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# A Statewide Assessment of BLM-Managed Streams and Rivers in Colorado

## Technical Note 458

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# A Statewide Assessment of BLM-Managed Streams and Rivers in Colorado

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# Contents

# Abstract

Throughout Colorado, the Bureau of Land Management (BLM) oversees approximately 33,800 square kilometers of land containing more than 3,600 km of perennial streams and rivers. This technical note presents the results of a statewide assessment of chemical, physical, and biological conditions of BLM-managed streams and rivers in Colorado. From 2013 to 2017, 209 reaches (2,313 stream kilometers) were sampled during summer baseflow conditions using the BLM's Assessment, Inventory, Monitoring methods. Benchmarks were established for 12 indicators that relate to BLM Colorado land health standards. Results are reported in terms of the extent of streams having minimal, moderate, or major departure from benchmarks with a ±90% confidence interval. For water quality indicators, such as pH, water temperature, and nutrients (i.e., total nitrogen and phosphorus), with standards set by the Colorado Department of Public Health and Environment, less than 16% of stream kilometers exceeded these standards. Similarly, more than 85% of BLM-managed stream kilometers met the state's macroinvertebrate biological condition criteria. Although not in exceedance of state standards, nutrient and specific conductance levels were elevated above reach potential for 34–51% of streams, which is a potential concern for downstream cumulative effects. Indicators characterizing riparian and instream habitat, such as bank stability and cover, fine sediment, nonnative woody riparian vegetation, and floodplain connectivity, generally identified more exceedances of BLM land health standards than those related to water quality. Floodplain connectivity was compromised for 48% of stream and river kilometers, and 47% had nonnative woody riparian vegetation species. The BLM can use this quantitative, unbiased baseline assessment to track the cumulative effectiveness of management actions over time.

# Introduction

Throughout the State of Colorado, the Bureau of Land Management (BLM) oversees approximately 33,800 square kilometers of land containing more than 3,600 km of perennial streams and rivers. BLM stream and riparian systems are among the most important, productive, diverse, and sensitive ecosystems in the state. They provide habitat for a wide range of aquatic and terrestrial species and support ecosystem services, such as a clean reliable source of water for humans, wildlife, livestock, and irrigated agriculture.

Under the Federal Land Policy and Management Act (FLPMA), the BLM manages public lands for multiple uses and sustained yield (section 102(a)(7)) in a manner that protects the quality of scientific, scenic, historical, ecological, environmental, air and atmospheric, water resource, and archeological values (section 102(a)(8)). Thus, watersheds are managed both for conservation of natural resources and for activities, such as livestock grazing, timber harvest, mining, energy development, and dispersed and developed recreation, that use or potentially impact riparian and stream and river resources (hereafter referred to as lotic systems). Consequently, knowing the condition and trend of riparian and lotic systems is critical to achieving the BLM's mission, which is to sustain the health, diversity, and productivity of the public lands for the use and enjoyment of present and future generations.

Section 201(a) of FLPMA requires current and continuous inventory of renewable resource condition and trend. Following the BLM's Assessment, Inventory, and Monitoring (AIM) strategy for lotic systems (BLM 2015), the lotic AIM protocol is actively used by more than 60 field offices from Alaska to New Mexico to justify and assess the efficacy of restoration and reclamation actions, assess resource management plan effectiveness (BLM Instruction Memorandum 2016-139), and ensure the sustainability of permitted uses.

This technical note presents the results of a statewide assessment of chemical, physical, and biological conditions of BLM-managed streams and rivers in Colorado. The five main objectives of conducting the assessment include:

1. Assess achievement of BLM Colorado land health standards for streams and rivers (BLM 1997).
2. Establish baseline conditions from which trends can be assessed.
3. Document the process by which benchmarks were developed and used to evaluate land health standard achievement.
4. Identify and rank the stressors contributing to degraded lotic conditions, if not achieving standards.
5. Prioritize step-down monitoring and adaptive management strategies to improve riparian and lotic habitats on BLM-managed lands.

# Methods

Data were compiled from the Western Rivers and Streams Assessment (2013–2015) and various ecoregional and field office-scale monitoring efforts that occurred between 2014 and 2017. In total, this study includes 209 stream reaches from the target population of BLM-managed streams and rivers in Colorado (figure 1).

All sample locations originated from probability-based survey designs, from which reaches were selected in approximate proportion to the linear extent of streams by Strahler stream order categories: small streams are first and second order; large streams are third and fourth order; and rivers are fifth order and greater. Stream order provides a means of ranking the relative sizes of streams within a drainage basin, whereby a second order stream is formed by the junction of any two first order streams, third order by the junction of any two second order streams, and so on (Strahler 1952). The use of Strahler stream order ensures the distribution of sample locations from small headwater streams to large river systems. The use of both random reach selection and standard field methods among lotic AIM studies allows results among monitoring efforts to be combined to report on the condition of BLM-managed streams statewide with known levels of confidence. For example, the authors conclude that 79.1% of BLM-managed streams and rivers in Colorado met standards (90% confidence interval ± 3.7%).

The 209 reaches were sampled during the summers of 2013–2017 using lotic AIM methods (BLM 2017), which collectively address three BLM Colorado land health standards (standards 2, 4, and 5) applicable to riparian and lotic systems (table 1). Based on field data from the reaches sampled, six indicators were applicable to Colorado standard 2 (riparian and stream channel function), six indicators were applicable to Colorado standard 5 (water quality), and those 12 indicators were applicable to Colorado standard 4 (special status species), such as cold and warm water fishes (table 1).

To assess stream condition objectively, benchmarks were established for each of the 12 indicators (appendix A). Benchmarks are indicator values or ranges of values used to evaluate whether a reach is achieving or not achieving standards based on how observed conditions compare to reach potential under minimal anthropogenic constraints (i.e., best available conditions). Benchmarks were largely set based on best available environmental conditions for Colorado streams and rivers. Specifically, benchmarks followed Colorado Department of Public Health and Environment (CDPHE) Regulation 31 (The Basic Standards and Methodologies for Surface Water). When CDPHE regulations did not specify benchmarks for a given indicator, published literature values, best professional judgement, or existing networks of least disturbed stream and river monitoring locations were used to characterize the range of reach potential by ecoregion (appendix 1, table A1). During this assessment, CDPHE was revising benchmarks for the water quality indicators total nitrogen and total phosphorus, which were assessed in terms of both CDPHE benchmarks and predicted natural conditions. Indicator values for the 209 sampled reaches were assigned a condition class based on whether they exhibited minimal, moderate, or major departure from benchmarks. Indicators scoring major departure were considered to not achieve BLM Colorado land health standards (see appendix A for details).

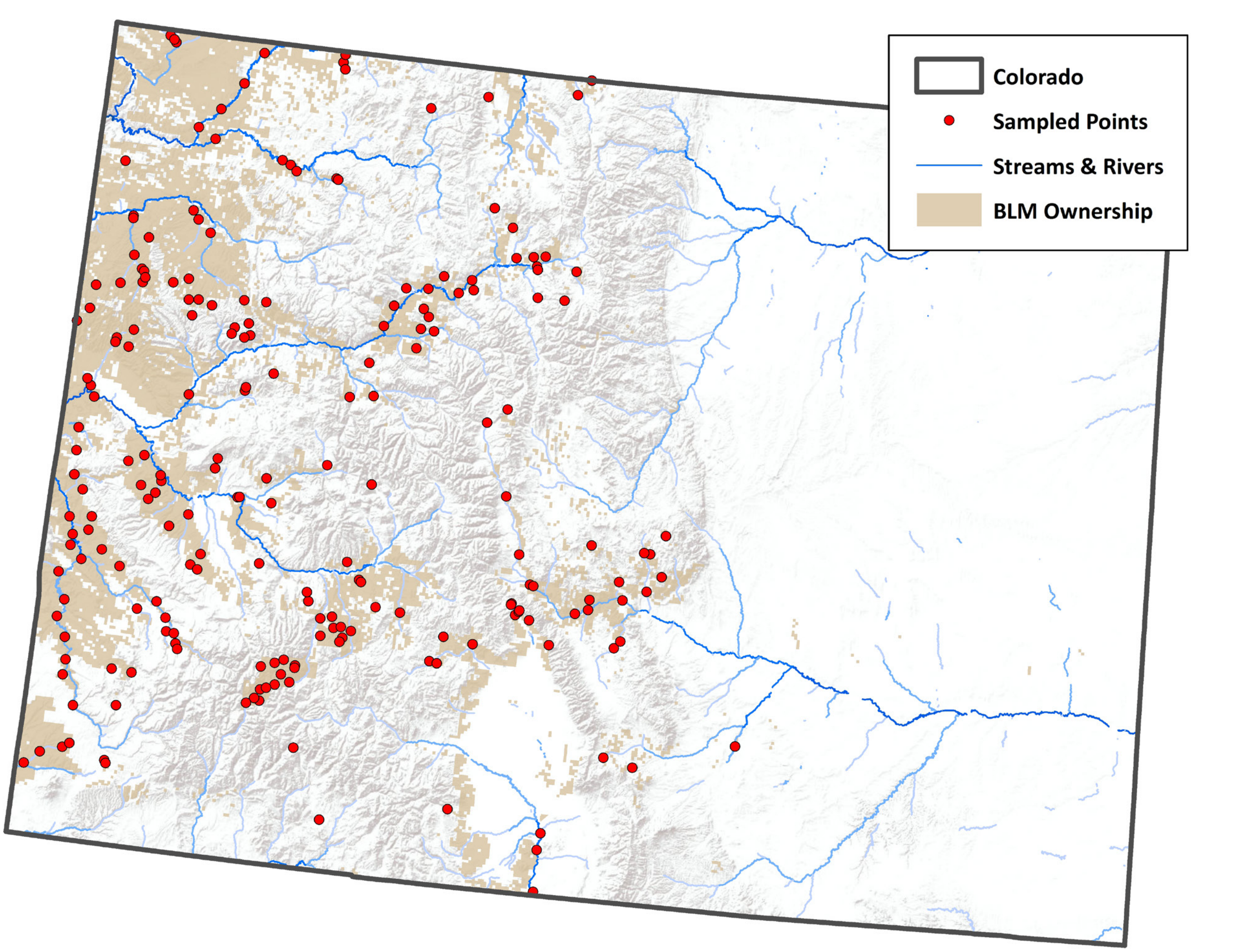


**Figure 1.** Distribution of the 209 perennial stream and river reaches sampled between 2013 and 2017 throughout BLM-managed lands in Colorado. Only rivers with a Strahler stream order greater than four are shown for geographic context.

Results are reported in terms of the extent of BLM-managed streams in Colorado having minimal, moderate, or major departure from benchmarks with a ±90% confidence interval (i.e., relative extent). Because the sample reaches were randomly selected, inferences can be made to all BLM-managed lotic systems in Colorado with known levels of precision and accuracy. The reporting units are the entire State of Colorado and each of the three BLM districts[1]: Northwest, Southwest, and Rocky Mountains (figure 1).

To complement indicator relative extent estimates, "relative risk" is also reported as a measure of potential impact of each indicator to macroinvertebrate biological condition (Van Sickle et al. 2006). All indicators can be potential stressors to macroinvertebrates in terms of alterations to chemical, physical, or biological habitat conditions. Relative risk values provide insight into what the presence of a stressor means to one of the designated beneficial uses, which for many BLM-managed streams includes aquatic life support under the Clean Water Act (see sidebar for additional explanation). Land managers can collectively use relative extent and relative risk results to determine how pervasive a stressor or problem is throughout a region and the potential impact to stream health.

[1]This assessment was completed before a BLM district realignment in 2020 in Colorado, which now includes a fourth district, the Upper Colorado River District.

**Table 1.** BLM Colorado land health standards applicable to riparian and lotic systems and lotic AIM indicators that relate to the standards. Standards 1 and 3 are not presented since they only apply to upland systems.

| Colorado Land Health Standard | Indicators Associated with Land Health Standard | Related Lotic AIM Indicators Used in the Assessment |
|---|---|---|
| **Standard 2:** Riparian systems associated with both running and standing water function properly and have the ability to recover from major disturbance such as fire, severe grazing, or 100-year floods. Riparian vegetation captures sediment, and provides forage, habitat, and biodiversity. Water quality is improved or maintained. Stable soils store and release water slowly. | • There is vegetation with diverse age class structure, appropriate vertical structure, and adequate composition, cover, and density.<br>• Streambank vegetation is present and is comprised of species and communities that have root systems capable of withstanding high streamflow events.<br>• Stream is in balance with the water and sediment being supplied by the watershed (e.g., no headcutting, no excessive erosion or deposition).<br>• An active floodplain is present.<br>• Residual floodplain vegetation is available to capture and retain sediment and dissipate flood energies.<br>• Woody debris contributes to the character of the stream channel morphology. | • Bank stability and cover<br>• Floodplain connectivity<br>• Fine sediment<br>• Nonnative woody riparian vegetation<br>• Woody vegetative complexity<br>• Bank overhead cover |
| **Standard 4:** Special status, threatened and endangered species (federal and state), and other plants and animals officially designated by the BLM, and their habitats are maintained or enhanced by sustaining healthy, native plant and animal communities. | • There are stable and increasing populations of endemic and protected species in suitable habitat.<br>• Suitable habitat is available for recovery of endemic and protected species. | See lotic AIM indicators listed for standards 2 and 5 |
| **Standard 5:** The water quality of all water bodies, including ground water where applicable, located on or influenced by BLM lands will achieve or exceed the water quality standards established by the State of Colorado. Water quality standards for surface and ground waters include the designated beneficial uses, numeric criteria, narrative criteria, and antidegradation requirements set forth under state law as found in (5 CCR 1002-8), as required by Section 303(c) of the Clean Water Act. | • Appropriate populations of macroinvertebrates, vertebrates, and algae are present.<br>• Surface and ground waters only contain substances (e.g., sediment, scum, floating debris, odor, heavy metal precipitates on channel substrate) attributable to humans within the amounts, concentrations, or combinations as directed by the water quality standards established by the State of Colorado (5 CCR 1002-8). | • Macroinvertebrate biological condition<br>• pH<br>• Water temperature<br>• Specific conductance<br>• Total nitrogen<br>• Total phosphorus |

# Stressor Identification: Understanding AIM Results (SIDEBAR)

This technical note characterizes conditions of BLM-managed streams and rivers in Colorado and identifies priority stressors to inform step-down monitoring and adaptive management. Following the BLM's land health standards, benthic macroinvertebrates are used to assess biological condition, and chemical and physical indicators are used to characterize the relative importance of various stressors (e.g., excessive thermal, sediment, or nutrient loading). Priority stressors are identified through relative extent and relative risk.

**Relative extent:** proportion of total BLM-managed streams exhibiting major departure from benchmarks for a given indicator or stressor.

For example, specific conductance had the greatest extent of stream kilometers with major departure from benchmarks across the state, and water temperature had the least (figure A). The use of random reach selection and standardized field methods allows estimates of relative extent with known levels of confidence for all BLM-managed streams and rivers in Colorado.

**Relative risk:** association between macroinvertebrate biological condition and the condition of each chemical or physical indicator (Van Sickle et al. 2006).

Relative risk (RR) is computed as a ratio of conditional probabilities and provides insight into what the presence of a given stressor means to one of Colorado's designated beneficial uses. For example, associations between pH and macroinvertebrate biological condition are quantified in the following terms:

$$RR = \frac{\textit{Probability (Major macroinvertebrate departure, given major pH departure)}}{\textit{Probability (Major macroinvertebrate departure, given minimal pH departure)}}$$

Statewide, the relative risk of pH was 5.8, meaning that a stream reach is 5.8 times more likely to not meet macroinvertebrate biological condition benchmarks when a reach also does not meet the pH (figure A).

