Carbon County Resource Council 2022-2024 Rock Creek Water Quality Data Analysis – MSU Student Project

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Forward and Acknowledgements

This work was conducted as part of a one semester Montana State University undergraduate research course, led by Dr. Adam Sigler with support from Gabrielle Jawer. Samuel Gabrielson and Wesley Cousin were the undergraduate students assigned to the CCRC monitoring program for the course.

This work was conducted in consultation with the Carbon County Resource Council representatives Jeff DiBenedetto, Scott Hancock, Dan Erikson, and Karen Walmsley.

Fall 2025 was the second year of this pilot course, with the intention to produce useful data summaries for volunteer monitoring programs while simultaneously providing hands on student learning opportunities.

This work is supported by funding from Montana Department of Environmental Quality (MDEQ) and Abbie Ebert with MDEQ provided valuable comments on report drafts.

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Introduction

Rock Creek is a 55-mile-long tributary to the Clarks Fork Yellowstone River (Figure 1). Rock Creek begins high in the Absaroka Beartooth Wilderness and flows through National Forest Land, as well as the towns of Red Lodge, Fox, Roberts, Joliet, and Boyd. It also flows through multiple subdivisions, farms, and ranches before merging with the Clarks Fork Yellowstone River south of Laurel, MT. Rock Creek runs along highway 212 for most of its length with adjacent land uses including residential development, cultivated crops, and pasture/hay land. (Figure 2). West Fork Rock Creek, Red Lodge Creek and Clear Creek are additional tributaries covered under this project. Flows in Red Lodge Creek are affected by storage and release from the Cooney Reservoir dam. In late summer, Rock Creek is periodically dewatered along some segments upstream of its confluence with the Clarks Fork (DiBenedetto, 2024).

The Volunteer Rock Creek Water Quality Monitoring Project is in partnership with the Clarks Fork Yellowstone partnership (CFYP), the Carbon County Resource Council (CCRC), and Montana Fish, Wildlife, and Parks (MTFWP). The CCRC is composed of citizens who care about the responsible use of water resources with the goal of finding solutions to environmental issues that impact quality of life in proximity to Rock Creek. CCRC collects water quality data by participating in Monitoring Montana Waters (MMW) Volunteer Water Quality Program. The group samples at 11 sites, the watersheds for which are delineated in Figure 1 to help visualize the landscape contributing to each site. CCRC works with the Clarks Fork Yellowstone Partnership (CFYP), who monitors water quality on the Clarks Fork Yellowstone River. The CCRC and CFYP coordinate with Montana Department of Environmental Quality (MDEQ) to establish baseline water quality data. The objective of the CCRC-RCWQMO program is to gather baseline data on nutrients, sediment, temperature, and discharge. The group's goal is to provide useful data to promote better stewardship of Rock Creek.

Methods

Study Area

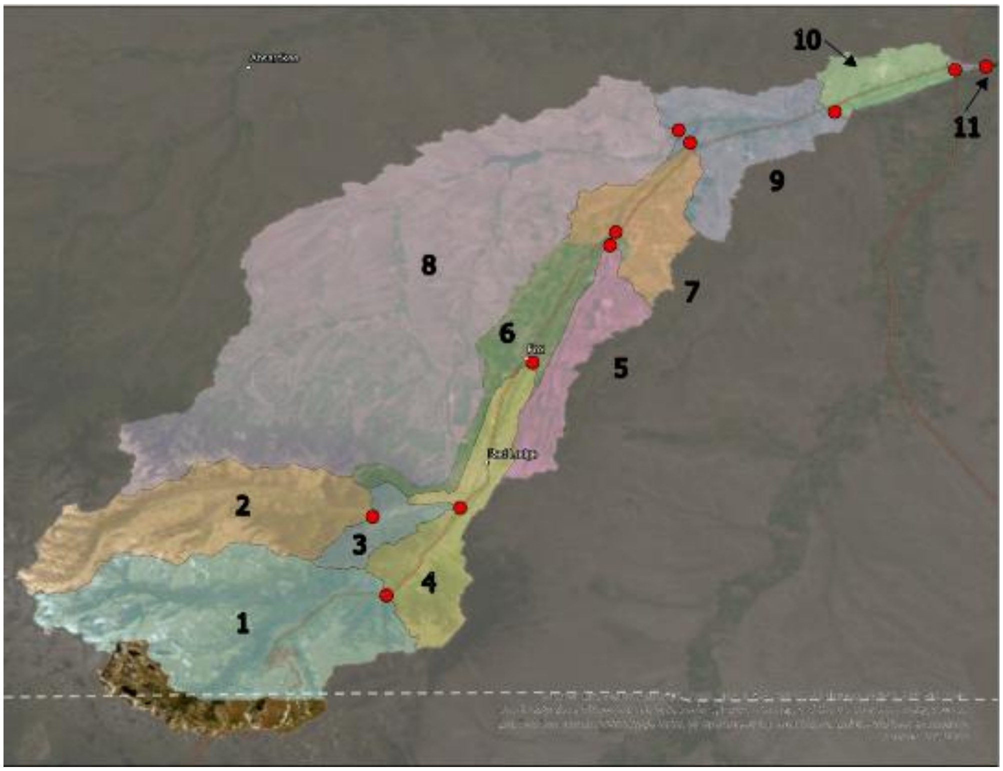

Figure 1. Site and sub-watersheds map. *Colors indicate each sub-watershed delineated within the Rock Creek watershed study area. Red dots show the sample site associated with the sub-watershed, which is indicated by site number according to Table 1, below. An error occurred during the watershed delineation process resulting in the inadvertent exclusion of the area at the far southern extent, which is why the far south end of Watershed 1 in this figure is not shaded (further detail in the methods section on watershed delineation).*

Site Name	***Plot Order***
Rock Creek near F.S. Boundary	1
W Fork Rock Creek Silver Run Bridge	2
W Fork Rock Creek	3
Rock Creek at Fox	4
Clear Creek	5
Rock Creek near Roberts	6
Rock Creek near Boyd	7
Red Lodge Creek	8
Rock Creek near Joliet	9
Rock Creek near Rockvale	10
Rock Creek Gibson Bridge	11

Table 1. Sample Sites. *Site Order ~ Upstream to Downstream. Rock Creek Gibson Bridge is the uppermost site before it merges with the Clarks Fork Yellowstone River.*

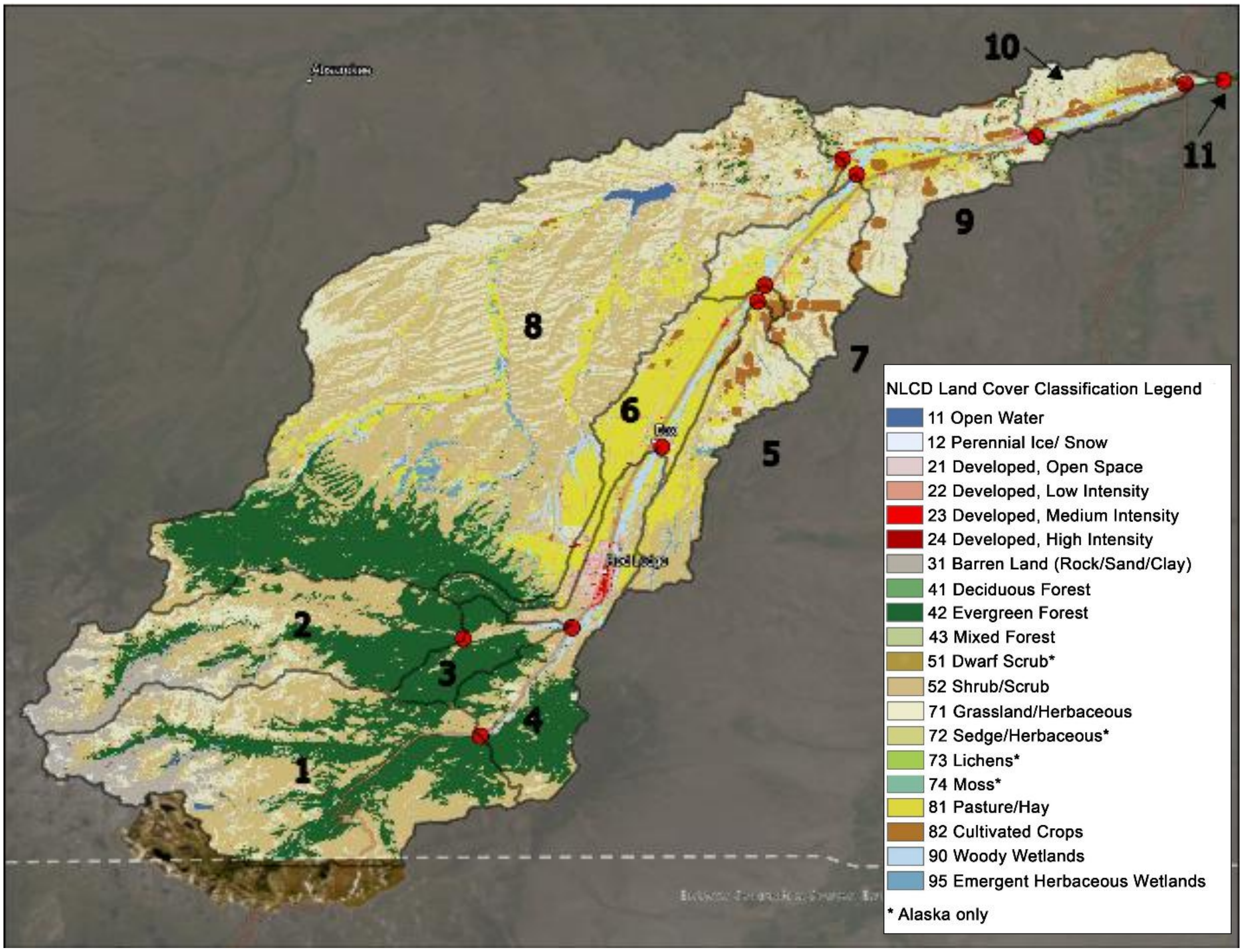

Figure 2. Land Use Map. *Land use in the watershed is displayed by color. Each color represents a different land cover/use as defined by the Annual National Land Cover Database Collection. The main uses analyzed are: Yellow (pasture/hay land cover), Red-various shades (developed land cover), and brown (annually cultivated land cover). Red dots indicate sample sites that correlate with site numbers based on Table 1.*

