Water Quality Condition of Streams and Rivers in the North Platte, South Platte and Niobrara Basins, Wyoming

Results of the 2016 Platte Probabilistic Survey

Wyoming Department of Environmental Quality – Water Quality Division

July 2022

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July 2022

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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 Platte River Basin was conducted in 2016. Results from this survey provide an objective representation of the biological condition, drinking water suitability and human health condition of Platte perennial streams and rivers. This study also identifies the most common stressors and their relative impact to biological condition. Information obtained from this and other probabilistic surveys also allows Wyoming to fulfill State obligations under §305(b) of the federal Clean Water Act.

The Platte survey included all non-headwater, perennial streams that are not located in United States Forest Service wilderness areas. This equates to a target population of approximately 4,995 miles of perennial streams and rivers or over 68% of the 7,394 total miles of perennial streams and rivers in the Platte.

Of the 4,995 perennial stream miles initially considered for the Platte survey, only 2,123 miles were assessed. The remaining 2,872 stream miles were ephemeral or intermittent, human constructed, wetlands, inaccessible, or access was denied. Biological condition was evaluated using benthic macroinvertebrates as the biological indicator at both the Platte scale and for six watershed units (i.e. HUC clusters) that comprise the Platte: Upper North Platte, Middle North Platte, Lower North Platte and South Platte, Sweetwater, and Medicine Bow.

Findings from this study indicate that 66% of the perennial streams in the Platte were in the least-disturbed biological condition or comparable to reference condition. Approximately 11% of perennial stream miles were considered most-disturbed, implying an appreciable deviation from reference expectations associated with anthropogenic stressors. The remaining 23% of perennial stream miles were considered indeterminate with respect to biological condition.

Of 20 stressors evaluated, Nitrate+Nitrite-N (31% of stream miles), channel instability (26% of stream miles), total suspended solids (18%), total phosphorus 18%), and riparian disturbance (17%) were the five most extensive stressors that influence biological condition in the Platte. Nutrients (nitrate+nitrite-N and total phosphorus) were most prevalent in the Laramie, Middle North Platte and the Lower North Platte and South Platte, whereas physical stressors were more prevalent in the Laramie, Medicine Bow, and Upper North Platte.

Based on relative extent and relative risk, riparian disturbance, channel instability, and total phosphorus were the most important factors that influenced biological condition of Platte streams. Streams are 3 to 4 times more likely to be in a most-disturbed biological condition when these stressors are present as when they are not present.

Total selenium was not an extensive stressor in the Platte, but where present in most-disturbed conditions, posed a relatively high relative risk to biological condition.

Sixty-six percent (67%) of perennial streams in the Platte had *Escherichia coli* (an indicator of human health risk for recreational uses of water) concentrations in the least-disturbed condition, whereas a most-disturbed condition occurred in 33% of perennial streams. One-hundred percent of stream miles in the Platte exhibited concentrations of total cadmium, nitrate+nitrate-N, total selenium, total cadmium, and total zinc in the least-disturbed condition with respect to suitability of the water for drinking. Most perennial stream miles were in the least-disturbed condition for dissolved iron (99%), total arsenic (94%), and dissolved manganese (89%). This indicates that the vast majority of perennial streams in the Platte would require minimal treatment as potential drinking water sources with respect to the aforementioned constituents.

The Platte is slightly better than the entire state of Wyoming with regard to the percentage of stream miles in the least-disturbed biological condition (66% Platte vs. 58% Wyoming). The Platte also has fewer miles in the most-disturbed biological condition (11% Platte vs. 18% Wyoming). The Platte fairs better than the Western Mountains, Northern and Southern Plains, and Xeric regions of the United States with regard to least-disturbed (66% Platte vs. 51% Western Mountains 50% Northern Plains, 33% Southern Plains, and 22% Xeric) and most-disturbed (11% Platte vs. 30% Western Mountains, 38% Northern Plains, 26% Southern Plains, and 44% Xeric) biological conditions.

Nutrients (nitrate+nitrite-N and total phosphorus) emerged as top stressors in the Platte. These parameters affected 18% and 31% of perennial streams in the Platte, respectively, whereas the Green (8% and 9%) and Northeast (14% and 7%) exhibited lesser relative extents of these parameters.

Nationally (lower 48 contiguous states), the percentage of stream miles in the least-disturbed biological condition (30%) is much less relative to the Platte (66%). Likewise, the percentage of national stream miles in the most-disturbed biological condition is 44% - much greater than the Platte estimate of 11%.

When compared to the three previous rotating basin probabilistic surveys, the Platte (66% least-disturbed) is in better biological condition than the Bighorn/Yellowstone (38%) and Northeast (52%), and similar to the Green (63%). With regard to stressor extents, all four superbasins had channel instability and riparian disturbance as dominant stressors to biological condition. Channel instability is a top two stressor in all four regions, although channel instability is more extensive in the Bighorn/Yellowstone and Northeast (~35% of stream miles) than in the Green (20%) and Platte (26%). Riparian disturbance is prevalent in the Green and Northeast (24-26% of stream miles), but less so in the Platte and Bighorn/Yellowstone (~17%). These comparisons show that physical impacts to stream channels and riparian zones are important factors for biological conditions across much of Wyoming.

Among the five stressors evaluated at different geographic scales, riparian disturbance, excess sediment, and total phosphorus are the most extensive stressors in the Platte (17-18%), with excess sediment and riparian disturbance the most common throughout Wyoming (36-37%) (Figure 7). Total phosphorus is the fourth most extensive throughout Wyoming (14% of stream miles). Interestingly, total phosphorus is the most extensive stressor nationwide (58%) and in the Western Mountains of the western US (50%). Total nitrogen is an inconsequential stressor to streams in the Platte but is an extensive stressor across the Nation (43%).

Applying the relative risk values derived at the Platte scale, and considering the relative extents of stressors within each HUC 8 cluster, the Lower North Platte and South Platte emerges as an area with the greatest potential need for additional investigation into support of aquatic life uses and eventual point and nonpoint- source pollution reduction. Individual and combined influences of channel instability, riparian disturbance and elevated concentrations of total phosphorus, nitrate-nitrite, and TSS degrade water quality. Among the six HUC 8 clusters, the highest relative extent for most of the aforementioned stressors and the greatest extent of most-disturbed *E. coli* conditions occur within the Lower North Platte and South Platte.