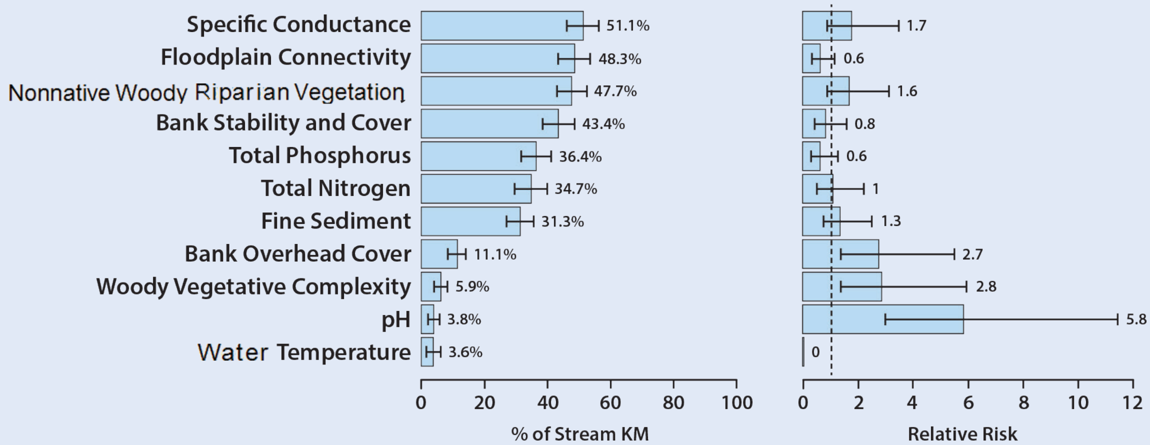


**Figure A.** (left) Relative extent of stream kilometers estimated to have major departure from benchmarks for all BLM-managed lotic systems and (right) the relative risk of each stressor to macroinvertebrate biological condition (± 90% confidence intervals).

To identify priority indicators or stressors for a region, both the relative extent and relative risk were used. Indicators with both a high relative extent and high relative risk are of greatest concern because they are both pervasive and likely to be detrimental to biological condition. For example, excessive salt (specific conductance) and nonnative woody riparian vegetation were identified as priority stressors.

# Results and Discussion

## Inventory of Perennial Streams and Rivers

Based on the U.S. Geological Survey's National Hydrography Dataset, an estimate of 3,609 km of BLM-managed perennial streams and rivers in Colorado was derived after removing canals, ditches, and other artificial flow paths. Based on the dataset, the Southwest, Rocky Mountain, and Northwest Districts were estimated to have 1,153, 1,132, and 1,323 km of perennial streams and rivers, respectively. After reach evaluation and sampling, 19% of those streams (679 km) were considered nontarget because they were not on BLM-managed land or were dry, an irrigation canal, or wetland (figure 2). In addition, an inference could not be made for 17% (617 km) of the total stream kilometers because of access issues.

The percentage of nontarget and inaccessible stream kilometers was relatively similar among districts, with the Rocky Mountain District having the highest percentage of both nontarget (22%) and inaccessible (20%) stream kilometers and the Southwest District the lowest (figure 2). Ultimately, for the study period (2013–2017), the extent of BLM-managed perennial lotic systems in Colorado was estimated to be 2,930 km. Within those stream kilometers, the BLM randomly placed 209 reaches to make inference to 2,313 stream and river kilometers, attributing the difference (2,930 km - 2,313 km) to access issues.

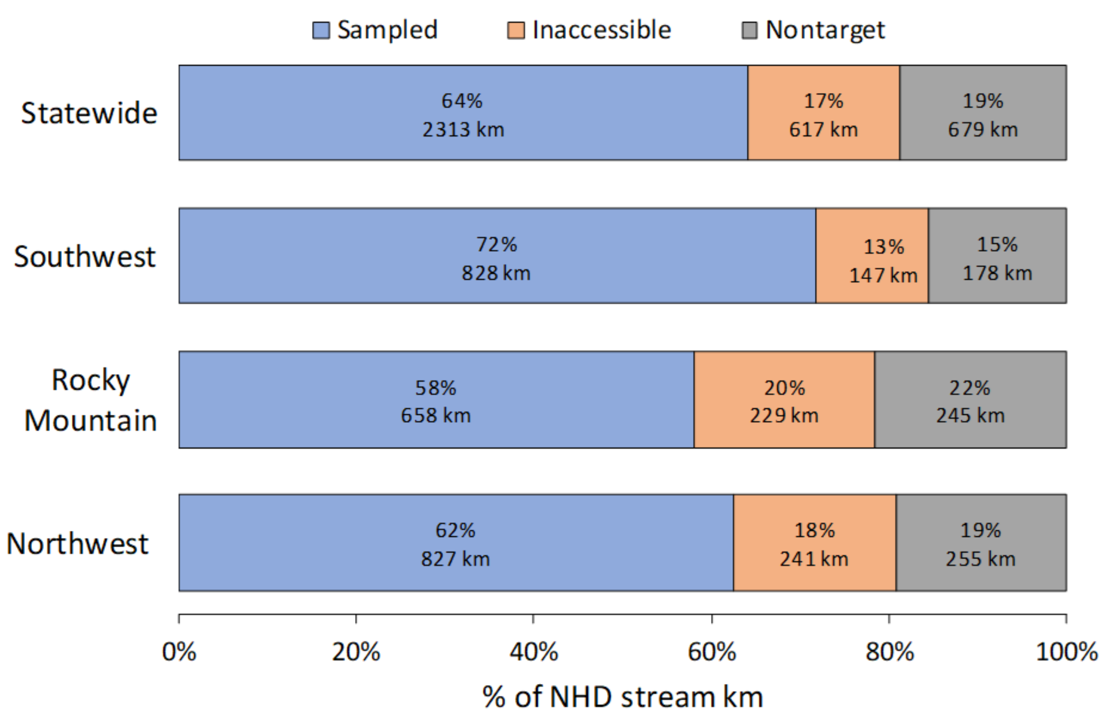


**Figure 2.** Percent of BLM-managed perennial stream kilometers from the National Hydrography Dataset that were sampled, inaccessible, and determined to be nontarget for the entire State of Colorado and each of the three BLM districts. Nontarget refers to streams originally thought to be on BLM-managed land or to possess perennial flow, but they did not during the time of the study.

## Water Quality Conditions

For water quality indicators, such as pH, water temperature, and nutrients (i.e., total nitrogen and phosphorus), with numeric or narrative standards set by CDPHE, less than 16% of stream kilometers exceeded these standards (figures 3 and 4). Nutrients and macroinvertebrate biological condition showed the most departure from standards. Statewide, 9.7% of stream kilometers did not meet the total phosphorus standard, with the Rocky Mountain District having the highest percentage (15.7%) (figure 4). For macroinvertebrate biological condition, 8.6% of stream kilometers did not meet the standard statewide, with the highest percentage (12.5%) of streams with significant departure occurring in the Rocky Mountain District (figure 6).

Excessively high or low pH values were rare and occurred in less than 4% of BLM-managed lotic systems in Colorado (figure 3). However, when out of balance pH levels were observed in areas such as the Rocky Mountain District (11.6% of stream km), they were associated with degraded macroinvertebrate biological condition; failure to meet the macroinvertebrate biological condition benchmark was 3.8 times more likely in streams with pH irregularities (figure 11). Such pH conditions were most likely related to isolated and historic mining activities (low pH). Alternatively, high rates of photosynthesis (high pH) or respiration (low pH) in the presence of aquatic macrophytes or high algal densities can alter pH values (Tank et al. 2009; Hogsden and Harding 2012).

The extent of stream kilometers exceeding state water quality standards was low, but further analysis of nutrient concentrations and indicators, such as specific conductance, highlight concerns about potential downstream cumulative effects and biological impacts. In the absence of Colorado specific conductance standards and because of the coarse nature of nutrient standards, models were used to assess the extent to which observed specific conductance or nutrient concentrations exceeded potential natural conditions (see appendix A for more details).

For nutrients, a significant proportion of BLM-managed streams in Colorado exceeded reach potential—specifically, 34.7% and 36.4% for total nitrogen and phosphorus, respectively (figure 5). Streams in the Northwest District had the lowest exceedance (22.4% total nitrogen and 22.5% total phosphorus) of nutrients, while streams in the Rocky Mountain District had the highest exceedance (37.8% total nitrogen and 47.7% total phosphorus). For specific conductance, 51.1% of BLM-managed lotic systems in Colorado exceeded reach potential, with the Southwest (60.6%) and Northwest (52.3%) Districts having the greatest exceedances (figure 6).

These exceedances may have impacts to instream organisms. For example, where elevated specific conductance values were observed in the Northwest District (52.3% of stream km), degraded macroinvertebrate biological condition was 2.7 times more likely to occur (figure 11). Similar patterns were observed for elevated nutrient levels. For example, where total phosphorus exceeded reach potential in the Southwest District (41.2% of stream km), degraded macroinvertebrate biological condition was 2.2 times more likely to occur (figure 11). Similarly, all reaches in the Southwest District having elevated specific conductance also had degraded biological condition. (Note: Relative risk was not able to be estimated for specific conductance in the Southwest District for statistical reasons.)

Consequently, although not in violation of state water quality standards, observed nutrient and specific conductance exceedances were both pervasive and associated with adverse impacts to stream biota in some districts. Assessments are based on one-time grab samples collected during summer baseflow conditions. Therefore, these observations require validation through more temporally intensive sampling. However, the large number of reaches with elevated nutrient and specific conductance concentrations suggests the results are likely to persist with more temporally intensive sampling.

Future studies should confirm that exceedances are the result of anthropogenic activities and, if so, determine the source of exceedances and quantify their impacts more directly on biota. Management activities that accelerate erosion rates, change biogeochemical processes, or directly add nutrients or dissolved cations and anions to streams, such as logging, cattle grazing, mining, or agriculture, can significantly increase nutrient and salt loading (Allan and Castillo 1995). Eutrophication can have adverse impacts to water quality conditions such as lowered dissolved oxygen levels resulting from increased rates of primary production and subsequent organic matter decomposition. Eutrophication can also indirectly impact biological assemblages, such as macroinvertebrates and fishes, through changing the trophic basis for secondary production and subsequent food web structure, as well as through alterations to physical habitat such as water clarity and benthic substrates (Dodds 2006; Miller and Crowl 2006; Dunck et al. 2015). Salinization can disrupt the ionic balance between organisms and their environments leading to reduced fitness, shifts in assemblage composition, species loss, and alterations to ecosystem processes (Miller et al. 2007; Schäfer et al. 2012; Szöcs et al. 2014).

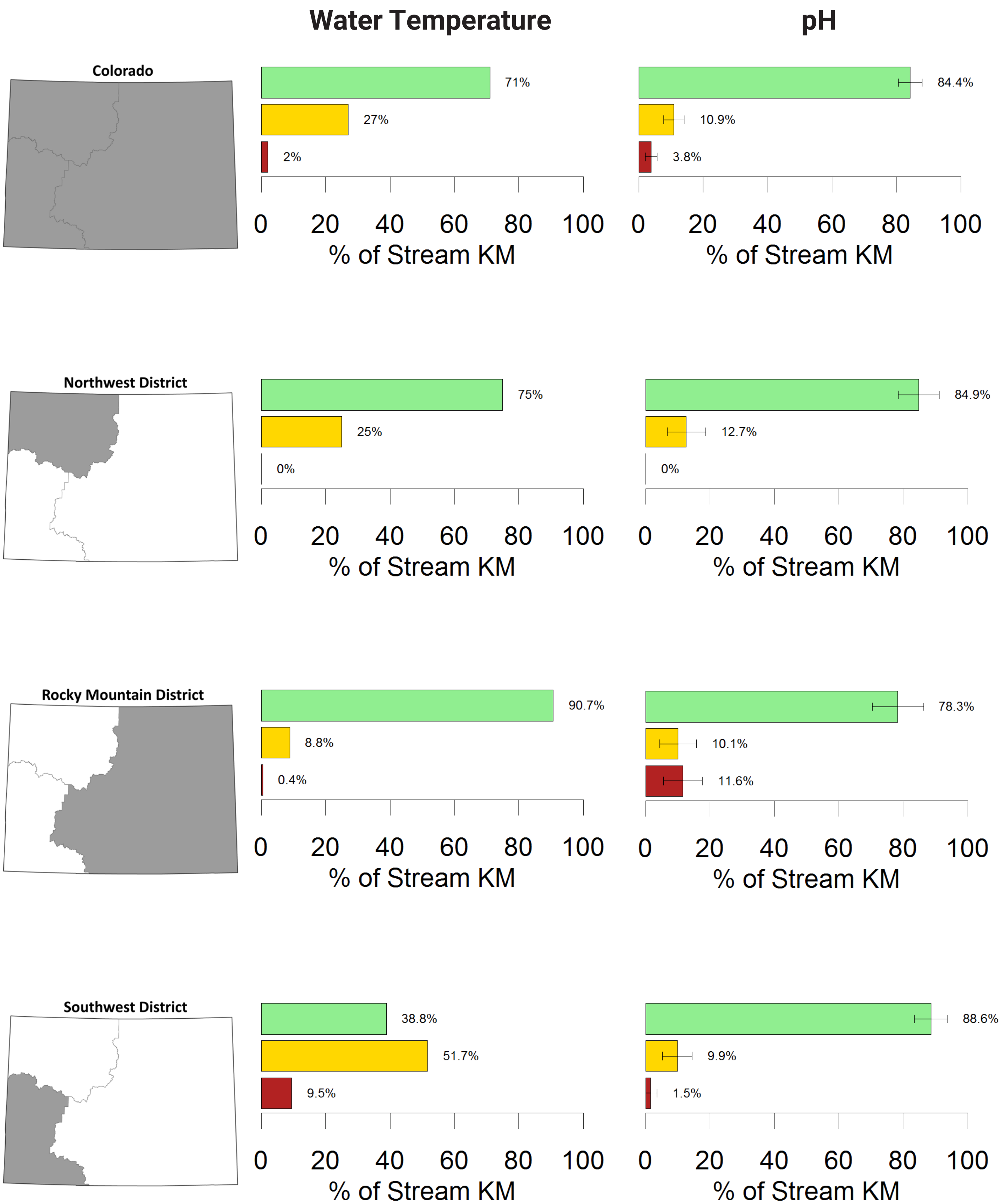


**Figure 3.** Relative extent of stream kilometers found to have minimal (green), moderate (yellow), or major (red) departure from benchmarks for temperature and pH (±90% confidence interval). The benchmarks used to derive the three condition categories are explained in appendix A. Figures of raw indicator values are presented in appendix B. For some indicators, the sum of the three condition categories does not equal 100% because of missing field measurements.

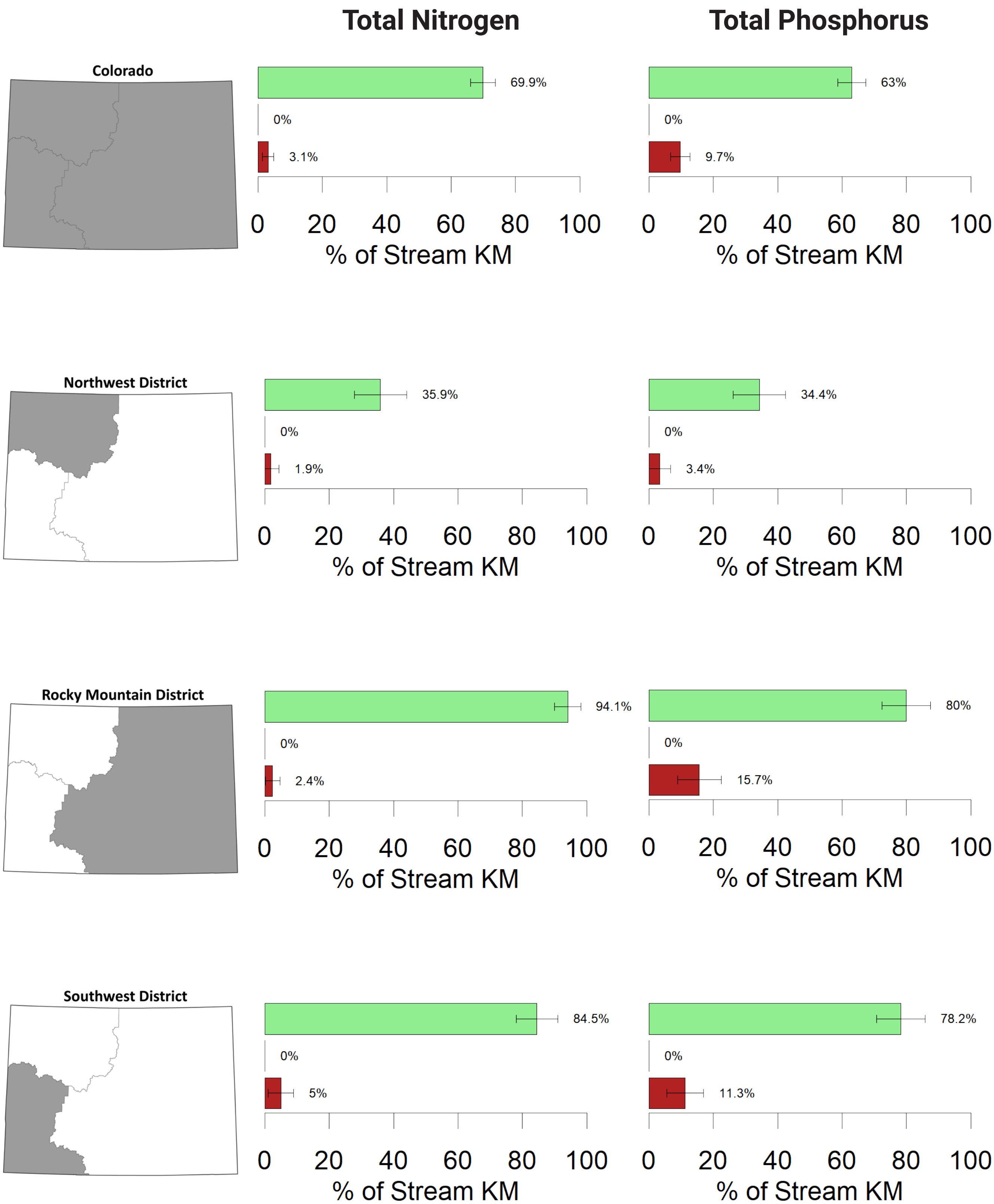


**Figure 4.** Relative extent of stream kilometers found to have minimal (green) or major (red) departure from CDPHE Regulation 31 benchmarks for total nitrogen and phosphorus (±90% confidence interval). Note that the CDPHE does not use a moderate departure category, and thus estimates are only shown for minimal and major departure. The benchmarks used to derive the two condition categories are explained in appendix A. Figures of raw indicator values are presented in appendix B. For some indicators, the sum of the three condition categories does not equal 100% because of missing field measurements.

