork Watershed Septic Program, Tri-State Water Quality Council, Sand Point, ID, 2009)

1) Promote development of a mentoring system for sanitarians, septic pumpers, installers, and maintainers, and potentially homeowners
    a. Maybe a phone or website with FAQ
2) Develop Septic Maintenance Education Program and Education Materials
    a. Increase awareness of water quality/drinking water issues
    b. Increase regular maintenance to septic systems
    c. Include information on geologic issues in education materials
    d. Should begin with survey of a representative sample of county residents to determine their understanding of septic issues.
    e. Education materials should respond to results of the survey.
    f. Should capitalize on cost savings to homeowners. A preventative measure to avoid astronomical expense.
    g. Education Materials
        i. One Maintenance Reminder Checklist with dated entries for the future
        ii. Steps for septic maintenance targeting homeowners
        iii. Existing new technologies and alternative treatment systems
3) Encourage Septic Pumpers to provide periodic Septic Maintenance Reminders.
    a. Available preconstructed electronic database that is easy to use and modify
        i. Potentially design one or get septic pumpers who already use one to provide an empty database
    b. Accompanying universal short concise education materials to pass to homeowners
4) Improved information systems for homeowner notification of cost sharing systems for septic maintenance and replacement
    a. Create county, state, and/or local grant funded or tax break programs to increase and/or cost share on maintenance for those who cannot afford it

5) Promote connections between groups who can encourage septic system maintenance. Convene this group periodically to coordinate the distribution and dissemination of materials about septic maintenance.
    a. Realtors
    b. Bankers
    c. Mortgage Groups
    d. Septic Installers and Pumpers
    e. Homeowners Associations
6) Increase capacity to accept septage
    a. Through diluted land application
    b. Through municipal wastewater treatment plants
    c. Create a market to trade and sell septage
7) Encourage greater study of impacts of water softeners on septic systems
8) Require and track septic system inspection and/or maintenance at time of sale
9) Develop a septic maintenance district to require and track periodic septic maintenance
    a. Use onlineRME.com to track septic maintenance permits and decrease administrative costs.
10) Map or otherwise characterized uncharacterized potentially sensitive areas
    a. Identify critical areas
11) Address nitrogen impacts from all human sources on county and state level and meet TMDL requirements
    a. Create a nutrient trading system to reward communities reducing their cumulative impacts
    b. Capitalize on existing technologies to remove more nitrogen and other nutrients in septic waste and explore ways to cut related maintenance costs
12) Bolster web based information on local, county, and state websites
13) Encourage septic design policies based on treatment performance instead of prescriptive system requirements
14) Capitalize on existing technologies to remove more nitrogen and other nutrients in septic waste and explore ways to cut related maintenance costs
    a. Develop educational information for homeowners on existing technologies and alternative treatment systems

15) Install systems that are easier to maintain in regards to small structures constructed over the tank, location of power lines, gas lines, landscaping
    a. Review and assist in distribution of homeowners packet developed by the Septic Pumpers Advisory Committee
    b. Improve communication between Environmental Health Department and Planning Departments
16) During the permitting process, identify potential replacement drain field locations
17) Require inspections of drainfields for signs of failure or malfunction

NATURAL RESOURCES CONSERVATION SERVICE
CONSERVATION PRACTICE STANDARD

NUTRIENT MANAGEMENT

(Ac.)

CODE 590

DEFINITION

Managing the amount (rate), source, placement (method of application), and timing of plant nutrients and soil amendments.

PURPOSE

- To budget, supply, and conserve nutrients for plant production.
- To minimize agricultural nonpoint source pollution of surface and groundwater resources.
- To properly utilize manure, municipal and industrial biosolids, and other organic by-products as plant nutrient sources.
- To protect air quality by reducing odors, nitrogen emissions (ammonia, oxides of nitrogen), and the formation of atmospheric particulates.
- To maintain or improve the physical, chemical, and biological condition of soil.

CONDITIONS WHERE PRACTICE APPLIES

This practice applies to all lands where plant nutrients and soil amendments are applied.

CRITERIA

General Criteria Applicable to All Purposes

Develop a nutrient management plan for nitrogen, phosphorus, and potassium that considers the crop requirements and all potential sources of nutrients including, but not limited to:

- commercial fertilizer
- animal manure
- legume credits and green manure,
- crop rotation
- municipal and industrial biosolids and other organic by-products
- compost
- waste water
- organic matter and soil nutrient availability
- removal of crop materials
- irrigation water.

Documents cited in this standard may be periodically updated or replaced. Use the most recent version available. Find additional technical information on nutrient management at www.agronext.iastate.edu/soilfertility.

Soil Sampling, Testing, and Analysis

Base the nutrient management plan on soil test results for, at a minimum, organic matter, phosphorus (P), potassium (K), pH, and buffer pH. Test, at a minimum, every 4 years of row crops or once during an extended rotation which includes perennial crops. For initial plans use tests no older than 2 years and account for nutrients applied at rates in excess of crop replacement since the last soil test.