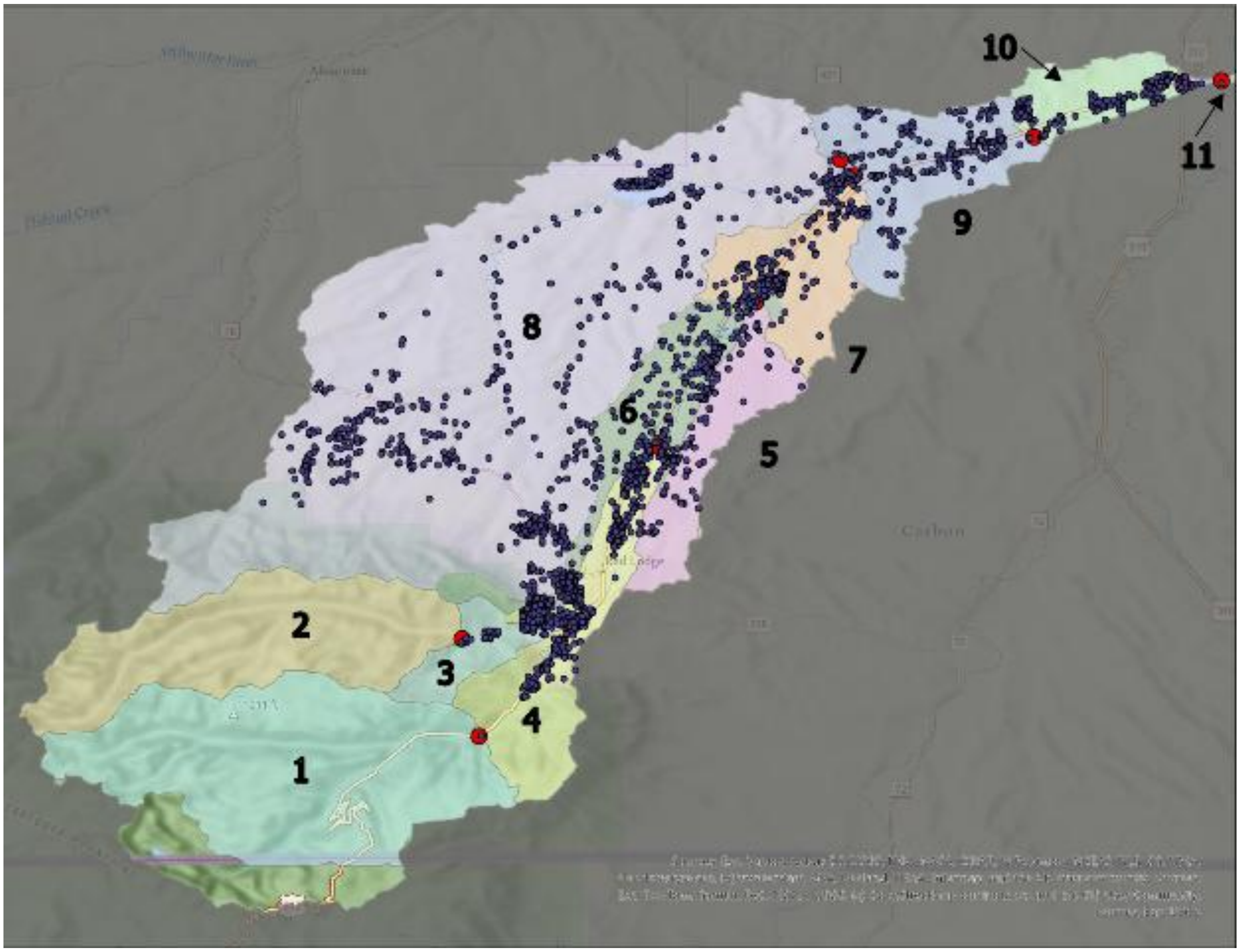

Figure 3. Septic map. *Septic systems are shown by blue dots in the watershed. Red dots indicate sample sites which correlate with site numbers based on Table 1.*

Data

This report used water quality samples collected by the Volunteer Rock Creek Water Quality Monitoring Project (RCWQMP) and analyzed by the FLBS Freshwater Research Lab that include total suspended solids (TSS), total nitrogen (TN), nitrate-N, total phosphorous (TP), orthophosphate (ortho-p), discharge, and temperature. The physical and chemical data in this report was collected by the Carbon County Resource Council Volunteer Monitoring Team and downloaded from the National Water Quality Exchange (USEPA, 2025). All discharge data was sourced from the US Geological Survey (USGS, 2025) and the Montana Department of Natural Resources and Conservation (MDNRC, 2025).

Land use and land cover data were downloaded from the National Land Cover Database (USGS, 2025). The database defines Pasture/Hay as “areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation;" Cultivated Crops as "areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20% of total vegetation. This class also includes all land being actively tilled." Developed land is defined as "areas with a mixture of some constructed materials."

Septic systems were estimated in accordance with DEQ's MEANSS methodology: the location of each septic system was estimated using the center of each structure classified as "dwelling", "mobile home" or "farm/ranch" (locations can be verified using available aerial photography) in the "Montana Structures and Addresses Data" Geographic Information System (GIS) layers. We then removed all structures located within Incorporated Towns and Cities, Sewer Districts, and Water Districts according to Montana State Library's Montana Administrative Boundaries Framework dataset.

Data Curation and Analysis

The majority of data analysis was conducted in Excel. A series of Excel sheets were used to track raw data, keep inventory, and plot data. Non-detect points were approximated as concentrations of zero. Data from all the monitoring group's 11 sites were included throughout the analysis. Some site names were shortened for clarity on plots and assigned a site number for visualization (Table 1). Additional data processing was performed in R Statistical software. Excel files and R related files used for this report are available through the MSU Extension Water Quality website.

Reference nutrient values and land use

In addition to sunlight and temperature, the amount of nitrogen and phosphorus present in stream water are the top controls on nuisance algae growth. The concentration of nitrogen and phosphorus naturally present in streams varies by season, by ecoregion, and there is natural variability among streams within ecoregions. With increases in nitrogen and phosphorus above natural background levels, nuisance algae growth is more likely. The total nitrogen (TN) lab analyses accounts for all forms of nitrogen including particulate, dissolved organic, and dissolved inorganic forms (which includes nitrate and nitrite). Soluble forms of nitrogen and phosphorus are the more plant available and are the most direct indictor of potential nuisance algae growth. However, these soluble forms can be taken up by algae during the growing season, masking the nutrient issue when looking only at instream soluble nutrient concentration. Nitrate-N (a soluble form of nitrogen) is interpreted relative to a 0.1 mg/L threshold identified by MDEQ as a concentration above which nuisance algae is more common (MDEQ 2013). Lab analysis and reports are for "nitrate plus nitrite as N", but we simplify to presenting this data as simply "nitrate" in this report because nitrite concentrations are typically very low in surface water. TN and TP are interpreted relative to MDEQ observations at reference sites during growing season months (July through September) for different ecoregions (Suplee and Watson, 2013). During runoff when sediment loads are naturally higher in streams, the levels of TN and TP are also expected to be higher. It is useful to assess nutrient concentrations during different seasons and flow levels to get a full picture of nutrient loss to streams, but the high flow TN and TP concentrations are not directly comparable to the reference site data that was only collected during July-September. For this reason, we include TN and TP plots for all data as well as for data separated out to only include samples from the growing season.

This report does not attempt to explicitly attribute nutrients in streams to specific sources. We present information about land use relative to nitrate concentration to explore the patterns for clues about possible sources, which must be followed up in more detail to accomplish source attribution. Sources of nitrogen to water can include septic systems, municipal wastewater, residential fertilizer application, farming practices, livestock operations, and industrial facilities (US EPA, 2021). Nitrate is an inorganic form of nitrogen that is dissolved and commonly reaches streams through groundwater, making it useful as an indicator of groundwater based sources of nitrogen in some cases. Nitrate in groundwater can come from a variety of sources including septic tanks, animal waste, or farming practices (US EPA, 2021) and can also be generated from explosives used in mining operations (Dignazio, et al. 1998; Storb, et al., 2023). Phosphorus sources generally align with those listed above for nitrogen (except explosives) and are commonly tightly coupled with sediment that enters streams with soil and stream bank erosion (Novotny, 2003).

<u>Watershed delineation and land use assessment</u>

Sub-watersheds associated with each sample site were delineated using ESRI ArcGIS Pro. This process started with a digital elevation model (DEM) from USGS, then flow direction and flow accumulation were calculated. The sample sites were used as pour points to facilitate creation of a shape file for the sub-watershed draining to each sample site. GIS data was collected from the Montana State Library GIS Clearinghouse and the USGS National Land Cover Dataset. During watershed delineation, the digital elevation model was clipped to include only the state of Montana, which inadvertently excluded the small portion of watershed at the far southern end that flows in from Wyoming and including a portion of that watershed that wraps back North into Montana. This error is why the very southern portion of Watershed #1 is not colored in Figure 2. We do not expect that this error affects results or conclusions in a significant way due to similarity between land use in that small omitted area and the remainder of the watershed.

Results

Nitrogen

General Total Nitrogen and Nitrate Patterns

Total nitrogen (TN) concentrations ranged from 0.13 mg/L to 2.22 mg/L across the sites (Figure 4). The three uppermost sampling sites (Rock Creek near F.S. Boundary, WF Rock Creek at Silver Run Bridge, and WF Rock Creek) had lower median TN concentrations (0.19 to 0.20 mg/L) than the downstream sites (0.24 to 0.57 mg/L). The highest median (0.57 mg/L), mean (0.66 mg/L), and outlier (2.22 mg/L) concentrations were observed at Clear Creek. All observed TN concentrations were greater than the median concentration of samples collected between July and September for reference sites for Middle Rockies and Northwestern Great Plains Transitional ecoregions. All observations at the Clear Creek site and 75% of observations at five sites (Rock at Fox, Roberts, Rockvale, Gibson, and Red Lodge Creek) were greater than the 90th percentile of values observed for the ecoregion.

Nitrate-N concentrations ranged from non-detect (<0.0015 mg/L) to 0.63 mg/L (Figure 5). Red Lodge Creek did not have any concentrations above 0.1 mg/L, while all other sites did. The upstream most six sites had a median and mean nitrate-N concentration above the 0.1 mg/L threshold, while the last five sites were below this threshold. Clear Creek had the highest median (0.23 mg/L) and mean (0.27 mg/L) concentrations, and the largest variability in concentrations with a range of 0.02 to 0.63 mg/L. Rock Creek Gibson Bridge had the lowest median concentration (0.01 mg/L), and Red Lodge Creek had the lowest mean concentration (0.03 mg/L). Six of the eleven sites had one outlier concentration, and those six sites were all in the middle to downstream reach of the watershed.

The fraction of total nitrogen present as nitrate ranged from essentially zero to approximately 100%, with some sites demonstrating more consistent ratios than others (Figure 6). Across all sites and samples, only 14% of variability in nitrate is correlated to variability in TN. However, all five samples with TN greater than 1.5 were collected on May 30th of 2022 from Rock Creek at Joliet, Rockvale, Roberts, Boyd, and Clear Creek (Figure 6A). If those five observations are omitted from the regression, the r^2 value increases to 0.35 and the slope increases to 0.42. Nitrate relative to TN is more consistently high for the two headwaters sites where the regression slopes indicate ~88% of TN at Silver run is nitrate and ~72% at FS Boundary (Figure 6B). For Clear Creek, if the highest outlier TN value (2.2 mg/L) from May 30th 2022 is removed, the slope of the nitrate-N to TN regression is 0.68, indicating roughly 68% of the TN at the site is composed of nitrate for most site visits. The highest nitrate-N concentration observed at Clear Creek (0.63 mg/L) was on April 23rd of 2023 and the only concentration below 0.1 mg/L was observed on June 24th, 2024.

