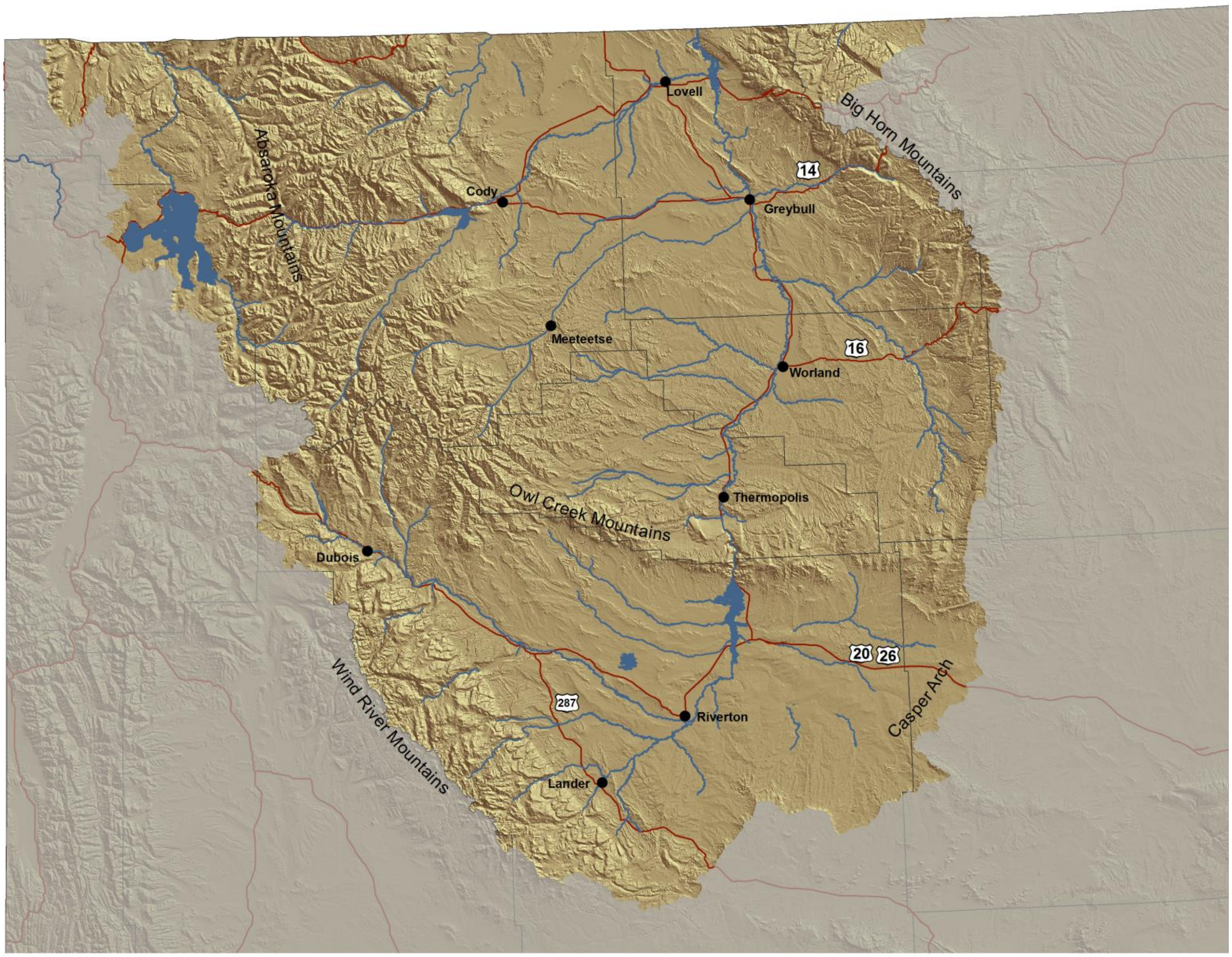
Water Quality Condition of Perennial Streams and Rivers in the Bighorn and Yellowstone Basins

Results of the 2010 Bighorn/Yellowstone Probabilistic Survey






Wyoming Department of Environmental Quality – Water Quality Division

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Results of the 2010 Bighorn/Yellowstone Probabilistic Survey

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Wyoming Department of Environmental Quality
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EXECUTIVE SUMMARY

The Wyoming Department of Environmental Quality-Water Quality Division's (WDEQ/WQD) probabilistic survey of perennial streams and rivers in the greater Bighorn and Yellowstone basins (BYS) was conducted in 2010. Results from this survey provide an objective representation of the current status of the biological condition, drinking water suitability and human health condition of BYS 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.

WDEQ/WQD's BYS survey included all non-headwater (>1st Strahler order) perennial streams and rivers that are not located in national parks, United States Forest Service wilderness areas and the Wind River Reservation. This equates to approximately 3,614 miles (based on the 1:100,000 NHD+ digital stream coverage) of perennial streams and rivers or almost one-third of the total miles (10,976 miles) of perennial streams and rivers in the BYS. Of the 3,614 stream miles initially considered for the BYS survey, only 2,304 miles were assessed. The remaining 1,310 stream miles were identified as ephemeral intermittent, human constructed, wetlands, inaccessible or access was denied. Biological condition was evaluated using benthic macroinvertebrates as the biological indicator at both the BYS scale and for four clusters of 8-digit hydrologic unit code (HUC) units: Big Horn Basin, West Big Horn, Wind River and Yellowstone-Shoshone.

Findings from this study indicate that 56% of the perennial streams and rivers in the BYS were in the least-disturbed biological condition or comparable to reference expectations. Approximately 26% of BYS perennial stream and river length were considered most-disturbed, implying an appreciable deviation from reference expectations associated with anthropogenic stressors. The remaining 18% of BYS perennial stream miles were considered indeterminate with respect to biological condition.

The percentage of perennial streams in the least-disturbed biological condition for the Wind River HUC 8 cluster was 97%, 57% for the West Big Horn, Yellowstone-Shoshone was 39% and 27% in the Big Horn Basin. The percentage of perennial streams in the most-disturbed biological condition was lowest in the Wind River HUC 8 cluster at 3% followed by the Yellowstone-Shoshone at 19%. The percentage of perennial stream miles in the West Big Horn with a most-disturbed biological condition was 34% and highest in the Big Horn Basin at 48%. A combination of historic and current anthropogenic disturbances and accelerated channel morphological alterations exacerbated by record high flows are presumed to be primarily responsible for the less favorable biological condition in areas of the BYS such as the Big Horn Basin.

Of fourteen stressors evaluated, elevated salinity (38% of stream miles), channel instability (34% of stream miles) and elevated total suspended solids (TSS) (26% of stream miles) were the three most common stressors that can influence biological condition in the BYS. Of the 34% of perennial stream miles with channel instability, 94% were due to excess sediment, 28% attributed to accelerated bank erosion and 25% linked to channel incision. Elevated salinity was the most common stressor in the Big Horn Basin and West Big Horn at 70% and 42%, respectively of perennial stream miles. Channel instability was within the top three most common stressors in all HUC 8 clusters: 46% Big Horn Basin, 43% Yellowstone-Shoshone, 25% West Big Horn and 23% Wind River. Elevated TSS was the second most common stressor in the Big Horn Basin (50%) and Wind River (15%). Some form of nutrient enrichment (elevated concentrations of total nitrogen, nitrate+nitrite-N

or total phosphorus) was among the top four most common stressors in all HUC 8 clusters (11% - 44% of perennial stream miles).

With regard to the potential influence of stressors on biological condition, elevated salinity ranked highest among stressors likely to be associated with degraded biological condition in BYS streams. Specifically, stream benthic macroinvertebrates in the BYS were 5.1 times more likely to be in a most-disturbed biological condition when elevated salinity was present than when elevated salinity was not present. The fact that elevated salinity is the most wide-spread and of greatest potential influence to biological condition emphasizes its importance as a pollutant of focus in the BYS. Total phosphorus (4.9) and channel instability (2.7) ranked second and third, respectively, among stressors associated with degraded biological condition. Degraded biological condition was just as likely to occur with or without elevated TSS. As such, TSS likely poses no additional risk to benthic macroinvertebrates when present in BYS streams. Rather, its subsequent deposition has the most likely direct impact to the benthic macroinvertebrate component of the aquatic community. Nevertheless, TSS attains the third highest stressor prevalence in the BYS and may pose a risk to other aquatic organisms such as fish that are potentially more directly affected by suspended sediment.

With regard to human health condition, 70% of perennial streams in the BYS had *Escherichia coli* (an indicator of human health risk for recreational uses of water) concentrations in the least-disturbed condition. However, the potential for a most-disturbed *E. coli* condition is greatest within the Yellowstone-Shoshone and Big Horn Basins. One-hundred percent of stream miles in the BYS exhibited concentrations of total cadmium, nitrate+nitrate-N, total selenium and total zinc in the least-disturbed condition with respect to suitability of the water for drinking. Similar findings were evident for 98% of perennial stream miles with respect to total arsenic. This indicates that the vast majority of the evaluated perennial streams in the BYS would require minimal treatment as potential drinking water sources with respect to the aforementioned constituents.

The BYS is similar to the entire State of Wyoming (based on WDEQ/WQD's 2008-2011 second statewide probabilistic survey) with regard to least-disturbed (56% BYS vs. 58% Wyoming) biological condition. The BYS, however, attains a greater percentage of biologically most-disturbed stream miles than Wyoming (26% BYS vs. 18% Wyoming). Perennial streams in the BYS fare better than the mountainous and arid regions of twelve western States (i.e. West) (based on the U.S. Environmental Protection Agency's 2008-2009 National Rivers and Streams Assessment (NRSA)) in terms of least-disturbed (56% BYS vs. 42% West) and most-disturbed (26% BYS vs. 30% West) biological conditions. Excess sediment (which was the largest of the three sub-stressors that comprised channel instability in the BYS) was a common stressor throughout the BYS and Wyoming, affecting 32% and 37% of stream miles, respectively. Excess sediment affected only 18% of stream miles in the West. Elevated total phosphorus was found to be the most common stressor throughout the West (37%), while this stressor occurred in only 14% of Wyoming streams (5th ranked) and 21% of streams in the BYS (6th ranked). Riparian disturbance occurred in 24% of streams in the West (4th ranked), 36% in Wyoming (3rd ranked) and was least common in the BYS at 17% (7th ranked).

Perennial streams and rivers of the BYS also fair far better than the national estimates of least-disturbed (56% BYS vs. 21% national) and most-disturbed (26% BYS vs. 55% national) biological condition (based on USEPA's 2008-2009 NRSA). Whereas total phosphorus was the most common stressor nationally (40%), it was the sixth most common stressor in the BYS at 21%. Excess sediment was considered a stressor in only 15% of streams nationally (5th ranked) and less than the 32% estimated for the BYS. Riparian disturbance was the fourth most common stressor nationally at 20%.

Elevated salinity and channel instability's commonality, combined with their moderate to high influence to aquatic life, suggest that efforts aimed at reduction in these two stressors could have broad benefits to biological condition of the BYS. Because of its dominant influence to channel instability and its function as a transport mechanism for other pollutants such as nutrients, efforts to reduce excess sediment in BYS streams would not only help address channel instability but may also reduce nutrient loading. This same logic also applies to elevated TSS. However, because of its varying influences on the aquatic community, evaluations on the effects of elevated TSS may require investigation into an additional component of the aquatic community such as fish. Fish may be more directly affected by suspended sediment than benthic macroinvertebrates that are more likely to experience detrimental effects once the sediment is deposited. The commonality of elevated total phosphorus in particular areas combined with its second highest relative risk to biological condition, suggests efforts to reduce this stressor at watershed-scales could improve overall water quality condition through minimizing the onset of eutrophication that could lead to episodes of hypoxia or toxic algal blooms.

Of the four HUC 8 clusters that comprise the greater BYS, the Big Horn Basin and Yellowstone-Shoshone emerge as two areas with the greatest potential need for additional investigation into whether aquatic life uses are being supported with respect to the influences of channel instability (namely excess sediment), elevated TSS and elevated total phosphorus. The highest relative extent percentage for nitrate+nitrite-N was also found in the Yellowstone-Shoshone. In addition, the highest percentages of perennial stream miles with elevated salinity, total selenium, sulfate, chloride and zinc were found in the Big Horn Basin. Combined, this information suggests that where aquatic life may not be supported in these areas, the causes may be many and their effects to aquatic life variable and perhaps inter-related.

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 these State obligations to the CWA, Wyoming uses a cost-effective approach known as probabilistic surveys to monitor and evaluate trends in surface water quality condition. 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 very 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 wadeable 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 and temporal changes in the ecological condition of Wyoming's perennial streams and rivers and the extent to which major stressors could potentially influence this ecological condition.

The findings from both statewide surveys were informative on the biological condition and stressors affecting perennial streams and rivers at the statewide scale. However, statewide surveys do not provide sufficient information 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 and unbiased means of identifying waters of high quality and those where designated use-support may not be supported. 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 has phased-out statewide probabilistic surveys and replaced with rotating basin probabilistic surveys.

Wyoming's probabilistic rotating basin approach establishes an order of rotation and sampling years among five 'superbasins' within the State delineated based on six-digit hydrologic unit codes (HUCs) and geographic location (WDEQ/WQD 2010). The five superbasins, their associated HUC 6 basins and projected 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] – To be determined

The WDEQ/WQD implemented and completed its first rotating-basin probabilistic survey within the Bighorn/Yellowstone (BYS) in 2010. The BYS was designed to:

- Determine the biological condition of perennial streams and rivers within the BYS and its sub-basins
- Determine the most common stressors that could potentially influence biological condition in the BYS and its sub-basins
- Determine the relative influence of stressors on biological condition in the BYS
- Provide recommendations on focus pollutants and areas where additional investigation could be conducted to determine whether aquatic life uses are being supported

In addition, data collected as part of the BYS survey were used to:

- Evaluate human health condition with respect to the pathogen indicator *Escherichia coli* and drinking water suitability with respect to total arsenic, total cadmium, nitrate+nitrite-N, total selenium and total zinc within the BYS

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). Assessments of pollutant problems and their impact on designated uses are incorporated into Wyoming's Integrated 305(b) and 303(d) Report (hereafter Integrated Report) that is submitted to the USEPA biennially.

Probabilistic surveys provide a systematic, broad-scale and quantitative estimate of overall water quality within the targeted population of streams and rivers 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 2013a) 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 2013b).

Findings from probabilistic surveys are summarized in Wyoming's Integrated Report. However, data collected as part of the probabilistic surveys are not intended to be used to make designated use-support determinations, including 303(d) listings. Rather, probabilistic surveys may be used to prioritize future targeted sampling on which designated use support determinations and 303(d) listings may be made.

STUDY AREA

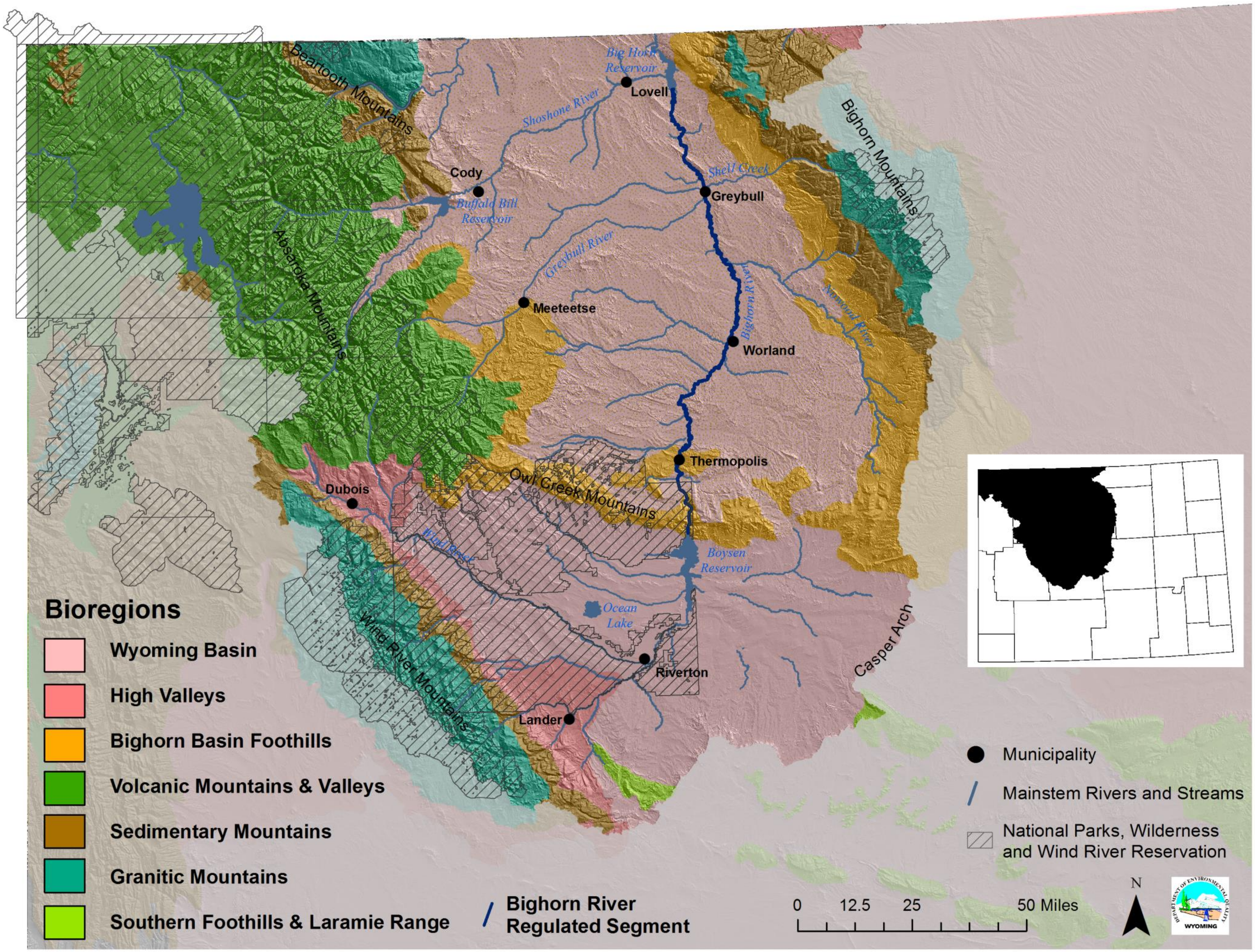
The BYS encompasses 26,349 mi^2 or about 27% of Wyoming's 97,100 mi^2 area. The interior of the BYS is characterized as an arid intermontane basin dominated by shrubs and grasslands interrupted by buttes and badlands (Chapman et al. 2003). The BYS is nearly surrounded by the forest-covered Absaroka, Beartooth, Bighorn and Wind River Mountains and the arid high elevation plains/desert plateau of the Casper Arch. The west-to-east Owl Creek Mountains bisect the BYS into the Bighorn Basin to the north and the Wind River Basin to the south. Abrupt topographical relief and numerous types of exposed granitic, volcanic and sedimentary bedrock are typical throughout the BYS. Elevation ranges from approximately 3,500 ft where the Bighorn River crosses into Montana to 13,804 ft at the summit of Gannett Peak in the Wind River Mountains. Average annual precipitation ranges from 6 inches in the interior up to 70 inches along the peaks of the surrounding mountains (WWDC 2010), which is mostly in the form of snow. As with precipitation, air temperature in the BYS varies widely due to the great topographic relief and resultant orographic effect of the area. For example, mean monthly maximum and minimum temperatures for the basin interior range from 29°F to 90°F and 0°F to 55°°F, respectively (WWDC 2010).

The BSY is divided into seven bioregions (Figure 1): Bighorn Basin Foothills, Granitic Mountains, High Valleys, Sedimentary Mountains, Southern Foothills & Laramie Range, Volcanic Mountains & Valleys and the Wyoming Basin (Hargett 2011). Bioregions are geographic classifications that represent groups of streams with similar habitat, chemical and biological characteristics.

The Bighorn Basin Foothills (Owl Creek Mountains and foothills of the Absaroka and Bighorn Mountains), Granitic Mountains and Sedimentary Mountains (Bighorn, Beartooth, and Wind River Mountains), Southern Foothills & Laramie Range (Rattlesnake Range foothills and isolated mountains) and Volcanic Mountains & Valleys (Absaroka Mountains) collectively represent the mountainous regions of the BYS with bedrock geology and elevation as the primary delineators between these five bioregions. The mid to upper montane elevations of these mountains are largely covered by 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. The mountainous regions of the BYS are the source of the major perennial rivers and streams that provide water resources for the arid intermontane basin. Recreation, logging and summer livestock grazing are common land uses in the mountainous areas of the BYS.

The interior of the BYS is represented by the High Valleys and Wyoming Basin bioregions. The High Valleys is considered 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 of the BYS is an arid desert shrubland represented by escarpments, mesas, hills and alkaline depressions. The perennial streams and rivers of the BYS interior have a mixture of spring and montane snow-melt origins.

Figure 1 – Bioregions; national parks, wilderness and the Wind River Reservation; and selected municipalities of the Bighorn/Yellowstone Superbasin.



Man-made dams, diversions and trans-basin inputs have altered the natural flow regimes of many perennial streams and rivers within the High Valleys and Wyoming Basin bioregions of the BYS (WWDC 2010). The BYS interior is used for livestock grazing, energy extraction and irrigated agriculture with hay and sugar beets the dominant crops (WWDC 2010).

