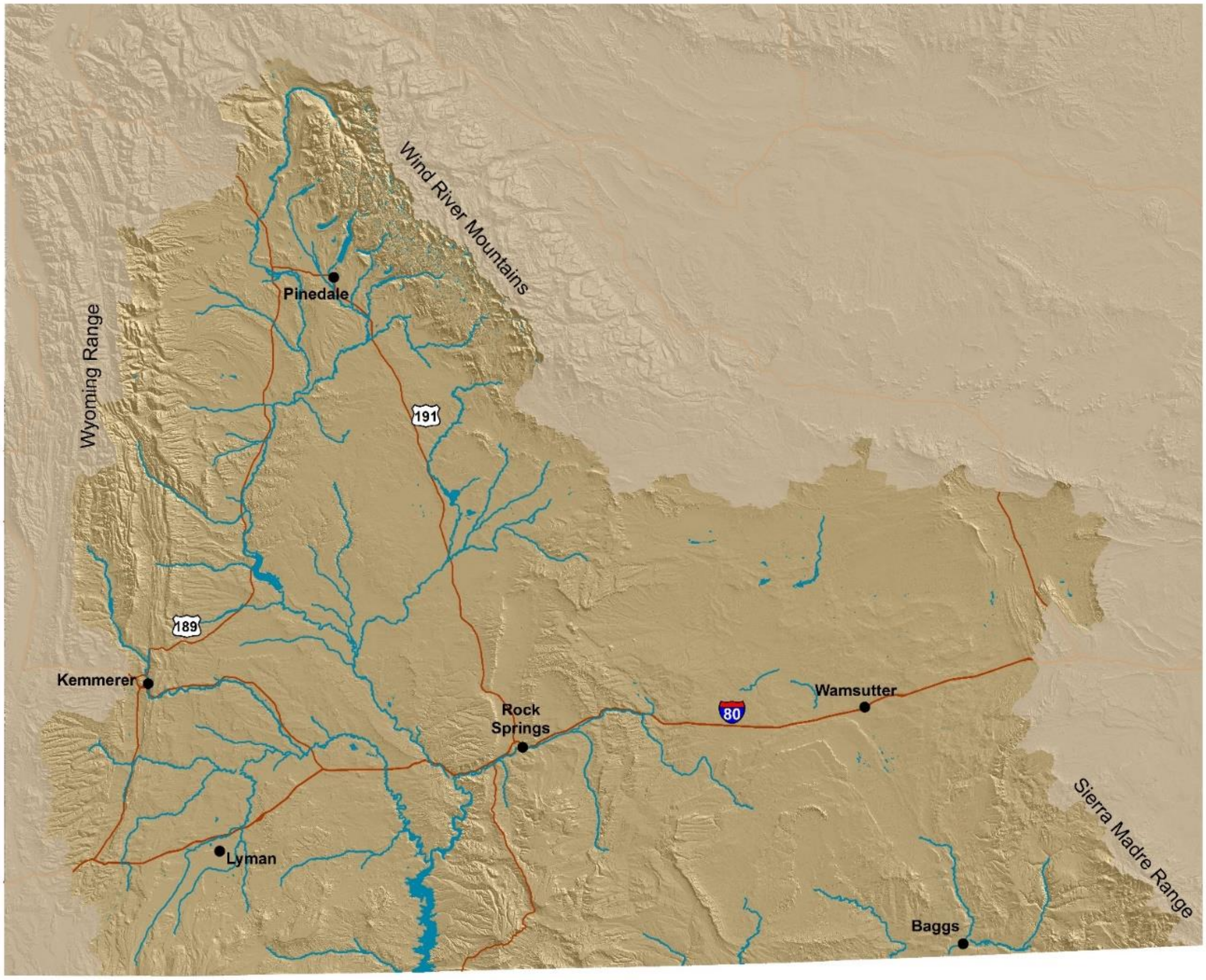
Water Quality Condition of Streams and Rivers in the Green River Basin, Wyoming

Results of the 2015 Green River Basin Probabilistic Survey



Wyoming Department of Environmental Quality – Water Quality Division

November 2021

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Results of the 2015 Green River Basin Probabilistic Survey

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Table of Contents

Figures

Tables

Appendices

EXECUTIVE SUMMARY

The Wyoming Department of Environmental Quality-Water Quality Division (WDEQ/WQD) conducted a probabilistic survey of perennial streams and rivers in the greater Green River Basin (hereafter referred to as the Green) in 2015. Results from this survey provide an objective representation of the biological condition, drinking water suitability and human health condition of Green perennial streams and rivers. This study also identifies the most common stressors and their relative impact to biological condition. Information obtained from this and other probabilistic surveys also allows Wyoming to fulfill State obligations under §305(b) of the federal Clean Water Act.

The Green survey included all non-headwater, perennial streams that are not located in United States Forest Service wilderness areas. This equates to approximately 3,493 miles of perennial streams and rivers or over 90% of the 4,944 total miles of perennial streams and rivers in the Green.

The survey encompassed 1,493 of the 3,493 perennial stream miles initially considered for the Green survey. The remaining 2,000 stream miles were ephemeral or intermittent, human constructed, wetlands, or inaccessible. Evaluation of biological condition used benthic macroinvertebrates as the biological indicator at both the Green scale and for three watershed units: Upper Green – New Fork, Big Sandy – Blacks Fork – Muddy, and Lower Green – Little Snake.

Findings from this study indicate that 63% of the perennial streams in the Green are in the least-disturbed biological condition or comparable to reference expectations. Approximately 8% of perennial stream miles are considered most-disturbed, implying an appreciable deviation from reference expectations associated with anthropogenic stressors. The remaining 29% of perennial stream miles are indeterminate with respect to biological condition.

Of 20 stressors evaluated, riparian disturbance (24% of stream miles), channel instability (20% of stream miles), and total phosphorus (9% of stream miles) are the three most extensive stressors that influence biological condition in the Green. Riparian disturbance in the Green associates with low overhead cover, minimal woody vegetation, and hoof shear/trampling along the stream banks. Of the perennial stream miles with channel instability, accelerated bank erosion is the most extensive substressor. Anthropogenic disturbances to stream channels and their riparian zones are the most important factors that influence biological condition of Green streams. Streams are 7 to 16 times more likely to be in a most-disturbed biological condition when riparian disturbance or channel instability are present as when they are not present.

After riparian disturbance and channel instability, the next most extensive stressor is total phosphorus. Streams have a 3.8 times greater risk of having a most-disturbed biological condition when a most-disturbed total phosphorus condition is present.

Dissolved iron, dissolved aluminum, and total selenium are not extensive stressors in the Green, but where present in most-disturbed conditions, pose a high relative risk to biological condition.

Sixty-six percent (66%) of perennial streams in the Green have *Escherichia coli* (an indicator of human health risk for recreational uses of water) concentrations in the least-disturbed condition, whereas a most-disturbed condition occurs in 34% of perennial streams. One-hundred percent of stream miles in the Green exhibit concentrations of nitrate+nitrate-N, total selenium, total cadmium, and total zinc in the least-disturbed condition with respect to suitability of the water for drinking. Most perennial stream miles are in the least-disturbed condition for dissolved iron (99%), total arsenic (96%), and dissolved manganese (90%). This indicates that the vast majority of the evaluated perennial streams in the Green require minimal treatment as potential drinking water sources with respect to the aforementioned constituents.

The Green is similar to the entire state of Wyoming with regard to the percentage of stream miles in the least-disturbed biological condition (63% Green vs. 58% Wyoming). The Green has fewer miles in the most-disturbed biological condition (8% Green vs. 18% Wyoming). The Green fairs better than the Western Mountains and Xeric regions of the United States with regard to least-disturbed (63% Green vs. 51% Western Mountains and 22% Xeric) and most-disturbed (8% Green vs. 30% Western Mountains and 44% Xeric) biological conditions. Among the five stressors evaluated at different geographic scales, riparian disturbance is the most extensive stressor in the Green (24%) and the second most common throughout Wyoming (36%). Total phosphorus is the second most extensive stressor in the Green (9%) and fourth most extensive throughout Wyoming (14% of stream miles). Interestingly, total phosphorus is the most extensive stressor nationwide (58%) and in the Western

Mountains of the western US (50%). Total nitrogen affects a small percentage of streams in the Green but is an extensive stressor across the Nation (43%).

Nationally (lower 48 contiguous states), the percentage of stream miles in the least-disturbed biological condition (30%) is much less relative to the Green (63%). Likewise, the percentage of national stream miles in the most-disturbed biological condition is 44% - much greater than the Green estimate of 8%.

When compared to the two previous rotating basin probabilistic surveys, the Green (63% least-disturbed) is in better biological condition than both the Bighorn/Yellowstone (38%) and Northeast (52%). With regard to stressor extents, all three superbasins have channel instability and riparian disturbance as dominant stressors to biological condition. Channel instability is a top two stressor in all three regions, although channel instability is more extensive in the Bighorn/Yellowstone and Northeast (~35% of stream miles) than in the Green (20%). Riparian disturbance is prevalent in the Green and Northeast (24-26% of stream miles), but less so in the Bighorn/Yellowstone (17%). These comparisons show that physical impacts to stream channels and riparian zones are important and common factors influencing biological conditions across much of Wyoming.

Among all three HUC 8 clusters, the highest relative extent percentages for each of the aforementioned stressors is found within the Lower Green – Little Snake, in addition to having the greatest extent of most-disturbed *E. coli* conditions. The combination of multiple stressors along with varying extents and relative risks imply that that where degraded biological condition occurs there may be multiple causes and their effects to aquatic life variable and perhaps inter-related.

Green survey results provide objective representative estimates of biological and human health condition and identify associated stressors in perennial streams and rivers of the Green River Basin of southwest Wyoming. While Green survey results cannot determine if specific waterbodies are impaired or non-supportive of their designated aquatic life uses, the results highlight areas that may warrant additional investigation to ultimately improve or protect water quality, and provide a baseline to measure future progress. This information supports existing strategic planning, management directives and pollutant reduction efforts at the federal, state and local levels. In particular, the Green survey documented the overall good biological conditions in the Green, and identified several candidate watersheds for voluntary water quality protection.

INTRODUCTION AND OBJECTIVES

The federal Clean Water Act (CWA) §305(b) requires delegated States to describe the water quality condition of all their surface waters. To help fulfill State obligations under the CWA, Wyoming uses a cost-effective approach known as probabilistic surveys to monitor status and trends in perennial stream and river water quality. Probabilistic surveys yield unbiased, statistically-derived estimates of the condition of surface waters based on a representative sample of the resource with a known level of statistical confidence or certainty. Probabilistic surveys are efficient because they require sampling relatively few locations to make valid scientific statements about the condition of waters at the State or regional scale.

The Wyoming Department of Environmental Quality – Water Quality Division (WDEQ/WQD) conducted its first statewide probabilistic survey of perennial streams and rivers from 2004 to 2007 followed by a second survey conducted from 2008 to 2011 (Hargett and ZumBerge 2013). The purposes of both statewide probabilistic surveys were to ascertain the current ecological condition of Wyoming's perennial streams and rivers, the extent to which major stressors could potentially influence this ecological condition, and potentially evaluate changes in condition and stressors over time.

Both statewide surveys were informative about the biological condition and stressors affecting perennial streams and rivers at the statewide scale. However, statewide surveys do not provide sufficient resolution to characterize biological condition and stressor extents at the regional or watershed scales. Smaller scale probabilistic surveys can provide this level of information and can lead to better-informed decisions on future watershed-based monitoring and management priorities. In addition, smaller-scale probabilistic surveys provide a more focused, cost-effective and unbiased method for identifying both high quality and potentially impaired waters. Furthermore, smaller scale surveys can provide a useful measure of the cumulative effectiveness of numerous efforts to improve water quality. For these reasons, the WDEQ/WQD phased-out statewide probabilistic surveys in 2010 and replaced with rotating basin probabilistic surveys.

Wyoming's probabilistic rotating basin approach established an order and sampling years among five 'superbasins' within the State delineated based on sixdigit hydrologic unit codes (HUCs) and geographic location (WDEQ/WQD 2010). The five superbasins, their associated HUC 6 basins and year of sampling are:

- Bighorn/Yellowstone [Bighorn and Yellowstone Basins] - 2010
- Northeast [Belle Fourche, Cheyenne, Little Missouri, Powder and Tongue Basins] - 2011
- Green [Great Divide, Green and Little Snake Basins] - 2015
- Platte [Niobrara, North Platte and South Platte Basins] - 2016
- Bear/Snake [Bear and Snake Basins] – 2021

The WDEQ/WQD implemented and completed its first rotating-basin probabilistic survey within the Bighorn/Yellowstone in 2010 followed by the Northeast (NE) survey in 2011, the Green in 2015, and Platte in 2016. The Green is the focus of this report. Objectives of the Green survey were to:

- Determine the biological condition of perennial streams and rivers (hereafter referred to as 'perennial streams') within the Green and its sub-basins
- Determine the most extensive stressors that could potentially influence biological condition in the Green and its sub-basins
- Determine the relative risk of stressors to biological condition in the Green
- Provide recommendations on focus pollutants and areas where additional investigation could be conducted to determine whether aquatic life and human health uses are being supported
- Evaluate recreational use with respect to the pathogen indicator *Escherichia coli* and drinking water suitability with respect to dissolved iron, dissolved manganese, total arsenic, total cadmium, nitrate+nitrite-N, total selenium, total zinc, and a suite of herbicides and pesticides within the Green.

PROBABILISTIC SURVEYS AND WYOMING'S INTEGRATED REPORT

In addition to requiring States to describe the water quality condition of all their waters, CWA §303(d) directs each State to develop a list of all waters which do not fully support their designated uses and require development of a Total Maximum Daily Load (TMDL). Wyoming's Integrated 305(b) and 303(d) Report (hereafter referred to as the Integrated Report) documents assessments of pollutant problems and their impact on designated uses.

Probabilistic surveys provide a systematic, broad-scale and quantitative estimate of overall water quality within the targeted population of streams in a region of interest. Conversely, Wyoming's Integrated Report describes water quality issues identified by the WDEQ/WQD's Monitoring Program and other federal, state and local government agencies, non-profit organizations and private entities. Water quality issues are normally derived through focused multi-year studies, the results of which are evaluated against Wyoming's surface water quality standards (WDEQ/WQD 2018) to make determinations of designated use support including those waters that do not fully support their designated uses (i.e., 303(d) list) (WDEQ/WQD 2020).

Summarized findings from probabilistic surveys are included in Wyoming's Integrated Report, but not for designated use-support determinations, including 303(d) listings. Rather, probabilistic surveys identify candidate streams (both potentially good and poor condition) to prioritize for future targeted sampling to assess designated use support.

STUDY AREA

The Green encompasses 21,047 mi^2 or about 21% of Wyoming. The interior of the Green is an arid intermontane basin dominated by shrubs and grasslands interrupted by buttes and badlands (Chapman et al. 2003). The mostly forested Wind River Range and Wyoming Range surround the Green in the upper portion and the Sierra Madre Range borders the Green to the southeast. The mountainous regions of the Green are the source of the major rivers and streams that provide water resources for the basin, with streams in the interior being ephemeral to perennial and having a mixture of spring and montane snowmelt origins. The east-central portion of the Green includes the closed Great Divide Basin, which does not technically drain into the Green River or its tributaries, but is generally included as part of the Green River Basin. Abrupt topographical relief and numerous types of exposed granitic and sedimentary bedrock are typical throughout the Green. Elevation ranges from approximately 6,040 feet where the Green River crosses into Utah to 13,804 feet at the summit of Gannett Peak in the Wind River Range. Precipitation in the basin averages between 10 to 15 inches per year, but varies from less than 6 inches in portions of the interior up to 51 inches along the peaks of the surrounding mountains (WWDC

2010), which falls mostly in the form of snow. As with precipitation, air temperature in the Green varies due to differing topographic relief and resultant orographic effect of the area. For example, average annual temperatures for the basin range from 40 to 45°F in the interior, to less than 25°F in the areas surrounding the mountain peaks (WWDC 2010).

Six bioregions comprise the Green (Figure 1): Granitic Mountains, High Valleys, Sedimentary Mountains, Southern Foothills & Laramie Range, Southern Rockies, and the Wyoming Basin (Hargett 2011). Bioregions are WDEQ-derived geographic classifications that represent groups of streams with similar habitat, chemical and biological characteristics.

The Granitic Mountains and Sedimentary Mountains (Wind River Range and Wyoming Range), as well as the Southern Foothills & Laramie Range and Southern Rockies (Sierra Madre Range and isolated mountains) collectively represent the mountainous regions of the Green with bedrock geology and elevation as the primary delineators between these four bioregions. The mid- to upper-montane elevations of these mountains contain coniferous forest, aspen groves, subalpine meadows and/or alpine tundra. Vegetation cover for the low elevation foothills is a mosaic of conifers, shrubs, sagebrush and grassland. Recreation, logging and summer livestock grazing are common land uses in the mountainous areas of the Green. The High Valleys and Wyoming Basin bioregions comprise the interior of the Green. The High Valleys is an ecotone between nearby mountains and the basin proper. Physiographically, the High Valleys are sub-irrigated wet meadow systems found in the broad floodplains, low terraces and alluvial fans commonly covered by cottonwood, sagebrush, mixed-grass prairie and scattered conifer (Chapman et al. 2003). Lastly, the Wyoming Basin bioregion is an arid desert shrubland represented by escarpments, mesas, hills and alkaline depressions. Land use in the Green interior includes livestock grazing, mineral extraction and irrigated agriculture, with alfalfa and grass hay the dominant crops (WWDC 2010).

Agriculture, industry and recreation are primary human surface water uses. Dams, diversions and trans-basin augmentation have altered the natural flow regimes of many streams and rivers within the intermontane basins of the Green (WWDC 2010). There are 23 major diversion structures within the Green with records, which transfer approximately 200,000 acre-feet (AF) of water per year, of which the City of Cheyenne transfers 15,300 AF from the Little Snake River Basin into the North Platte River Basin (WWDC 2010). Of the nearly 590,000 AF per year of surface water considered consumptive use in the Green (including reservoir evaporation), approximately 390,000 AF (66%) is used for agriculture, 56,800 AF (10%) for industrial applications and 22,000 AF (4%) for municipal use, which includes the water diverted by the City of Cheyenne (WWDC 2010). The remaining 20% of water use in the Green is lost to evaporation. A majority of the consumptive water use for agriculture (predominantly-irrigation) comes from reservoirs constructed throughout the basin (which uses also include municipal, flood control and power generation), and to a lesser extent major alluvial and sedimentary aquifers. The Green River and major tributaries supply water for all of the large reservoirs within the Green (Flaming Gorge, Fontenelle and Viva Naughton) that in conjunction with smaller reservoirs and groundwater wells serve over 330,000 acres of irrigated lands (WWDC 2010). Major industrial uses in the Green include power generation and the soda ash (trona) industry, which consume approximately 70% and 29% of the industrial water usage, respectively. The trona deposits in the Green are the largest in the world, and supply two-thirds of the world's soda ash. Of the water used for industrial applications in 2010, 97% came from surface water. Most municipalities in the Green obtain their drinking water from surface water sources, with the exception of small isolated municipalities that obtain water from groundwater wells. Produced water from power plants, the soda ash industry, municipal wastewater facilities and other natural resource extraction often discharge to surface waters of the Green as treated effluent authorized under permits issued by the WDEQ Wyoming Pollution Discharge Elimination System (WYPDES) Program. In 2015, the WYPDES Program had 23 active permits in the Green, which discharged an estimated 27,000 AF of treated effluent into surface waters.

The Green provides exceptional outdoor recreation opportunities for the state, most of which are non-consumptive. For example, the Green and New Fork Rivers support blue ribbon fisheries, the Flaming Gorge Reservoir is a National Recreation Area and the Bridger Wilderness provides over 1,000 lakes for recreation. These recreational activities include boating, fishing, hunting and wildlife viewing among others. Public lands in the Green, which includes land managed by local, state and federal agencies, account for nearly 75% of the Green's total area (Martinson 2018). Recreation and recreation-based travel in the Green generated more than $550 million and 5,750 jobs in 2007 alone (WWDC 2010).

