

An Assessment of the Chemical, Physical and Biological Condition of Utah BLM Wadeable Streams



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EXECUTIVE SUMMARY

To provide more consistent, quantitative information regarding the condition and trend of Utah Bureau of Land Management (BLM) aquatic resources, the Fisheries, Riparian and Soil, Water and Air Programs are working collaboratively with the BLM's Assessment, Inventory and Monitoring Strategy (AIM). Here we report on a pilot of the BLM's AIM-National Aquatic Monitoring Framework (AIM-NAMF) designed to provide unbiased, quantitative estimates of the condition of UT BLM Wadeable, perennial streams and rivers at multiple spatial scales. We used standardized indicators collected with consistent, quantitative sampling methodologies and a statistically valid sampling design to assess the attainment of BLM's aquatic and to a lesser extent riparian Land Health Standards.

The information generated from this study fills an important information gap in meeting monitoring requirements set out by the Federal Land Policy Management Act and the Clean Water Act. The objectives of this assessment were to:

- Determine whether Utah Aquatic Land Health Standards (e.g., Water quality, Geomorphic processes, Aquatic biodiversity, Riparian processes) are attained at the State and District scales;
- Identify and rank the stressors contributing to degraded conditions, if standards are not attained;
- Prioritize indicators and geographic areas for more intensive monitoring and determine the causes for failing to meet Land Health Standards;
- Inform the development of the BLM's AIM-National Aquatic Monitoring Framework.

The results of this assessment show that only 36% of the length of Utah BLM Wadeable streams had minimal departure from reference conditions across all indicators (See figures starting on p. 22). Of the four Utah BLM districts, streams in the West Desert appear to be in the best condition, with 60% of streams having minimal departure from reference. The Green River District, and to a lesser extent the Canyon Country District, present the most concerns, with more than 70% of the length of streams estimated to significantly depart from reference conditions for at least one indicator. However, results from the Canyon Country District should be interpreted with extreme caution because of low sample size relative to the other districts.

Across the state, water quality impacts were by far the most pervasive; specifically, elevated levels of total phosphorous, nitrogen and salinity (64, 48 and 62%, respectively). More than 70% of stream kilometers had minimal biological departure from reference conditions, as indicated by aquatic macroinvertebrate assemblages. Riparian and stream channel indicators generally scored well with no pervasive concerns except for lower than expected stream bank stability and isolated occurrences of low canopy cover and large woody debris in the stream channel.

Our next steps are to: 1. Supplement data from this assessment with similar data collected by the Utah Department of Environmental Quality and additional AIM sampling; 2. Work with individual districts and field offices to implement AIM monitoring for land-use plan effectiveness monitoring; 3. Identify the likely anthropogenic sources for observed water quality impacts; and 4. Complete a similar assessment for Grand Staircase-Escalante National Monument.

INTRODUCTION

The Bureau of Land Management (BLM) oversees approximately 92,202 km² of land throughout the State of Utah (UT) containing an estimated 8,200 km of perennial streams (BLM 2012). BLM stream and riparian systems are among the most important, productive and diverse ecosystems in UT, which support diverse of aquatic species (e.g., cold and warm water fishes, amphibians) and ecosystem services (e.g., drinking water, flood attenuation, nutrient cycling). Concurrently, BLM's multiple-use mandate requires watersheds to be managed for activities that potentially impact aquatic resources, such as livestock grazing, mining, energy development and recreation. Consequently, knowing the condition and trend of aquatic systems is critical to achieving the Bureau's mission of "sustaining the health, diversity and productivity of public lands for the use and enjoyment of present and future generations".

To provide more consistent, quantitative information regarding the condition and trend of UT BLM aquatic resources, the Fisheries, Riparian and Soil, Water and Air Programs are working collaboratively with the BLM's Assessment, Inventory and Monitoring Strategy (AIM). Here we report on a pilot of the BLM's AIM-National Aquatic Monitoring Framework (AIM-NAMF) (Miller et al. 2015) designed to provide unbiased, quantitative estimates of the condition of UT BLM wadeable, perennial streams and rivers (hereafter referred to as streams) at multiple spatial scales. We used standardized indicators collected with consistent, quantitative sampling methodologies and a statistically valid sampling design to assess the attainment of BLM's aquatic and to a lesser extent riparian Land Health Standards.

At the broadest spatial scale, data generated from this project was designed to serve as a state-wide assessment of the condition of UT BLM streams. At the district scale, we sought to identify pervasive deviations from BLM's Land Health Standards and the likely land-uses associated with degraded conditions. Such information can be used to prioritize more spatially and temporally intensive monitoring, adaptive management strategies and to identify aquatic and riparian areas of high conservation or restoration potential. At smaller spatial scales, individual BLM districts and field offices will have empirical data to guide more targeted monitoring efforts (i.e., what and where to monitor), set restoration targets and to inform the NEPA and Land Use Planning process, among other applications. The overarching monitoring objectives included:

1. Determine whether aquatic Land Health Standards are attained across multiple spatial scales. Specifically, to determine the condition of:
 - a. Water quality
 - b. Geomorphic processes
 - c. Aquatic biodiversity
 - d. Riparian processes;
2. Determine the likely stressors contributing to degraded conditions, if standards are not attained;
3. Prioritize areas for more intensive monitoring and determinations of the factors contributing to deviations from the Land Health Standards.

BACKGROUND

The systematic inventory of aquatic resource condition is mandated by the Federal Land Policy and Management Act (FLPMA)(1976), the Clean Water Act (CWA) of 1987, as amended (33 U.S.C. 1251) and the Soil and Water Resources Conservation Act of 1977 (16 U.S.C. 2001) among other policy. To date, the BLM has largely approached resource condition and trend monitoring on a program-by-program basis with a focus on targeted, local scale resource issues. Although this information can be invaluable for single objective or site specific monitoring, the disparate sampling methods, non-random sampling design and frequent use of qualitative methodologies negate landscape-scale or overall assessments of stream condition and trend.

Given the increasingly complex nature of socio-environmental issues and the vastness of the National System of Public Lands, the BLM is increasingly trying to manage from a landscape-scale perspective (BLM 2013). For example, under the Bureau's multiple use mandate, the more than 92,000 km² of UT BLM lands are managed for domestic cattle and sheep grazing throughout more than 1,500 allotments, recreation, mining, oil and gas development and renewable energy production. Occurring throughout this same region is grazing by wild horses and burros, as well as priorities related to the sustainable management of cultural, soil, water, vegetative and wildlife resources. Wildlife resources encompass several species of management concern including sage-grouse, Bonneville and Colorado cutthroat trout and the three species (roundtail chub, bluehead sucker, flannelmouth sucker) among others. Complicating the management of these land uses and resources are wildfires of increasing area and severity and climate change. For example, the Green River watershed, one of the major drainages in UT, experienced the most severe drought in the last 90 years and among the 15th worst droughts in the last 500 years between 2000 and 2004 (Timilsena et al. 2007).

Despite the myriad of resource management issues throughout UT, many of them share the common theme of requiring information regarding the location, abundance, condition and trend of soil, vegetative and water resources. This information is mandated by BLM policy (43 CFR 4180) and fundamental to assessing the efficacy of management actions occurring from the stream reach to the watershed scale. Despite such commonalities, there is a paucity of consistently collected aquatic data throughout the state. For example, the recently completed Rapid Ecoregional Assessment for the Colorado Plateau was hampered by a lack of aquatic resource information to adequately characterize areas of high conservation or restoration potential.

Given these challenges, reduced managerial decision space because of increasing legal challenges and Office of Management and Budget programmatic evaluations, the BLM developed the AIM strategy (Toevs et al. 2011). AIM is designed to facilitate integrated, cross-program resource monitoring at multiple spatial scales of management. AIM is a critical component of the BLM's Landscape Approach (BLM 2013) and to achieving the objectives of recent Secretarial (3289, 3323, 3330) and Executive (13514) Orders related to climate change and the adoption of a landscape approach to managing the National System of Public Lands. Specifically, AIM seeks to improve the quality, consistency and applicability of BLM monitoring data by: 1. using consistent, quantitative core indicators; 2. the increased use of statistically valid sampling designs; 3. adopting electronic data acquisition and management plans; 4. developing analytical tools to facilitate data driven management decisions; and 5.

integrating remote sensing technologies. The BLM is actively implementing the terrestrial component of the AIM strategy and the aquatic component is in development. This project represents one of the first applications of the AIM-NAMF.

METHODS

Survey Design: How Were Sample Reaches Selected

Our goal was to derive unbiased, quantitative estimates of the percent of UT BLM stream kilometers having least, moderate and most departure from reference condition for each of the aquatic BLM Land Health Standards. We used the medium resolution National Hydrography Dataset Plus (NHD) to define the population of streams for which we sought to derive estimates. Our sampling and subsequent inference was limited to 2nd – 5th order (i.e., wadeable) perennial streams occurring on UT BLM lands (i.e., the target population); both perennial flow and stream order (sensu Strahler, 1957) were assigned from the NHD Plus. We excluded first order streams because of known inaccuracies regarding the presence of perennial flow in the NHD streams layer and thus the high likelihood of traveling to intermittent or ephemeral streams. From this population, we selected a random subset of stream reaches for sampling using a random or probability-based survey design.

To account for the physiographic diversity of UT BLM streams, as well as BLM management units, the target population was stratified by four BLM districts (Fig. 1). In other words, we sought to sample a minimum number of stream reaches within each district for reporting purposes. We used a generalized random tessellation stratified (GRTS) survey design (Stevens and Olsen, 2004) to randomly select 50 sample reaches per district for potential sampling¹. Within each district, the 50 reaches were spatially located in proportion to the availability of 2nd – 5th order stream segments (i.e., unequal probability selection). For example, of the 50 reaches selected in the West Desert District, 25, 16, 8 and 1 reach, were allocated to 2nd – 5th order stream reaches, respectively. We were uncertain as to the total number of sample reaches that could be sampled over two years per district given personnel and budget constraints; therefore, we selected 50 candidate reaches, with the goal of sampling a minimum of twenty per district.

¹We randomly selected NHD stream segments for sampling and located the sample reach in the approximate middle of the NHD segment. For reporting population estimates of the extent of stream kilometers in a given condition class, this design assumes that the randomly selected sample reach is representative of the entire segment. Future AIM-NAMF designs will not be designed this way to eliminate the needs for such assumptions (i.e., all points along the NHD will have a non-zero probability of being selected).