SURVEY DESIGN

The total length of all waterways (perennial, intermittent, ephemeral, canals) in the BYS is 28,338 miles based on the USEPA-United States Geological Survey (USGS) 1:100,000 scale enhanced National Hydrography Dataset (NHD+). Approximately 10,976 (39%) miles in the BYS are categorized as perennial streams and rivers according to NHD+. It is important to note that the locations and total length of perennial streams and rivers defined by NHD+ may not be entirely accurate due to the coarse scale from which the coverage was derived. In reality, the total length of perennial streams and rivers in the BYS is likely less than that represented by NHD+ once factors including anthropogenic alterations and fragmented flow regimes are considered.

The design for the BYS is based on the approach developed by Stevens and Olsen (2004 and 1992) and previously implemented in WYDEQ/WQD's first and second statewide probabilistic surveys (Hargett and ZumBerge 2013) and USEPA's EMAP-West (Stoddard et al. 2005) and 2008-2009 NRSA (USEPA 2013). Site locations that represent a known proportion of the target population (in this case perennial streams and rivers) 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 can be calculated.

The stratified survey design for the BYS selected sites from perennial, non-headwater (>1st Strahler order) rivers and streams that are not located in national parks, United States Forest Service wilderness and the Wind River Reservation within the NHD+ sample frame. This equated to a target population of approximately 3,614 miles of perennial streams and rivers for the BYS (about one-third the total miles of perennial streams and rivers in BYS). The random site selection was performed with Geographic Information Systems (GIS) by the USEPA's Health and Environmental Effects Research Laboratory in Corvallis, Oregon.

The statistical procedures used in selecting site locations from sample frames using GRTS are fully described in Stevens and Olsen (2004 and 1992) with a brief summary found in Hargett and ZumBerge (2013).

Sample size for the BYS 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 on perennial streams and rivers. To ensure spatial uniformity in the design, the 50 sample sites were equally allocated among four eight-digit HUC clusters within the BYS: Bighorn Basin, West Bighorn, Wind River and Yellowstone-Shoshone (Figure 2). Following the same design and stratification, a population of 100 oversample sites was generated for the BYS. Oversample sites were used as replacements when primary sites could not be sampled due to access denial, inaccessibility or they were non-target (e.g. ephemeral, intermittent, canal, wetland, etc.). Within each

HUC 8 cluster, sites were sampled in the order of selection by the GRTS design.

Results of the BYS survey are presented at two levels of geographic resolution: BYS and the four HUC 8 clusters.

DATA COLLECTION

All data collections in 2010 were conducted during what were considered typical baseflow conditions. Chloride, dissolved arsenic, dissolved cadmium, dissolved zinc, *Escherichia coli*, nitrate+nitrite-N, total nitrogen, total phosphorus, total selenium, sulfate and total suspended solids (TSS) were analyzed from grab samples collected at the base of a riffle at each site (WDEQ/WQD 2012). Instantaneous water temperature, dissolved oxygen, pH and specific conductance were measured directly in the field (WDEQ/WQD 2012).

Benthic macroinvertebrates were collected from a representative riffle, when present, within each monitoring site following standard procedures in WDEQ/WQD (2012). 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. At low-gradient sites where riffles were absent, benthic macroinvertebrates were collected from multiple habitats (WDEQ/WQD 2012). The multi-habitat sample was a composite of 20 discrete 'jab' samples (each approximately 1.3 ft^2) collected with a dip net, from multiple habitats weighted proportionally based on representation, within a 300 ft reach. Organisms were preserved in the field with 99% ethyl alcohol. Sample processing followed methods described in WDEQ/WQD (2012) and included removal of large and rare organisms followed by a 500-organism fixed-count subsampling procedure. Most taxa were identified to genus or species.

Substrate particle size and mean embeddedness within riffles where benthic macroinvertebrates were collected were estimated by measuring at least 100 randomly selected particles using a modification of the Wolmann pebble count method (WDEQ/WQD 2012). Mean riffle embeddedness is the degree to which coarse materials are covered or surrounded by very fine gravel, sands and silts. Surveys were also performed at permanent cross-sections within representative riffles to calculate existing channel dimensions for Rosgen channel classification (Rosgen 1996) and to evaluate relative departure from general expected conditions. Wolman pebble counts (100 count) were conducted reachwide to characterize substrate composition and for use 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 (2012). Twelve human activities (logging, mining, buildings, roads, landfills, riprap, pavement, pipes, lawn, row crops, pasture and grazing) were evaluated for presence/absence, proximity and relative influence to water quality conditions. Combined, these physical parameters were used to make conservative inferences on the degree of riparian disturbance and relative channel stability.

All sites were evaluated as to the degree and relative extent the natural stream hydrology was affected by dams, flow diversions and/or flow augmentation. The number and type of surface water diversions or inputs upstream of the site in addition to information on water operations in the watershed were used to determine whether flow alterations were present in the watersheds. Sources of this information included but were not limited to the Wyoming State Engineers Office and the U.S. Bureau of Reclamation. In addition, sites where reservoirs (as depicted on a USGS 1:100,000 scale map) affected 50% or more of the upstream watershed were noted as reservoir influenced. Lastly, a site was noted as effluent dominant (WDEQ/WQD 2013a) if the flow at the site for the majority of the year was known to be primarily attributable to the permitted discharge of waste or production water. Information on permitted discharges was obtained from the WDEQ/WQD's Wyoming Pollutant Discharge Elimination System program.

All chemical, physical and biological data collected during 2010 that did not meet quality assurance/quality control standards (WDEQ/WQD 2001) were excluded from analyses. Otherwise, all remaining data were determined to be complete and accurate.

SETTING EXPECTATIONS OF STREAM AND RIVER CONDITION

INDICATORS OF BIOLOGICAL CONDITION

To assess the biological condition of the BYS's streams and rivers 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 that are derived from benthic macroinvertebrate data collected at a network of over 200 minimal or least-impacted reference sites. Benthic macroinvertebrates are one of the most common indicators used to assess the biological condition of streams and rivers. 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 and rivers in the BYS. Because results from the WSII and WY RIVPACS provide strong inference about water quality conditions over a multi-year period, they are extremely important tools for evaluating the biological condition of the BYS's perennial streams and rivers.

WYOMING STREAM INTEGRITY INDEX (WSII) is a statewide regionally-calibrated macroinvertebrate-based multimetric index designed to assess biological condition in Wyoming perennial streams (Hargett 2011). Index scores for the WSII are calculated by averaging the standardized values of selected metrics (composition, structure, tolerance, functional guilds) derived from the riffle-based macroinvertebrate sample. The selected metrics are those that best discriminate between reference and degraded waters. 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 and two reservoir-regulated large river segments.

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 imply high biological condition while values <1 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 (Table 1). Sites that fall between these two categories are categorized as 'indeterminate'.

The WSII and WY RIVPACS were designed to evaluate only riffle-based benthic macroinvertebrate samples thus application to samples collected with multi-habitat sampling procedures is limited. For the two sites in the BYS survey where multi-habitat procedures were used, biological condition was determined through the use of multiple lines of biological, chemical and physical evidence, alternative analytical procedures, comparisons to applicable numeric criterion protective of aquatic life and professional judgment.

The biological condition of large perennial rivers where inflows are largely controlled by reservoir operations is expected to be quite different and commonly lower compared to the generally un-regulated streams (Nestler et al. 1986, Petts 1984, Poff et al. 1997, Stanford et al. 1996, Walburg et al. 1980 and Ward and Stanford 1995) from which the WY RIVPACS and bioregional indices of the WSII were developed. To address this issue, only the large river multimetric index for the reservoir-regulated Bighorn River, developed as part of the WSII, was applied to riffle-based samples collected on this waterbody in the BYS. Scores from this large river index were codified into one of three narrative aquatic life use-support categories of 'least-disturbed', 'indeterminate' and 'most-disturbed' (Table 1). Numerical expectations for the narrative categories were empirically derived from available data on the regulated reach to represent the best-attainable conditions. For samples collected in other large reservoir-controlled perennial rivers where an applicable biological index is unavailable biological condition defaulted to 'indeterminate'.

The biological condition of effluent dominant streams is almost entirely dependent on the quality and quantity of wastewater in addition to any physical changes to the channel as a result of the effluent discharges. The chemical and physical conditions of effluent dominant streams limit potential biological condition relative to naturally perennial non-effluent dominant streams. Consequently, the use of the WSII and WY RIVPACS is limited in the assessment of biological condition for effluent dominant systems. Biological condition for the three effluent dominant sites sampled as part of the BYS survey was evaluated through comparisons to applicable numeric criteria protective of aquatic life, multiple lines of chemical, physical and biological evidence and professional judgment.

With the exception of the large river index and special considerations for effluent-dominant waters and multi-habitat samples, results from the WSII and WY RIVPACS were incorporated into Wyoming's aquatic life use-support decision matrix (WDEQ/WQD 2013b). 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

Although this report focuses almost exclusively on the biological condition of perennial streams, five analytes (total arsenic, total cadmium, nitrate+nitrite-N, total selenium and total zinc) were also evaluated with respect to suitability of perennial streams in the BYS as drinking water sources. In addition, the pathogen indicator *Escherichia coli* (*E. coli*) was evaluated with respect to human health condition in the BYS.

According to the USEPA (http://water.epa.gov/drink/contaminants/index.cfm), long-term drinking water intake of elevated concentrations of arsenic, cadmium,

Table 1 – Drinking water suitability and human health condition thresholds used to establish condition categories for stream and rivers within the Bighorn/Yellowstone survey. Equations used to translate dissolved concentrations to total concentrations are found within brackets for each constituent.

	Bighorn / Yellowstone Superbasin
Total Selenium (µg/L)	<50
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 Zinc (µg/L)	<5000 [Total Zinc as µg/L = Dissolved Zinc as µg/L(1 + K_p^z * 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})]
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 $\infty = -0.73$ (USEPA 1995 and 1996)

$K_p^z = K_{po}TSS^{\infty}$ where $K_{po} = 1.25X10^6$ and $\infty = -0.70$ (USEPA 1995 and 1996)

$K_p^c = K_{po}TSS^{\infty}$ where $K_{po} = 4.00X10^6$ and $\infty = -1.13$ (USEPA 1995 and 1996)

Table 2 – Biological condition stressor thresholds used to establish condition categories for stream and rivers within bioregions of the Bighorn/Yellowstone survey. Biological condition thresholds are represented as (least-disturbed) / (most disturbed) except 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>Bighorn Basin Foothills</th><th>Granitic Mountains</th><th>Sedimentary Mountains</th><th>Volcanic Mountains & Valleys</th><th>High Valleys</th><th>Wyoming Basin</th></tr>
<tr><td rowspan="12">Water Chemistry</td><td>Conductivity (µS/cm)</td><td>< 230 / ≥ 409</td><td>< 42 / ≥ 148</td><td>< 215 / ≥ 426</td><td>< 88 / ≥ 214</td><td>< 175 / ≥ 574</td><td>< 264 / ≥ 551</td></tr>
<tr><td>Total Selenium (µg/L)</td><td colspan="6">< 5 / ≥ 5</td></tr>
<tr><td>Dissolved Arsenic (µg/L)</td><td colspan="6">< 150 / ≥ 150</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>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>TSS (mg/L)</td><td>< 3 / ≥ 17</td><td>< 3 / ≥ 7</td><td>< 3 / ≥ 8</td><td>< 3 / ≥ 17</td><td>< 3 / ≥ 10</td><td>< 3 / ≥ 18</td></tr>
<tr><td>Nitrate+Nitrite-N (mg/L)</td><td colspan="6">< 0.200 / ≥ 0.200</td></tr>
<tr><td>Total Phosphorus (mg/L)</td><td colspan="3">< 0.100 / ≥ 0.100</td><td>< 0.100 / ≥ 0.151</td><td colspan="2">< 0.100 / ≥ 0.100</td></tr>
<tr><td>Total Nitrogen (mg/L)</td><td colspan="4">< 0.100 / ≥ 0.500</td><td colspan="2">< 0.275 / ≥ 0.690</td></tr>
<tr><td>Chloride (mg/L)</td><td colspan="6">< 230 / ≥ 230</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="3">Biological Condition</td><td>WSII</td><td>> 60.9 / < 40.6</td><td>> 60.3 / < 40.2</td><td>> 52.3 / < 34.8</td><td>> 69.3 / < 46.2</td><td>> 48.8 / < 32.5</td><td>> 39.9 / < 26.2</td></tr>
<tr><td>WSII Large River</td><td colspan="6">Bighorn River (> 0.62 / < 0.32)</td></tr>
<tr><td>WY RIVPACS</td><td>> 0.85 / < 0.63</td><td>> 0.88 / < 0.65</td><td>> 0.82 / < 0.68</td><td>> 0.87 / < 0.65</td><td>> 0.86 / < 0.69</td><td>> 0.82 / < 0.64</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 unvegetation 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>

nitrate+nitrate-N, selenium and zinc increases the risk for following effects to 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). Wyoming's most-stringent numeric criteria protective of human health (fish consumption and drinking water) were used to represent the least-disturbed condition for drinking water suitability (WDEQ/WQD 2013a). Specifically, the least-disturbed thresholds are: 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) (Table 1). Concentrations of these parameters that equal or exceed the least-disturbed thresholds represent the most-disturbed drinking water suitability condition. Only the dissolved fractions of these analytes were collected as part of the BYS survey. Therefore, translator equations (USEPA 1996, 1995) 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 described in Table 1.

E. coli is a fecal coliform bacterium commonly found in the intestines of warm-blooded animals and humans and is used as an indicator of public health risk of recreational waters in Wyoming (WDEQ/WQD 2013a). 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 cfu/100 mL that is protective of primary contact recreation was used to represent the least-disturbed human health condition for streams and rivers in the BYS (WDEQ/WQD 2013a). 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 or river. Wyoming has water quality criteria to protect designated aquatic life uses of streams and rivers (WDEQ/WQD 2013a). For parameters such as pH, chloride and select metals, Wyoming's respective numeric aquatic life criteria were used to evaluate conditions throughout the BYS and for each HUC 8 cluster. The water quality condition was considered least-disturbed when concentrations were less than the numeric criterion. Conversely, water quality condition was considered most-disturbed when the numeric criterion was equaled or exceeded.

For parameters without numeric criteria, percentile distributions (25th and 95th percentiles) of reference site values within individual or collective bioregions in the BYS were used to establish 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 2013). Stressor thresholds developed by Stoddard et al. (2005) and USEPA (2013) were not used in this study as they were developed for broad regions of the United States and may have limited representativeness in certain areas of Wyoming.

It is important to emphasize that these percentile-based stressor thresholds were established only for the objectives of this study and are not to be viewed as future numeric criteria. Furthermore, 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 be necessary to determine if aquatic life uses are in fact impaired. Temperature and dissolved oxygen were not evaluated as stressors for this study because their diurnal fluctuations are not accurately represented by the instantaneous measurements collected as part of this project. Stressors used in this report, their descriptions and the established expectations are described below.

CHEMICAL STRESSORS

NUTRIENTS – Parameters such as nitrate+nitrite-N (commonly referred to as nitrate), total nitrogen and total phosphorus are essential to the biological productivity of streams and rivers, though are generally found in low concentrations naturally and are therefore considered limiting constituents for plant and algal growth. However, 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 be increased above ambient concentrations through land fertilization, animal and human wastes from direct deposits, 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 2013). Nutrient enrichment can negatively affect aquatic communities through high concentrations of nitrogen in the form of ammonia (NH_3), dissolved-oxygen depletion (hypoxia), increases in pH, or decreases in habitat quality (EPA 2013, Munn and Hamilton 2003, Peterson et al. 2007). Nuisance levels of plant and algal growth interfere with aesthetic and recreational uses of streams and rivers 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 snow-melt 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. The WDEQ/WQD currently has no numeric aquatic life criteria for total phosphorus, total nitrogen or nitrates. Therefore, nitrate thresholds were derived using conservative 25th and 95th percentiles of nitrate concentrations among Wyoming reference sites for all mountainous and xeric bioregions combined, that represented the least and most-disturbed conditions, respectively (Table 1). Reference-based nitrate data were pooled for all bioregions due to the high proportion of laboratory non-detect results and the similarity in detectable concentrations among bioregions. Total nitrogen thresholds were derived similarly though developed from pooled data for the mountainous bioregions and for xeric bioregions due in large part to the similarity in detectable concentrations within each of the pooled groups in addition to the limited total nitrogen data within each individual bioregion (Table 1). For these same reasons, total phosphorus thresholds were developed for

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

the collective xeric bioregions. This approach was also applied to the mountainous bioregions with the exception of the Volcanic Mountain & Valleys bioregion where total phosphorus concentrations are naturally higher relative to other mountainous bioregions and therefore unique total phosphorus thresholds were developed for this bioregion. (Table 2). The percentile-derived most-disturbed total phosphorus condition of 0.100 mg/L equates to the concentration that is generally considered unacceptably high for maintenance of aquatic life (Dodds et al. 2002, Peterson et al. 2004, Vollenweider 1971). The Volcanic Mountains & Valleys bioregion most-disturbed total phosphorus condition is higher at 0.151 mg/L.

TOTAL SUSPENDED SOLIDS - TSS is the concentration of both inorganic 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 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, sewage discharges, animal waste, and elevated upland or bank erosion may contribute to elevated TSS beyond ambient concentrations. There is no federal or Wyoming criterion for TSS protective of aquatic life. Therefore, least and most-disturbed TSS expectations for each bioregion were derived from the 25th and 95th percentiles of TSS concentrations among BYS reference sites, respectively (Table 2).

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 and rivers varies considerably and is primarily dependent on geology and soils of the watersheds. Elevated salinity may cause negative effects to soils and drinking water, as well as physiological processes, structure and functions 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 and rivers. There is no federal or Wyoming criterion for specific conductance protective of aquatic life. Therefore, least and most-disturbed salinity expectations for each bioregion were derived from the 25th and 95th percentiles of specific conductance measurements among reference sites in the BYS, respectively (Table 2).

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

ARSENIC – Arsenic is a naturally occurring element found largely in trace concentrations. Elevated concentrations are directly toxic to aquatic life that can result in morphological alterations, liver neoplasms or death. Human sources of arsenic include pesticides, coal-fired power plants and mine tailings. The WDEQ/WQD has established a numeric aquatic life chronic criterion of 150 µg/L dissolved arsenic (WDEQ/WQD 2013a). Dissolved arsenic concentrations that equal or exceed the 150 µg/L criterion were used to represent the most-disturbed biological condition for this stressor (Table 2).

CADMIUM – The most common forms of cadmium are naturally occurring and found in combination with other elements in low concentrations. Cadmium is bioaccumulative and elevated concentrations are directly toxic to aquatic life that can result in reduced growth, reproductive disruptions and mortality. Anthropogenic sources of cadmium include mine drainage and tailings, phosphate fertilizers, coal or oil facilities, and industrial effluent. The WDEQ/WQD has established formula-based hardness-dependent numeric acute and chronic dissolved cadmium criteria considered protective of aquatic life uses (WDEQ/WQD 2013a). Dissolved cadmium concentrations that equal or exceed the chronic formula-based hardness-dependent criterion were used to represent the most-disturbed biological condition for this stressor (Table 2).

CHLORIDE - This is a naturally occurring constituent commonly found as a compound with sodium, potassium or magnesium and as noted previously can contribute to the salinity of a stream or river. Elevated concentrations of chloride can be toxic to aquatic life and can interfere with municipal and industrial processes. Human sources of chloride include sewage and industrial effluent, fertilizers, irrigation drainage and road salt application. The WDEQ/WQD has established a numeric chloride aquatic life chronic criterion of 230 mg/L considered protective of game or non-game fisheries (WDEQ/WQD 2013a). Chloride concentrations that equal or exceed the 230 mg/L criterion would represent the most-disturbed condition for this stressor (Table 2).

PH - The pH of a stream or river 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 that can contribute to alterations in pH from background include byproducts of industrial processes and indirectly from nutrient enrichment. The WDEQ/WQD has established a pH chronic criteria range of 6.5 to 9.0 as protective of aquatic life in all waters of Wyoming (WDEQ/WQD 2013a). Values of pH < 6.5 or > 9.0 would be considered most-disturbed (Table 2).

SELENIUM – A contributor to salinity and an essential trace element for animal nutrition, selenium can occur naturally in many areas 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 can also 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 (coal mines, oil treaters, refineries) and runoff from certain mining activities are anthropogenic sources of selenium. The WDEQ/WQD has established a numeric total selenium aquatic life chronic criterion of 5 µg/L (WDEQ/WQD 2013a). Total selenium concentrations that equal or exceed the 5 µg/L criterion would represent the most-disturbed condition for this stressor (Table 2).

SULFATE – As with chloride, sulfate occurs naturally in aquatic systems 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 (coal mines and oil treaters in particular), irrigation induced leaching of sulfate rich soils and agricultural runoff. There are currently no national or WDEQ/WQD water quality criteria for sulfate protective of aquatic life. However, the Illinois Environmental Protection Agency (ILEPA 2012) and Pennsylvania Department of Environmental Protection (PDEP 2012) have promulgated and drafted sulfate criteria, respectively, based 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, were used to set appropriate sulfate expectations in Wyoming. Sulfate concentrations that exceeded the chloride and hardness-dependent criteria described in Table 2 represented 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 oil treater effluent. A bioaccumulative element, dissolved zinc in elevated concentrations is toxic to aquatic life resulting in disruptions to growth, reproduction and survival. The WDEQ/WQD has established a formula-based hardness-dependent numeric aquatic life chronic zinc criterion (WDEQ/WQD 2013a). Dissolved zinc concentrations that equal or exceed the chronic formula-based hardness-dependent criterion would represent the most-disturbed condition for this stressor (Table 2).