Use Iowa State University’s (ISU) PM-287 “Take a Good Soil Sample to Help Make Good Decisions” for soil testing guidance. For variable rate systems use NCMR-348 “Soil Sampling for Variable Rate Fertilizer and Lime Application” for additional guidance.

For soil analysis, use a lab that is certified by the Iowa Soil Testing Laboratory Certification Program, Commercial Feed and Fertilizer Bureau of the Iowa Department of Agriculture and Land Stewardship (IDALS).

To interpret the soil test results, use PM-1688 “General Guide for Crop Nutrient and Limestone Recommendations in Iowa” and PM-1310 “Interpretations of Soil Test Results.”

The 4Rs
Consider the 4Rs of nutrient management – apply the **R**ight nutrient source at the **R**ight rate at the **R**ight time in the **R**ight place – to improve nutrient use efficiency by the crop and to minimize nutrient losses to the surface and groundwater and to the atmosphere.

Nutrient Application Rates
Determine the nutrient application rate to:

- Meet the crop's nutrient requirements for production
- Account for nutrient credits and rotational effects
- Account for removal of crop materials
- Conserve resources as indicated by the erosion and nutrient risk assessments, and
- Integrate the management of manure, municipal and industrial biosolids, and other waste products as crop nutrients.

Plan to meet the crop nutrient requirements for nitrogen, phosphorus, potassium, and other nutrients according to Iowa State University recommendations.

Nitrogen Application Rates
To determine nitrogen rates for corn in a continuous corn or corn-soybean rotation, use ISU's Corn Nitrogen Rate Calculator or use PM-1714 "Nitrogen Fertilizer Recommendations for Corn in Iowa."

For within season sampling to determine sidedress nitrogen application rates, follow ISU procedures for the late-spring soil nitrate test in PM-1714 or leaf chlorophyll values in PM-2026 "Sensing Nitrogen Stress in Corn."

For additional nitrogen rate information and recommendations use ISU publications:

- PM-2015 "Concepts and rationale for regional nitrogen rate guidelines for corn",
- PM-1714 "Nitrogen Fertilizer Recommendations for Corn in Iowa",
- PM-869 "Fertilizing Pasture",
- PM-1584 "Cornstalk Testing to Evaluate Nitrogen Management",
- PM-2026 "Sensing nitrogen stress in corn".

Use of the end-of-season cornstalk test especially in conjunction with on-farm field trials is encouraged to evaluate the nitrogen management program. See ISU publication PM-1584 "Corn Stalk Test to Determine Nitrogen" and NRCS Agronomy Technical Note No. 7, "Adaptive Nutrient Management Process". The corn stalk test provides post season feedback on nutrient management that can be used to adjust the nutrient source, rate, timing, and/or placement. Document how results will be reviewed and incorporated into future management.

Phosphorus and Potassium Application Rates
For P_2O_5 and K_2O requirements for most common crops, use soil test results and PM-1688 "General Guide for Crop Nutrient and Limestone Recommendations in Iowa". Use PM-869 "Fertilizing Pasture" for pasture nutrient requirements. Express phosphorus and potassium nutrient values in pounds of P_2O_5 and K_2O.

P_2O_5 and K_2O can be managed annually or for multiple years. Sum the nutrient requirements for all the crops in the years planned (i.e. a rotation) and apply once or split as convenient.

Phosphorus and potassium application rates may exceed the crop's nutrient requirements when manure, municipal and industrial biosolids, and other organic by-products are applied based on the N rate or need to be disposed. See Additional Criteria Applicable to Properly Utilize Manure Municipal and Industrial Biosolids, and Other Organic By-Products as a Plant Nutrient Source for management criteria.

Realistic Yield Potential
Estimate the field's realistic yield potential using:

- an average of two or more years of field yield data using producer records plus 10%, or
- the crop yield estimate for the dominant soil in the field as found in the Field Office Technical Guide, or
- PM-1268 "Establishing Realistic Yields" (1986) to calculate a more precise estimate if desired.

Nutrient Credits
To determine the nutrient application rate subtract the nutrient credits for legumes, manure, municipal and industrial biosolids, and/or other organic sources from the crop's nutrient requirements. Note that ISU nitrogen recommendations already accounts for the rotational effects and legume credit for corn following soybeans.

Legume credits can be found in ISU Publication PM-1714 "Nitrogen Fertilizer Recommendations for Corn in Iowa". Use PMR-1003 "Using manure nutrients for crop production" to determine the 2nd and 3rd year manure credits.

Other Rate Criteria
Account for all applied nutrients including starter, in-furrow starter (pop-up), biosolids, and the N in MAP and DAP.

Consider the impact on yield of poor soil quality, drainage, pH, weather, and other factors that influence production, as well as the source, timing, and placement of nutrients before concluding that nutrients are deficient.

Nutrients and lime may be applied at lower-than-recommended rates if the grower's objectives are met.