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

INTRODUCTION AND OBJECTIVES

The federal Clean Water Act (CWA) §305(b) requires delegated States to describe the water quality condition of all their surface waters. To help fulfill State obligations under the CWA, Wyoming uses probabilistic surveys to monitor status and trends in wadable stream and river water quality. Probabilistic surveys yield unbiased, statistically-derived estimates of the condition of surface waters based on a representative sample of the resource with a known level of statistical confidence or certainty. Probabilistic surveys are cost-effective and 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 wadable 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 biological condition of Wyoming's perennial streams and rivers, the extent to which major stressors could potentially influence this biological condition, and potentially evaluate changes in condition and stressors over time.

Both statewide surveys were informative about the biological condition and stressors affecting wadable streams and rivers at the statewide scale. However, statewide surveys do not provide sufficient resolution to characterize biological condition and stressor extents at the regional or watershed scales, nor are they efficient to implement given the wide distribution of sites. Smaller scale probabilistic surveys can provide this level of information and can lead to better-informed decisions on future watershed-based monitoring and management priorities. In addition, smaller-scale probabilistic surveys provide a more focused, cost-effective and unbiased method for identifying both high quality and potentially impaired waters. Furthermore, smaller scale surveys can provide a useful measure of the cumulative effectiveness of numerous efforts to improve water quality. For these reasons, the WDEQ/WQD phased-out statewide probabilistic surveys in 2010 and replaced with rotating basin probabilistic surveys.

Wyoming's probabilistic rotating basin approach 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 year of sampling are:

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

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

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

PROBABILISTIC SURVEYS AND WYOMING'S INTEGRATED REPORT

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

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

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

STUDY AREA

The North Platte, South Platte and Niobrara River Basins encompass approximately 26,000 mi^2 or about 26% of Wyoming. The Medicine Bow and Sierra Madre Ranges surround the upper North Platte in Wyoming with the river originating in the North Park area surrounding Walden, Colorado. The Sweetwater River watershed extends eastward from the southern Wind River Range to its terminus at Pathfinder Reservoir near Alcova, Wyoming.

The North Platte continues in a horseshoe bend for nearly 350 miles, circling the Laramie Range then flowing through the SE Wyoming Plains before exiting the State near Torrington. The South Platte in Wyoming consists primarily of the Lodgepole Creek and Crow Creek tributaries that flow eastward from the Laramie Range. The Niobrara River originates as an intermittent stream in the SE Wyoming Plains in southern Niobrara County. The Niobrara flows easterly past Lusk and then southeast into northwestern Nebraska, and eventually to the Missouri River.

The mountainous regions of the Platte are the source of the major rivers and streams that provide water resources for the basin, with streams in the interior being ephemeral to perennial and having a mixture of spring and montane snowmelt origins. Abrupt topographical relief and numerous types of exposed granitic and sedimentary bedrock are typical throughout the Platte. Elevation ranges from approximately 4,000 feet where the North Platte River crosses into Nebraska to over 12,000 feet at Medicine Bow Peak in Wyoming and multiple peaks surrounding North Park, Colorado. Precipitation in the basin varies from 9-10 inches in portions of the interior up to 60 inches in portions of the Sierra Madre (WWDC 2016). Generally, the Basin experiences cold, windy winters and warm, relatively dry summers. Summer rains, often in the form of isolated, intense, short duration thunderstorms, often producing hail, are common. These storms can scour small and medium sized tributary channels resulting in flash flooding. Hailstorms, especially on the eastern plains are common and frequently damage property and crops. In much of the Platte, evaporation significantly exceeds precipitation. The combination of low humidity, breezy conditions and summer heat result in significant pan evaporation and evapotranspiration losses in agricultural areas of eastern Wyoming (WWDC 2017).