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 smaller streams. Vegetation is also critical for providing 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 can accelerate natural geomorphic processes and can threaten the physical stability of a stream, which in turn can limit its ability to support aquatic life. The degree of riparian disturbance was evaluated in this study by combining several semi-quantitative measures. Specifically, evaluations of human activity, mean percentage of riparian stream bank cover, percentage of bare ground and stream bank and riparian zone condition were estimated at each sampled site. Riparian disturbance was noted most-disturbed when either mean streambank cover was < 70% or bare ground represented > 40% of the riparian zone within 30 feet of the channel (Table 2) (Cowley 2002, USDA/NRCS 1998, USDI/BLM 1998, USEPA 1998). Riparian disturbance was also conservatively documented as most-disturbed when at least four of seventeen indicators noted in Table 1 were documented in the reach within 30 feet of the channel. At least four indicators were chosen to minimize false positive assignments of riparian disturbance.

Riparian disturbance can impact aquatic life through alterations to habitat.

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 that result in an accelerated rate of morphological changes (e.g. stream bank erosion, incision, aggradation) that ultimately create instability of the channel and its habitat for aquatic life.

In short, accelerated stream bank erosion, active channel incision and/or excess sediment create conditions of channel bed and bank instability (hereafter referred to as channel instability) that have major impacts on stream ecosystems. These impacts can 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 noted as 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 described below.

Excess Sediment - Excess sediment has been labeled the most important pollutant in United States streams and rivers (Waters 1995). In the latest USEPA summary of the Nation's water quality, excess sediment was again recognized as one of the top four stressors to streams and rivers and posed the greatest risk to the biological condition of the Nation's waters (Paulsen et al. 2008, USEPA 2009). Excess sediment creates unstable physical conditions that can lead to channel aggradation or degradation. This pollutant can also smother fish eggs and fill interstitial spaces in stream beds as well as scour those beds where benthic organisms live, thereby severely impacting growth, reproduction, recruitment and survival. Direct abrasion to aquatic life is also possible. Excess sediment can also clog surface water diversion headgates and reduce channel capacity; raise the channel bed elevation (aggradation) potentially increasing flood stage and flood hazard 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 can result in an accumulation of sediment.

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

Excess sedimentation often results in the development of un-vegetated mid-channel, transverse, delta and side bars (Barbour et al. 1999, Rosgen 2006 and 2008, Schumm 1977). Bimodal distributions in bed material (Rosgen 2006) and elevated riffle embeddedness (Sylte and Fischenich 2002) can be indicative of excess sedimentation. Though variable, the combined results from several studies suggest that a conservative threshold of at least 30% mean riffle embeddedness may be 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% may be a reasonable threshold for detection of channel aggradation. Excess sediment was noted as present when either mean riffle embeddedness was ≥50% or when both of the following were documented in the reach: bimodal reachwide particle distribution, new or extensive unvegetated bar development (Table 2).

Accelerated Bank Erosion - Stable stream banks are able to 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 generally 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 more of the bank surface is exposed above bankfull elevation and 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 not only reduces in-stream aquatic habitat along the banks but also 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 (Table 2).

Channel Incision - Accelerated stream bank erosion and excess sediment are sometimes associated 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 may be triggered by a variety of historic and/or current causes, though 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 noted as 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 was documented within the reach (Table 2).

Channel incision and accelerated bank erosion can be triggered by alterations to channel boundary conditions such as from disturbances to the riparian zone.

RANKING OF STRESSORS

Findings from the BYS can be used for making policy and management decisions when framed as the relative importance of elevated (most-disturbed) stressors on the biological condition. This study defines the 'importance' of each most-disturbed stressor on biological condition within the context of relative extent and relative risk.

Relative Extent

Relative extent is presented as a percentage and looks at how extensive the most-disturbed stressor condition is among the evaluated perennial stream length of the BYS. Conceptually, stressors in the most-disturbed condition can be found 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 would be considered to have a high relative extent. For this study, stressors are ranked according to their relative extents at both the BYS 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 BYS was used to evaluate 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 (VanSickle 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. Relative risk values for stressors in this study are only ranked at the BYS scale. Valid relative risk values were generally not obtainable at the HUC 8 Cluster scale due to small sample sizes.

DATA ANALYSIS

All probabilistic survey analyses were performed using modifications of the ‘spsurvey.analysis’ scripts developed in the R programming language (Version 3.0.1) by the USEPA’s Office of Research and Development in Corvallis, Oregon or with STATISTICA (Version 10) (Statsoft 2011). 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 Van Sickle and Paulsen (2008) and VanSickle et al. (2006).

2010 STREAM FLOWS

The BYS survey was conducted during a year with above average snowpack particularly within the Wind River Basin (WSCO 2013). During June, abundant rainfall combined with the above average snowpack and increasing air temperatures resulted in rapid snowmelt throughout the BYS (NOAA 2013). This rapid snowmelt triggered above average peak flows throughout the BYS. Data collected at several USGS stream gage stations distributed throughout the BYS show appreciable above average peak flows in 2010 (Table 2). At the BYS scale, peak flows in 2010 were on average 43% (range: -20 to 167%) above the mean peak flows for the periods of record. Despite the above average peak flows, the mean of

2010 mean annual flows for these same gages was only 3% (range: -28 to 55%) above the mean annual flow for the periods of record.

RESULTS

EXTENT OF RESOURCE

A total of 77 sites were evaluated as part of the BYS survey that represented 3,614 perennial stream and river (hereafter referred to as just stream) miles or the target stream length. The target stream length equates to almost one-third of the 10,976 total perennial stream miles in the BYS. Approximately 16% (565 miles) of the target stream length was found to be non-target (Figures 2 and 3). Non-target sites were those identified as ephemeral, intermittent, wetlands or human constructed channels such as irrigation canals. Approximately 21% (745 miles) of the target streams could not be assessed because access was denied or the streams were inaccessible due to unsafe wading conditions or rugged terrain. The remainder of the sampling frame represented the assessed targeted stream length for the BYS survey – 2,304 miles (52 sites) (Figure 2, Table 3). This assessed targeted length represents 21% of the total perennial stream length in the BYS (less wilderness, national parks and the Wind River reservation) and 64% of the targeted perennial stream length from the GRTS modified sample frame.

An important finding from the BYS survey is that a relatively small portion of the targeted perennial stream length was found to be non-target based on field determinations. This indicates that the NHD+ overestimates targeted perennial stream length in the BYS by approximately 16%. Among all HUC 8 clusters, overestimates of target perennial stream length in the BYS was greatest in the Big Horn Basin (29%) due to the greater occurrence of irrigation canals misidentified in the NHD+ as perennial streams.

Of the 2,304 assessed targeted stream miles in the BYS survey, approximately 4% (97 miles) were identified as effluent dominant. All effluent dominant streams were located in either the Big Horn Basin or Yellowstone-Shoshone HUC 8 clusters.

The flow regimes of approximately 14% (318 miles) of the assessed targeted stream miles for the first statewide survey were reservoir influenced (≥50% of the respective watershed areas).

Flow alterations represented by diversions or trans-basin inputs had varying influences on approximately 64% (1,475 miles) of the 2,304 assessed targeted stream miles for the BYS survey. Flow alterations were identified throughout the BYS with the greatest prevalence in the Big Horn Basin HUC 8 cluster.

Sampling sites on the assessed targeted streams were near equally distributed among the Big Horn Basin (13), West Big Horn (13), Wind River (12) and Yellowstone-Shoshone (14) HUC 8 clusters.

BIOLOGICAL CONDITION

The WSII is a compilation of several bioregion-specific multimetric indices that measure a variety of metrics associated with the structure, composition, functional feeding group, habitat and tolerances of the benthic macroinvertebrate community (Hargett 2011). WY RIVPACS on the other hand, measures the presence/absence of specific taxa expected within the community (Hargett 2012). The general responses of the WY RIVPACS and WSII to environmental stressors is similar, however, the output of each model is unique since each model measures different ecological attributes of the benthic macroinverbrate community. Therefore, the results of each individual model along with the final biological condition output using the model results in the aquatic life use matrix (WDEQ/WQD 2013b) are presented.

Figure 2 – Target, non-target, access denied and inaccessible sites evaluated as part of the Bighorn/Yellowstone Superbasin probabilistic survey including HUC 8 clusters; municipalities; and national parks, wilderness and the Wind River Reservation.

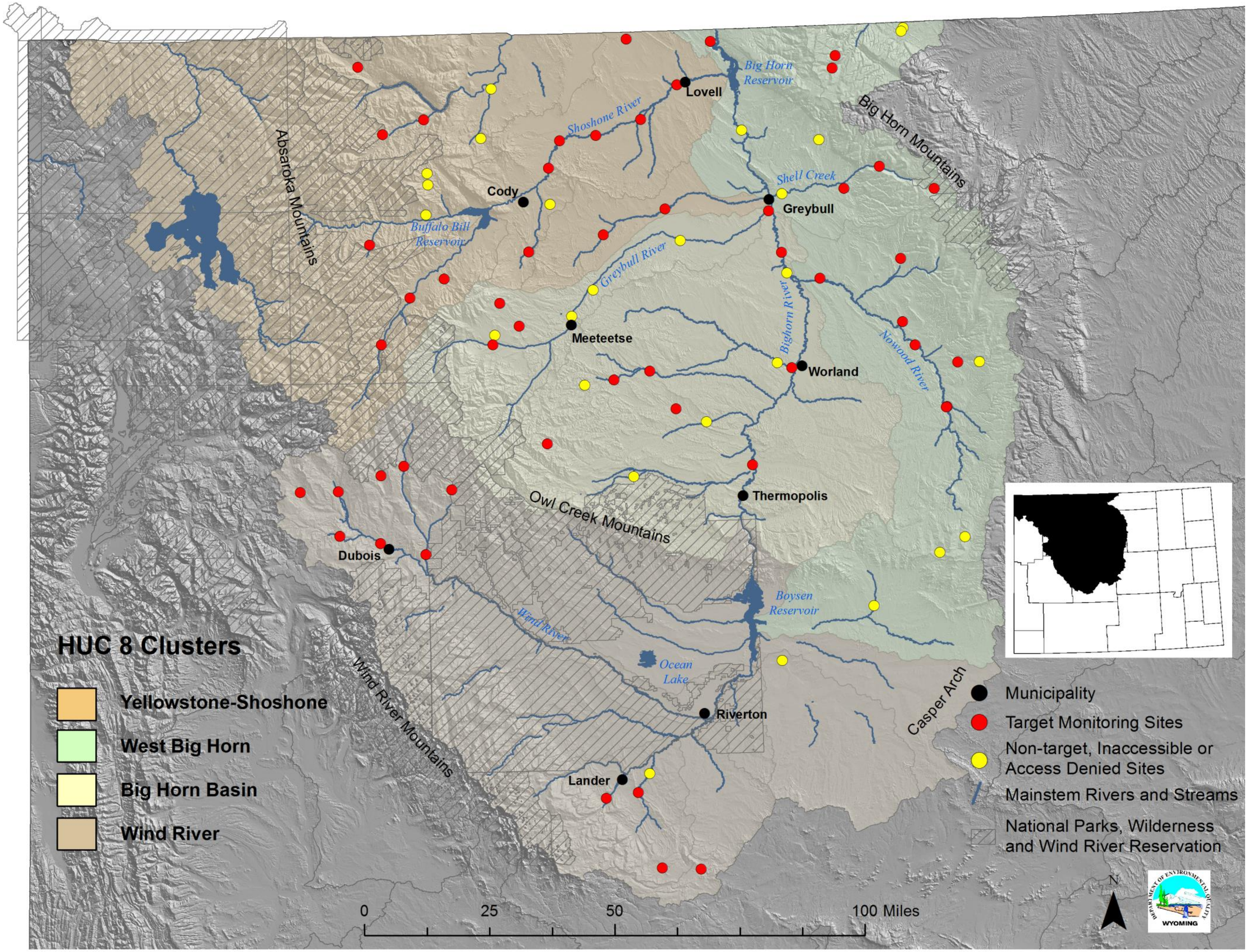


Table 3 - Relative departures of 2010 flow statistics from means for the periods of record at selected USGS stream gages within the Bighorn/Yellowstone Superbasin.

USGS Gage ID	USGS Gage Name	Period of Record	2010 Peak Flow (cfs)	Mean Peak Flow (cfs) Period of Record	% Departure from Mean Peak Flow for Period of Record	2010 Mean Annual Flow (cfs)	Mean Annual Flow (cfs) Period of Record	% Departure from Mean Annual Flow for Period of Record
06186500	Yellowstone River at Yellowstone Lake Outlet YNP	1927-2012	5,440.0	5,382.0	1.1	1,304.0	1,338.0	-2.5
06188000	Lamar River nr. Tower Ranger Station YNP	1924-2012	17,600.0	10,510.0	67.5	823.4	873.8	-5.8
06191000	Gardner River nr. Mammoth YNP	1985-2012	2,110.0	1,273.0	65.8	169.2	205.9	-17.8
06191500	Yellowstone River at Corwin Springs, MT	1890-2012	26,000.0	18,118.0	43.5	2,974.0	3,122.0	-4.7
06207500	Clarks Fork Yellowstone River nr. Belfry, MT	1922-2012	10,100.0	8,701.0	16.1	752.2	934.0	-19.5
06218500	Wind River nr. Dubois, WY	1946-2012	9,966.0	12,150.0	-18.0	126.2	167.5	-24.7
06221400	Dinwoody Creek abv. Lakes, nr. Burris, WY	1958-2012	1,180.0	939.6	25.6	136.3	139.3	-2.2
06224000	Bull Lake Creek abv. Bull Lake, WY	1942-2012	4,240.0	2,285.0	85.6	252.6	285.3	-11.5
06225000	Bull Lake Creek nr. Lenore, WY	1919-2012	21,606.0	10,147.0	112.9	290.8	270.0	7.7
06225500	Wind River nr. Crowheart, WY	1946-2012	87,906.0	75,887.0	15.8	1,084.0	1,173.0	-7.6
06227600	Wind River nr. Kinnear, WY	1992-2012	105,006.0	67,563.0	55.4	797.1	650.4	22.6
06228000	Wind River at Riverton, WY	1913-2012	63,706.0	58,266.0	9.3	549.2	759.0	-27.6
06235500	Little Wind River nr. Riverton, WY	1942-2012	133,006.0	49,821.0	167.0	867.9	558.7	55.3
06236100	Wind River abv. Boysen Reservoir, nr. Shoshoni, W	1991-2012	192,006.0	96,396.0	99.2	1,520.0	1,082.0	40.5
06259000	Wind River blw. Boysen Reservoir, WY	1952-2012	71,506.0	45,055.0	58.7	1,655.0	1,359.5	21.7
06274300	Bighorn River at Basin, WY	1984-2012	120,006.0	81,909.0	46.5	2,078.0	1,599.0	30.0
06278300	Shell Creek abv. Shell Creek Reservoir	1957-2012	864.0	772.8	11.8	31.2	33.3	-6.3
06279500	Bighorn River at Kane, WY	1930-2012	136,006.0	117,778.0	15.5	2,455.0	2,143.0	14.6
06279940	North Fork Shoshone River at Wapiti, WY	1990-2012	94,505.0	71,964.0	31.3	783.9	839.0	-6.6
06280300	South Fork Shoshone River nr. Valley, WY	1957-2012	38,605.0	32,444.0	19.0	392.5	407.2	-3.6
06281000	South Fork Shoshone River abv. Buffalo Bill Reservo	1974-2012	57,105.0	45,208.0	26.3	360.4	351.5	2.5
06285100	Shoshone River nr. Lovell, WY	1967-2012	47,206.0	59,143.0	-20.2	776.3	882.0	-12.0
06289000	Little Bighorn River at Stateline nr. Wyola, MT	1940-2012	1,790.0	1,146.5	56.1	169.6	149.0	13.8
				Departure Range:	-20.2 to 167.0		Departure Range:	-27.6 to 55.3
				Mean Departure:	43.1		Mean Departure:	2.5

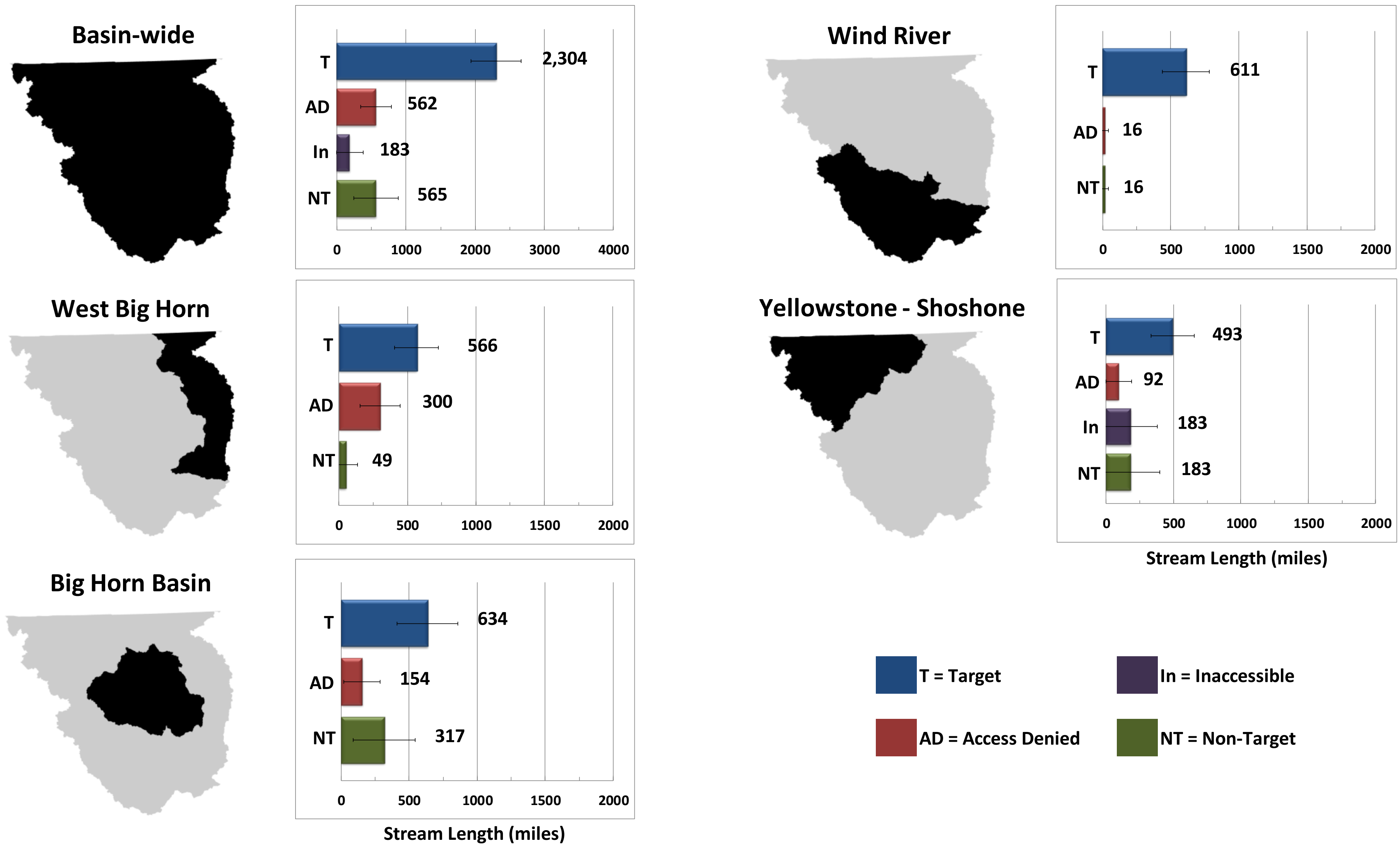
Table 4 – Target sites sampled as part of the 2010 Bighorn/Yellowstone Superbasin survey.