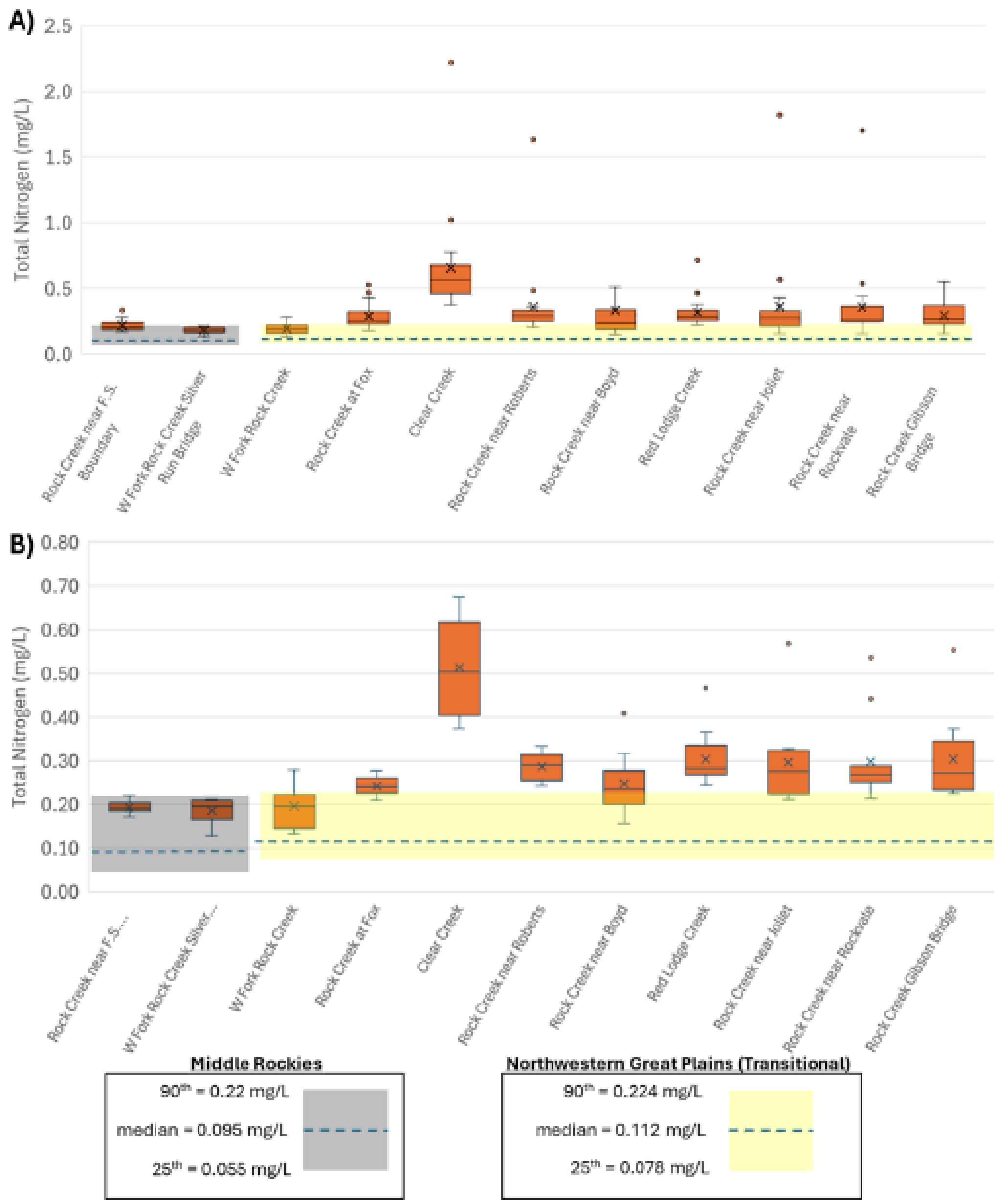

Figure 4. Total Nitrogen by Site. *Total nitrogen (TN) concentrations (mg/L, y-axis) are represented for samples collected by CCRC between May 2, 2022 and October 27, 2024. Data from all samples are represented in panel A), while panel B) includes only samples from growing season months (July through September), which aligns with timing of sample collection at the reference sites (note the smaller maximum on y-axis for panel B). Sites are organized from upstream to downstream (left to right, x-axis). The lines within the boxes are the median concentrations and X's are mean concentrations. Box plots follow standard notation where the box indicates the interquartile range (25th and 75th percentiles). The whiskers extend to the furthest concentration that is not classified as an outlier. The points beyond the whiskers are outliers, defined as values more than 1.5 times the interquartile range away from the box. The shaded range and dashed lines are concentrations observed at reference sites within the ecoregions associated with each site (Suplee and Watson, 2013; Tables 3-1A and 3-11A). The lower extent of the shading is the 25th percentile of reference site observations, the upper extent of shading at the 90th percentile, and the dashed line is the median observed concentration at reference sites for each ecoregion.*

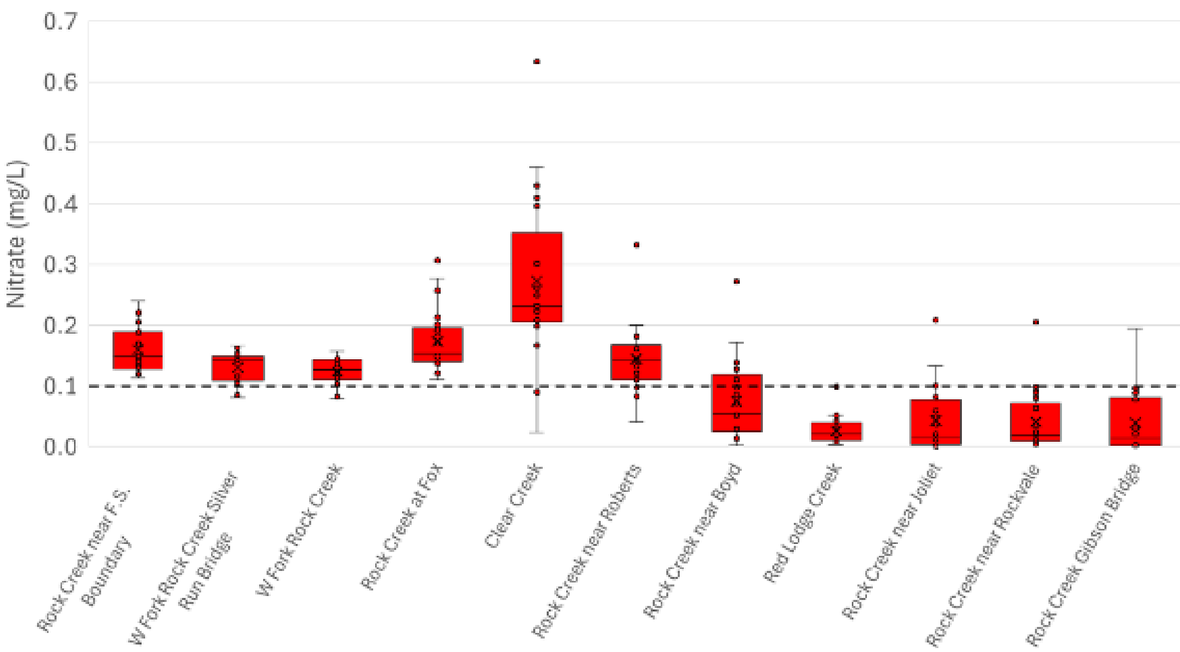

Figure 5. Nitrate-N by site. *Nitrate-N concentrations (mg/L, y-axis) are represented for samples collected by CCRC between 2022 and 2025, downloaded from WQX. Sites are organized from upstream to downstream (left to right), on the x-axis. The horizontal line is the Nitrate-N threshold of 0.10 mg/L, from MT DEQ technical memo (MTDEQ, 2014), above which nuisance algae can be more likely. The X's within the boxes are the mean and the lines are the median concentrations. Boxplots follow standard notation where the box indicates the interquartile range (25th and 75th percentiles). The whiskers extend to the furthest concentration that is not classified as an outlier. The points beyond the whiskers are outliers, defined as values more than 1.5 times the interquartile range away from the box.*

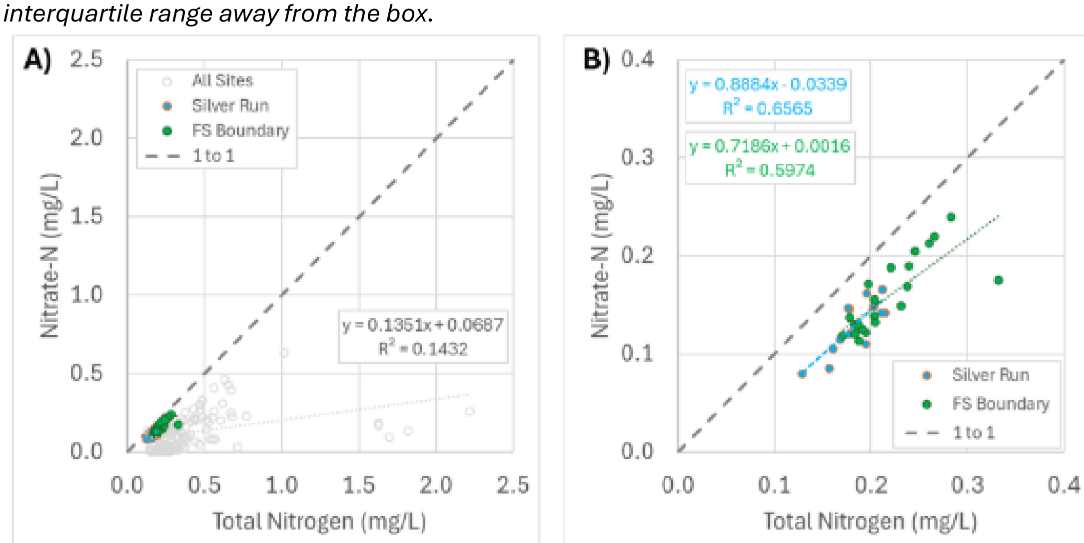

Figure 6. Nitrate versus Total Nitrogen. *Nitrate-N versus total nitrogen (TN) for all data (A) and for only the two headwater sites (B) with a 1 to 1 relationship indicated by the gray dashed line. The light gray line in the left panel is a linear regression fit to all data with relationship equation and R2 in the box. The blue and green dotted lines in the right panel are linear regressions fit to data for each of the two headwater sites independently and relationship equations and R2 values in the boxes (green = FS Boundary; blue = Silver Run).*

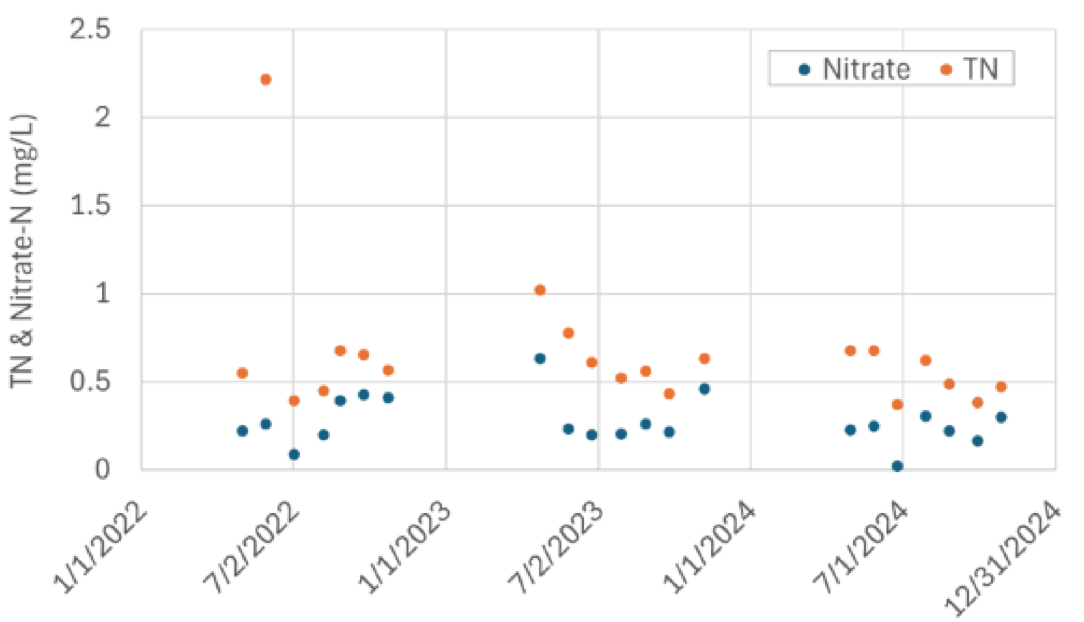

Figure 7. Total nitrogen and Nitrate-N over time at Clear Creek. *TN and Nitrate-N concentrations (mg/L, left y-axis) are represented by blue and orange points for samples collected by CCRC between 2022 and 2025, downloaded from WQX. Total Nitrogen concentrations (mg/L, right Y axis) are represented by orange points for samples collected by CCRC between 2022 and 2025, downloaded from WQX.*

<u>*Nitrate and flow at the FS Boundary and Silver Run*</u>

The highest annual nitrate-N concentrations for Rock Creek near FS Boundary generally occurred shortly before spring runoff, with maximum values of 0.19 mg/L on May 2nd, 2022, 0.24 mg/L on April 23rd, 2023, and 0.22 mg/L on April 29th, 2024 (Figure 8). Nitrate concentration decreased during high flow and then increased again over the July to October period each year. Nitrate-N concentrations in Rock Creek at FS Boundary ranged from 0.11 to 0.24 mg/L for the discharge range of 24 to 716 cfs on the days of sample visits (Figure 9). The highest nitrate-N concentrations (0.20–0.24 mg/L) were observed at low discharge/flow conditions (<100 cfs), and concentrations generally decreased with increasing discharge. At flows exceeding 400 cfs, nitrate-N concentrations ranged from 0.11 to 0.15 mg/L. There is a significant ($p < 0.001$) inverse relationship between nitrate concentration and flow at Rock Creek near FS Boundary, such that approximately half (51%) of the variability in nitrate concentration can be predicted by flow.

Nitrate-N concentrations at WF Rock Creek Silver Run Bridge ranged from 0.08 to 0.17 mg/L, and discharge on the day of sampling ranged from 29 to 428 (Figure 10 and Figure 11). Discharge at baseflow was in the range of 100 cfs and lower. The highest nitrate-N concentrations (0.14–0.17 mg/L) were observed below 125 cfs and concentrations generally decreased at higher flows, but the relationship was not significant ($r2 = 0.036$, $p = 0.61$).