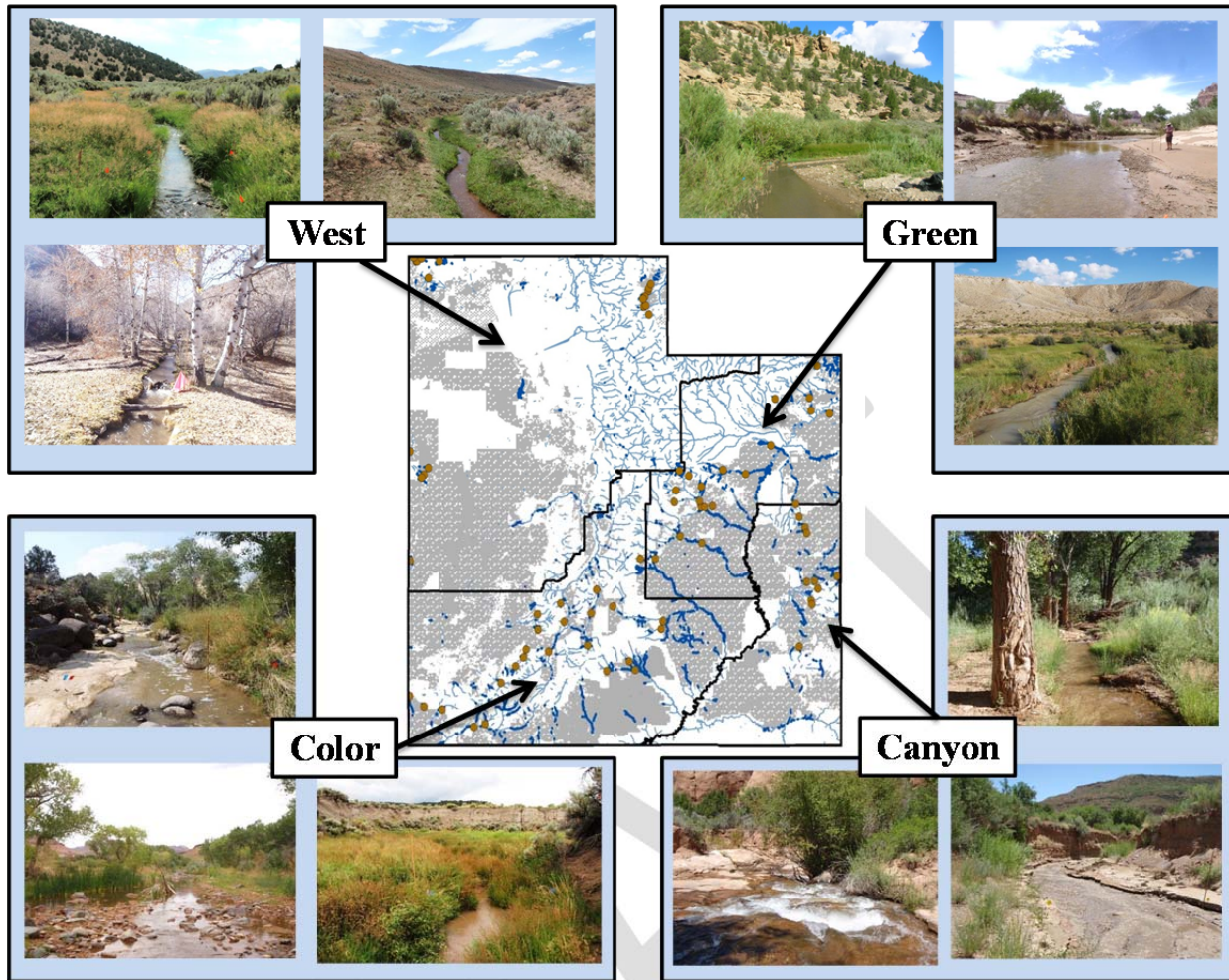


Figure 1. Map of the 2011 and 2012 sample reaches (brown points) across the four UT BLM districts. Only perennial stream systems are shown, with BLM streams highlighted in darker blue. BLM lands are indicated by grey stippling.

Site Scouting

To determine whether the selected stream reaches were truly members of the target population and could be safely accessed, all reaches were evaluated both in the office and field. To be considered part of the target population, the reach needed to be located on BLM land, a natural stream or river channel (manmade canals or ditches were not sampled) and contain water throughout 50% of the sample reach during the index period of June 1st – September 30th. We verified the presence of perennial flow by continuously measuring stream temperature from June 1st – September 30th, the index period of the study.

Sample reaches could be ‘slid’ upstream or downstream of the center point to meet the 50% water requirement or to avoid private property or safety concerns, so long as the sample point remained within the selected stream reach (150 m or 20x bankfull width –see methods sections below for details). Field crews were not permitted to slide reaches up or downstream to avoid road crossings, fence lines or other anthropogenic activities, as we sought to quantify the effects of these activities. If field crews could not sample a reach because of unsafe wading conditions, access or other issues, the reach was rescheduled for sampling at a future date or deemed permanently inaccessible, but retained within the target population. Sample reaches that we deemed permanently inaccessible or that were not part of the target population were replaced with ‘over sample’ reaches within a specific strata and stream size category in efforts to maintain desired sample sizes.

Training and Quality Assurance/Quality Control

Field sampling was conducted by crews managed by the National Aquatic Monitoring Center (NAMC), a joint partnership between the BLM and Utah State University (USU). All NAMC field crews underwent intensive training regarding site scouting and protocol implementation. Specifically, all crew members attended the U.S Forest Service’s Pacfish Infish Biological Opinion Effectiveness Monitoring Program (PIBO) training in June of 2011 and 2012. In addition to the PIBO training, NAMC staff oversaw a multi-day training where crew members practiced protocols on a diversity of stream types and field crews underwent field audits by senior crew members.

Monitoring Indicators and Field Methods

Under the Rangeland Reform Act of 1994, the BLM is required to assess the efficacy of its management actions and ensure compliance with federal regulations (e.g., FLPMA, CWA) through the Fundamentals of Land Health (43 CFR 4180.1). Following the regulations in 43 CFR 4180, individual states and regions developed Land Health Standards (hereafter referred to as ‘standards’) for up to four fundamentals determined as critical to sustaining functioning rangeland ecosystems. For aquatic systems, the UT Resource Advisory Committee developed riparian and aquatic standards related to watershed function, both instream and riparian, desired species and water quality (Table 1). Following this guidance, we measured a series of chemical, physical and biological stream parameters to derive eleven indicators (Table 2 and Appendix A).

The general field sampling design was based on a reach length equal to 20 times the average bankfull width, with a minimum reach length of 150 m (Heitke et al. 2011). Along this sample reach, 21 equally spaced transects were temporarily established consisting of 11 main transects and 10 intermediate transects. Field measurements consisted of individual point measurements made at the bottom of the reach (e.g., water quality indicators) or measurements at each of the eleven main (e.g., canopy cover, bankfull width and depth) or 21 total transects (e.g., substrate, bank stability) (Table 2). All field measurements were taken during base flow conditions from June 1st – September 30th of 2011 and 2012 (i.e., index period).

Assessments of instream and riparian function (Standard 2) are a major component of the BLM's Land Health Standards (Table 1). Standard 2 calls for assessments of whether channel form and function are characteristics for the region and whether riparian areas are in proper functioning condition. These same indicators are critical to determining the habitat viability for native, threatened and/or sensitive species (i.e., similar to the maintenance of cold or warm-water fisheries under the CWA). Our assessments of channel form and function focused on quantifying streambed particle size distributions, large woody debris and floodplain connectivity (Table 2 & Appendix A). Additional measurements of channel habitat units (e.g., pools, riffles, runs), fine sediment and channel cross-sections were made, but are not presented because of ongoing efforts to establish benchmarks (i.e., reference conditions) from which objective condition determinations can be made.

To assess riparian function, we measured bank stability and percent canopy cover (i.e., shading), as well as the previously mentioned channel function indicator of floodplain connectivity (Table 2 & Appendix A). Furthermore, we took measurements of bank angle, but they are not utilized at this time because of ongoing efforts to establish benchmarks (i.e., reference conditions) from which objective condition determinations can be made. Measurements of canopy cover, LWD and floodplain connectivity were only taken in 2012.

To address both the desired species standard (Standard 3) and the biotic water quality standard (Standard 4), we sampled aquatic macroinvertebrates (Table 2 & Appendix A). In addition to quantifying instream biological integrity, we used the macroinvertebrate data to assess the presence or absence of invasive invertebrates (Appendix A). Additional water quality indicators (Standard 4) included temperature, specific conductance (hereafter referred to as conductivity) and total nitrogen and phosphorous (Table 1&2; Appendix A). These indicators are not meant to be representative of all UT water quality standards, but rather the common chemical stressors resulting from land uses such as irrigation water withdrawals, grazing, mining, timber harvest and other activities occurring on or near public lands. While one-time grab samples (see Appendix A) can be used to identify potential water quality priorities requiring additional sampling and/or to make correlations with macroinvertebrate condition estimates, our sampling was not adequate to determine the attainment of state water quality standards, which require the temporal resolution of sampling to be customized to the individual parameter.

Table 1. UT BLM's three aquatic related Land Health Standards. Also presented are the indicators recommended for assessing standard attainment and the indicators utilized in this assessment.

Land Health Standards	Recommended indicators	Utilized indicators
<i>Standard 2</i> - Stream channel form and function are characteristic for the soil type, climate and landform; riparian areas are in proper functioning condition (i.e., vegetation is adequate to dissipate energy, stabilize stream banks, reduce incoming solar radiation)	Vegetative cover and composition, stream bank stability, large woody debris, channel width:depth ratios, pool:riffle ratios, substrate stability, floodplain connectivity	Substrate size distribution, bank stability and cover, floodplain connectivity, large woody debris, canopy cover
<i>Standard 3</i> - Desired species, including native, threatened, endangered, and special status-species, are maintained at a level appropriate for the site and species involved	Composition, diversity, density, and/or age class of desired species, habitat connectivity, recovery from disturbance, vegetative composition and cover	Benthic macroinvertebrates
<i>Standard 4</i> - Water has characteristics to support existing beneficial uses and complies with CWA and state standards	Temperature, nutrients, conductivity, pH, fecal coliform, turbidity, dissolved oxygen, macroinvertebrates	Total nitrogen and phosphorous, conductivity, temperature, benthic macroinvertebrates

Table 2. Summary field methodologies and predicted response to disturbance for the indicators used to assess UT BLM's aquatic Land Health Standards. Unless otherwise noted, field methodologies followed Heitke et al. (2011). The methods used to make condition determinations are presented in table 3.

Standard	Indicator	Summary field methodology	Predicted response to disturbance
Stream channel and riparian function	Fine sediment (%)	5 particles randomly selected and measured from each of 21 transects	Increase
	LWD (# pieces / 100 m) ¹	Count and measure LWD (> 1 m length; 10cm dia.) within bankfull channel	Decrease
	Floodplain connectivity ^{1,2}	Bankfull and wetted width measured at 21 transects	Decrease
	Bank stability	Stability and cover plots for left and right bank at 21 transects	Decrease
	Canopy cover ²	Densiometer readings at 10 transects	Decrease
Desired species	Macroinvertebrate biological integrity (O/E)	8 Surber samples (0.74 m ²) from 4 riffles or 8 transects	Decrease
	Invasive benthic macroinvertebrates	See macroinvertebrate protocol above	Increase
Water quality	Macroinvertebrate biological integrity (O/E)	See macroinvertebrate protocol above	Decrease
	Water temperature (°C)	Hobo thermistors: July 15th – Sept. 15th	Increase
	Conductivity (µS/cm)	Single, in-situ YSI measurement	Increase
	Total nitrogen and phosphorous (µg/L) ²	Single sample collected for lab processing	Increase

¹Indicator only measured in 2012

²Field methodology followed U.S. EPA, (2009)

SETTING EXPECTATIONS

The attainment of BLM's Land Health Standards are evaluated on an individual basis for each unique indicator. This approach is akin to a limiting factor analysis, where the failure to meet anyone component of a standard can initiate changes in management. The objective evaluation of whether a standard is met requires a comparison of field measurements to the range of conditions one would expect to occur at a site in the absence of anthropogenic alterations (i.e., reference conditions). For example, total nitrogen values characterize ambient nutrient concentrations at a single point in time (i.e., status), but without appropriate benchmarks, such measurements lack context and cannot be used to make objective condition determinations regarding potential eutrophication. Because of the paucity of knowledge regarding pre-European stream and river conditions as well as numeric water quality criteria, least disturbed or minimally impacted conditions are commonly used to establish reference conditions (Hughes et al. 1994, Stoddard et al. 2006, Hawkins et al. 2010b) and are utilized herein.

Given the tremendous spatial variability inherent of lotic systems, one of the central challenges to making accurate condition determinations is the ability to effectively discriminate between natural sources of spatial variability and anthropogenic gradients (reviewed in Hawkins et al. 2010a). We utilized two different methods for determining the chemical, physical and biological conditions one would expect to occur at a site in the absence of anthropogenic impacts. Both approaches relied on networks of reference sites sampled by state and federal agencies using similar methodologies as those utilized herein.