Survey ID	Type	StationID	WaterbodyName - Reach Name	Latitude	Longitude	HUC 6 Basin	Elevation (ft)	Watershed Area (mi^2)	HUC 8 Cluster	BIOREGION
WY09C-101	Base	WB0362	BIGHORN RIVER - LUCERNE	43.735811	-108.161486	BIGHORN	4262	9044.0	Big Horn Basin	WYOMING BASIN
WY09C-107	Base	MRW0186	SOUTH FORK COTTONWOOD CREEK - BELOW FOREST BOUNDARY	43.814683	-108.977775	BIGHORN	7829	5.1	Big Horn Basin	VOLCANIC MOUNTAINS & VALLEYS
WY09C-109	Base	WB0368	FRANCS FORK - ABOVE GREYBULL CONFLUENCE	44.105144	-109.187256	BIGHORN	6841	43.3	Big Horn Basin	BIGHORN BASIN FOOTHILLS
WY09C-110	Base	WB0372	DRY CREEK - YU BENCH	44.415200	-108.730056	BIGHORN	4963	143.3	Big Horn Basin	WYOMING BASIN
WY09C-111	Base	WB0365	GOOSEBERRY CREEK - BLUE RIDGE	44.017436	-108.559981	BIGHORN	5208	237.5	Big Horn Basin	WYOMING BASIN
WY09C-115	Base	WB0350	TRAPPER CREEK - ABOVE SHELL	44.525790	-107.753497	BIGHORN	4289	65.0	West Big Horn	BIGHORN BASIN FOOTHILLS
WY09C-116	Base	WB0337	MEDICINE LODGE CREEK - BELOW CAPTAIN JACK CREEK	44.316927	-107.535692	BIGHORN	4933	35.9	West Big Horn	BIGHORN BASIN FOOTHILLS
WY09C-120	Base	WB0341	OTTER CREEK - BELOW UPPER NOWOOD ROAD	43.883294	-107.376223	BIGHORN	4545	94.3	West Big Horn	BIGHORN BASIN FOOTHILLS
WY09C-121	Base	WB0339	NOWOOD RIVER - SCHOOL SECTION	44.269171	-107.863253	BIGHORN	3893	1905.0	West Big Horn	WYOMING BASIN
WY09C-122	Base	WB0338	NOWOOD RIVER - ABOVE LITTLE COTTONWOOD CREEK	44.066437	-107.492567	BIGHORN	1094	1094.0	West Big Horn	WYOMING BASIN
WY09C-123	Base	MRC0120	SHELL CREEK - ABOVE SHELL FALLS	44.585827	-107.607724	BIGHORN	6300	93.8	West Big Horn	GRANITIC MOUNTAINS
WY09C-125	Base	MRC0119	MANN CREEK - BOYD RIDGE	44.912120	-107.767861	BIGHORN	8670	6.0	West Big Horn	SEDIMENTARY MOUNTAINS
WY09C-127	Base	WB0357	EAST FORK WIND RIVER - BAIN DRAW	43.504567	-109.468086	BIGHORN	6593	432.9	Wind River	HIGH VALLEYS
WY09C-128	Base	MRW0180	DU NOIR CREEK - STATE LAND	43.688575	-109.814272	BIGHORN	7397	74.9	Wind River	HIGH VALLEYS
WY09C-129	Base	WB0358	BEAVER CREEK - ROCKY FORD	42.572314	-108.415036	BIGHORN	6275	92.7	Wind River	SOUTHERN FOOHILLS & LARAMIE RANGE
WY09C-130	Base	WB0361	HORNECKER CREEK - SHEEP CONFLUENCE	42.785786	-108.779581	BIGHORN	5721	9.1	Wind River	HIGH VALLEYS
WY09C-131	Base	MRW0183	HORSE CREEK - CARSON	43.732175	-109.643181	BIGHORN	8106	38.4	Wind River	VOLCANIC MOUNTAINS & VALLEYS
WY09C-132	Base	WB0356	WIND RIVER - MICKEL DRIVE	43.536325	-109.649894	BIGHORN	6935	366.8	Wind River	HIGH VALLEYS
WY09C-134	Base	WB0360	LITTLE POPO AGIE RIVER - HOT SPRING	42.799769	-108.652211	BIGHORN	5262	290.3	Wind River	HIGH VALLEYS
WY09C-135	Base	MRW0181	WIND RIVER - LAVA MOUNTAIN	43.686936	-109.968697	BIGHORN	7873	40.7	Wind River	SEDIMENTARY MOUNTAINS
WY09C-136	Base	MRW0185	EAST FORK WIND RIVER - RANGER STATION	43.688406	-109.363831	BIGHORN	8429	48.4	Wind River	VOLCANIC MOUNTAINS & VALLEYS
WY09C-138	Base	WB0359	TWIN CREEK - TWEED	42.579447	-108.567636	BIGHORN	6581	18.4	Wind River	HIGH VALLEYS
WY09C-139	Base	MRW0175	CLARKS FORK - L BAR T RANCH	44.914411	-109.709015	YELLOWSTONE	6708	186.0	Yellowstone-Shoshone	GRANITIC MOUNTAINS
WY09C-140	Base	WB0349	SOUTH FORK SHOSHONE RIVER - ABOVE ALDRICH CREEK	44.245113	-109.513731	BIGHORN	6070	322.0	Yellowstone-Shoshone	WYOMING BASIN
WY09C-142	Base	WB0343	SAGE CREEK - HOO DOO RANCH	44.371713	-109.033727	BIGHORN	5590	47.2	Yellowstone-Shoshone	BIGHORN BASIN FOOTHILLS
WY09C-143	Base	MRW0179	SUNLIGHT CREEK - ABOVE ELK CREEK	44.760255	-109.447617	YELLOWSTONE	6066	145.0	Yellowstone-Shoshone	SEDIMENTARY MOUNTAINS
WY09C-145	Base	WB0346	SHOSHONE RIVER - BELOW EAGLENEST CREEK	44.691164	-108.896870	BIGHORN	4397	1881.0	Yellowstone-Shoshone	WYOMING BASIN
WY09C-146	Base	WB0348	SHOSHONE RIVER - ABOVE SAGE CREEK LOVELL	44.842635	-108.417330	BIGHORN	3792	2440.0	Yellowstone-Shoshone	WYOMING BASIN
WY09C-150	Base	MRW0178	SOUTH FORK SHOSHONE RIVER - ABOVE CABIN CREEK	44.111488	-109.635283	BIGHORN	6464	194.0	Yellowstone-Shoshone	VOLCANIC MOUNTAINS & VALLEYS
WY09C-401	OverSample	WB0373	DRY CREEK - BRIDGER	44.485111	-108.478203	BIGHORN	4522	295.8	Big Horn Basin	WYOMING BASIN
WY09C-402	OverSample	WB0364	GOOSEBERRY CREEK - BELOW ENOS	43.994836	-108.704144	BIGHORN	5582	149.3	Big Horn Basin	WYOMING BASIN
WY09C-404	OverSample	WB0370	SPRING CREEK - CORRALS	44.224272	-109.155514	BIGHORN	7816	2.4	Big Horn Basin	BIGHORN BASIN FOOTHILLS
WY09C-405	OverSample	WB0371	GREYBULL RIVER - TOWN OF GREYBULL	44.471406	-108.060947	BIGHORN	3822	1234.2	Big Horn Basin	WYOMING BASIN
WY09C-406	OverSample	WB0366	FIFTEENMILE CREEK - BIG HORN CANAL	44.012986	-107.992461	BIGHORN	4061	555.8	Big Horn Basin	WYOMING BASIN
WY09C-407	OverSample	WB0367	BIGHORN RIVER - ORCHARD BENCH	44.347200	-108.011511	BIGHORN	3845	13921.0	Big Horn Basin	WYOMING BASIN
WY09C-408	OverSample	WB0369	RAWHIDE CREEK - TONOPAH	44.157169	-109.080117	BIGHORN	6552	31.4	Big Horn Basin	WYOMING BASIN
WY09C-409	OverSample	WB0363	GRASS CREEK - RED RIDGE	43.905339	-108.459450	BIGHORN	4968	127.9	Big Horn Basin	WYOMING BASIN
WY09C-427	OverSample	MRC0118	DUNCUM CREEK - ABOVE WAGONBOX CREEK	44.875576	-107.782492	BIGHORN	7590	9.6	West Big Horn	GRANITIC MOUNTAINS
WY09C-429	OverSample	WB0334	BUFFALO CREEK - ABOVE NOWOOD RIVER	44.134624	-107.538645	BIGHORN	4315	29.8	West Big Horn	WYOMING BASIN

Table 4 (cont.) – Target sites sampled as part of the Bighorn/Yellowstone Superbasin survey.

Survey ID	Type	StationID	WaterbodyName - Reach Name	Latitude	Longitude	HUC 6 Basin	Elevation (ft)	Watershed Area (mi^2)	HUC 8 Cluster	BIOREGION
WY09C-430	OverSample	WB0340	OTTER CREEK - ABOVE NOWOOD RIVER	43.883068	-107.378610	BIGHORN	4543	99.4	West Big Horn	BIGHORN BASIN FOOTHILLS
WY09C-432	OverSample	WB0336	CROOKED CREEK - ABOVE YELLOWTAIL RESERVOIR	44.965038	-108.273967	BIGHORN	3646	118.5	West Big Horn	BIGHORN BASIN FOOTHILLS
WY09C-433	OverSample	WB0335	CANYON CREEK - RED BLUFF	44.010211	-107.524408	BIGHORN	4568	41.0	West Big Horn	BIGHORN BASIN FOOTHILLS
WY09C-435	OverSample	MRC0117	ADELAIDE CREEK - ABOVE ADELAIDE LAKE	44.515029	-107.387411	BIGHORN	9274	1.7	West Big Horn	GRANITIC MOUNTAINS
WY09C-453	OverSample	MRW0184	WIGGINS FORK - CALDWELL	43.759142	-109.552283	BIGHORN	7818	154.4	Wind River	VOLCANIC MOUNTAINS & VALLEYS
WY09C-454	OverSample	MRW0182	WARM SPRINGS CREEK - UNION PASS ROAD	43.558553	-109.811350	BIGHORN	8279	76.3	Wind River	SEDIMENTARY MOUNTAINS
WY09C-477	OverSample	WB0344	SAGE CREEK - ABOVE FRANNIE	44.979817	-108.616634	BIGHORN	4209	241.4	Yellowstone-Shoshone	WYOMING BASIN
WY09C-478	OverSample	WB0347	SHOSHONE RIVER - ABOVE WILLWOOD DRAW	44.703855	-108.750234	BIGHORN	4176	1987.0	Yellowstone-Shoshone	WYOMING BASIN
WY09C-480	OverSample	WB0342	ROCK CREEK - ABOVE BUTTONHOLE CREEK	44.299227	-109.377178	BIGHORN	6630	20.4	Yellowstone-Shoshone	VOLCANIC MOUNTAINS & VALLEYS
WY09C-481	OverSample	WB0351	WHISTLE CREEK - HERITAGE FLP	44.746228	-108.567036	BIGHORN	4056	98.4	Yellowstone-Shoshone	WYOMING BASIN
WY09C-482	OverSample	WB0345	SHOSHONE RIVER - CORBETT TUNNEL	44.612089	-108.945226	BIGHORN	4560	1810.0	Yellowstone-Shoshone	WYOMING BASIN
WY09C-483	OverSample	MRW0177	LITTLE SUNLIGHT CREEK - ABOVE LITTLE SULPHUR CREEK	44.719770	-109.614924	YELLOWSTONE	7011	12.3	Yellowstone-Shoshone	SEDIMENTARY MOUNTAINS
WY09C-484	OverSample	MRW0176	ELK FORK - ABOVE FROST CREEK	44.400322	-109.674992	BIGHORN	6492	86.1	Yellowstone-Shoshone	VOLCANIC MOUNTAINS & VALLEYS

Figure 3 – Estimated target stream and river length relative to access denied, inaccessible and non-target lengths at the Bighorn/Yellowstone Superbasin and HUC 8 cluster scales based on 77 evaluated sites. Error bars represent the 95% confidence intervals.



Statewide, the WSII assigned 38% of perennial stream length to both 'least-disturbed' and 'most-disturbed' whereas 24% was considered 'indeterminate'. Among the four HUC 8 clusters, the Wind River exhibited the largest percentage of least-disturbed stream miles with 63%. The Big Horn Basin cluster attained the lowest percentages of least-disturbed stream miles with 21%. The highest percentages of most-disturbed stream miles were located in the West Big Horn and Big Horn Basin HUC 8 clusters with 51% and 67%, respectively.

The WY RIVPACS assigned a greater percentage of stream miles to the least-disturbed condition - 44% relative to the WSII (Figure 5). Somewhat less than the WSII, the percentage of stream length in the most-disturbed condition according to the WY RIVPACS was 30%. Approximately 62% of stream length in the Wind River was in the least-disturbed condition (Figure 5). Similar to the WSII, the highest percentages of most-disturbed stream miles from the WYRIVPACS were found in the West Big Horn (43%) and Big Horn Basin (38%). Contrary to the WSII, the lowest percentage of least-disturbed streams was found in the West Big Horn at 31%.

Information from both the WSII and WY RIVPACS ratings along with considerations for multi-habitat samples and effluent dominant systems, were incorporated into WDEQ/WQD's aquatic life use matrix to determine the final biological condition for the BYS. Approximately 56% and 26% of the BYS assessed targeted perennial streams were in the 'least-disturbed' and 'most-disturbed' condition, respectively (Figure 6).

Among the four HUC 8 clusters, the Wind River attained the highest percentage of 'least-disturbed' stream miles at 97% and consequently the lowest percentage of 'most-disturbed' stream miles at 3% (Figure 6). Among all HUC 8 clusters, the Big Horn Basin exhibited the highest percentage of 'most-disturbed' stream miles at 48% while also possessing the lowest number of 'least-disturbed' stream miles at 27% (Figure 6). The West Big Horn and Yellowstone-Shoshone had 'least-disturbed' percentages of 57% and 39%, respectively (Figure 6). The 'most-disturbed' percentages for the West Big Horn and Yellowstone-Shoshone were 34% and 19%, respectively (Figure 6).

DRINKING WATER SUITABILITY AND HUMAN HEALTH CONDITION

For the BYS survey, 70% of the assessed targeted perennial streams were in the least-disturbed condition for *E. coli* concentrations (Appendix 1, Table 5). Among HUC 8 clusters, the Big Horn Basin attained the lowest percentage of least-disturbed *E. coli* condition stream miles at 55% while the highest percentage was found in the Wind River (84%). All concentrations of total cadmium, nitrate+nitrite-N, total selenium and total zinc were below the least-disturbed thresholds for drinking water suitability. Approximately 98% of perennial streams in the BYS had total arsenic concentrations below the least-disturbed threshold for drinking water suitability.

PHYSICOCHEMICAL STRESSORS TO BIOLOGICAL CONDITION

NUTRIENTS

Throughout the BYS, the percentage of stream length in the least-disturbed nitrate+nitrite-N condition was 67% whereas 23% of streams were in the most-disturbed condition (Appendix 2, Table 6). The highest percentage of BYS streams in the most-disturbed nitrate+nitrite-N condition (42%) occurred in the Yellowstone-Shoshone.

Approximately 79% of BYS stream length was in the least-disturbed total phosphorus condition (Appendix 3, Table 6). Twenty-one percent of perennial streams in the BYS were in the most-disturbed total phosphorus condition (Appendix 3, Table 4). The percentage of stream miles in

Figure 4 – Biological condition of targeted perennial streams and rivers in the Bighorn/Yellowstone Superbasin based on results from the Wyoming Stream Integrity Index (WSII). Error bars represent the 95% confidence intervals.

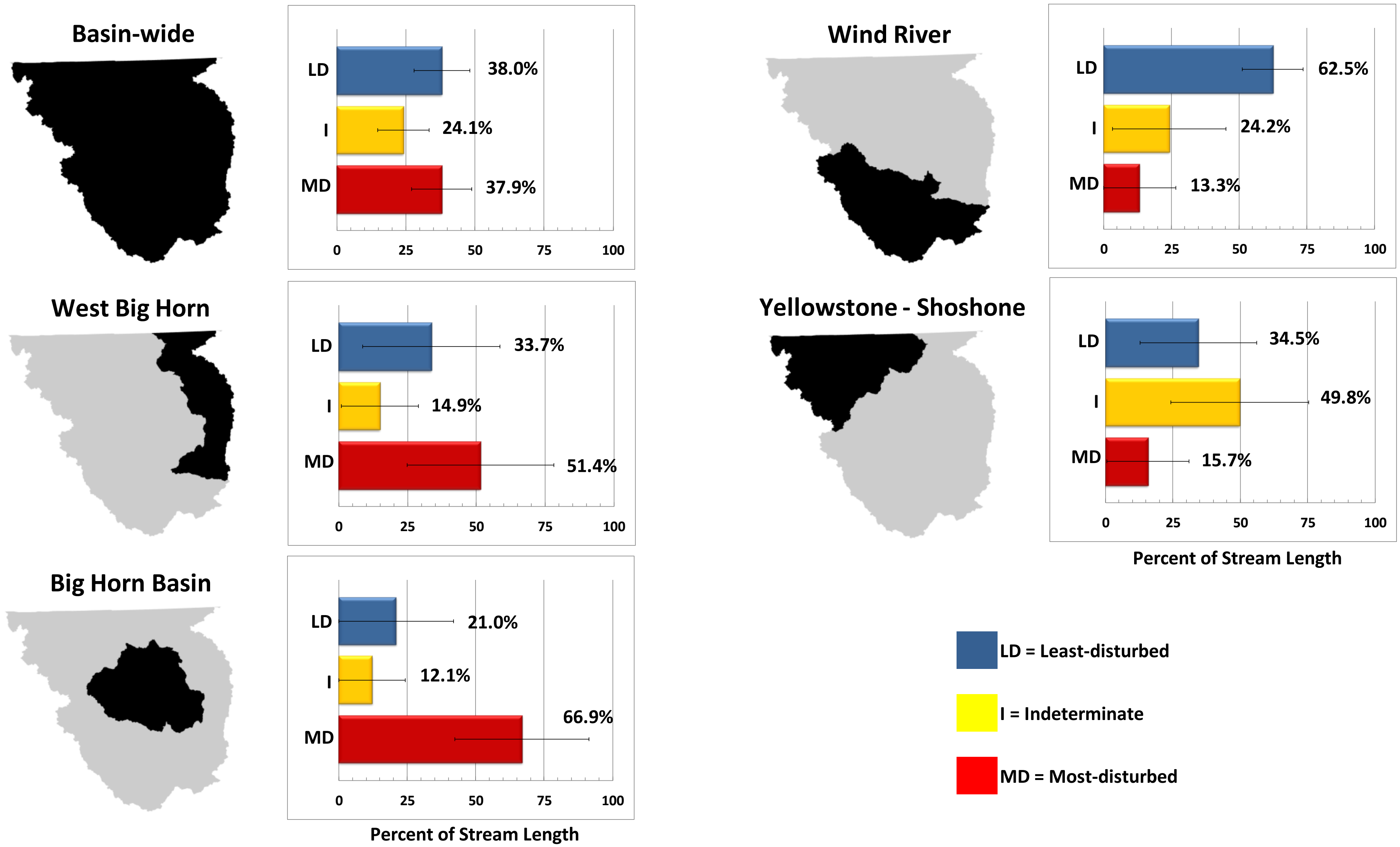


Figure 5 - Biological condition of targeted perennial streams and rivers in the Bighorn/Yellowstone Superbasin based on results from the Wyoming River InVertebrate Prediction And Classification System (WY RIVPACS). Error bars represent the 95% confidence intervals

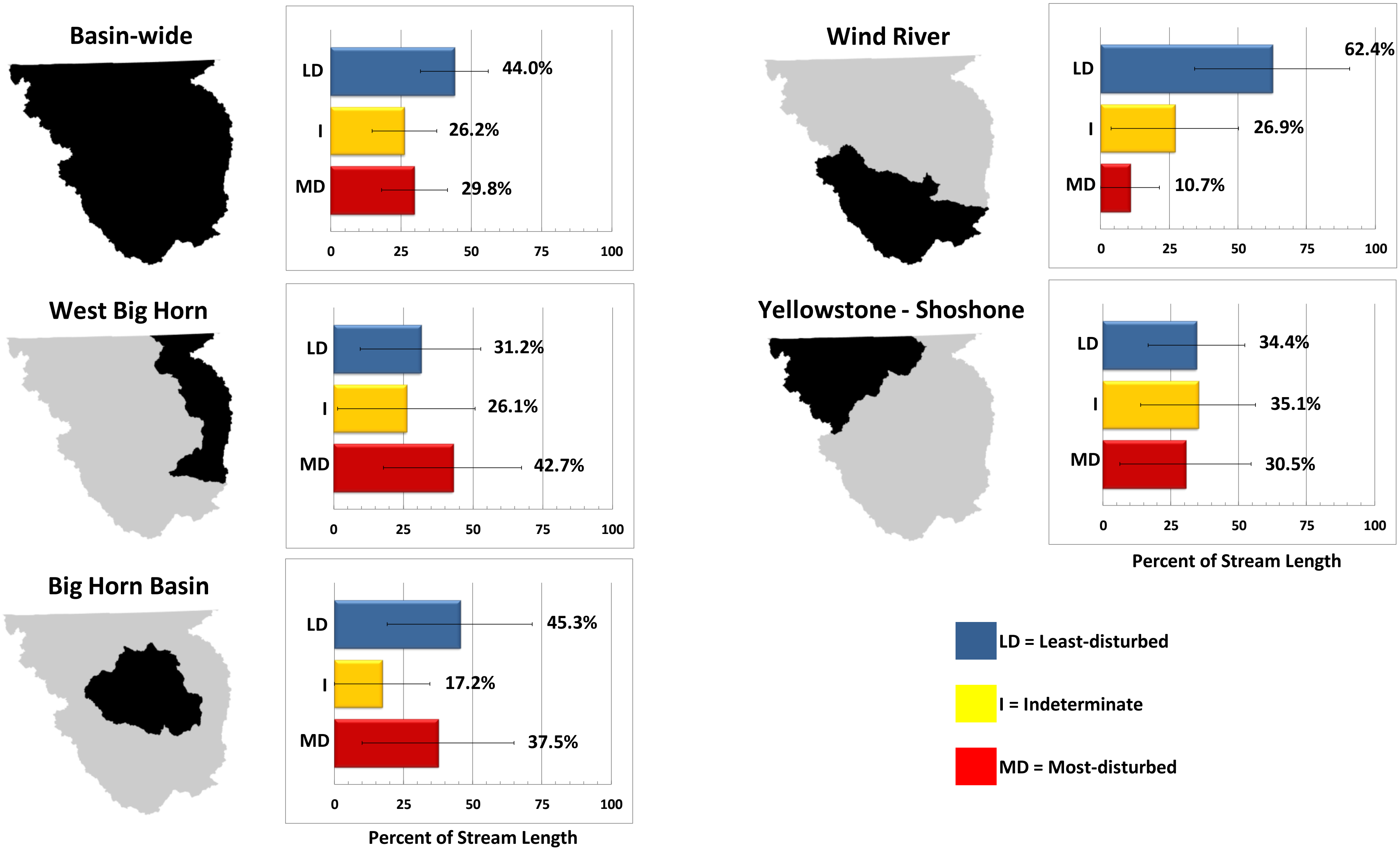


Figure 6 - Biological condition of targeted perennial streams and rivers in the Bighorn/Yellowstone Superbasin based on WDEQ/WQD's aquatic life use matrix. Error bars represent the 95% confidence intervals.