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

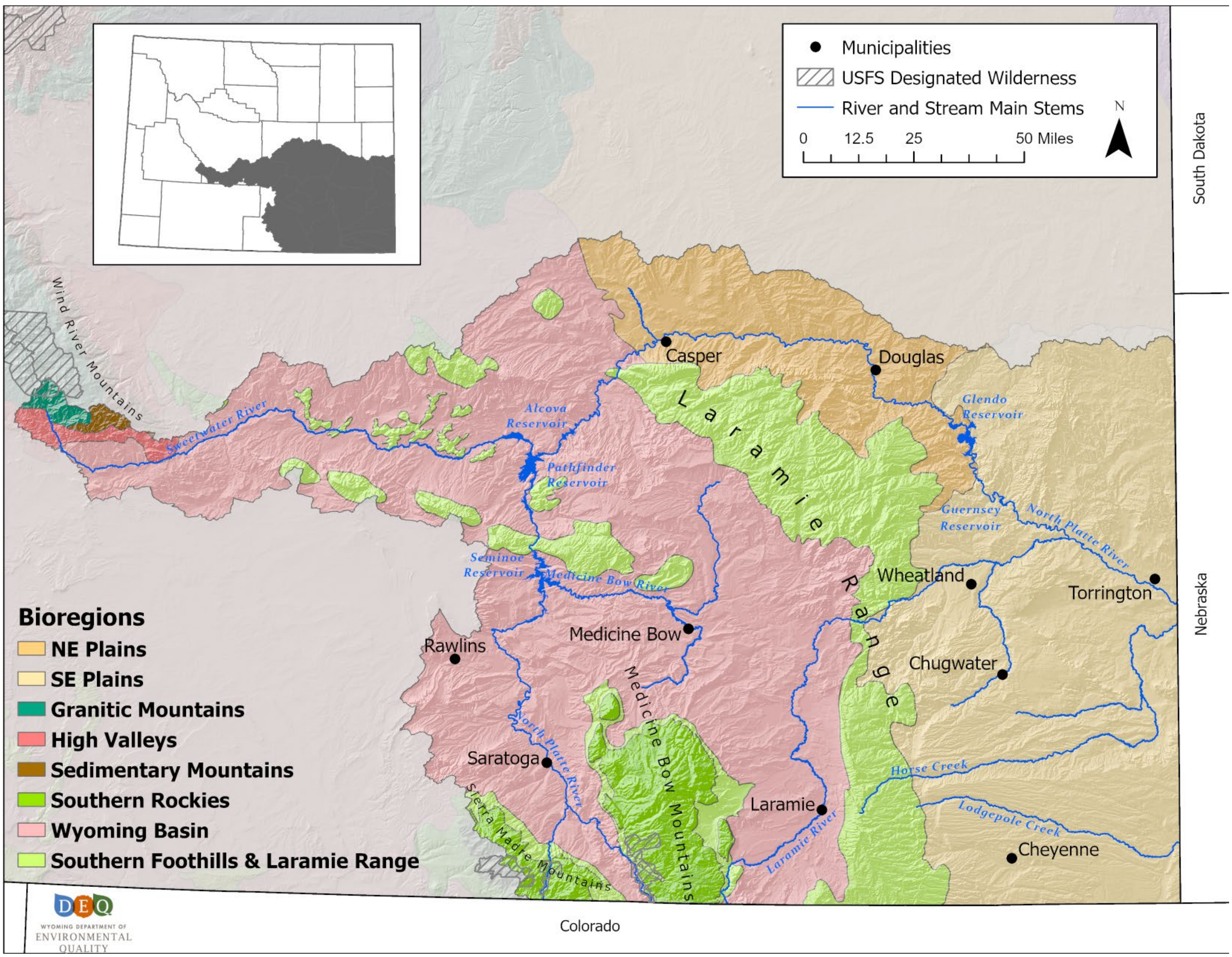
The Granitic Mountains and Sedimentary Mountains (southern extent of the Wind River Range), as well as the Southern Foothills & Laramie Range and Southern Rockies (Sierra Madre, Medicine Bow, and Laramie Ranges and isolated mountains) collectively represent the mountainous regions of the Platte with bedrock geology and elevation as the primary delineators between these eight bioregions. The mid- to upper- montane elevations of these mountains contain coniferous forest, aspen groves, subalpine meadows and/or small areas of alpine tundra. Vegetation cover for the low elevation foothills is a mosaic of conifers, shrubs, sagebrush and grassland. Recreation, logging and summer livestock grazing are common land uses in the mountainous areas of the Platte. The NE and SE Plains and Wyoming Basin bioregions comprise the interior of the Platte. The NE and SE plains are irregular and dissected plains and tablelands consisting of mixed grass prairie and a predominance of intermittent and ephemeral streams other than larger perennial streams of mostly montane origin. The Wyoming Basin bioregion is an arid desert shrubland represented by escarpments, mesas, hills and alkaline depressions. The High Valleys is an ecotone between nearby mountains and the basin proper. Physiographically, the High Valleys are sub-irrigated wet meadow systems found in the broad floodplains, low terraces and alluvial fans commonly covered by cottonwood, sagebrush, mixed-grass prairie and scattered conifer (Chapman et al. 2003). Land use in the Platte includes livestock grazing, mineral extraction, dry rangeland, and irrigated pasture and crops. Alfalfa and grass hay are the most common crops overall, although row crops such as corn, beans, and sugar beets are economically important crops in the lower valley near Torrington.

Irrigated agriculture and, secondarily, industry are the largest consumptive users of surface water. Dams, diversions and trans-basin augmentation have altered the natural flow regimes of many streams and rivers within the Platte (WWDC 2016). Of the approximately 749,000 AF considered consumptive use in the Platte in 2015, approximately 556,000 AF (74%) was used for agriculture, 157,000 AF (21%) for industrial applications and 30,000 AF (4%) for municipal and rural domestic use (WWDC 2016). Much of the consumptive water use for agriculture (predominantly-irrigation) comes from reservoirs constructed throughout the basin (which uses also include municipal, flood control and power generation), and to a lesser extent major alluvial and sedimentary aquifers. The North Platte River and major tributaries supply water for all of the large reservoirs within the Platte (Seminoe, Pathfinder, Alcova, Glendo, and Guernsey) that in conjunction with smaller reservoirs and groundwater wells serve over 524,000 acres of irrigated lands (WWDC 2016). Major industrial uses in the Platte include power generation and mineral extraction. Most municipalities in the Platte obtain their drinking water from surface water sources, with the exception of small isolated municipalities that obtain water from groundwater wells.

Oil and gas facilities, mines, municipal wastewater facilities, confined animal feeding operations, power plants and other industrial facilities discharge treated effluent to surface waters of the Platte under permits issued by the WDEQ Wyoming Pollution Discharge Elimination System (WYPDES) Program. In 2015, the WYPDES Program had 121 individual permits with a combined 152 outfalls in the Platte.

The Platte provides exceptional water-based outdoor recreation opportunities for the state. For example, three segments of the North Platte River support blue ribbon fisheries, the North Platte reservoir system provides extensive fishing and boating opportunities, and the Snowy Range has many streams and high elevation lakes. Federal lands in the Platte account for 30% of the total area.

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



SURVEY DESIGN

The total length of all waterways (perennial, intermittent, ephemeral, canals) in the Platte is 25,303 miles, based on the USEPA-United States Geological Survey (USGS) 1:100,000 scale enhanced National Hydrography Dataset (NHD+). Approximately 7,394 miles (29%) in the Platte are perennial streams; intermittent and ephemeral streams represent approximately 15,745 miles (62%).

A portion of the Platte stream miles classified perennial in NHD+ are spring-fed plains streams that generally flow for extended periods in the spring, early summer and/or fall, but not year-round. Extended flow periods during the growing season and permanent pools or wet areas that function as aquatic refuges during drier periods make them ecologically significant features deserving inclusion in the Platte survey. The term 'perennial streams' represents the target population of streams for the Platte survey, which includes all streams classified as perennial by NHD+.

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

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

The stratified survey design for the Platte selected sites from perennial, non-headwater (>1st Strahler order) streams that are not located in United States Forest Service wilderness within the NHD+ sample frame. The design excluded streams in wilderness areas since most are not reasonably accessible given objectives and logistical considerations of this study. The design also excluded headwater (1st order) streams since the majority within the basin are non-perennial. This equated to a target population of approximately 4,995 miles of perennial streams (68% of the total miles of perennial streams in the Platte).