The first method involved the application of multi-site, empirical models which compare the observed field values to those expected to occur if the site was in reference condition (i.e., observed/expected [O/E] models). Such models account for natural environmental gradients and were used to make site specific predictions for the water quality and macroinvertebrate indicators (Table 3). This approach works by first modeling the natural spatial variability among a network of reference sites for a given parameter using geospatial predictors. Such models are then used to predict the conditions expected to occur at test sites in the absence of impairment. For example, Hill et al. (2013) used nine readily available GIS derived variables (e.g., air temperature, watershed area, reservoir index) to explain 87% of the spatial variability in mean summer stream temperature among 481 reference sites throughout the conterminous U.S. (RMSE 1.9°C). We used this model to predict the average summer temperature expected to occur at a test site in the absence of impairment and then compared that value to the measured field value to estimate the degree of departure. In addition to stream temperature, we used O/E models to establish least disturbed conditions for total nitrogen and phosphorous (Olson 2012), conductivity (Olson and Hawkins 2012) and aquatic macroinvertebrates (UTDEQ, unpublished model) (Table 3).

The condition classes resulting from comparison of the observed indicator values to those expected to occur in the absence of impairment included: 'least departure', 'moderate departure' and 'most departure'. One of the three condition classes were assigned based on the magnitude of deviation of measured field values to those predicted to occur in the absence of impairment. The magnitude of deviation used to designate different condition classes was based on model error rates (i.e., model residuals), where measurements within 75% of model residuals were scored as least departure, values between 75 and 95% moderate departure and field measurements greater than 95% model residuals scored as most departure (Table 3).

All of the stream and riparian function indicators lacked predictive models; therefore, we utilized the range of variability among regional reference sites to set thresholds for making condition determinations (Hughes et al. 1986, Paulsen et al. 2008). The range of natural variability approach relies on existing networks of sampled reference sites (least disturbed) located within a relatively homogenous physiographic region (e.g., Omernik level III ecoregions). For our application, we utilized data from 248 reference sites throughout four hybrid level II/III ecoregions contained within the State of Utah (e.g., Stoddard et al. 2005) (Fig. 2). The observed variance among reference sites for each of the physical habitat indicators was used as an estimate of the range of natural variability expected to occur in the absence of anthropogenic impairment. Thresholds were then established at the extremes of reference site distributions to identify significant departures from reference (Table 4). For example, the 75th and 95th percentiles of reference site fine sediment values (<6 mm) for the Xerix – Eastern Plateau ecoregion, 47 and 80% respectively, were used to separate least departure, moderate departure and most departure from reference conditions, respectively. In other words, sites were categorized as most departure if fine sediment measurements exceeded levels observed among 95% of reference sites.

Table 3. Utilized methods and threshold for assigning the condition determinations of least, moderate and most departure from reference conditions for the desired species and water quality indicators.

Standard	Indicator	Condition determination method	Thresholds ¹
Desired species	Macroinvertebrate biological integrity	1 and 2 standard deviations of model error for the UTDEQ O/E model ²	>0.85 < >0.68 <
	Invasive benthic macroinvertebrates	Presence / absence	NA
Water quality	Water temperature (°C)	75th and 95th percentile of model predictions ³	< model prediction + 1.1 < > model prediction + 3.23°C
	Conductivity (µS/cm)	75th and 95th percentile of model predictions ⁴	< model prediction + 27.1 < > model prediction + 53.7 µS/cm
	Total nitrogen (µg/L)	75th and 95th percentile of model predictions ⁵	< model prediction + 52.1 < > model prediction + 114.7 µg/L
	Total phosphorous (µg/L)	75th and 95th percentile of model predictions ⁵	< model prediction + 9.9 < > model prediction + 21.3 µg/L

¹thresholds listed from least to most departure conditions

²UTDEQ O/E model; ³Hill et al., 2013; ⁴Olson and Hawkins, 2012; ⁵Olson, 2012

Table 4 Regional reference values for U.S. EPA hybrid level II/III ecoregions used to assign the condition classes of least, moderate and most departure from reference conditions for the stream channel and riparian function indicators. The 'moderate departure' category corresponded to values between the least and most departure thresholds.

Indicator	Percentile of reference condition	EPA hybrid ecoregion							
		Xeric - Eastern Plateau		Xeric - North		Xeric - South		Mtns. Southern Rockies	
		Least dep.	Most dep.	Least dep.	Most dep.	Least dep.	Most dep.	Least dep.	Most dep.
Fine sediment (%)	75 th and 95 th	<47	>80	<45	>70	<49	>75	<24	>44
LWD (# pieces / 100 m)	25 th and 5 th	>0.4	0	>5.4	0	>2.7	0	>5.4	0
Floodplain connectivity	75 th and 95 th	<0.35	>0.71	<0.4	>0.85	<0.42	>0.8	<0.3	>0.49
Percent canopy cover	25 th and 5 th	>7	<1	18	1	30	0	27	3
Bank stability ¹	NA	>80	<60	>80	<60	>80	<60	>80	<60

¹The bank stability thresholds of 60 and 80% stability were based on professional judgment for all ecoregions

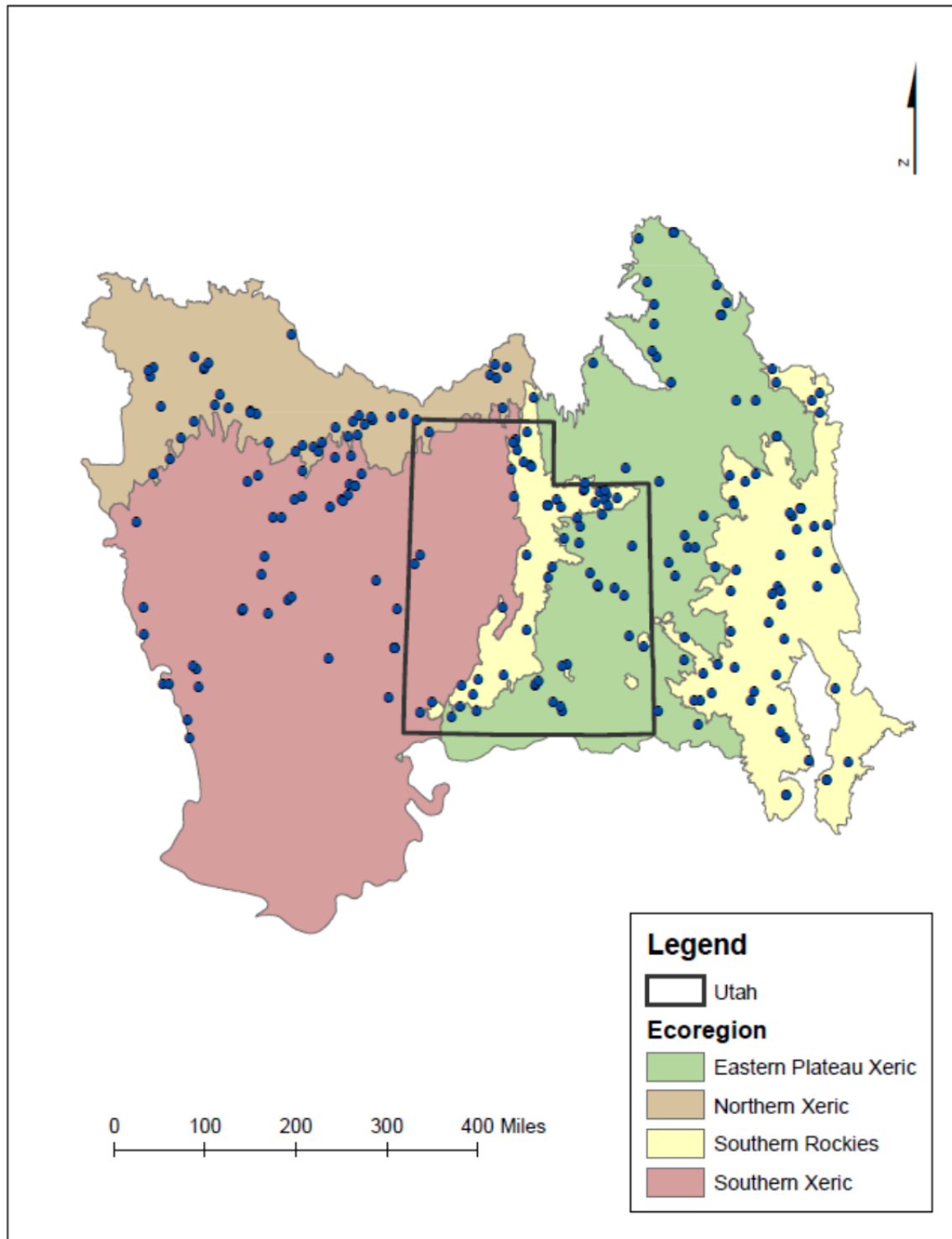


Figure 2. Distribution of the 248 U.S. EPA reference sites among the four hybrid ecoregions used to assign the condition classes of least, moderate and most departure from reference conditions for the stream channel and riparian function indicators.

INVENTORY OF UT BLM WADEABLE STREAMS

The NHD Plus estimated the original target population of 2nd – 5th order perennial streams occurring on UT BLM lands as 3,146 km. Based on site scouting, we found that 603 of those stream kilometers (19%) were either non-perennial or not a member of the target population for other reasons (e.g., non-BLM land, irrigation canal) (Fig. 3 – light grey UTAH bar); however, the overwhelming majority (99%) were omitted because of non-perennial flow. Among BLM districts, the NHD disproportionately overestimated the extent of perennial streams in the West Desert and Canyon Country Districts (Fig. 3 – light grey bars).

Of the estimated 2,543 km of UT BLM perennial streams (2nd – 5th order), 613 km (23%) were unsampleable because crews were denied access to adjoining private property or the reach was physically inaccessible due to excessive hikes, physical barriers or unsafe conditions (Fig. 3 – dark grey bars). Similar to the distribution of non-target or non-perennial stream reaches, the distribution of inaccessible stream kilometers was disproportionately distributed, with the Canyon and Color Country Districts having the greatest proportion of target streams that we cannot report on (Fig. 3 – dark grey bars). Of the target population, we are able to report on the condition of 76% of BLM streams state-wide, 94% for the West Desert District, 83% for the Green River District, 71% for the Color Country District and only 51% for the Canyon Country District (data not explicitly shown in Fig. 3, but the results can be inferred from the relative proportion of the black [sampled] versus dark grey [inaccessible] bars).

In total, we sampled 77 sites among all four districts between 2011 and 2012. The West Desert District had 24 total sites, the Color Country District 23 sites, the Green River District 21 sites and the Canyon Country District only 10 sites. Combined with the extent of inaccessible stream km (49%) and the low sample size, results from the Canyon Country District should be interpreted with extreme caution. Similarly, estimates for large woody debris, floodplain connectivity and canopy cover should also be interpreted with caution since they were only sampled in 2012 and thus have lower samples sizes.

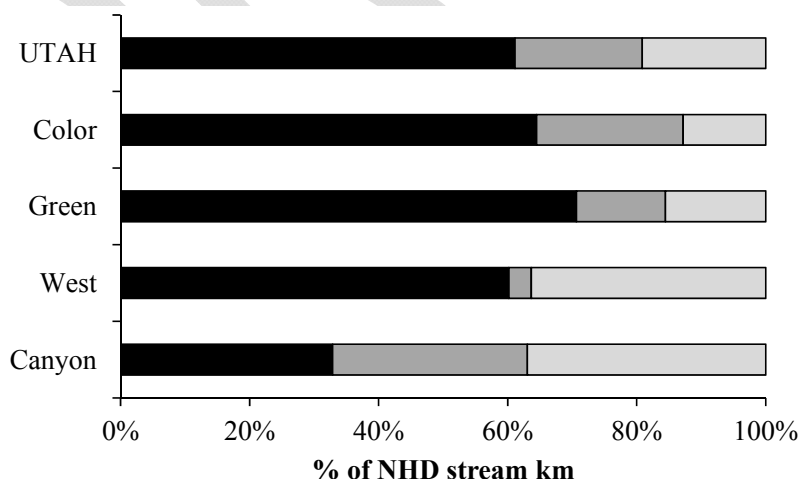


Figure 3. Proportion of the total stream kilometers identified from the National Hydrography Dataset that were non-target (light grey), target but inaccessible (dark grey) and sampled (black).