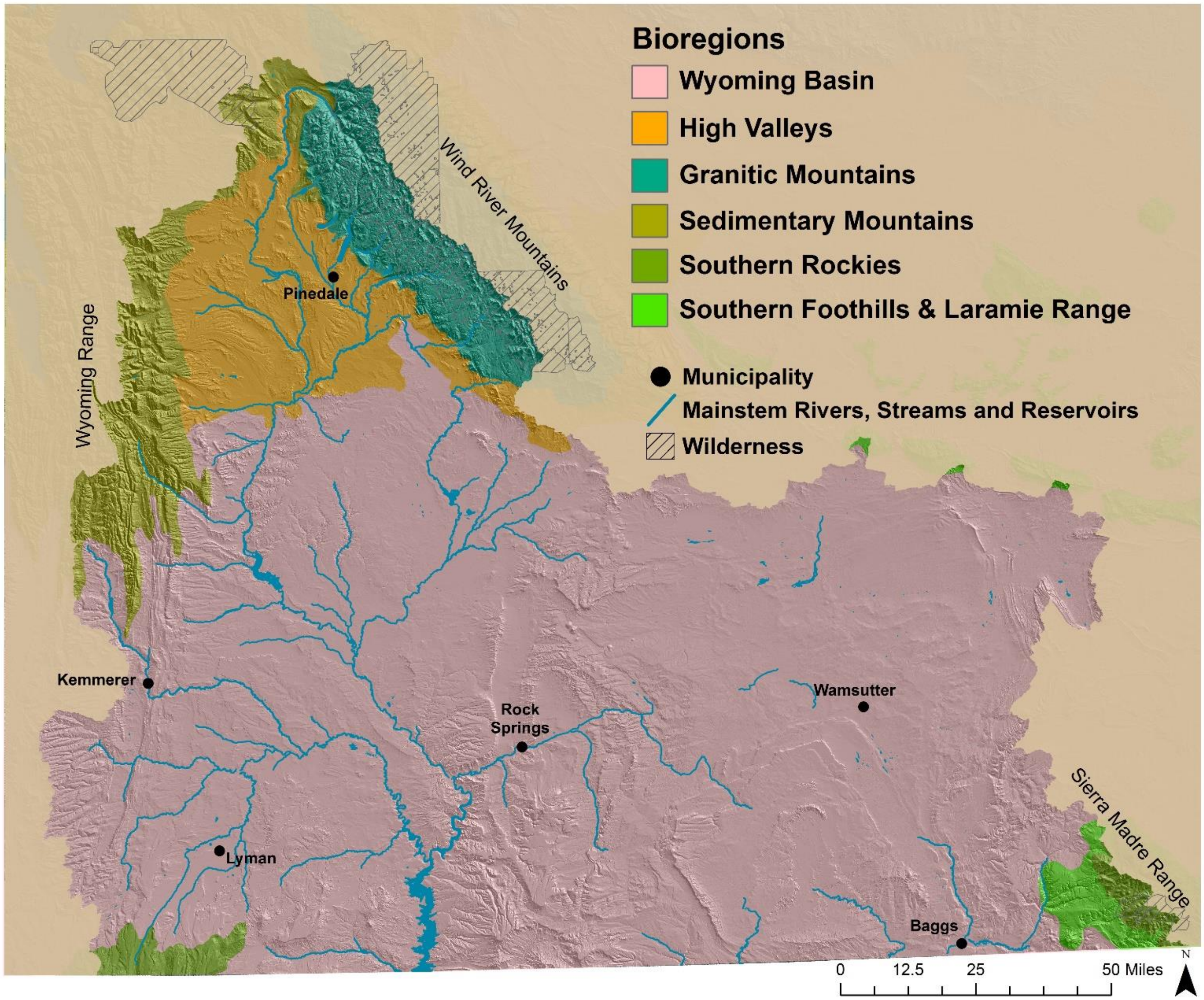


Figure 1. Bioregions, wilderness, and selected municipalities of the Green.

SURVEY DESIGN

The total length of all waterways (perennial, intermittent, ephemeral, canals) in the Green is 23,590 miles, based on the USEPA-United States Geological Survey (USGS) 1:100,000 scale enhanced National Hydrography Dataset (NHD+). Approximately 4,944 miles (21%) in the Green are perennial streams; intermittent and ephemeral streams represent approximately 17,852 miles (76%). Relative to other basins in the state, the interior of the Green receives little precipitation. As a result, a large portion of the stream miles classified in NHD+ as perennial in the Green are located in the montane and foothill areas that surround the basin. The term 'perennial streams' will be used throughout this report to represent the target population of streams for the Green survey, which includes all streams classified as perennial by NHD+ within the geographical limits of the survey described later in this section.

The survey design is based on the approach developed by Stevens and Olsen (2004 and 1992) and previously implemented in WDEQ/WQD statewide, Northeast, and Bighorn/Yellowstone probabilistic surveys (Hargett and ZumBerge 2017, 2014, and 2013) and USEPA's 2018, 2013, and 2008 NRSA (USEPA 2016). Site locations that represent a known proportion of the target population (in this case perennial streams as classified by NHD+) were computer generated randomly from the digitized NHD+ stream network sample frame using a Generalized Random Tessellation Stratified (GRTS) design.

The GRTS design assigns weights to user-specified categories such as Strahler order, ecoregion and other geographic variables based on their extents within the sample frame. The weight assignments are integral to GRTS designs so that combined, randomly selected sites fully represent the variety of streams in the sample frame. Each randomly selected site thus represents a known proportion of total stream miles within the sample frame. From this information, estimates of stream length and associated biological condition and stressor extents within different landscape categorizations are calculated.

The stratified survey design for the Green selected sites from perennial, non-headwater (>1st Strahler order) streams that are not located in United States Forest Service wilderness within the NHD+ sample frame. The design excluded streams in wilderness areas since most are not reasonably accessible given objectives and logistical considerations of this study. The design also excluded headwater (1st order) streams since the majority within the basin are non-perennial. This equated to a target population of approximately 3,493 miles of perennial streams (71% of the total miles of perennial streams in the Green).

Stevens and Olsen (2004, 1992) describe the statistical procedures used in selecting site locations from sample frames using GRTS. Hargett and ZumBerge (2013) gives a brief summary of the procedure. Sample size was based on a multi-density categorization of 2nd, 3rd, 4th and 5th+ Strahler orders for a total of 50 primary sites to be sampled. Equal allocation of the 50 sites among three eight-digit HUC clusters within the Green: Upper Green – New Fork, Big Sandy - Blacks Fork – Muddy, and Lower Green – Little Snake ensured spatial uniformity in the design (Figure 2). The same design and stratification generated 100 oversample sites that replaced primary sites not sampled due to access denial, inaccessibility or they were non-target (e.g., ephemeral, canal, wetland, etc.). Within each HUC 8 cluster, site selection occurred in the order presented by the GRTS design.

DATA COLLECTION

All data collections occurred during typical baseflow or near baseflow conditions. Chloride and sulfate; dissolved aluminum, arsenic, cadmium, iron, manganese, and zinc; total hardness, nitrogen, phosphorus, selenium, arsenic, zinc, cadmium, and suspended solids; *Escherichia coli*, nitrate+nitrite-N, and a suite of pesticides and herbicides were analyzed from grab samples collected at the base of a riffle at each site (WDEQ/WQD 2021a). Measurements of water temperature, dissolved oxygen, pH and specific conductance occurred in the field (WDEQ/WQD 2021a).

Benthic macroinvertebrates were collected from a representative riffle, when present, within each monitoring site following standard procedures in WDEQ/WQD (2021a). Eight randomly selected samples (each 1 ft^2) were collected from the representative riffle with a Surber sampler (500-µm mesh collection net), filtered with a 500-µm mesh sieve and combined into a single composite sample. Benthic macroinvertebrate sampling occurred at multiple habitats where riffles were atypical or absent. (WDEQ/WQD 2021a). The multi-habitat sample was a composite of 20 discrete 'jab' samples collected with a dip net, from multiple habitats weighted proportionally based on representation, within a 300-foot reach. Preservation of organisms occurred in the field with 99% ethyl alcohol. Sample processing followed methods described in WDEQ/WQD (2021a).

Estimations of riffle substrate particle size and mean embeddedness entailed measuring at least 100 randomly selected particles using a modification of the Wolmann pebble count method (WDEQ/WQD 2021a). Mean riffle embeddedness is the degree to which coarse materials are covered or surrounded by very fine gravel, sands and silts. Channel cross-sectional surveys of representative riffles quantified existing channel dimensions for Rosgen channel classification (Rosgen 1996) and relative departure from general expected conditions. Wolman pebble counts (100 count) conducted reachwide characterized substrate composition and aided in Rosgen channel classification. Additional semi-quantitative evaluations of streambank stability and cover, human influences within the riparian zone, stream bank and riparian zone condition and channel stability were measured at all sites (considering their inherent potential) following approved procedures in WDEQ/WQD (2021a). Samplers noted presence/absence, proximity to the channel and relative influence to water quality conditions for twelve human activities (logging, mining, buildings, roads, landfills, riprap, pavement, pipes, lawn, row crops, pasture and grazing), to make conservative inferences on the degree of riparian disturbance and relative channel stability.

Estimations of the degree and relative extent of hydrologic modification by dams, flow diversions and/or flow augmentation occurred for each site. Sources of this information included, but were not limited to, the Wyoming State Engineers Office and the U.S. Bureau of Reclamation. In addition, to be reservoir-influenced for this study, sites had 50% or more of the upstream watershed affected by a dam (as depicted on a USGS 1:100,000 scale map).

Data analyses were limited to chemical, physical and biological data that attained quality assurance/quality control standards (WDEQ/WQD 2021b).

SETTING EXPECTATIONS OF STREAM AND RIVER CONDITION

INDICATORS OF BIOLOGICAL CONDITION

To assess the biological condition of the Green's perennial streams requires the establishment of minimum biological thresholds. Wyoming uses a reference condition approach to develop minimum biological condition thresholds for different regions in the State derived from benthic macroinvertebrate data collected at a network of over 200 minimally- to least-impacted reference sites. Benthic macroinvertebrates are one of the most common indicators used to assess the biological condition of United States streams. The Wyoming Stream Integrity Index (WSII) and the WY RIVPACS, each of which were developed using Wyoming's reference dataset, were used to assess the biological condition of perennial streams in the Green. Because results from the WSII and WY RIVPACS infer water quality conditions over a multi-year period, they are important tools for evaluating the biological condition of perennial streams.

WYOMING STREAM INTEGRITY INDEX (WSII) is a statewide regionally-calibrated macroinvertebrate-based multimetric index designed to assess biological condition of perennial streams (Hargett 2011). The standardized values of selected metrics (composition, structure, tolerance, functional guilds) derived from the riffle-based macroinvertebrate sample are averaged to calculate a WSII index score. The selected metrics are those that best discriminate between reference and degraded sites. The assessment of biological condition is made by comparing the index score for a site of unknown biological condition to expected values that are derived from an appropriate set of regional reference sites that are minimally or least-impacted by human disturbance. WSII index values that fall within the range of expected, or reference values, imply high biological condition, whereas values lower than that observed at reference sites imply biological degradation. Index scores are codified into one of three narrative aquatic life use-support categories of 'full-support', 'indeterminate' and 'partial/non-support' based on numeric thresholds for each of Wyoming's eleven bioregions.

WYOMING RIVER INVERTEBRATE PREDICTION AND CLASSIFICATION SYSTEM (WYRIVPACS) is a statewide macroinvertebrate-based predictive model that assesses stream biological condition by comparing the riffle-based macroinvertebrate community observed at a site of unknown biological condition with that expected to occur under reference condition (Hargett 2012). The expected macroinvertebrate taxa are derived from an appropriate set of reference sites that are minimally or least-impacted by human disturbance. The deviation of the observed from the expected taxa, a ratio known as the O/E value, is a measure of compositional similarity expressed in units of taxa richness and thus a community level measure of biological condition. O/E values near 1.0 imply high biological condition while values <1.0 or >1.0 imply some degree of biological degradation. O/E values are codified into one of three narrative aquatic life use categories of 'full-support', 'indeterminate' and 'partial/non-support'.

The 'full-support' and 'partial/non-support' categories derived from the WSII and WY RIVPACS represent the 'least-disturbed' and 'most-disturbed' biological conditions, respectively (Appendix 1). Sites that fall between these two categories are 'indeterminate' which is not an attainment category, but is rather an intermediate category that acknowledges uncertainty in the models, and for formal assessment purposes would require the use of ancillary information and/or additional data in a weight-of-evidence evaluation to determine a proper narrative assignment (e.g. full or partial/non-support).

The WSII and WY RIVPACS apply only to riffle-based benthic macroinvertebrate samples, thus application to samples collected with multi-habitat sampling procedures is limited. For Green survey sites sampled with multi-habitat procedures, biological condition was determined through the use of multiple lines of biological, chemical and physical evidence; alternative analytical procedures; comparisons to applicable numeric criteria protective of aquatic life and professional judgment.

Wyoming's aquatic life use-support decision matrix (WDEQ/WQD 2020) aided interpretation of WSII and WY RIVPACS results. This matrix was used to determine overall biological condition using the three categories of least-disturbed, indeterminate and most-disturbed.

INDICATORS FOR DRINKING WATER SUITABILITY AND HUMAN HEALTH CONDITION

Drinking water suitability indicators included dissolved iron, dissolved manganese, total arsenic, total cadmium, nitrate+nitrite-N, total selenium, total zinc, and a suite of herbicides and pesticides.

According to the USEPA (http://water.epa.gov/drink/contaminants/index.cfm), long-term drinking water intake of elevated concentrations of the following contaminants may adversely affect human health: arsenic (skin problems and cancer), cadmium (kidney damage), nitrate+nitrate-N (blue baby syndrome in pregnant women), selenium (hair and fingernail loss along with circulatory problems) and zinc (taste, odor or gastrointestinal issues with drinking water). Elevated iron or manganese can result in undesirable taste, odor or color to drinking water supplies though are not considered health threatening according to the USEPA (http://water.epa.gov/drink/contaminants/secondarystandards.cfm). The health effects of herbicides and pesticides vary by parameter but in general, negative health effects, where documented, occur at relatively low concentrations. Wyoming's most-stringent numeric criteria protective of human health (fish consumption and drinking water) represented the least-disturbed condition for drinking water suitability (WDEQ/WQD 2018). Specifically, the least-disturbed thresholds are dissolved iron (300 µg/L), dissolved manganese (50 µg/L), total arsenic (10 µg/L), total cadmium (5 µg/L), nitrate+nitrate-N (10 mg/L), total selenium (50 µg/L) and total zinc (5,000 µg/L) (Appendix 2).

Concentrations that equal or exceed the least-disturbed thresholds represent the most-disturbed drinking water suitability condition. Sample analyses included only the dissolved fractions of these analytes as part of the Green survey. Therefore, translator equations (USEPA 1996, 1985) using the dissolved fraction concentrations were used to estimate the total fraction concentrations for each analyte that were then compared to the least-disturbed thresholds. These translator equations are in Appendix 2.

Water quality human health criteria (WDEQ/WQD 2018) served as thresholds between least- and most-disturbed for 13 of the 71 sampled herbicides and pesticides. Where criteria do not exist, thresholds would be determined on a case-by-case basis to the extent possible using available literature and guidance documents.

E. coli is a fecal coliform bacterium present in the intestines of warm-blooded animals and humans and is an indicator of public health risk of recreational waters in Wyoming (WDEQ/WQD 2018). Elevated concentrations of *E. coli* increase the risk that humans may contract pathogens, and thus gastrointestinal illnesses through recreational use of the water. Anthropogenic sources of *E. coli* are human or warm-blooded animal fecal material conveyed via multiple pathways that include septic systems, wastewater effluent, storm drains, overland runoff and direct deposit in or near the stream. Wyoming's 60-day geometric mean *E. coli* criterion of 126 colony forming units/100 mL that is protective of primary contact recreation, applied as a single-sample threshold for this study, represents the least-disturbed human health condition for perennial stream in the Green (WDEQ/WQD 2018). Conversely, *E. coli* concentrations equal to or greater than the least-disturbed threshold represent the most-disturbed human health condition.

STRESSORS TO BIOLOGICAL CONDITION

For the purposes of this study, stressors are chemical and physical factors that negatively affect the biological condition of a stream. Wyoming has water quality criteria to protect designated aquatic life uses of streams (WDEQ/WQD 2018). Wyoming's numeric aquatic life criteria for pH, chloride, and select metals were used to evaluate conditions throughout the Green and for each HUC 8 cluster. For parameters with acute and chronic criteria, the chronic criterion applied. Water quality condition was least-disturbed when concentrations were less than the numeric criterion. Conversely, water quality condition was most-disturbed when the numeric criterion was equaled or exceeded.

For parameters without numeric criteria, percentile distributions (25^{th} and 95^{th} percentiles) of reference site values within individual or collective bioregions in the Green formed the least and most-disturbed thresholds for each stressor, respectively. This percentile-based methodology for establishing least and most-disturbed thresholds is similar to that used for EMAP-West (Stoddard et al. 2005) and the NRSA (USEPA 2015).

Exceedance of these percentile-derived thresholds does not imply the stream is 'impaired' with respect to support of designated aquatic life uses. Rather, an exceedance of the most-disturbed percentile threshold suggests an increased risk of detrimental effects to the aquatic life uses from that stressor. Further investigation would determine if aquatic life uses are in fact impaired. Stressors used in this report, their descriptions and the established expectations are described below.

Water quality aquatic life criteria exist for so few of the sampled herbicides and pesticides that thresholds were not developed for these parameters.

CHEMICAL STRESSORS

NUTRIENTS – Nitrate+nitrite-N (commonly referred to as nitrate), total nitrogen and total phosphorus are essential to the biological productivity of streams, though are generally found in low concentrations naturally and are therefore considered limiting to plant and algal growth. Excess contributions of nutrients associated with human activities, otherwise known as nutrient enrichment, can cause problems that range from annoyances to serious effects to aquatic life (USEPA 2000). Nutrient concentrations in streams may exceed ambient concentrations through land fertilization, direct deposits of animal and human wastes, sewage discharges or leaking septic systems, and elevated upland or bank erosion (USEPA 2000). Nutrient enrichment may stimulate excessive growth of phytoplankton (free-floating algae) in slow moving rivers, periphyton (algae attached to substrate) in shallow streams and macrophytes (aquatic vascular plants) in all waters (USEPA 2015).

Nutrient enrichment can stimulate excessive growth of algae and aquatic macrophytes.

Nutrient enrichment can negatively affect aquatic communities through high concentrations of nitrogen in the form of ammonia (NH3), dissolved-oxygen depletion (hypoxia), increases in pH, or decreases in habitat quality (USEPA 2015, Munn and Hamilton 2003, Peterson et al. 2007). Nuisance levels of plant and algal growth interfere with aesthetic and recreational uses of streams and can clog water intakes. Blooms of certain blue-green algae produce toxins that can affect animal and human health (USEPA 2000).

Excess nutrients may either run off the land during storms and snowmelt or infiltrate into groundwater aquifers. Nutrients may reside in groundwater aquifers for years to decades before reaching a stream. Excess nutrients can enter a stream through decomposition of excess accumulations of organic material in the channel. In the absence of numeric aquatic life criteria for total phosphorus, total nitrogen or nitrates, thresholds were derived using conservative 25th and 95th percentiles of concentrations among all Green River Basin reference sites combined, that represented the least and most-disturbed conditions, respectively (Appendix 1). Reference-based data were pooled for all bioregions due to the high proportion of laboratory results below reporting concentrations among bioregions. The percentile-derived most-disturbed total phosphorus condition of 0.100 mg/L equates to the concentration considered by some ecologists as unacceptably high for maintenance of aquatic life (Dodds et al.

2002, Peterson et al. 2004, Vollenweider 1971) in perennial streams.

TOTAL SUSPENDED SOLIDS - TSS is one measure of the concentration of both sediment and organic materials suspended in the water column. Natural TSS concentrations are seasonally variable and normally highest during spring snowmelt runoff and after thunderstorms. Elevated TSS concentrations, beyond ambient, may affect aquatic life through alterations to feeding mechanisms, reduced photosynthesis by algae and macrophytes, physical abrasion, streambed scouring and increased water temperatures. Elevated concentrations of suspended solids can also interfere with agricultural, municipal and industrial uses of the water. Human activities such as construction, mining, logging, irrigation drainage, dam operations, sewage discharges, animal waste, and elevated upland or bank erosion may contribute to elevated TSS beyond ambient concentrations. In the absence of aquatic life criteria for TSS, least and most-disturbed thresholds for each bioregion were derived from the 25th and 95th percentiles of TSS concentrations among reference sites for each bioregion respectively (Appendix 1).

Elevated TSS can interfere with gill function and feeding ability of aquatic life in addition to human uses of the water.

SALINITY - Specific conductance is an indicator of salinity or the concentration of dissolved salts. Dissolved salts may include ions of chloride, nitrate, phosphate, sulfate, selenium, magnesium, calcium, sodium and iron. Natural salinity of streams varies considerably and is primarily dependent on geology and soils of the watersheds. Elevated salinity may negatively affect soils and drinking water, as well as structure and function of aquatic communities.

Human sources of salinity occur as byproducts from activities such as irrigated agriculture, mineral and industrial development, municipal wastewater discharges and road salt application. Elevated soil erosion can also increase the salinity of streams. In the absence of aquatic life criteria for salinity, least and most-disturbed thresholds were derived from the 25th and 95th percentiles of specific conductance measurements among reference sites for each bioregion, respectively (Appendix 1).

ALUMINUM – Aluminum is the most abundant naturally occurring metal in the earth's crust typically found in very low concentrations in streams. Elevated concentrations interfere with gill function and influence growth of aquatic life, particularly at low pH. Human sources of aluminum include coalmines, coal-fired power plants, oil production facilities, sewage, accelerated bank erosion or channel degradation and mine tailings. Wyoming has a numeric acute and a hardness and pH-dependent chronic aquatic life criterion for dissolved aluminum (WDEQ/WQD 2018). Dissolved aluminum concentrations that equal or exceed the chronic criterion represent the most-disturbed biological condition for this stressor (Appendix 1).

ARSENIC – Arsenic is a naturally occurring element found largely in trace concentrations in streams. Elevated concentrations can occur naturally in some streams where arsenic rich soils and sedimentary geology are common. Arsenic is bioaccumulative through dietary pathways and in elevated water column concentrations, beyond ambient conditions, can ultimately result in morphological alterations, liver neoplasms or death of aquatic life. Human sources of arsenic include pesticides, coal-fired power plants, mine tailings, and irrigation induced leaching of arsenical soils and geology. Wyoming has a numeric aquatic life chronic criterion of 150 µg/L dissolved arsenic (WDEQ/WQD 2018). Dissolved arsenic concentrations that equal or exceed the 150 µg/L criterion represent the most-disturbed biological condition for this stressor (Appendix 1).