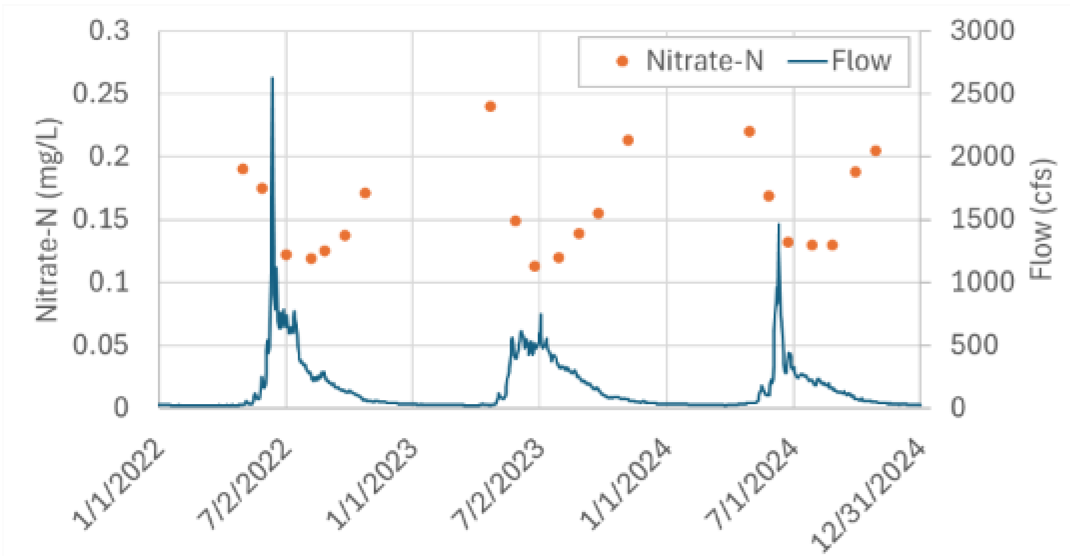

Figure 8. Nitrate-N and Flow at Rock Creek near F.S. Boundary. *Nitrate-N (mg/L, left y-axis, orange points) are represented for CCRC sampling events between 5/2/2022 to 10/27/2024, downloaded from WQX. Discharge (cfs, right y-axis, blue line) is represented for stream gauge data collected by USGS at WF Rock Creek F.S Boundary, downloaded from USGS.*

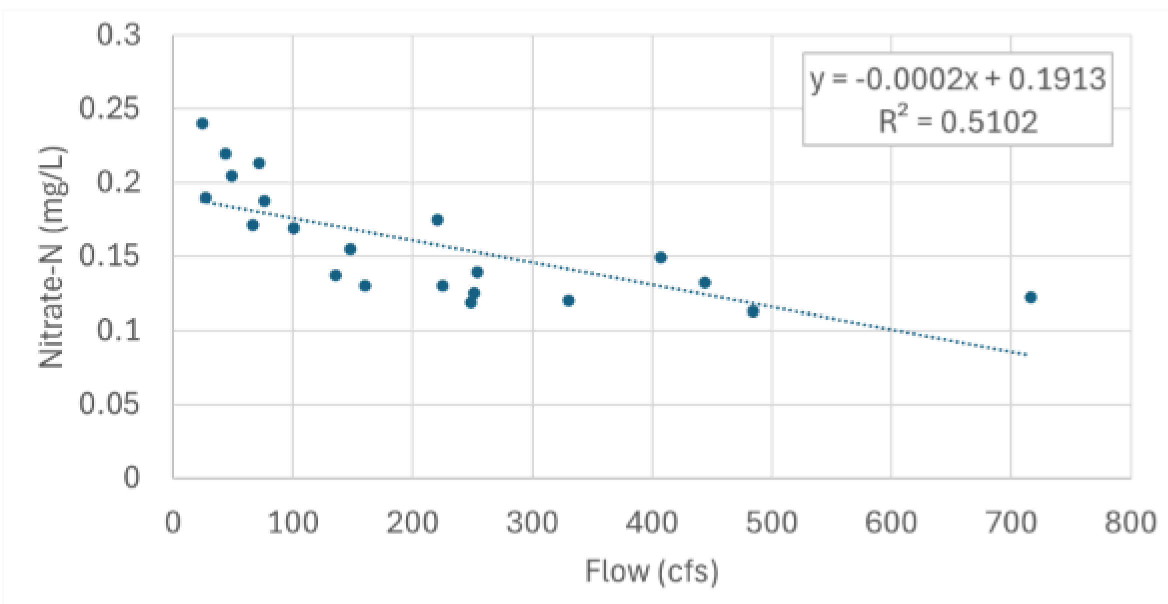

Figure 9. Regression of Nitrate-N versus Flow for Rock Creek near F.S. Boundary. *Nitrate-N concentrations (mg/L, y-axis) are represented for samples collected by CCRC between 5/2/2022 to 10/27/2024. Discharge (cfs, x-axis) is represented for data collected by USGS at F.S Boundary, downloaded from USGS. Points represent Nitrate-N concentrations at given discharge values. The dashed line represents the linear relationship between nitrate-N and discharge ($p < 0.001$).*

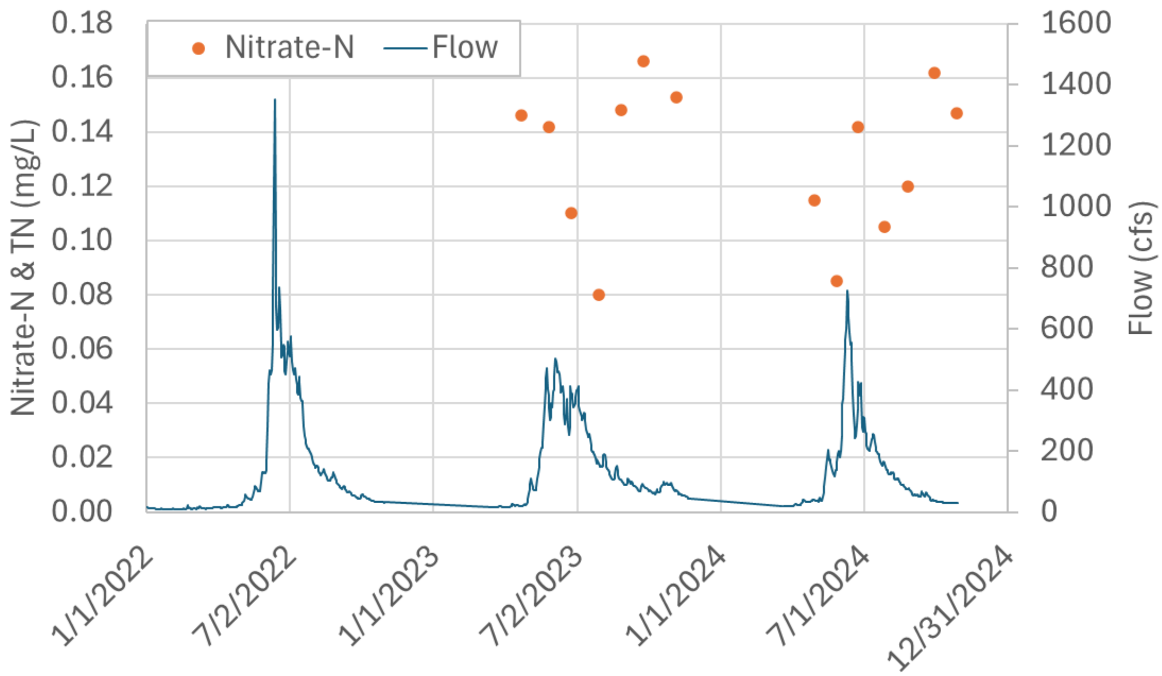

Figure 10. Total Nitrogen, Nitrate-N, and Flow for Rock Creek at Silver Run Bridge. *Nitrate-N concentrations (mg/L, left y-axis) are represented by orange points for samples collected by CCRC between 4/23/2023 and 10/27/2024, downloaded from WQX. Discharge (cfs, right y-axis) is represented by a blue line for data collected by DNRC, downloaded from DNRC.*

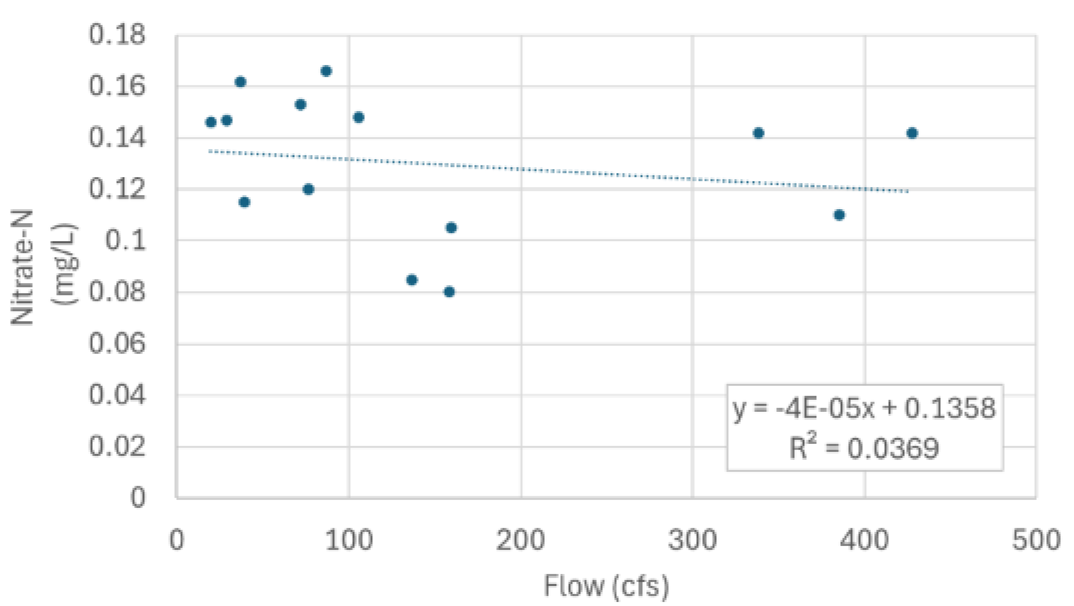

Figure 11. Regression of Nitrate-N vs. Flow for Rock Creek at Silver Run Bridge. *Nitrate-N concentrations (mg/L) are plotted on the Y axis and stream discharge (cfs) is plotted on the X axis. The dotted line represents a linear regression with the equation and r^2 value displayed on the plot, but the relationship is not significant (p = 0.61). Data points represent individual sampling events.*

Land use and nitrogen concentrations

The sample site sub-watershed with the highest septic density was Rock Creek at Fox, with 4.4 septic systems per 100 acres, while no septic systems were identified upstream from the two headwater sites (Table 2). Rock Creek near Gibson Bridge had the highest number of septic systems across watersheds at 2,227, which is implicit in the calculation because the Gibson Bridge watershed encompasses all other site sub-watersheds. The Clear Creek sub-watershed had the highest percent developed area at 4.8%, and the headwater sites had the lowest percent development areas (0.5 to 0.6%). Percent pastureland ranged from zero at headwater sites to 25% for the Clear Creek site sub-watershed. Cultivated crop area across the sample site watersheds ranged from zero at the two headwater sites to 7.1% for the Clear Creek site.

No significant associations were distinguished between land use characteristics and mean nitrate concentrations across the 11 site sub-watersheds (Figure 12; all p-values > 0.1). In contrast, mean TN concentration had a significant positive correlation to three of the four land use metrics assessed (cultivated $p < 0.001$, pasture/hay $p < 0.001$, and developed land $p < 0.005$). Septic density did not have a significant relationship with mean TN concentration ($p = 0.85$).