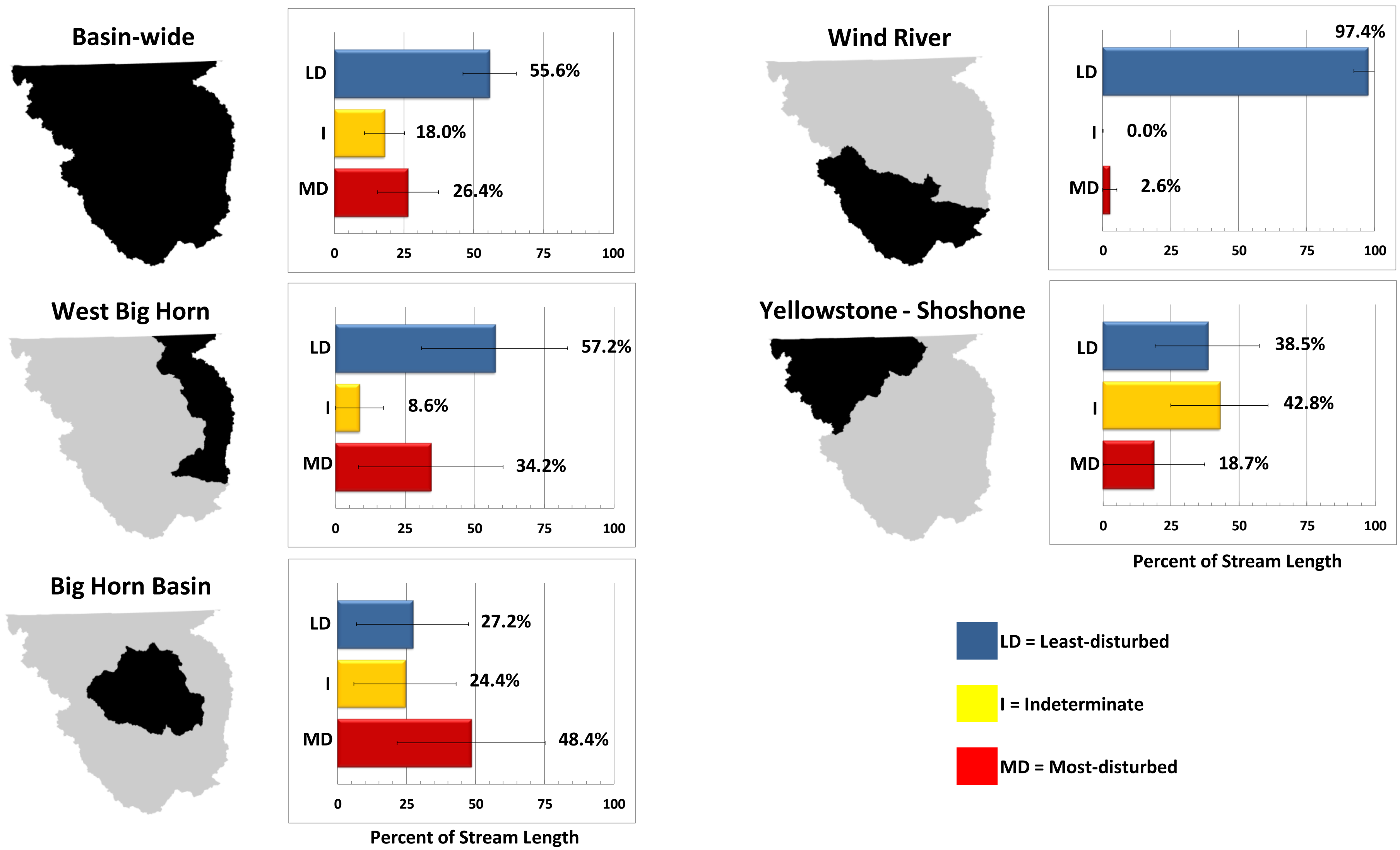


Table 5 –Stressor condition estimates associated with drinking water suitability and human health condition for WDEQ/WQD's 2010 Bighorn/Yellowstone survey.

		Bighorn/Yellowstone Superbasin	Bighorn/Yellowstone Superbasin HUC 8 Clusters			
			Big Horn Basin	West Big Horn	Wind River	Yellowstone/Shoshone
Stressor [Human Health Condition]		% of Stream Length	% of Stream Length	% of Stream Length	% of Stream Length	% of Stream Length
Escherichia coli	Least-disturbed	70	55	75	84	65
	Most-disturbed	30	45	25	16	35
Stressor [Drinking Water Suitability]						
Nitrate+Nitrite-N	Least-disturbed	100	100	100	100	100
	Most-disturbed	0	0	0	0	0
Total Arsenic	Least-disturbed	98	96	100	100	96
	Most-disturbed	2	4	0	0	4
Total Cadmium	Least-disturbed	100	100	100	100	100
	Most-disturbed	0	0	0	0	0
Total Zinc	Least-disturbed	100	100	100	100	100
	Most-disturbed	0	0	0	0	0
Total Selenium	Least-disturbed	100	100	100	100	100
	Most-disturbed	0	0	0	0	0

Table 6 - Stressor condition estimates associated with biological condition for WDEQ/WQD's 2010 Bighorn/Yellowstone survey.

		Bighorn/Yellowstone Superbasin	Bighorn/Yellowstone Superbasin HUC 8 Clusters: Big Horn Basin	West Big Horn	Wind River	Yellowstone/ Shoshone
Biological Condition		**% of Stream Length**	**% of Stream Length**	**% of Stream Length**	**% of Stream Length**	**% of Stream Length**
	Least-disturbed	56	27	57	97	38
	Intermediate	18	24	9	0	43
	Most-disturbed	26	48	34	3	19
Stressor [Indicator]						
Nitrate+Nitrite-N	Least-disturbed	67	72	55	88	50
	Intermediate	9	8	9	12	8
	Most-disturbed	23	20	36	0	42
Total Phosphorus	Least-disturbed	79	56	83	100	81
	Most-disturbed	21	44	17	0	19
Total Nitrogen	Least-disturbed	45	25	44	76	31
	Intermediate	33	50	31	13	37
	Most-disturbed	23	25	26	11	31
Salinity	Least-disturbed	25	9	22	38	33
	Intermediate	38	21	36	47	50
	Most-disturbed	38	70	42	15	17
TSS	Least-disturbed	5	8	0	8	0
	Intermediate	70	42	91	77	73
	Most-disturbed	26	50	9	15	27
Chloride	Least-disturbed	97	88	100	100	100
	Most-disturbed	3	12	0	0	0
Sulfate	Least-disturbed	97	88	100	100	100
	Most-disturbed	3	12	0	0	0
pH	Least-disturbed	100	100	100	100	100
	Most-disturbed	0	0	0	0	0
Dissolved Arsenic	Least-disturbed	100	100	100	100	100
	Most-disturbed	0	0	0	0	0
Dissolved Cadmium	Least-disturbed	100	100	100	100	100
	Most-disturbed	0	0	0	0	0
Dissolved Zinc	Least-disturbed	97	90	100	100	100
	Most-disturbed	3	10	0	0	0
Total Selenium	Least-disturbed	92	83	91	100	96
	Most-disturbed	8	17	9	0	4
Riparian Disturbance	Least-disturbed	83	67	84	86	100
	Most-disturbed	17	33	16	14	0
Channel Instability	Least-disturbed	66	54	75	77	57
	Most-disturbed	34	46	25	23	43
Excess Sediment	Least-disturbed	68	54	83	77	57
	Most-disturbed	32	46	17	23	43
Accelerated Bank Erosion	Least-disturbed	91	84	92	89	100
	Most-disturbed	9	16	8	11	0
Channel Incision	Least-disturbed	91	96	88	88	100
	Most-disturbed	9	4	12	12	0

the most-disturbed total phosphorus condition was highest in the Big Horn Basin at 44%.

The percentage of BYS streams in the least-disturbed total nitrogen condition was 45% with 23% in the most-disturbed condition (Appendix 4, Table 6). Among the four HUC 8 clusters, the Yellowstone-Shoshone exhibited the highest percentage of most-disturbed stream miles for total nitrogen at 31%. BYS stream miles in the most-disturbed total nitrogen condition were often associated with the most-disturbed total phosphorus condition.

SALINITY

The BYS survey identified least-disturbed salinity conditions in 25% of streams (Appendix 5, Table 6). Approximately 38% of streams for the BYS survey were in the most-disturbed condition (Appendix 5, Table 6). Among the four HUC 8 clusters, the Big Horn Basin (70%) and West Big Horn (42%) exhibited the highest percentages of most-disturbed stream miles for salinity.

SELENIUM

The BYS survey identified 8% of stream miles in the most-disturbed condition for selenium with the remaining 92% in the least-disturbed condition (Appendix 6, Table 6). All HUC 8 clusters, with the exception of the Wind River (which had 0%), contained stream miles within the most-disturbed selenium condition with the Big Horn Basin attaining the highest percentage at 17%. BYS stream miles in the most-disturbed selenium condition were often associated with the most-disturbed salinity and/or TSS conditions.

TOTAL SUSPENDED SOLIDS

Throughout the BYS, 26% of streams miles were in the most-disturbed condition and 5% in the least-disturbed condition for total suspended solids (Appendix 7, Table 6). The vast majority of BYS streams (70%) were in the indeterminate TSS condition. The highest percentage of stream miles in the most-disturbed TSS condition was found in the Big Horn Basin (50%). Similar to the BYS scale results, the majority of stream miles among the four HUC 8 clusters were found to be in the indeterminate TSS condition.

CHLORIDE, pH and SULFATE

Approximately 97% of stream miles were in the least-disturbed condition for chloride (Appendix 8, Table 6). The remaining 3% of BYS stream miles represented the most-disturbed condition which was found entirely within the Big Horn Basin HUC 8 cluster. All waters monitored for the BYS survey were within WDEQ/WQD's pH criteria range protective of aquatic life uses (Table 6).

Only 3% of stream miles were in the most-disturbed sulfate condition with the remaining 97% in the least-disturbed condition (Appendix 9, Table 6). BYS stream miles in the most-disturbed sulfate condition were represented exclusively in the Big Horn Basin HUC 8 cluster. Stream miles in the most-disturbed sulfate condition were all associated with the most-disturbed chloride condition.

ARSENIC, CADMIUM and ZINC

All streams monitored as part of the BYS survey for dissolved arsenic and dissolved cadmium were in the least-disturbed condition (Table 6). The most-disturbed dissolved zinc condition was present in 3% of BYS stream miles (97% least-disturbed) all of which were found within the Big Horn Basin HUC 8 cluster (Appendix 10, Table 6).

PHYSICAL STRESSORS TO BIOLOGICAL CONDITION

RIPARIAN DISTURBANCE

Riparian disturbance exceeded the most-disturbed condition thresholds in only 17% of stream length in the BYS (Appendix 11, Table 6). Riparian disturbance in the BYS was often associated with limited or absent riparian vegetation cover along stream banks combined with low diversity in age-class and/or composition of riparian/wetland vegetation. The most-disturbed riparian disturbance condition was most prevalent in the Big Horn Basin at 33% of stream length.

CHANNEL INSTABILITY

Throughout the BYS, 34% of stream length exhibited indicators of channel instability (excess sediment, accelerated bank erosion and/or active channel incision) (Appendix 11, Table 6). The highest proportion of streams with channel instability occurred in the Big Horn Basin (46%) though the Yellowstone-Shoshone was a close second at 43%.

Partitioning channel instability into its three component sub-stressors revealed that a large proportion (32%) of BYS stream miles with channel instability problems were attributed to excess sediment (Appendix 12, Table 6). The percentages of stream miles in the BYS with accelerated bank erosion or active channel incision were each 9% (Appendix 12, Table 6). Among the four HUC 8 clusters, excess sediment (46%) and accelerated bank erosion (16%) were most common in the Big Horn Basin. Active channel incision, though relatively low throughout the BYS, attained the highest relative extents (12% each) in the West Bighorn and Wind River HUC 8 clusters.

RANKING OF STRESSORS

Relative Extent – For both the BYS and HUC 8 clusters, stressors are ranked according to the proportion of stream length that was in the most-disturbed condition for that stressor (Figure 7). Salinity was the most common stressor (38%) that has the potential to affect aquatic life in perennial streams of the BYS (Figure 7). Channel instability was the second most common stressor affecting 34% of perennial stream miles, followed by TSS, which affected 26% of stream miles. Nutrients (nitrate+nitrite-N, total phosphorus and total nitrogen) and riparian disturbance were mid-range among stressor rankings for relative extent, affecting anywhere from 17% to 23% of perennial stream lengths within the BYS (Figure 7). Total selenium, sulfate, chloride and zinc were the least common stressors, each affecting approximately 8% or less of BYS perennial stream length (Figure 7).

Salinity and TSS were the most common stressors within the Big Horn Basin (70% and 50%, respectively) HUC 8 cluster (Figure 7). Channel instability (23%) was the top stressor in the Wind River, with salinity and TSS a tie for second at 15% (Figure 7). Salinity (42%) and nitrate+nitrate-N (36%) were the two most common stressors in the West Big Horn whereas channel instability (43%) and nitrate+nitrite-N (42%) were the top stressors within the Yellowstone-Shoshone (Figure 7).

Relative Risk - For the biological condition of BYS perennial streams and rivers as measured with benthic macroinvertebrates, elevated salinity presents the greatest relative risk at 5.1 (Figure 8). In other words, the most-disturbed biological condition is 5.1 times more likely to occur in streams having the most-disturbed salinity condition as streams with the least-disturbed salinity condition. Elevated total phosphorus exhibits the second-highest risk at 4.9 and elevated total selenium poses the third-highest risk of 3.7 (Figure 8). Results also indicate that elevated TSS and total nitrogen present little direct risk to the benthic macroinvertebrate communities of the BYS assuming no interactive effects with other pollutants.

DISCUSSION

Results from the 2010 BYS survey provide the first focused and standardized baseline evaluation on the biological and human health condition of perennial streams and rivers within the Bighorn and Yellowstone basins of Wyoming. The BYS survey represented the first of five ‘superbasins’ that will be monitored as part of WDEQ/WQD’s rotating basin probabilistic survey. Building upon the success of WDEQ’WQD’s statewide probabilistic surveys, results from the BYS survey enhance WDEQs ability to provide the most representative picture of water-quality conditions, presently and over

Figure 7 – Most-disturbed condition relative extent (% stream length) of chemical and physical stressors to biological condition at the Bighorn/Yellowstone Superbasin and HUC 8 Cluster scales. Error bars represent the 95% confidence intervals.

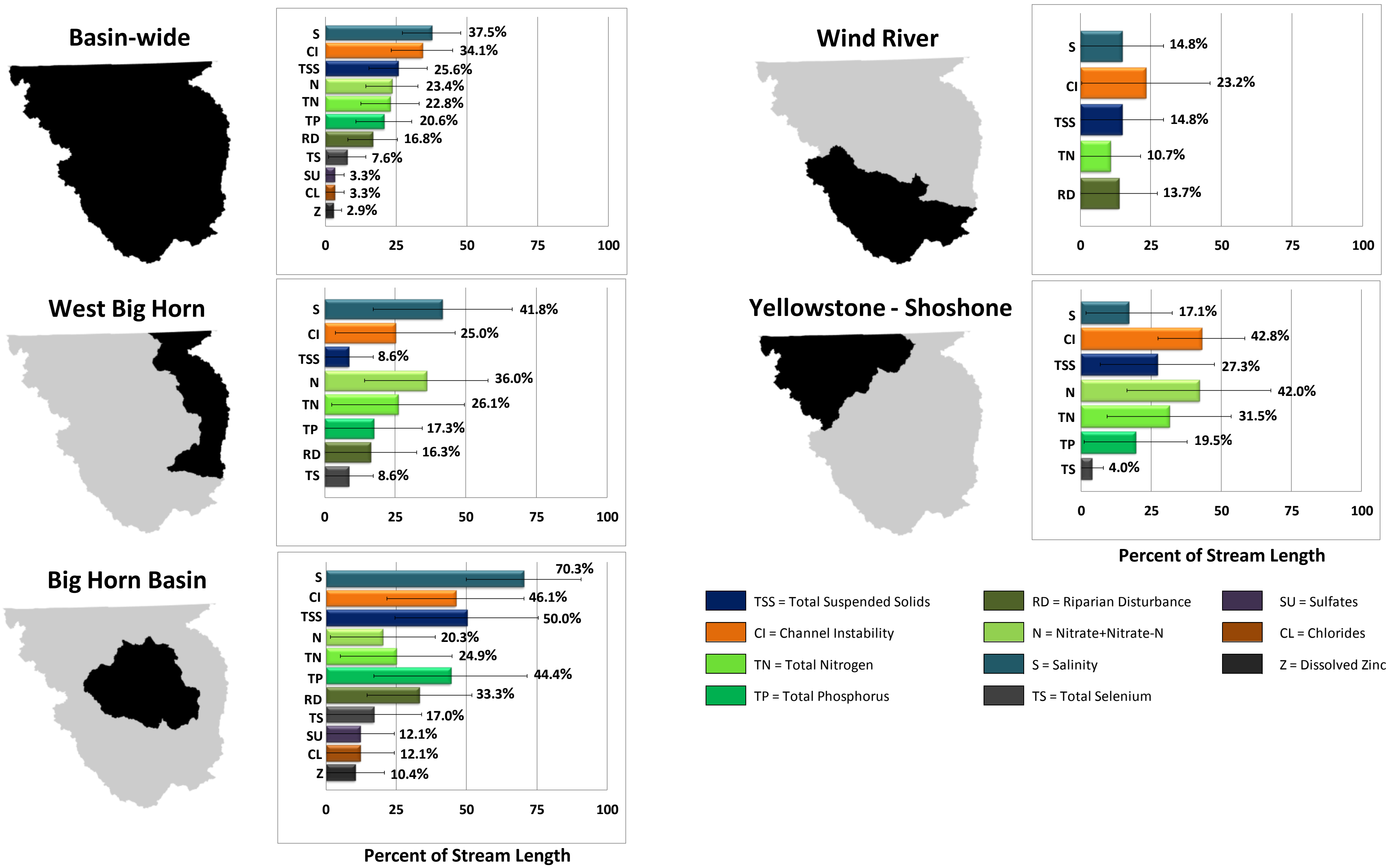
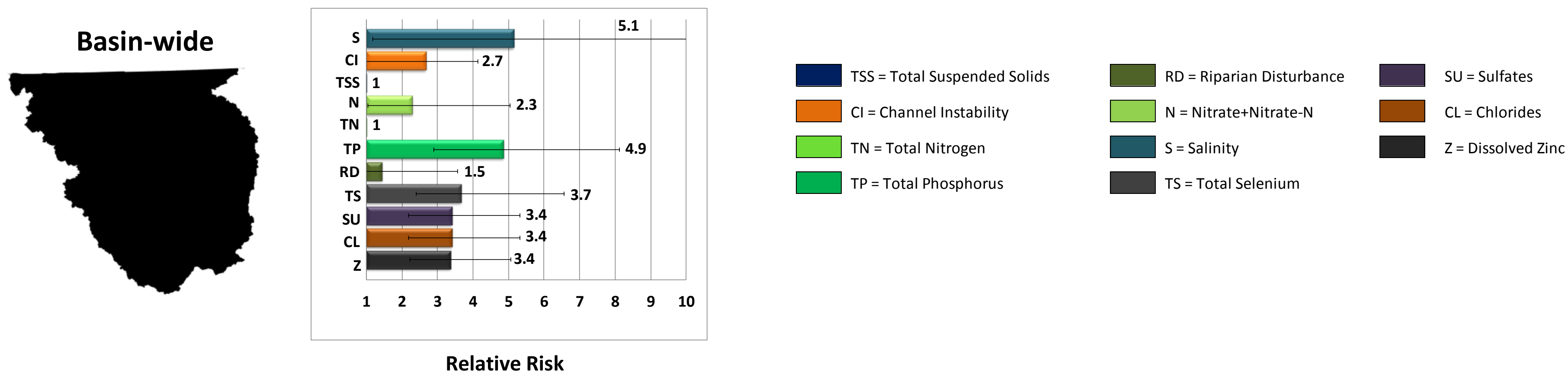


Figure 8 - Relative risk values of chemical and physical stressors to biological condition at the Bighorn/Yellowstone Superbasin scale. Error bars represent the 95% confidence intervals.



time and identify chemical and physical stressors to biological and human health condition without a complete census of all perennial streams and rivers within the basin.