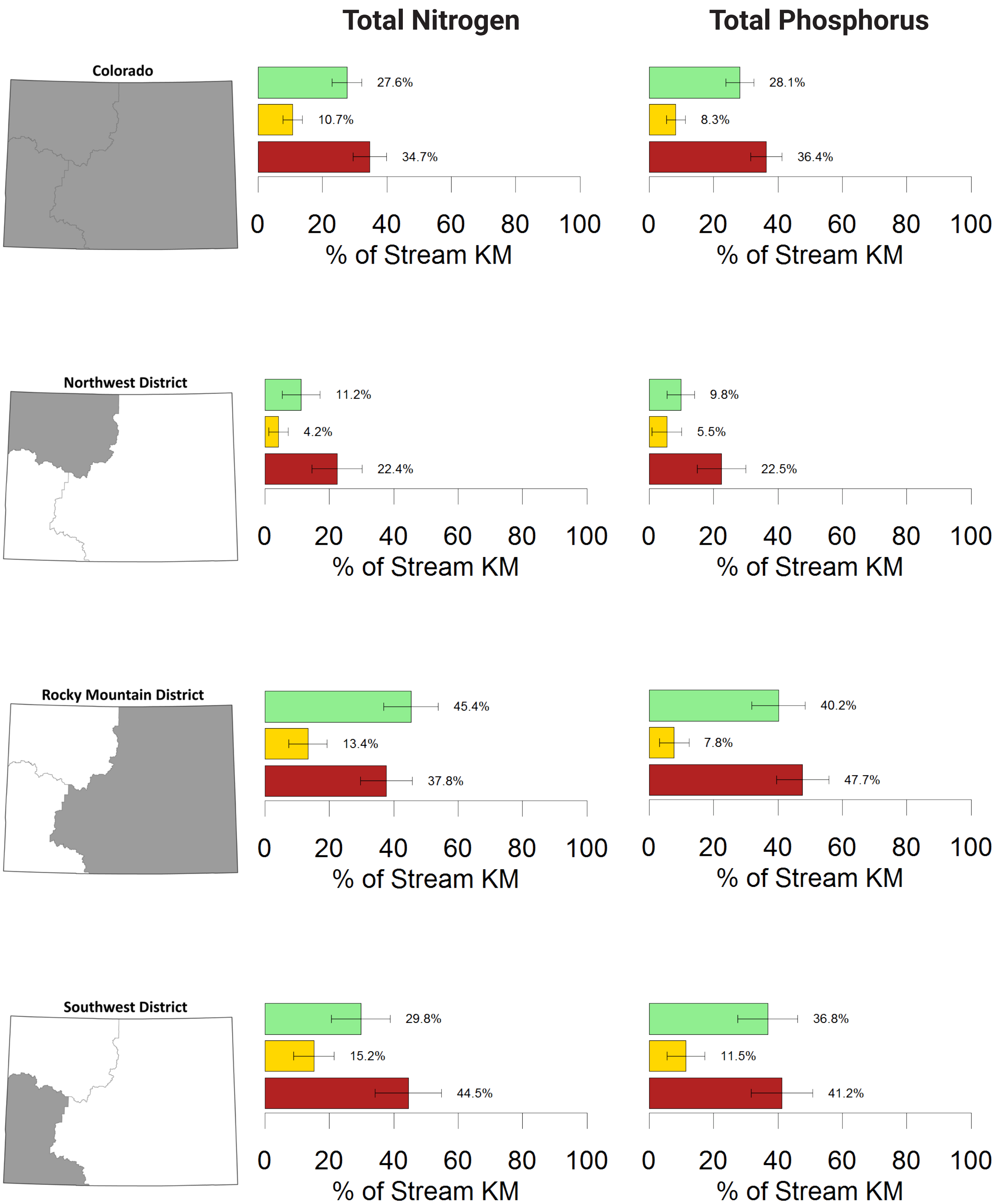


**Figure 5.** Relative extent of stream kilometers found to have minimal (green), moderate (yellow), or major (red) departure from predicted natural condition or reach potential benchmarks for total nitrogen and phosphorus (±90% confidence interval). The benchmarks used to derive the three condition categories are explained in appendix A. Figures of raw indicator values are presented in appendix B. For some indicators, the sum of the three condition categories does not equal 100% because of missing field measurements.

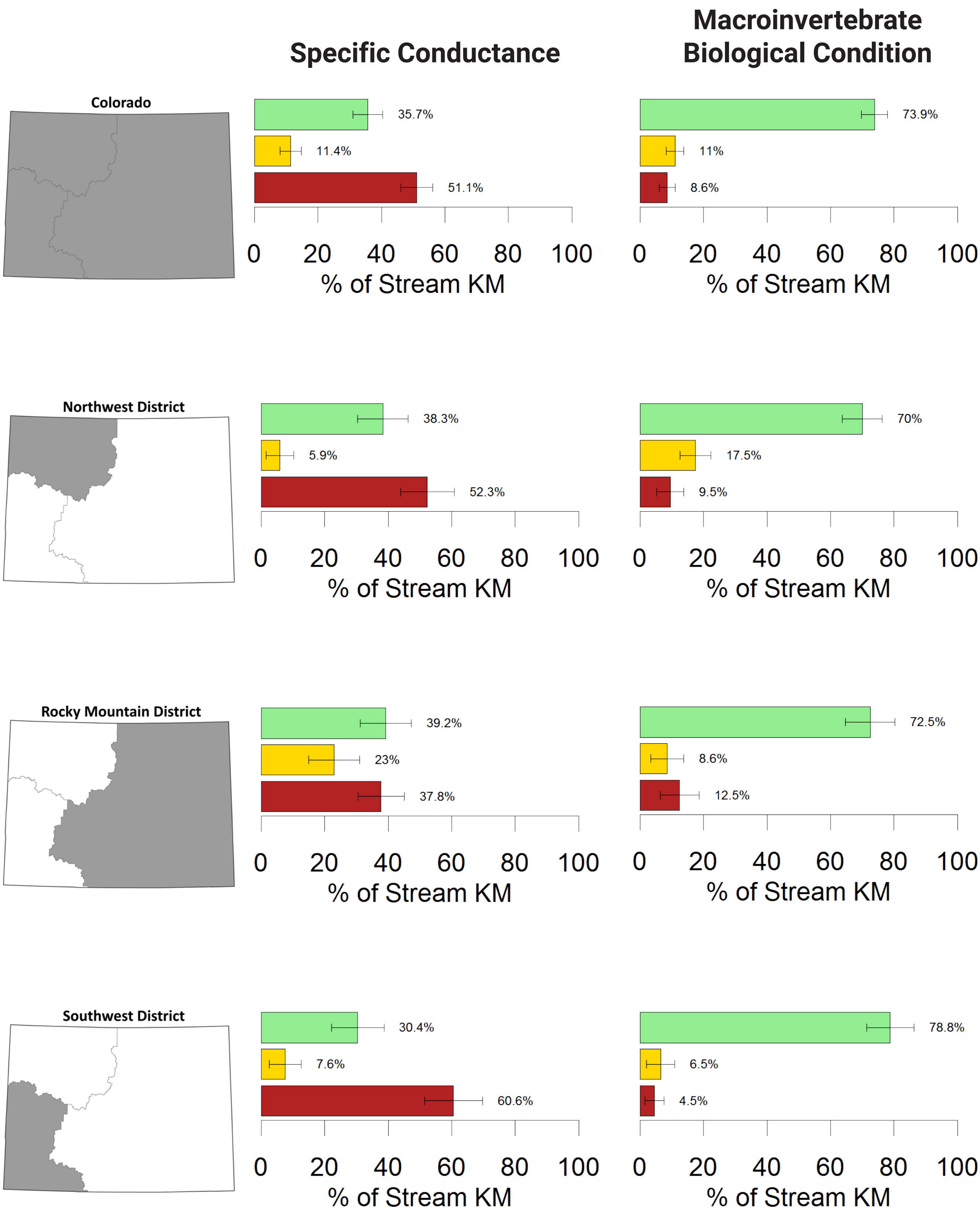


**Figure 6.** Relative extent of stream kilometers found to have minimal (green), moderate (yellow), or major (red) departure from benchmarks for specific conductance and macroinvertebrate biological condition (±90% confidence interval). The benchmarks used to derive the three condition categories are explained in appendix A. Figures of raw indicator values are presented in appendix B. For some indicators, the sum of the three condition categories does not equal 100% because of missing field measurements.

## Riparian and Instream Habitat Conditions

Indicators characterizing riparian and instream habitat generally identified more exceedances of BLM land health standards than those related to water quality. Streams and rivers were in the best condition for woody vegetative complexity and bank overhead cover, whereas bank stability and cover, fine sediment, nonnative woody riparian vegetation, and floodplain connectivity issues were more pervasive.

Fine sediment was the only riparian and instream habitat indicator with state standards under CDPHE Regulation 31, and 31.3% of BLM stream kilometers exceeded the standard. The Northwest (37.8%) and Rocky Mountain (34.2%) Districts had the highest percentages of stream kilometers exceeding the fine sediment standard (figure 7). However, excessive fine sediment levels were most detrimental to macroinvertebrate biological condition in the Southwest District where degraded biological condition was 20.6 times more likely when excessive fine sediment was present versus 1.5 times more likely in the Rocky Mountain and 1.2 times more likely in the Northwest Districts (figure 11).

For riparian and instream habitat, nonnative woody riparian vegetation and bank stability and cover issues were prevalent. For example, 68.5% and 43.9% of stream kilometers in the Southwest and Northwest Districts, respectively, had nonnative woody riparian vegetation species present, largely Russian olive or tamarisk (figure 9). The presence of nonnative woody riparian vegetation was not associated with degraded instream biological condition in the Southwest District (relative risk 0.3) but was detrimental in the Northwest (relative risk 3.2) and Rocky Mountain (relative risk 2.1) Districts (figure 11). Similarly, bank stability and cover issues occurred in 43.4% of all stream kilometers, with the highest occurrences in the Northwest District (50.6%) (figure 8). However, impacts to macroinvertebrate biological condition did not frequently co-occur, possibly because banks were stable but not covered. If uncovered banks become unstable in the future, this may lead to lower bank stability and excessive sediment inputs to streams (see appendix B, figure B10).

Lastly, BLM-managed streams and rivers had adequate floodplain connectivity for 17.7% of stream kilometers and moderate departure from reach potential for 17.5% (figure 7). In contrast, 48.3% of stream kilometers had major departure from reach potential. Floodplain connectivity issues were greatest in the Northwest (60.0%) and Southwest (47.2%) Districts. Degraded macroinvertebrate biological condition did not consistently co-occur with a loss of floodplain connectivity in any district (figure 11).

The assessment of multiple indicators of riparian and instream habitat conditions presents a consistent story of BLM stream conditions. For example, minimal problems were observed with woody vegetative complexity or bank overhead cover, suggesting adequate shading of streams and rivers, which was supported by the very low relative extent of water temperature exceedances of state standards. However, the high relative extent of nonnative woody riparian vegetation highlights that some portion of riparian function results from Russian olive or tamarisk. The conversion of riparian areas from native to nonnative vegetation threatens the sustainability of habitat for species of management concern such as riparian songbirds and ecosystem processes such as the energy subsidies provided by riparian areas to stream systems in the form of leaf litter and woody debris (Mineau et al. 2012). Observed loss of floodplain connectivity could also result from the invasion of Russian olive and tamarisk, which has been shown to stabilize streambanks, promote bank aggradation, and ultimately reduce channel incision (Manners et al. 2014).

Elevated fine sediment levels were common, with district exceedances ranging from 22.5–37.8% of stream kilometers. Excessive fine sediment is among the most deleterious stressors to aquatic biota (Wood and Armitage 1997; Paulsen et al. 2008; Bryce et al. 2010). Fine sediment can reduce food resource availability for benthic organisms (Henley et al. 2000), decrease benthic egg survival (Bjornn and Reiser 1991), and decrease habitat quality by filling interstitial spaces, which are important microhabitats for macroinvertebrates and smaller fishes (Cunjak and Power 1986; Gries and Juanes 1998). The collected field data point to watershed-scale processes and not local streambank erosion rates as driving elevated sediment levels. For example, more than 75% of sampled reaches were characterized as having stable streambanks, with low occurrences of bank instability features such as active sloughs, slump blocks, or bank fractures. Thus, excessive local bank instability and erosion did not appear to be the driver. Although caution should be exercised, as low bank overhead cover suggests that many reaches could unravel in response to high flow events and/or pressure from cattle grazing, recreation, or other local impacts. Potential sediment sources include excessive upland erosion and overland flow, road networks which can accelerate sediment delivery, or hydrologic alterations related to dams and irrigated agriculture which can reduce stream sediment transport capacity (Gaeuman et al. 2005; Al-Chokhachy et al. 2016).

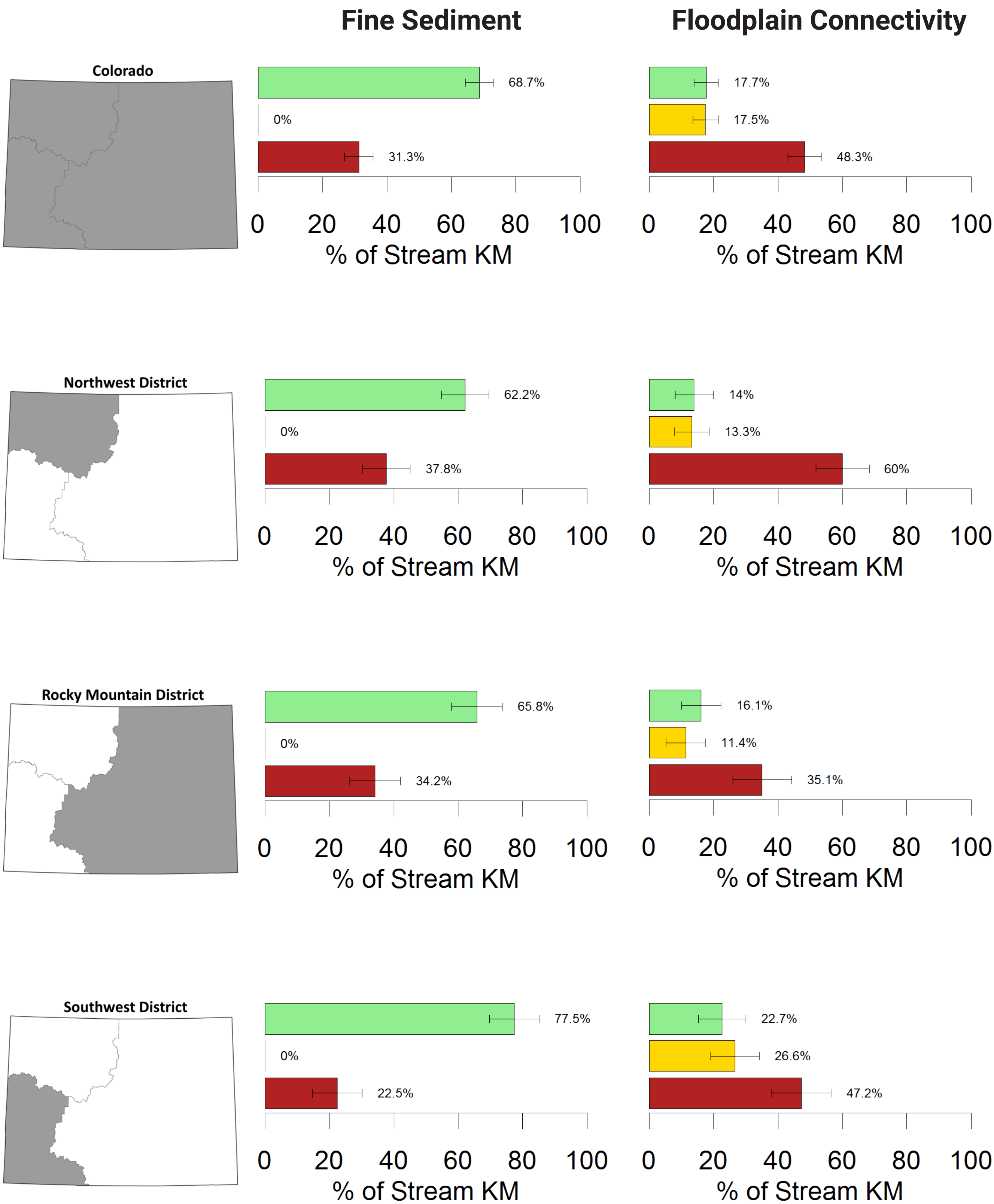


**Figure 7.** Relative extent of stream kilometers found to have minimal (green), moderate (yellow), or major (red) departure from benchmarks for fine sediment and floodplain connectivity (±90% confidence interval). The benchmarks used to derive the three condition categories are explained in appendix A. Figures of raw indicator values are presented in appendix B. For some indicators, the sum of the three condition categories does not equal 100% because of missing field measurements.