Site	#	Average Nitrate-N (mg/L)	Average TN (mg/L)	Developed (%)	Cultivated (%)	Pasture & Hay (%)	Septic/100 acres
Rock Creek near F.S. Boundary	1	0.16	0.22	0.5	0.0	0.0	0.0
W Fork Rock Creek Silver Run Bridge	2	0.13	0.18	0.6	0.0	0.0	0.0
W Fork Rock Creek	3	0.12	0.20	0.8	0.0	0.0	0.2
Rock Creek at Fox	4	0.17	0.29	2.7	0.0	1.4	4.4
Clear Creek	5	0.27	0.66	4.8	7.1	25.1	0.1
Rock Creek near Roberts	6	0.14	0.36	3.7	1.1	10.1	0.9
Rock Creek near Boyd	7	0.07	0.33	3.8	1.7	11.3	0.7
Red Lodge Creek	8	0.03	0.32	2.5	0.6	8.9	0.4
Rock Creek near Joliet	9	0.04	0.36	3.4	1.8	10.3	0.6
Rock Creek near Rockvale	10	0.04	0.35	3.5	2.2	10.3	0.6
Rock Creek Gibson Bridge	11	0.04	0.29	3.5	2.2	10.3	0.6

Table 2. Land use for each sample site sub-watershed. *Average Nitrate-N and TN concentrations with land use characteristics within the sub-watershed delineated for each of the eleven CCRC sample sites. This is the data plotted in regressions in Figures 12 and 13. Land covers are from the 2024 National Land Cover Dataset; see methods for details on septic density.*

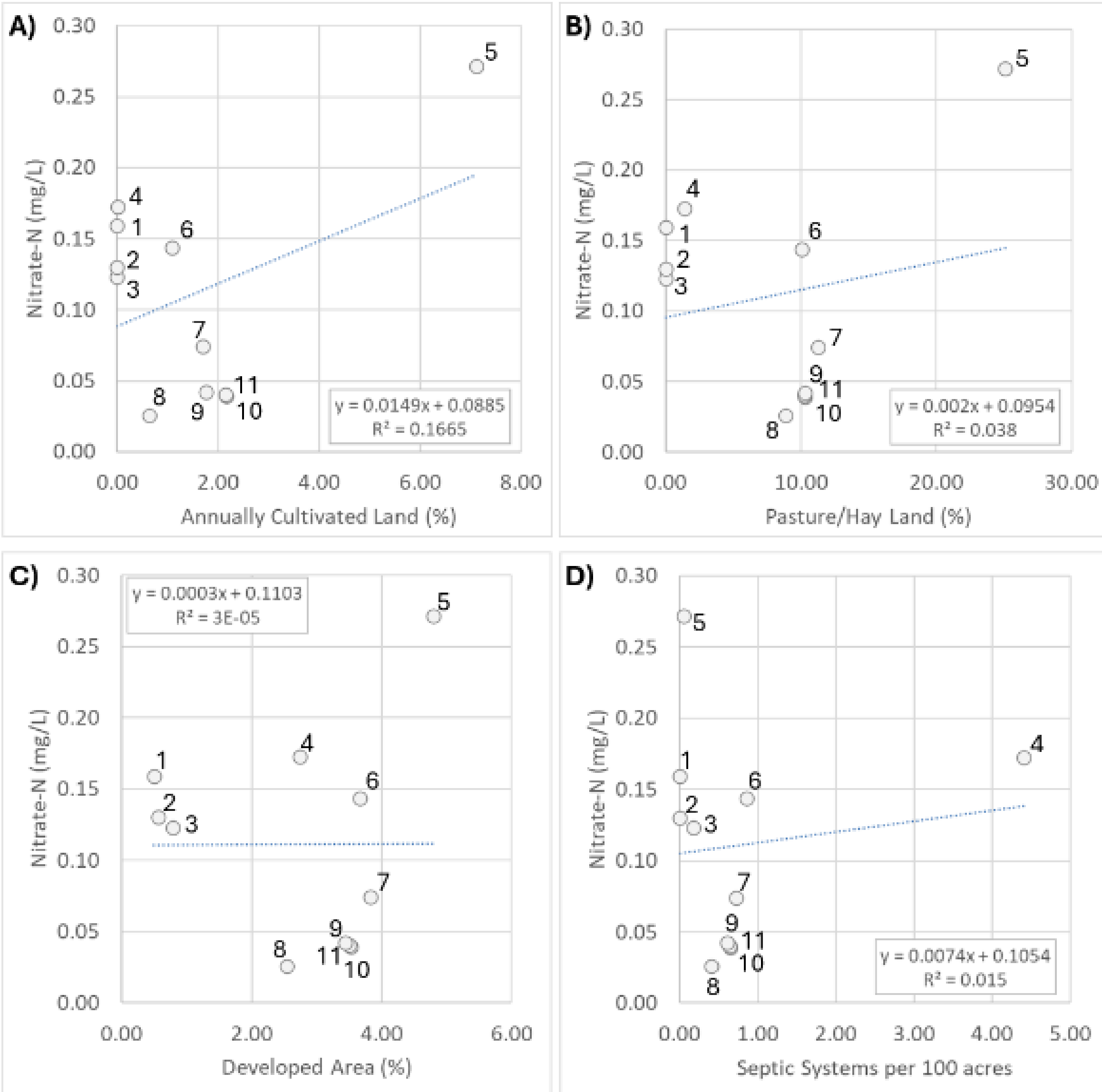

Figure 12. Nitrate-N versus land use for each sample site watershed. *Mean Nitrate-N concentrations (y-axis) for eleven CCRC sample sites are plotted versus different land use characteristics for the watershed delineated for each site. Sample sites are identified by the number next to each point, corresponding to the plot order in Table 1 and used in the nitrate boxplot (Figure 5). X axis values are A) percent of watershed area in annual cultivation (p = 0.17); B) percent of watershed area in perennial vegetation as pasture/hay land (p = 0.50); C) percent of watershed area in developed land area, including all four development density classes (p = 0.85); D) septic systems per 100 acres within the watersheds (p = 0.75). The dotted blue line represents a linear regression with the equation and R2 value displayed on the plot. Land covers are from the 2024 National Land Cover Dataset; see methods for details on septic density.*

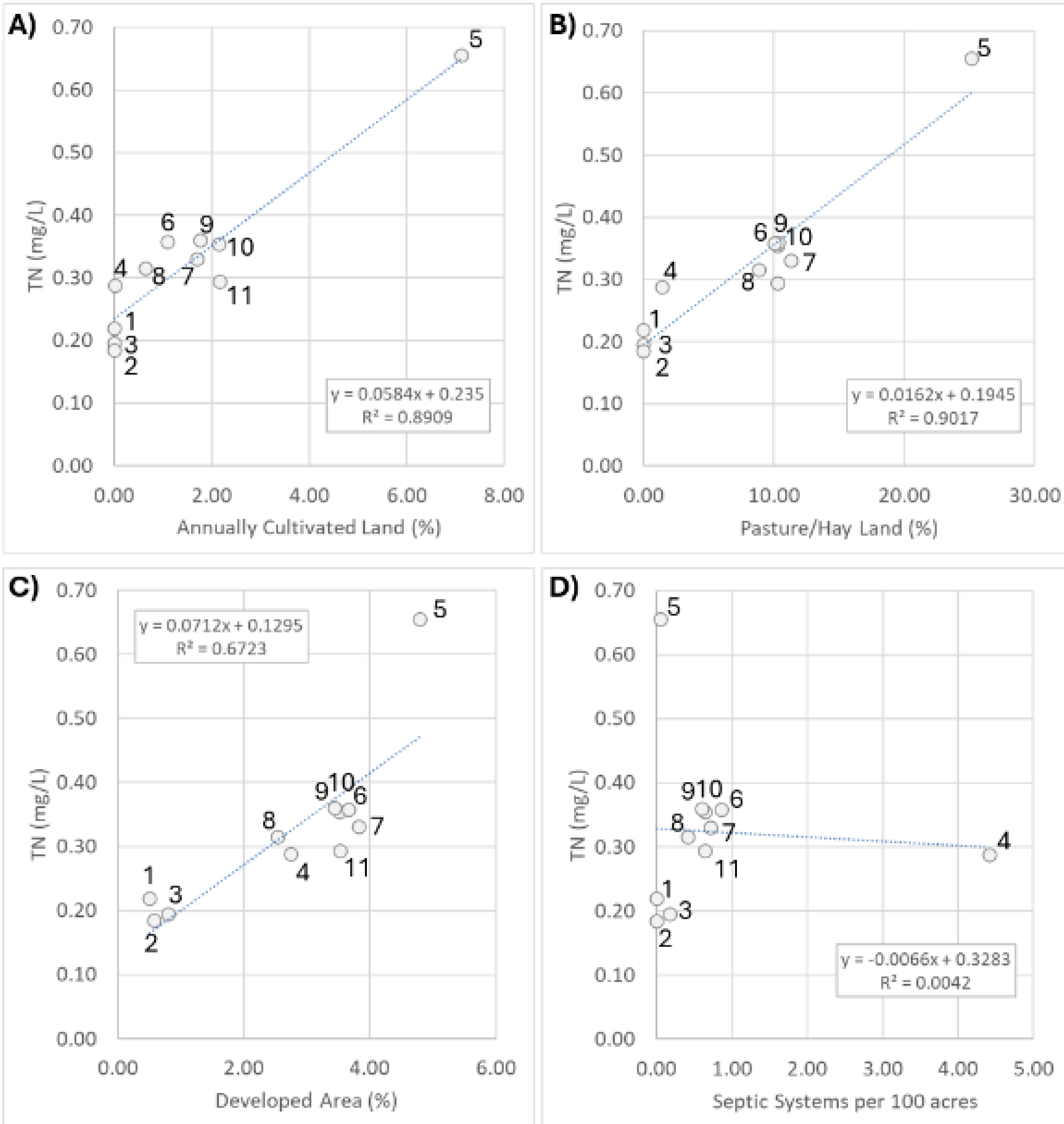

Figure 13. TN versus land use for each sample site watershed. *Mean TN concentrations (y-axis) for eleven CCRC sample sites are plotted versus different land use characteristics for the watershed delineated for each site. Sample sites are identified by the number next to each point, corresponding to the plot order in Table 1 and used in the nitrate boxplot (Figure 5). X axis values are A) percent of watershed area in annual cultivation ($p < 0.001$); B) percent of watershed area in perennial vegetation as pasture/hay land ($p < 0.001$); C) percent of watershed area in developed land area, including all four development density classes ($p < 0.005$); D) septic systems per 100 acres within the watersheds ($p = 0.85$). The dotted blue line represents a linear regression with the equation and R2 value displayed on the plot. Land covers are from the 2024 National Land Cover Dataset; see methods for details on septic density.*