The water quality condition of perennial streams and rivers in the BYS is favorable, with over one-half (56%) of the resource currently considered in the least-disturbed biological condition and only 26% of the resource in the most-disturbed condition. Among the four HUC 8 clusters, perennial streams and rivers in the Wind River are in much better condition biologically (97% least-disturbed) relative to those in the West Big Horn (57% least-disturbed), Yellowstone-Shoshone (39% least-disturbed) and Big Horn Basin (27% least-disturbed). The Big Horn Basin possesses the highest percentage of perennial stream miles in the most-disturbed condition (48%) compared to the West Big Horn (34%), Yellowstone-Shoshone (19%) and Wind River (3%).

This survey found that the most widespread or common stressors in the BYS were salinity and channel instability, affecting approximately 38% and 34% of perennial stream and river miles, respectively. Salinity was also the dominant stressor in the Big Horn Basin (70%) and West Big Horn (42%). Total suspended solids (TSS) (50%) and nitrate+nitrate-N (36%) were the second most common stressors in the Big Horn Basin and West Big Horn, respectively. Channel instability (43%) and nitrate+nitrate-N (42%) were near equivalent as the top two stressors in the Yellowstone-Shoshone. Channel instability (23%) was also the dominant stressor in the Wind River with salinity and TSS tied for second at 15%.

The percentage of perennial stream miles affected by elevated salinity may be overestimated within the interior xeric region of the BYS (i.e Wyoming Basin bioregion), due to limitations within Wyoming's reference network. A large proportion of reference sites representative of xeric regions in Wyoming are located within ecotones between the mountains and basin environments. Consequently, the reference salinity range for xeric regions is more representative of these ecotones rather than the more arid interior. This has relevance because salinity is a conservative parameter in that it does not decay or interact with other constituents. Stream salinity persists and can increase due to evapoconcentration, evapotranspiration and important in the BYS, contact with alkaline soils and geology as water travels downstream into the interior. Salinity within some of these ecotone regions may be less than what would occur naturally downstream in the xeric interior. This presents a challenge when developing a single set of percentile-based salinity thresholds applicable throughout the BYS interior. This challenge notwithstanding, salinity measurements in many xeric region BYS streams were two to thirteen times the most-disturbed salinity threshold. Also, many of the streams with elevated salinity are influenced by effluent from industrial and municipal facilities as well as irrigated agriculture and higher degrees of flow alteration. Together, this information highlights that elevated salinity is worthy of attention as a pollutant to biological condition in the BYS. Indeed, biological condition in BYS streams is 5.1 times more likely to be in a most-disturbed condition when elevated salinity is present than when elevated salinity is not present.

The second most common stressor in the BYS, channel instability, is a composite physical stressor that includes excess sedimentation, accelerated stream bank erosion and channel incision. Excess sedimentation was by far the dominant of the three sub-stressors in the BYS (32%) and among all four regions' (17% to 44%) stream miles documented for channel instability. The elevated percentage of excess sedimentation during the BYS survey may be attributed to increased rates of geomorphic adjustments initiated by historic anthropogenic disturbances that occurred anytime between a few decades to a century in the past. Rates of these adjustments could have been exacerbated by the record flows of 2010 causing accelerated bank erosion, active channel incision and lateral channel migration to occur. This inference is supported by evidence indicating that some streams with channel instability were deeply incised with minimal active floodplains had accelerated erosion of steep banks with minimal surface protection and high bank-height ratios despite the fact that riparian disturbance was minimal to absent. Accelerated bank erosion tends to increase the risk for accelerated lateral channel migration. This migration can in turn increase the risk for channel avulsions (abandonment of part or all of a channel) that can also trigger channel incision. For this reason, increases in channel incision may also be partially linked to increases in accelerated bank erosion. Considered together, these observations suggest instability associated with legacy impacts (e.g. channel relocation, meander cutoffs, riparian vegetation removal). In addition, there is a high likelihood that the documented channel instability in some perennial streams can also be attributed to current anthropogenic impacts to the riparian area. This is important in the Big Horn Basin considering riparian disturbance was documented as a stressor for 1/3 of perennial stream miles in this area (the highest among all four HUC 8 clusters).

Flow alterations, particularly withdrawals, can also facilitate excess sedimentation via a reduction in sediment transport capacity of the channel. Flow alterations affect almost 64% of perennial stream and river miles in the BYS. However, while the detrimental effect of flow manipulations to biological condition is likely, the magnitude of these alterations and influence to biological condition remains largely speculative without additional investigation. Together, channel adjustment processes due to past and present anthropogenic disturbances, as well as record high flows were likely the most important factors driving the widespread excess sediment and channel instability stressors that influenced biological condition of BYS streams and rivers in 2010. The wide-spread extent of channel instability in the BYS (which was nearly equivalent to salinity) and its potential effect on aquatic life is apparent in that BYS streams are 2.7 times more likely to be in a most-disturbed biological condition when channel instability is present as when channel instability is not present.

The prevalence of TSS as the third most common stressor throughout the BYS and the second most common stressor in the Big Horn Basin raises questions as to the potential sources of TSS and its relative influence on aquatic life. As mentioned previously, TSS consists of both organic and inorganic suspended materials and is naturally greater during runoff from snowmelt or thunderstorms. TSS samples gathered for this study were collected during the typical baseflow season, therefore flow-dependent increases in TSS were minimized as a possible cause of elevated TSS in the BYS. Elevated TSS in some BYS streams can occur naturally as their watersheds may contain highly erodible silt/clay bearing geology and soils combined with naturally sparse vegetation cover (Peterson et al. 2004). However, in areas absent such overriding natural influences, human activities associated with irrigation drainage, flow augmentation and industrial or municipal effluent may contribute to BYS streams with a most-disturbed TSS condition.

Anthropogenic contributions of inorganic TSS (silts and clays) may also be a transport mechanism for other pollutants in the BYS (Peterson et al. 2004). Indeed, 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 reasonable linkage between TSS and nutrients in the BYS, as several streams with a most-disturbed TSS condition were also assigned a most-disturbed condition for one or more nutrients. Whether TSS-linked detrimental effects to aquatic life occur in the BYS 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 no additional risk to aquatic life when present in BYS streams. This apparent dichotomy in TSS between its third highest extent and no additional risk may be due in large part to the fact that TSS indirectly impacts the biological indicator selected for this study. Definitive data on the direct effects of suspended inorganic sediment to benthic macroinvertebrates is limited (Ward 1992). Existing empirical studies suggest that stream insects as a group are relatively tolerant of elevated concentrations of TSS and that the most dramatic effects of inorganic suspended sediment occur after deposition on the channel bed (Ward 1992). Thus, the use of benthic macroinvertebrates as the biological indicator for this study may have precluded the ability to detect direct effects from TSS to the aquatic benthos. Once elevated 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. What cannot be accounted for in this study though, is the capture of elevated TSS by abundant benthic algae which can result in a dense algal/sediment matrix that is of particular importance in some large rivers of the BYS. 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 light of these complexities, the prevalence of elevated TSS in the BYS may warrant further investigation to ascertain whether TSS in the most-disturbed condition translates to a direct degradation of biological condition.

Nutrients (nitrate+nitrite-N, total phosphorus and total nitrogen) were mid-range among stressor rankings, affecting anywhere from 21% to 23% of perennial streams within the BYS. Some regions such as the Big Horn Basin and Yellowstone-Shoshone exhibited higher percentages of perennial streams with most-disturbed conditions for one or more nutrient stressors. Total nitrogen, total phosphorus and nitrate+nitrite-N are not directly toxic to aquatic life. However, the processes that control metabolism and nutrient cycling in rivers, their influences to parameters such as dissolved oxygen and pH, and the critical thresholds at which different aquatic life (e.g. fishes versus benthic macroinvertebrates) begin to be negatively affected can vary considerably in streams and rivers. The percentages of BYS perennial streams in the most-disturbed condition for one or more nutrients, does suggest there may be a higher probability of detrimental influences to aquatic life. Indeed, aquatic life in BYS streams are 4.9 and 2.3 times more likely to be in a most-disturbed biological condition when total phosphorus and nitrate+nitrite-N are present, respectively, in the most-disturbed condition. Interestingly, there was no higher risk of a most-disturbed biological condition when total nitrogen was elevated in a BYS stream as when total nitrogen was not elevated. Total nitrogen is an amalgamation of ammonia-N, nitrate+nitrite-N and organic nitrogen. Each component of total nitrogen can result in varying effects to aquatic life. However, when these three components are evaluated as one stressor, the individual effect of one component such as nitrate+nitrite-N may be negated by the remaining components for which effects are absent or variable. This may be at least one reason for total nitrogen's apparent lack of influence on biological condition.

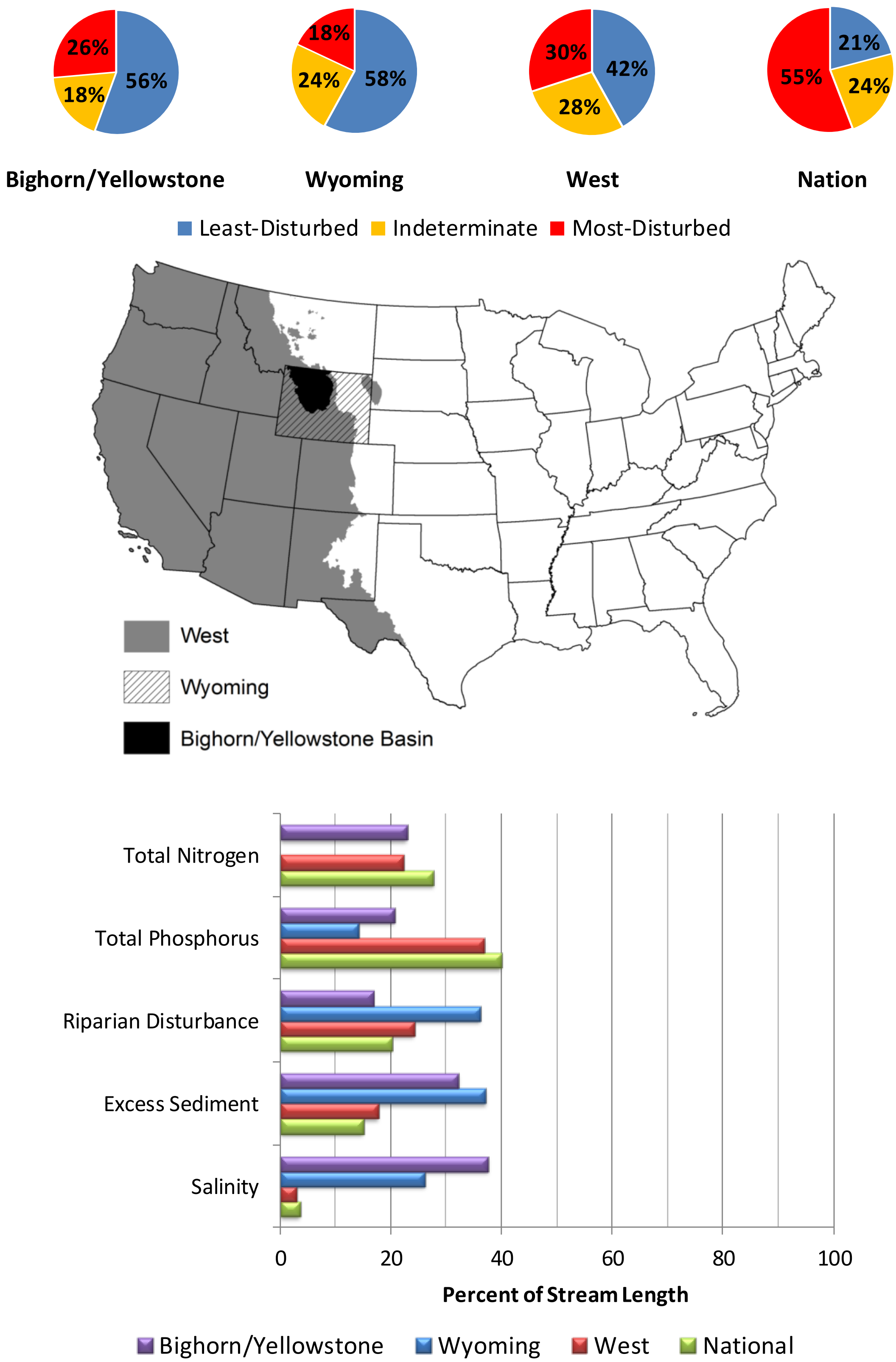
Dissolved arsenic, dissolved cadmium, chloride, sulfate, total selenium and dissolved zinc are known toxins to aquatic life at elevated concentrations. However, the most-disturbed condition relative extents for these analytes were low or absent in the BYS. Specifically, less than 8% of stream miles in the BYS exhibited most-disturbed conditions for total selenium, sulfate, chloride and dissolved zinc. Stream miles in the most-disturbed total selenium condition exhibited total selenium concentrations that were only marginally above the threshold and could be influenced by a combination of anthropogenic sources (e.g. industrial effluent, irrigation-induced soil leaching) and natural seleniferous-bearing soils and marine shale geology. Concentrations of dissolved arsenic and dissolved cadmium and levels of pH sampled during the BYS survey were all below their associated least-disturbed thresholds for biological condition.

The extent of most-disturbed *E. coli* concentrations (an indicator of human health condition for recreational uses) in the BYS survey was 30%. Among the four regions, the Big Horn Basin (45%) and Yellowstone-Shoshone (35%) exhibited the highest percentages of the most-disturbed *E. coli* condition. Overall, these results imply that there is a high recreational condition at the BYS scale though the potential for a most-disturbed *E. coli* condition is greatest within the Big Horn Basin and Yellowstone-Shoshone regions. All concentrations of total cadmium, nitrate+nitrite-N, total selenium and total zinc were less than their associated least-disturbed drinking water suitability thresholds. Similarly, 98% of perennial stream miles in the BYS had total arsenic concentrations less than the least-disturbed threshold. This information suggests that waters within the BYS would require minimal treatment for these parameters to be suitable as drinking water supplies.

To place these results into a regional and national perspective, the BYS was compared to Wyoming, the combined mountainous and arid regions of twelve western states (i.e. 'West') and nationally with respect to biological condition and associated stressors. Comparisons of the BYS 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 the West and the lower 48 contiguous states of the nation are limited as a result of differences in biological expectations and stressor thresholds. Nevertheless, comparisons were justified since many of the same fundamental principles and design methodology were applied to the evaluation of biological condition regardless of scale or location. Only stressors common to the BYS, Wyoming, West and national surveys were compared.

The BYS is nearly equivalent to the entire state of Wyoming with regard to the percentage of stream miles in the least-disturbed biological condition (56% BYS vs. 58% Wyoming) (Figure 9) (Hargett and ZumBerge 2013). However, the percentage of stream miles in the BYS with a most-disturbed biological condition (26%) was greater than at the Wyoming scale (18%) (Figure 9). The BYS fairs better than the western United States with regard to least-disturbed (56% BYS vs. 42% West) though nearly equivalent in the most-disturbed (26% BYS vs. 30% West) biological conditions (USEPA 2013) (Figure 9). Excess sediment was the most common sub-stressor of channel instability throughout the BYS (32%) and Wyoming (37%) (Figure 9). Riparian disturbance was a notable stressor at all spatial scales (36% Wyoming, 24% West) though was least common in the BYS (17%) where the stressor ranked seventh among all stressors evaluated in the study. Both total nitrogen and total phosphorus were considered stressors in similar percentages of stream miles in both the BYS (23% and 21%, respectively) and the western United States (22% and 37%, respectively) (Figure 9). However, total phosphorus was the sixth-ranked stressor in the BYS (21%) and fifth-ranked at the Wyoming scale (14%).

Figure 9 - Biological condition (top) of perennial streams and rivers (by percentage of respective stream length) and relative extents (bottom) of stressors common to the Bighorn/Yellowstone Superbasin, Wyoming (Hargett and ZumBerge 2013), mountainous and arid regions of the western United States (USEPA 2013) and national (USEPA 2013) probabilistic surveys.



Nationally (lower 48 contiguous states), the percentage of stream miles in the least-disturbed biological condition (21%) is much less relative to the BYS (56%) (USEPA 2013) (Figure 9). Likewise, the percentage of national stream miles in the most-disturbed biological condition is 55% - much greater than the BYS's estimate of 26%. Whereas total phosphorus was the most common (40% of stream miles) stressor nationally, it was considered a stressor in only 21% of BYS stream miles or 6th ranked in terms of relative extent (Figure 9). Total nitrogen and riparian disturbance (28% and 20% of stream miles, respectively) were the second and third most common stressors nationally whereas estimates for these parameters were less in the BYS (23% and 17%, respectively). Excess sediment and salinity are less common stressors (15% and 4%, respectively) nationally relative to the BYS (32% and 38%, respectively).

RECOMMENDATIONS

The BYS survey was designed to provide an objective representative 'snap-shot' of biological and human health condition and identify associated stressors in perennial streams and rivers of the greater Bighorn and Yellowstone basins. While the BYS survey was not designed to determine if specific waterbodies are impaired or non-supportive of their designated aquatic life uses, the results do provide a baseline from which future progress can be measured and areas that may warrant additional investigation to ultimately improve water quality. This information can be integrated with existing planning, management directives and current pollutant reduction efforts being organized and implemented at the federal, state and local levels. It should be noted that 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.

Based on the results of this survey, elevated salinity, channel instability and elevated TSS were the three most common stressors in the BYS. The commonality of salinity and channel instability combined with their moderate to high relative risks, suggest that where benthic macroinvertebrates communities are determined to be degraded, efforts aimed at reduction in these two stressors could have broad benefits on biological condition of the BYS. Excess sediment was the most prominent of the three sub-stressors that comprised channel instability. Efforts to reduce excess sediment contributions to streams will not only help address channel instability, but may also reduce nutrient loading to streams in the BYS since sediment can function as a transport mechanism for pollutants such as total phosphorus. Because of its varying influences on different components of the aquatic community, evaluations of the effects of elevated TSS may require investigation into an additional component of the aquatic community. Specifically, fishes may be more directly affected by suspended sediment than benthic macroinvertebrates that are more likely to experience detrimental effects once the sediment is deposited. Because TSS can also serve as a vector for nutrients and other pollutants, linkages between TSS and these pollutants should be considered as part of these investigations. Elevated total phosphorus (6th most common stressor) occurred in 21% of stream miles within the BYS though possesses the second highest relative risk to biological condition. Elevated total phosphorus attained its greatest relative extents within the Big Horn Basin (44%) and Yellowstone-Shoshone (20%) regions. This information makes total phosphorus a potential target for reduction efforts in select areas of these regions where it may be a concern. This same rationale could be applied to elevated nitrate+nitrite-N, total selenium, sulfate, chlorides and zinc which all had moderate relative risks though varied in their commonality among different regions of the BYS.

Applying the relative risk values derived at the BYS scale and considering the relative extents of stressors within each HUC 8 cluster, the Big Horn Basin and Yellowstone-Shoshone emerge as two areas with the greatest potential need for additional investigation into whether aquatic life uses are being supported with respect to the influences of channel instability, elevated TSS and elevated total phosphorus. The highest relative extent percentage for nitrate+nitrite-N was also found in the Yellowstone-Shoshone. Similarly, the highest relative extent percentages for elevated salinity, total selenium, sulfate, chloride and zinc were found in the Big Horn Basin. The combination of multiple stressors along with varying extents and relative risks imply that where aquatic life may not be supported, the causes may be many and their effects to aquatic life variable and perhaps inter-related.

As of the writing of this report and based in part on the findings from the BYS survey, the WDEQ/WQD, in cooperation with other entities is continuing a multi-site targeted monitoring of the Shoshone River (located in the Yellowstone-Shoshone HUC 8 cluster) to determine aquatic life use support and identify the relative extent of potential causes/sources of non-support with a focus on suspended and excess sediment (WDEQ/WQD 2013c). Also based on the findings from the BYS survey, the WDEQ/WQD has implemented a multi-site targeted monitoring of Rawhide Creek (located in the Big Horn Basin HUC 8 cluster), a tributary to the Greybull River, to determine aquatic life use support and identify the relative extent of potential causes/sources of non-support with a focus on excess sediment (WDEQ/WQD 2013c).