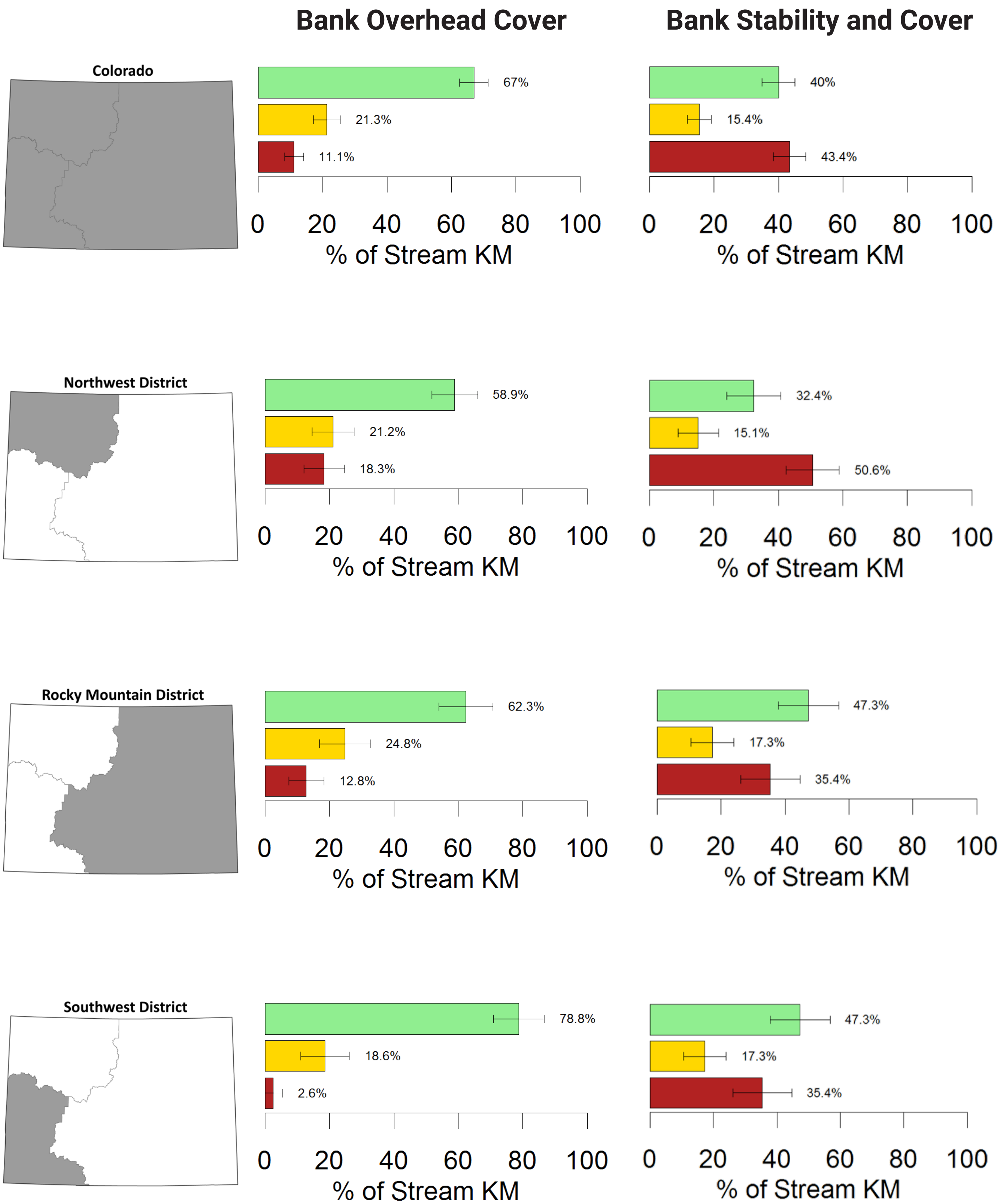


**Figure 8.** Relative extent of stream kilometers found to have minimal (green), moderate (yellow), or major (red) departure from benchmarks for bank overhead cover and bank stability and cover (±90% confidence interval). The benchmarks used to derive the three condition categories are explained in appendix A. Figures of raw indicator values are presented in appendix B. For some indicators, the sum of the three condition categories does not equal 100% because of missing field measurements.

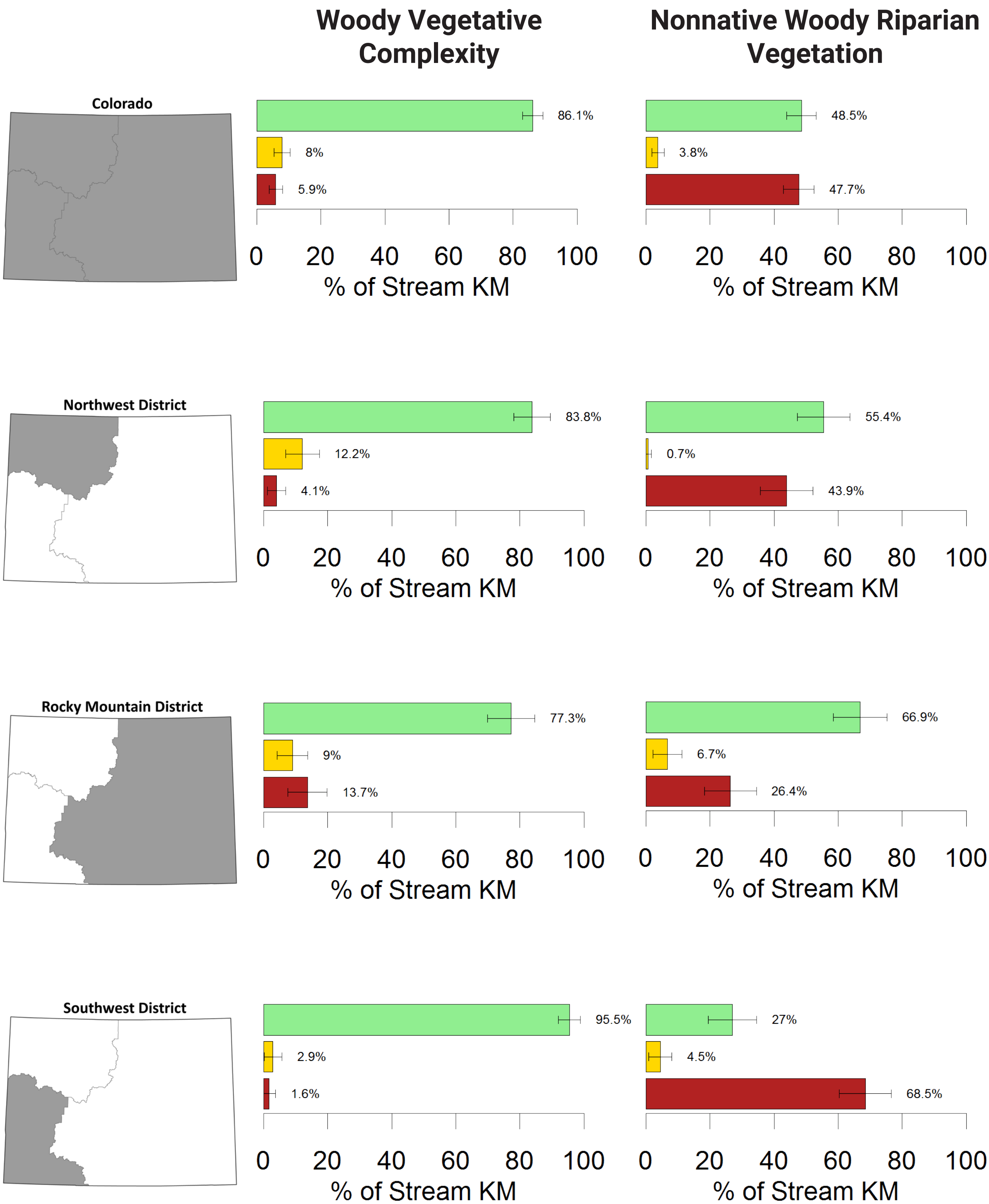


**Figure 9.** Relative extent of stream kilometers found to have minimal (green), moderate (yellow), or major (red) departure from benchmarks for woody vegetative complexity and nonnative woody riparian vegetation (±90% confidence interval). The benchmarks used to derive the three condition categories are explained in appendix A. Figures of raw indicator values are presented in appendix B. For some indicators, the sum of the three condition categories does not equal 100% because of missing field measurements.

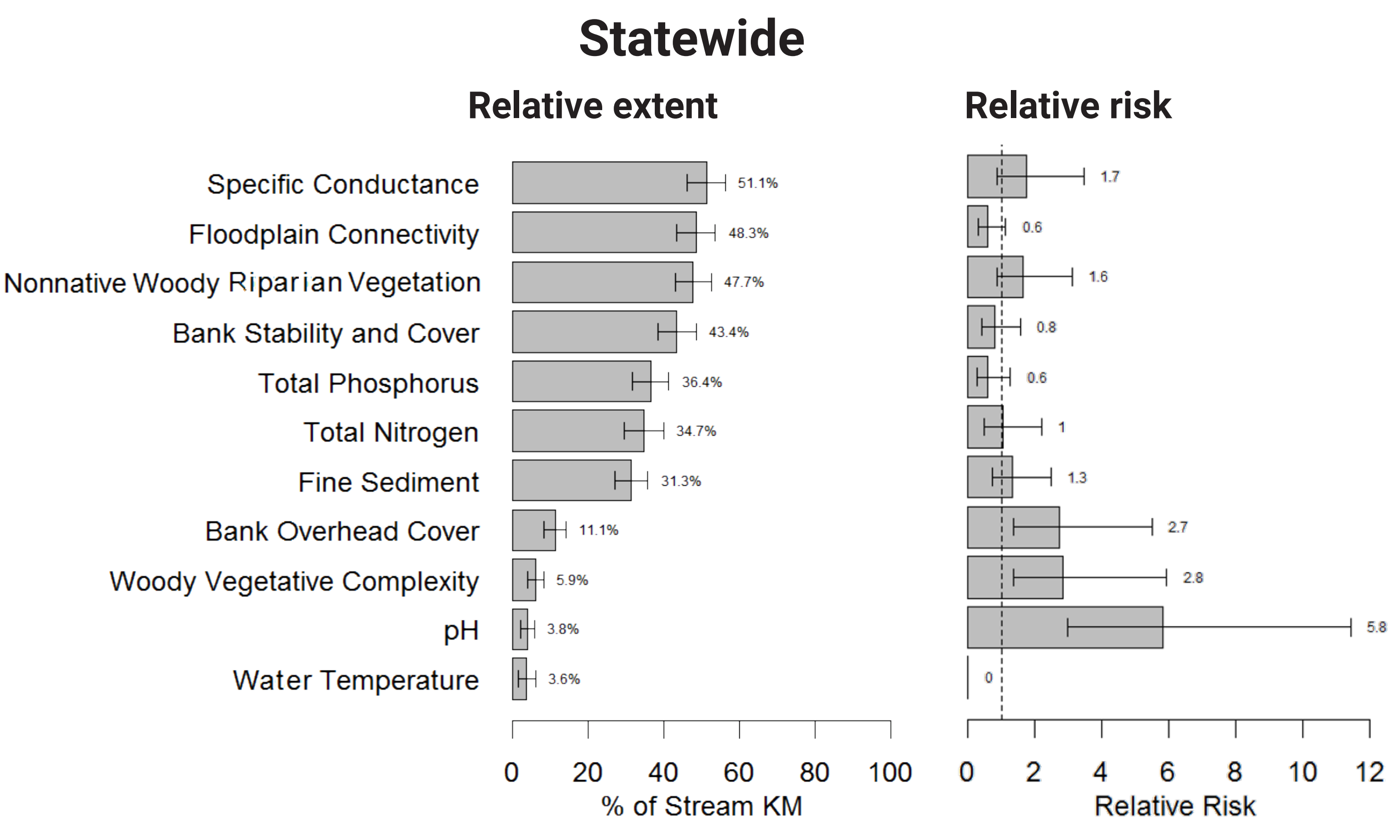


**Figure 10.** (left) Relative extent of stream kilometers found to have major departure from benchmarks for BLM-managed streams and rivers in Colorado (±90% confidence intervals) and (right) the relative risk of each stressor to macroinvertebrate biological condition (±90% confidence intervals).

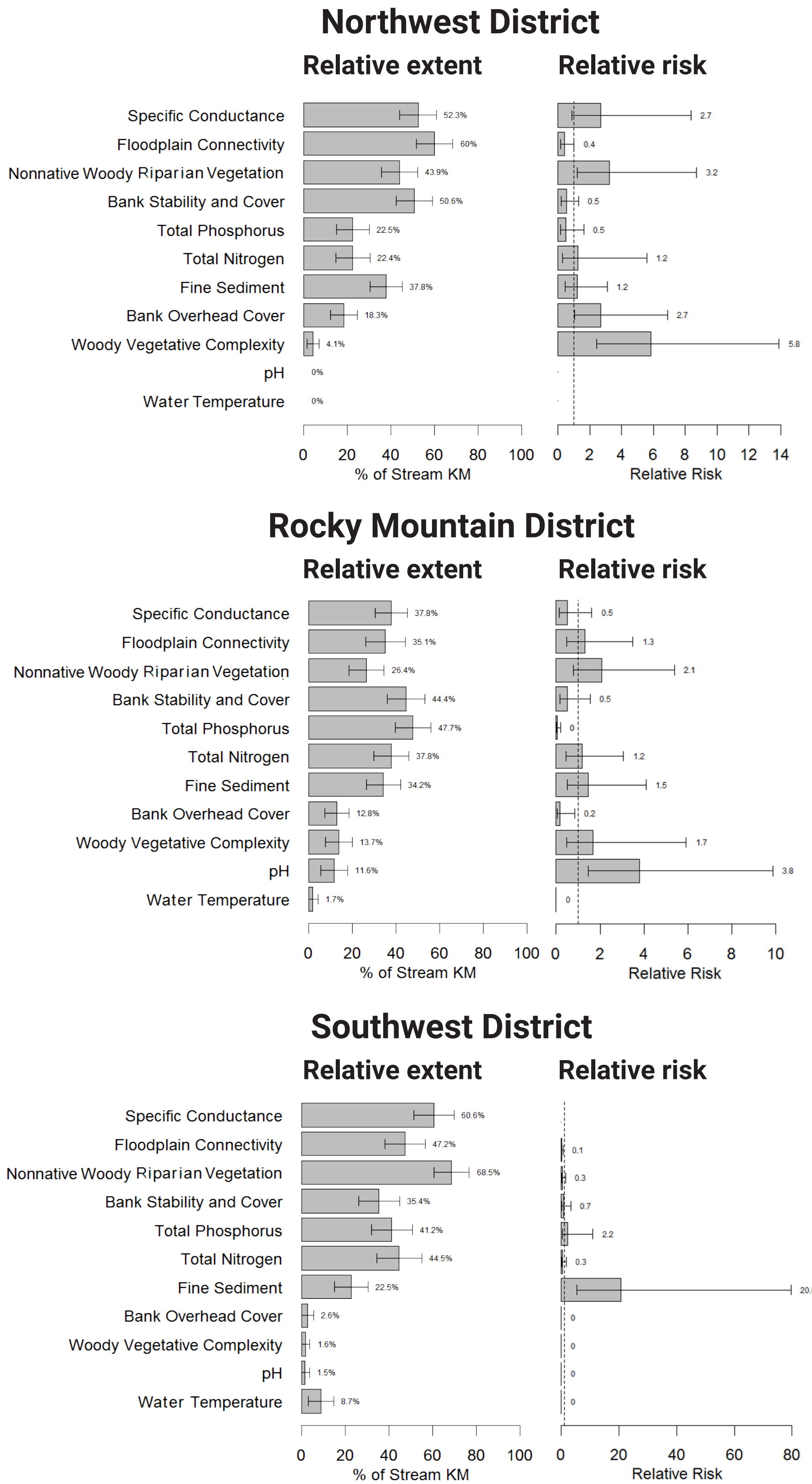


**Figure 11.** (left) Relative extent of stream kilometers found to have major departure from benchmarks for BLM-managed streams and rivers in the Northwest, Rocky Mountain, and Southwest Districts (±90% confidence intervals) and (right) the relative risk of each stressor to macroinvertebrate biological condition (±90% confidence intervals). Relative risk was not able to be estimated for specific conductance in the Southwest District for statistical reasons, but macroinvertebrate biological condition was found to have major departure from benchmarks where specific conductance had major departure.