Phosphorus

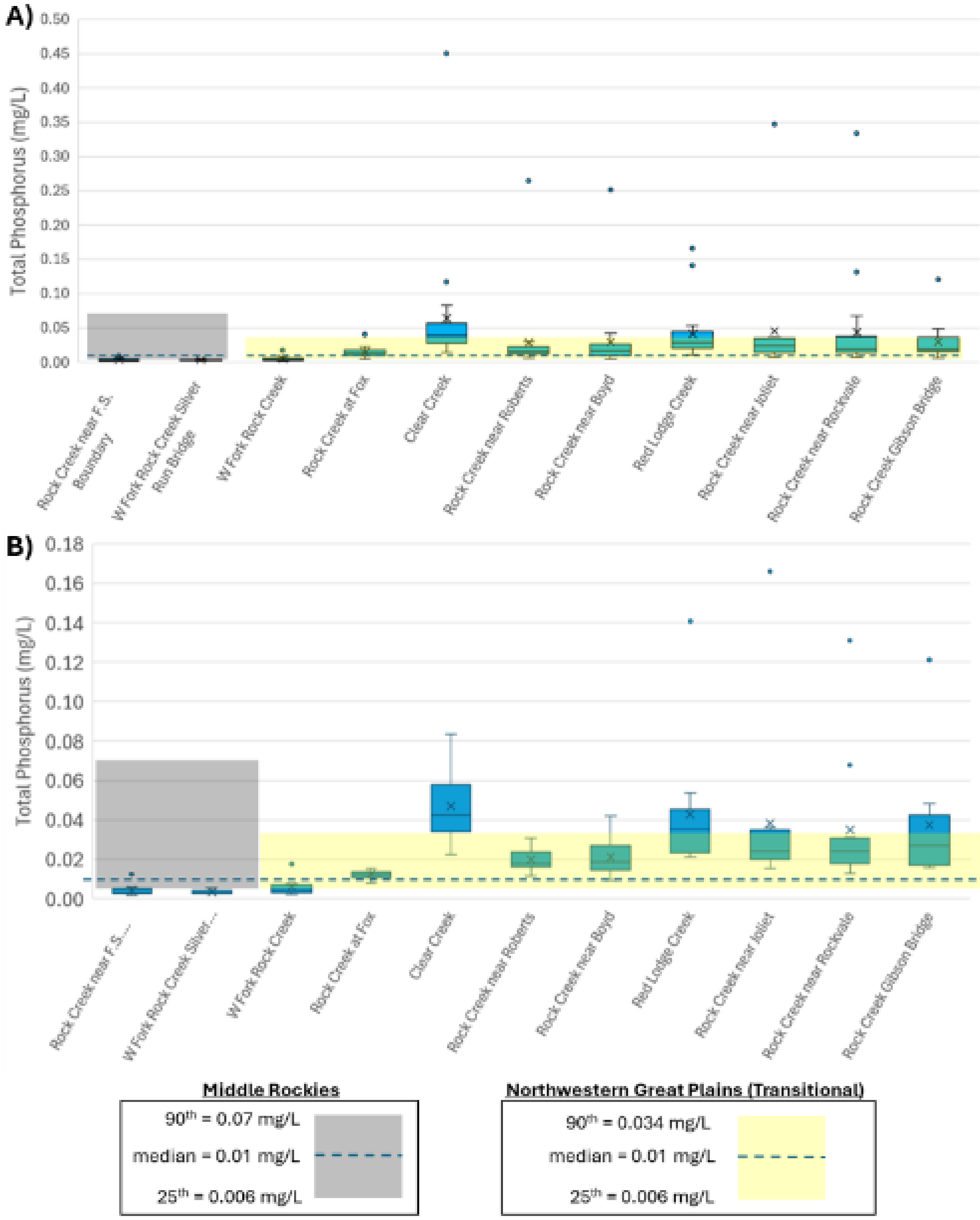

Figure 14. Total Phosphorus by site. *Total phosphorus (TP) concentrations (mg/L, y-axis) are represented for samples collected by CCRC between May 2, 2022 and October 27, 2024. Data from all samples are represented in panel A), while panel B) includes only samples from growing season months (July through September), which aligns with timing of sample collection at the reference sites (note the smaller maximum on y-axis for panel B). The lines within the boxes are the median concentrations and X's are mean concentrations. Box plots follow standard notation where the box indicates the interquartile range (25th and 75th percentiles). The whiskers extend to the furthest concentration that is not classified as an outlier. The points beyond the whiskers are outliers, defined as values more than 1.5 times the interquartile range away from the box. The shaded range and dashed lines are concentrations observed at reference sites within the ecoregions associated with each site (Suplee and Watson, 2013; Tables 3-1A and 3-11A). The lower extent of the shading is the 25th percentile of reference site observations, the upper extent of shading at the 90th percentile, and the dashed line is the median observed concentration at reference sites for each ecoregion.*

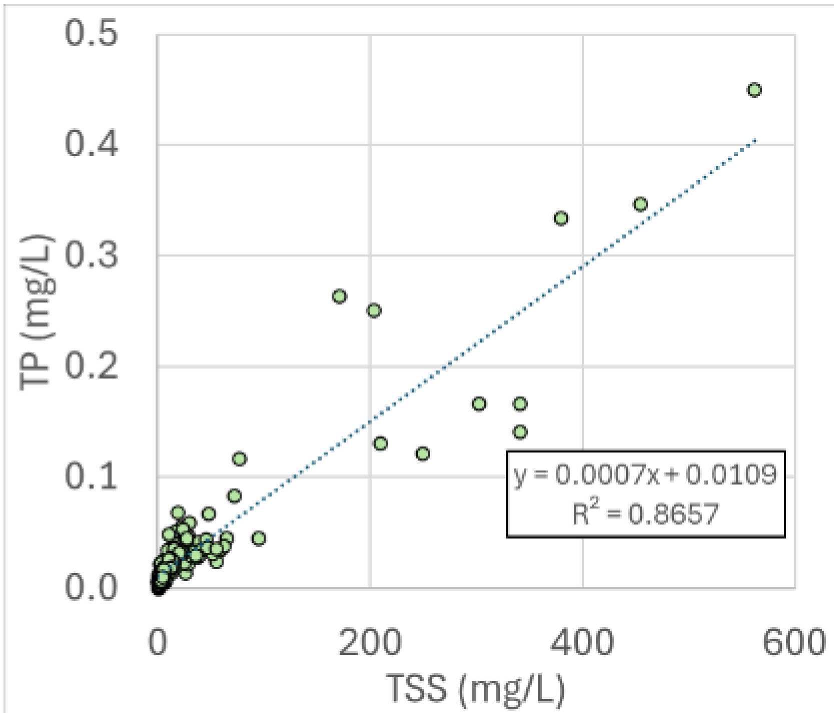

Figure 15. Total Phosphorus versus Total Suspended Solids. *TP concentrations are plotted on the Y axis versus TSS concentrations on the X axis. The dotted line represents a linear regression with the equation and* r^2 *value displayed on the plot (p value < 0.001). Data points represent individual sampling events.*

Total Phosphorus (TP) concentrations ranged from non-detects (<0.0015 mg/L) to 0.45 mg/L across all sites (Figure 12). The three uppermost sampling sites (Rock Creek near F.S Boundary, WF Rock Creek at Silver Run Bridge, and WF Rock Creek) had lower median TP concentrations (<0.007 mg/L) than the remaining eight downstream sites (0.01 to 0.04 mg/L). The highest median (0.04 mg/L), mean (0.06 mg/L), and outlier (0.45 mg/L) concentrations were observed at Clear Creek.

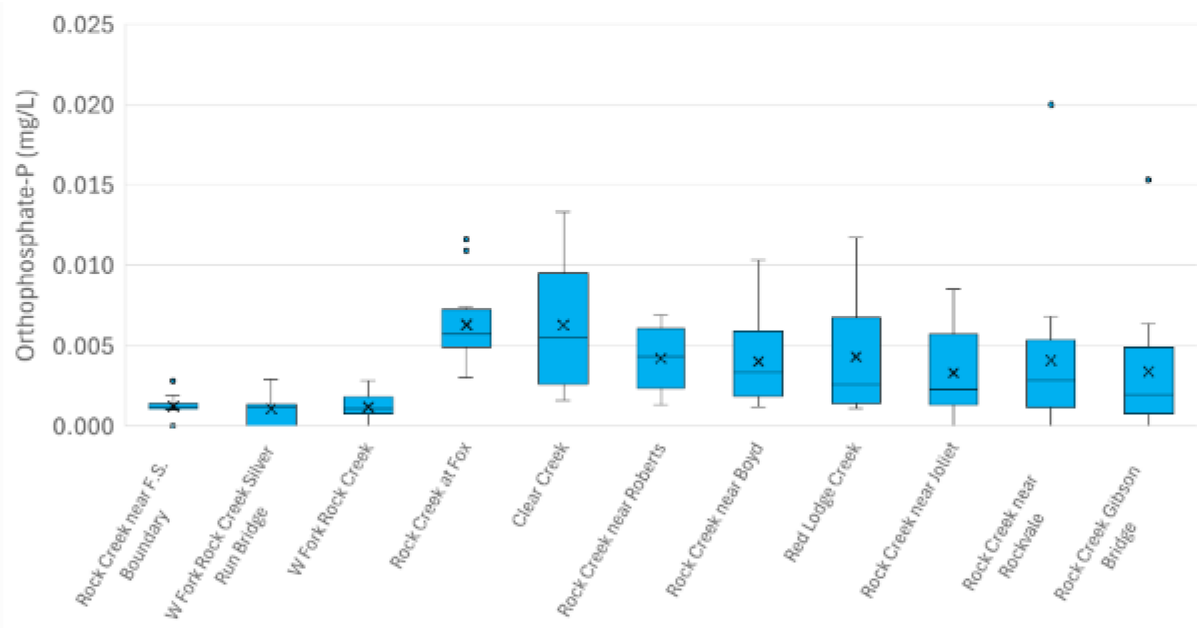

Figure 16. Orthophosphate by site. *Orthophosphate concentrations (mg/L, y-axis) are represented for samples collected by CCRC between May 2, 2022 and October 27, 2024. Sites are organized from upstream to downstream (left to right, x-axis). The lines within the boxes are the median concentrations and X's are mean concentrations. Box plots follow standard notation where the box indicates the interquartile range (25th and 75th percentiles). The whiskers extend to the furthest concentration that is not classified as an outlier. The points beyond the whiskers are outliers, defined as values more than 1.5 times the interquartile range away from the box.*

Orthophosphate concentrations ranged non-detects (<0.0008 mg/L) to 0.02 mg/L across the sites (Figure 16). The three uppermost sampling sites (Rock Creek near F.S Boundary, WF Rock Creek at Silver Run Bridge, and WF Rock Creek) had lower median orthophosphate concentrations (0.0012 mg/L) than the downstream sites (all sites after WF Rock Creek) (0.0023 to 0.0057 mg/L). The highest median concentration (0.0057 mg/L) occurred at Rock Creek at Fox; the highest mean concentration (0.0063 mg/L) was shared by Rock Creek at Fox and Clear Creek; the maximum observed concentration (0.02 mg/L) was recorded at Rock Creek near Rockvale.

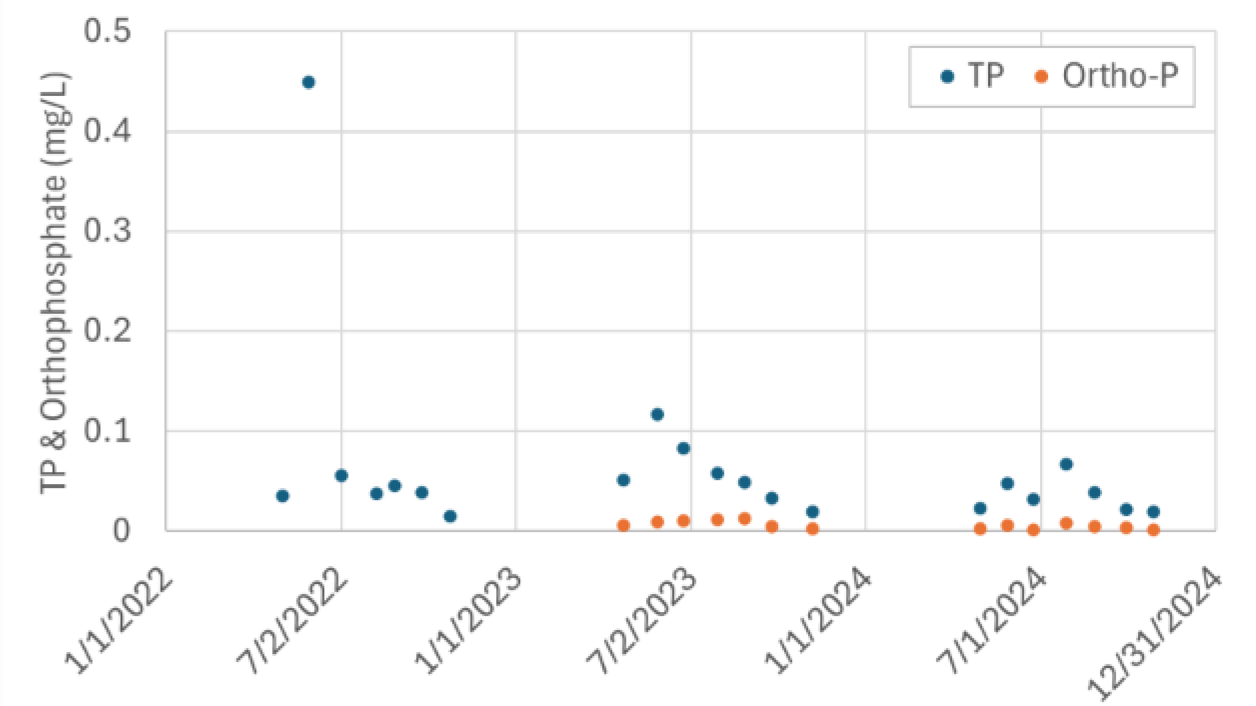

Figure 17. Total Phosphorus and Orthophosphate at Clear Creek. *Total phosphorus (TP) (blue) and orthophosphate (Ortho-P) (orange) are represented in mg/L on the y-axis. Concentrations are represented as points for samples collected by CCRC between 5/2/2022 and 10/27/2024, downloaded from WQX.*

Total phosphorus concentrations in Clear Creek ranged from 0.01 to 0.45 mg/L over the monitoring period, while orthophosphate (Ortho-P) concentrations ranged from 0.0016 to 0.0133 mg/L (Figure 14). The highest TP concentration (0.45 mg/L) was observed in May 2022. The highest ortho-p concentration (0.0133 mg/L) was measured on August 28th,2023. The lowest concentration for TP was 0.0148 mg/L on 10/24/2022. The lowest concentrations for TP were typically observed during the final sample event of each year (10/24/2022, 11/6/2023, and 10/27/2024).