CADMIUM – The most common forms of cadmium are naturally occurring and found in combination with other elements in low concentrations in streams. Cadmium is bioaccumulative and elevated concentrations can result in reduced growth, reproductive disruptions and mortality in aquatic life. Anthropogenic sources of cadmium include automobile emissions, mine drainage and tailings, phosphate fertilizers, and industrial effluent from coalmines, refineries, oil or coal bed natural gas facilities. Wyoming has formula-based hardness-dependent numeric acute and chronic dissolved cadmium criteria considered protective of aquatic life uses (WDEQ/WQD 2018). Dissolved cadmium concentrations that equal or exceed the chronic formula-based hardness-dependent criterion represent the most-disturbed biological condition for this stressor (Appendix 1).

CHLORIDE - This is a naturally occurring constituent commonly found as a compound with sodium, potassium or magnesium and can contribute to the salinity of streams. Elevated concentrations of chloride are toxic to aquatic life and interfere with municipal and industrial processes. Human sources of chloride include sewage; industrial effluent from coalmines, refineries, oil or coal bed natural gas facilities; fertilizers; irrigation drainage and road salt application. Wyoming has a numeric chloride aquatic life chronic criterion of 230 mg/L considered protective of game or non-game fisheries (WDEQ/WQD 2018). Chloride concentrations that equal or exceed the 230 mg/L criterion represent the most-disturbed condition for this stressor (Appendix 1).

IRON – The fourth most abundant element in the earth's crust, iron can occur naturally in streams at elevated concentrations where geological formations and soils contain abundant iron oxides. Iron in appreciably elevated concentrations impairs growth and survival of aquatic life by motion inhibiting or smothering effects of iron precipitates on the gills, eggs and other surfaces. Formation of iron precipitates on stream channel surfaces has an indirect effect on the survival, growth and reproduction of aquatic life. Anthropogenic sources of iron include mine drainage, irrigation returns, fertilizers, industrial effluent (coalmines, oil treaters, coal bed natural gas, refineries) and sewage discharges. Wyoming has a numeric dissolved iron aquatic life chronic criterion of 1,000 µg/L (WDEQ/WQD 2018). Dissolved iron concentrations that equal or exceed the chronic criterion represent the most-disturbed biological condition for this stressor (Appendix 1).

MANGANESE – This naturally occurring metal can be elevated in streams where surrounding geology and soils contain abundant manganese oxides, silicates or carbonates. The toxicity of elevated manganese concentrations to aquatic life is hardness-dependent and can result in disruptions to osmoregulation, growth and reproduction. Human sources of manganese include mine drainage, irrigation returns, fertilizers, industrial effluent (coalmines, oil treaters, coal bed natural gas, refineries) and sewage discharges. Wyoming has numeric hardness-dependent dissolved manganese aquatic life acute and chronic criteria (WDEQ/WQD 2018). Dissolved manganese concentrations that equal or exceed the chronic criterion represent the most-disturbed biological condition for this stressor (Appendix 1).

pH - The pH of a stream has important implications to the growth and survival of aquatic life since it can affect physiological functions and the toxicity of constituents such as heavy metals and ammonia. Human sources contribute to alterations in pH from background including byproducts of industrial processes and indirectly from nutrient enrichment. Wyoming has a pH aquatic life chronic criteria range of 6.5 to 9.0 (WDEQ/WQD 2018). Values of pH < 6.5 or > 9.0 represent the most-disturbed condition (Appendix 1).

SELENIUM – A contributor to salinity and an essential trace element for animal nutrition, elevated selenium can occur naturally in many streams of the west where seleniferous soils and marine shales are common. Selenium is bioaccumulative primarily through dietary pathways and in elevated concentrations causes skeletal deformities and disruptions to growth and survival of aquatic life. Mortality, birth defects and reproductive failures occur in waterfowl and other birds that feed on aquatic life whose tissues contain elevated selenium concentrations. Irrigation-induced leaching of seleniferous soils and marine shales, industrial effluent (coalmines, oil treaters, refineries, coal bed natural gas) and runoff from certain mining activities are anthropogenic sources of selenium. Wyoming has a numeric total selenium aquatic life chronic criterion of 5 µg/L (WDEQ/WQD 2018). Total selenium concentrations that equal or exceed 5 µg/L represent the most-disturbed condition for this stressor (Appendix 1).

SULFATE – As with chloride, sulfate occurs naturally in streams and generally originates from the decomposition of organic matter, atmospheric deposition or geologic weathering. Depending on the background concentrations of chloride and hardness, elevated concentrations of sulfate may be toxic to aquatic life (Soucek and Kennedy 2005). Anthropogenic sources of sulfate include sewage and industrial effluent (coalmines and oil treaters in particular), irrigation induced leaching of sulfate rich soils and agricultural runoff. There are currently no national or Wyoming water quality criteria for sulfate protective of aquatic life. However, the Illinois Environmental Protection Agency (ILEPA 2012) and Pennsylvania Department of Environmental Protection (PDEP 2017) have promulgated sulfate criteria based in part on the study by Soucek and Kennedy (2005). Because the toxicity of sulfate varies with chloride and hardness and results from the Soucek and Kennedy (2005) study appear to be applicable nation-wide, these criteria, rather than percentiles based on distributions of sulfate from Wyoming reference sites, set appropriate sulfate expectations in Wyoming. Sulfate concentrations that exceeded the chloride and hardness-dependent criteria described in Appendix 1 represent the most-disturbed condition for this stressor.

ZINC – Zinc is an essential mineral for nutrition and ubiquitous in the environment at varying concentrations depending on the origin and composition of soils and geology. Human sources of zinc include mining activities and industrial effluent from coalmines, refineries, oil or coal bed natural gas facilities. A bioaccumulative element, elevated dissolved zinc is toxic to aquatic life by disrupting growth, reproduction and survival. Wyoming has a formula-based hardness-dependent numeric zinc aquatic life chronic criterion (WDEQ/WQD 2018). Dissolved zinc concentrations that equal or exceed the chronic formula-based hardness-dependent criterion represent the most-disturbed condition for this stressor (Appendix 1).

PHYSICAL STRESSORS

RIPARIAN DISTURBANCE - The riparian zone, or the interface between a stream and surrounding uplands, helps to protect streams from both natural and human disturbances when adequate vegetation is present. In many streams, this vegetation is vital to stream bank integrity, allowing stream banks to withstand the erosive forces of water at high flows. The vegetation also captures surface flows, which facilitates groundwater recharge and reduces flooding while filtering sediment, nutrients and other constituents (Gregory et al. 1991). Aquatic life depends on riparian vegetation for habitat (e.g. roots and large woody debris) and shading which helps maintain cooler stream temperatures in small to mid-sized streams. Vegetation provides food such as leaf litter for macroinvertebrates and terrestrial insects for fish. Anthropogenic disturbances to the riparian zone can negatively affect one or more of these processes. The closer human disturbances are to a stream, the greater the risk of negative impact to the stream and its aquatic life. When severe, these disturbances accelerate natural geomorphic processes and threaten the physical stability of a stream, which in turn limits its ability to support aquatic life.

Riparian disturbance impacts aquatic life through alterations to habitat.

Evaluation of riparian disturbance in this study entailed combining semi-quantitative measures of human activity, mean percentage of riparian stream bank cover, percentage of bare ground and stream bank and riparian zone condition at each sampled site. Riparian disturbance was considered most-disturbed when either mean streambank cover was < 70% or bare ground represented > 40% of the riparian zone within 30 feet of the channel (Appendix 1) (Cowley 2002, USDA/NRCS 1998, USDI/BLM 1998, USEPA 1998). Riparian disturbance was also conservatively determined as most-disturbed when at least four of seventeen indicators noted in Appendix 1 were documented in the reach within 30 feet of the channel. Presence of at least four indicators minimized false positive assignments of riparian disturbance.

CHANNEL INSTABILITY - Changes in sediment load or channel boundary conditions (e.g., slope, dimension, profile, planform, stream bank stability) can disrupt the dynamic equilibrium of streams, resulting in accelerated rates of morphological change (e.g., stream bank erosion, incision, aggradation) that ultimately degrade habitat for aquatic life.

In short, accelerated stream bank erosion, active channel incision and/or excess sediment deposition (aggradation) create conditions of channel bed and bank instability (hereafter referred to as channel instability) that have major impacts on stream ecosystems. These impacts include reduced aquatic habitat diversity and quality for spawning and rearing; reduced recruitment, growth and reproduction of aquatic life; altered food resources and in-stream cover; increased temperatures and ultimately a diminished and less diverse aquatic life community comprised of generalist, short-lived taxa tolerant to elevated levels of environmental stressors.

Channel instability was most-disturbed when any of the three following sub-stressors were present: accelerated stream bank erosion, channel incision or excess sediment. Descriptions of each sub-stressor and their most-disturbed thresholds are below.

Excess Sediment - Excess sediment may be the most important pollutant in United States streams (Waters 1995). In the latest USEPA summary of the National Rivers and Stream Assessment, excess sediment again was a top stressor to streams and presented elevated risk to the biological condition of the Nation's waters (USEPA 2020). Excess sediment creates unstable physical conditions including channel aggradation or degradation and consequently degrades habitat for aquatic life. This pollutant smothers fish eggs, fills interstitial spaces in streambeds, and scours habitats where benthic organisms live, thereby severely impacting growth, reproduction, recruitment and survival. Direct abrasion to aquatic life also occurs. Excess sediment may clog surface water diversions and reduce channel capacity; increase flood stage and flood hazard through aggradation and accelerate reservoir sedimentation and reduce storage. In addition to riparian disturbance, alterations to a natural flow regime that reduce sediment transport competency or capacity may result in an accumulation of sediment.

Excess sediment forms extensive un-vegetated mid-channel, transverse, delta and side-bars (Barbour et al. 1999, Rosgen 2006 and 2008, Schumm 1977). Bimodal distributions in bed material size classes (Rosgen 2006) and elevated riffle embeddedness (Sylte and Fischenich 2002) may indicate excess sedimentation. Though variable, the combined results from several studies suggest that a conservative threshold of at least 30% mean riffle embeddedness is suitable for detection of channel aggradation in cobble-bed streams (Sylte and Fischenich 2002). The mean riffle embeddedness that corresponded to the 95th percentile of the reference site distribution in Wyoming was 38%. Considering this information and accounting for the diversity of substrate composition among reference sites in Wyoming and a margin of sampling error, a conservative mean riffle embeddedness of ≥50% is a reasonable threshold for detection of channel aggradation. Excess sediment was noted as present when mean riffle embeddedness was ≥50% or when both of the following were documented in the reach: bimodal reachwide particle distribution, and new or extensive unvegetated bar development (Appendix 1).

Accelerated bank erosion is a common source of excess sediment that impacts aquatic life and interferes with water supply intakes, surface water diversions and accelerates reservoir filling.

Accelerated Bank Erosion - Stable stream banks dissipate stream energy at high flows, minimizing alterations to channel dimension, pattern or profile while also capturing sediment and other pollutants (Waters 1995). Accelerated bank erosion occurs when riparian areas and stream banks are lacking adequate vegetation with well-developed root structures due to riparian vegetation removal, trampling, hoof shear, or recreational traffic and thus cannot retain soil and stabilize streambanks during high flows. Accelerated bank erosion may occur when stream banks exhibit high bank-height ratios where much of the bank surface above bankfull elevation is exposed and unstable, thus the bank is at greater risk for surface erosion, bank slumping and failure and mass erosion processes (Rosgen 2006). Accelerated bank erosion is a form of channel degradation that reduces in-stream aquatic habitat along the banks and contributes excess sediment to a channel. Cowley (2002) suggests that 70% unaltered stream banks appear to be the minimum level that would maintain stable conditions. In addition, Rosgen F and G channels are deeply entrenched, highly susceptible to changes in dimension, profile and planform and are general indicators of channel bed or bank instability in valley types where they are unexpected (Rosgen 1996). Therefore, accelerated bank erosion was noted as present when either mean streambank stability was < 70% or Rosgen F or G channels were present in valley types where they are unexpected (Appendix 1).

Channel Incision - Accelerated stream bank erosion and excess sediment sometimes associate with channel incision. Channel incision is abandonment of an active floodplain and a lowering of the channel bed with concomitant lowering of the water table. Channel incision is often associated with channel enlargement or straightening (channelization). Other causes of channel incision include reduced sediment load due to upstream dams, increased peak flows caused by anthropogenic activities and land use changes (Fischenich and Morrow 2000, Galay 1983). Channel incision was present when evidence of active channel incision (e.g., evident headcuts or unexpected shifts in channel gradient) or recent (within the past 10 years) channelization occurred within the reach (Appendix 1).

Alterations to channel boundary conditions such as from disturbances to the riparian zone trigger channel incision and accelerated bank erosion.

RANKING OF STRESSORS

Relative Extent

Relative extent (as a percentage) quantifies how extensive the most-disturbed stressor condition is among perennial streams of the Green. Conceptually, stressors in the most-disturbed condition occur in all geographic regions though their pervasiveness may vary. Areas where a stressor in the most-disturbed condition occurs in a high percentage of stream miles will have a high relative extent. For this study, stressor relative extents are evaluated at both the Green and HUC 8 Cluster scales.

Relative Risk

A concept that originates from medical epidemiology, relative risk is a measure of the strength of association between a stressor and a response variable. Relative risk (RR) in the Green evaluates the potential effect of each stressor on biological condition using the following equation:

$$RR = \left(\frac{PRmdb/PRmds}{PRmdb/PRlds}\right)$$

Where *PR* is the percentage of stream miles, *mdb* is the most-disturbed biological condition given a most-disturbed stressor condition, *mds* the most-disturbed stressor condition and *lds* the least-disturbed stressor condition.

Relative risk simply measures the likelihood that a stream is in the most-disturbed biological condition when a stressor in the most-disturbed condition is present (Van Sickle et al. 2006). Relative risk does not imply that a most-disturbed biological condition will occur in the presence of a most-disturbed stressor condition, only the likelihood that it could occur. Relative risk values of 1 indicate that the most-disturbed biological condition is just as likely to occur under a most-disturbed stressor condition as they are under a least-disturbed stressor condition. However, relative risk values greater than 1 suggest an increased association between the stressor and biological condition. The higher the relative risk of a stressor, the more likely that stressor is to be associated with a most-disturbed biological condition.

One fundamental disadvantage with relative risk is that the simultaneous interactive and cumulative effects of multiple stressors are not considered.

Stressor relative risk values are ranked only at the Green scale. Valid relative risk values generally were not obtainable at the HUC 8 Cluster scale due to small sample sizes.

DATA ANALYSIS

All probabilistic survey analyses were performed by WDEQ/WQD using modifications of the 'spsurvey.analysis' scripts developed in R (Version 4.0.3) by the USEPA's Office of Research and Development in Corvallis, Oregon or with STATISTICA (Version 14.0.0.15) (Tibco 2020). The statistical procedures used in 'spsurvey.analysis' to extrapolate estimates of evaluated and assessed stream lengths and biological condition, stressor relative extents and stressor relative risks from collected data are fully described in Paulsen (2008), Van Sickle and Paulsen (2008) and Van Sickle et al. (2006).

2015 STREAM FLOWS

The Green survey occurred during a year of average precipitation and snowpack (NRCS 2021). Data collected at 14 USGS stream gages present in the Green show approximately average peak and mean annual flows in 2015 (Appendix 3). At the Green scale, peak flows in 2015 were on average 5% (range: -36% to +52%) below the mean peak flows for the periods of record, and the mean annual flows were 1.5% (range: -72% to +69%) above the average mean annual flows.

RESULTS

EXTENT OF RESOURCE

The Green survey represents 3,493 perennial stream miles or the target stream length. The target stream length equates to 71% of the 4,944 total perennial stream miles in the Green. Approximately 16% (573 miles) of the target stream length is non-target based on the proportion of survey sites where desktop or field reconnaissance identified features that identified non-target characteristics (Figures 2 and 3). Non-target sites are those identified as ephemeral or intermittent, wetlands or human constructed channels such as irrigation canals. Approximately 39% (1,369 miles) of the target stream length was not assessed based on the proportion of survey sites where the landowner denied access, or could not be contacted. The remainder of the sampling frame represents the assessed targeted stream length for the Green survey – 1,493 miles (Figures 2-3, Appendix 4). This assessed targeted length represents 43% of the target perennial stream miles in the Green and 30% of the total perennial stream miles from the GRTS modified sample frame.

The distribution of the target stream length for the Green survey at the HUC 8 cluster scale is as follows (Figures 2-3, Appendix 4). Upper Green – New Fork: 57% target (810 miles), 32% access denied (442 miles) and 11% non-target (155 miles). Big Sandy – Blacks Fork - Muddy: 30% target (383 miles), 49% access denied (640 miles), 18% non-target (238 miles), and 3% inaccessible (36 miles). Lower Green – Little Snake: 38% target (300 miles), 36% access denied (287 miles), 23% non-target (180 miles), and 3% inaccessible (23 miles).

The flow regimes of approximately 25% (375 miles) of the assessed perennial streams for the Green survey are reservoir influenced (≥50% of the respective watershed areas). Reservoir influenced streams are least prevalent in the Lower Green – Little Snake HUC 8 cluster.

Flow alterations represented by diversions, push-up dams or trans-basin inputs have varying influences on approximately 64% (954 miles) of the 1,493 assessed perennial stream miles for the Green survey. Flow alterations are common throughout the Green.

Sampling sites on the assessed targeted stream miles are near equally distributed among the Upper Green – New Fork (17), Big Sandy – Blacks Fork - Muddy (16), and Lower Green – Little Snake (17) HUC 8 clusters.

BIOLOGICAL CONDITION

Approximately 63% of the Green assessed perennial stream miles are in the 'least-disturbed' condition, whereas 8% are in the 'most-disturbed' condition (Figure 4).

Among the three HUC 8 clusters, the Upper Green – New Fork attained the highest percentage of least-disturbed stream miles at 70% (Figure 4). Among all HUC 8 clusters, the Lower Green – Little Snake exhibited the highest combined percentage of most-disturbed and indeterminate stream miles at 51.5% (Figure 4).

DRINKING WATER SUITABILITY AND HUMAN HEALTH CONDITION

For the Green survey, 66% of the assessed perennial stream miles are in the least-disturbed condition for *E. coli* (Appendix 5, Table 1). Among HUC 8 clusters, the Upper Green – New Fork has the greatest percentage of least disturbed E. coli condition (77%) and the Lower Green – Little Snake has the lowest percentage (34%). All streams are in the least disturbed condition for drinking water suitability with respect to total cadmium, nitrate+nitrite-N, total selenium, and total zinc. Approximately 99%, 96%, and 90% of assessed perennial stream miles in the Green are in the least-disturbed condition for drinking water suitability with regard to iron, arsenic and manganese, respectively.

All of the sampled herbicides and pesticides are in the least disturbed condition for drinking water suitability as none of the parameters were detected at survey sites for the Green.

PHYSICOCHEMICAL STRESSORS TO BIOLOGICAL CONDITION

NUTRIENTS

Throughout the Green, the percentage of stream miles in the least-disturbed nitrate+nitrite-N condition is 92% whereas 8% of streams are in the most-disturbed condition (Appendix 6, Table 2). The highest percentage of stream miles in the most-disturbed nitrate+nitrite-N condition (21%) occurrs in the Lower Green – Little Snake.

The percentage of stream miles in the least-disturbed total nitrogen condition is 26% with the majority considered indeterminate (73%) and 1% in the most-disturbed condition (Appendix 8, Table 2). Among the three HUC 8 clusters, the Upper Green – New Fork exhibits the greatest percentage of least-disturbed stream miles for total nitrogen at 36%, whereas the Lower Green – Little Snake has the greatest percentage of most disturbed stream miles (6%).

Approximately 91% of stream miles are in the least-disturbed total phosphorus condition (Appendix 7, Table 2). Nine percent of stream miles are in the most-disturbed total phosphorus condition. The percentage of stream miles in the most-disturbed total phosphorus condition is highest in the Lower Green – Little Snake at 39%.

SALINITY

The Green has least-disturbed salinity conditions in 27% of stream miles (Appendix 9, Table 2). Approximately 6% of stream miles are in the most-disturbed condition. Among the four HUC 8 clusters, the Upper Green – New Fork has the greatest percentage of least-disturbed stream miles (38%), whereas the Big Sandy – Blacks Fork – Muddy has the greatest percentage of most-disturbed stream miles (16%).

SELENIUM

The Green has 99% of stream miles in the least-disturbed condition for selenium and the remaining 1% are in the most-disturbed condition (Appendix 10, Table 2). Among HUC 8 clusters, only the Lower Green – Little Snake contain stream miles within the most-disturbed selenium condition at 6%.

TOTAL SUSPENDED SOLIDS

The Green has 41% of streams miles in the least-disturbed condition for total suspended solids and 5% in the most-disturbed condition (Appendix 11, Table 2). The largest percentage (54%) are indeterminate. The highest percentage of stream miles in the combined indeterminate and most-disturbed TSS condition occur in the Lower Green – Little Snake (73%).

CHLORIDE, pH and SULFATE

The least-disturbed conditions for chloride and sulfate occur in 100% of stream miles in the Green (Appendix 12, Table 2).