For crops without specific ISU guidance, base nutrient application rates on university recommendations from neighboring states and/or plant nutrient removal.

Nutrient Sources
Use nutrient sources compatible with the application timing, tillage and planting system, soil properties, crop, crop rotation, soil organic content, and local climate to minimize risk to the environment.

Use fertilizers which have been verified by IDALS Feed and Fertilizer Bureau to contain the nutrients claimed on the label. For Enhanced Efficiency fertilizer products use the Association of American Plant Food Control Officials definitions for these products.

On Certified Organic or Certified Transitional Organic operations, use nutrient sources and manage nutrients consistent with the USDA's National Organic Program.

See Additional Criteria Applicable to Properly Utilize Manure, Municipal and Industrial Biosolids, and Other Organic By-products as a Plant Nutrient Source section below for criteria for these nutrient sources.

Nutrient Application Timing and Placement
Consider the nutrient source, cropping system limitations, soil properties, weather conditions, drainage system, soil biology, and nutrient risk assessment to develop optimal timing and placement of nutrients.

- For nitrogen, timing and placement should correspond as closely as practical with crop uptake.
- For phosphorus avoid surface application when the runoff potential is high.
- For anhydrous ammonia, to avoid losses during application apply when soil moisture conditions are conducive to proper injection and sealing.

Fall versus Spring Application
Corn nitrogen rate guidelines for Iowa (see the Corn Nitrogen Rate Calculator website for rates and PM-2015 "Concepts and Rationale for Regional Nitrogen Rate Guidelines for Corn" for an explanation of the method) are based on spring or sidedress N application research trials. In comparison to fall application, spring N application improves crop uptake efficiency and reduces the loss of nitrate. Fall application increases the risk for nitrogen loss and reduces nitrogen use efficiency. However, with some manure and biosolid sources, such as bedded manure, fall application increases the mineralization of organic N and improves early season N supply.

In general, plan to apply N in the spring for most nutrient sources. If for logistical or other reasons N is fall applied – such as anhydrous ammonia, manure in which > 20 lbs/acre NH_4^+-N is applied, or MAP/DAP – plan to apply late in the fall when the mid-day soil temperature, at 4" soil depth, is below 50ºF and trending colder. The actual application timing may occasionally vary due to fall weather, the weather forecast, soil conditions including vulnerability to compaction, and logistics. Do not fall apply urea and urea-ammonium nitrate solutions (UAN) due to the high risk for N loss.

For small grains planted in the fall, part of the N can be applied in the fall, typically in conjunction with phosphorus application, with the remainder applied topdress in the spring.

Rescue Nitrogen Application
Nitrogen applied at any time is subject to leaching if the fertilizer contains nitrate or converts to nitrate and excess soil wetness occurs before crop uptake. This risk increases with fall application, especially early fall application, due to greater conversion to nitrate by the springtime. If losses are suspected, use the Late Spring Soil Nitrate Test (ISU publication PM-1714, "Nitrogen Fertilizer Recommendations

for Corn in Iowa") or the crop canopy sensing technique outlined in ISU publication PM-2026, "Sensing Nitrogen Stress in Corn" to assess the loss and determine the application rate of rescue N. New in-season nitrogen assessment technologies are being developed. As they are proven, these can be chosen as alternatives.

If rescue N is needed on fields in which a full rate of N is applied in the fall, evaluate the likely causes and formulate and consider alternative nitrogen management options. Consider testing N management alternatives using strip trials over multiple years and fields. See NRCS Agronomy Technical Note No. 7: "Adaptive Nutrient Management Process" for guidance. Especially consider switching to split, spring, and/or sidedress application to reduce the loss of N from fall application.

Surface application of Nutrients to Frozen, Snow-Covered, and Saturated Soils

Design the manure and fertilizer storage and management system to avoid the need to surface apply nutrients when the risk of runoff is high, including when:

- the soils are frozen and/or snow-covered or
- the top 2 inches of the soil are saturated.

Manure may be surface applied to frozen, snow covered or saturated soils on an emergency basis if storage capacity becomes insufficient due to a natural disaster, unusual weather conditions, equipment or structural failure, or other similar events and failure to apply creates a risk of an uncontrolled release of manure.

For such emergency cases, prepare a manure disposal plan which includes the:

1) Circumstances the manure may be applied to frozen, snow covered, or saturated ground (Ex: storage capacity exceeded);
2) Rates of application;
3) Areas of application which excludes slopes greater than 5% and sensitive areas and their setbacks;
4) Which demonstrates that all other nutrient management criteria are met including the erosion and nutrient risk assessment criteria; and
5) Meets state law.

Cover Crops

Cover crops can be effective scavengers of nitrogen, immobilizing the N in the organic matter, impacting when the nitrogen will be available, and potentially preventing N leaching. However, management systems to optimize immobilization and to make subsequent agronomic N management decisions still need to be developed and tested. On-farm cover crop field trials are encouraged to test management options (species, planting method, timing of planting, timing of manure application, timing and method of killing, etc.), to estimate subsequent N availability, and to assess the impact on water quality. Variances to this standard can be made to encourage innovative work to use cover crops in the nutrient management system.