Total Suspended Solids

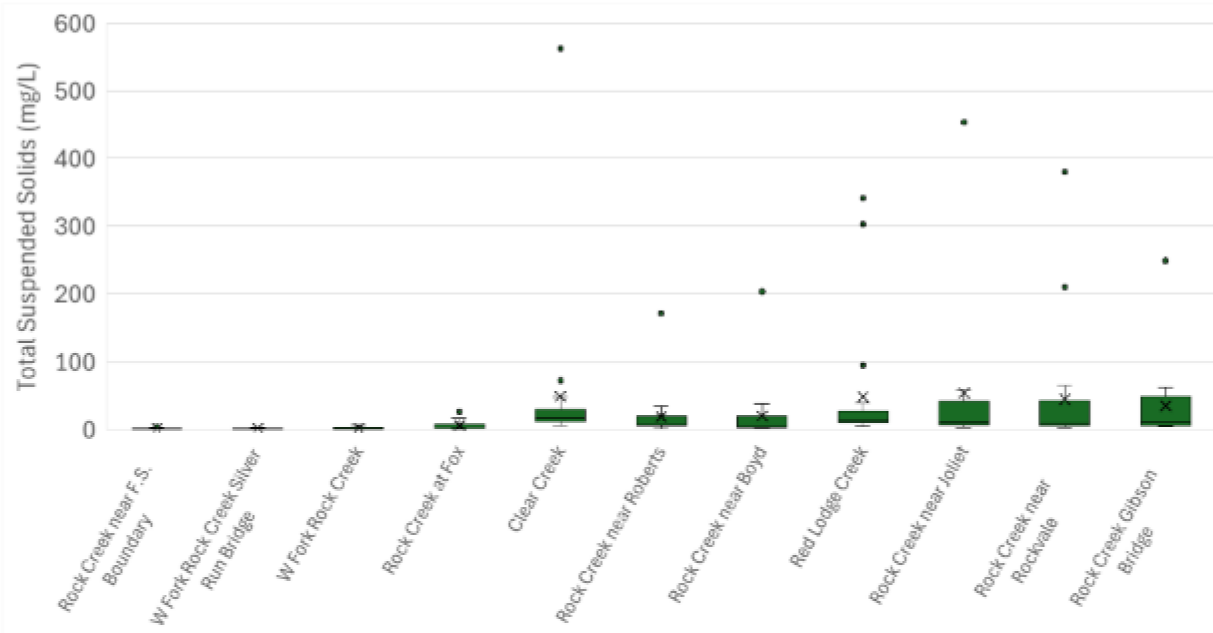

Figure 18. Total suspended solids by site. *Total suspended solids (TSS) concentrations (mg/L, y-axis) are represented for samples collected by CCRC between 2022 and 2025, downloaded from WQX. Sites are organized from upstream to downstream (left to right), on the x-axis. The X's within the boxes are the mean and the lines are the median concentrations. Boxplots follow standard notation where the box indicates the interquartile range (25th and 75th percentiles). The whiskers extend to the furthest concentration that is not classified as an outlier. The points beyond the whiskers are outliers, defined as values more than 1.5 times the interquartile range away from the box.*

Total suspended solids (TSS) concentrations exhibited a general trend of increasing concentrations from upstream to downstream locations (Figure 18). The uppermost three sites (Rock Creek near F.S. Boundary, WF Rock Creek Silver Run Bridge, and WF Rock Creek) had the lowest median TSS concentrations, ranging from 1.0 to 1.4 mg/L. Clear Creek had a median concentration of 17 mg/L, and a mean of 50 mg/L. Sites including Rock Creek at Fox and those further upstream had all TSS values less than 35 mg/L. The eight sites lowest in the watershed all had at least one high outlier concentration, and these high values occurred during the months of May and June.

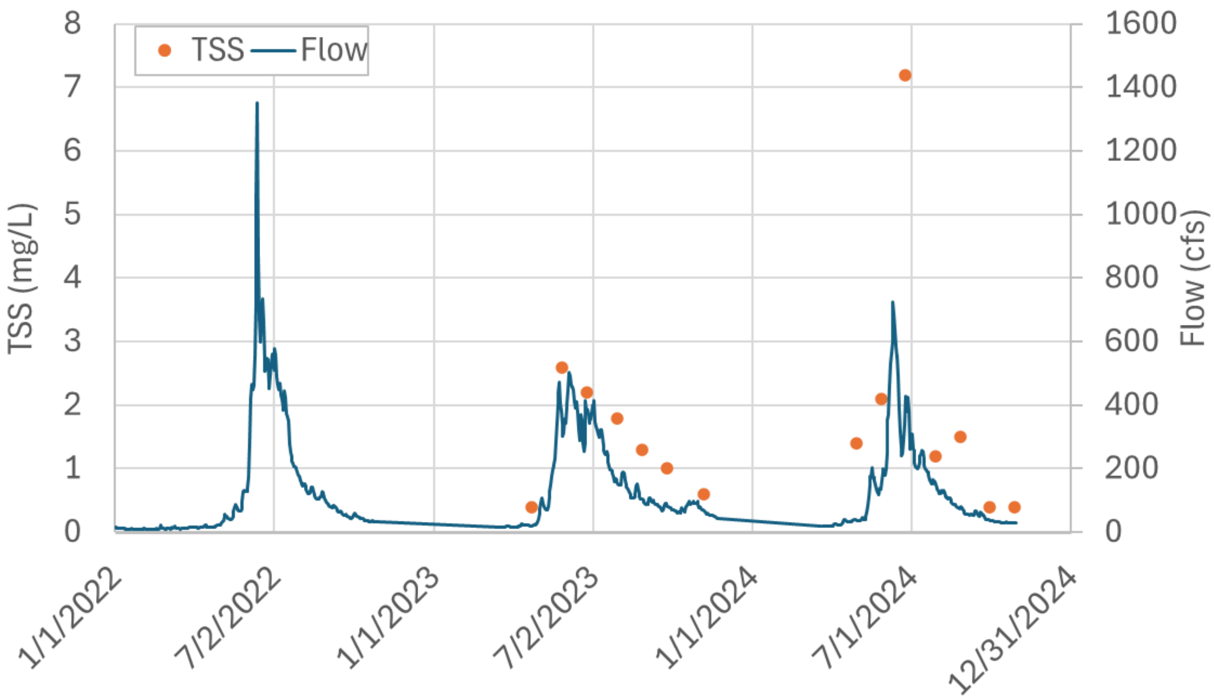

Figure 19. Total Suspended Solids and Flow for Rock Creek at Silver Run Bridge. *Total suspended solids (TSS) (mg/L, left y-axis) concentrations are represented by orange points for samples collected by CCRC between 4/23/2023 and 10/27/2024, downloaded from WQX. Discharge (cfs, right y-axis) is represented by the blue line for data collected by DNRC, downloaded from DNRC.*

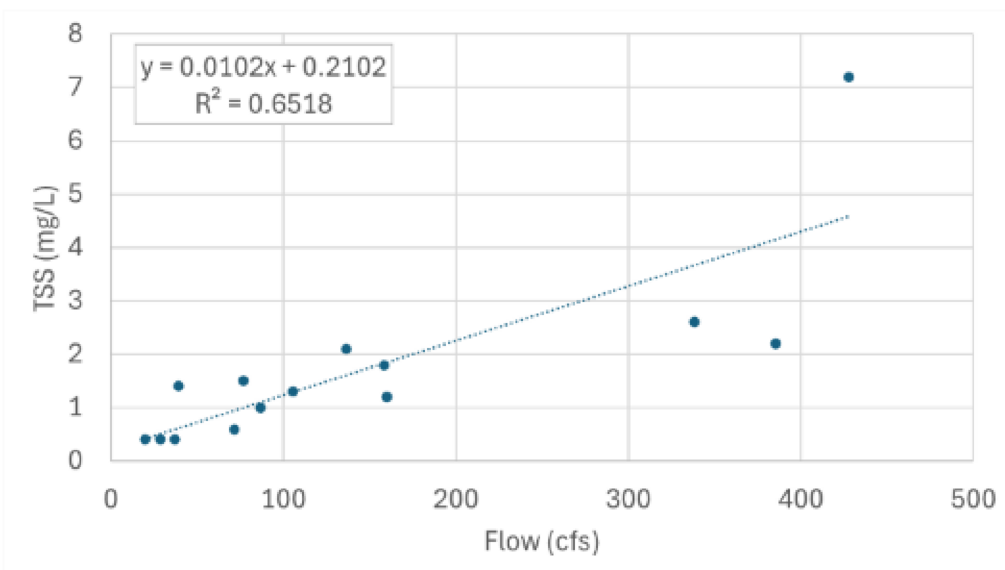

Figure 20. Regression of Total Suspended Solids and Flow for Rock Creek at Silver Run Bridge. *Total suspended solids (TSS) concentrations (y-axis) are represented for samples collected by CCRC between 4/23/2023 and 10/27/2024, downloaded from WQX. Discharge (cfs, x-axis) is represented for data collected by DNRC at WF Silver Run Bridge, downloaded from DNRC. Points represent TSS concentrations at given discharge values. The dashed line represents the relationship between TSS concentrations and discharge.*

Total suspended solids (TSS) concentrations at Silver Run Bridge ranged from 0.4 to 7.2 mg/L with daily discharge values on the day of sampling ranging from 20 to 428 cfs (Figures 19 and 20). TSS concentrations peaked in the spring, with annual maximums of 7.2 mg/L on June 24th, 2024, and 2.6 mg/L on May 28th, 2023, and then decreased over the June to November period. Stream discharge displayed seasonal patterns with peak flows occurring during spring months, reaching maximum values of approximately 504 cfs in spring 2023 and 726 cfs in spring 2024. The majority of TSS measurements occurred at flows below 200 cfs, with concentrations ranging from 0.4 to 2.1 mg/L. At higher discharge conditions (>300 cfs), TSS concentrations ranged from 2.2 to 7.2 mg/L, with that maximum concentration observed at 428 cfs. The linear regression yielded an equation of $y = 0.01x + 0.2$ with an R^2 value of 0.65, indicating that approximately 65% of the variability in TSS concentration can be explained by stream discharge. The positive slope of the regression line indicates a positive relationship between discharge and TSS concentration, meaning that higher flow produces higher TSS.