CONDITION OF STREAM AND RIPARIAN FUNCTION INDICATORS

Our use of a statically valid design for selecting sample reaches allowed us to use the data from the sampled reaches to make quantitative estimates of the proportion of total target stream kilometers having least, moderate and most departure from reference conditions with known levels uncertainty. Below we use the condition thresholds established from both observed to expected empirical models (water quality and desired species indicators) and regional reference conditions (stream and riparian function indicators) to make quantitative estimates of the proportion of stream kilometers in each condition class at the state and district levels.

Fine sediment

Fine sediment levels exceeded regional reference thresholds (i.e., most departure) for only 10% of stream kilometers throughout the entire state (Fig. 4). The Green (21%) and West Desert (15%) districts had the greatest proportion of stream kilometers significantly departing (i.e., most departure) from reference condition for fine sediment. All districts, except the Canyons, had roughly equal proportions of stream length with least and moderate departure, suggesting that efforts to mitigate sediment loading should continue throughout the state, especially for reaches believed to be in the moderate departure category.

Large woody debris (LWD)

Statewide, the overwhelming majority of stream kilometers had moderate departure from reference conditions (74%) for LWD, with only 18% having most departure and 8% least departure (Fig. 4). The West Desert had the greatest extent of stream kilometers significantly departing from reference (40%) along with the Canyons, but the Canyon estimates were only based on a sample size of two. Furthermore, LWD measurements were only taken in 2012, resulting in low samples sizes ($n < 11$) among all districts. Despite the low sample sizes, the results suggest an overwhelming number of BLM streams as needing to be managed for increased LWD recruitment to promote proper geomorphic form and function, as well as aquatic habitat.

Percent canopy cover

We estimated that 55% of UT BLM stream kilometers had least departure from reference for the amount of canopy cover; however, a greater proportion of stream kilometers significantly departed (i.e., most departure) from reference conditions (23%) compared to that estimated for stream temperature (9%) (see temperature results below) (Fig. 5). The most significant deviations from reference condition for canopy cover were observed in the Green River (51%) and West Desert Districts (27%); however, the estimates for both districts were highly variable. Estimates for the Canyons District should be interpreted with extreme caution because of low sample sizes, despite the apparent high precision.

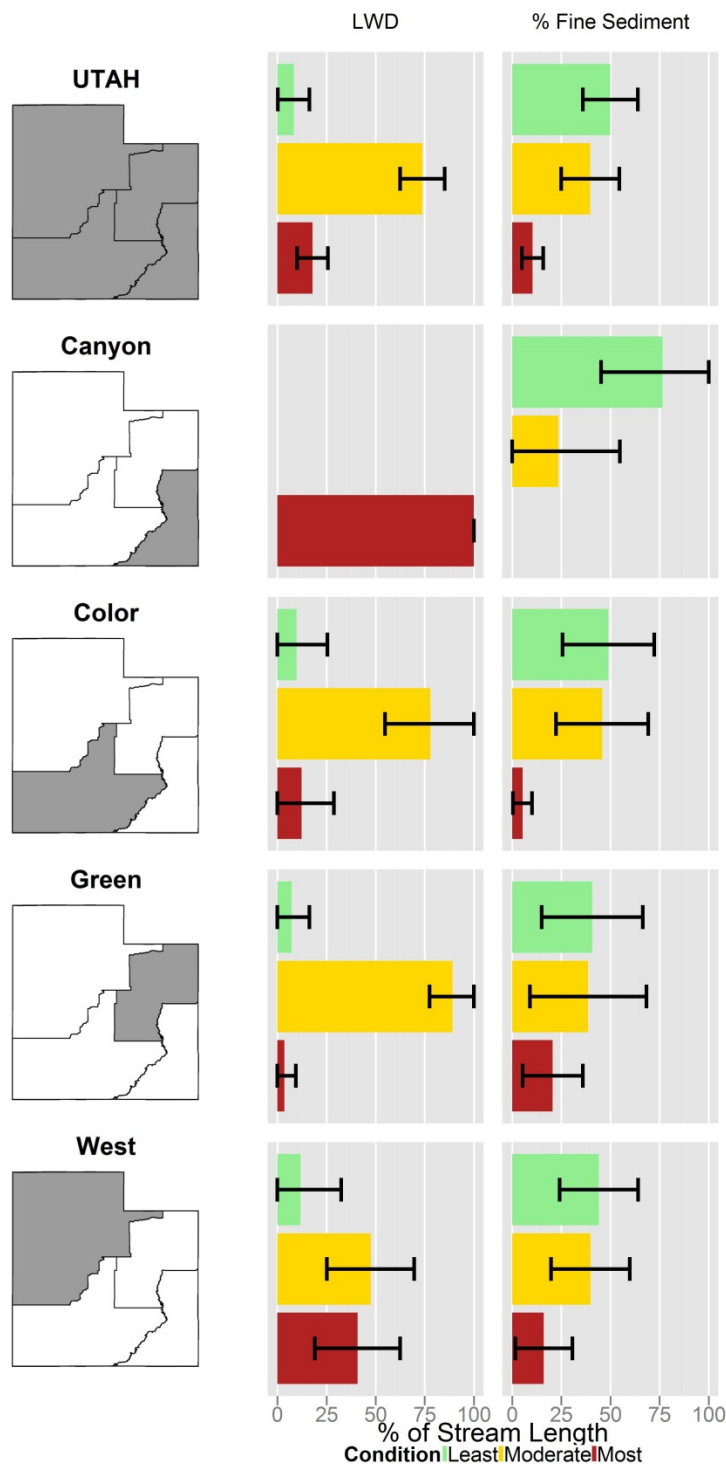


Figure 4. Percent ($\pm$ 95% CI) of UT BLM wadeable streams having least, moderate and most departure from reference conditions for the stream function indicators of large woody debris (LWD) and percent fine sediment. Results are presented for all UT BLM streams and for each of the four districts. LWD estimates for the Canyons District are based on < 5 reaches and thus should be interpreted with extreme caution.

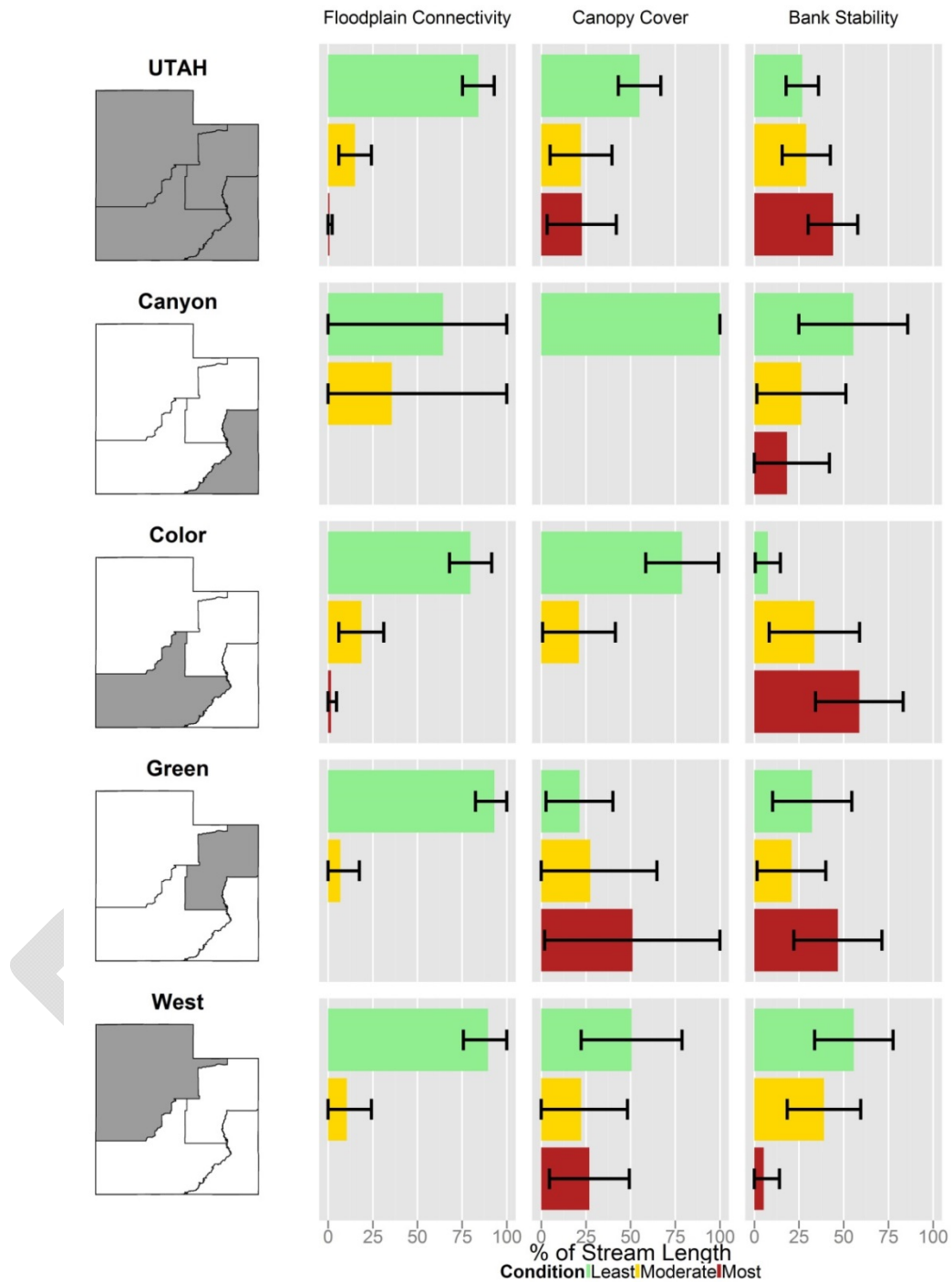


Figure 5. Percent ($\pm$ 95% CI) of UT BLM wadeable streams having least, moderate and most departure from reference conditions for the riparian function indicators of floodplain connectivity, canopy cover and bank stability. Results are presented for all UT BLM streams and for each of the four districts. Floodplain connectivity and canopy cover estimates for the Canyons District are based on < 5 reaches and thus should be interpreted with extreme caution.

Bank stability

Despite the presence of adequate canopy cover at a majority of the sampled reaches, bank stability appeared to be a potential problem; we estimated that 44% of UT BLM stream kilometers have a majority (<60%) of unstable banks and 29% had between 60 and 80% bank instability (Fig. 5). The extent of unstable stream banks was not equally distributed among districts, as the West Desert and Canyons Districts had less than 20% of stream kilometers significantly departing from reference compared to greater than 46% in the Green and Color Country Districts. Despite the apparent patterns among districts, the district level estimates were highly variable. Lastly, differences among districts could reflect natural variability in the potential of bank stability resulting from factors such as soil types and vegetative cover and composition, which were not accounted for.

Floodplain connectivity

Compared to the channel dimensions among reference sites, the large majority of UT BLM stream kilometers (84%) are estimated to have adequate floodplain connectivity and thus minimal departure from reference conditions (Fig. 5). This pattern was ubiquitously observed among districts, with no district having greater than 2% of streams significantly departing from reference conditions. Similar to the other stream and riparian function indicators that were only measured in 2012 and for the Canyons District, these values should be viewed with caution and as preliminary estimates.