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

DATA COLLECTION

All data collections occurred during typical baseflow or near baseflow conditions. Dissolved aluminum, arsenic, cadmium, iron, manganese, and zinc; total hardness, nitrogen, phosphorus, selenium, arsenic, zinc, cadmium, chloride, sulfate and suspended solids; *Escherichia coli* bacteria:

nitrate+nitrite-N: and a suite of pesticides and herbicides were analyzed from grab samples collected at the base of a riffle at each site (WDEQ/WQD 2021a). Measurements of water temperature, dissolved oxygen, pH and specific conductance occurred in the field (WDEQ/WQD 2021a).

Benthic macroinvertebrates were the primary indicator of biological condition. Benthic macroinvertebrates were collected from a representative riffle, when present, within each monitoring site following standard procedures in WDEQ/WQD (2021a). At most sites, 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. In some cases, deeper riffles not suitable for Surber samplers were sampled with a modified sampler and procedure. Benthic macroinvertebrate sampling occurred at multiple habitats where riffles were atypical or absent. (WDEQ/WQD 2021a). The multi-habitat sample was a composite of 20 discrete 'jab' samples collected with a dip net, from multiple habitats weighted proportionally based on representation, within a 300-foot reach. Preservation of organisms occurred in the field with 99% ethyl alcohol. Sample processing followed methods described in WDEQ/WQD (2021a).

Estimations of riffle substrate particle size and mean embeddedness entailed measuring at least 100 randomly selected particles using a modification of the Wolmann pebble count method (WDEQ/WQD 2021a). Mean riffle embeddedness is the degree to which coarse materials are covered or surrounded by very fine gravel, sands and silts. Channel cross-sectional surveys of representative riffles quantified existing channel dimensions for Rosgen channel classification (Rosgen 1996) and relative departure from general expected conditions. Wolman pebble counts (100 count) conducted reachwide characterized substrate composition and aided in Rosgen channel classification.

Additional semi-quantitative evaluations of streambank stability and cover, human influences within the riparian zone, stream bank and riparian zone condition and channel stability were measured at all sites (considering their inherent potential) following approved procedures in WDEQ/WQD (2021a). Samplers noted presence/absence, proximity to the channel and relative influence to water quality conditions for twelve human activities (logging, mining, buildings, roads, landfills, riprap, pavement, pipes, lawn, row crops, pasture and grazing), to make conservative inferences on the degree of riparian disturbance and relative channel stability.

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

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

SETTING EXPECTATIONS OF STREAM AND RIVER CONDITION

INDICATORS OF BIOLOGICAL CONDITION

To assess the biological condition of the Platte's perennial streams requires the establishment of biological condition thresholds. Benthic macroinvertebrates were the primary indicator of biological condition. Biological condition thresholds were derived using a reference condition approach with data collected at a network of over 200 minimally- to least-impacted reference sites over the past 25+ years. The Wyoming Stream Integrity Index (WSII) and the WY RIVPACS, each of which were developed using Wyoming's reference dataset, were used to assess the biological condition of perennial streams in the Platte. Because results from the WSII and WY RIVPACS infer water quality conditions over a multi-year period, they are important tools for evaluating the biological condition of perennial streams.

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

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

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

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

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

INDICATORS FOR DRINKING WATER SUITABILITY AND HUMAN HEALTH CONDITION

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

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

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

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

STRESSORS TO BIOLOGICAL CONDITION

For the purposes of this study, stressors are chemical and physical factors that negatively affect the biological condition of a stream. Wyoming has water quality criteria to protect designated aquatic life uses of streams (WDEQ/WQD 2018). Wyoming's numeric aquatic life criteria for pH, chloride, and select metals were used to evaluate conditions throughout the Platte and for each HUC 8 cluster. For parameters with acute and chronic criteria, the chronic criterion applied. Water quality conditions were least-disturbed when concentrations were less than the numeric criterion. Conversely, water quality conditions were 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 Platte formed the least and most-disturbed thresholds for each stressor, respectively. This percentile-based methodology for establishing least and most-disturbed thresholds is similar to that used for EMAP-West (Stoddard et al. 2005) and the NRSA (USEPA 2015).

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

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

CHEMICAL STRESSORS

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

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

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

Excess nutrients may either run off the land during storms and snowmelt or infiltrate into groundwater aquifers. Nutrients may reside in groundwater aquifers for years to decades before reaching a stream. Excess nutrients can enter a stream through decomposition of excess accumulations of organic material in the channel. In the absence of numeric aquatic life criteria for total phosphorus, total nitrogen or nitrates, thresholds were derived using conservative 25th and 95th percentiles of concentrations among all Platte River Basin reference sites combined, that represented the least and most-disturbed conditions, respectively (Appendix 1). Reference-based data were pooled for all bioregions due to the high proportion of laboratory results below reporting concentrations among bioregions. The percentile-derived most-disturbed total phosphorus condition of 0.100 mg/L equates to the concentration considered by some ecologists as unacceptably high for maintenance of aquatic life (Dodds et al. 2002, Peterson et al. 2004, Vollenweider 1971) in perennial streams.

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

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

Human sources of salinity occur as byproducts from activities such as irrigated agriculture, mineral and industrial development, municipal wastewater discharges and road salt application.

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

Elevated soil erosion can also increase the salinity of streams. In the absence of aquatic life criteria for salinity, least and most-disturbed thresholds were derived from the 25th and 95th percentiles of specific conductance measurements among reference sites for each bioregion, respectively (Appendix 1).