Water Temperature

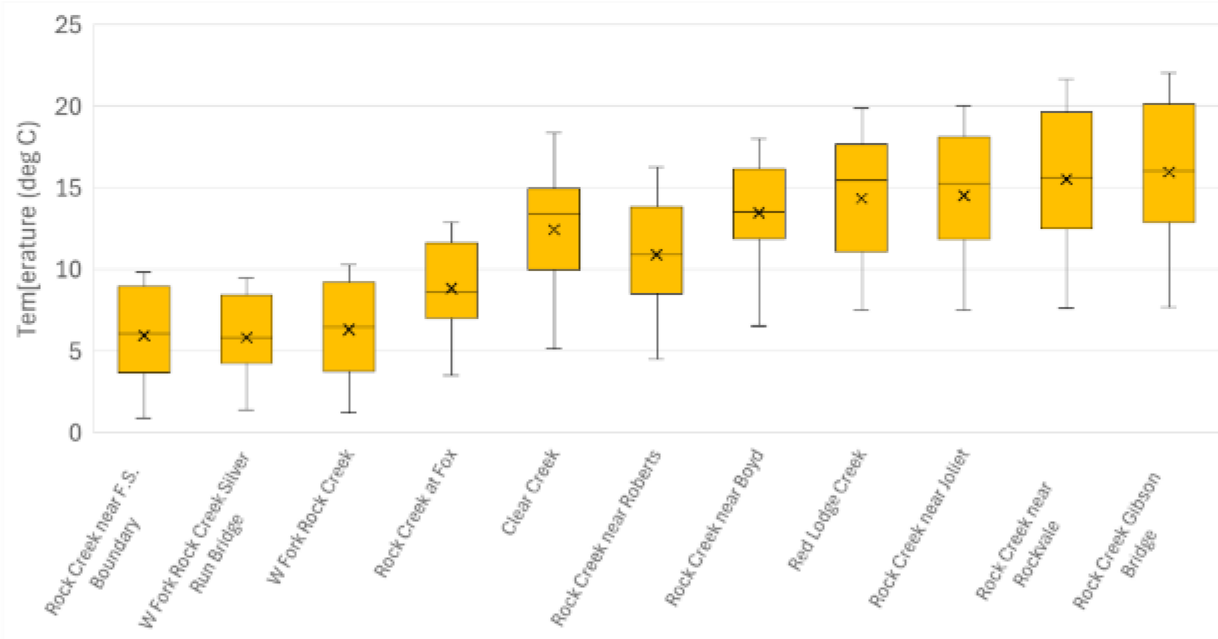

Figure 21. Water temperature by site. *Water temperature concentrations (°C, y-axis) are represented for samples collected by CCRC between 5/2/2022 and 10/27/2024, downloaded from WQX. Sites are organized from upstream to downstream (left-to-right), on the x-axis. The Xs within the boxes are the mean and the lines are the median concentrations. Following standard notation for boxplots, the box indicates the interquartile range (25th to 75th percentiles). The whiskers extend to the furthest concentration that is not classified as an outlier.*

Water temperature exhibited a warming trend from upstream to downstream sites (Figure 21). The uppermost sites (WF Rock Creek F.S. Boundary, WF Rock Creek Silver Run Bridge, and WF Rock Creek) displayed the lowest median temperatures, ranging between 5.8 and 6.5°C. Rock Creek at Fox had a median temperature of 8.6°C with a range extending from 3.5 to 12.9°C. The four furthest downstream sites (Red Lodge Creek, Rock Creek near Boyd, Rock Creek near Rockvale, and Rock Creek Gibson Bridge) exhibited the highest median temperatures, ranging from 15.2 to 16.0°C.

		Rock Creek near F.S. Boundary	W Fork Rock Creek Silver Run Bridge	W Fork Rock Creek	Rock Creek at Fox	Clear Creek	Rock Creek near Roberts	Rock Creek near Boyd	Red Lodge Creek	Rock Creek near Joliet	Rock Creek near Rockvale	Rock Creek Gibson Bridge
Nitrate-N	mean	0.159	0.130	0.123	0.172	0.272	0.144	0.074	0.026	0.042	0.040	0.039
	median	0.149	0.142	0.126	0.152	0.231	0.143	0.053	0.020	0.016	0.018	0.014
Total Nitrogen	mean	0.219	0.185	0.195	0.288	0.655	0.358	0.331	0.315	0.360	0.355	0.294
	median	0.204	0.187	0.190	0.257	0.565	0.292	0.237	0.286	0.277	0.261	0.266
Total Phosphorus	mean	0.0037	0.0034	0.0053	0.0148	0.0638	0.029	0.0297	0.0416	0.0453	0.044	0.0306
	median	0.0031	0.0033	0.004	0.0136	0.039	0.0166	0.0174	0.0295	0.024	0.02	0.0191
Phosphorus, Ortho	mean	0.0013	0.0013	0.0014	0.0063	0.0063	0.0042	0.004	0.0043	0.0036	0.005	0.004
	median	0.0012	0.0012	0.0012	0.0057	0.0055	0.0043	0.0034	0.0026	0.0023	0.003	0.0029
Total Suspended Solids	mean	1.2	1.7	2.1	6.2	49.2	18.7	20.0	48.6	53.7	45.0	35.2
	median	1.0	1.4	1.1	2.1	16.9	7.1	5.3	15.2	10.7	9.6	10.5
Temperature, Water	mean	5.94	5.82	6.29	85.68	12.42	10.88	13.45	14.33	14.49	15.51	15.95
	median	6.09	5.84	6.47	8.55	13.35	10.92	13.46	15.43	15.21	15.64	16.01

Table 3. Summary statistics. *Mean and median values of Nitrate-N, TN, TP, Ortho-P, TSS, and water temperature are presented for all sites, with significant figure according to values from lab results.*

Discussion

Nitrogen

TN concentrations for the three most upstream sites were largely below the 90^{th} percentile of reference site growing season concentrations, while sites from Rock Creek at Fox and below all had the majority of concentrations above the 90^{th} percentile of reference sites (Figure 4). This pattern with majority of concentrations for those lower sites above the 90^{th} percentile of reference sites was present both when all data were included and when only growing season data (July – September) was included. The fraction of TN composed of nitrate was variable across sites and time, but upstream sites generally had more TN composed of nitrate than downstream sites. In contrast to the concentration of TN generally increasing below the Fox site, the concentration of nitrate decreased along the Rock Creek mainstem from Fox to Gibson Bridge. This pattern is consistent with nitrate present in the upper reaches being taken up by algae, microalgae, or aquatic plants in lower reaches and being converted to instream biomass, which can contribute to TN as biomass slough off into the water column. The fact that the two most upstream sites on Rock Creek have the majority of nitrate-N concentrations above the 0.1 mg/L threshold and the downstream sites having TN concentrations above the 90^{th} percentile of reference sites suggests that the entire Rock Creek watershed has potential for nuisance algae growth from a nitrogen perspective.

Clear Creek consistently displayed the highest nitrate-N concentrations (median of 0.231 mg/L) with more than 75% of observations exceeding the 0.1 mg/L threshold associated with increased nuisance algae potential. While these elevated nitrate-N concentrations for Clear Creek and for Rock Creek at Roberts and Fox are consistent with higher land use intensity, the median concentrations above 0.1 mg/L observed at the two headwaters sites are higher than is typical for watersheds draining primarily US Forest Service managed land.

The TN at the two headwater sites is primarily composed of nitrate (~72 to 89%). This large fraction of TN composed of nitrate, coupled with the negative correlation between nitrate and flow suggests that nitrate is likely entering the streams through groundwater. The negative correlation between nitrate and flow is much stronger for the Rock Creek at FS Boundary site ($p < 0.001$) than at the West Fork Rock Creek at Silver Run site, where the relationship is not statistically significant ($p = 0.61$). While the Silver Run site shows evidence of dilution, the dilution appeared delayed behind peak flow in 2023. In 2024, one relatively high nitrate concentration observed during higher flows indicates more complexity in nitrate sourcing than simple even spatial distribution of elevated nitrate in groundwater. While the structure based septic mapping approach did not identify any septic systems in these headwater watersheds, this analysis has limitations for septic identification and does not capture other possible sources of human waste such as faulty vault toilets, dispersed camping, etc. In addition to further assessment for human sources of nitrate in the headwaters, geologic or other physiographic anomalies could be evaluated as explanations.

Assessment of land use across watersheds relative to nitrogen concentrations measured at sample sites revealed contrasting patterns for TN and nitrate. While septic systems, residential development, and cultivated agriculture can all contribute nitrate to groundwater, there were no significant correlations between nitrate and the four land use metrics evaluated (Figure 12). When TN was evaluated however, mean concentrations were positively correlated with percent of the sub-watershed in cultivated land, pasture/hay, and developed land area (Figure 13). For watersheds with a mixture of land uses, this relatively simple assessment of each land use separately cannot tease out the relative importance of sources. However, the analysis does indicate a clear pattern across the Rock Creek watershed: that areas with higher land use intensity are experiencing higher loading of nitrogen to streams.

Septic system density did not emerge as a strong predictor or either nitrate (Figure 12D) or TN (Figure 13D). However, septic systems do contribute nitrate to groundwater and at high density can be an important contributor of nitrogen to surface water via groundwater pathways. The Rock Creek at Fox site had the highest septic density among all sub-watersheds at 4.4 per 100 acres. While the nitrate-N concentrations above 0.1 mg/L at sample sites above Fox do not seem to be attributable to septic systems, the increase from those sites to a median of 0.17 mg/L at Fox could be attributed to relatively high septic density. Additional work is needed to understand sources of nitrate at headwater sites and the relative contribution of nitrate from septic systems to Rock Creek through the corridor of higher development intensity near Red Lodge.

Phosphorus

In contrast to nitrogen that is elevated relative to reference sites throughout the Rock Creek watershed, TP starts relatively low in the headwaters and begins to increase around the Rock Creek at Fox site. Most observations of TP are below the 90th percentile of observations at reference sites, with the exception of Clear Creek where more than half of the observations are above the reference site 90th percentile. The sites with the largest number of TP observations above reference site 90th percentile, are Clear Creek and Red Lodge Creek, indicating these two tributaries as potentially higher risk for phosphorus related nuisance algae growth.

Phosphorus is typically strongly associated with sediment, and this pattern is observed with strong correlations between TP and TSS for the Rock Creek watershed. Across all observations, 87% of variability in TP can be predicted by TSS (Figure 15). TSS is typically strongly predicted by flow, and this relationship was observed at Rock Creek at Silver Run Bridge (Figure 20). This indicates that most phosphorus mobilization is happening at high flow, likely associated with erosion of some combination of upland soil and stream banks.

For the Clear Creek site, an interesting contrast was observed in 2023 betweenTP and orthophosphate, the primary soluble form of the nutrient. While the concentration of TP decreased over the season from a peak of 0.12 mg/L on May 28th, the concentration of orthophosphate increased over that period to a maximum concentration of 0.013 mg/L on August 28th. While most phosphorus is present in streams in particulate form, the fraction composed of orthophosphate is readily available to plants. If nuisance algae occurs in Clear Creek, additional observations of possible soluble phosphorus sources during summer months could provide useful insights.

TSS

Total suspended solids displayed typical seasonal trends, whereby concentrations peaked during spring runoff and decreased over the summer months as flows diminished. TSS exhibits this positive relationship with flow due to (1) snowmelt and precipitation collecting sediment during overland travel and (2) high instream flows carving sediment out of riparian banks. As 65% of variability in TSS at Rock Creek at Silver Run Bridge can be predicted by flow (Figure 20), this indicates 35% of variability may be prompted by other factors, such as erosion outside of peak flows or direct contributors of sediment to the stream.

TSS concentrations increased from upstream to downstream, with the seven most downstream sites all having at least one outlier concentration >150 mg/L during spring runoff (Figure 18). The three uppermost sites, however, had no measured TSS concentrations above 10 mg/L, even during peak runoff. This pattern is consistent with course substrate in headwater areas resulting in relatively little sediment mobilization and increasing erosion in lower reaches where more erodible soils are present and land use intensity is higher.

Limitations and Future Work

The sampling design to collect observations from May through October covers a wide range of flow and temperature conditions. For isolation of groundwater contributions to stream nitrate concentrations, additional sample collection during baseflow conditions could be useful. A November sampling event could lend insights into baseflow nitrate conditions across sites.

Concentration data is very useful for identifying patterns across the watershed. Insights about sources of nutrients would benefit from ability to calculate loads, which requires concentration and flow collected at the same time. To address this need, we understand that effort has been made to align sample timing with DEQ sample events when discharge is measured, which is great. Where possible the addition of flow data to augment the concentration data would be great.

The relatively high nitrate concentrations at the two headwater sites with an absence of well-characterized high intensity land use pose further questions. Are there land uses up stream from the headwater sites that are contributing nitrate to the streams, and/or are there natural sources of nitrate relatively unique to the region?

The land use analysis was conducted on a watershed scale and for each land use independently. Follow up analysis could use multiple linear regression to account for multiple land uses contributing nutrients within the same watershed. Analysis could also be enhanced to apply weighting to land uses that are closer to the stream network, acknowledging that those more proximate land uses could have a larger effect on stream water quality than those farther away. Septic influence assessment could also assess septic density, soils, proximity to streams, and possibly groundwater flow direction or other key watershed attributes.

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