# Management Priorities and Next Steps

Since completion of the state and district lotic AIM assessment, the next step is to identify whether land uses are associated with priority stressors and degraded macroinvertebrate biological condition. Specifically, it is important to determine whether BLM-permitted activities are causal factors in the observed departures from land health standards. Based on both the relative extent and the relative risk of stressors to macroinvertebrate biological condition, the top three stressors in each district include:

- **Northwest District:**
    - Specific conductance
    - Nonnative woody riparian vegetation
    - Bank overhead cover
- **Southwest District:**
    - Specific conductance
    - Fine sediment
    - Total phosphorus
- **Rocky Mountain District:**
    - Nonnative woody riparian vegetation
    - Fine sediment
    - pH

In addition, although the following stressors did not always have appreciable impacts on macroinvertebrate biological condition, reduced floodplain connectivity, low bank stability and cover, and excessive nutrient loading were pervasive among all three districts.

The BLM will use this information to identify best management practices, strengthen collaborations with state and federal partners to improve watershed health, and ensure the productivity and sustainability of BLM-managed rangelands and permitted activities. To that end, the BLM is implementing AIM monitoring projects at the field office scale throughout the State of Colorado. The objectives of these efforts are multifaceted and include assessing the effectiveness of resource management plans, providing data to inform land health determinations, and assessing restoration efficacy. Data resulting from these projects are compatible with the statewide assessment, and the BLM will use these data to better understand causes for observed conditions.

Lastly, an important element of AIM and the BLM's assessment efforts is the ability to track change in the chemical, physical, and biological condition of streams and rivers through time. This technical note provides a quantitative, unbiased baseline from which the BLM can track the cumulative effectiveness of management actions over time. In Colorado, the BLM will continue repeat sampling for trend.

# Appendix A: Description of Reference Reach Networks and Methods Used for Benchmark Development

To objectively assess stream conditions, benchmarks were established for each of the 12 indicators and used to assign the condition categories of minimal, moderate, and major departure from reference condition for each indicator and reach. The primary source of information used to set benchmarks was Colorado Department of Public Health and Environment (CDPHE) Regulation 31 (The Basic Standards and Methodologies for Surface Water). When CDPHE regulations did not specify benchmarks for a given indicator, published literature values, best professional judgement, or existing networks of least disturbed stream and river monitoring locations were used to characterize the range of reach potential by ecoregion (table A1). Some indicators, such as total nitrogen and phosphorus, were assessed both in terms of CDPHE standard attainment and modeled predictions of reach potential because of the perceived coarse nature of CDPHE standards.

Reference reach networks were used to develop benchmarks for specific conductance, total nitrogen, total phosphorus, fine sediment, and bank overhead cover. The specific network of reference reaches depended on the indicator, as no single network encompassed all indicators. Specifically, reference networks compiled by Olson and Hawkins (2012, 2013) were used for specific conductance, total nitrogen, and total phosphorus. Reference networks developed from Environmental Protection Agency (EPA) stream assessment data by Herlihy et al. (2008) were used for bank overhead cover and woody vegetative complexity. All approaches for quantifying reach potential sought to minimize the presence of human impacts, as indicated by land uses and surface disturbances, such as percent agriculture or urban land use, road density, timber harvest, and grazing, while maintaining environmental representativeness. Regardless of the reference network, a group of BLM resource specialists used best professional judgement to ensure the benchmarks made ecological, hydrologic, or geomorphic sense.

Benchmarks were established in one of two ways using the relevant reference network. The first method involved the use of empirical models to make reach-specific predictions of the conditions expected to occur in the absence of anthropogenic impairment—predicted natural conditions (table A1). The alternative method quantified the range of variability among reference reaches by ecoregion and stream size (small and large streams for both the Southern Rockies and Eastern Xeric Basin hybrid Level III ecoregions). For either approach, the analysis asked whether observed conditions exhibited minimal, moderate, or major departure from reach-specific predictions or the distribution of reference conditions, respectively, to make condition determinations.

**Table A1.** Summary field and indicator condition benchmarks (minimal, moderate, and major departure from benchmarks) for the subset of 12 lotic AIM indicators used to report on the condition of BLM-managed streams and rivers in Colorado.

| Indicator | Condition Benchmark |
|---|---|
| Total nitrogen | Colorado Department of Public Health and Environment (CDPHE) Regulation 31: rated as minimal if < 1,250 µg/L for cold water systems and < 2,010 µg/L for warm water systems<br>Empirical models were also used where: model prediction plus 75th (moderate) and 95th (major) percentiles of model error, 52.1 µg/L and 114.7 µg/L, respectively[1] |
| Total phosphorus | CDPHE Regulation 31: rated as minimal if < 110 µg/L for cold water systems and < 170 µg/L for warm water systems<br>Empirical models were also used where: model prediction plus 75th (moderate) and 95th (major) percentiles of model error, 9.9 µg/L and 21.3 µg/L, respectively[1] |
| Specific conductance | Empirical models were used where: model prediction plus 75th (moderate) and 95th (major) percentiles of model error, 27.1 µS/cm and 74.5 µS/cm, respectively[1] |
| pH | CDPHE Regulation 31: acidic (7, 6.5) and alkaline (8.5, 9) for moderate and major departure from reference, respectively |
| Water temperature | CDPHE Regulation 31: Predicted temperature ≤ 17 °C (minimal), > 17 °C and < 21.7 °C (moderate), ≥ 21.7 °C (major) |
| Macroinvertebrate biological condition | CDPHE Multimetric Index biotypes: biotype 1 ≥ 52 (minimal), > 42 and < 52 (moderate), ≤ 42 (major); biotype 2 ≥ 50 (minimal), > 42 and < 50 (moderate), ≤ 42 (major); biotype 3 ≥ 37 (minimal), > 22 and < 37 (moderate), ≤ 22 (major) |
| Fine sediment (< 2 mm) | Rated as minimal departure for three regions: < 27.5% for region 1, < 29.3% for region 2, or < 41% for region 3. For reaches that did not fall in one of these three regions, ecoregional benchmarks were applied. |
| Bank stability and cover | Rated by two ecoregions: Southern Rockies ≥ 80% (minimal), < 80% and > 70% (moderate), ≤ 70% (major); Eastern Xeric Basin ≥ 70% (minimal), < 70% and > 50% (moderate), ≤ 50% (major)[2] |
| Bank overhead cover | Rated by stream size for two ecoregions: Southern Rockies minimal ≥ 68.4 for SS, ≥ 72.0 for LS, ≥ 7.2 for boatable; moderate < 68.4 and > 45.3 for SS, < 72.0 and > 62.2 for LS, < 7.2 and > 1.1 for boatable; major ≤ 45.3 for SS, ≤ 62.2 for LS, ≤ 1.1 for boatable. Eastern Xeric Basin minimal ≥ 74.4 for SS, ≥ 32.0 for LS, ≥ 14 for boatable; moderate < 74.4 and > 44.5 for SS, < 32.0 and > 16.9 for LS, < 14.0 and > 6.5 for boatable; major ≤ 44.5 for SS, ≤ 16.9 for LS, ≤ 6.5 for boatable[2] |
| Woody vegetative complexity | Rated by stream size for two ecoregions: Southern Rockies minimal ≥ 0.57 for SS, ≥ 0.68 for LS, ≥ 0.36 for boatable; moderate < 0.57 and > 0.42 for SS, < 0.68 and > 0.51 for LS, < 0.36 and > 0.26 for boatable; major ≤ 0.42 for SS, ≤ 0.51 for LS, ≤ 0.26 for boatable. Eastern Xeric Basin minimal ≥ 0.50 for SS, ≥ 0.30 for LS, ≥ 0.37 for boatable; moderate < 0.50 and > 0.24 for SS, < 0.30 and > 0.11 for LS, < 0.37 and > 0.18 for boatable; major ≤ 0.24 for SS, ≤ 0.11 for LS, ≤ 0.18 for boatable[2] |
| Nonnative woody riparian vegetation | Minimal departure is < 1%; moderate departure is 1–5%; and major departure is > 5%[3] |
| Floodplain connectivity | Minimal is ≥ 1.0 and ≤ 1.3; moderate is > 1.3 and < 1.5; major is ≥ 1.5[4] |

[1] Potential natural conditions derived from models of Olson and Hawkins (2012, 2013).

[2] Benchmarks for woody vegetative complexity and bank overhead cover based on the percentiles of regional reference conditions following Kaufmann et al. (1999) and Stoddard et al. (2005). Percentiles computed for aggregate Level III ecoregions including the Southern Rockies and Eastern Xeric Basin for streams less than 10 m (SS = small stream) and greater than 10 m (LS = large stream) in bankfull width, as well as reaches requiring a boat (boatable) to sample.

[3] Benchmark based on best professional judgement.

[4] Benchmarks based on Rosgen (1996).

## Overview of Specific Conductance, Total Nitrogen, and Total Phosphorus Predictive Models and Reference Criteria

For the water quality indicators specific conductance, total nitrogen, and total phosphorus, predictive models were used to establish reach potential in the absence of anthropogenic impacts. During this assessment, CDPHE had specific conductance standards, while total nitrogen and total phosphorus standards were undergoing revision. The predictive models are empirically based and use geospatial predictors to describe natural spatial variability among reference reaches for a given indicator.

The predictive models were used to determine the chemical conductions expected to occur at reaches in the absence of anthropogenic impact (i.e., reach potential). Condition was then determined based on the deviation of the observed indicator value from field data from the reach-specific predicted value. If this deviation was greater than specified percentiles of model error (e.g., 90th percentile), the value was assigned a condition of having "major" departure from a given water quality benchmark. Predictive modeling approaches are advantageous because they result in reach-specific predictions, take into account natural environmental gradients, and have known levels of accuracy and precision (Hawkins et al. 2010).

Specific conductance benchmarks were established using the methods of Olson (2012). This model uses 15 geographic information system (GIS)-derived variables (e.g., percent calcium carbonate in local geology, air temperature, precipitation) to explain 71% of the spatial variability in baseflow specific conductance concentrations (root-mean-square error 84.2 µS/cm) among reference reaches throughout the contiguous Western United States. Reach-specific benchmarks were then established by taking the reach-specific predicted natural conditions from the model and adding the 75th percentile (moderate departure) or 95th percentile (major departure) of model error to the prediction.

Total nitrogen and total phosphorus benchmarks were established using the methods in Olson and Hawkins (2013). The total nitrogen model uses 12 GIS-derived variables (e.g., atmospheric nitrogen deposition, air temperature, precipitation) to explain 23% of the spatial variability in baseflow total nitrogen values (root-mean-square error 80.1 µg/L). The total phosphorus model uses 15 GIS-derived variables (e.g., percent calcium carbonate in local geology, air temperature, precipitation) to explain 46% of the spatial variability in baseflow total phosphorus values (root-mean-square error

20.5 µg/L) among reference reaches throughout the contiguous Western U.S. Benchmarks for total nitrogen and total phosphorus were established similar to specific conductance.

The reference network (figure A1) used by Olson and Hawkins (2012, 2013) was derived by compiling data from state and national water quality monitoring efforts for which the sampled reaches were identified as being in reference quality by the original collection agency (table 2-4 in Olson 2012). Olson and Hawkins confirmed the quality of these reaches following a two-step process. First, field-based physical habitat and water quality data for the sampled reaches were used to screen data for anomalous water quality values. Second, Google Earth and U.S. Geological Survey quad maps were used to screen reaches for any evidence of human impacts (e.g., ranches, mines, agriculture, clear-cuts).

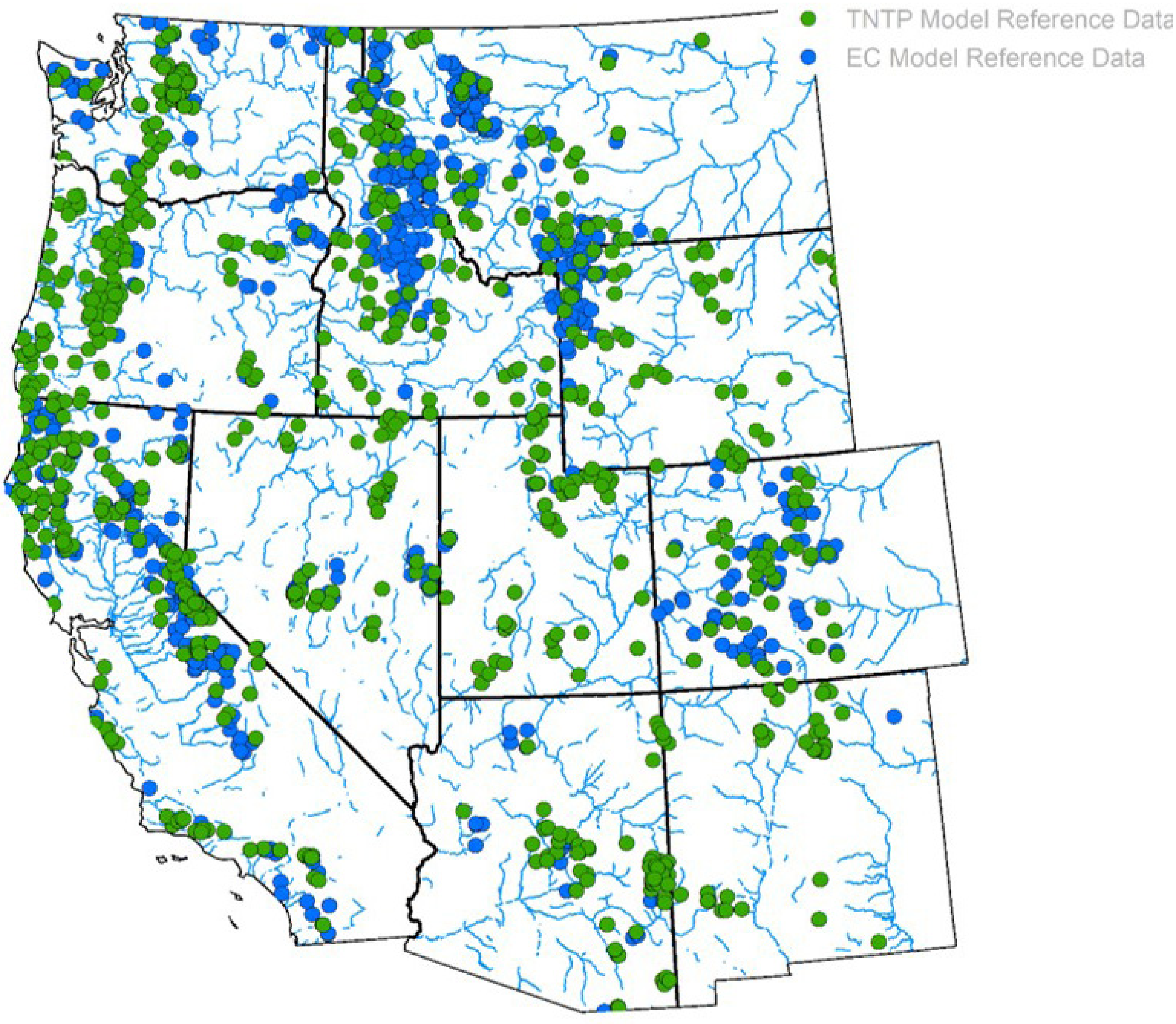


**Figure A1.** Spatial distribution of the reference reaches used to develop predictive models for total nitrogen, total phosphorus, and specific conductance (Olson and Hawkins 2012, 2013).