Most stream miles are in the least- disturbed condition for pH (99%).Most-disturbed conditions are rare and found only in the Big Sandy – Blacks Fork – Muddy, with 5% of the stream miles being in the most-disturbed condition (Appendix 13, Table 2).

ALUMINUM, ARSENIC, CADMIUM, IRON, MANGANESE and ZINC

All stream miles in the Green are least-disturbed for the dissolved fractions of arsenic, cadmium, manganese and zinc (Table 2). Small percentages of stream miles are in the most-disturbed condition for aluminum and iron (1% each), with the remainder being least-disturbed for these parameters. The small percentages of most-disturbed stream miles for aluminum and iron occur in the Lower Green – Little Snake.

PESTICIDES and HERBICIDES

All of the sampled herbicides and pesticides are considered least disturbed for biological condition as none of the parameters were detected at survey sites for the Green.

PHYSICAL STRESSORS TO BIOLOGICAL CONDITION

RIPARIAN DISTURBANCE

Riparian disturbance is in the most-disturbed condition in only 24% of stream miles in the Green; whereas 76% are in the least-disturbed condition (Appendix 13, Table 2). Riparian disturbance in the Green is often associated with low overhead cover, minimal woody vegetation, and hoof shear/trampling along the stream banks. The most-disturbed riparian disturbance condition is greatest in the Upper Green – New Fork (26%) and Lower Green – Little Snake (27%) HUC8 clusters.

CHANNEL INSTABILITY

Throughout the Green, 20% of stream miles exhibit indicators of channel instability (excess sediment, accelerated bank erosion and/or active channel incision) (Appendix 13, Table 2). The highest proportion of stream miles with channel instability occur in the Lower Green – Little Snake (33%).

Partitioning channel instability into its three component sub-stressors revealed that of the 20% of stream miles with channel instability, almost all (19%) have accelerated bank erosion whereas only 4% exhibit excess sediment and 2% active channel incision (Appendix 14, Table 2). Accelerated bank erosion is the dominant channel instability sub-stressor in all three HUC8 clusters.

RANKING OF STRESSORS

Relative Extent – For both the Green and HUC 8 clusters, stressors are ranked according to the proportion of target stream miles that was in the most-disturbed condition for that stressor (Figure 5). Riparian disturbance is the most common stressor (24%) that has the potential to affect aquatic life in the Green (Figure 5). Channel instability is the second most common stressor affecting 20% of stream miles, followed by total phosphorus (9%), nitrate+nitrite-N (8%), salinity (6%), and TSS (5%). Iron, aluminum, selenium, total nitrogen, and pH are the least common stressors, each affecting approximately 1% of Green stream miles (Figure 5).

Riparian disturbance and channel instability are the most common stressors within the Upper Green – New Fork and Big Sandy – Blacks Fork - Muddy HUC 8 clusters (Figure 5). Total phosphorus and channel instability are the top two stressors in the Lower Green – Little Snake (39% and 33%, respectively), with riparian disturbance, total suspended solids, and nitrate+nitrite-N all exceeding 20%.

Relative Risk - Channel instability presents the greatest relative risk (16) to the biological condition of targeted streams as measured with benthic macroinvertebrates. (Figure 6). In other words, the most-disturbed biological condition is 16 times more likely to occur in streams having the most-disturbed channel instability condition as streams with the least-disturbed channel instability condition. Iron, aluminum, and selenium exhibit the second-highest risks at 10.6 each (Figure 6). TSS and riparian disturbance present the third-highest relative risk to biological condition at similar values of 7.1 and 6.7, respectively (Figure 6). Results also indicate that elevated sulfate, TN, and pH present little direct risk to the benthic macroinvertebrate communities of the Green assuming no interactive effects with other pollutants. The 95% confidence intervals for

Figure 2 – Target and non-target/access denied sites evaluated as part of the Green probabilistic survey including HUC 8 clusters, municipalities and wilderness.

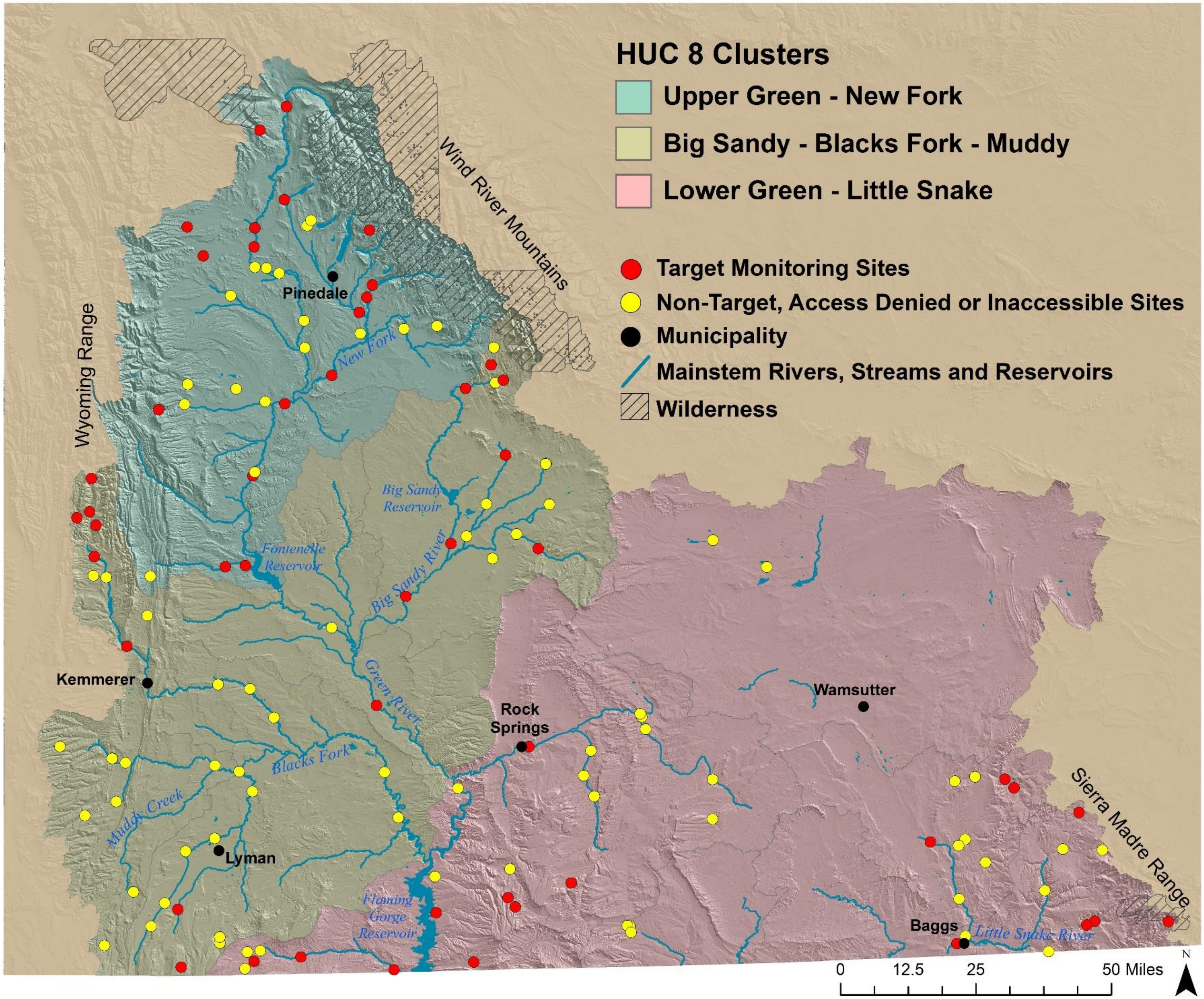


Figure 3 – Estimated percentage of target stream miles relative to access denied and non-target miles at the Green and HUC 8 cluster scales. Error bars represent the 95% confidence intervals.

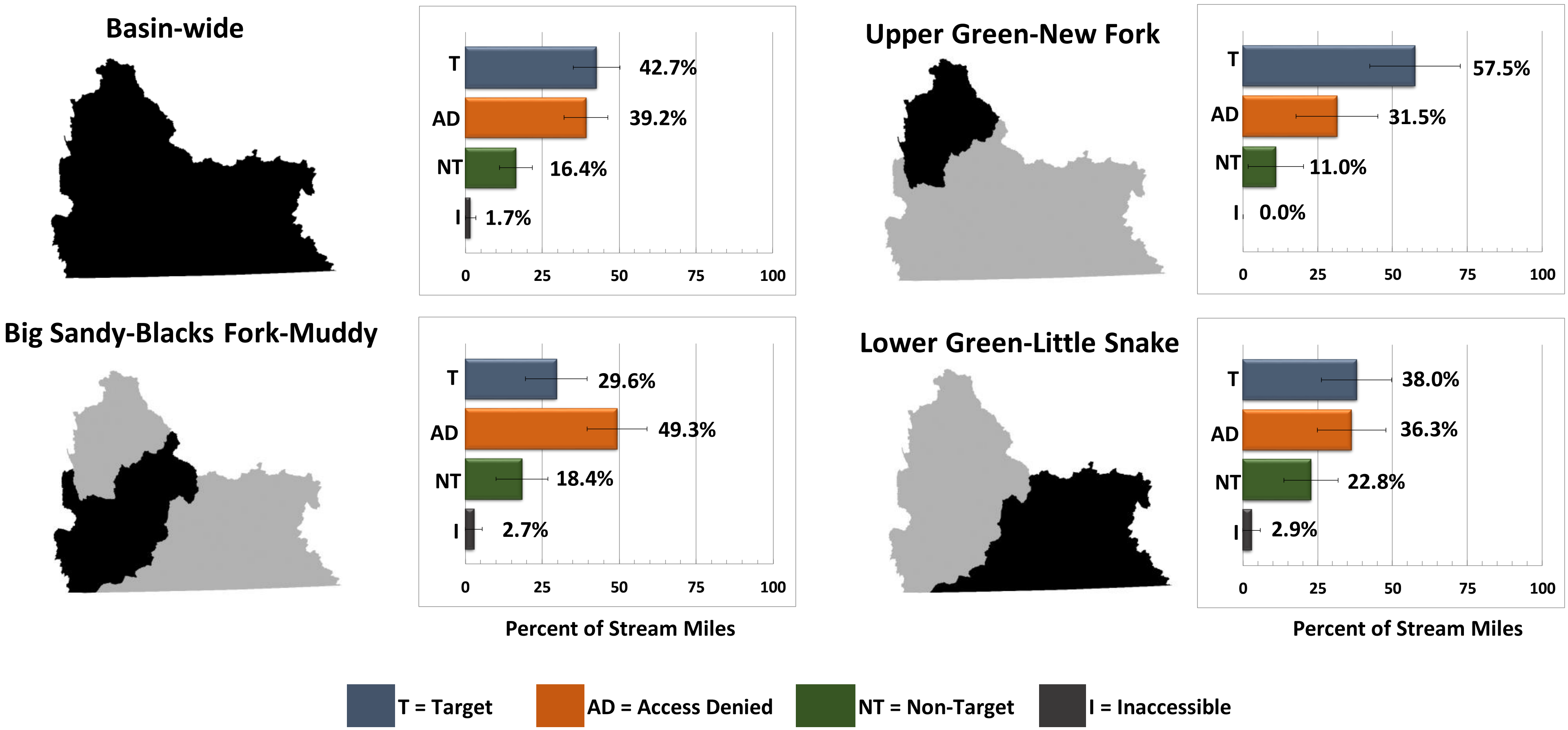


Figure 4 - Biological condition of perennial streams and rivers in the Green based on WDEQ/WQD's aquatic life use matrix. Error bars represent the 95% confidence intervals.

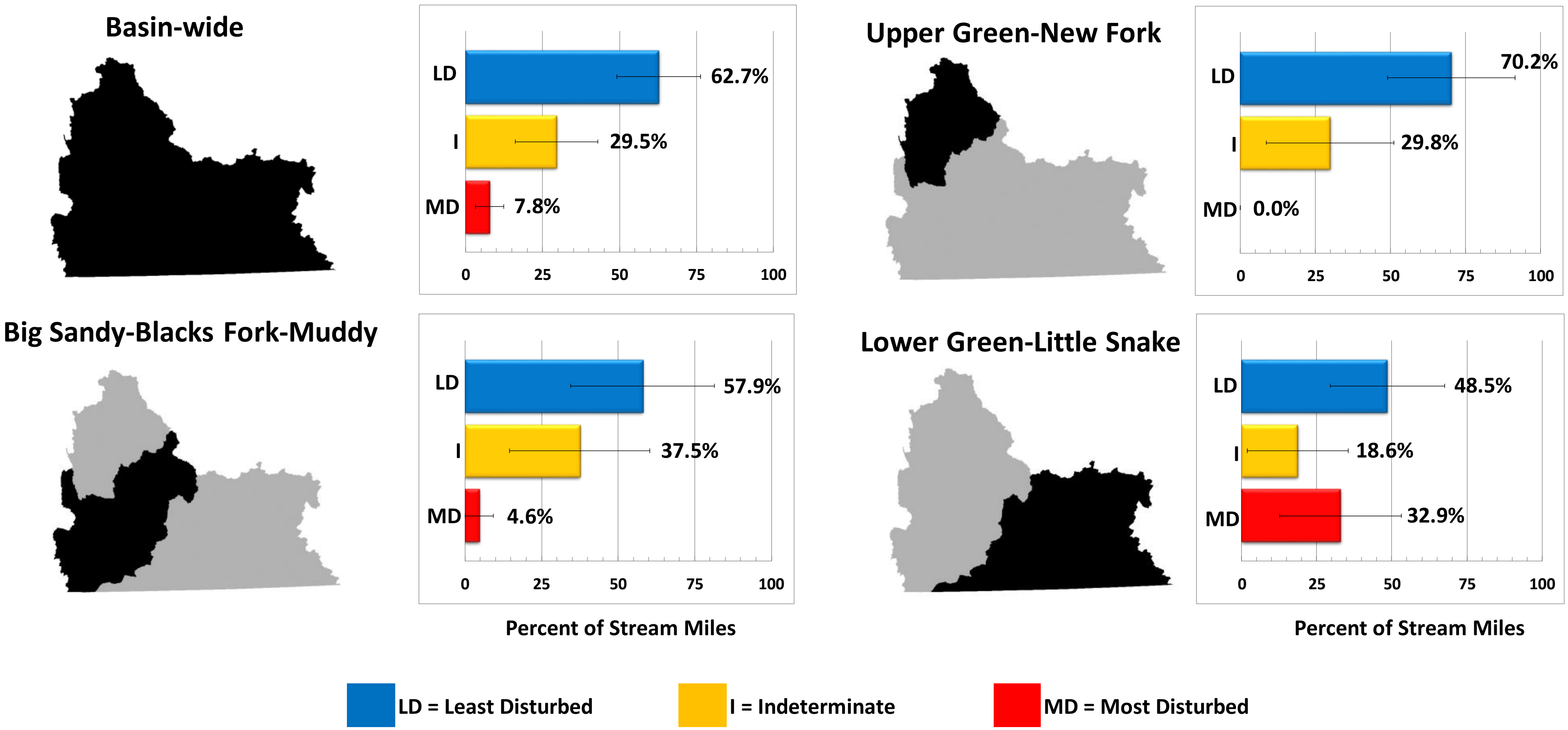


Table 1 –Stressor condition estimates associated with drinking water suitability and human health condition for WDEQ/WQD's 2015 Green survey.

			Green Superbasin HUC 8 Clusters		
		Green Superbasin	Upper Green - New Fork	Big Sandy - Blacks Fork - Muddy	Lower Green - Little Snake
Stressor [Recreation]		% of Stream Miles	% of Stream Miles	% of Stream Miles	% of Stream Miles
Escherichia coli	Least-disturbed	66	77	69	34
	Most-disturbed	34	23	31	66
Stressor [Drinking Water & Fish Consumption Suitability]					
Nitrate+Nitrite-N	Least-disturbed	100	100	100	100
	Most-disturbed	0	0	0	0
Dissolved Iron	Least-disturbed	99	100	100	94
	Most-disturbed	1	0	0	6
Dissolved Manganese	Least-disturbed	90	100	74	83
	Most-disturbed	10	0	26	17
Total Arsenic	Least-disturbed	96	100	95	86
	Most-disturbed	4	0	5	14
Total Cadmium	Least-disturbed	100	100	100	100
	Most-disturbed	0	0	0	0
Total Zinc	Least-disturbed	100	100	100	100
	Most-disturbed	0	0	0	0
Total Selenium	Least-disturbed	100	100	100	100
	Most-disturbed	0	0	0	0

Table 2 - Stressor condition estimates associated with biological condition for WDEQ/WQD's 2015 Green survey.

		Green Superbasin	Green Superbasin HUC 8 Clusters		
			Upper Green - New Fork	Big Sandy - Blacks Fork - Muddy	Lower Green - Little Snake
Biological Condition		**% of Stream Miles**	**% of Stream Miles**	**% of Stream Miles**	**% of Stream Miles**
	Least-disturbed	63	70	58	48
	Indeterminate	29	30	37	19
	Most-disturbed	8	0	5	33
Stressor [Indicator]					
Nitrate+Nitrite-N	Least-disturbed	92	94	100	79
	Most-disturbed	8	6	0	21
Total Phosphorus	Least-disturbed	91	100	95	61
	Most-disturbed	9	0	5	39
Total Nitrogen	Least-disturbed	26	36	14	12
	Indeterminate	73	64	86	82
	Most-disturbed	1	0	0	6
Salinity	Least-disturbed	27	38	19	8
	Indeterminate	67	62	65	81
	Most-disturbed	6	0	16	11
TSS	Least-disturbed	41	39	57	28
	Indeterminate	54	61	43	50
	Most-disturbed	5	0	0	22
Chloride	Least-disturbed	100	100	100	100
	Most-disturbed	0	0	0	0
Sulfate	Least-disturbed	100	100	100	100
	Most-disturbed	0	0	0	0
pH	Least-disturbed	99	100	95	100
	Most-disturbed	1	0	5	0
Dissolved Aluminum	Least-disturbed	99	100	100	94
	Most-disturbed	1	0	0	6
Dissolved Arsenic	Least-disturbed	100	100	100	100
	Most-disturbed	0	0	0	0
Dissolved Cadmium	Least-disturbed	100	100	100	100
	Most-disturbed	0	0	0	0
Dissolved Iron	Least-disturbed	99	100	100	94
	Most-disturbed	1	0	0	6
Dissolved Manganese	Least-disturbed	100	100	100	100
	Most-disturbed	0	0	0	0
Dissolved Zinc	Least-disturbed	100	100	100	100
	Most-disturbed	0	0	0	0
Total Selenium	Least-disturbed	99	100	100	94
	Most-disturbed	1	0	0	6
Riparian Disturbance	Least-disturbed	76	74	81	73
	Most-disturbed	24	26	19	27
Channel Instability	Least-disturbed	80	89	72	67
	Most-disturbed	20	11	28	33
Excess Sediment	Least-disturbed	96	100	91	92
	Most-disturbed	4	0	9	8
Accelerated Bank Erosion	Least-disturbed	81	89	77	67
	Most-disturbed	19	11	23	33
Channel Incision	Least-disturbed	98	100	100	92
	Most-disturbed	2	0	0	8

relative risk estimates should be considered when interpreting these results.

DISCUSSION

The Green survey provides the first focused and standardized evaluation of the biological and human health condition of streams within the Green River basin of southwest Wyoming. The Green survey was the third of five 'superbasins' monitored as part of WDEQ/WQD's rotating basin probabilistic surveys. The Green survey provides a representative picture of water quality conditions and identifies chemical and physical stressors to biological and human health.

Water quality condition generally is favorable in perennial streams in the Green, and exceeds that found in the Bighorn/Yellowstone (Hargett and ZumBerge 2014) and Northeast (Hargett and ZumBerge 2017) probabilistic surveys with approximately two-thirds (63%) of the resource currently considered in the least-disturbed biological condition and only 8% of the resource in the most-disturbed condition. Among the three HUC 8 clusters, the Upper Green – New Fork and Big Sandy – Blacks Fork – Muddy are in better condition biologically (0% and 5% most-disturbed, respectively) relative to those in the Lower Green – Little Snake (33% most-disturbed).

The most extensive stressors in the Green are riparian disturbance and channel instability, affecting approximately 24% and 20% of stream miles, respectively. Riparian disturbance is also the dominant stressor in the Upper Green – New Fork (26%) and channel instability is a top-two stressor in all three HUC8 clusters. TP is the top stressor in the Lower Green – Little Snake (39%). The Lower Green – Little Snake has five stressors that each affected over 20% of the target stream miles in that HUC8 cluster, with the other two HUC8 clusters having just one stressor exceeding 20%.

Riparian disturbance characterizes vegetative cover on streambanks and within the riparian zone, and the presence of other human influences proximate to the stream channel. Channel instability is a composite physical stressor that includes excess sediment, accelerated stream bank erosion and channel incision. Accelerated stream bank erosion is the dominant of the three channel instability sub-stressors in the Green (19%) and among the three HUC8 clusters (11% to 33%). The percentage of accelerated bank erosion documented during the Green survey corresponds with riparian disturbance. This inference is supported by evidence that indicates streams in the Green with accelerated bank erosion often also exhibited indicators of riparian disturbance, predominantly in the form of marginal (mean: 54%) riparian vegetative bank cover. Corresponding to the low percentage of riparian vegetative bank cover are limited overhead cover and riparian woody vegetation and common hoof shear/tramping. Riparian disturbance is the most extensive stressor in the Upper Green – New Fork (26%), second most in the Big Sandy – Blacks Fork – Muddy (19%), and third in the Lower Green – Little Snake. Presence, density and condition of riparian vegetation greatly influence rates of bank erosion (which contribute to channel instability).