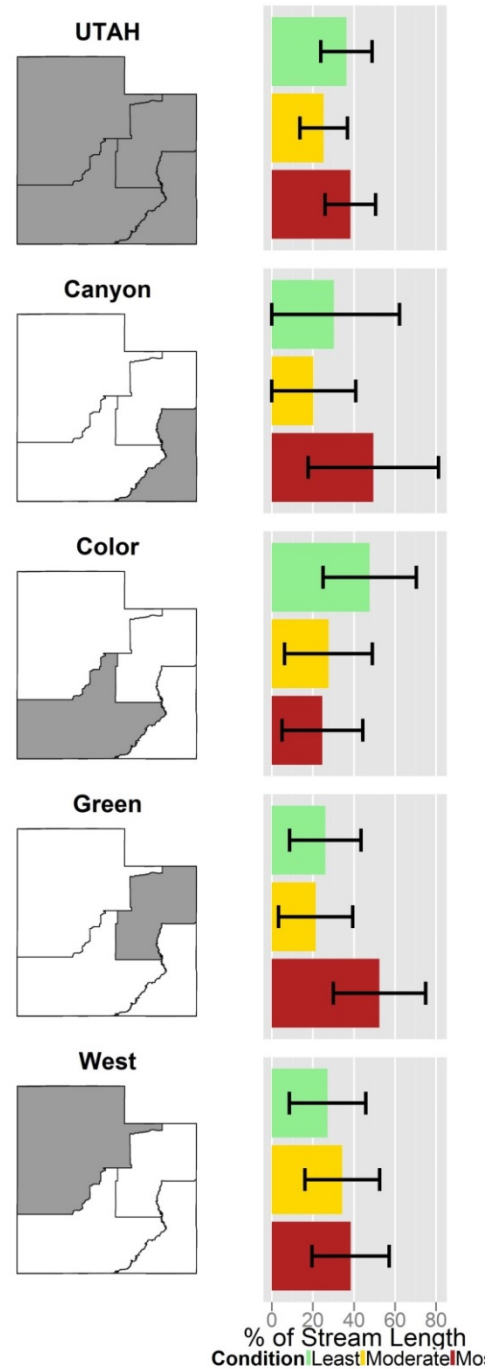


Figure 6. Percent ($\pm$ 95% CI) of UT BLM wadeable streams having least, moderate and most departure from reference conditions for the desired species and biological water quality indicator, benthic macroinvertebrates. Results are presented for all UT BLM streams and for each of the four districts.

CONDITION OF WATER QUALITY AND DESIRED SPECIES INDICATORS

Benthic macroinvertebrates

An estimated 38% of 2nd – 5th order wadeable, UT BLM streams have significant departure from reference conditions compared to 25% having moderate and 36% least departure (Fig. 6). All districts had between 26 and 47% of stream kilometers with least departure from reference, while the most variation among districts existed for the moderate and most departure categories. For example, the Green and Canyons Districts had the greatest proportion of stream kilometers having significant (i.e., most) departure, 52% and 49%, respectively. This is in comparison to 38 and 24% in the West and Color Country districts.

Invasive invertebrates

Invasive invertebrates were nearly absent from all sampled stream reaches, with only an estimated 0.9% of stream length containing invasives in the Color Country District (Data not shown). The sole invasive invertebrate collected was the New Zealand mudsnail (*Potamopyrgus antipodarum*). However, our sampling likely underestimated the presence of invasive invertebrates since they can exist at low densities and more mobile taxa such as crayfish are often missed by one-time benthic sampling with Surber or kicknet samplers.

Conductivity

State-wide, conductivity was the second most pervasive water quality impairment, with 63% of wadeable, BLM stream kilometers estimated to have significant departures from reference, compared to 32% having minimal departures (Fig. 7). The Green River and Color Country districts had the greatest proportion of stream kilometers significantly departing from reference, 72 and 69%, respectively. In contrast, excessive conductivity levels appeared less of an issue in the West and Canyons districts.

Total phosphorous and nitrogen

Total phosphorous was the most ubiquitous stressors state-wide. Approximately 64% of stream length had most departure from reference (Fig. 7). This same trend was present among all of the BLM management districts, except for the West District, where only 18% of stream length significantly departed compared to 75% in Color Country, 69% in the Green River and 50% in the Canyons District. Similar patterns emerged for total nitrogen, although the extent of stream kilometers significantly departing was reduced overall (42% compared to 64% for total phosphorous), as well as within the Green River (67%), Color Country (47%) and Canyons (20%) Districts. Only the West (32%) District had higher nitrogen than phosphorous loading.

Water temperature

Water temperature had the least amount of stream kilometers departing from reference among water quality indicators (9%) (Fig. 7). The Canyons District had the greatest extent of potential thermal pollution (most departure = 34%), albeit highly variable. However, the majority of stream kilometers throughout all districts did not exhibit excessive thermal loading. The only exception was the Color Country District, with approximately 50% of stream kilometers having moderate departure.

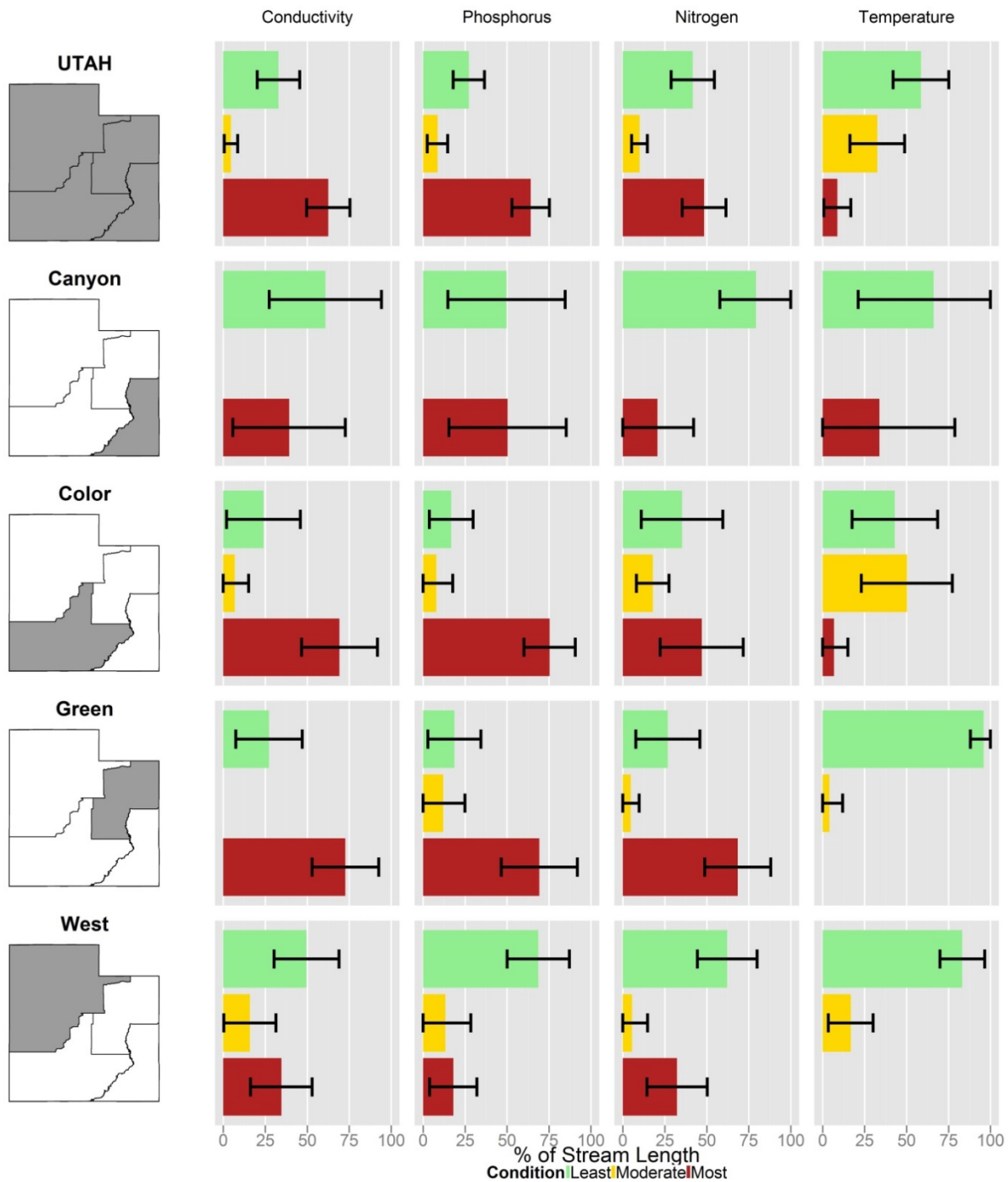


Figure 7. Percent ($\pm$ 95% CI) of UT BLM wadeable streams having least, moderate and most departure from reference conditions for the water quality indicators of conductivity, total phosphorous and nitrogen and water temperature. Results are presented for all UT BLM streams and for each of the four districts.

RELATIVE EXTENT OF MOST DEGRADED CONDITIONS

To assess which indicators consistently deviated from expected conditions or the natural range of variability, we compared the relative geographic extent or proportion of stream kilometers classified as having ‘most departure’ from reference conditions among the eleven indicators. We computed these rankings for the entire state and for each of the four UT BLM districts to identify impacts for which more intensive monitoring and determinations (i.e., identifying the causes for failing to meet Land Health Standards) should be prioritized. State-wide, water quality and to a lesser extent riparian function were the Land Health Standards that consistently departed from reference conditions. Specifically, total phosphorous (64%), conductivity (63%), total nitrogen (48%), bank stability (44%) and biological integrity (38%) had the greatest proportion of stream kilometers classified as most departure from reference (Fig. 8).

At the district scale, we observed very similar patterns, with the water quality indicators having the greatest proportion of stream kilometers classified as most departure from reference. However, the West Desert, Green River and to a lesser extent, the Canyons District also had a high proportion of streams depauperate in LWD and canopy cover. Again, the Canyon District’s results should be viewed as very preliminary given the small sample sizes. Similarly, our results might have underestimated the relative importance of several stream and riparian function indicators (e.g., LWD, canopy cover, floodplain connectivity) for two reasons: 1. they were only measured in 2012; and 2. the use of regional reference conditions to make condition determinations might have resulted in less stringent thresholds than those derived from empirical models causing a high rate of false negatives (i.e., classifying a site as having minimal or moderate departure when the true condition is significant departure).

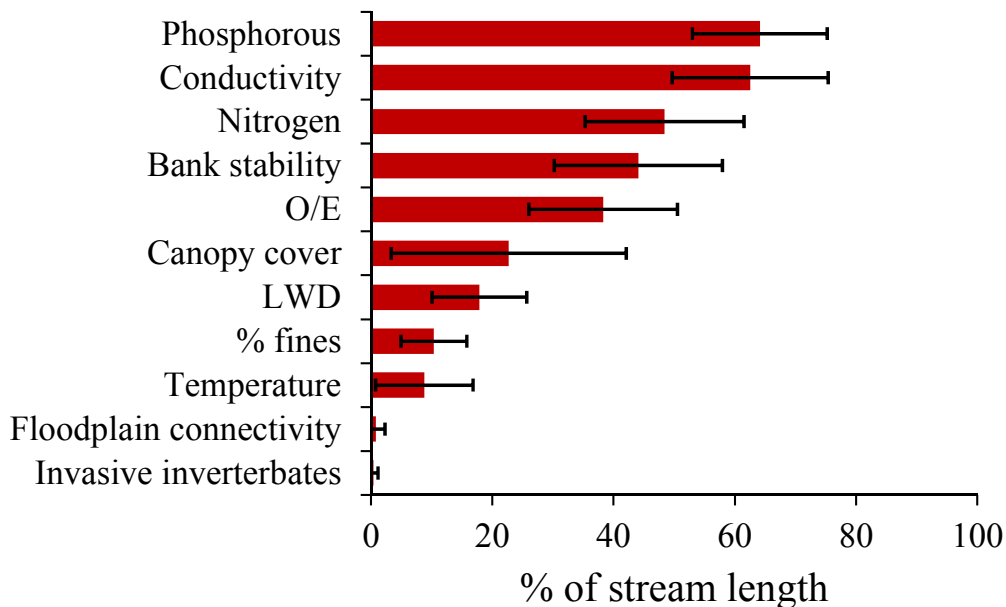


Figure 8. Relative extent (proportion of stream kilometers $\pm$ 95% CIs) for the indicators classified as most departure from reference conditions throughout BLM wadeable streams and rivers, Utah.