## Overview of Methods Used to Develop Benchmarks for Overhead Cover and Woody Vegetative Complexity

All riparian and instream habitat indicators generally lacked CDPHE standards, except for fine sediment. Benchmarks for bank overhead cover and woody vegetative complexity were therefore based on the percentiles of regional reference conditions (Hughes et al. 1986; Stoddard et al. 2006). Specifically, EPA data from 117 reference reaches were used for the two hybrid Level III ecoregions encompassing the State of Colorado—71 reference reaches for the Southern Rockies and 46 reaches for the Eastern Xeric Basin (figure A2).

Reference reaches were used to characterize the natural range of indicator variability expected to occur in the absence of anthropogenic impairment. Benchmarks were established at the extremes of reference reach distributions to identify significant departures from reference for each of two stream sizes: small wadeable reaches (≤ 10 m bankfull width) and large wadeable reaches (> 10 m bankfull width). For example, the 70th percentile of reference reach bank overhead cover values for small wadeable streams in the Eastern Xeric Basin ecoregion (74.4%) was used to determine if individual reaches were attaining versus not attaining the bank overhead cover benchmark. In other words, reaches were categorized as not attaining the percent bank overhead cover benchmark if measurements were below levels observed among 70% of reference reaches. Graphical examples of each water quality and riparian and instream habitat indicator are presented in appendix B.

An EPA dataset was used to identify the range of variability among least disturbed reaches (i.e., reference) by Omernick hybrid Level III ecoregions. The dataset was comprised of 226 reaches sampled between 2000 and 2009 as part of EPA Wadeable Streams Assessment, Western Environmental Monitoring and Assessment Program, and National Rivers and Streams

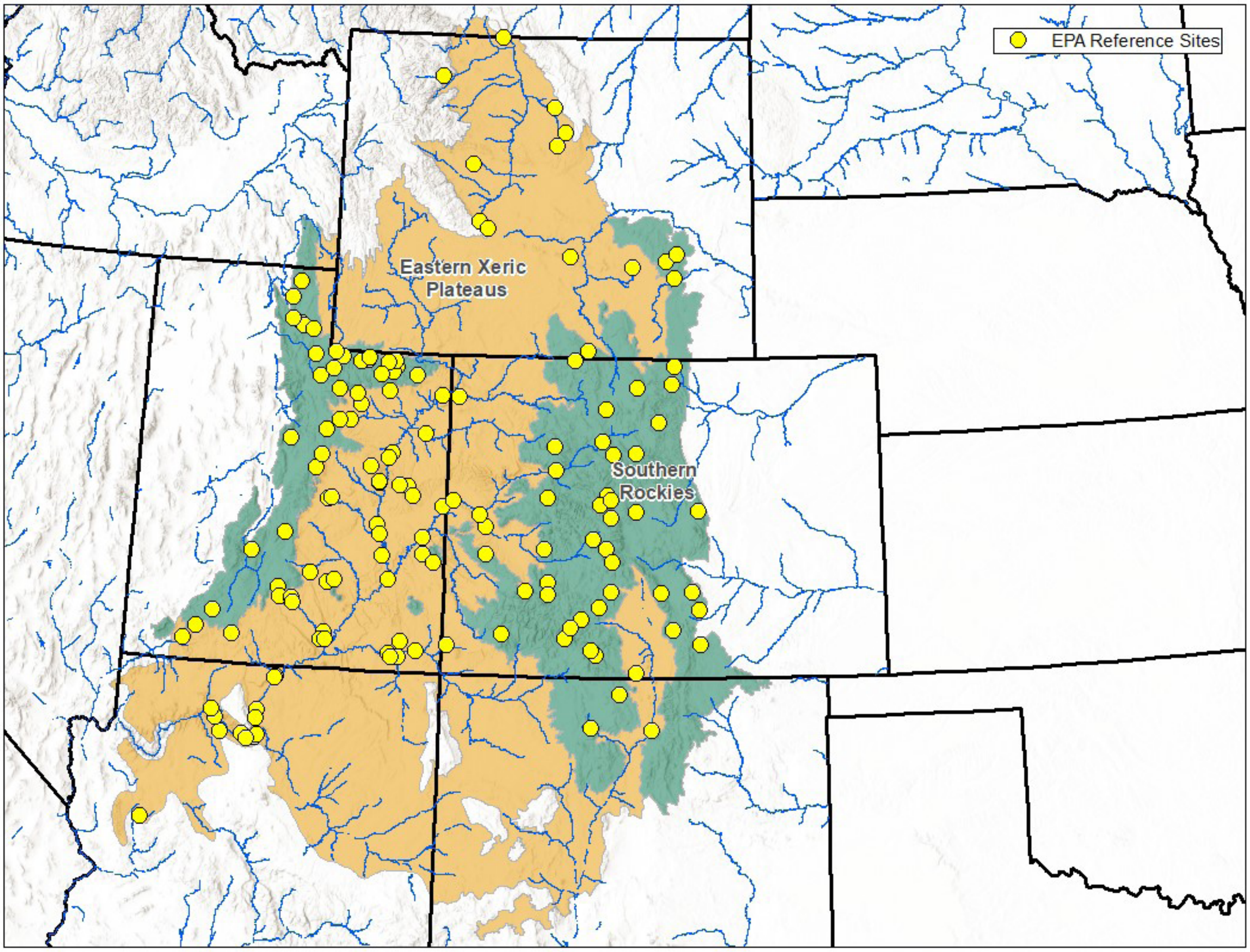


**Figure A2.** Spatial distribution of 117 reference reaches used to characterize the natural range of variability among the Southern Rockies (n = 71) and Eastern Xeric Basin (n = 46) hybrid ecoregions for fine sediment, bank overhead cover, and floodplain connectivity.

Assessment surveys (Stoddard et al. 2005; Olsen and Peck 2008; Herlihy et al. 2008). The EPA had previously screened this dataset to determine which reaches were in reference condition; however, the screening process differed among EPA surveys. Therefore, all three datasets were used in this assessment to maximize sample sizes within each ecoregion, and these reaches were rescreened using the following process.

First, both landscape- and reach-scale metrics were used to filter out reaches with anthropogenic impacts (table A2). At the landscape scale, GIS-derived metrics of land use (e.g., agriculture, urban land use) and other anthropogenic activities (e.g., dams, impoundments) were used to screen reaches (table A2). At the reach scale, field observations of the magnitude and proximity of streamside human activities such as roads, agricultural and urban development, and riparian disturbance were used as described by Kaufmann et al. (1999) and Herlihy et al. (2008). Secondly, reaches were screened if they made it through this filter and the EPA had previously flagged them as major departure from reference condition due to instream habitat variables or water chemistry data (see Kaufmann et al. 1999 and Herlihy et al. 2008 for more information). Reaches were rescreened using Google Earth imagery to ensure that no roads or other disturbances were within the watershed.

**Table A2.** Reference reach screening criteria used by the three different networks.

| Reference Screening Criteria | Environmental Protection Agency | Olson and Hawkins[1] |
|---|---|---|
| Grazing | NA | Visual assessment using aerial imagery. No numeric criteria applied. |
| Timber harvest | NA | |
| Road density | < 1 km/km$^2$ | |
| Percent agricultural land | < 3% | < 5% |
| Percent urban | < 3% | < 5% |
| Percent agricultural + urban | < 5% | NA |
| Dam density | < 0.005 | Visual assessment using aerial imagery. No numeric criteria applied. |
| Mine density | 0 | |
| National Pollutant Discharge Elimination System | 0 | |
| Riparian human disturbance[2] | < 1.5 | < 2 |

[1] Olson and Hawkins also utilized field-based water quality criteria for establishing reference conditions following the guidance of Herlihy et al. (2008).

[2] This information is from a database that provides a direct measure of human disturbance (e.g., road, dam, railroad) in the riparian zone and is a variable used to determine least disturbed reference sites (EPA 2020).

## Development of Ecoregion/Size Groupings

Given a lack of predictive models of riparian and instream habitat indicators, the national AIM team attempted to minimize natural variability associated with reaches within a given hybrid ecoregion. Like the approach taken by the EPA in the Western Environmental Monitoring and Assessment Program surveys, the national AIM team used EPA hybrid level II/III ecoregions to divide reference reaches into relatively homogenous physiographic regions. Then within a given ecoregion, bankfull width was used to separate reference reaches into small streams (≤ 10 m bankfull width) and large streams (> 10 m bankfull width). The team chose 10 m as an arbitrary cutoff based on balancing sample sizes and maximizing discriminatory efficiency for individual indicators between the two groups. Bankfull width was used as a surrogate for watershed area, stream power, and other factors that naturally influence stream geomorphic conditions.

Using this approach, most indicators had a substantial difference between benchmark values for small streams and large streams that made ecological sense, while still providing adequate sample sizes for a given ecoregion and stream size (e.g., > 20 reaches). For example, the benchmark for major departure from reference for bank overhead cover in the Eastern Xeric Basin was 44.5% for small streams (which generally support more overhead cover than large streams) and was 16.9% for large streams.

# Appendix B: Raw Indicator Values Compared to Benchmarks

This appendix presents graphical examples, including box plots (figures B2 through B12), of raw indicator values for each water quality and riparian and instream habitat indicator. Box plots are an effective way to show how indicator values vary across a landscape. The box plots are standardized representations of data based on five statistics: minimum value (bottom whisker shown as 1.5 times the inner quartile range), first quartile (bottom of box), median (bold line in box), third quartile (top of box), and maximum value (top whisker shown as 1.5 times the inner quartile range). Individual circles represent outlier values. Blue and red lines are benchmarks for moderate and major departure, respectively.

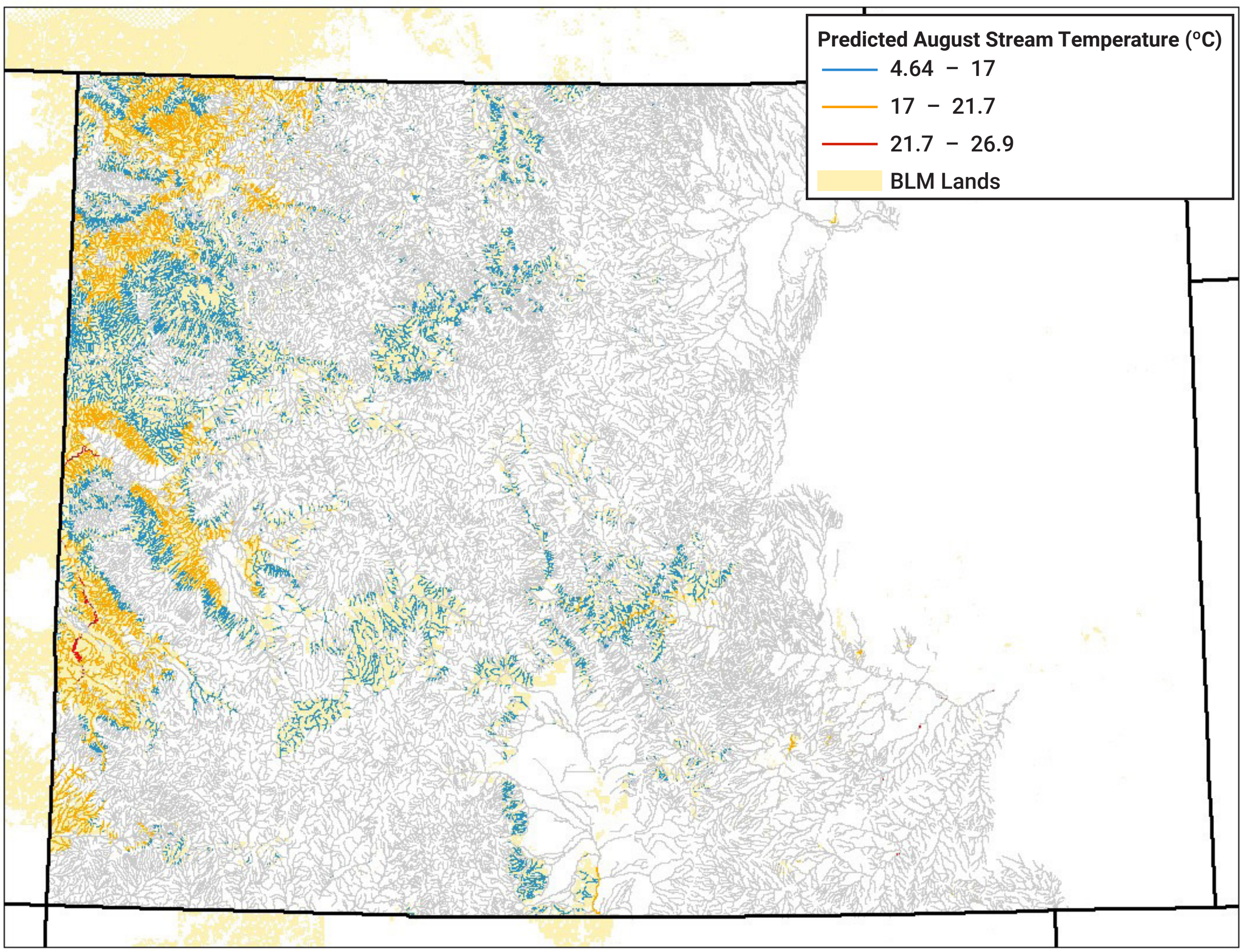


**Figure B1.** Predicted stream temperature of BLM-managed streams and rivers in Colorado color-coded by minimal (blue), moderate (orange), or major (red) departure from reference conditions. Predicted temperatures are reach-specific predictions of the 19-year mean August stream temperature for the period of 1993–2011, as derived from NorWeST models (Isaak et al. 2016).

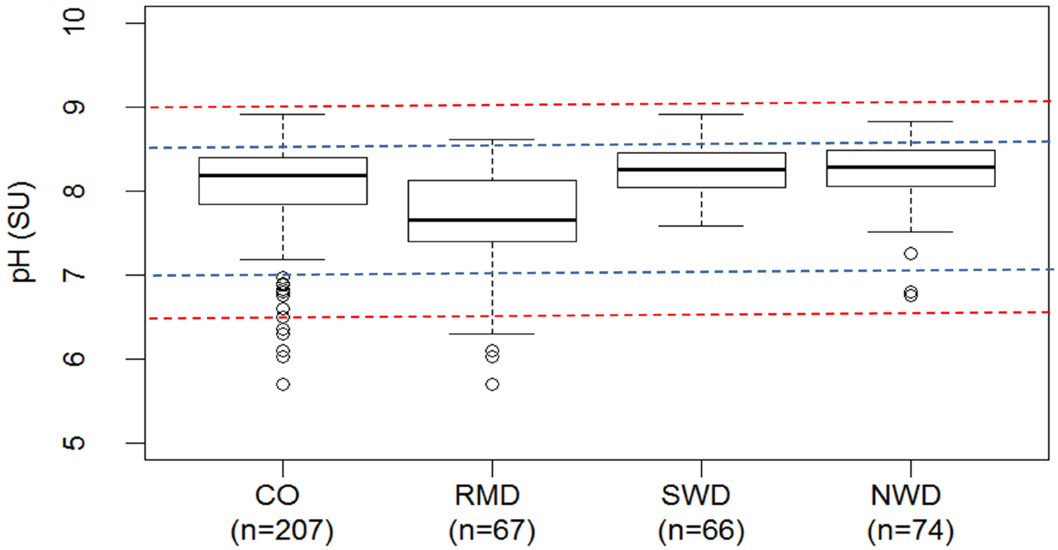


**Figure B2.** pH values of the 209 sampled reaches compared among the State of Colorado and each individual BLM district (CO = Colorado; RMD = Rocky Mountain District; SWD = Southwest District; NWD = Northwest District). The pH water quality standard (promulgated by the Colorado Department of Public Health and Environment) is between 6.5 and 9 and is applicable to both warm and cold water biota (see appendix 1, table A1).