Other Timing and Placement

For pasture fertilization consult PM-569 "Warm-Season Grasses for Hay and Pasture" and PM-869 "Fertilizing Pasture" for guidance. Time nitrogen applications to pastures when crop demand is the greatest.

To avoid salt damage, follow ISU guidelines for the rate and placement of applied nitrogen and potassium in starter/pop-up fertilizers.

Additional Criteria to Minimize Agricultural Nonpoint Source Pollution of Surface and Groundwater

Use the tools below to assess the risk that the management system will impact water quality. When there is a high risk of transport of nutrients, apply conservation practices to control or trap manure, biosolids, and nutrients before they can leave the field by surface or subsurface (e.g., tile, groundwater) drainage.

Erosion and Nutrient Risk Assessment

On each field calculate the risk to soil and water resources using the:

- Revised Universal Soil Loss Equation 2 (RUSLE2) to estimate soil erosion,
- Leaching Index (LI) to determine the relative risk of N leaching to ground or surface water.

Phosphorus Index

Use the Iowa Phosphorus Index (P-Index) to estimate the risk that P will contaminate surface water. The P-Index is required when one or more of the following applies:

- The phosphorus application rate exceeds land-grant university fertility rate guidelines for the planned crop(s) in the rotation, or
- Manure, municipal and industrial biosolids, and/or organic by-products are applied, or

- Soil loss exceeds the tolerable level, or
- The average soil test phosphorus for the field is in the very high range for corn based on ISU PM-1688.

The Iowa P-Index is implemented in the Iowa Phosphorus Index Calculator and in Purdue's Manure Management Planner software. PM-2021 "Data Collection Worksheet for RUSLE2 and Iowa Phosphorous Index" provides guidance to use the calculator.

Meet the criteria of the Iowa Phosphorus Index as stated in the P-Index's "Interpretations of Site Vulnerability Ratings for the P-Index" found in the Calculator. For additional information consult "Iowa Technical Note 25: Iowa Phosphorus Index."

<u>Municipal Well Protection</u>
Determine if the field is in a municipal well capture zone. Water infiltrating soil in these areas is likely to flow to the wellhead in 10 years or less. There is an elevated risk that nitrogen and other products applied on this land will contaminate the public well. To reduce the pollution risk, consider additional measures listed below.

Nutrient Management Strategies to Reduce Nonpoint Source Pollution

Consider using the following nutrient-use efficiency strategies or technologies:

- include crops in the rotation and manage the crop sequence to require less added nitrogen For further guidance, see conservation practices:
  - 328 Conservation Crop Rotation
  - 512 Forage and Biomass Planting
- more efficient timing and number of applications
- incorporation or injection
- calibrate application equipment and apply nutrient materials uniformly
- coordinate nutrient applications with optimum crop nutrient uptake
- slow and controlled release fertilizers
- nitrification and urease inhibitors
- late-spring soil nitrate test and chlorophyll meters (SPAD) for in-season nitrogen evaluation and to determine sidedress rates
- end-of-season cornstalk test to evaluate nitrogen management
- other ISU demonstrated and/or accepted technologies that improve nutrient-use efficiency and minimize surface or groundwater resource concerns.

Strategies to Control and Trap Phosphorus

Use the P-Index to formulate and evaluate conservation alternatives to control phosphorus and sediment runoff and/or to trap it before it can reach surface water. Some conservation practices to consider are:

- 329 Residue and Tillage Management, No-Till/Strip Till/Direct Seed
- 345 Residue and Tillage Management, Mulch Till
- 330 Contour Farming
- 340 Cover Crops
- 393 Filter Strip
- 391 Riparian Forest Buffer
- 412 Grass Waterway
- 638 Water & Sediment Control Basin
- 600 Terrace
- 656 Constructed Wetland

Strategies to Trap Nitrogen

Agronomically appropriate nitrogen rates still often lead to surface and groundwater pollution. Consider the following conservation practices to trap the nitrogen not utilized by the crop.

- 340 Cover Crops
- 393 Filter Strip
- 332 Contour Buffer Strips
- 656 Constructed Wetland
- 554 Drainage Water Management
- 747 Denitrifying Bioreactors
- 739 Vegetated Subsurface Drain Outlet

As appropriate, prioritize in-field nitrogen management and trapping practices over edge-of-field practices.

Sensitive Area Nutrient Application Restrictions

A sensitive area is water we are trying to protect from pollution or direct conduits to that water. If a sensitive area is protected by a minimum 50 foot Filter Strip (NRCS Conservation Standard 393) then surface, unincorporated application of phosphorus and nitrogen can be made to the edge of the filter strip. Otherwise, do not apply phosphorus and nitrogen to the following sensitive areas unless injected or incorporated within 24 hours:

- Within 200 feet upslope of sinkholes, drainage wells, wells, classic gullies, drainage ditches, tile line surface and blind inlets for tile lines which run unmitigated to surface or

groundwater[1], or other direct conduits to surface or groundwater.
- Within 200 feet of lakes, ponds, streams, other perennial water bodies, or Iowa Designated Wetlands.
- Within 800 feet of state designated High Quality Water Resources. See DNR 117 “High Quality Water Resources” for listing.