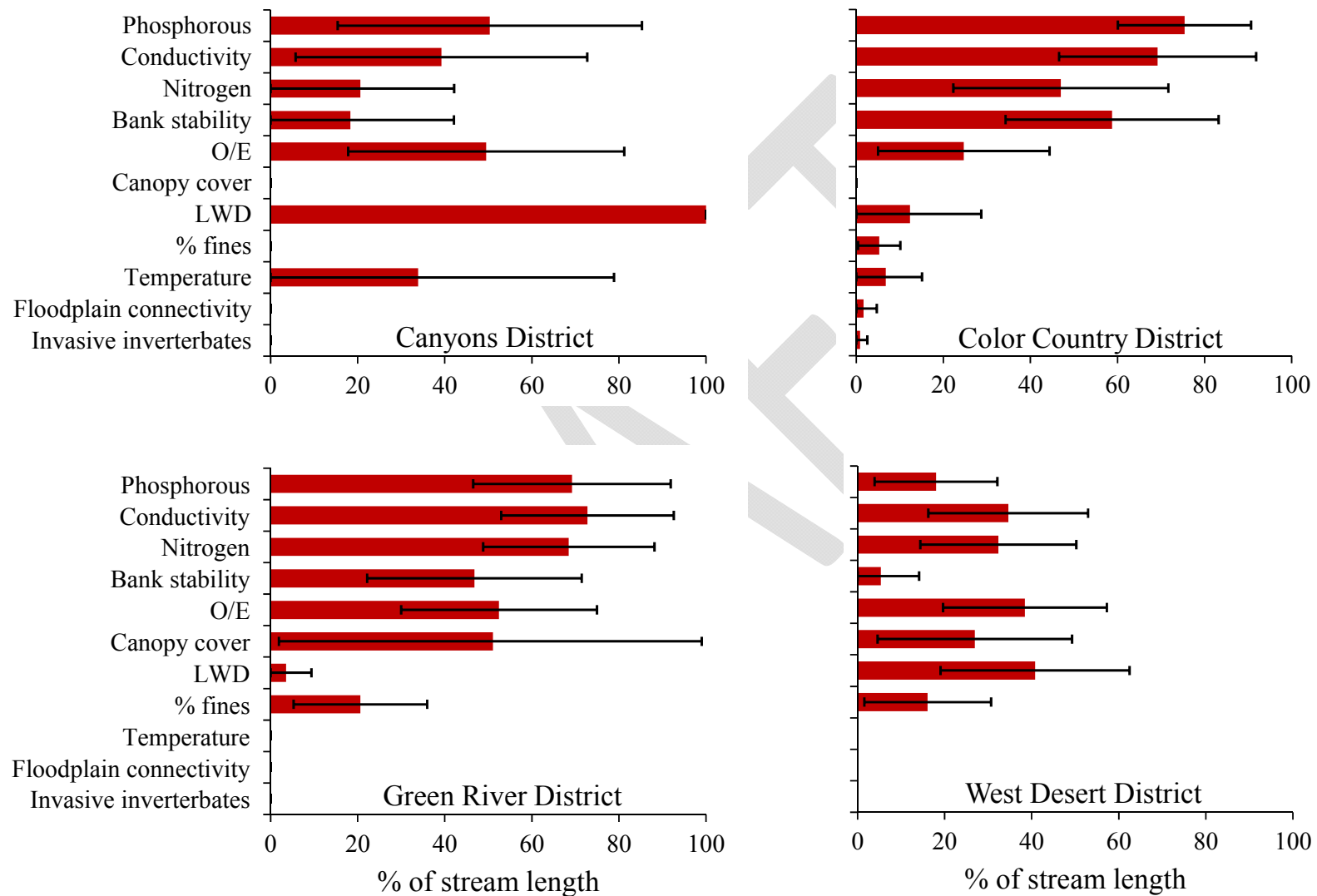


Figure 9. Relative extent (proportion of stream kilometers $\pm$ 95% CIs) for the indicators classified as having most departure from reference condition by UT BLM district. The order of the indicators is set by the relative extent for the state-wide estimates.

IDENTIFYING LAND-USES ASSOCIATED WITH DEGRADED CONDITIONS

As a first step towards identify the land uses associated with observed departures from the Land Health Standards (i.e., a determination), we modeled spatial variation for the indicators having the greatest extent of stream kilometers classified as ‘most departure’ from reference at the state scale (total phosphorous and nitrogen, conductivity, bank stability and macroinvertebrate O/E scores, Fig. 8). Except for bank stability, all indicators were analyzed as ratios of the observed field values to those values expected to occur in the absence of anthropogenic impairment (O/E). Therefore, response variables should not vary with natural environmental gradients like geology, soils, topography or climate. Thus, we were able to focus exclusively on understanding the extent to which different land uses, derived from Geographic Information System (GIS) data layers, were related to deviations from expected values (Table 5). However, because land use impacts can be context dependent, all models were also run with natural environmental predictors included (Appendix B); however, in no instance did the inclusion of these natural predictors improve model performance or interpretability (results not shown) and thus the presented models include anthropogenic predictors only.

We anticipated a high degree of non-linear responses and complex interactions among predictors; therefore, we utilized a non-parametric modeling procedure having relaxed assumptions compared to techniques such as multiple linear regression. Specifically, we used random forest (RF) regression models (Breiman 2001, Liaw and Wiener 2002) to identify casual relationships among the measured indicators and anthropogenic land-uses. RF is a tree-based tool that uses bootstrap sampling to fit hundreds of classification or regression trees to a data set where each split is based on a subset of predictors randomly chosen at each node (Breiman 2001). The algorithm is robust to outliers, prevents over fitting, can handle a large number of categorical and continuous variables and frequently generates more stable and accurate model results than traditional modeling approaches (Breiman 2001, Cutler et al. 2007, Siroky 2009).

Because we lacked a means to quantify geographic differences in the potential of bank stability, we ran two sets of random forest models. First we ran a model with only natural predictors to account for gradients in the potential of stream bank stability (predictors in Appendix B). We then used the residuals (left over variance not explained by the model) from the top natural model as a response variable for running models with only anthropogenic predictors.

For each of the five response variables (O/E values), random forest models were first run including all land use predictors (i.e., global model). Predictors were then iteratively removed in a stepwise fashion until the percent variance explained by the model was maximized. Results are presented for both the global model (Fig. 10) to compare the relative importance of the different land uses and for the best, most parsimonious model per indicator (Table 6). All models were run using the randomForest package within program R in regression mode, with model results averaged across 500 trees. Model performance was assessed using a cross-validated r-squared (R^2) computed by applying the final model to data withheld from the bootstrap sample (Pang et al. 2006). Individual variable importance was assessed by computing increases in the mean squared error when the validation data for an individual variable was permuted (Goodwin et al. 2008). Final relationships were visually assessed using partial dependency plots, which characterize the effect of the each individual predictor in the top model on the response while all other predictor variables are held constant.

Table 5. Land use variables and their data sources used in random forest models to predict spatial variability in Land Health Standard indicators with the greatest proportion of stream kilometers classified as having most departure from reference conditions.

Predictor	Predictor description	GIS data source
AG_WS	Percent of watershed classified as agricultural (%)	National Land Cover Database (Homer et al. 2007)
URB_WS	Percent of watershed classified as urban (%)	National Land Cover Database (Homer et al. 2007)
RdDens	Road density (km of roads/km ²)upstream of the sample point	UDOT (www.gis.utah.gov/data)
Sum_DamVol	The total volume (km ³) of all dams within the watershed divided by watershed area	National Inventory of Dams (USACE 2009)
HydrAlt_km	Total NHD stream kilometers classified as "Canal", "Ditch", or "Pipeline" (km)	NHDPlus (http://www.horizon-systems.com/nhdplus/)
MINEperSQKM	Mine density (number of mines/km ²)	USGS mineral resources data system (http://mrdata.usgs.gov)
OilGasCoun	Number of oil and gas wells in the watershed (#/km ²)	Utah Department of Natural Resources Oil and Gas and Mining Division (www.oilgas.ogm.utah.gov)
SumGrazing	Percent of watershed composed of BLM allotments, pastures and range pastures (%)	UT BLM (www.blm.gov/ut/st/en/prog/more/geographic_information/gis_data_and_maps.html)
HorsePct	Percent of watershed composed of wild horse and burro management areas (%)	UT BLM (www.blm.gov/ut/st/en/prog/more/geographic_information/gis_data_and_maps.html)
NPDES_Dist_m	Straight line distance to nearest National Pollutant Discharge Elimination System (NPDES) in the watershed (m)	UT DEQ (www.gis.utah.gov/data)
BLMPct	Percent of the watershed that is owned by BLM (%)	UT BLM (www.blm.gov/ut/st/en/prog/more/geographic_information/gis_data_and_maps.html)
PrivPct	Percent of the watershed that is privately owned (%)	UT BLM (www.blm.gov/ut/st/en/prog/more/geographic_information/gis_data_and_maps.html)

Model results

Spatial variation in excessive conductivity, total nitrogen and bank instability were related to land use, while total phosphorous and macroinvertebrate conditions were poorly correlated (Table 6 & Fig. 10). Excessive conductivity was the most predictable indicator, with positive relationships observed with the percent of the watershed in agriculture, the density of oil and gas wells and the length of hydrologically altered stream kilometers (Fig. 11). Total nitrogen was also positively correlated with the density of oil and gas wells in the watershed, measures of hydrologic alteration and agricultural land use. Although 13% of the spatial variability in bank instability was accounted for, the relationships with percent urban, agriculture, mine density and hydrologic alterations were not interpretable, as bank stability increased as land use intensity increased, which is unlikely except in artificial or heavily armored channels.

Table 6. The most parsimonious random forest models and variance explained for specific conductance (EC), total nitrogen (TN), percent bank stability, macroinvertebrate observed to expected (O/E) and total phosphorous (TP). Model predictors are listed in order of variable importance and the nature of the relationships (+: increasing; -: decreasing) are indicated in parentheses. Predictor abbreviations are described in table 5.

Response	Predictors	% variance explained
EC (O/E)	AG_WS (+), HydrAlt_km (+), OilGasCoun (+)	65
TN (O/E)	HydrAlt_km (+), OilGasCoun(+), Sum_DamVol (+)	25
% bank stability	URB_WS (+-), PrivPct (+), NPDES_Dist_m (+), MINEperSQKM (+-)	13
Macroinvertebrates (O/E)	MINEperSQKM (-), HydrAlt_km (-), URB_WS (-)	6
TP (O/E)	No significant predictors	0