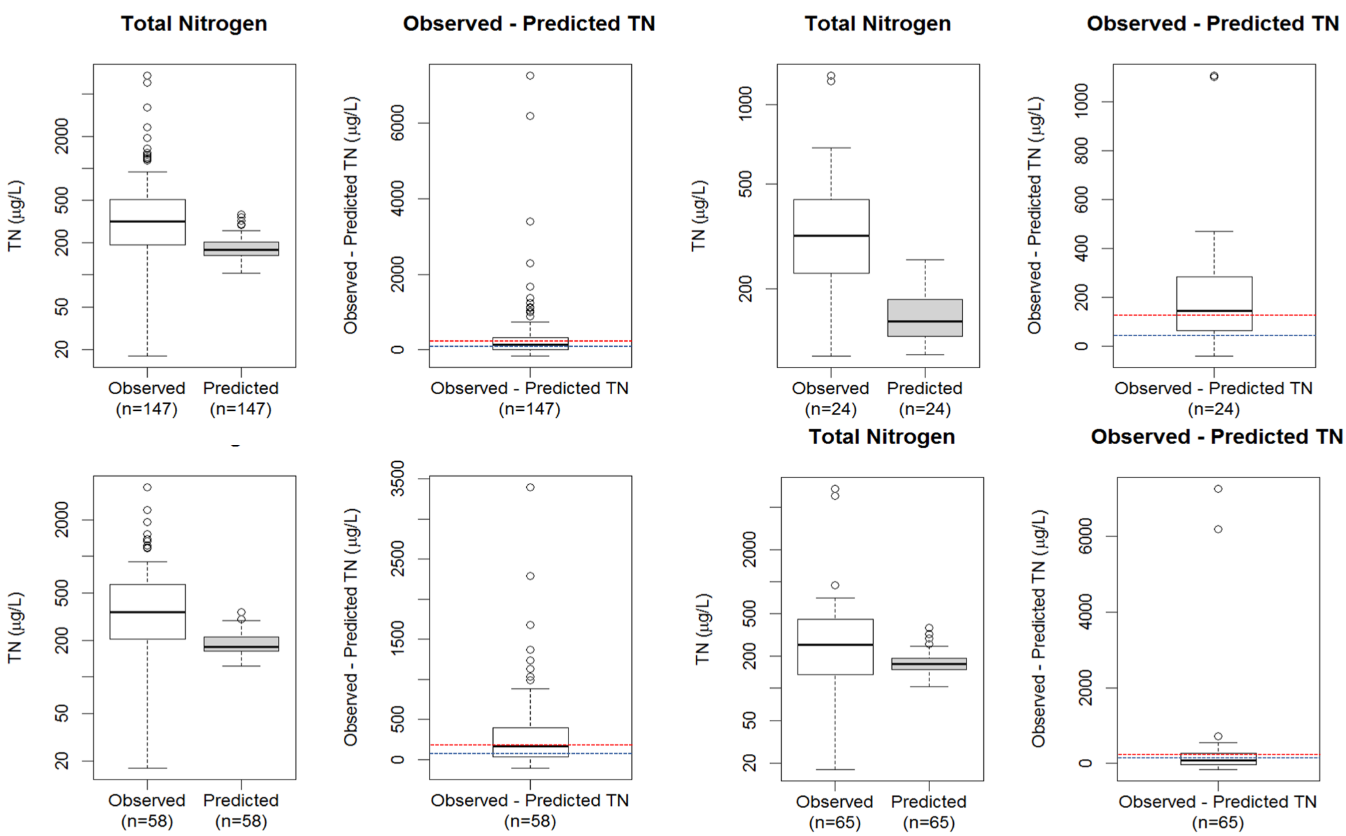


**Figure B3.** Total nitrogen values of the 209 sampled reaches compared with observed and predicted conditions among the State of Colorado (top left) and each individual BLM district (Northwest, top right; Southwest, bottom left; Rocky Mountain, bottom right). Also included are plots of the difference between observed and predicted conditions.

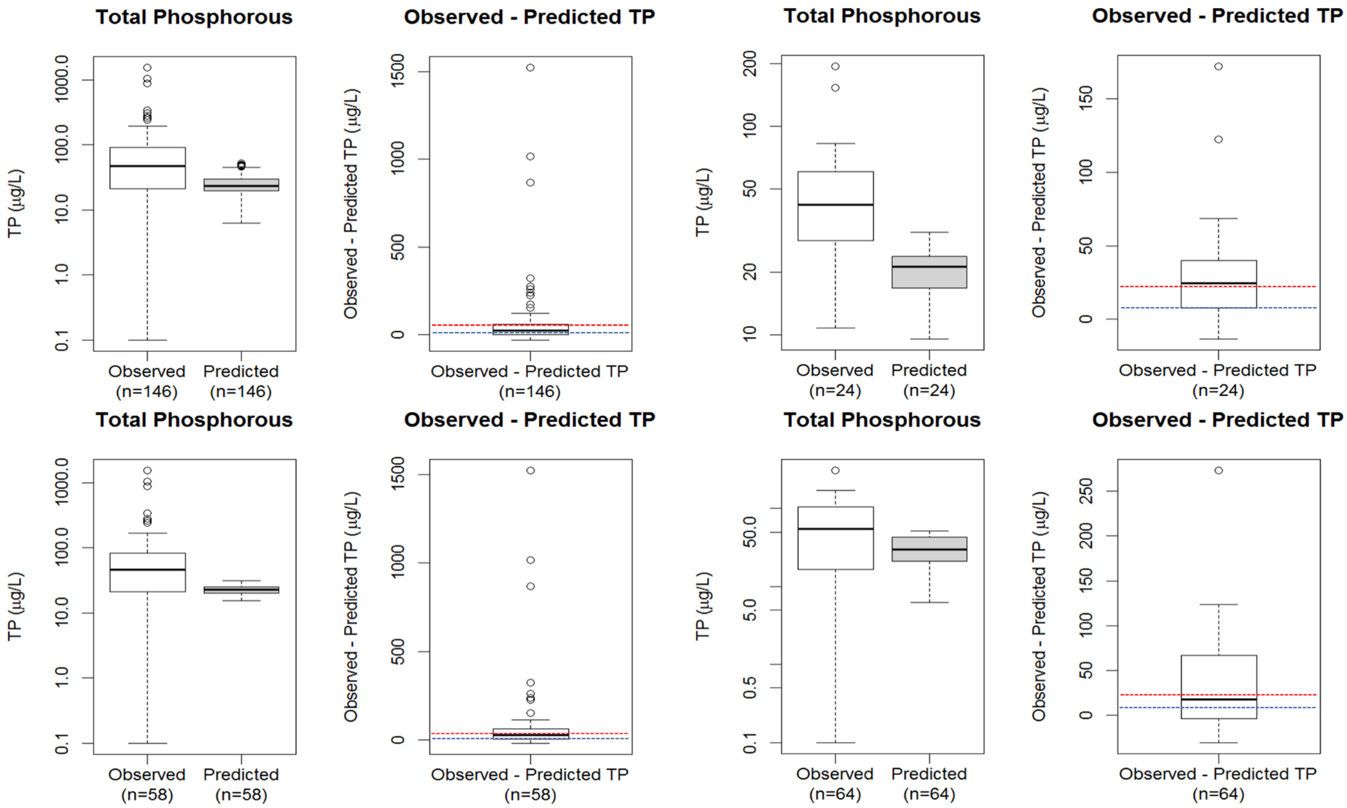


**Figure B4.** Total phosphorus values of the 209 sampled reaches compared with observed and predicted conditions among the State of Colorado (top left) and each individual BLM district (Northwest, top right; Southwest, bottom left; Rocky Mountain, bottom right). Also included are plots of the difference between observed and predicted conditions.

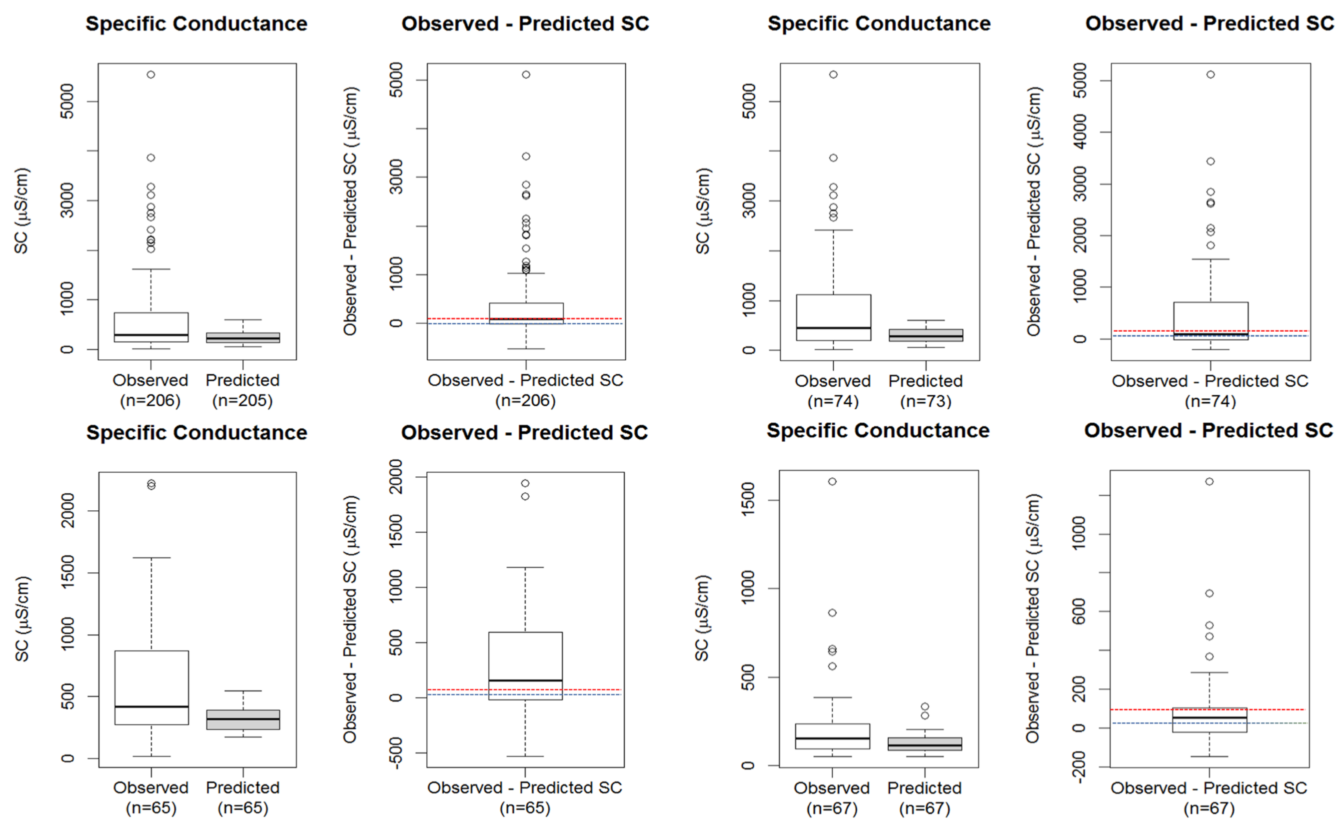


**Figure B5.** Specific conductance values of the 209 sampled reaches compared with observed and predicted conditions among the State of Colorado (top left) and each individual BLM district (Northwest, top right; Southwest, bottom left; Rocky Mountain, bottom right). Also included are plots of the difference between observed and predicted conditions.

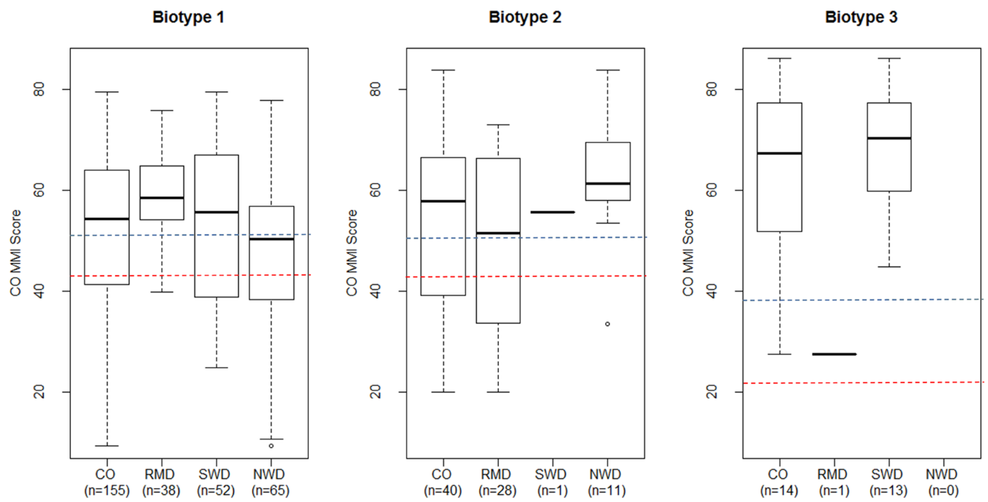


**Figure B6.** Macroinvertebrate multimetric index (MMI) values of the 209 sampled reaches compared among the State of Colorado and each individual BLM district (CO = Colorado; RMD = Rocky Mountain District; SWD = Southwest District; NWD = Northwest District) for three Colorado Department of Public Health and Environment (CDPHE) biotypes. See table A1 for explanation of CDPHE MMI biotypes.

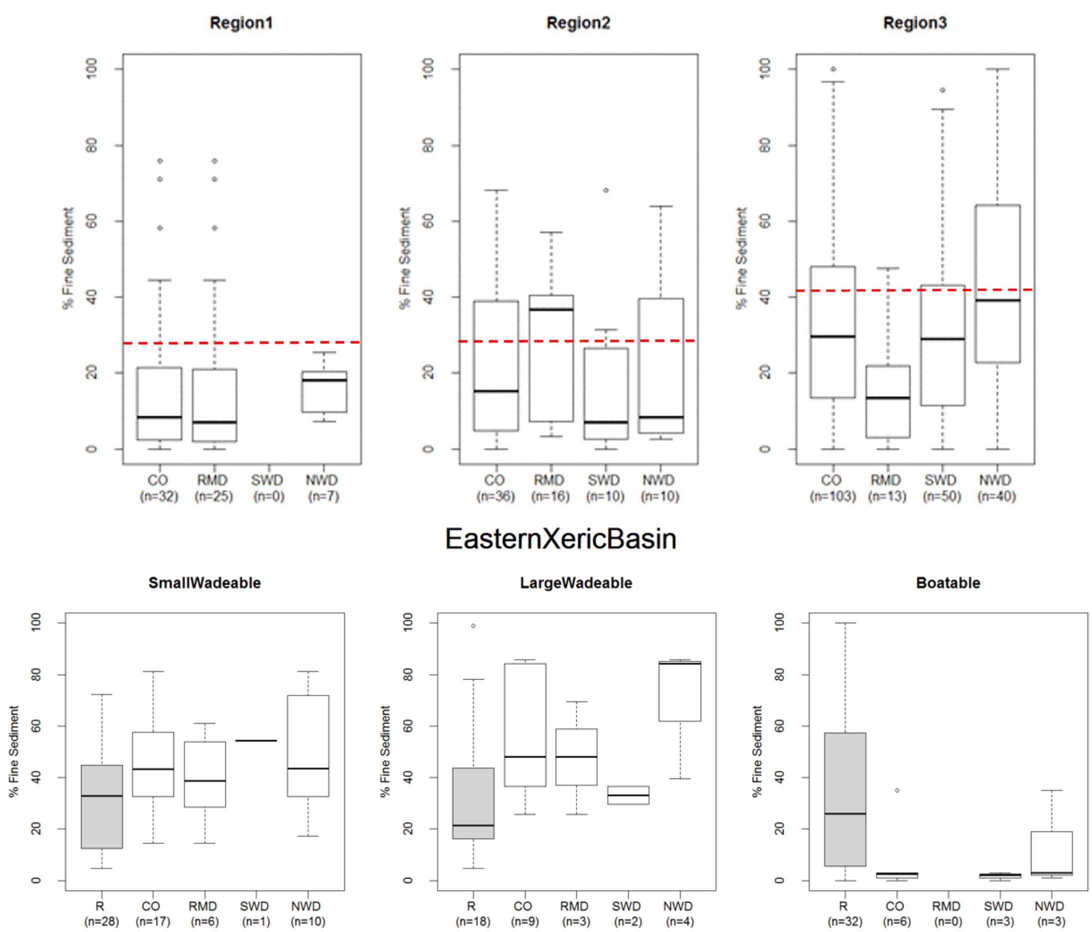


**Figure B7.** (top) Fine sediment values compared among the State of Colorado and each individual BLM district (CO = Colorado; RMD = Rocky Mountain District; SWD = Southwest District; NWD = Northwest District) for three sediment regions. (bottom) Fine sediment values that did not fall under the three sediment regions and do fall under stream size benchmarks (small wadeable is ≤ 10 m bankfull width; large wadeable is > 10 m bankfull width; and boatable means a boat was required to sample) for the Eastern Xeric Basin ecoregion. R indicates reference sites with n being number of sites. Six reaches not shown here fell in other ecoregions.