Sidedress fertilizer applications, fertigation, and foliar applications may be made when the crops have emerged and there is a diminished chance of surface runoff.

Additional application restrictions may apply. See Iowa Department of Natural Resources (DNR) document DNR 113 “Separation Distances for Land Application of Manure” and DNR 117 “High Quality Water Resources.”

Other Nonpoint Source Pollution Criteria
During the peak flood periods (April, May, June, July) do not apply phosphorus and nitrogen on land that floods more than once every 10 years.

Apply irrigation water and use fertigation and chemigation in a manner which minimizes the risk of nutrient loss to surface and groundwater.

Additional Criteria Applicable to Properly Utilize Manure, Municipal and Industrial Biosolids, and Other Organic By-products as Plant Nutrient Sources

Coordinate manure storage and management with the cropping system so that manure can be applied at the right time and in the right place (surface, incorporated, or injected) so that:
- the rate of mineralization releases nutrients when the crop can use them;
- the loss of N due to denitrification or ammonia volatilization is minimized; and
- P runoff is minimized.

Nutrient Content Analysis of Manure, Municipal and Industrial Biosolids, and Organic By-products
Analyze or estimate the nutrient content of manures, municipal and industrial biosolids, and other organic by-products prior to land application. At a minimum, analyze for total nitrogen (N), ammonium N, total phosphorus (P) or P_2O_5, total potassium (K) or K_2O, percent moisture, and percent solids.

For manures, use ISU’s PM-1588 “How to Sample Manure for Nutrient Analysis” for detailed guidance. To interpret the results and estimate the plant availability of nutrients use ISU’s PM-3014 “How to Interpret Your Manure Analysis” and PMR-1003 “Using Manure Nutrients for Crop Production.”

Test annually, at a minimum, to build a test history. If test values are stable for three consecutive years, testing can then be done every three to five years. Retest when operational changes occur (feed management, animal type, manure handling strategy, storage time, etc.) which might change the nutrient content or concentration in the manure.

Use a laboratory certified through the Minnesota Department of Agriculture Manure Testing Laboratory Certification program (MTLCP).

When planning for new or modified livestock operations, use “book values” from the NRCS Chapter 4: Agricultural Waste Characteristics in the Agricultural Waste Management Field Handbook or analyses from similar operations in the geographical area.

Municipal and, especially, industrial biosolids can be sources of heavy metals. Test, land apply, and ensure records are kept for biosolids according to state and federal law. Account for N, P, and K applied with the biosolids.

Manure, Municipal and Industrial Biosolids, and Organic By-Products Application Rate
Generally, apply manure, municipal and industrial biosolids, and organic by-products up to a rate equal to the recommended phosphorus application, or up to the estimated phosphorus removal in harvested plant biomass for the crop rotation, or up to the cumulative rate for crops over multiple years. Do not exceed the recommended nitrogen application rate during

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[1] Tile line surface and blind inlets can provide a direct conduit to surface waters. Mitigating this is a challenge and potential solutions are being explored. Many tile inlets currently exist – especially as part of terrace or sediment basin structures – for which it will be difficult to install a filter strip or set back the application of solid manures. As an interim mitigation practice, surface application of nutrients (e.g. solid manures, MAP, DAP) may be made within the 200 foot setback area when, in the inlet drainage area, the soil loss is ≤ T **and**:
1. A cover crop is established, and/or
2. A no-tillage cropping system is used.

the year of application or harvest cycle. Do not apply additional phosphorus during the years for which the rate is calculated.

However, if the **Iowa Phosphorus Index** rates the risk that P will move offsite as **Very Low** risk, **Low** risk, or **Medium** risk, the application of manure, municipal and industrial biosolids, or organic by-products may be made based on the nitrogen application rates. *Applied P may exceed crop needs and removal rates and will accumulate in the soil. This practice will not be sustainable over the long term.*

If the Iowa P-index rating is **Medium** risk, avoid accumulating phosphorus to levels that will increase the rating of the field above the medium risk category.

If the Iowa P-index rating is **High** or **Very High** risk, implement practices to reduce that risk to Medium or below. Do not apply P until the risk is reduced.

Manure Application on Legumes

Manure, municipal and industrial biosolids, and/or organic by-products may be applied on legumes at rates up to the estimated annual removal of nitrogen in the harvested portion of the crop.

Manure Application Criteria

When applying liquid manure:

- do not exceed the soil's infiltration or water holding capacity at crop rooting depth
- avoid runoff or loss to subsurface tile drains.