Historic or legacy disturbances such as flow alterations, channelization, riparian vegetation removal, historic grazing management, and tie drives influence present day channel stability.

Flow alterations are one of the more pervasive stressors statewide. Flow reductions facilitate excess sedimentation via a reduction in sediment transport capacity of the channel or in the case of flow augmentation, accelerated bank erosion and/or incision due to increased shear stresses from above normal flows. Dams store sediment produced in the watershed causing sediment deficiency immediately downstream that promotes incision, reduces thermal amplitude, and tempers peak sediment flushing flows farther downstream from the dam. Varying degrees of flow alterations affect almost 64% of perennial stream miles in the Green.

Figure 5 – Most-disturbed condition relative extent (% stream miles) of chemical and physical stressors to biological condition at the Green and HUC 8 Cluster scales. Error bars represent the 95% confidence intervals.

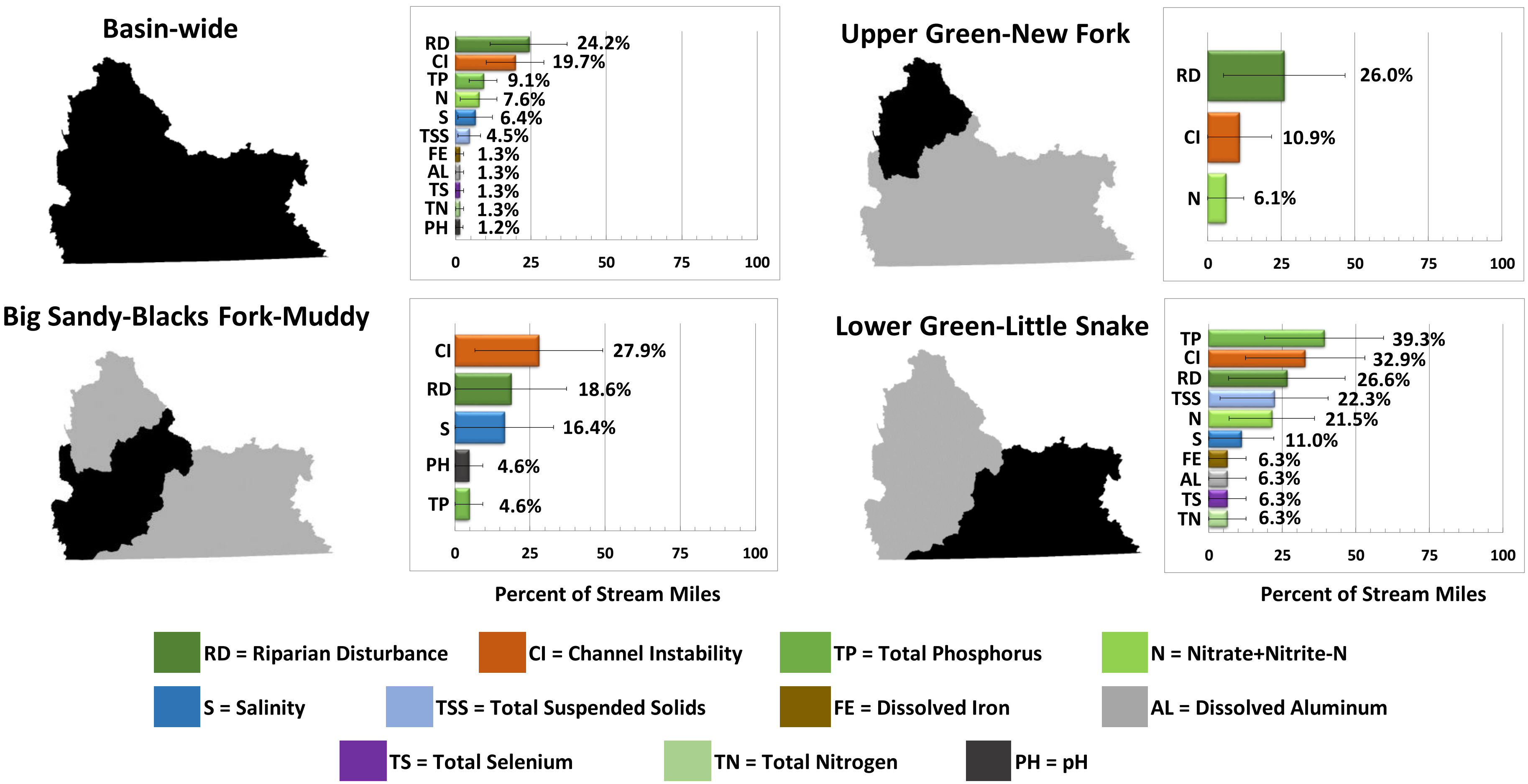
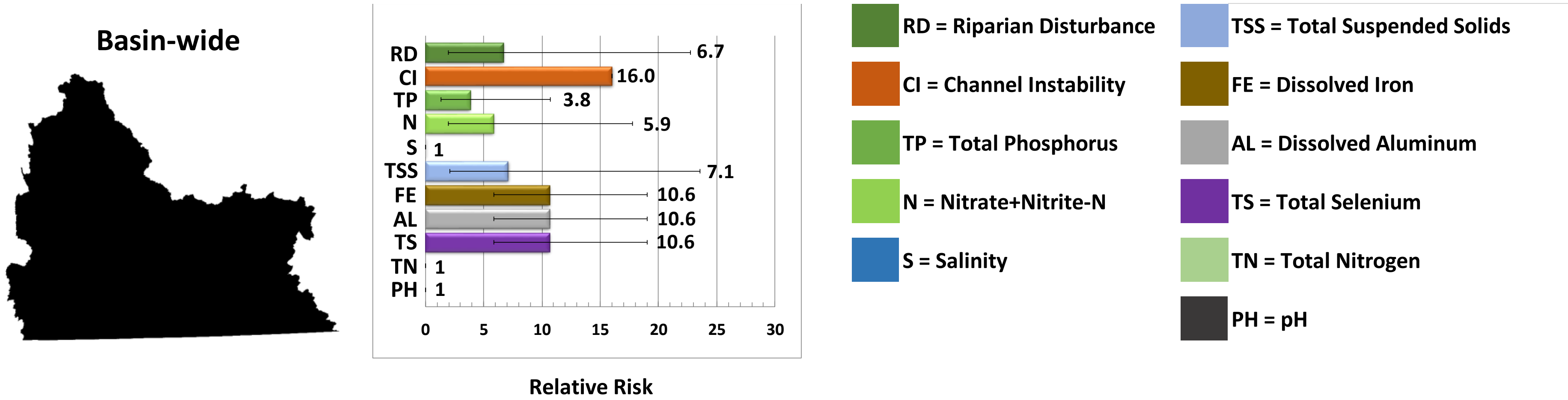


Figure 6 - Relative risk values of chemical and physical stressors to biological condition at the Green scale. Error bars represent the 95% confidence intervals.



Together, anthropogenic disturbances that influence physical attributes of the channel are the most important factors driving channel instability stressors that influence biological condition of perennial streams. The extent of channel instability in the Green and its potential effect on aquatic life is apparent in that perennial streams are 7 to 16 times more likely to be in a most-disturbed biological condition when riparian disturbance or channel instability are present as when they are not present.

After riparian disturbance and channel instability, the next most extensive stressor is total phosphorus where the most-disturbed condition relative extent is approximately 9% of stream miles. While relatively low, there is a 3.8 times greater risk of having a most-disturbed biological condition when a most-disturbed total phosphorus condition is present. Not known is the degree to which TP contributes to the most-disturbed biological condition when other known biological condition stressors occur in elevated concentrations.

Nitrate+nitrite-N affects 7% of targeted streams in the Green. Nutrients such as nitrate+nitrite-N, total nitrogen and total phosphorus are not directly toxic to aquatic life. However, the processes that control metabolism and nutrient cycling in streams, their influences to parameters such as dissolved oxygen and pH, and the critical thresholds where negative effects to aquatic life (e.g., fishes versus benthic macroinvertebrates) begin can vary considerably in streams. Streams have almost six times greater risk of a most-disturbed biological condition when elevated nitrate+nitrite-N is present.

Total nitrogen, contrary to total phosphorus and nitrate+nitrite-N is low across the Green with very low relative extent and relative risk. The relative extents of total phosphorus and nitrate+nitrite-N is by far the greatest in the Lower Green – Little Snake, averaging approximately 30% of stream miles in the most-disturbed condition.

Salinity is the only other stressor where relative extent exceeded 5% in the Green. All of the stream miles in the most disturbed condition for salinity are in the Big Sandy – Blacks Fork – Muddy and Lower Green – Little Snake. Streams that exhibited elevated salinity are predominantly basin streams with salinity levels that narrowly exceed the most-disturbed salinity threshold. Chloride, which is one component of salinity, was not elevated in any streams of the Green. Macroinvertebrate and fish communities of basins and plains streams are adapted to harsh and stochastic environments (Dodds et al. 2004, Fausch and Bestgen 1997, Higgens and Wilde 2005, Matthews 1988, Taylor et al. 1993) such as naturally elevated and wide-ranging salinities dependent on geology and flow regime. The direct influences of elevated salinity may not be as readily observable in communities with such adaptive tolerances, thus salinity narrowly exceeding reference expectations is unlikely to induce observable biological effects.

While TSS is not an extensive stressor basin-wide, 22% of stream miles are in the most-disturbed condition within the Lower Green – Little Snake. TSS consists of both organic and inorganic suspended materials and is naturally greater during runoff from snowmelt or thunderstorms. TSS sample collection occurred during baseflow or near baseflow conditions, minimizing flow-dependent increases in TSS as a possible cause of elevated TSS. Elevated TSS in some streams in the Green can occur naturally, as their watersheds may contain highly erodible silt/clay bearing geology and soils combined with naturally sparse vegetation cover. However, in areas absent such overriding natural influences, human activities associated with irrigation drainage, flow augmentation and industrial effluent may be chronic contributors to Green, and particularly Lower Green – Little Snake streams with a most-disturbed TSS condition.

Anthropogenic contributions of inorganic TSS (silts and clays) are a transport mechanism for other pollutants. Silt and clay are often chemically active and pollutants such as nutrients, metals, pesticides or their breakdown products are strongly bound to these particles. There may be a linkage between TSS and nutrients in the Lower Green – Little Snake, as several streams with a most-disturbed TSS condition are in a most-disturbed condition for one or more nutrients. Whether TSS-linked detrimental effects to aquatic life occur may vary considerably depending on the size of particles in question, the frequency and duration of elevated TSS, the mechanisms of influence (e.g., physical abrasion, scouring, reduced visibility, altered feeding dynamics, increased water temperatures), the influence of bounded pollutants and the aquatic organism(s) affected (i.e., benthic macroinvertebrates, fishes, periphyton). From a relative risk perspective, a most-disturbed TSS condition apparently poses seven times greater risk to aquatic life when present in Green streams.

Once TSS is deposited, the excess sediment and its influence to aquatic life can be accounted for (in many cases) by the channel instability stressor evaluated as part of this study. Not accounted for is the capture of elevated

TSS by abundant benthic algae resulting in a dense algal/sediment matrix.

Excess sediment while in suspension may be more problematic for fishes due to reduced visibility, physical abrasion of extremities including gills and increased heat absorption. In summary, excess sediment can have varying detrimental effects on different components of the aquatic community depending on whether it is in suspension or deposited and the detection of such effects may be dependent on the biological indicator used in addition to their varying levels of natural tolerance to elevated TSS among watersheds. In light of these complexities, the extent of elevated TSS in the Lower Green – Little Snake may warrant further investigation to ascertain whether TSS in the most-disturbed condition translates to a direct degradation of biological condition.

Dissolved fractions of aluminum, arsenic, cadmium, iron, manganese and zinc as well as sulfate and total selenium are detrimental to aquatic life at elevated concentrations. However, all of these are in the most-disturbed condition for only 1% or less of stream miles basin-wide. Stream miles in the most-disturbed total selenium condition exhibit concentrations that were approximately equal to the threshold and influenced possibly by natural seleniferous-bearing soils and marine shale geology. A small number of stream miles narrowly exceed the most-disturbed threshold for pH.

The extent of most-disturbed *E. coli* concentrations (an indicator of human health condition for recreational uses) in the Green is 34%. Relative extents of the most-disturbed *E. coli* condition vary widely among all three regions of the Green (23-66%) with the Lower Green – Little Snake having the greatest extent of most-disturbed E. coli condition. All streams are in the least-disturbed condition for drinking water suitability with respect to total cadmium, nitrate+nitrite-N, total selenium, and total zinc. Approximately 90% to 99% of stream miles in the Green are in the least-disturbed condition for drinking water suitability with regard to iron, arsenic and manganese, with most-disturbed conditions confined to the Big Sandy – Blacks Fork – Muddy and Lower Green – Little Snake regions. Potential sources of the elevated manganese are predominantly associated with the local geology and soils though industrial effluent may be a factor in some circumstances. The combined information suggests that waters within the Green would require minimal treatment for these parameters to be suitable as drinking water supplies.

Comparison of the Green to Wyoming, the mountainous and xeric regions of the western Unites States, and nationally with respect to biological condition and associated stressors place these results into a regional and national perspective. Comparisons of the Green survey to the most recent statewide probabilistic survey for Wyoming are relatively straightforward due to similarities in design and evaluation. Comparisons made to the most current biological condition status for western and xeric regions and the lower 48 contiguous states of the nation are complicated by differences in biological expectations and stressor thresholds. Nevertheless, comparisons were justified since many of the same fundamental principles and design methodology apply to the evaluation of biological condition regardless of scale or location. Comparisons are limited to stressors common to the Green, Wyoming, Western Mountains, Xeric, and national surveys.

The Green is similar to the entire state of Wyoming with regard to the percentage of stream miles in the least-disturbed biological condition (63% Green vs. 58% Wyoming). The Green has fewer miles in the most-disturbed biological condition (8% Green vs. 18% Wyoming) (Figure 7) (Hargett and ZumBerge 2013). The Green fairs better than the Western Mountains and Xeric regions of the United States with regard to least-disturbed (63% Green vs. 51% Western Mountains and 22% Xeric) and most-disturbed (8% Green vs. 30% Western Mountains and 44% Xeric) biological conditions (USEPA 2020) (Figure 7). Among the five stressors evaluated at different geographic scales, riparian disturbance is the most extensive stressor in the Green (24%) and the second most common throughout Wyoming (36%). (Figure 7). Total phosphorus is the second most extensive stressor in the Green (9%) and fourth most extensive throughout Wyoming (14% of stream miles). Interestingly, total phosphorus is the most extensive stressor nationwide (58%) and in the Western Mountains of the western US (50%). Total nitrogen affects a small percentage of streams in the Green but is an extensive stressor across the Nation (43%).

Nationally (lower 48 contiguous states), the percentage of stream miles in the least-disturbed biological condition (30%) is much less relative to the Green (63%) (USEPA 2020) (Figure 7). Likewise, the percentage of national stream miles in the most-disturbed biological condition is 44% - much greater than the Green estimate of 8%.

When compared to the two previous rotating basin probabilistic surveys, the Green (63% least-disturbed) is in better biological condition than both the

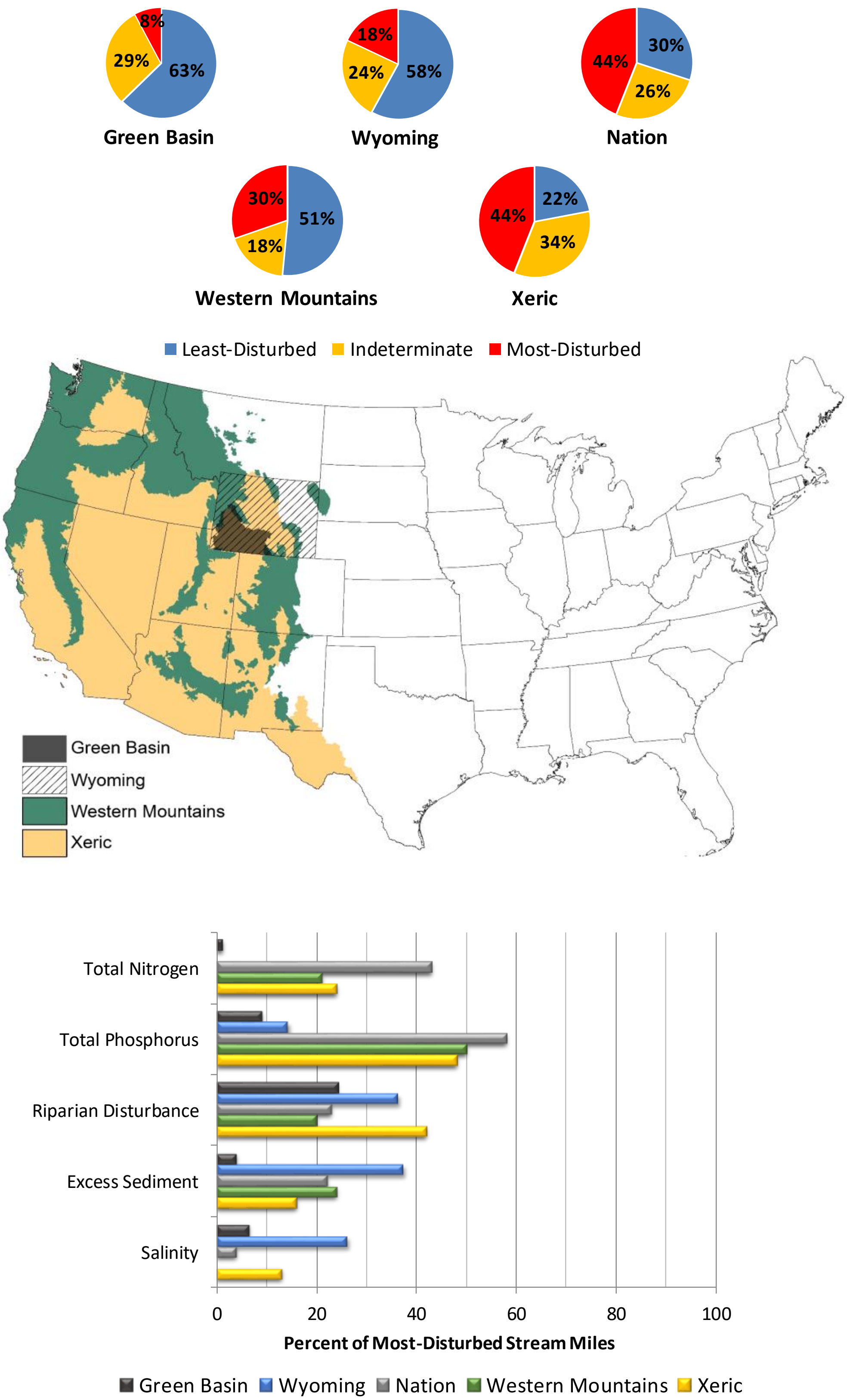
Bighorn/Yellowstone (38%) and Northeast (52%). With regard to stressor extents, all three superbasins had channel instability and riparian disturbance as dominant stressors to biological condition. Channel instability is a top two stressor in all three regions, although channel instability is more extensive in the Bighorn/Yellowstone and Northeast (~35% of stream miles) than in the Green (20%). Riparian disturbance is prevalent in the Green and Northeast (24-26% of stream miles), but less so in the Bighorn/Yellowstone (17%). These comparisons show that physical impacts to stream channels and riparian zones are important factors for biological conditions across much of Wyoming.

RECOMMENDATIONS

Survey results provide an objective representative evaluation of biological and human health condition and identify associated stressors in perennial streams and rivers of the Green River Basin of southwest Wyoming. This information supports existing strategic planning, management directives and pollutant reduction efforts implemented at the federal, state and local levels. The results highlight areas that may warrant additional investigation to ultimately improve or protect water quality, and provide a baseline to measure future progress. In particular, the Green survey documented the overall good biological condition in the Green, and identified several high quality watersheds to consider for voluntary water quality protection.

Results from this survey do not account for the synergistic effects of multiple stressors nor do they identify all the potential environmental stressors that may be limiting the biological condition of particular streams. Survey results indicate that riparian disturbance and channel instability are the most common stressors in the Green, followed by nutrients (total phosphorus and nitrate-nitrite N). The commonality of channel instability and riparian disturbance combined with their moderate to high relative risks suggest that efforts aimed at reducing these two stressors in degraded streams would benefit biological conditions in the Green. The probable linkage between these two stressors indicate that efforts to address one will likely benefit the other. Accelerated bank erosion is the most prominent of the three sub-stressors that comprised channel instability. Efforts to reduce accelerated bank erosion will not only help to address channel instability, but may also reduce nutrient loading to streams in the Green since sediment can function as a transport mechanism for pollutants such as total phosphorus. While total phosphorus is the third most common stressor, it was elevated in only 9% of stream miles throughout the Green and had relatively low relative risk to biological condition. Elevated total phosphorus attained the greatest relative extents within the Lower Green – Little Snake (39%) region. Total phosphorus reduction efforts could have a greater benefit in this region compared to the Green as a whole. Applying the relative risk values derived at the Green scale, and considering the relative extents of stressors within each HUC 8 cluster, the Lower Green – Little Snake emerges as an area with the greatest potential need for additional investigation into support of aquatic life uses. Individual and combined influences of channel instability, riparian disturbance and elevated concentrations of total phosphorus, nitrate-nitrite, and TSS appear to pose the most risk to biological condition. Among all three HUC 8 clusters, the highest relative extent for each of the aforementioned stressors are found within the Lower Green – Little Snake, in addition to the greatest extent of most-disturbed *E. coli* conditions. The combination of multiple stressors along with varying extents and relative risks imply that where degraded biological condition occurs there may be multiple causes and their effects to aquatic life variable and perhaps inter-related.