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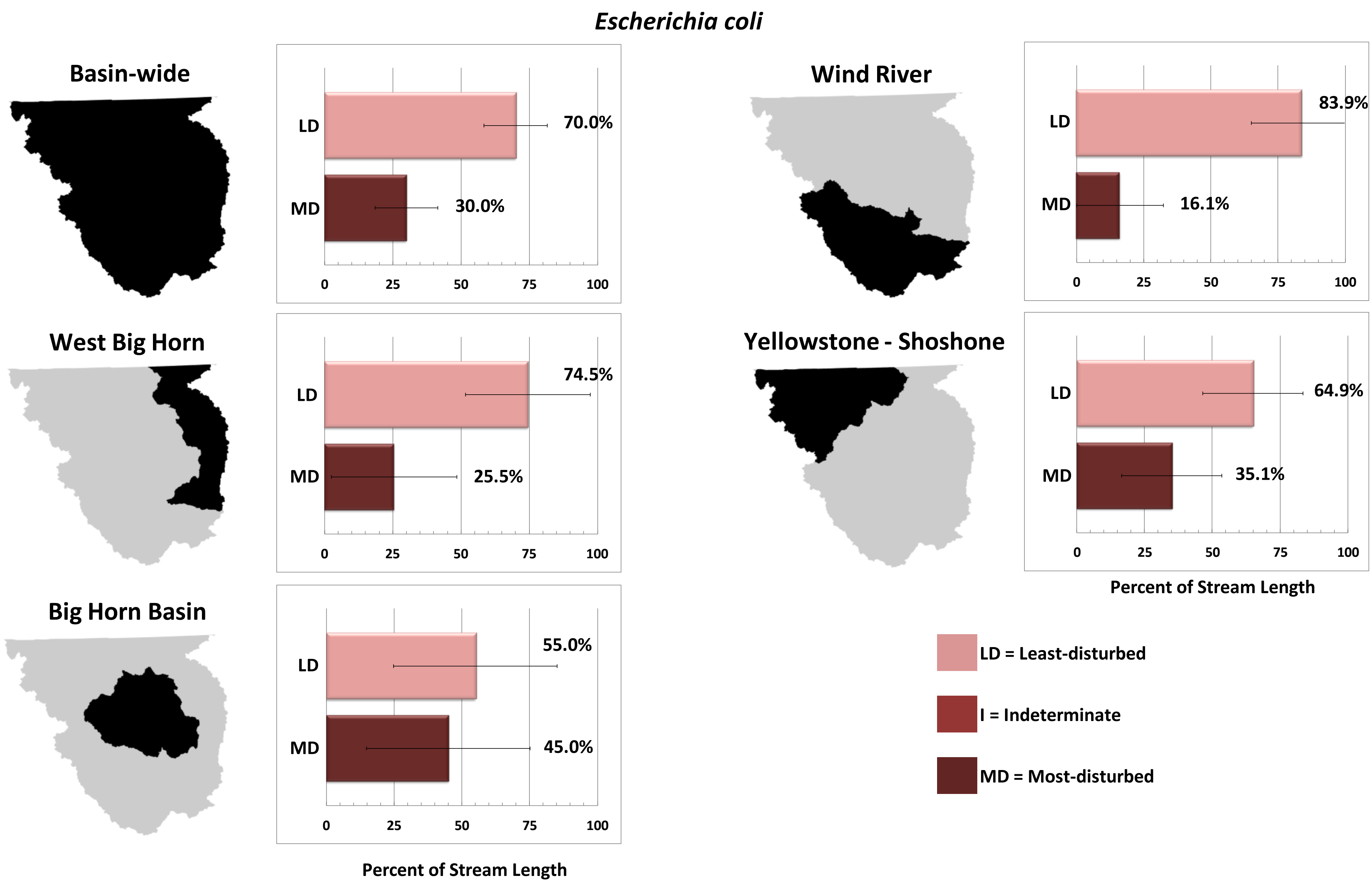
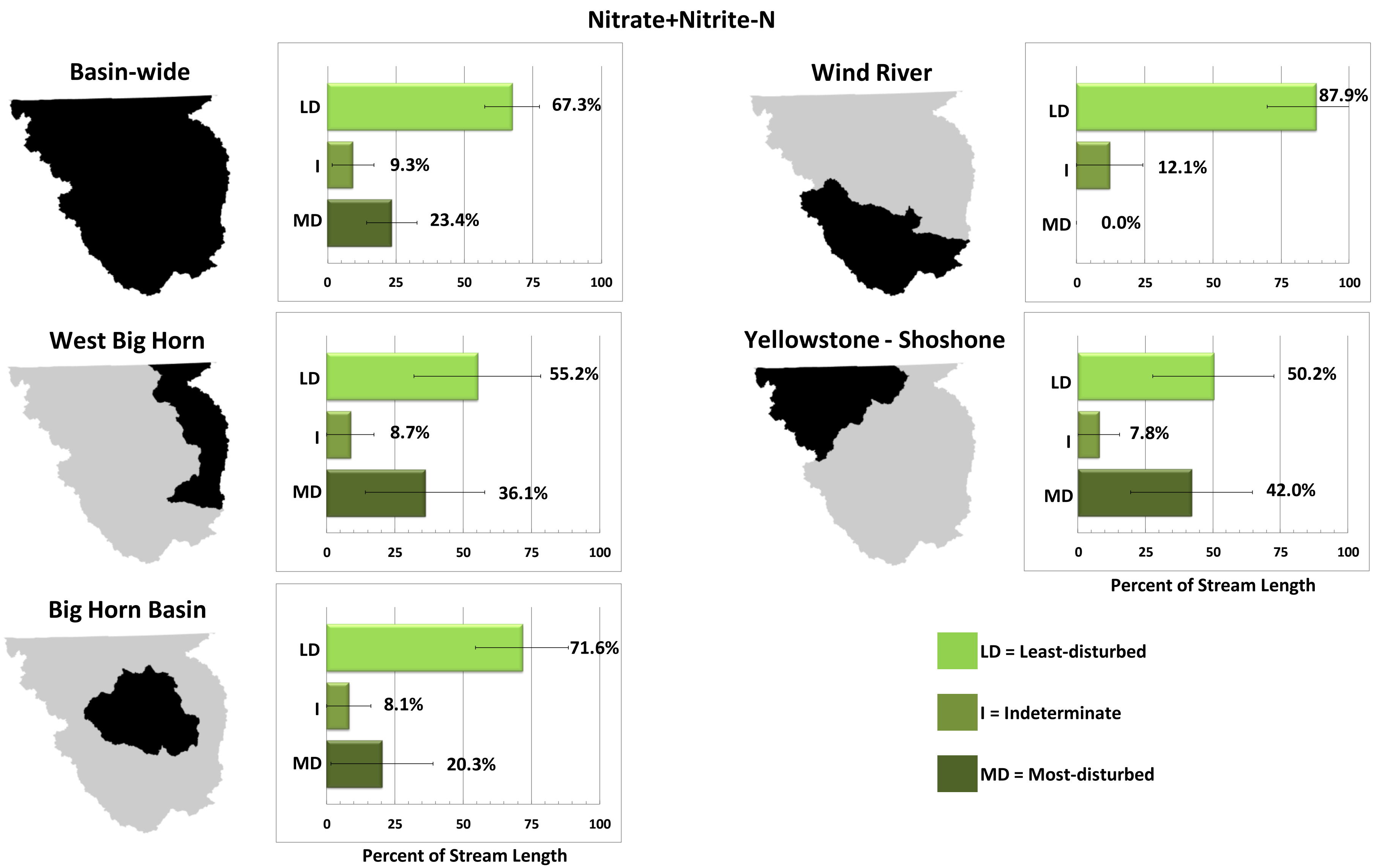
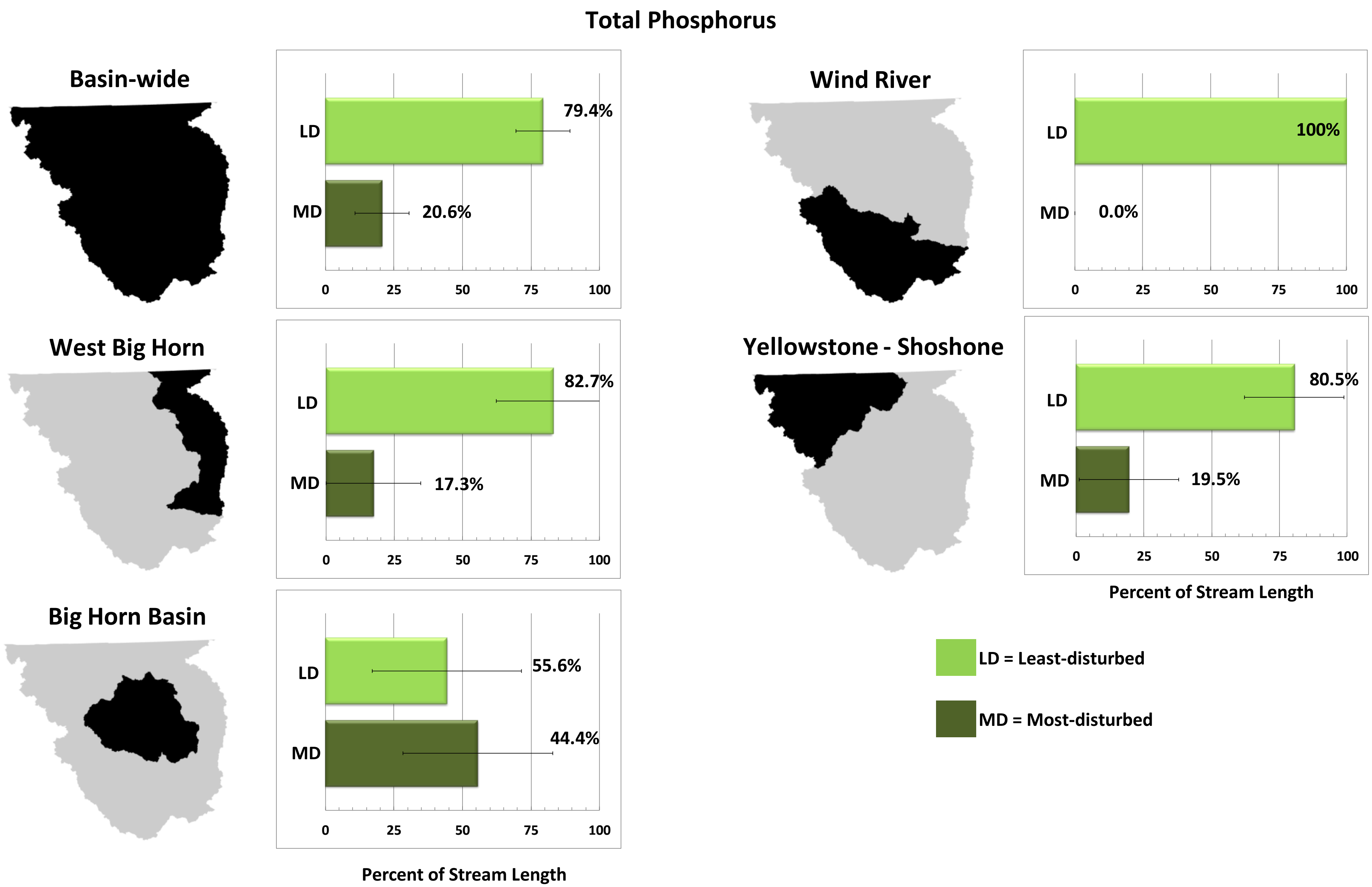
Appendix 1 - Summary of *Escherichia coli* results for the Bighorn/Yellowstone Superbasin and corresponding HUC 8 Clusters. Error bars represent the 95% confidence intervals.



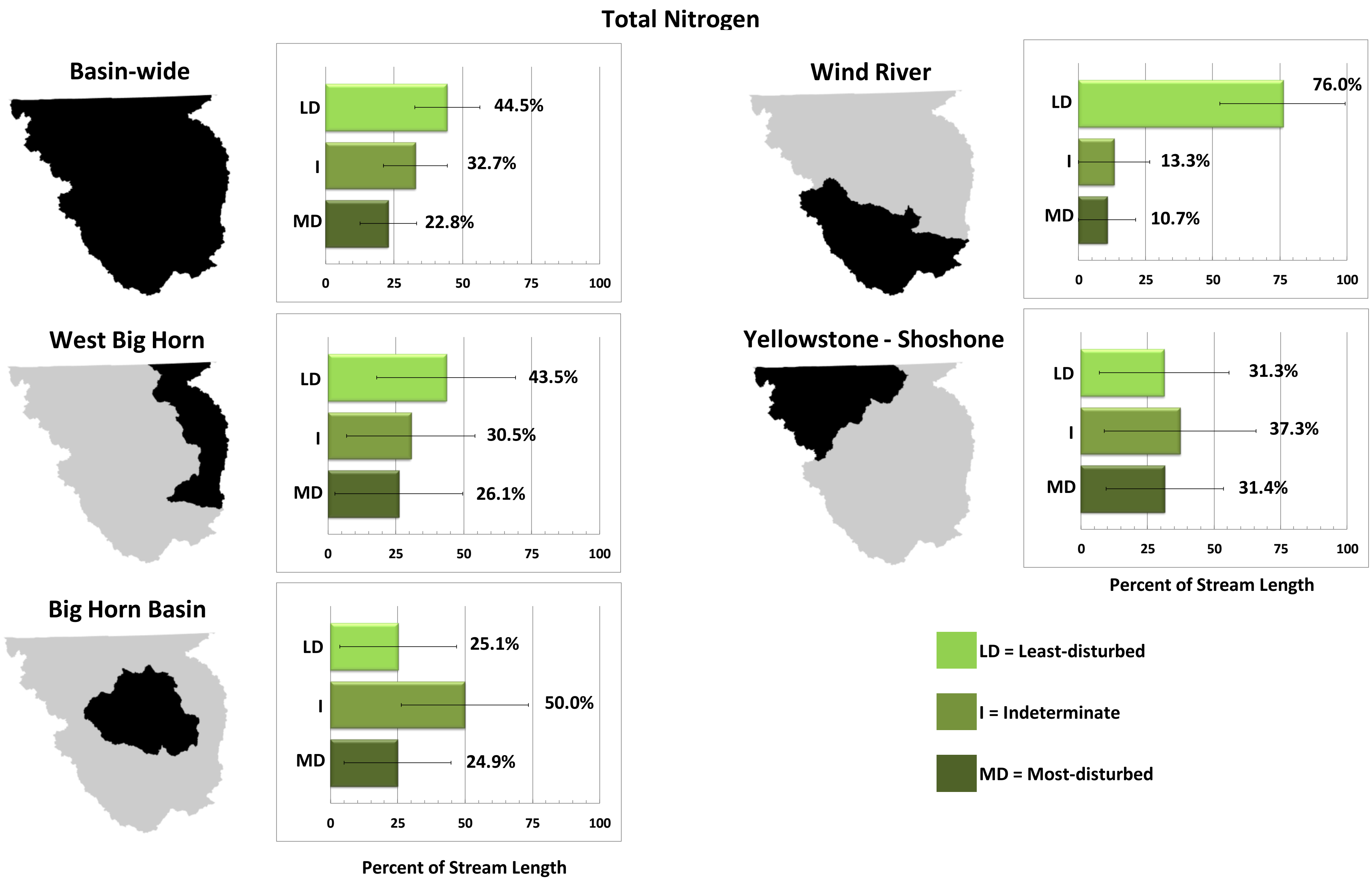
Appendix 2 – Summary of nitrate+nitrite-N results for the Bighorn/Yellowstone Superbasin and corresponding HUC 8 Clusters. Error bars represent the 95% confidence intervals.



Appendix 3 - Summary of total phosphorus results for the Bighorn/Yellowstone Superbasin and corresponding HUC 8 Clusters. Error bars represent the 95% confidence intervals.

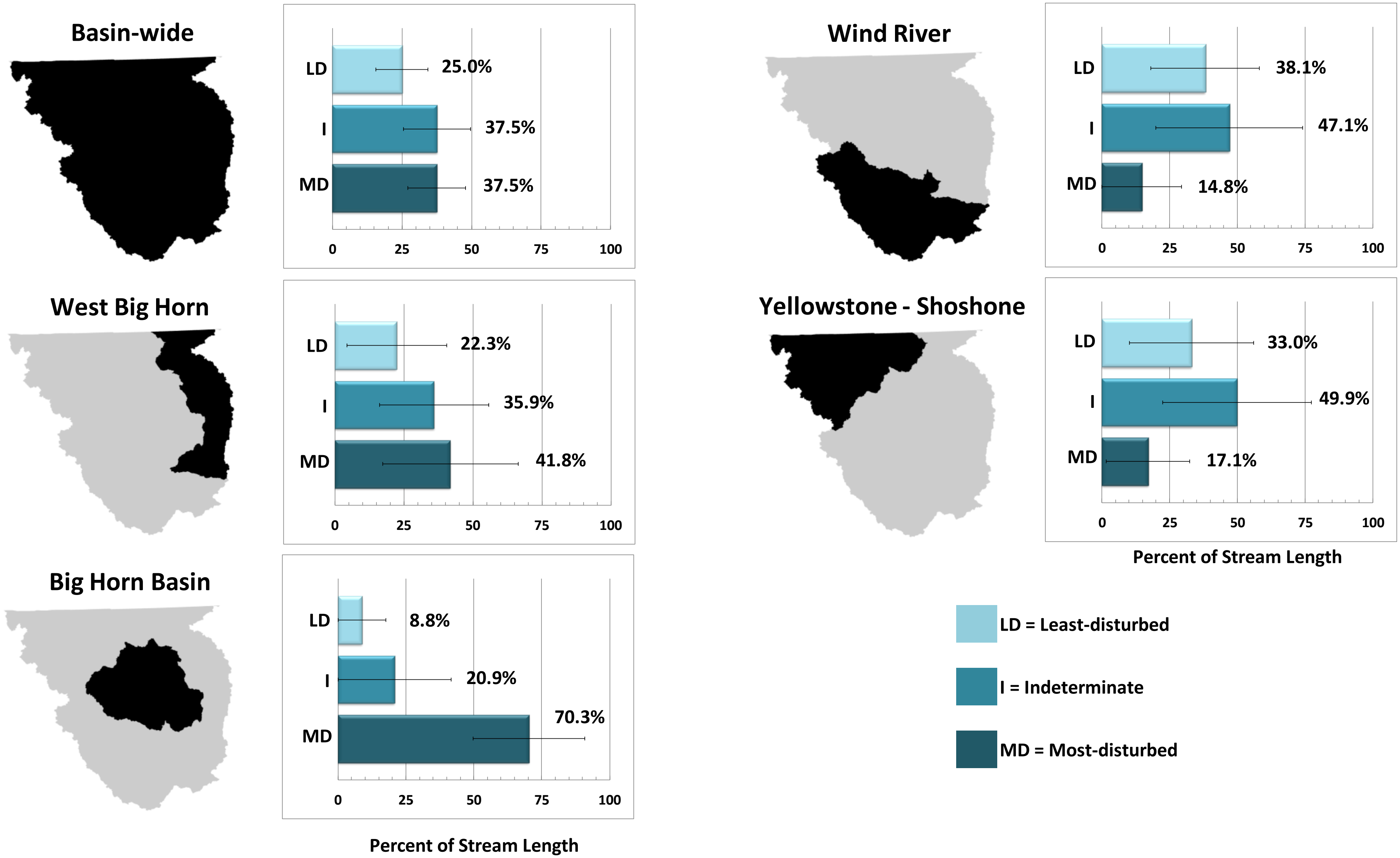


Appendix 4 - Summary of total nitrogen results for the Bighorn/Yellowstone Superbasin and corresponding HUC 8 Clusters. Error bars represent the 95% confidence intervals.



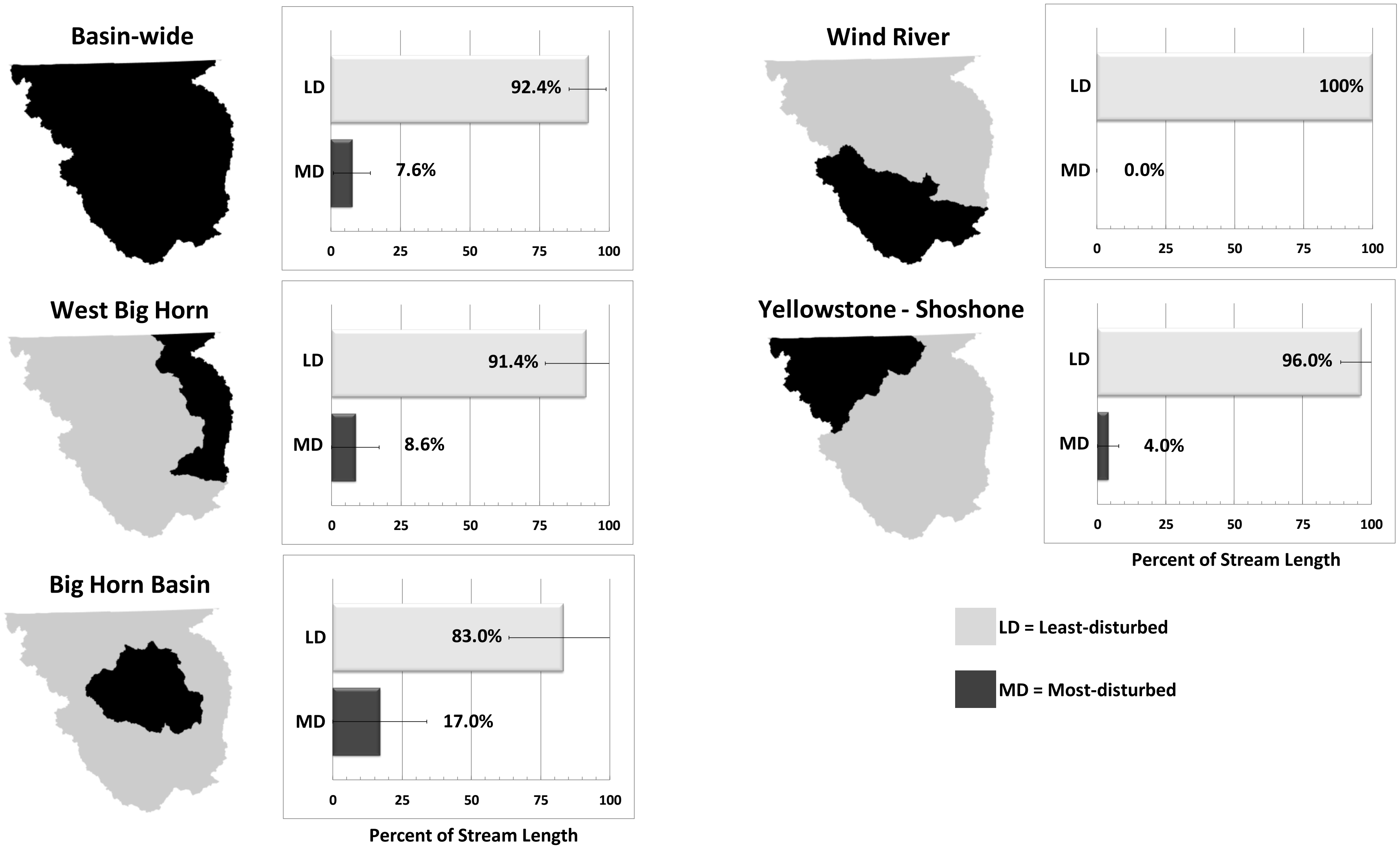
Appendix 5 - Summary of salinity results for the Bighorn/Yellowstone Superbasin and corresponding HUC 8 Clusters. Error bars represent the 95% confidence intervals.