Additional Criteria to Protect Air Quality by Reducing Odors, Nitrogen Emissions and the Formation of Atmospheric Particulates

To address air quality concerns caused by odor, nitrogen, sulfur, and/or particulate emissions, adjust the source, timing, amount, and placement of nutrients to minimize air pollution and negative human health impacts. One or more of the following may be used:

- urease inhibitors for surface applied urea fertilizers
- incorporation
- injection
- residue and tillage management
- no-till or strip-till
- other technologies that minimize the impact of these emissions

Do not apply poultry litter – or manure, municipal and industrial biosolids, or organic by-products of similar dryness/density – when there is a high probability that wind will blow the material offsite.

Additional Criteria to Maintain or Improve the Physical, Chemical, and Biological Condition of the Soil

Manage or apply nutrients to maintain or improve the physical, chemical, or biological condition of the soil to enhance soil quality for crop production and environmental protection.

When possible, avoid applying nutrients when the potential for soil compaction and rutting is high.

Maintain soil pH at levels indicated in ISU Publication PM-1688 "General Guide for Crop Nutrient Requirements in Iowa." All recommendations are based on Effective Calcium Carbonate Equivalents (ECCE). For soil tests requiring less than 2000 pounds per acre ECCE, the lime requirement may be waived.

CONSIDERATIONS

Use nutrient management strategies such as cover crops, crop rotations, and perennials in the rotation to improve nutrient cycling and reduce energy inputs.

Use no-till/strip-till in combination with cover crops to sequester nutrients, increase soil organic matter, increase aggregate stability, reduce compaction, improve infiltration, and enhance soil biological activity to improve nutrient-use efficiency.

Use legume crops and cover crops to provide nitrogen through biological fixation and nutrient recycling.

Elevated soil test phosphorus levels are detrimental to soil biota. Avoid building P in the soil to excessive levels.

Excessive levels of some nutrients can cause induced deficiencies of other nutrients, e.g., high soil test phosphorus levels can result in zinc deficiency in corn. Avoid over-applying nutrients.

If increases in soil phosphorus levels are expected from, for instance, a large application of biosolids or manure, consider retesting the soil prior to the next nutrient application.

Use soil tests, plant tissue analyses, and field observations to check for secondary plant nutrient and micronutrient deficiencies or toxicity that may impact plant growth or availability of the primary nutrients.

Use the adaptive nutrient management learning process to improve nutrient-use efficiency on farms as outlined in the NRCS Agronomy Technical Note No. 7: “Adaptive Nutrient Management Process.”

Do not apply potassium where an excess (greater than soil test potassium recommendation) causes nutrient imbalances in crops or forages.

Avoid applying potash and other fertilizers when the risk of runoff is high, including when:
- the soils are frozen and/or snow-covered or
- the top 2 inches of the soil are saturated.

Though potassium is not considered a water pollutant, applying under these conditions can lead to the loss of the nutrient and the need and cost of re-application.

Variable Rate Nutrient Management

Use variable-rate nitrogen, phosphorus, and potassium application rates based on site-specific variability in crop yield, soil variability, soil test values, and/or other factors as proven.

Develop site-specific yield maps using a yield monitoring system. Use the data to further diagnose low- and high- yield areas, or zones, and make the necessary management changes. See Title 190, Agronomy Technical Note (TN) 190.AGR.3, Precision Nutrient Management Planning.

Safety

Protect workers from and avoid unnecessary contact with plant nutrient sources. Take extra precaution when handling anhydrous ammonia or when dealing with organic wastes stored in unventilated enclosures.

Utilize material generated from cleaning nutrient application equipment in an environmentally safe manner. Collect and store or field apply excess material in an appropriate manner.

Recycle nutrient containers in compliance with State and local guidelines or regulations.

Considerations to Minimize Agricultural Nonpoint Source Pollution of Surface and Groundwater

Use application methods and timing strategies that reduce the risk of nutrient transport by ground and surface waters, such as:
- split applications of nitrogen to deliver nutrients during periods of maximum crop utilization,
- band nitrogen and/or phosphorus to improve nutrient availability, and
- delay field application of animal manures, biosolids, or organic by-products if precipitation capable of producing runoff and erosion is forecast within 24 hours of the time of the planned application.

Use the Agrichemical Handling Facility (309) conservation practice to protect air, soil, and water quality.

Avoid surface applying manure and fertilizer to grassed waterways, ditches, and other places of concentrated water flow especially during times of the year when runoff is likely.

Nutrients applied to coarse soils and karst topography are especially at risk to leach into the groundwater. Consider additional measures to reduce the pollution risk.

Target Iowa DNR’s Outstanding Iowa Waters listed watersheds with conservation practices to protect these unique Iowa watersheds.

Considerations to Properly Utilize Manure, Municipal and Industrial Biosolids and Other Organic By-products as a Plant Nutrient Source

For animal feeding operations which apply manure more than once a year, sample manure more frequently to account for seasonal differences.

Use manure management conservation practices to manage manure nutrients to limit losses prior to nutrient utilization.