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

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

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

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

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

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

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

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

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

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

PHYSICAL STRESSORS

RIPARIAN DISTURBANCE - The riparian zone, or the interface between a stream and surrounding uplands, helps to protect streams from both natural and human disturbances when adequate vegetation is present. In many streams, this vegetation is vital to stream bank integrity, allowing stream banks to withstand the erosive forces of water at high flows. The vegetation also captures surface flows, which facilitates groundwater recharge and reduces flooding while filtering sediment, nutrients and other constituents (Gregory et al. 1991). Aquatic life depends on riparian vegetation for habitat (e.g. roots and large woody debris) and shading which helps maintain cooler stream temperatures in small to mid-sized streams. Vegetation provides food such as leaf litter for macroinvertebrates and terrestrial insects for fish. Anthropogenic disturbances to the riparian zone can negatively affect one or more of these processes. The closer human disturbances are to a stream, the greater the risk of negative impact to the stream and its aquatic life. When severe, these disturbances accelerate natural geomorphic processes and threaten the physical stability of a stream, which in turn limits its ability to support aquatic life. Evaluation of riparian disturbance in this study entailed combining semi-quantitative measures of human activity, mean percentage of riparian stream bank cover, percentage of bare ground and stream bank and riparian zone condition at each sampled site. Riparian disturbance was considered most-disturbed when either mean streambank cover was < 70% or bare ground represented > 40% of the riparian zone within 30 feet of the channel (Appendix 1) (Cowley 2002, USDA/NRCS 1998, USDI/BLM 1998, USEPA 1998). Riparian disturbance was also conservatively determined as most-disturbed when at least four of seventeen indicators noted in Appendix 1 were documented in the reach within 30 feet of the channel. Presence of at least four indicators minimized false positive assignments of riparian disturbance.

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

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

Riparian disturbance affects aquatic biological condition through alterations to aquatic and riparian habitat.

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

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

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

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

Accelerated bank erosion supplies excess sediment that degrades aquatic habitat, interferes with water supply intakes and surface water diversions, and accelerates reservoir filling.

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

Disturbances to the riparian zone and alterations of the flow regime alter channel boundary conditions causing channel incision and accelerated bank erosion.

RANKING OF STRESSORS

Relative Extent

Relative extent (as a percentage) quantifies how extensive the most-disturbed stressor condition is among perennial streams of the Platte. Conceptually, stressors in the most-disturbed condition occur in all geographic regions, though their pervasiveness may vary. Areas where a stressor in the most-disturbed condition occurs in a high percentage of stream miles will have a high relative extent. For this study, stressor relative extents are evaluated at both the Platte 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 Platte evaluates the potential effect of each stressor on biological condition using the following equation:

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

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

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

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

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

DATA ANALYSIS

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

2016 STREAM FLOWS

Data collected at 14 USGS stream gage stations present in the Platte show above average peak and mean annual flows in 2016 (Appendix 3). At the Platte scale, peak flows in 2016 were on average 70% (range: -16% to +324%) above the mean peak flows for the periods of record, and the mean annual flows were 52% (range: 9% to +265%) above the average mean annual flows.

RESULTS

EXTENT OF RESOURCE

The Platte survey represented 4,995 perennial stream miles or the target stream length. The target stream length equates to 68% of the 7,394 total perennial stream miles in the Platte. Approximately 26% (1313 miles) of the target stream length was non-target based on the proportion of survey sites where desktop or field reconnaissance identified features that identified non-target characteristics (Figures 2 and 3). Non-target sites were those identified as completely ephemeral or intermittent, wetlands or human constructed channels such as irrigation canals. Approximately 30% (1,491 miles) of the target stream length were not assessed based on the proportion of survey sites where the landowner denied access or could not be contacted, or where sites were physically inaccessible. A small percentage (1%) of stream miles were physically inaccessible. The remainder of the sampling frame represented the assessed targeted stream length for the Platte survey – 2,123 miles (Figures 2-3, Appendix 4). This assessed targeted length represents 43% of the target perennial stream miles in the Platte and 29% of the total perennial stream miles from the GRTS modified sample frame.

The distribution of the target stream length for the Platte survey at the HUC 8 cluster scale is as follows (Figures 2-3, Appendix 4). Laramie: 40% target (472 miles), 32% access denied (376 miles) and 29% non-target (343 miles). Medicine Bow: 31% target (196 miles), 49% access denied (305 miles), and 20% non-target (127 miles). Sweetwater: 51% target (270 miles), 35% access denied (185 miles), and 14% non-target (77 miles). Lower North Platte and South Platte: 58% target (421 miles), 37% access denied (274 miles), and 5% non-target (38 miles). Middle North Platte: 35% target (415 miles), 23% access denied (271 miles), 40% non-target (482 miles), and 3% inaccessible (34 miles). Upper North Platte: 49% target (350 miles), 11% access denied (81 miles), 35% non-target (249 miles), and 5% inaccessible (34 miles).

The flow regimes of approximately 25% (539 miles) of the assessed targeted stream miles for the Platte survey were reservoir influenced (≥50% of the respective watershed areas). Reservoir influenced streams were most prevalent in the Lower North Platte – South Platte and least prevalent in the Medicine Bow HUC 8 cluster.

Flow alterations represented by diversions, spreader dikes or trans-basin inputs had varying influences on approximately 82% (1745 miles) of the 2,123 assessed perennial stream miles for the Platte survey. Flow alterations were common throughout the Platte.

BIOLOGICAL CONDITION

Approximately 66% of the Platte assessed perennial stream miles were in the 'least-disturbed' condition, whereas 11% were in the 'most-disturbed' condition (Figure 4).

Among the six HUC 8 clusters, the Upper North Platte and Sweetwater attained the highest percentage of 'least-disturbed' stream miles at 87% and 78%, respectively (Figure 4). Among all HUC 8 clusters, the Laramie exhibited the highest combined percentage of 'most-disturbed' and 'indeterminate' stream miles at 53% (Figure 4).

DRINKING WATER SUITABILITY AND HUMAN HEALTH CONDITION

For the Platte survey, 67% of the assessed perennial stream miles were in the least-disturbed condition for *E. coli* (Appendix 5, Table 1). Among HUC 8 clusters, the Sweetwater had the greatest percentage of least disturbed *E. coli* condition (89%) and the Lower North Platte & South Platte had the lowest percentage (31%). All streams were in the least disturbed condition for drinking water suitability with respect to total cadmium, nitrate+nitrite-N, total selenium, and total zinc. Approximately, 99%, 94%, and 89% of assessed perennial stream miles in the Platte were in the least-disturbed condition for drinking water suitability with regard to iron, arsenic and manganese, respectively.

All but one of the sampled herbicides and pesticides were in the least disturbed condition for drinking water suitability as all but one site had concentrations below reporting limits. The single reportable concentration did not have a corresponding numeric criterion thus was considered indeterminate. Stressor relative extents were not calculated for herbicides and pesticides.