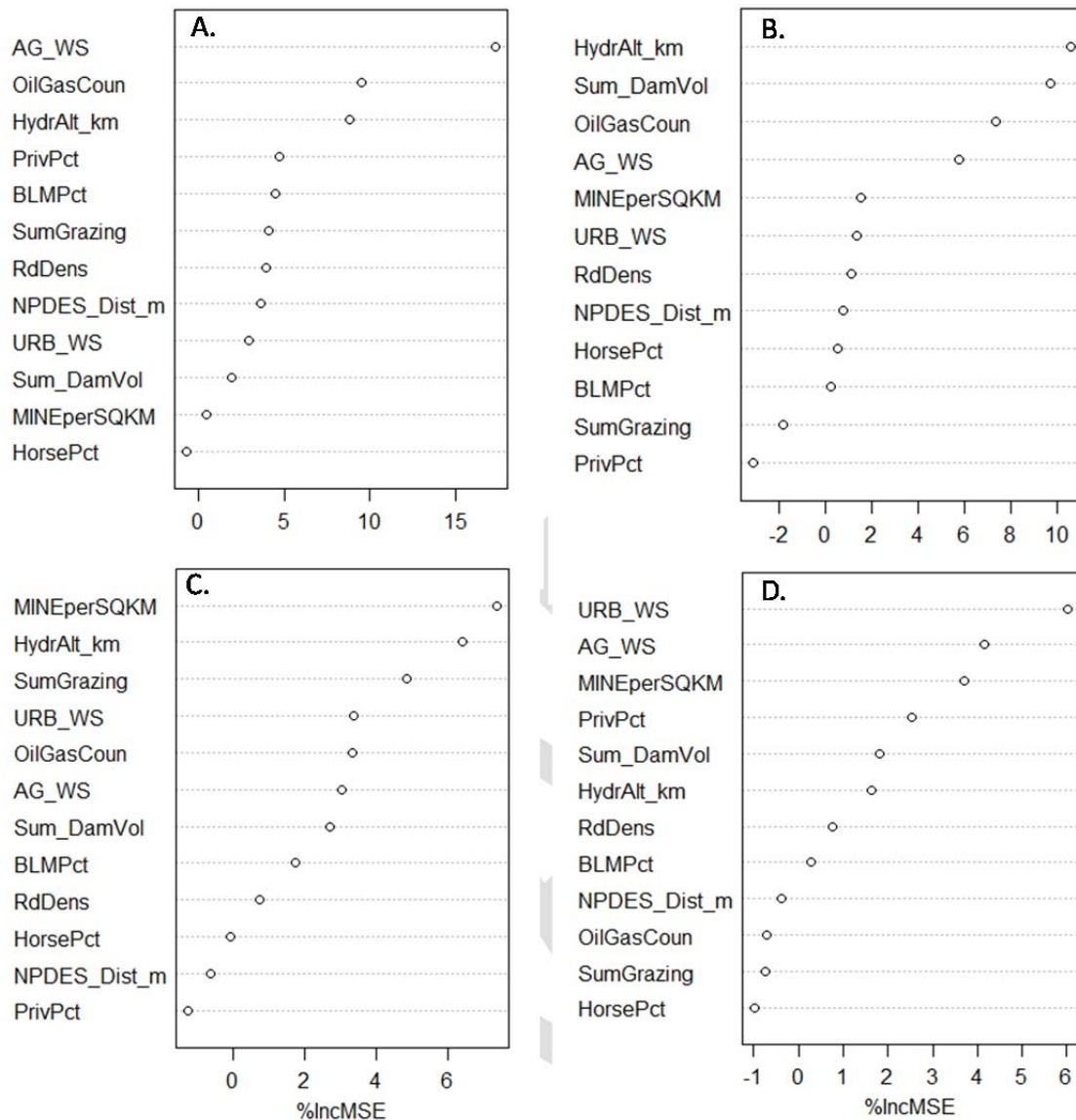


Figure 10. Variance importance plots comparing the relative importance of the land use predictors in explaining spatial variability in exceedances of A. conductivity, B. total nitrogen, C. macroinvertebrate O/E scores and D. stream bank stability.

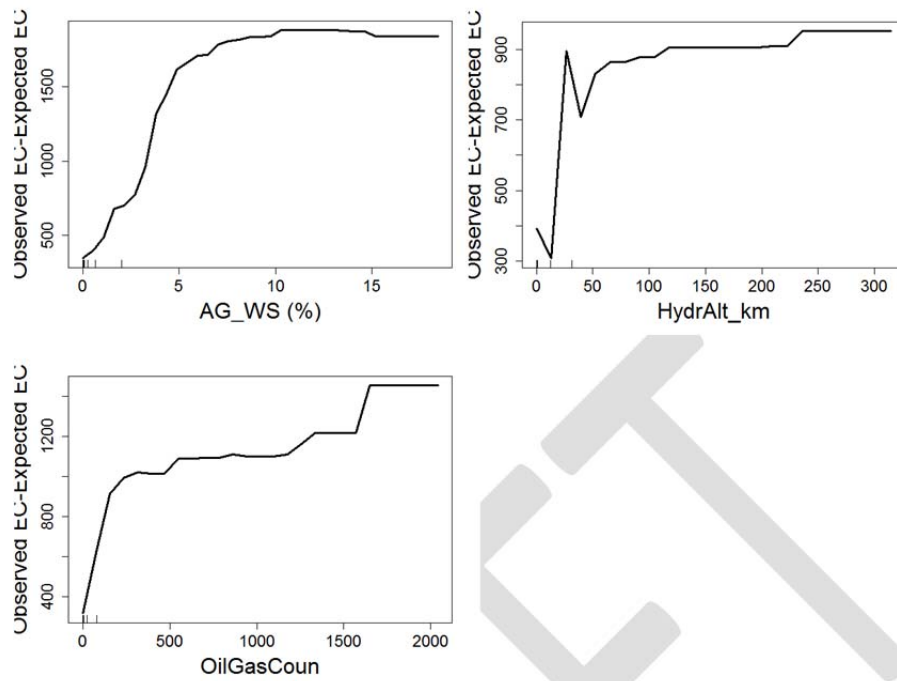


Figure 11. Partial dependency plots showing the relationship of conductivity exceedances with the top three model predictors: percent agricultural land use, percent hydrologic alteration and the density of oil and gas wells.

CONCLUSIONS AND NEXT STEPS

Under the BLM's multiple-use mandate watersheds are managed for a diversity of activities from recreation, to oil and gas development and the preservation of cultural resources. The BLM has programs in place to monitor the sustainability of individual uses, while the cumulative effectiveness of the multitude of management decision occurring within a field office, district or state has been more difficult to assess. However, the BLM's Land Health Standards provide a common set of interdisciplinary questions that the Bureau seeks to answer from the scale of individual grazing allotments to national level reporting to ensure the sustainable management of functioning aquatic ecosystems. The key to answering these questions in a consistent, efficient and defensible manner is the use of a consistent set of indicators, standardized field methodologies and statistically valid site selection, as outlined by the AIM-NAMF.

For aquatic resources, particularly wadeable streams and rivers, we demonstrated how a two person crew (equivalent to GS-5) with proper training can apply the principles of the BLM's AIM-NAMF to collect information regarding resource location, abundance and condition in a cost-effective manner. The baseline information obtained from this project fills a critical data gap for UT BLM from which future trends can be monitored as land use, climate, disturbance regimes and other factors change through time. Furthermore, this effort develops a template for the development and implementation of the BLM's AIM-NAMF. Below we highlight the next steps for the project, both the UT BLM and AIM-NAMF development and implementation, with a focus on field office scale engagement to better understand conditions patterns across the state and the drivers of the observed stressors.

Next steps: monitoring intensification and determinations

The temporal resolution of the collected water quality data cannot be used to determine the attainment of state water quality standards, but it raises numerous red flags regarding potential nutrient and salinity issues state-wide. Given the diffuse nature of many of the activities occurring on BLM lands, the prevalence of water quality issues might be surprising. However, given the downstream position of BLM lands in many watersheds and the mixed landownership, activities occurring both on and off BLM lands are likely contributing to the prevalence of the observed stressors. Our preliminary modeling results provide support for this idea, with activities such as oil and gas development actively occurring on both public and private lands, whereas agricultural activities and the associated hydrologic alterations are more prevalent on private lands. Given the hypothesized drivers for some stressors, collaborations with other state and federal agencies will be critical to determining the sources and ultimately the means by which pollutant loads can be reduced.

Our next step is to work with individual field offices to identify priority streams for the collection of more temporally intensive data to validate our findings; our first priority will be the Vernal and Price Field offices within the Green River District given the prevalence of potential exceedances. We will also work collaboratively with the Utah Department of Environmental Quality given their ongoing efforts in this geographic region to sample biological condition, water quality and physical habitat. Watersheds for more intensive water quality monitoring will be prioritized by applying the model results to identify areas with the greatest likelihood of having water quality exceedances.

We are also working with the Rapid Ecoregional Assessment Team for the Colorado Plateau Ecoregional Assessment, which is being down-scaled and applied to the entire State of Utah, to refine our understanding of the land uses driving the observed stressors and to inform determinations of the anthropogenic activities causing significant departures from reference.

In addition to the intensification of the water quality data through on the ground data collection, we are also working with the Utah Department of Environmental Quality, the U.S. EPA and AIM-NAMF projects to increase sample sizes within individual districts, especially the Canyon Country District, to improve the precision of our estimates. These collaborations are facilitated by the use of consistent field parameters and survey designs among agencies. Furthermore, efforts are underway to increase sample sizes throughout the entire Colorado Plateau, as well as in Grand Staircase Escalante National Monument to answer more local scale questions related to oil and gas development and grazing permit renewals. We recommend working collaboratively with the Utah Department of Environmental Quality and the U.S. EPA to repeat this effort between 2016 and 2018 to assess trend and to compare conditions on BLM lands to those within the entire State of Utah.

Lessons learned to inform the development of the NAMS strategy

This project represents one of the BLM's first attempts to use dedicated field crews to collect a set of standardized indicators using consistent field methods. Using a single, two person crew working intermittently from May through September, we were able to sample 77 sites between 2011 and 2012. The attendance at mandatory trainings, use of field audits and electronic data capture technologies were all employed to maximize the completeness and precision of collected data. Future efforts should formally test these assumptions through the re-sampling of a minimum of 10% of sites sampled per crew by a second independent crew within a two week period to quantify the precision of field estimates. We recommend such quality control procedures for data collected under the AIM-NAMF.

Over 20% of the segments in the NHD were estimated to be incorrectly classified as perennial when the system was really intermittent and these estimates do not include first order streams, which are likely to have higher error rates. In arid regions where BLM lands are largely distributed, this is likely to be a significant problem that creates inefficiencies for field crews needing to travel to streams that do not contain perennial water. The systematic implementation of the AIM-NAMF across BLM lands would benefit from revisions to the NHD. Furthermore, consideration should be given to the applicability of select indicators to dry stream channels, since the perennial nature of sampled reaches can change from year to year.

Monitoring parameters were collected using methods from the USFS/BLM PIBO protocol. These methods have been extensively developed and tested and appeared applicable to the systems sampled throughout UT. The only perceived drawback to this approach was for making condition determinations. Specifically, the PIBO protocol is not actively used throughout UT; therefore, no reference data was available to aid in the interpretation of indicators such as bank angle, pool depth and frequency, and fine sediment. We recommend that future monitoring efforts utilize the methods outlined in the AIM-NAMF and the forthcoming methods TR, which

were developed to be compatible with existing programs such as the BLM's MIM protocol, PIBO, U.S. EPA and the BLM/USFS AREMP efforts. We also recommend protocol overlap studies to understand the compatibility of similar indicators derived from different field protocols.

Lastly, LWD, canopy cover and floodplain connectivity were added in 2012 to more comprehensively address the watershed and riparian function standards and are recommended for use in future monitoring to adequately address standards related to the Watershed Function and Desired Species Fundamentals. In addition, qualitative or quantitative estimates of riparian vegetative cover, structure and/or composition should be made to provide multiple lines of evidence for assessment of the riparian standard following the recommendation in the AIM-NAMF.

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APPENDIX A: DESCRIPTION OF THE INDICATORS USED TO ASSESS THE UTAH BLM AQUATIC LAND HEALTH STANDARDS

Standard 2: Stream channel and riparian function indicators

Fine sediments – Excessive fine sediment is among the most deleterious stressors to aquatic biota (Wood and Armitage 1997, Paulsen et al. 2008). 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 the interstices of larger bed materials, which are important for macroinvertebrates and smaller fishes (Cunjak and Power 1986, Gries and Juanes 1998). To quantify bed particle size distributions for a given reach, we measured five surface bed particles at equal intervals within the active channel (i.e., no bank material) at each of 21 transects. We measured the b-axis of the selected particles and computed the percent of particles finer than 2 mm during each sampling occasion.

Large woody debris – Large woody debris (LWD) is an important source of cover and velocity breaks for fishes (Abbe and Montgomery 1996) and a driving geomorphic force in the creation of complex channel units (Montgomery et al. 1995). We enumerated all LWD >10 cm in diameter (measured at one third of the way up from the base) and >1 m in length for estimates of LWD frequency within each site (# pieces/km). LWD was estimated at reaches sampled in 2012 only.