Apply manure at a rate that will result in an “improving” Soil Conditioning Index (SCI) without exceeding acceptable risk of nitrogen or phosphorus loss.

Modify animal feed diets to reduce the nutrient content of manure following guidance contained in Conservation Practice Standard (CPS) Code 592, Feed Management.

Considerations to Protect Air Quality by Reducing Nitrogen and/or Particulate Emissions to the Atmosphere

Avoid applying manure and other by-products upwind of inhabited areas.

Use high-efficiency irrigation technologies (e.g., reduced-pressure drop nozzles for center pivots) to reduce the potential for nutrient losses.

When tillage is feasible and otherwise does not cause erosion or soil quality issues, incorporate within 24 hours surface applied manure or fertilizer nitrogen formulations that are subject to volatilization (e.g., urea).

Use the National Air Quality Site Assessment Tool to explore options to improve management.

Considerations to Maintain or Improve the Physical, Chemical, and Biological Condition of the Soil

To maintain or improve the physical, chemical, or biological condition of the soil use the concepts and technologies in the NRCS nutrient management for soil quality technical note (available soon).

PLANS AND SPECIFICATIONS

Develop the nutrient management plan to reflect the objectives and decisions of the owner/operator of the land planned. Adapt the form of the plan – from field names to equipment size – to the particular needs of the producer to facilitate plan implementation.

Specifications for All Plans

Include in the nutrient management plan:

- producer objectives
- statement of resource concerns that will be addressed in the plan
- statement of local, state, and/or federal standards and/or requirements the plan is designed to meet; tools and data sources used; and assumptions made.
- aerial site photograph(s)/imagery or site map(s)
- soil survey map of the site,
- soil information including: soil type surface texture, pH, drainage class, permeability, available water capacity, depth to water table, restrictive features, and flooding and/or ponding frequency,
- fields delineated with ID and acres, location of designated sensitive areas and the associated nutrient application restrictions and setbacks,
- for manure and biosolid applications, location of nearby residences, or other locations where humans may be present on a regular basis, and any identified meteorological (e.g., prevailing winds at different times of the year), or topographical influences that may affect the transport of odors to those locations,
- results of the RUSLE2, Leaching Index, and Iowa Phosphorus Index resource risk assessment tools,
- documentation that the Iowa Phosphorus Index's interpretations of site vulnerability ratings criteria are met,
- documentation that the conservation practices required to meet Iowa Phosphorus Index criteria are applied and/or the implementation scheduled,
- current and/or planned plant production sequence or crop rotation,
- soil, manure, municipal or industrial biosolid, organic by-product, plant tissue sample, and/or water analyses applicable to the plan,
- documentation of the realistic yield potentials for the crops and how they were derived,
- complete nutrient management plan for nitrogen, phosphorus, and potassium for the plant production sequence or crop rotation,
- specify the nutrient application source, timing, rate (except for precision/variable rate applications specify method used to determine rate), and placement of plant nutrients for each field or management unit and the source and reasoning for the choices,
- rationale for P applications in excess of crop removal when the P-Index is very low, low, or medium and soil test P is optimum or higher,
- when soil test phosphorus levels are high or very high and/or increasing,
  - ○ include a discussion of the risk associated with phosphorus accumulation,
  - ○ estimate using the P-Index when P should no longer be applied,
  - ○ propose a P stabilization or draw-down strategy to optimum soil test P, and

  - ○ formulate alternative manure management strategies to reduce application rates (i.e. use it to fertilize more land to better optimize the use of the resource), and
- guidance for implementation, operation and maintenance, and recordkeeping.

Additional Specifications for Precision/Variable Rate Plans

Include the following components in a precision/variable rate nutrient management plan:

- Document the geo-referenced field boundary and data collected that were processed and analyzed as a GIS layer or layers to generate nutrient or soil amendment recommendations.
- Document the nutrient recommendation guidance and recommendation equations used to convert the GIS base data layer or layers to a nutrient source material recommendation GIS layer or layers.
- Document if a variable rate nutrient or soil amendment application was made.
- Provide application records per management zone or as applied map within individual field boundaries (or electronic records) documenting source, timing, method, and rate of all applications that resulted from use of the precision agriculture process for nutrient or soil amendment applications.
- Maintain the electronic records of the GIS data layers and nutrient applications for at least 5 years.

OPERATION AND MAINTENANCE

Conduct periodic plan reviews to determine if adjustments or modifications to the plan are needed. At a minimum, plans must be reviewed, evaluated, and, if needed, revised, with

- each soil test cycle,
- changes in manure volume or analysis, or
- changes in crops or crop management.

Monitor fields receiving animal manures and/or municipal or industrial biosolids for the accumulation of phosphorus.

Continue to test each manure source based on PM-1558 “How to sample manure for nutrient analysis.” If feed management, animal numbers or type, manure handling strategy, storage time, etc., change significantly, re-inventory the manure resource and re-analyze the manure. The nutrient management plan may need to be revised accordingly.