Figure 7 - Biological condition (top) of perennial streams and rivers (by percentage of respective stream length) and relative extents (bottom) of stressors common to the Green, Wyoming (Hargett and ZumBerge 2013), Western Mountains and Xeric regions, and nationally (USEPA 2020).



ACKNOWLEDGMENTS

Appreciation is extended to the numerous private landowners to granted access to stream sites, as well as conservation districts and federal, state, county and local entities whom helped make the WDEQ/WQD Green probabilistic survey a success.

Particular gratitude is extended to the field crews, comprised of both full time and temporary WDEQ staff, who logged many hours both in the office and in the field to successfully implement this project. WDEQ/WQD Monitoring Program field crews consisted of Lanny Goyn and Eric Hargett (Cheyenne crew); Tavis Eddy, Kayla Huey, and Michael Wachtendonk (Lander crew); Jason Martineau and Chad Rieger (Sheridan crew); and Jeremy ZumBerge (Program Supervisor). Other WDEQ staff include Sol Brich, Cathy Norris, Michael Thomas, and Richard Thorp. Conservation District partners include Dawn Arnell, DeMont Grandy, Russell Hamilton, Joe Parsons, Kathy Raper and Kerri Sabey.

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WDEQ/WQD. 2010. Surface Water Monitoring Strategy 2010-2019. Wyoming Department of Environmental Quality. Water Quality Division. Cheyenne, Wyoming.

WWDC. 2010. Green River Basin Plan. Wyoming Water Development Commission, Cheyenne, Wyoming

Appendix 1a – Biological condition stressor thresholds used to establish condition categories for streams and rivers within bioregions of the Green survey. Biological condition thresholds are represented as (least-disturbed) / (most-disturbed) expect for sulfate where only most-disturbed values are provided according to the embedded matrix.

<table>
<tr><th rowspan="2"></th><th rowspan="2"></th><th colspan="6">Bioregion</th></tr>
<tr><th>Granitic Mountains</th><th>Sedimentary Mountains</th><th>Southern Rockies</th><th>High Valleys</th><th>Wyoming Basin</th><th>Southern Foothills & Laramie Range</th></tr>
<tr><td rowspan="15">Water Chemistry</td><td>Chloride (mg/L)</td><td colspan="6">< 230 / ≥ 230</td></tr>
<tr><td>Conductivity (µS/cm)</td><td>< 39 / ≥ 226</td><td>< 219 / ≥ 451</td><td>< 43 / ≥ 255</td><td>< 174 / ≥ 596</td><td>< 260 / ≥ 1552</td><td>< 70 / ≥ 459</td></tr>
<tr><td>Dissolved Aluminum (µg/L)</td><td colspan="6">< 87 (when pH< 7.00 and Total Hardness as mg/L CaCO3 < 50 mg/L) or < 750 (when pH ≥ 7.00 and Total Hardness as mg/L CaCO3 ≥ 50 mg/L)</td></tr>
<tr><td>Dissolved Arsenic (µg/L)</td><td colspan="6">< 150 / ≥ 150</td></tr>
<tr><td>Dissolved Cadmium (µg/L)</td><td colspan="6">$< e^{(0.7409[\ln(\text{Total Hardness as mg/L CaCO3})]-4.719)(1.101672-[\ln(\text{Total Hardness as mg/L CaCO3})]*0.041838)}$ / $\geq e^{(0.7409[\ln(\text{Total Hardness as mg/L CaCO3})]-4.719)(1.101672-[\ln(\text{Total Hardness as mg/L CaCO3})]*0.041838)}$</td></tr>
<tr><td>Dissolved Iron (µg/L)</td><td colspan="6">< 1000 / ≥ 1000</td></tr>
<tr><td>Dissolved Manganese (µg/L)</td><td colspan="6">$< e^{(0.5434[\ln(\text{Total Hardness as mg/L CaCO3})]+4.7850)}$ / $\geq e^{(0.5434[\ln(\text{Total Hardness as mg/L CaCO3})]+4.7850)}$</td></tr>
<tr><td>Dissolved Zinc (µg/L)</td><td colspan="6">$< e^{(0.8473[\ln(\text{Total Hardness as mg/L CaCO3})]+0.884)(0.986)}$ / $\geq e^{(0.8473[\ln(\text{Total Hardness as mg/L CaCO3})]+0.884)(0.986)}$</td></tr>
<tr><td>Nitrate+Nitrite-N (mg/L)</td><td colspan="6">< 0.100 / ≥ 0.100</td></tr>
<tr><td>TSS (mg/L)</td><td colspan="2">< 3 / ≥ 7</td><td>< 3 / ≥ 6</td><td>< 3 / ≥ 10</td><td>< 3 / ≥ 64</td><td>< 3 / ≥ 9</td></tr>
<tr><td>Total Phosphorus (mg/L)</td><td colspan="6">< 0.100 / ≥ 0.100</td></tr>
<tr><td>Total Nitrogen (mg/L)</td><td>< 0.100 / ≥ 0.505</td><td>< 0.100 / ≥ 0.710</td><td>< 0.100 / ≥ 0.505</td><td>< 0.129 / ≥ 0.640</td><td>< 0.160 / ≥ 1.062</td><td>< 0.100 / ≥ 0.710</td></tr>
<tr><td>Total Selenium (µg/L)</td><td colspan="6">< 5 / ≥ 5</td></tr>
<tr><td>Sulfate (mg/L)</td><td colspan="6"><table>
<tr><th></th><th>Cl < 5 mg/L</th><th>5 ≤ Cl < 25 mg/L</th><th>25 mg/L ≤ Cl</th><th></th></tr>
<tr><td>HD < 100 mg/L</td><td>500 mg/L</td><td>500 mg/L</td><td>500 mg/L</td><td>Cl = Chloride</td></tr>
<tr><td>100 ≤ HD ≤ 500 mg/L</td><td>500 mg/L</td><td>SO4 = [-57.478 + 5.79(HD) + 54.163 (Cl)] * 0.65</td><td>SO4 = [1276.7 + 5.508(HD) - 1.457(Cl)] * 0.65</td><td>HD = Hardness</td></tr>
<tr><td>HD > 500 mg/L</td><td>500 mg/L</td><td>2000 mg/L</td><td>2000 mg/L</td><td></td></tr>
</table></td></tr>
<tr><td>pH</td><td colspan="6">> 6.5 and < 9.0 / < 6.5 or > 9.0</td></tr>
<tr><td rowspan="2">Biological Cond</td><td>WSII</td><td>> 60.3 / < 40.2</td><td>> 52.3 / < 34.8</td><td>> 48.8 / < 32.6</td><td>> 48.8 / < 32.5</td><td>> 39.9 / < 26.2</td><td>> 66.7 / < 44.5</td></tr>
<tr><td>WY RIVPACS</td><td>> 0.88 / < 0.65</td><td>> 0.82 / < 0.68</td><td>> 0.89 / < 0.62</td><td>> 0.86 / < 0.69</td><td>> 0.82 / < 0.64</td><td>> 0.88 / < 0.68</td></tr>
<tr><td>Riparian Disturbance</td><td>Riparian Disturbance</td><td colspan="6">Most-disturbed when mean streambank cover < 70% or bareground > 40% within 30 feet of the channel. Otherwise, at least four of the following indicators must be documented within 30 feet of the channel (unless otherwise noted) to receive a most-disturbed rating: wall/dike/revetment/rip-rap/dam, buildings, pavement/cleared land, road/railroad, pipes/diversion structures, landfill/trash, park/lawn, row crops up to bank, logging operations, gas/oil/mineral mining activity, grazing, low riparian vegetation vigor, no diverse age-class or composition in riparian vegetation, dominant stream bank vegetation comprised of upland or facultative upland species, extensive hoof shear/trampling, < 10% woody riparian vegetation or < 10% overhanging vegetation</td></tr>
<tr><td rowspan="3">Channel Instability</td><td>Excess Sediment</td><td colspan="6">Most-disturbed when either mean riffle embeddedness ≥ 50% or both of the following must be in the reach to constitute a most-disturbed condition: bimodal reachwide particle distribution and new and extensive unvegetated bar development.</td></tr>
<tr><td>Accelerated Stream Bank Erosion</td><td colspan="6">Most-disturbed when mean streambank stability < 70% or the channel is classified as an unexpected Rosgen F or G considering its natural valley type.</td></tr>
<tr><td>Channel Incision</td><td colspan="6">Most-disturbed when either either active channel incision (e.g. evident headcuts or unexpected shifts in channel gradient) or recent (within the past 10 years) channelization is present.</td></tr>
</table>

Appendix 2 – Drinking water suitability and human health condition thresholds used to establish condition categories for streams and rivers within the Green survey. Equations used to translate dissolved concentrations to total concentrations are found within the brackets for each constituent.

	Green Superbasin
Total Arsenic (µg/L)	<10 [Total Arsenic as µg/L = Dissolved Arsenic as µg/L(1 + K_p^a * TSS as µg/L * 10^{-6})]
Total Cadmium (µg/L)	<5 [Total Cadmium as µg/L = Dissolved Cadmium as µg/L(1 + K_p^c * TSS as µg/L * 10^{-6})]
Total Selenium (µg/L)	<50
Total Zinc (µg/L)	<5000 [Total Zinc as µg/L = Dissolved Zinc as µg/L(1 + K_p^z * TSS as µg/L * 10^{-6})]
Dissolved Manganese (µg/L)	<50
Dissolved Iron (µg/L)	<300
Nitrate+Nitrite-N (mg/L)	<10
Escherichia coli (cfu/100 mL)	< 126

$K_p^a = K_{po}TSS^{\infty}$ where $K_{po} = 0.48X10^6$ and ∞ = -0.73 (USEPA 1985 and 1996)

$K_p^z = K_{po}TSS^{\infty}$ where $K_{po} = 1.25X10^6$ and ∞ = -0.70 (USEPA 1985 and 1996)

$K_p^c = K_{po}TSS^{\infty}$ where $K_{po} = 4.00X10^6$ and ∞ = -1.13 (USEPA 1985 and 1996)

Appendix 3 – Relative departures of 2015 flow statistics from means for the periods of record at selected USGS streams gages within the Green.

USGS Gage ID	USGS Gage Name	Period of Record	2015 Peak Flow	Mean Peak Flow (cfs) Period of Record	% Departure from Mean Peak Flow for Period of Record	2015 Mean Annual Flow (cfs)	Mean Annual Flow (cfs) for Period of Record	% Departure from Mean Annual Flow for Period of Record
9188500	GREEN RIVER AT WARREN BRIDGE, NEAR DANIEL, WY	1932-2015	2,500	2,906.6	-14%	449.9	492.0	-9%
9196500	PINE CREEK ABOVE FREMONT LAKE, WY	1955-2015	1,490	1,691.4	-12%	151.1	172.3	-12%
9205000	NEW FORK RIVER NEAR BIG PINEY, WY	1955-2015	3,780	5,054.9	-25%	661.5	710.6	-7%
9209400	GREEN RIVER NEAR LA BARGE, WY	1947-2015	7,690	9,046.7	-15%	1,626.0	1,542.5	5%
9210500	FONTENELLE C NR HERSCHLER RANCH, NR FONTENELLE, WY	1952-2015	379	447.8	-15%	76.7	70.9	8%
9211200	GREEN RIVER BELOW FONTENELLE RESERVOIR, WY	1964-2015	7,320	6,670.2	10%	1,743.0	1,554.7	12%
9217000	GREEN RIVER NEAR GREEN RIVER, WY	1952-2015	7,570	7,320.0	3%	1,757.0	1,588.6	11%
9217900	BLACKS FORK NEAR ROBERTSON, WY	1967-2015	1,370	1,693.5	-19%	152.9	154.3	-1%
9220000	EAST FORK OF SMITHS FORK NEAR ROBERTSON, WY	1940-2015	459	510.6	-10%	55.9	45.7	22%
9223000	HAMS FORK BELOW POLE CREEK, NEAR FRONTIER, WY	1953-2015	510	800.5	-36%	96.5	94.3	2%
9224700	BLACKS FORK NEAR LITTLE AMERICA, WY	1963-2015	2,380	2,782.8	-14%	264.4	290.9	-9%
9229500	HENRYS FORK NEAR MANILA, UT	2002-2015	1,640	1,076.5	52%	111.6	65.8	69%
9234500	GREEN RIVER NEAR GREENDALE, UT	1964-2015	8,190	5,451.7	50%	1,961.0	1,963.1	0%
9258980	MUDDY CREEK BELOW YOUNG DRAW, NEAR BAGGS, WY	2005-2015	246	326.6	-25%	5.2	18.7	-72%
				Depature Range:	-36.3% to 52.3%		Depature Range:	-72.1% to 69.5%
				Mean Departure:	-5%		Mean Departure:	1.5%

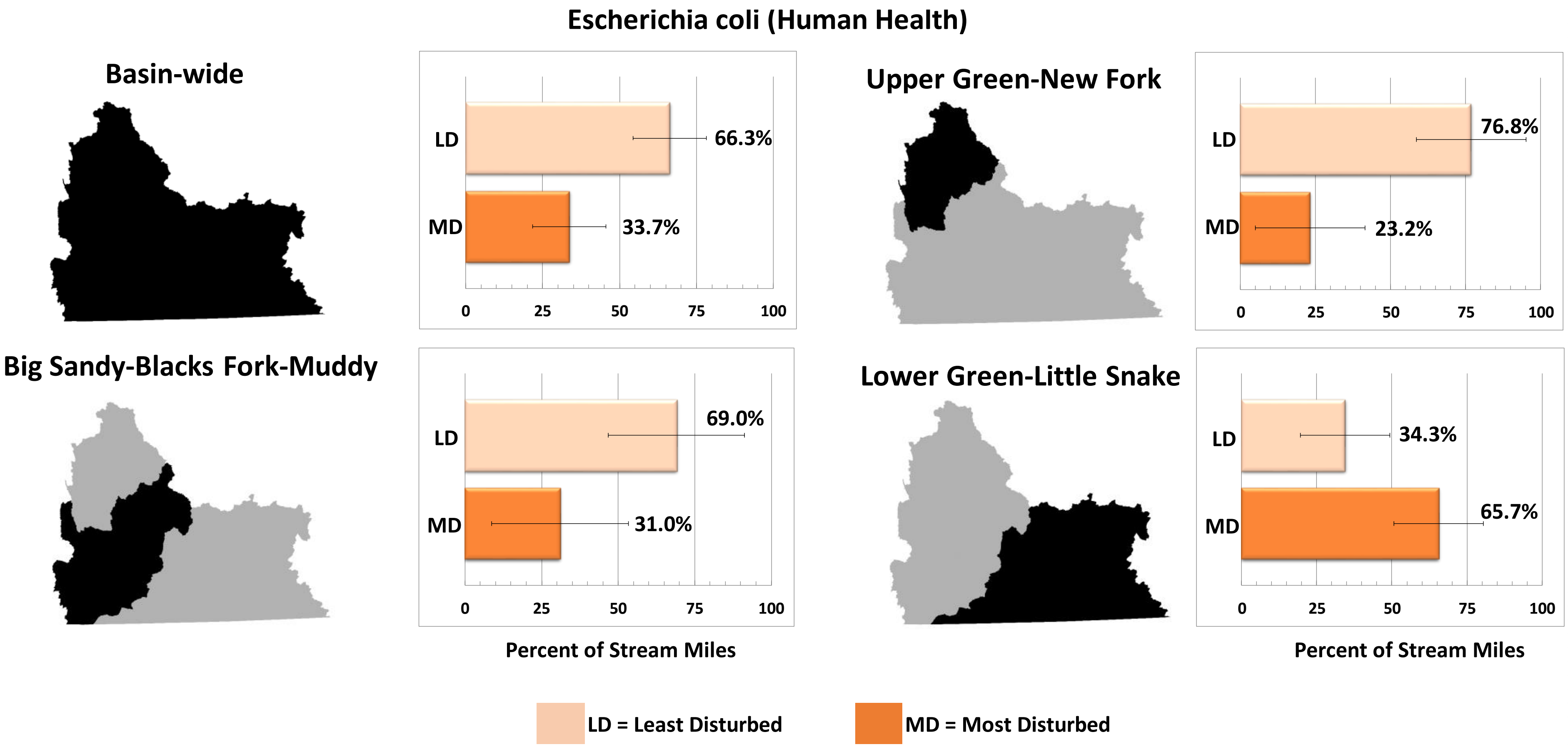
Appendix 4 – Target sites sampled as part of the 2015 Green survey.

Survey ID	Type	StationID	WaterbodyName - Reach Name	Latitude	Longitude	HUC 6 Basin	Elevation (ft)	Watershed Area (mi^2)	HUC 8 Cluster	BIOREGION
WY09C-205	Base	MRW0194	EAST FORK HAMS FORK - CASTOR	42.20056367	-110.71393340	GREEN	7,812	6.0	Big Sandy-Blacks Fork-Muddy	SEDIMENTARY MOUNTAINS
WY09C-207	Base	WB0441	SMITHS FORK - WEST MEADOW	41.17337043	-110.42950693	GREEN	7,375	136.0	Big Sandy-Blacks Fork-Muddy	WYOMING BASIN
WY09C-208	Base	WB0447	BIG SANDY RIVER - PIOLET BUTTE	42.00270694	-109.60538866	GREEN	6,394	1,631.0	Big Sandy-Blacks Fork-Muddy	WYOMING BASIN
WY09C-209	Base	MRW0199	WEST FORK HAMS FORK - NUGENT	42.22168868	-110.78312504	GREEN	7,815	20.0	Big Sandy-Blacks Fork-Muddy	SEDIMENTARY MOUNTAINS
WY09C-224	Base	SR0079	BATTLE CREEK - COTTONWOOD	41.07932687	-107.18841432	LITTLE SNAKE	7,170	57.4	Lower Green-Little Snake	SOUTHERN FOOTHILLS & LARAMIE RANGE
WY09C-226	Base	WB0443	TROUT CREEK - RAMSAY	41.19151201	-109.25985385	GREEN	7,200	8.1	Lower Green-Little Snake	WYOMING BASIN
WY09C-229	Base	WB0440	POISON CREEK - WEST CARTER	41.03158376	-110.15987034	GREEN	7,670	28.0	Lower Green-Little Snake	WYOMING BASIN
WY09C-233	Base	WB0442	SPRING CREEK - ABOVE MEADOW GULCH	41.02239800	-109.38499200	GREEN	6,580	13.0	Lower Green-Little Snake	WYOMING BASIN
WY09C-234	Base	WB0452	GREEN RIVER - ROARING FORK ROAD	43.31730182	-110.01062671	GREEN	7,762	209.0	Upper Green-New Fork	HIGH VALLEYS
WY09C-237	Base	WB0453	GREEN RIVER - FORTY ROD	42.94222521	-110.13631841	GREEN	7,295	624.0	Upper Green-New Fork	HIGH VALLEYS
WY09C-238	Base	WB0455	GREEN RIVER - THE FROG	42.33262195	-110.14868850	GREEN	6,586	3,495.0	Upper Green-New Fork	WYOMING BASIN
WY09C-239	Base	WB0460	SOUTH BEAVER CREEK - PROSPECT	42.99770022	-110.37864501	GREEN	7,966	17.0	Upper Green-New Fork	HIGH VALLEYS
WY09C-242	Base	MRW0197	SOUTH PINEY CREEK - NORTH MOUNTAIN	42.50937362	-110.48709173	GREEN	7,772	41.0	Upper Green-New Fork	SEDIMENTARY MOUNTAINS
WY09C-244	Base	WB0449	BOULDER CREEK - BOULDER	42.80493352	-109.72654852	GREEN	6,961	131.0	Upper Green-New Fork	HIGH VALLEYS
WY09C-246	Base	WB0450	FONTENELLE CREEK - PALISADES	42.08877198	-110.25023018	GREEN	6,581	185.0	Upper Green-New Fork	WYOMING BASIN
WY09C-249	Base	MRW0198	SWEENEY CREEK - WHITE PINE	42.98385017	-109.71463183	GREEN	9,004	4.0	Upper Green-New Fork	GRANITIC MOUNTAINS
WY09C-651	OverSample	MRW0201	HAMS FORK - BIG PARK	42.32592199	-110.73022171	GREEN	8,319	8.0	Big Sandy-Blacks Fork-Muddy	SEDIMENTARY MOUNTAINS
WY09C-654	OverSample	WB0446	BIG SANDY RIVER - BUCKSKIN CROSSING	42.55526186	-109.37601030	GREEN	7,110	108.0	Big Sandy-Blacks Fork-Muddy	WYOMING BASIN
WY09C-655	OverSample	MRW0195	ELK CREEK - 10159	42.23691534	-110.73716505	GREEN	7,829	10.0	Big Sandy-Blacks Fork-Muddy	SEDIMENTARY MOUNTAINS
WY09C-660	OverSample	WU0007	GILBERT CREEK - THUNDERBOLT MOUNTAIN	41.01698212	-110.41892529	GREEN	8,975	13.0	Big Sandy-Blacks Fork-Muddy	SOUTHERN ROCKIES
WY09C-661	OverSample	WB0430	GREEN RIVER - FILTRATION PLANT	41.71374532	-109.71410034	GREEN	6,190	7,372.0	Big Sandy-Blacks Fork-Muddy	WYOMING BASIN
WY09C-665	OverSample	MRW0203	SQUAW CREEK - LECKIE	42.57622184	-109.23909033	GREEN	8,025	20.0	Big Sandy-Blacks Fork-Muddy	GRANITIC MOUNTAINS
WY09C-668	OverSample	WB0436	LITTLE SANDY CREEK - 7MM	42.37546680	-109.23727702	GREEN	6,935	110.0	Big Sandy-Blacks Fork-Muddy	WYOMING BASIN
WY09C-670	OverSample	WB0435	JACK MORROW CREEK - MARINE SPRINGS	42.12337689	-109.12565208	GREEN	6,935	153.0	Big Sandy-Blacks Fork-Muddy	WYOMING BASIN
WY09C-674	OverSample	WB0426	BIG SANDY RIVER - FARSON	42.14245036	-109.43757034	GREEN	6,595	430.0	Big Sandy-Blacks Fork-Muddy	WYOMING BASIN
WY09C-675	OverSample	WB0431	HAMS FORK - BELOW POLE CREEK	42.11725868	-110.72308674	GREEN	7,480	127.0	Big Sandy-Blacks Fork-Muddy	WYOMING BASIN
WY09C-679	OverSample	WB0432	HAMS FORK - WESTFALL HOLLOW	41.87890537	-110.60631513	GREEN	7,015	285.0	Big Sandy-Blacks Fork-Muddy	WYOMING BASIN
WY09C-682	OverSample	MRW0200	BIG SANDY RIVER - DRIVEWAY	42.61947351	-109.28132698	GREEN	8,421	37.0	Big Sandy-Blacks Fork-Muddy	GRANITIC MOUNTAINS
WY09C-690	OverSample	SR0083	NORTH FORK LITTLE SNAKE RIVER - BELOW BOPU DIVERSION	41.06960851	-106.92881605	LITTLE SNAKE	8,910	3.1	Lower Green-Little Snake	SOUTHERN ROCKIES
WY09C-691	OverSample	SR0081	FISH CREEK - SAGE	41.37113180	-107.22723260	LITTLE SNAKE	7,720	3.9	Lower Green-Little Snake	WYOMING BASIN
WY09C-692	OverSample	WB0434	HENRYS FORK - ABOVE 530	41.00492206	-109.66944546	GREEN	6,067	520.6	Lower Green-Little Snake	WYOMING BASIN
WY09C-698	OverSample	WB0439	MUDDY CREEK - BELOW WETLANDS	41.30788021	-107.75784250	LITTLE SNAKE	6,480	621.3	Lower Green-Little Snake	WYOMING BASIN
WY09C-700	OverSample	WB0433	HENRYS FORK - BURNTFORK	41.04133208	-109.99689037	GREEN	6,990	400.0	Lower Green-Little Snake	WYOMING BASIN
WY09C-701	OverSample	WB0427	BITTER CREEK - SWANSON MINE	41.59429028	-109.17568880	GREEN	6,270	1,681.0	Lower Green-Little Snake	WYOMING BASIN
WY09C-703	OverSample	WB0437	LITTLE SNAKE RIVER - BELOW BAGGS	41.03420124	-107.67812551	LITTLE SNAKE	6,220	2,644.0	Lower Green-Little Snake	WYOMING BASIN
WY09C-704	OverSample	WB0429	GOOSEBERRY CREEK - ABOVE STRUCTURES	41.16632034	-109.23424219	GREEN	7,400	2.4	Lower Green-Little Snake	WYOMING BASIN
WY09C-708	OverSample	WB0444	UPPER MARSH CREEK - FLAMING GORGE	41.15502203	-109.51479546	GREEN	6,070	49.3	Lower Green-Little Snake	WYOMING BASIN
WY09C-709	OverSample	WB0438	MUDDY CREEK - BRIDGER	41.46696351	-107.48525754	LITTLE SNAKE	7,120	98.0	Lower Green-Little Snake	WYOMING BASIN
WY09C-710	OverSample	SR0080	BATTLE CREEK - BELOW STEMP SPRING	41.06928687	-107.21754265	LITTLE SNAKE	7,000	63.9	Lower Green-Little Snake	SOUTHERN FOOTHILLS & LARAMIE RANGE