PHYSICOCHEMICAL STRESSORS TO BIOLOGICAL CONDITION

NUTRIENTS

Throughout the Platte, the percentage of stream miles in the least-disturbed nitrate+nitrite-N condition was 69%, whereas 31% of streams were in the most-disturbed condition (Appendix 6, Table 2). The highest percentage of stream miles in the most-disturbed nitrate+nitrite-N condition (86%) occurred in the Lower North Platte & South Platte.

The percentage stream miles in the least-disturbed total nitrogen condition was 18% with the majority considered indeterminate (82%) (Appendix 8, Table 2). Among the six HUC 8 clusters, the Upper North Platte exhibited the greatest percentage of least-disturbed stream miles for total nitrogen at 52%.

Approximately 82% of stream miles were in the least-disturbed total phosphorus condition (Appendix 7, Table 2). Eighteen (18) percent of stream miles were in the most-disturbed total phosphorus condition (Appendix 7, Table 2). The percentage of stream miles in the most-disturbed total phosphorus condition was highest in the Lower North Platte and South Platte at 39%.

SALINITY

The Platte had least-disturbed salinity conditions in 27% of stream miles (Appendix 9, Table 2). Approximately 6% of stream miles were in the most-disturbed condition, with most stream miles in indeterminate condition (Appendix 9, Table 2). Among the six HUC 8 clusters, the Sweetwater had the greatest percentage of least-disturbed stream miles (79%), whereas the Middle North Platte and Lower North Platte and South Platte had the greatest percentage of most-disturbed stream miles (16%).

SELENIUM

The Platte had 98% of stream miles in the least-disturbed condition for selenium and the remaining 2% were in the most-disturbed condition (Appendix 10, Table 2). Among HUC 8 clusters, only the Middle North Platte contained stream miles within the most-disturbed selenium condition at 8%.

TOTAL SUSPENDED SOLIDS

The Platte had 55% of streams miles in the least-disturbed condition for total suspended solids and 18% in the most-disturbed condition (Appendix 11, Table 2). The highest percentage of stream miles in the most-disturbed TSS condition occurred in the Lower North Platte & South Platte (71%).

CHLORIDE, pH and SULFATE

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

Most stream miles were in the least- disturbed condition for pH (98%). Most-disturbed conditions occurred only in the Sweetwater, with 13% of the stream miles being in the most-disturbed condition in that HUC8 cluster (Appendix 13, Table 2).

ALUMINUM, ARSENIC, CADMIUM, IRON, MANGANESE and ZINC

All stream miles in the Platte were least-disturbed for the dissolved fractions of aluminum, arsenic, cadmium, iron, manganese and zinc (Table 2).

HERBICIDES AND PESTICIDES

All but one of the sampled herbicides and pesticides were in the least disturbed biological condition as all but one site had concentrations below reporting limits. The single reportable concentration did not have a corresponding numeric criterion thus was considered indeterminate. Stressor relative extents were not calculated for herbicides and pesticides.

PHYSICAL STRESSORS TO BIOLOGICAL CONDITION

RIPARIAN DISTURBANCE

Riparian disturbance was in the most-disturbed condition in only 17% of stream miles in the Platte; whereas 83% were in the least-disturbed condition (Appendix 13, Table 2). Riparian disturbance in the Platte was often associated with minimal overhead cover, minimal or heavily utilized woody vegetation, dominance of upland vegetation and common hoof shear/trampling on stream banks. The most-disturbed riparian disturbance condition was greatest in the Medicine Bow HUC8 cluster.

CHANNEL INSTABILITY

Throughout the Platte, 26% of stream miles exhibited indicators of channel instability (excess sediment, accelerated bank erosion and/or active channel incision) (Appendix 13, Table 2). The highest proportion of stream miles with channel instability occurred in the Laramie (52%).

Partitioning channel instability into its three component sub-stressors revealed that most stream miles with channel instability had excess sediment (18 of 26%) whereas 14% exhibited accelerated bank erosion and 4% active channel incision (Appendix 14, Table 2). Accelerated bank erosion was the most extensive channel instability substressor in some HUC8 clusters whereas excess sediment was more extensive in others.

RANKING OF STRESSORS

Relative Extent – For both the Platte and HUC 8 clusters, stressors were ranked according to the proportion of target stream miles that was in the most-disturbed condition for that stressor (Figure 5). Nitrate+nitrite-N was the most common stressor (31%) that has the potential to affect aquatic life in the Platte (Figure 5). Channel instability was the second most common stressor affecting 26% of stream miles, followed by TSS (18%), total phosphorus (18%), riparian disturbance (17%), and salinity (6%). Total selenium, pH, aluminum, total nitrogen, were the least common stressors, each affecting 2% or less of Platte stream miles (Figure 5).

Riparian disturbance or channel instability were the most common stressors within the Laramie, Medicine Bow, and Upper North Platte, whearas nutrients (total phosphorus or nitrate+nitrite-N) were the most extensive stressors in the Middle North Platte and Lower North Platte & South Platte (Figure 5).

Relative Risk - Total selenium presents the greatest relative risk to the biological condition of targeted streams as measured with benthic macroinvertebrates (Figure 6). In other words, the most-disturbed biological condition is eight times more likely to occur in streams having the most-disturbed total selenium condition as streams with the least-disturbed total selenium condition.