Calibration of Fertilizer Application Equipment

Calibrate fertilizer application equipment at least annually to ensure proper placement or material at planned rates. Use ISU guidance PM-1941 “Calibration and Uniformity of solid Manure Spreaders” or PM-1948 “Calibrating Liquid Tank Manure Applicators.” For custom applicators or rented equipment, verify that the operator or owner has calibrated applicators.

For anhydrous ammonia, verify that the applicator is properly plumbed. See PM-1875 “Improving the Uniformity of Anhydrous Ammonia Application” for guidance. Note that other effective manifolds are now available. Verify that anhydrous ammonia is injected to the proper depth and good soil coverage is provided.

Records for All Plans

Maintain records for at least 5 years – longer if required by other Federal, state or local ordinances, or program or contract requirements – to document plan implementation and maintenance. As applicable, include:

- soil, plant tissue, water, manure, biosolid, and organic by-product analyses resulting in recommendations for nutrient application.
- nutrient sources and analyses, rates as applied, placement, timing (dates) of nutrients applied, and a summary of actual pounds of nutrients applied per acre.
- weather conditions and soil moisture at the time of application; lapsed time to incorporation; and rainfall or irrigation event,
- record of equipment calibration.
- crops planted, planting and harvest dates, yields, nutrient analyses of harvested biomass (if applicable), and crop residues removed, and
- identify variations from the nutrient management plan, evaluate why the variation occurred, and determine if a plan needs to be updated. Document decision.
- dates of plan review, name of reviewer, and recommended changes resulting from the review.

Additional Records for Precision/Variable Rate Plans

Include:

- maps identifying the variable application source, timing, amount, and placement of all plant nutrients applied, and
- GPS-based yield maps for crops where yield data can be digitally collected.

REFERENCES

Iowa State University Extension Publications

Available at County Extension Offices or at ISU Extension Online Store: https://store.extension.iastate.edu/ or at the ISU Soil Fertility website: www.agronext.iastate.edu/soilfertility.

- ISU PM-287 “Take a Good Soil Sample to Help Make Good Decisions”
- ISU PM-569 “Warm-Season Grasses for Hay and Pasture”
- ISU PM-869 “Fertilizing Pasture"
- ISU PM-1268 “Establishing Realistic Yields"
- ISU PM-1310 “Interpretations of Soil Test Results”
- ISU PM-1558 “How to Sample Manure for Nutrient Analysis”
- ISU PM-1584 “Cornstalk Testing to Evaluate Nitrogen Management”
- ISU PM-1688 “A General Guide for Crop Nutrient and Limestone Recommendations in Iowa”
- ISU PM-1714 “Nitrogen Fertilizer Recommendations for Corn in Iowa”
- ISU PM-1875 “Improving the Uniformity of Anhydrous Ammonia Application”
- ISU PM-1941 “Calibration and Uniformity of Solid Manure Spreaders”
- ISU PM-1948 “Calibrating Liquid Tank Manure Applicators”
- ISU PM-2015 “Concepts and Rationale for Regional Nitrogen Rate Guidelines for Corn”
- ISU PM-2021 “Data Collection Worksheet for RUSLE2 and Iowa Phosphorous Index**”**
- ISU PM-2026 “Sensing Nitrogen Stress in Corn”
- ISU PM-3014 “How to Interpret Your Manure Analysis”
- ISU PMR-1003 “Using Manure Nutrients for Crop Production”
- NCMR-348 “Soil Sampling for Variable Rate Fertilizer and Lime Application”

USDA-NRCS Resources

Available on the USDA-NRCS website at: http://www.nrcs.usda.gov/wps/portal/nrcs/site/ia/home/

- Iowa Technical Note 25, “Iowa Phosphorus Index”
- Phosphorus Index Calculator (Excel Spreadsheet)
- Purdue’s Manure Management Planner (software)
- USDA-NRCS. 2008. Chapter 4: Agricultural Waste Characteristics. In Part 651 Agricultural Waste Management Field Handbook.
- USDA-NRCS. 2010. Agronomy Technical Note, (TN) 190-AGR-3, Precision Nutrient Management Planning. Washington, DC.
- USDA-NRCS. 2011. Title 190, General Manual, (GM), Part 402, Nutrient Management. Washington, DC.
- USDA-NRCS. 2011, Title 190, National Instruction (NI), Part 302, Nutrient Management Policy Implementation. Washington, DC.
- USDA NRCS. 2013. Agronomy Technical Note No. 7 “Adaptive Nutrient Management Process”

Iowa DNR Publications

Available on the Iowa DNR website at: www.iowadnr.gov

- Iowa DNR. 2008. DNR 113: Separation Distances for Land Application of Manure. Des Moines, IA.
- Iowa DNR. 2003. DNR 117: High Quality Water Resources. Des Moines, IA.

Other Publications

- Association of American Plant Food Control Officers (AAPFCO). 2013. Official Publication No. 66 (or latest). West Lafayette, IN.

Documents cited in this standard may be periodically updated or replaced. Use the most recent version available.