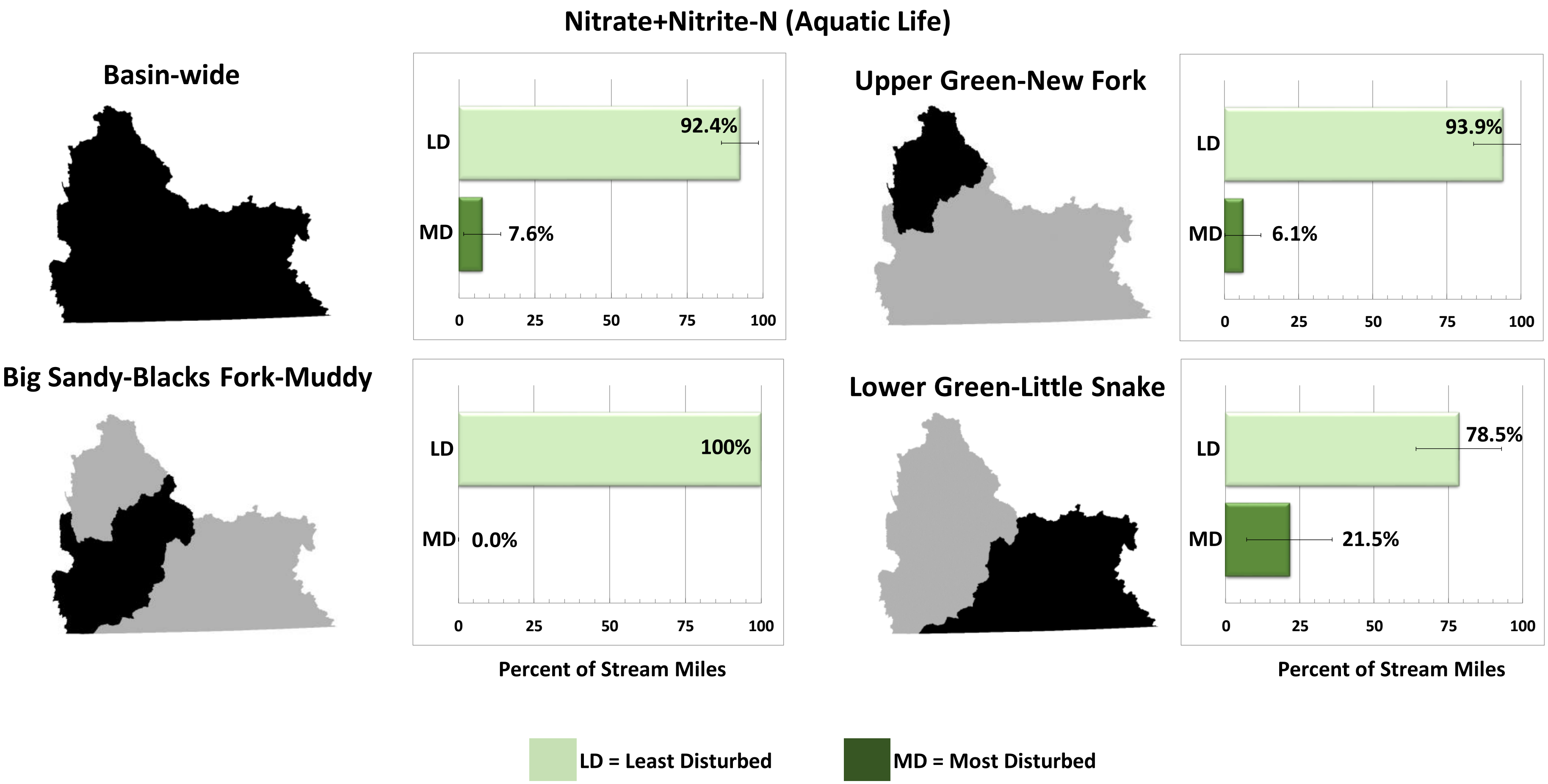
Appendix 4 (cont.) - Target sites sampled as part of the 2015 Green survey.

Survey ID	Type	StationID	WaterbodyName - Reach Name	Latitude	Longitude	HUC 6 Basin	Elevation (ft)	Watershed Area (mi^2)	HUC 8 Cluster	BIOREGION
WY09C-711	OverSample	SR0082	MUDDY CREEK - MCKEIL	41.44470351	-107.45340588	LITTLE SNAKE	7,180	37.9	Lower Green-Little Snake	WYOMING BASIN
WY09C-715	OverSample	WB0428	GAP CREEK - LANEY RIM	41.22762865	-109.03436556	GREEN	7,020	44.7	Lower Green-Little Snake	WYOMING BASIN
WY09C-718	OverSample	WB0448	BOULDER CREEK - OUTLET	42.83462185	-109.71179518	GREEN	7,245	126.0	Upper Green-New Fork	HIGH VALLEYS
WY09C-719	OverSample	WB0459	NORTH HORSE CREEK - MERNA BUTTE	42.91988023	-110.32039504	GREEN	7,555	46.0	Upper Green-New Fork	HIGH VALLEYS
WY09C-720	OverSample	WB0451	FONTENELLE CREEK - ABOVE RESERVOIR	42.09331697	-110.17820186	GREEN	6,481	225.0	Upper Green-New Fork	WYOMING BASIN
WY09C-721	OverSample	MRW0196	ROCK CREEK - BUTTES	43.25511184	-110.10935503	GREEN	8,459	10.0	Upper Green-New Fork	SEDIMENTARY MOUNTAINS
WY09C-724	OverSample	WB0458	NEW FORK RIVER - 351	42.59441023	-109.85803185	GREEN	6,811	1,234.0	Upper Green-New Fork	HIGH VALLEYS
WY09C-725	OverSample	WB0456	MARSH CREEK - CORA	43.06762352	-110.02357675	GREEN	7,574	12.0	Upper Green-New Fork	HIGH VALLEYS
WY09C-728	OverSample	WB0454	GREEN RIVER - THREE BRIDGES	42.52417025	-110.03252849	GREEN	6,701	2,685.0	Upper Green-New Fork	HIGH VALLEYS
WY09C-730	OverSample	WB0445	BEAVER CREEK - BRONX	42.99402354	-110.13241173	GREEN	7,421	149.0	Upper Green-New Fork	HIGH VALLEYS
WY09C-733	OverSample	WB0457	NEW FORK RIVER - LAST CHANCE	42.76220353	-109.75776352	GREEN	6,956	528.0	Upper Green-New Fork	HIGH VALLEYS

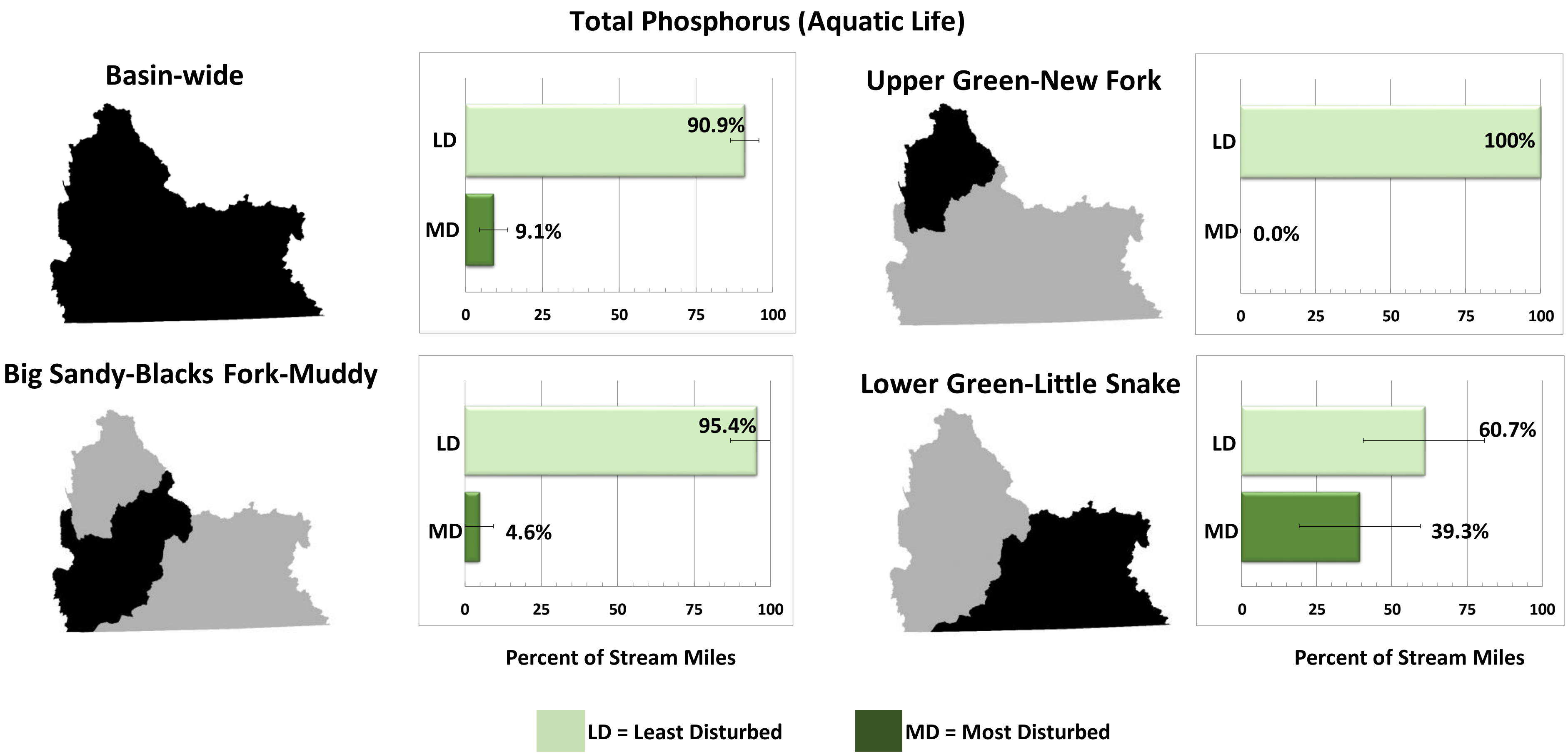
Appendix 5 - Summary of *Escherichia coli* results for the Green and corresponding HUC 8 Clusters. Error bars represent the 95% confidence intervals.



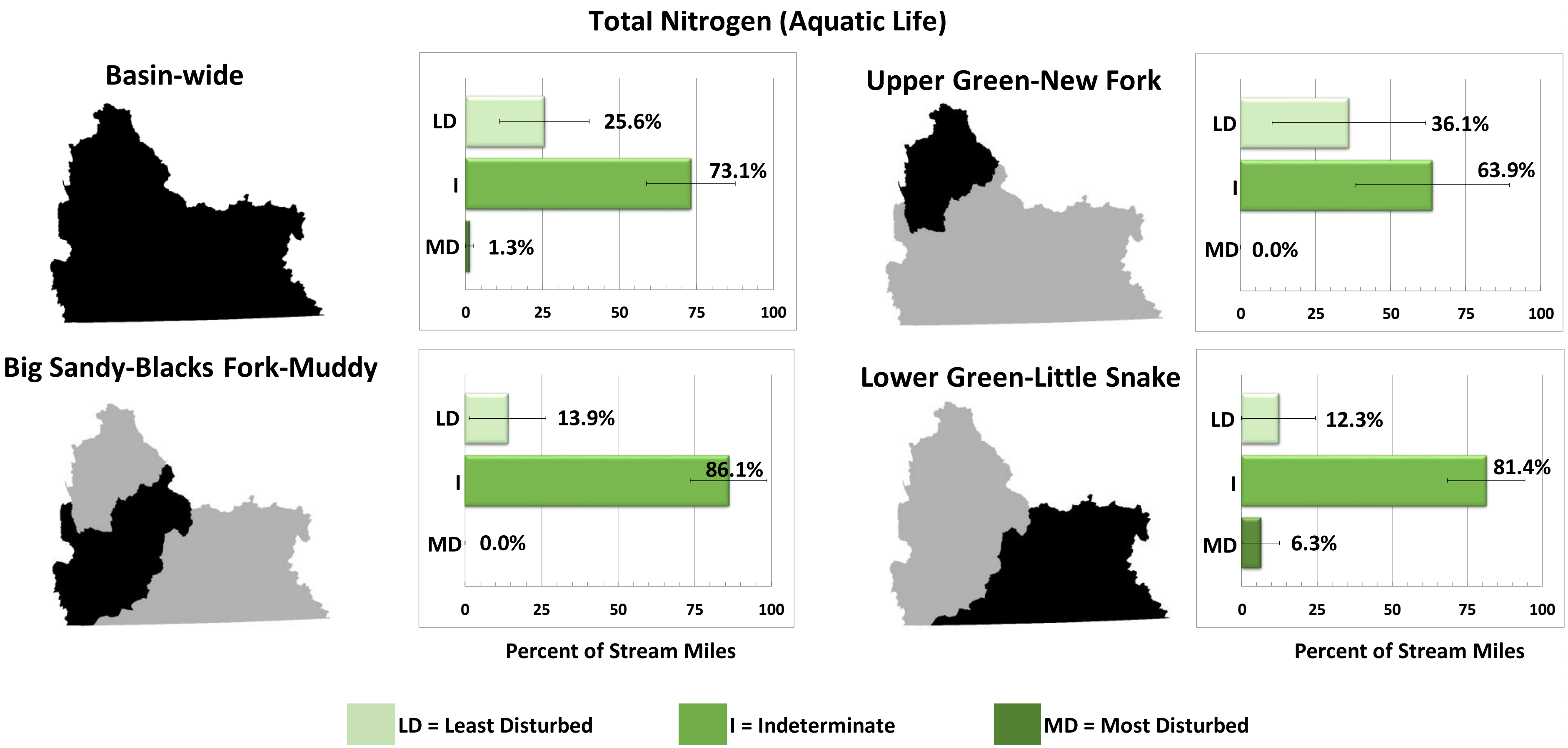
Appendix 6 – Summary of nitrate+nitrite-N results for the Green and corresponding HUC 8 Clusters. Error bars represent the 95% confidence intervals.



Appendix 7 - Summary of total phosphorus results for the Green and corresponding HUC 8 Clusters. Error bars represent the 95% confidence intervals.

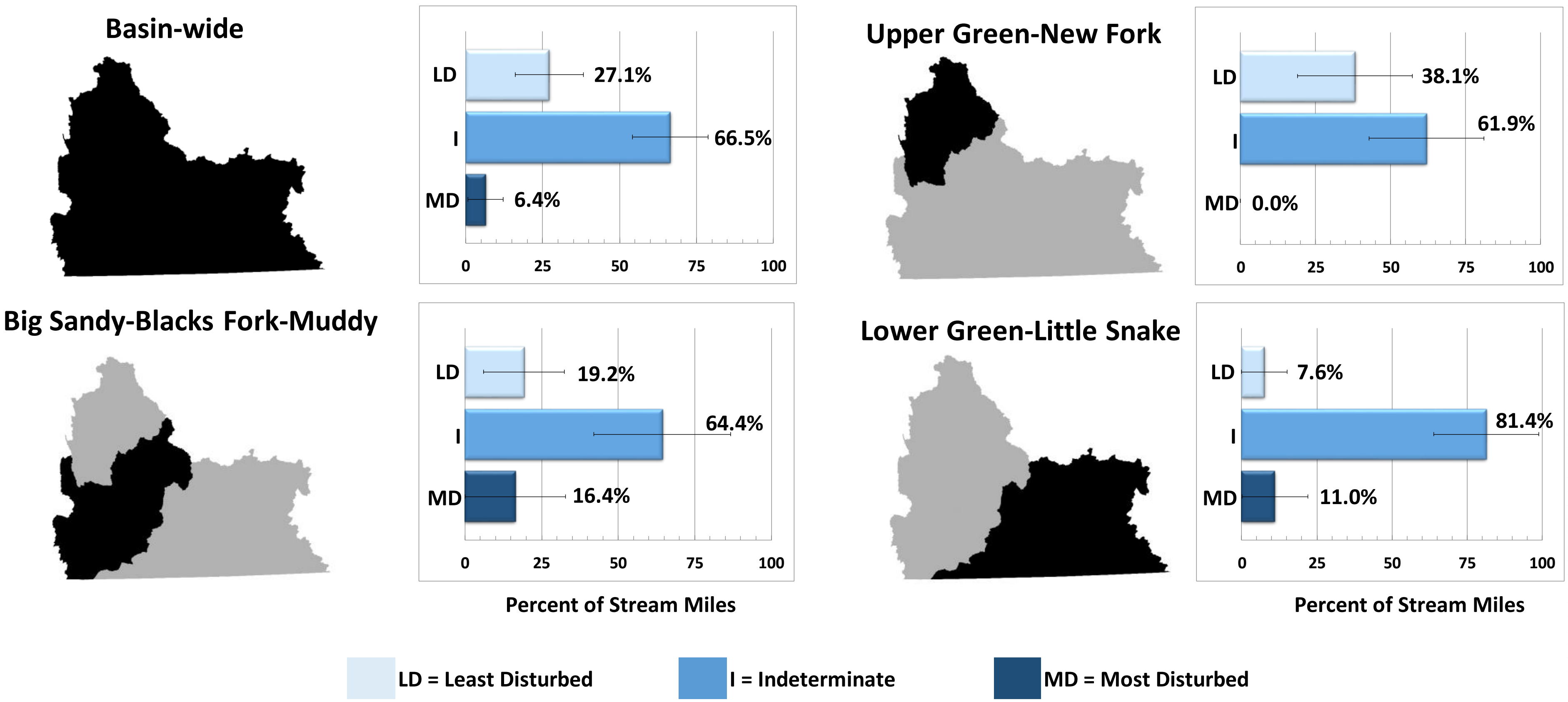


Appendix 8 - Summary of total nitrogen results for the Green and corresponding HUC 8 Clusters. Error bars represent the 95% confidence intervals.