Salinity

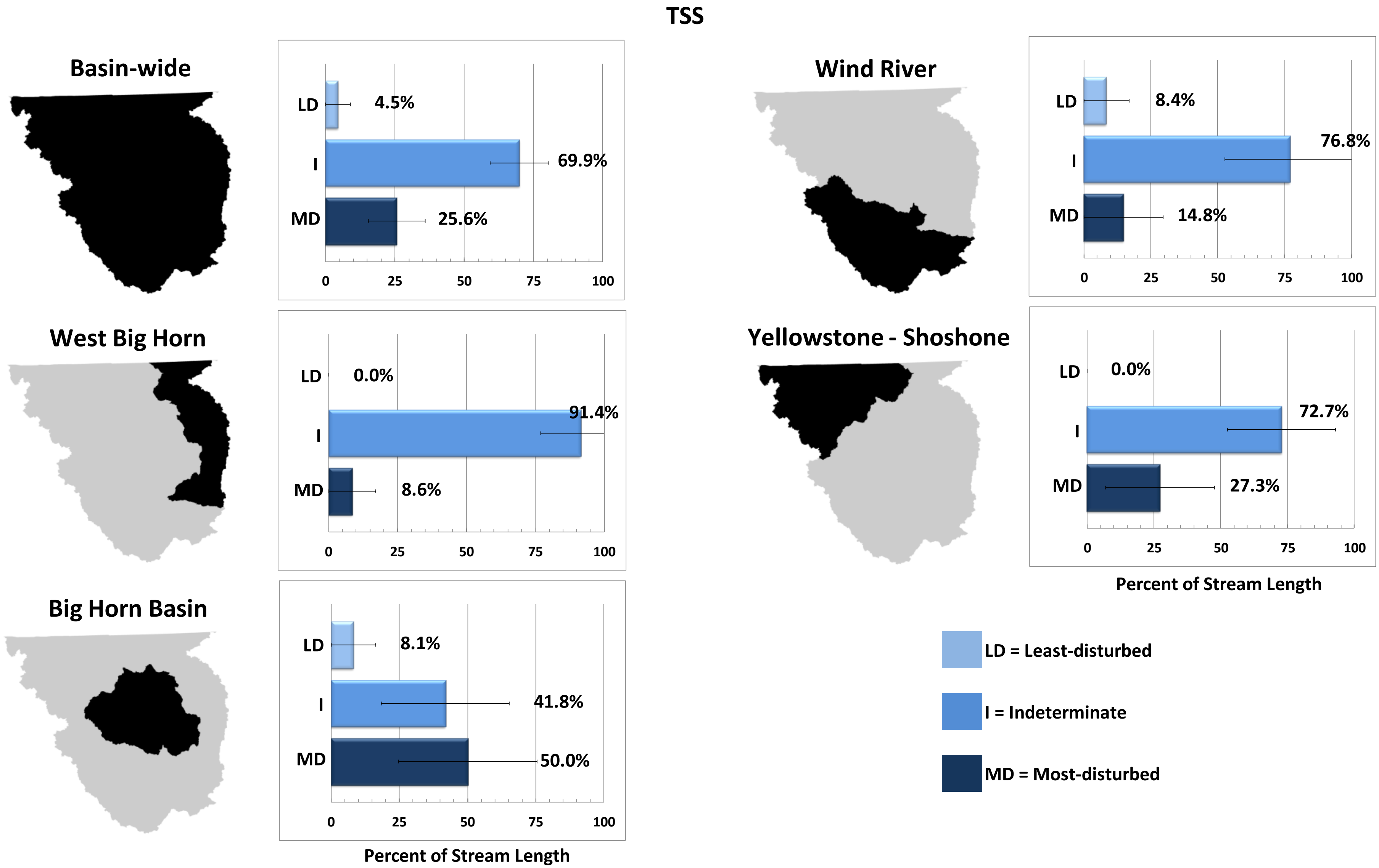


Appendix 6 - Summary of selenium results for the Bighorn/Yellowstone Superbasin and corresponding HUC 8 Clusters. Error bars represent the 95% confidence intervals.

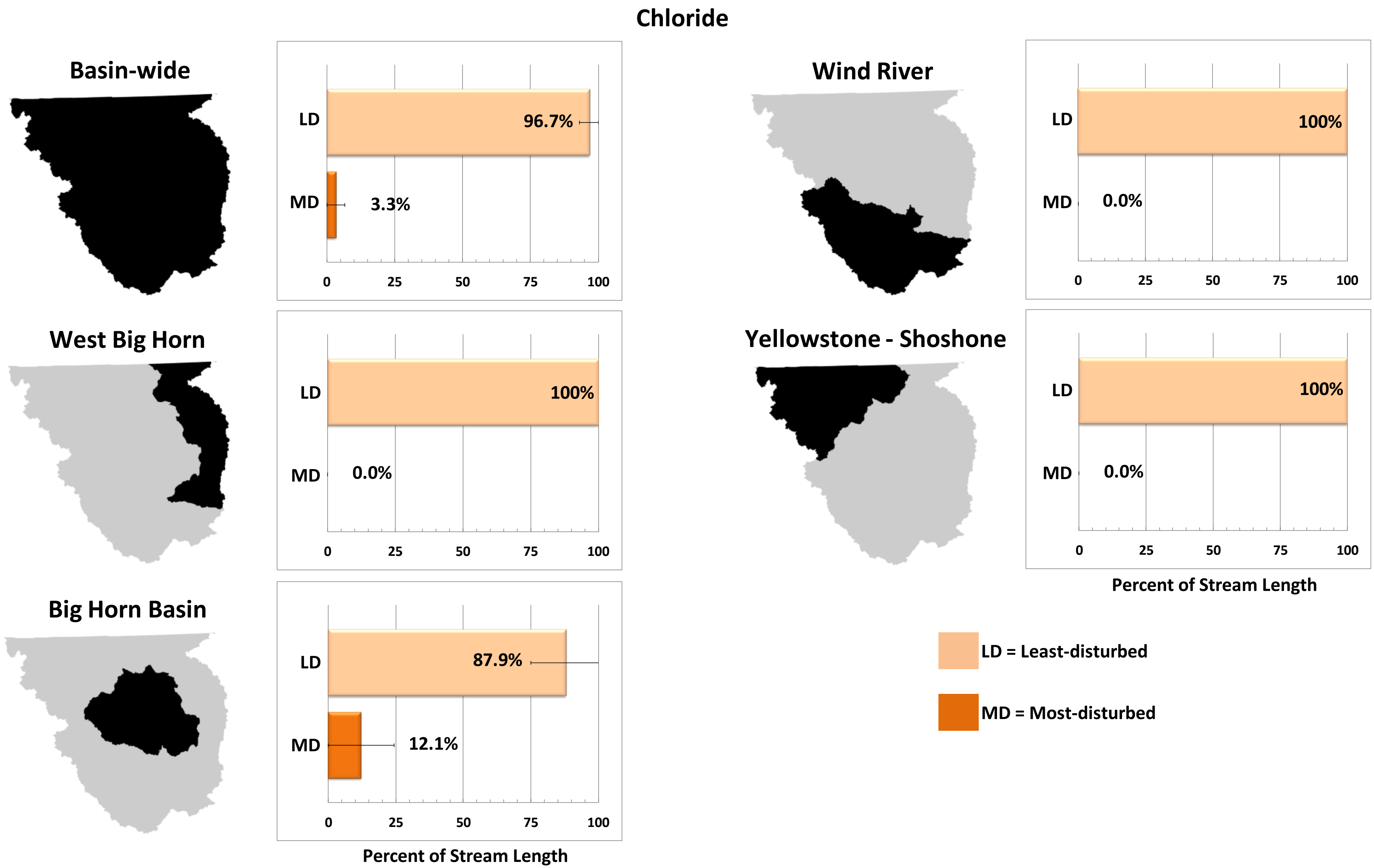
Selenium



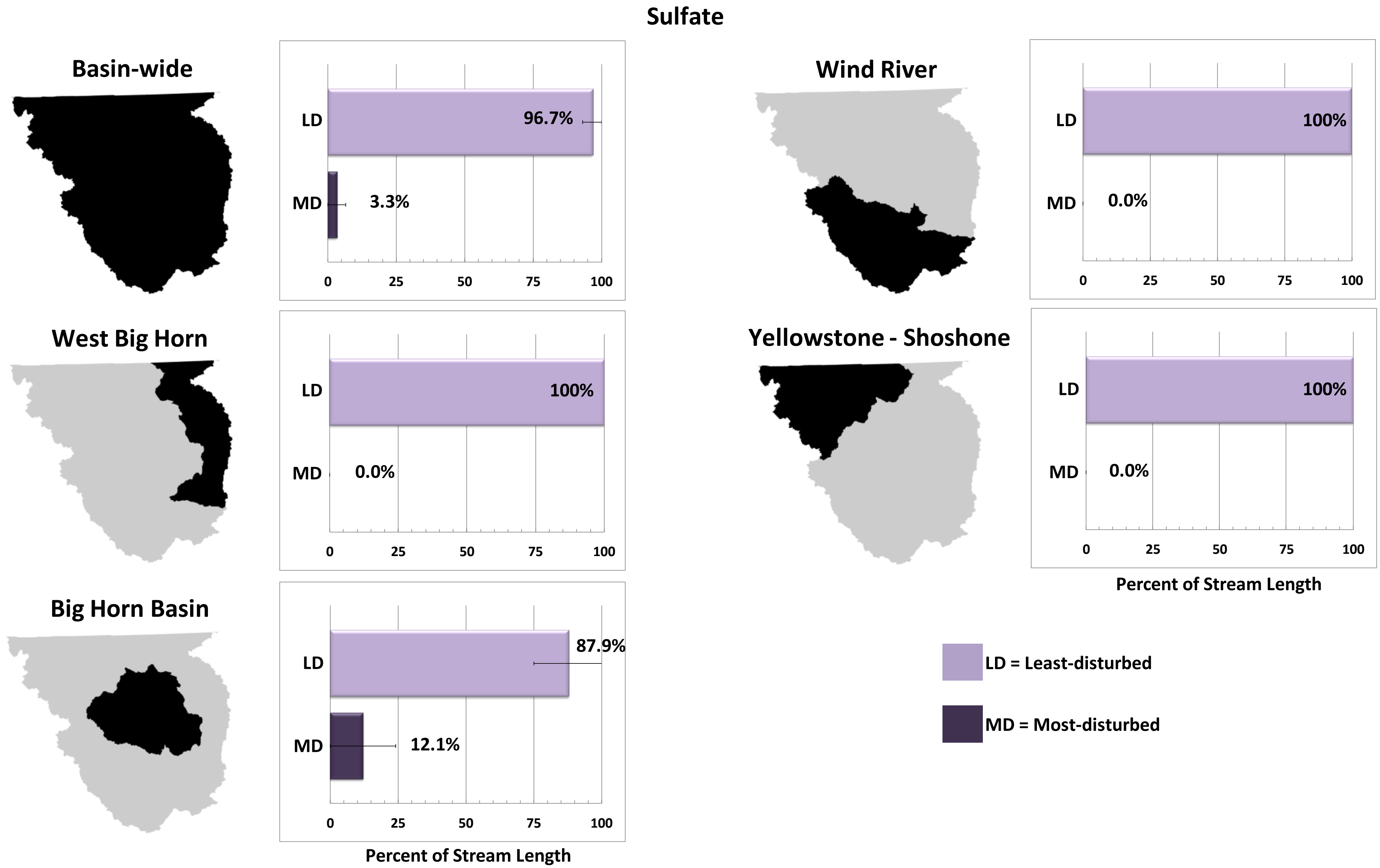
Appendix 7 - Summary of total suspended solids (TSS) results for the Bighorn/Yellowstone Superbasin and corresponding HUC 8 Clusters. Error bars represent the 95% confidence intervals.



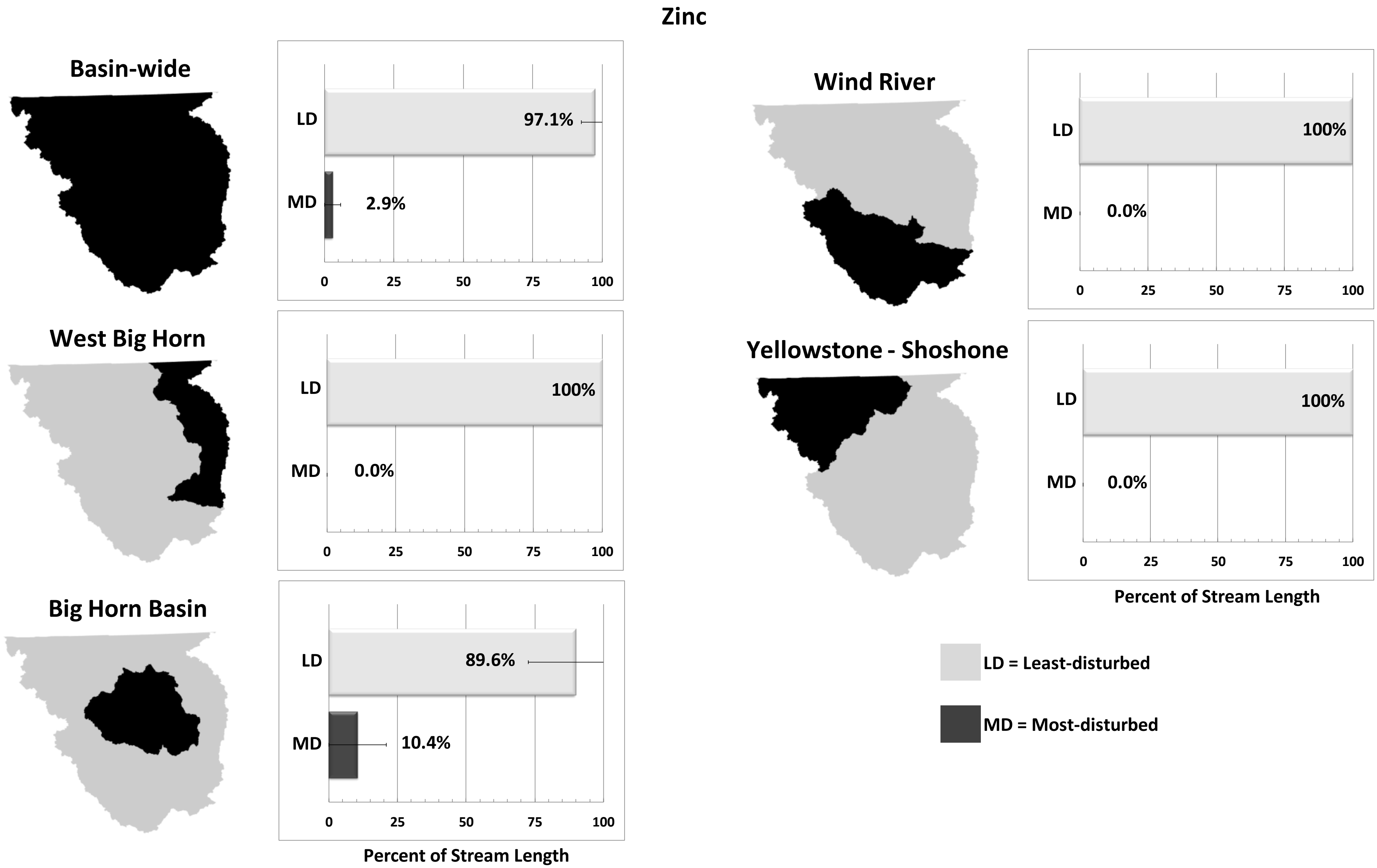
Appendix 8 - Summary of chloride results for the Bighorn/Yellowstone Superbasin and corresponding HUC 8 Clusters. Error bars represent the 95% confidence intervals.



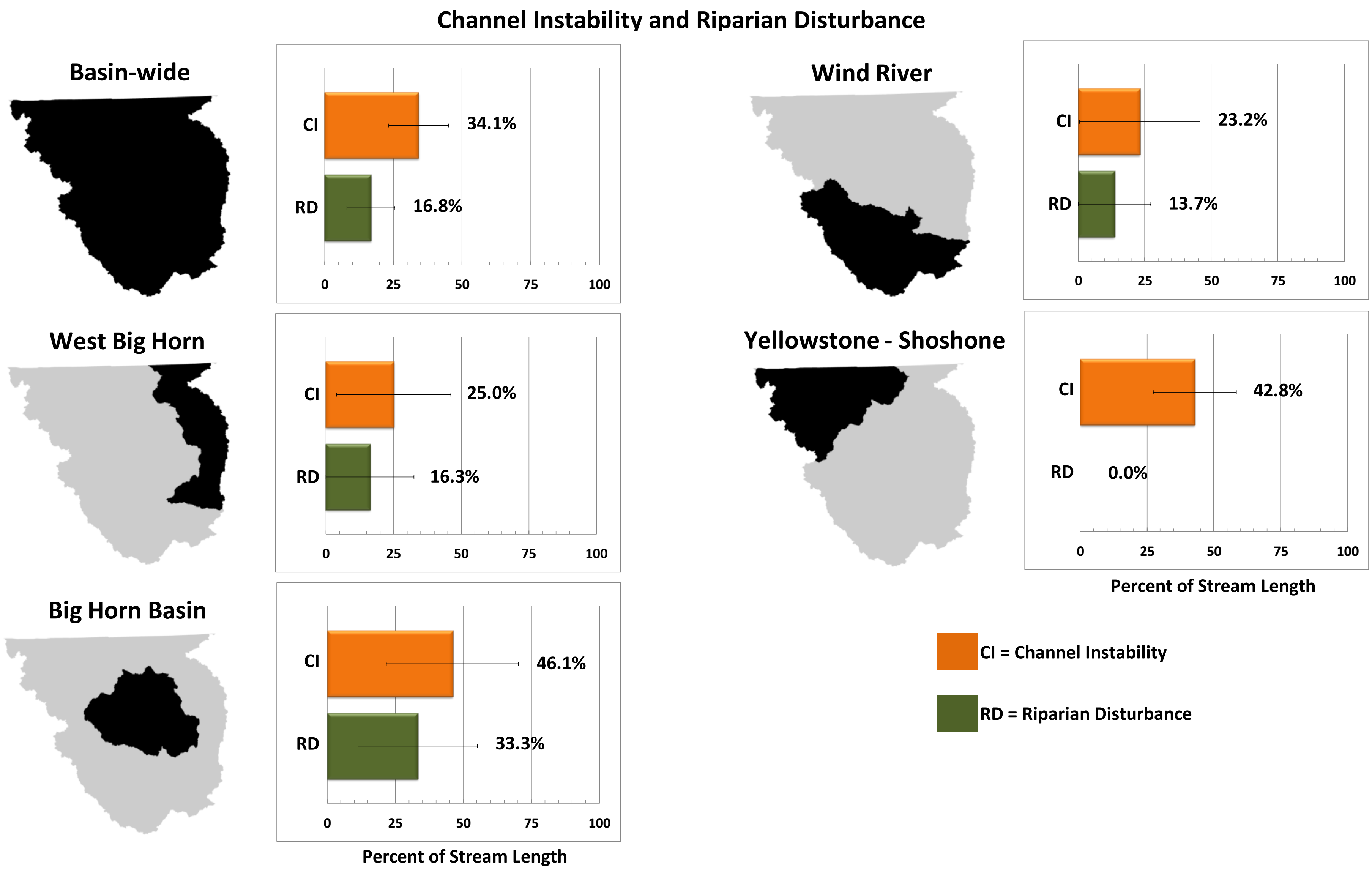
Appendix 9 - Summary of sulfate results for the Bighorn/Yellowstone Superbasin and corresponding HUC 8 Clusters. Error bars represent the 95% confidence intervals.



Appendix 10 - Summary of zinc results for the Bighorn/Yellowstone Superbasin and corresponding HUC 8 Clusters. Error bars represent the 95% confidence intervals.



Appendix 11 - Summary of physical stressor results (channel instability and riparian disturbance) for the Bighorn/Yellowstone Superbasin and corresponding HUC 8 Clusters. Error bars represent the 95% confidence intervals.



Appendix 12 - Summary of the three component sub-stressors that represent channel instability for the Bighorn/Yellowstone Superbasin and corresponding HUC 8 Clusters. Error bars represent the 95% confidence intervals.