Floodplain connectivity – The connectivity or access of a stream channel to its floodplain is critical for the maintenance and recruitment of riparian vegetation, the dissipation of energy during high flow events and the creation of seasonal habitats during inundation (Naiman and Decamps 1997). Through activities that alter the sediment and/or hydrologic regime or direct manipulation of the stream channel, humans can decrease the connectivity between streams and their adjacent floodplains. We quantified the degree of floodplain interaction as the average ratio of bankfull width to wetted width, derived from ten measurements of both bankfull width and wetted width. Floodplain interaction was estimated at reaches sampled in 2012 only.

Bank stability – Stream bank erosion is a source of fine sediment loading and channel widening resulting from natural or accelerated channel migration. Humans can increase bank erosion through activities that directly trample stream banks or change the composition and cover of stabilizing vegetation (Knapp and Matthews 1996, Coles-Ritchie et al. 2007, Herbst et al. 2012). We quantified bank stability using a 30 cm wide plot with an upper limit of 0.5 m above bankfull height for the left and right banks at each of 21 transects. Stream banks were classified based on bank type, cover and degree of erosion using the methods of Heitke et al. (2011).

Percent canopy cover – Canopy cover measures the capacity of riparian vegetation to mitigate thermal loading (i.e., provide shade) and thus moderate stream temperatures (Beschta 1997, Johnson and Jones 2000). The extent of the riparian canopy also provides information on the amount of potential leaf litter to subsidize aquatic food webs (Cummins 1974). We used a densitometer to quantify percent canopy cover at the center of 10 transects facing upstream, downstream, left bank and right bank following the methods of (SWAMP 2007). Percent canopy density was estimated at reaches sampled in 2012 only.

Water quality indicators (Standard 4)

Benthic macroinvertebrates – To address both the desired species standard and the biotic water quality standard, we sampled aquatic macroinvertebrates at each reach. Aquatic macroinvertebrates are ubiquitously used by state and federal agencies as the primary screening tool for assessing chemical, physical and biological conditions, with all 50 states using macroinvertebrates in biomonitoring programs (USEPA 2002). Macroinvertebrates are used to compliment more traditional chemical and physical monitoring techniques during baseline monitoring because they: 1. Are relatively long-lived and thus integrate conditions through time and space; 2. Are ubiquitously found in perennial stream systems; 3. Exhibit a variety of life history strategies, which can be used to discriminate among causes of impairment; and 4. Can be sampled and identified in an efficient and cost-effective manner (Bonada et al. 2006).

Macroinvertebrates were collected from fastwater habitats (i.e., riffles) using a Surber (0.093 m²) sampler fitted with a 500 µm mesh net. Specifically, two samples were collected from the first four fastwater habitats or 1 sample was collected from each of the first 8 transects if no fastwater habitats were present, with all samples composited into a single sample (0.74 m²) (Table 2). A random subsample of 600 individuals was identified by the Utah State University/BLM National Aquatic Monitoring Center following nationally recognized laboratory protocols (Cuffney et al. 1993, Vinson and Hawkins 1996).

Additional water quality indicators included temperature, conductivity and total nitrogen and phosphorous (Table 2).

Water temperature – The thermal regime is among the most important abiotic drivers of biological patterns and processes in river systems (B.W. et al. 1980). Over evolutionary time organisms have evolved strategies to maximize fitness in response to different thermal regimes (Ward and Stanford 1982), while in contemporary time temperature constrains the distribution, development and growth of aquatic organisms (Hauer and Benke 1987, Newbold et al. 1994). Consequently, activities such as grazing, dams and water diversions that alter thermal regimes represent primary threats to lotic ecosystems (Dynesius and Nilsson 1994). We collected stream temperatures at 60-minute intervals using Hobo data loggers deployed from July 15th to September 15th and calculated the average August stream temperature at each site for analysis.

Conductivity – Conductivity measures the capacity of water to conduct an electrical charge. Distilled water contains very low levels of ions and is a poor conductor of electricity, which results in a low specific conductance (i.e., conductivity standardized to 25°C). Specific conductance increases with the concentrations of ions in solution (e.g., nitrates, chloride, phosphate, magnesium, calcium, iron), which can be elevated by anthropogenic activities that increase erosion and/or ion loading (e.g., irrigation water withdrawals, mining, grazing) (Miller et al. 2007, Vander Laan et al. 2013). Excessive conductivity degrades the quality of domestic and/or animal drinking water and can impact freshwater organisms through acute toxicity or less dramatically through disrupting osmoregulation. Altered osmoregulation can decrease organismal fitness and/or change species distribution ranges (Clements et al. 2000, Blasius and Merritt 2002, Miller et al. 2007). Specific conductance was measured in-situ using a YSI multi-

parameter sonde (model 63) following the methods of Heitke et al. (2011) and is reported as microsiemens ($\mu\text{S}/\text{cm}$).

Total nitrogen and phosphorous – Nitrogen and phosphorous are the two major nutrients that influence rates of primary productivity in stream systems. The major natural sources of nitrogen loading to streams are dissolved nitrogen derived from N-fixation by soil microbes or vegetation and subsequent leaching or decomposition in the form of runoff, as well as groundwater inputs (reviewed in Allan and Castillo 1995). In contrast to nitrogen, the predominant phosphorous source is the weathering of soils and rocks, particularly the weathering of sedimentary rock deposits. For both nitrogen and phosphorous, anthropogenic activities such as logging, cattle grazing, accelerated erosion and agriculture have significantly increased nutrient loading (reviewed in Allan and Castillo 1995), making it among the ubiquitous freshwater stressors in the United States (Paulsen et al. 2008). A single grab sample was collected, stored frozen and processed for total nitrogen and phosphorous by the Utah State University Aquatic Biogeochemistry Analytical Laboratory (Logan, UT).

Desired species indicators (Standard 2)

In addition to quantifying instream biological integrity using benthic macroinvertebrates, we used the invertebrate data to assess the presence or absence of invasive invertebrates.

Invasive invertebrates – Using the invertebrate data, we also computed the presence/absence of several invasive invertebrates including non-native crayfish (e.g., northern crayfish, rusty crayfish) and non-native taxa within the phylum Mollusca (e.g., Asian clam, New Zealand mudsnail).

Appendix B. Natural variables used in random forest models to predict spatial variability in Land Health Standard indicators with the greatest proportion of stream kilometers in most degraded conditions.

Variable	Description
Awch_WS	Watershed mean of the high values of available water capacity (fraction) of soils from the State Soil Geographic (STATSGO) Database.
Bdh_WS	Watershed mean of the high values of soil bulk density (grams/cm ³) of soils from the State Soil Geographic (STATSGO) Database.
BFI_WS	Mean of all base flow index pixel values within the watershed. Estimates the percent of stream flow that is composed of ground water relative to event flow. Calculated from USGS generated 1-Km resolution grid of base flows derived by interpolating calculated base flows at 19,000 USGS stream flow gauging stations distributed across the conterminous USA (Wolock, 2003).
CAOMean_WS	Mean of all cells within the watershed, where cells represent the percent of the underlying bedrock composed of calcium oxide (CaO). Percentages are the average percent CaO for all lithologies within a cell, weighted by lithology prevalence. Lithologies and their prevalences were derived from the USGS Preliminary Integrated Geologic Map of the United States.
Dom_Geol	Geology type with largest percent coverage within the watershed derived from a simplified version of Reed & Bush (2001) - Generalized Geologic Map of the Conterminous United States.
ELVmax_WS	Maximum watershed elevation in meters.
ELVmean_WS	Mean watershed elevation in meters.
ELVmin_WS	Minimum watershed elevation in meters.
Hydr_PT	GIS raster calculated as $(\text{MIN}x_i) / (\text{MAX}x_i)$, where x_i = mean monthly discharge for month i for the period of record and $x_i \geq 12$ months of record. Values were calculated for each of 9,941 USGS gauging stations in the western USA and values for unmeasured locations were interpolated using inverse-distance-squared weighting of the 12 closest gauging stations within 100 kilometers. Each interpolated value represents a 4 x 4 kilometer cell.
Hydr_WS	Mean of all HYDR_PT values within the watershed.
Kfct_WS	Watershed mean of the soil erodibility factor (no units) of soils from the State Soil Geographic (STATSGO) Database.
MgOMean_WS	Mean of all cells within the watershed, where cells represent the percent of the underlying bedrock composed of magnesium oxide (MgO). Percentages are the average percent MgO for all lithologies within a cell, weighted by lithology prevalence. Lithologies and their prevalences were derived from the USGS Preliminary Integrated Geologic Map of the United States.
Omh_WS	Watershed mean of the high value of organic matter content (percent by weight) of soils from State Soil Geographic (STATSGO) Database.
Pmax_WS	Mean of all values within the watershed, where a value is derived from the GIS raster calculated as $\sum(\text{MAX}x_i)/30$ at the sampling point, where x_i = the modeled total precipitation (mm) for month i (1–12); values based on 30 y (1971–2000) of PRISM (http://www.prism.oregonstate.edu) climate estimates; each value represents a 900 x 900-m cell.
Pmin_WS	Mean of all values within the watershed, where a value is derived from the GIS raster calculated as $\sum\text{MIN}x_i/30$ at the sampling point, where x_i = the modeled total precipitation (mm) for month i (1–12); values based on 30 y (1971–2000) of PRISM climate estimates; each value represents a 900 x 900-m cell.

Appendix B Continued. Natural variables used in random forest models to predict spatial variability in Land Health Standard indicators with the greatest proportion of stream kilometers in most degraded conditions.

Variable	Description
Prmh_WS	Watershed mean of the high values of permeability (inches/hour) of soils from the State Soil Geographic (STATSGO) Database.
RHMean_WS	Mean of all values within the watershed, where a value is derived from the GIS raster calculated as $\sum(\text{SUM}x_i/12)/30$ at the sampling point, where x_i = the modeled mean relative humidity (%) for month i (1–12); values based on 30 y (1961–1990) of PRISM climate estimates; each value represents a 2 x 2-km cell.
SMean_WS	Mean of all cells within the watershed, where cells represent the percent of the underlying bedrock composed of sulfur (S). Percentages are the average percent S for all lithologies within a cell, weighted by lithology prevalence. Lithologies and their prevalences were derived from the USGS Preliminary Integrated Geologic Map of the United States.
Tmax_WS	Mean of all values within the watershed, where a value is derived from the GIS raster calculated as $\sum\text{MAX}x_i/30$ at the sampling point, where x_i = the modeled monthly average maximum air temperature (uC) for month i (1–12); values based on 30 y (1971–2000) of PRISM climate estimates; each value represents a 900 x 900-m cell; note that these values are modified from the PRISM annual maximum air temperature grid (http://www.prism.oregonstate.edu), which are calculated as $\sum(\text{SUM}x_i/12)/30$, where x_i = the modeled monthly average maximum air temperature (uC) for month i (1–12).
Tmean_WS	Mean of all values within the watershed, where a value is derived from the GIS raster calculated as $\sum(\text{SUM}x_i/12)/30$ at the sampling point, where x_i = the modeled mean air temperature (uC) for month i (1–12); the modeled monthly mean air temperature (x_i) is the average of the minimum and maximum monthly air temperatures (http://www.prism.oregonstate.edu/faq.phtml). Values based on 30 y (1971–2000) of PRISM climate estimates; each value represents a 900 x 900-m cell.
Tmin_WS	Mean of all values within the watershed, where a value is derived from the GIS raster calculated as $\sum\text{MIN}x_i/30$ at the sampling point, where x_i = the modeled monthly average minimum air temperature (uC) for month i (1–12); values based on 30 y (1971–2000) of PRISM climate estimates; each value represents a 900 x 900-m cell; note that these values are modified from the PRISM annual maximum air temperature grid (http://www.prism.oregonstate.edu), which are calculated as $\sum(\text{SUM}x_i/12)/30$, where x_i = the modeled monthly average minimum air temperature (uC) for month i (1–12).
UCSMean_WS	Mean of all cells within the watershed, where cells represent the average of uniaxial compressive strength (UCS) of the underlying bedrock. Cell values are the average UCS for all lithologies within that cell, weighted by lithology prevalence. Lithologies and their prevalences were derived from the USGS Preliminary Integrated Geologic Map of the United States.
WSA	Watershed area in square kilometers.