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

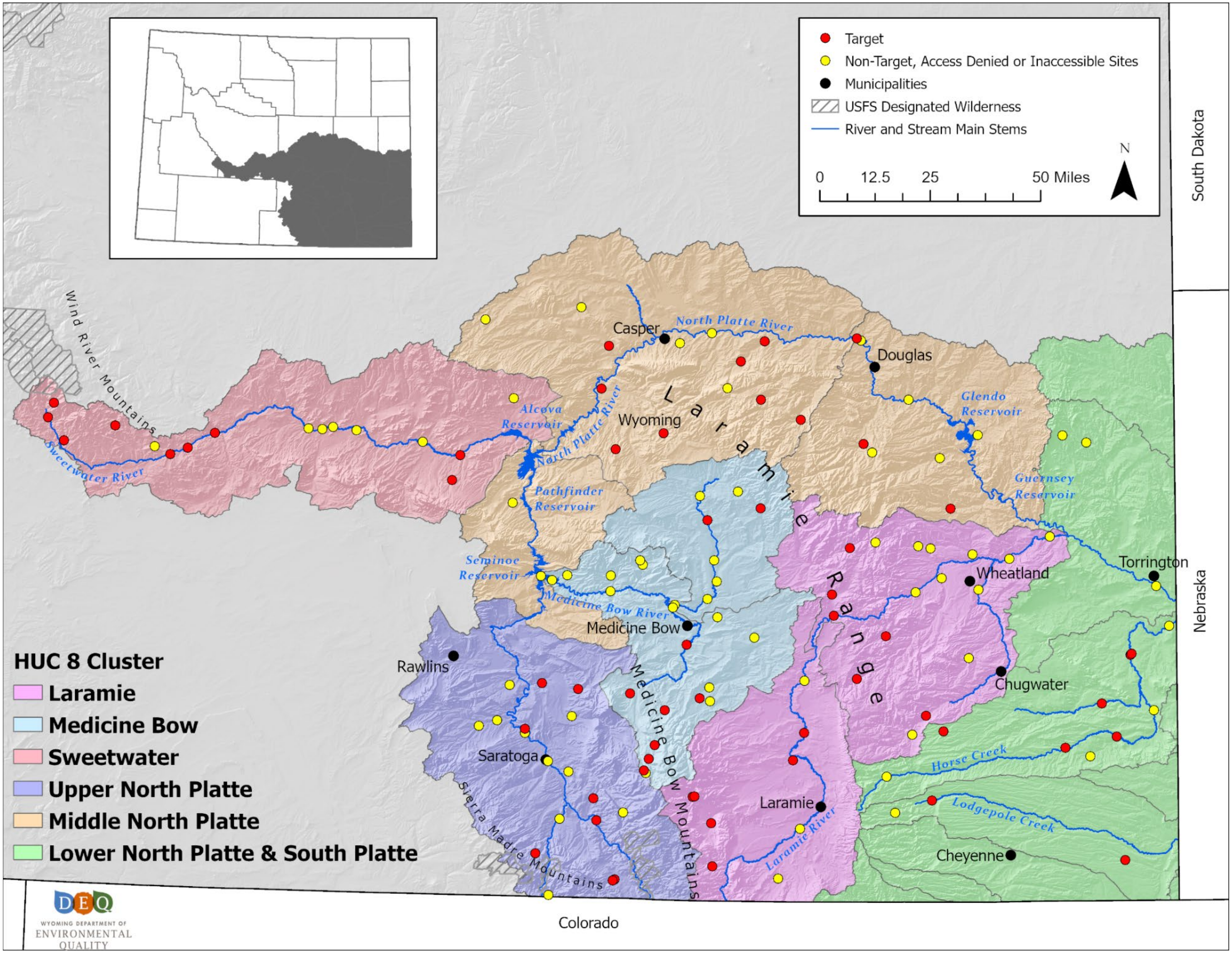


Figure 3 – Estimated percentage of target stream miles relative to access denied and non-target miles at the Platte and HUC 8 cluster scales. Error bars represent the 95% confidence intervals.

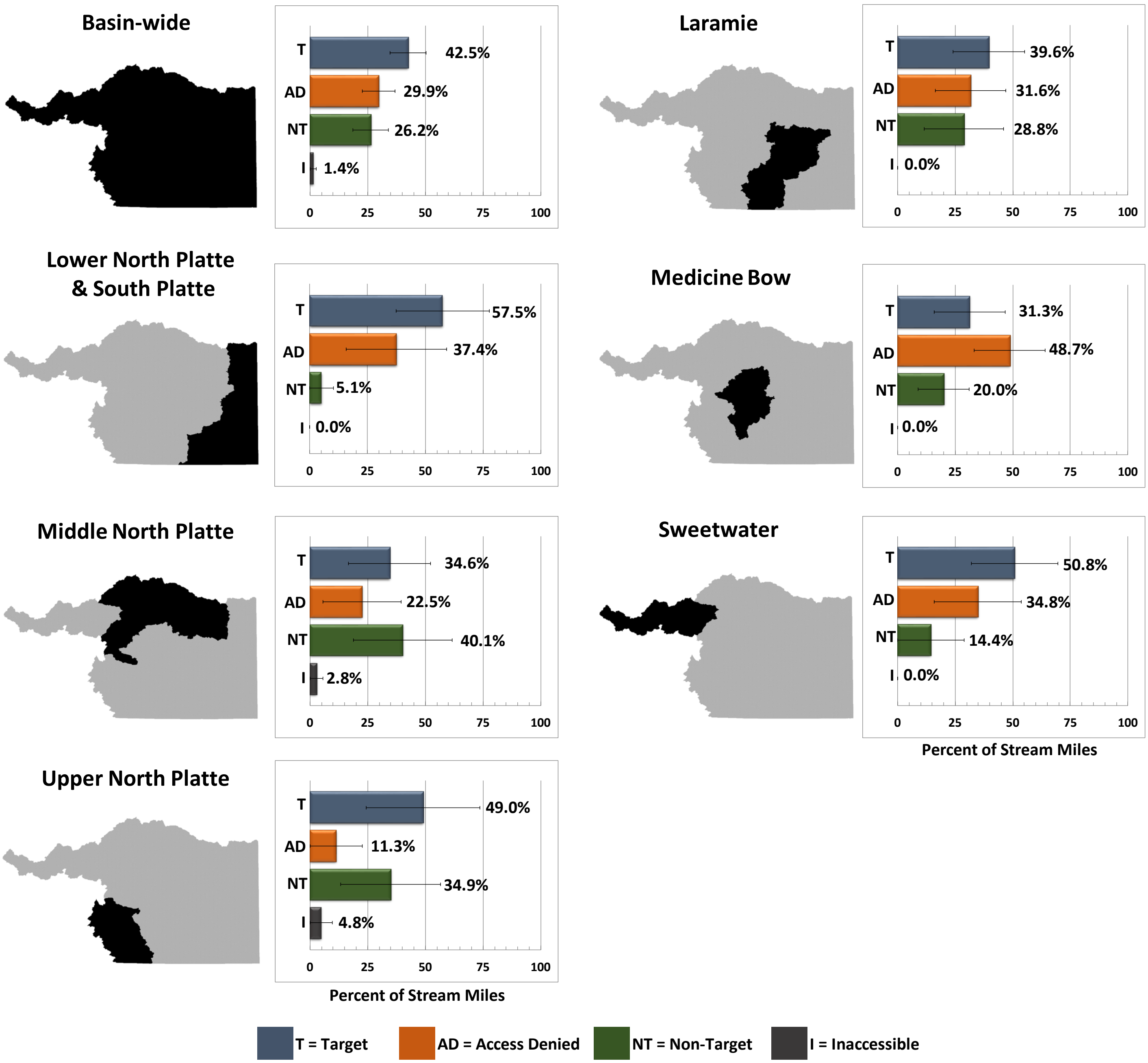


Figure 4 - Biological condition of targeted perennial streams and rivers in the Platte based on WDEQ/WQD's aquatic life use matrix. Error bars represent the 95% confidence intervals.