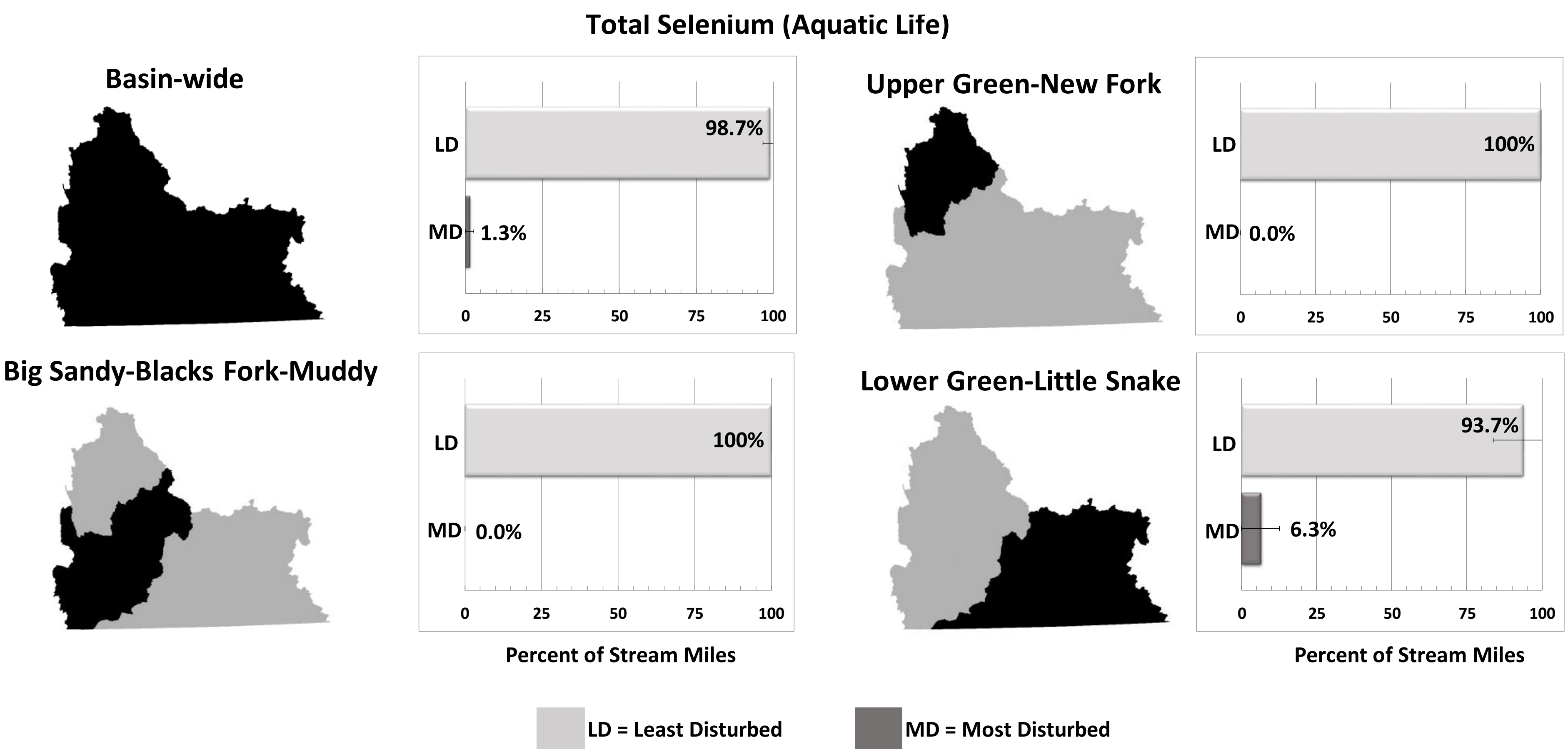


Appendix 9 - Summary of salinity results for the Green and corresponding HUC 8 Clusters. Error bars represent the 95% confidence intervals.

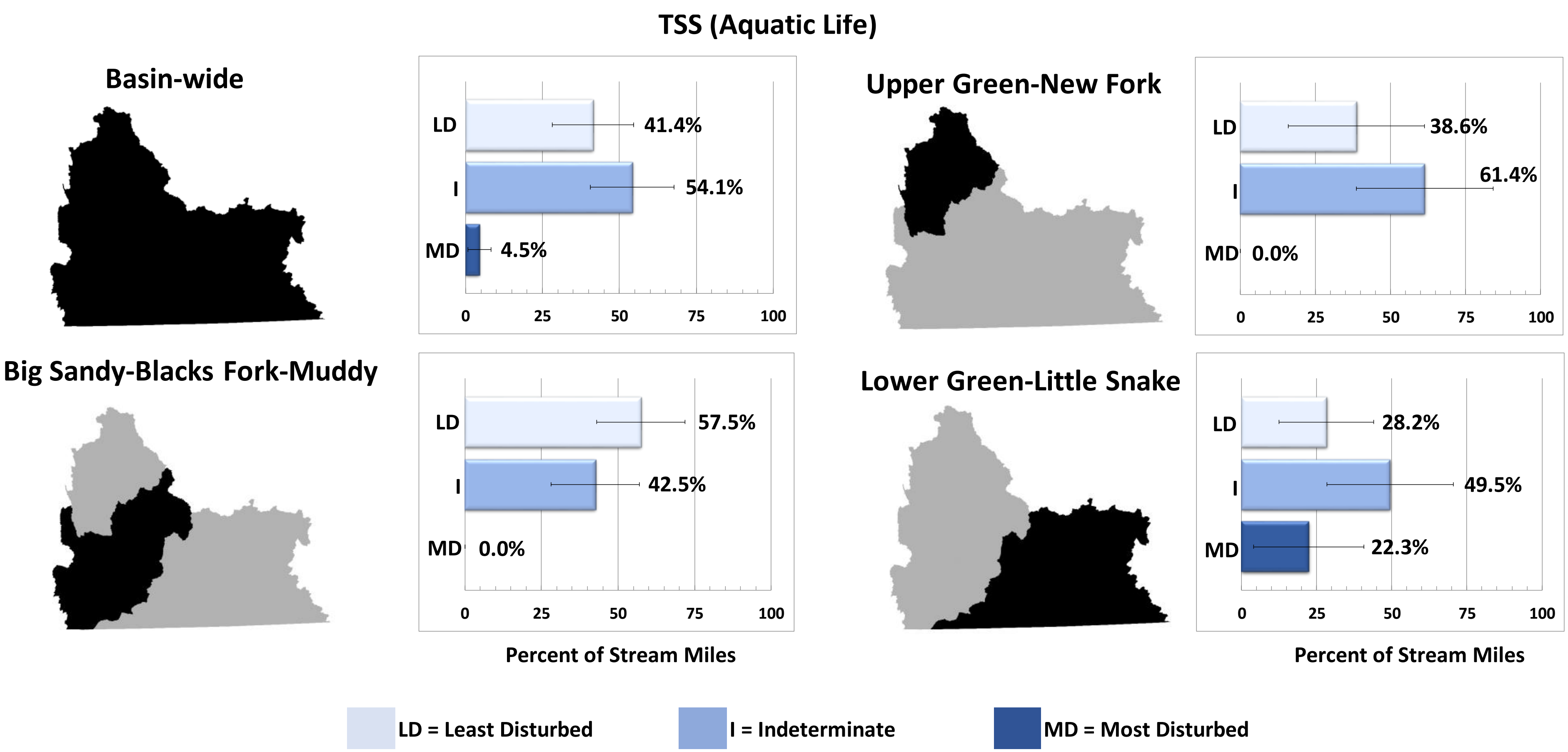
Salinity (Aquatic Life)



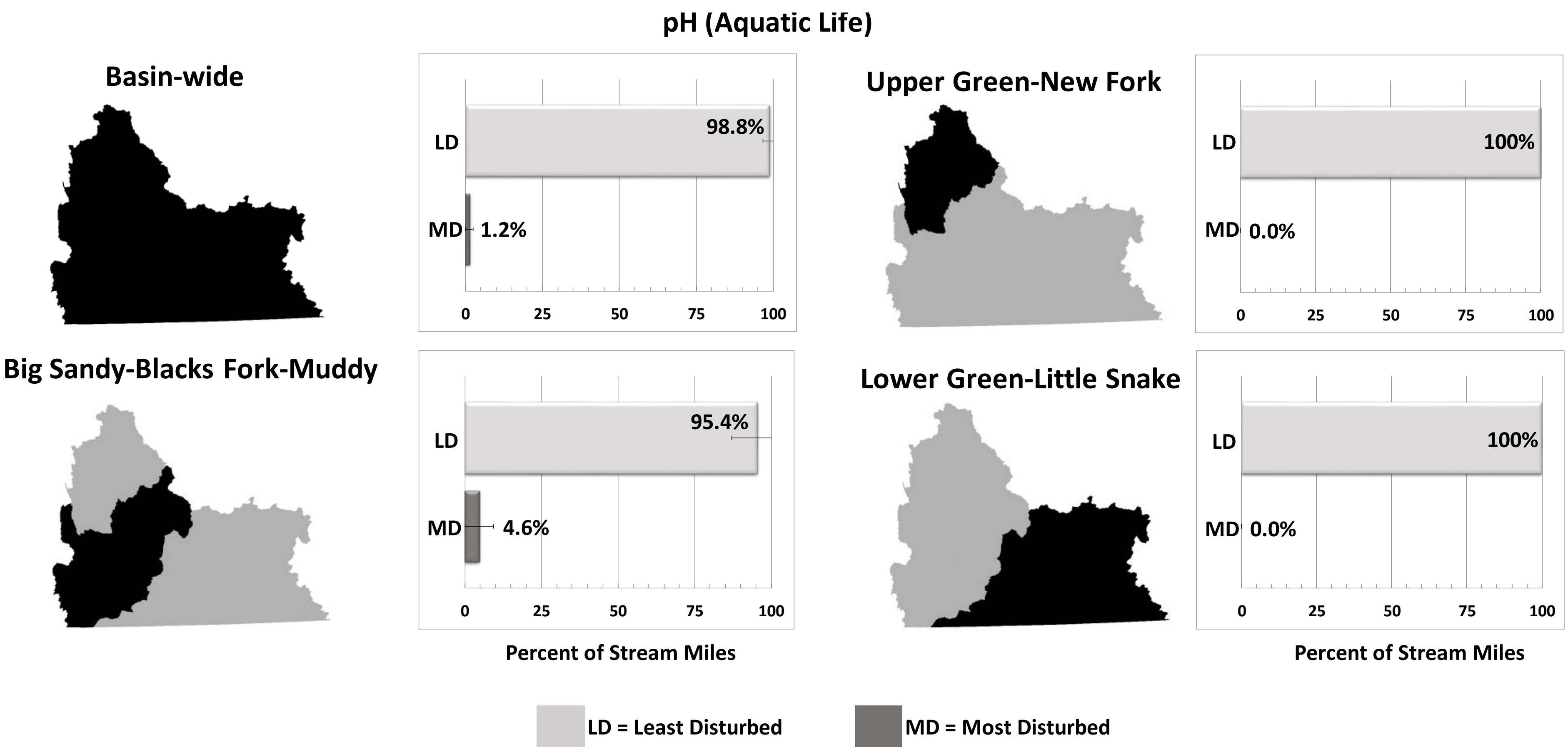
Appendix 10 - Summary of selenium results for the Green and corresponding HUC 8 Clusters. Error bars represent the 95% confidence intervals.



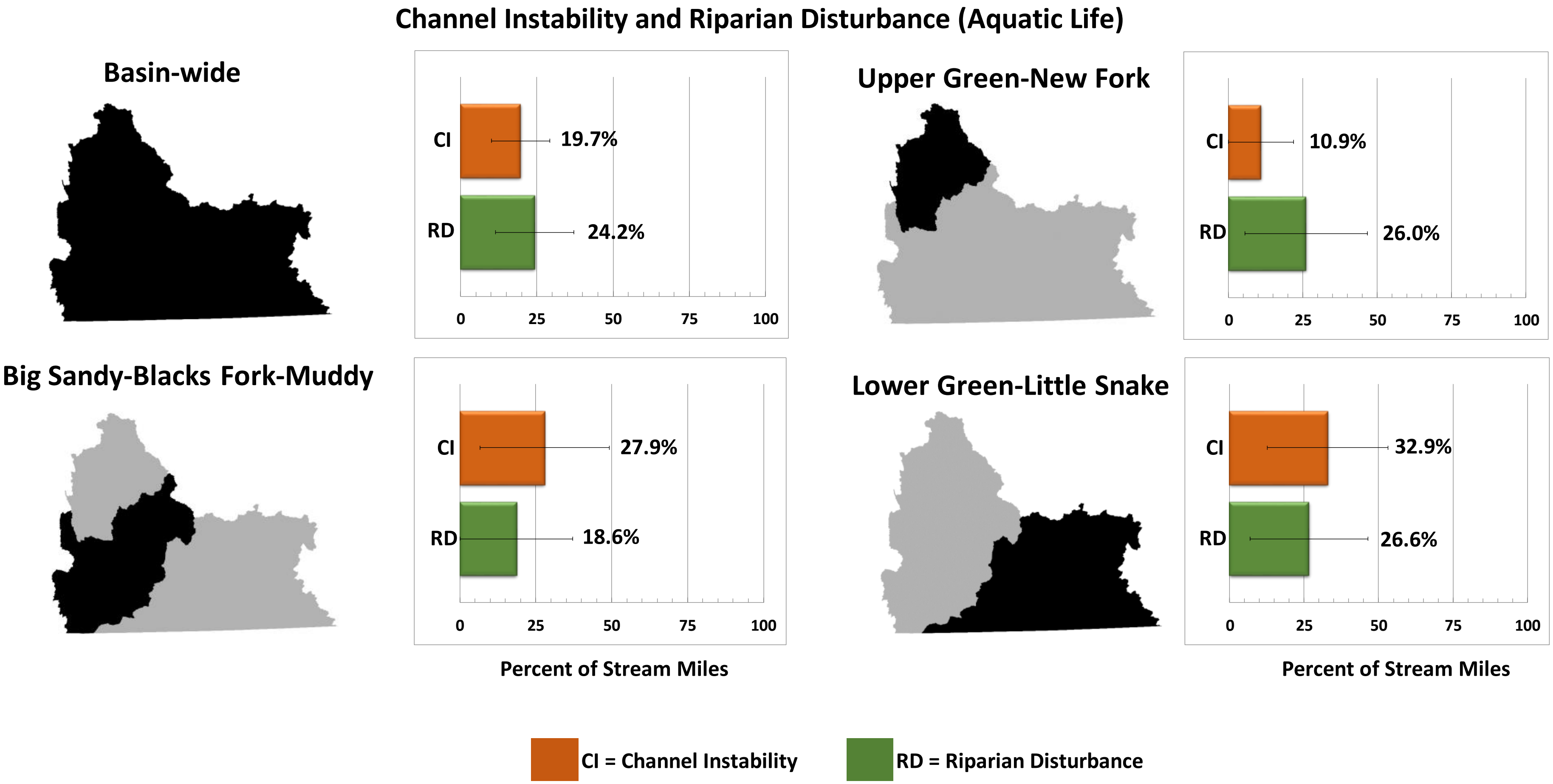
Appendix 11 - Summary of total suspended solids (TSS) results for the Green and corresponding HUC 8 Clusters. Error bars represent the 95% confidence intervals.



Appendix 12 - Summary of pH results for the Green and corresponding HUC 8 Clusters. Error bars represent the 95% confidence intervals.

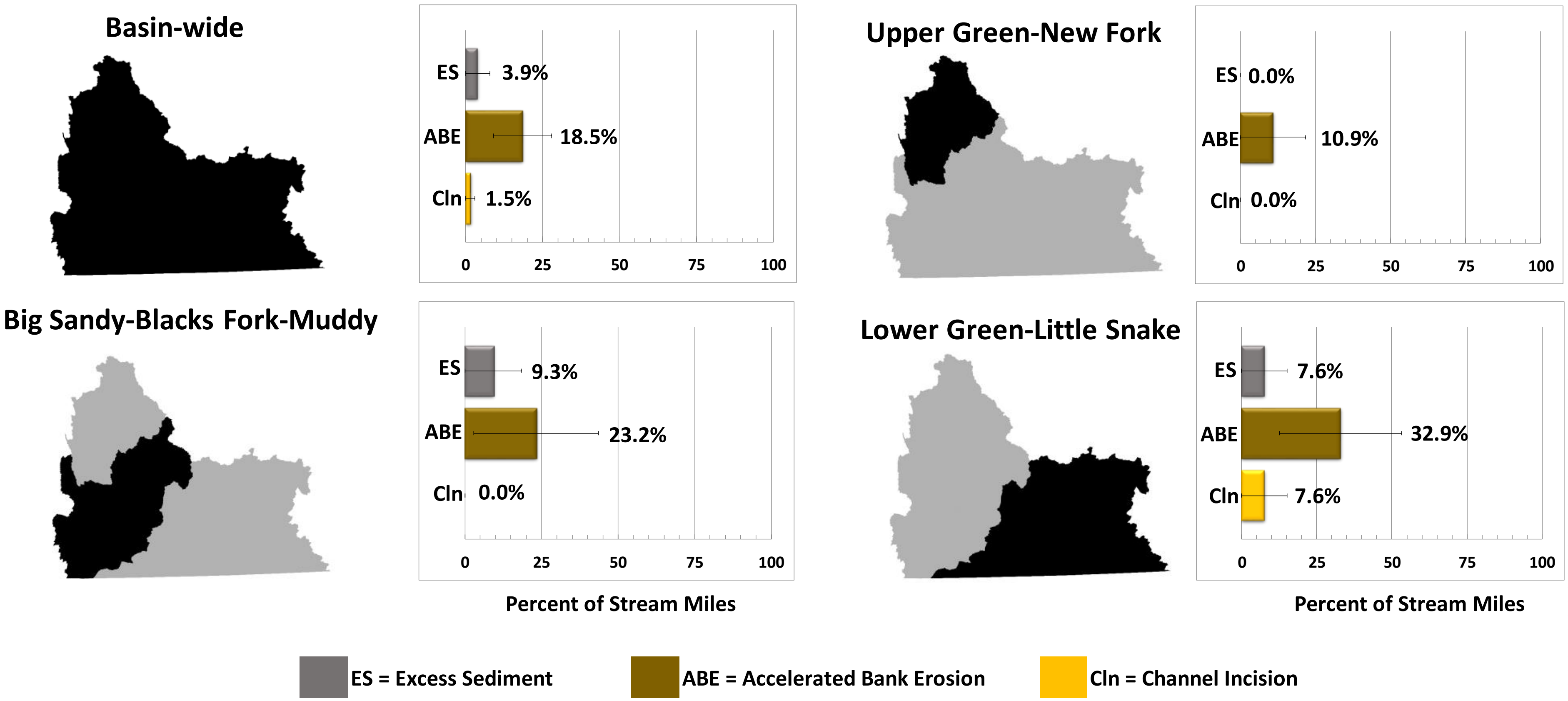


Appendix 13 - Summary of most-disturbed channel instability and riparian disturbance conditions for the Green and corresponding HUC 8 Clusters. Error bars represent the 95% confidence intervals.



Appendix 14 - Summary of the three component sub-stressors that represent most-disturbed channel instability conditions for the Green and corresponding HUC 8 Clusters. Error bars represent the 95% confidence intervals.

Channel Instability Substressors (Aquatic Life)



Appendix 15. Photos from a subset of the 50 sampled Green River probabilistic survey sites.


Battle Creek, Carbon County


Green River, Sweetwater County


Henry's Fork River, Uinta County


Muddy Creek, Uinta County


Smiths Fork River, Uinta County


Little Snake River, Carbon County


Jack Morrow Creek, Sweetwater County


Big Sandy River, Sweetwater County


North Horse Creek, Sublette County

Appendix 15 (cont). Photos from a subset of the 50 Green River probabilistic survey sites.

Big Sandy River, Sublette County

Green River, Sublette County

New Fork River, Sublette County

Squaw Creek, Sublette County

West Fork Hams Fork, Lincoln County

Hams Fork River, Lincoln County

Trout Creek, Sweetwater County

Hams Fork River, Lincoln County

Appendix 15 (cont). Photos from a subset of the 50 Green River probabilistic survey sites.


Fontenelle Creek, Lincoln County


Battle Creek, Carbon County


Sweeney Creek, Sublette County


East Fork Hams Fork, Lincoln County


Muddy Creek, Carbon County


Little Sandy River, Sublette County


Gilbert Creek, Uinta County


Bitter Creek, Sweetwater County


Hams Fork River, Lincoln County