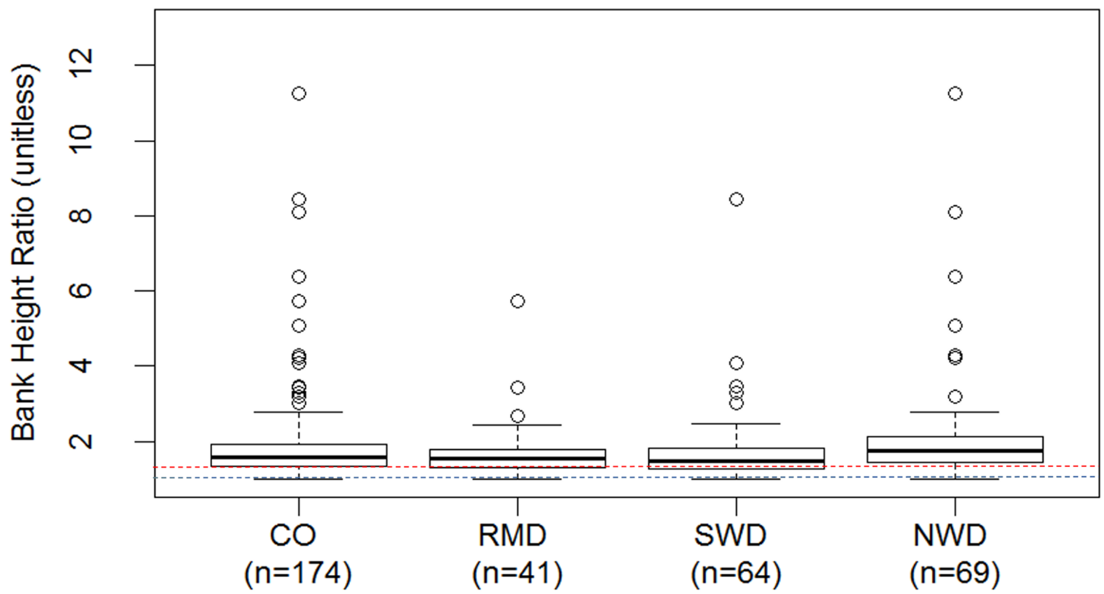


**Figure B8.** Floodplain connectivity values, as measured by the bank height ratio, compared among the State of Colorado and each individual BLM district (CO = Colorado; RMD = Rocky Mountain District; SWD = Southwest District; NWD = Northwest District). The bank height ratio is the ratio of the lowest bank height divided by maximum bankfull depth and infers the degree of incision in a stream channel (Rosgen 1996).

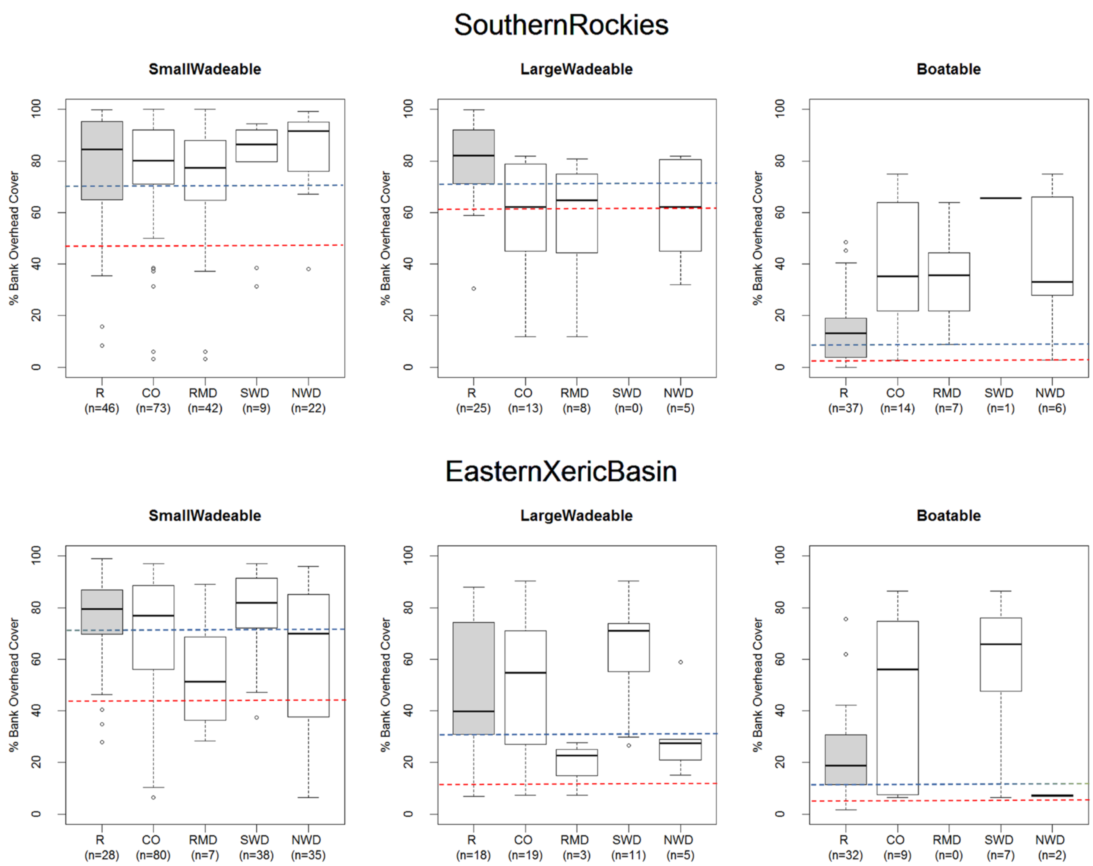


**Figure B9.** Bank overhead cover values of the 209 sampled reaches compared among the State of Colorado and each individual BLM district (CO = Colorado; RMD = Rocky Mountain District; SWD = Southwest District; NWD = Northwest District; R indicates reference sites with n being number of sites) for two hybrid ecoregions and stream sizes (small wadeable is ≤ 10 m bankfull width; large wadeable is > 10 m bankfull width; and boatable means a boat was required to sample).

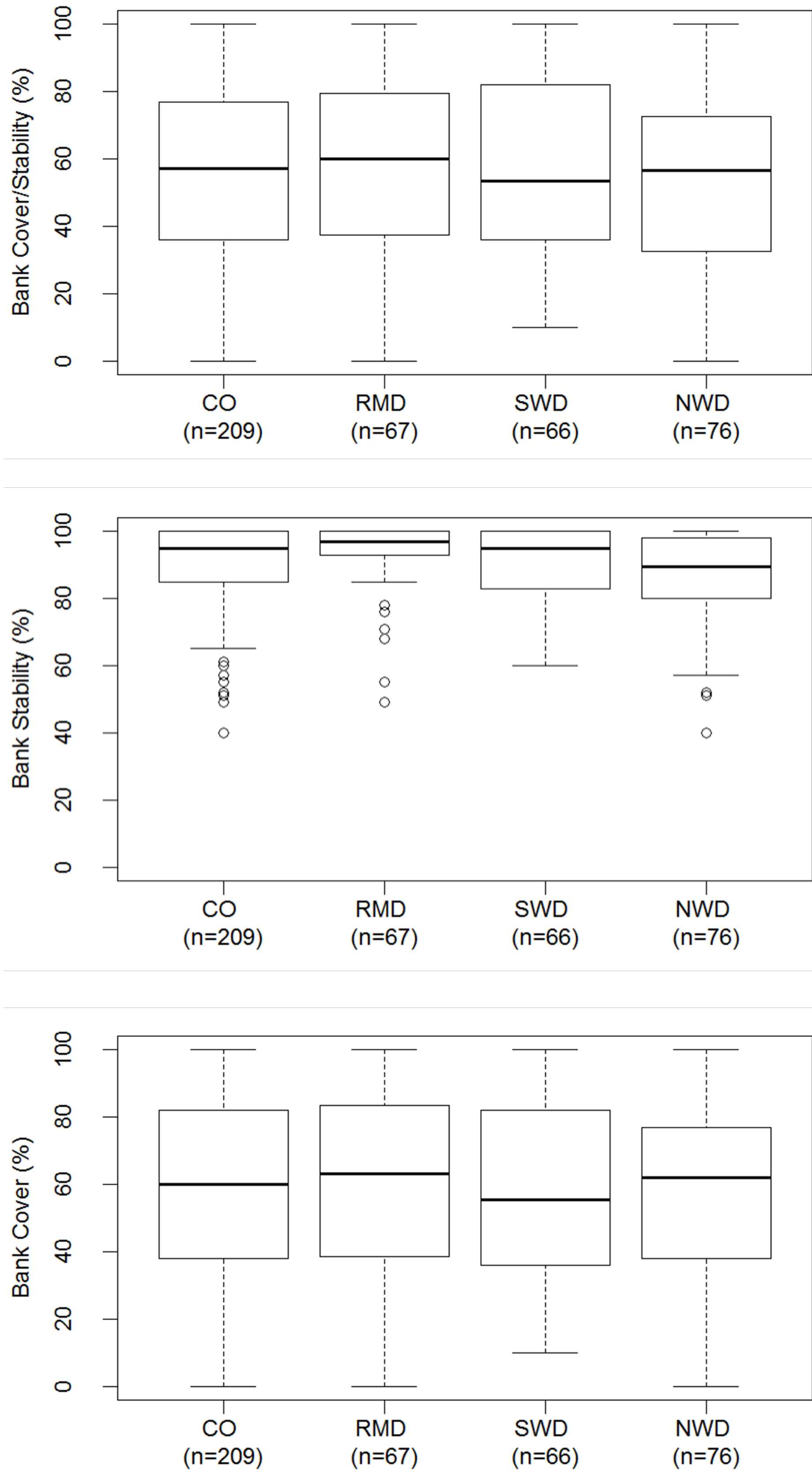


**Figure B10.** (top) Bank stability and cover, (middle) bank stability, and (bottom) bank cover values of the 209 sampled reaches compared among the State of Colorado and each individual BLM district (CO = Colorado; RMD = Rocky Mountain District; SWD = Southwest District; NWD = Northwest District).

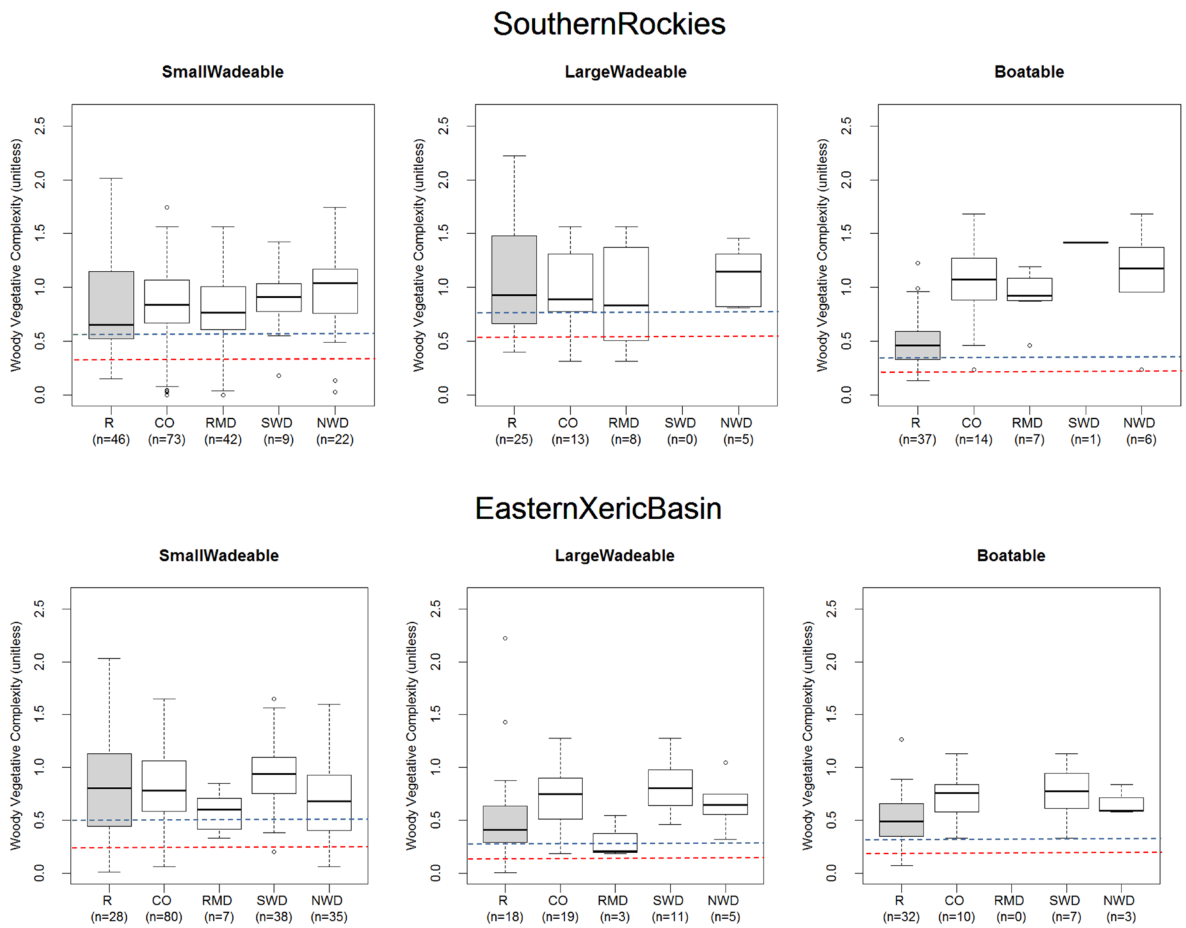


**Figure B11.** Woody vegetative complexity values of the 209 sampled reaches compared among the State of Colorado and each individual BLM district (CO = Colorado; RMD = Rocky Mountain District; SWD = Southwest District; NWD = Northwest District; R indicates reference sites with n being number of sites) for two hybrid ecoregions and stream sizes (small wadeable is ≤ 10 m bankfull width; large wadeable is > 10 m bankfull width; and boatable means a boat was required to sample).

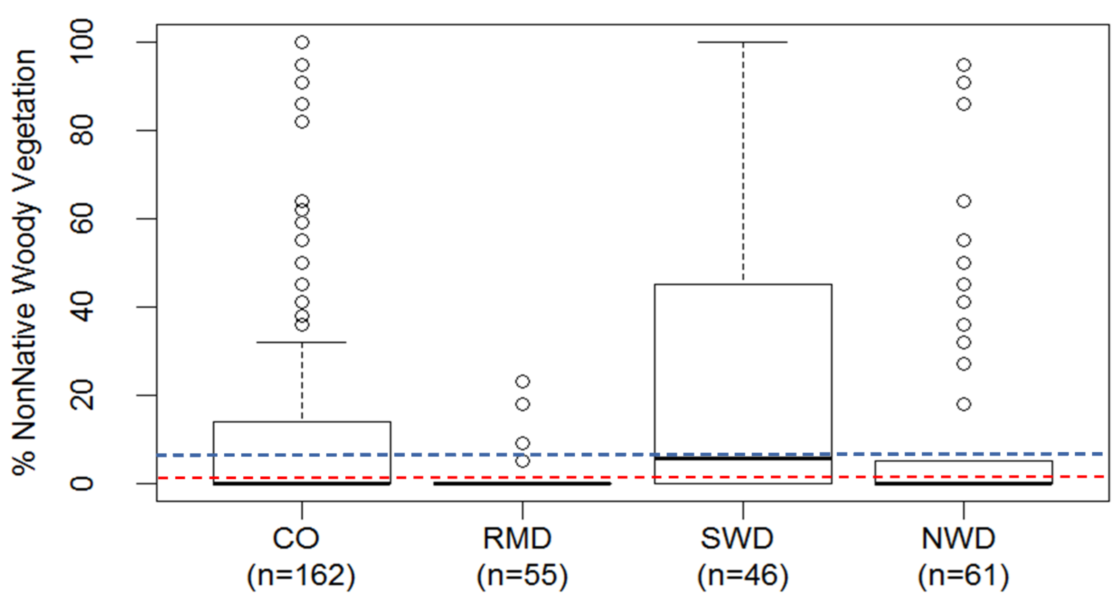


**Figure B12.** Nonnative woody riparian vegetation values compared among the State of Colorado and each individual BLM district (CO = Colorado; RMD = Rocky Mountain District; SWD = Southwest District; NWD = Northwest District).

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