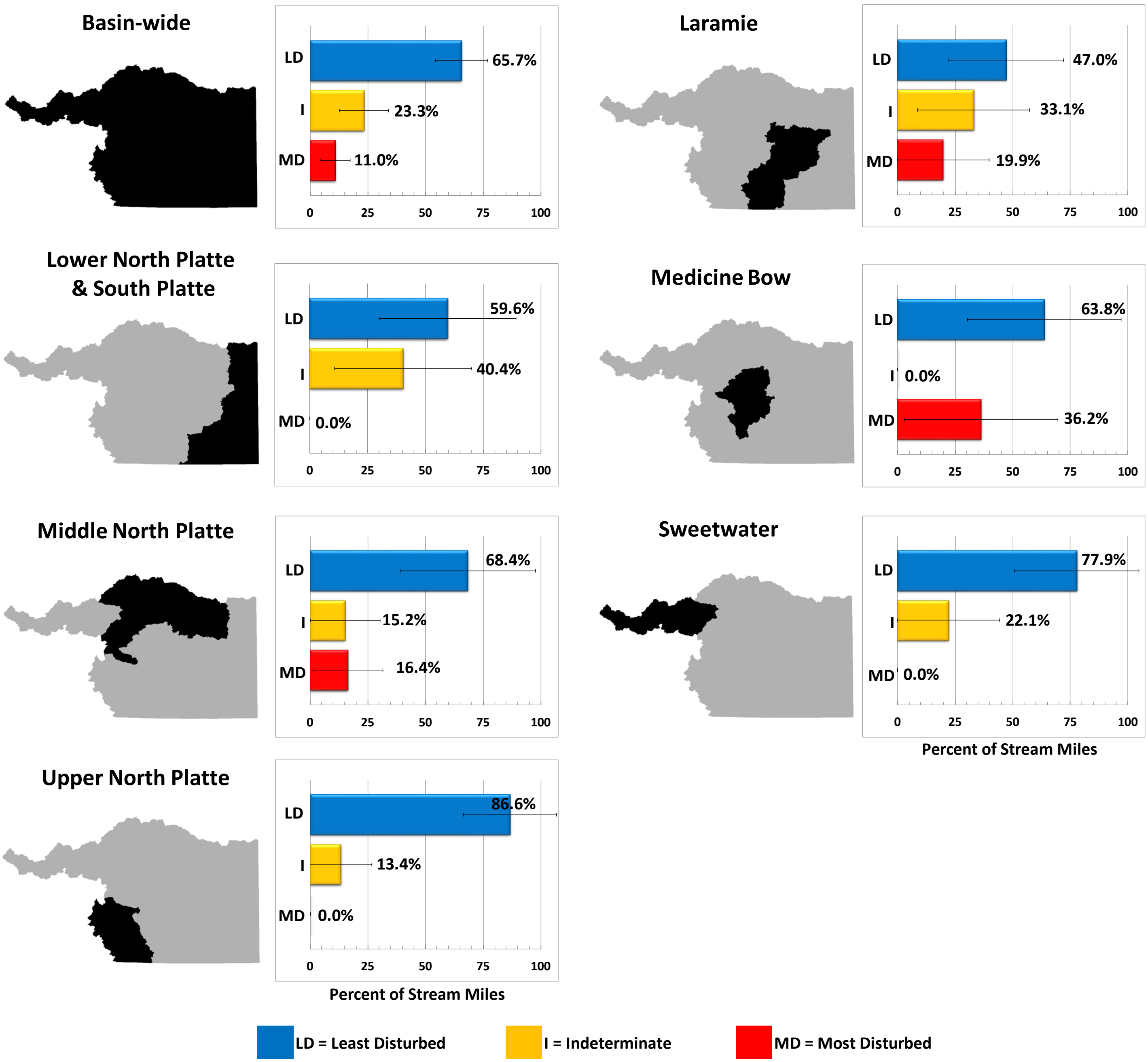


Table 1 –Stressor condition estimates associated with drinking water suitability and human health condition for WDEQ/WQD's 2016 Platte survey.

			Platte Superbasin HUC 8 Clusters					
		Platte Superbasin	**Laramie**	**Lower North Platte & South Platte**	**Medicine Bow**	**Middle North Platte**	**Sweetwater**	**Upper North Platte**
Stressor [Recreation]		**% of Stream Miles**	**% of Stream Miles**	**% of Stream Miles**	**% of Stream Miles**	**% of Stream Miles**	**% of Stream Miles**	**% of Stream Miles**
Escherichia coli	Least-disturbed	67	74	31	43	92	89	68
	Most-disturbed	33	26	69	57	8	11	32
Stressor [Drinking Water & Fish Consumption Suitability]								
Nitrate+Nitrite-N	Least-disturbed	100	100	100	100	100	100	100
	Most-disturbed	0	0	0	0	0	0	0
Dissolved Iron	Least-disturbed	99	100	100	100	100	100	96
	Most-disturbed	1	0	0	0	0	0	4
Dissolved Manganese	Least-disturbed	89	73	100	100	84	100	90
	Most-disturbed	11	27	0	0	16	0	10
Total Arsenic	Least-disturbed	94	100	69	100	100	100	100
	Most-disturbed	6	0	31	0	0	0	0
Total Cadmium	Least-disturbed	100	100	100	100	100	100	100
	Most-disturbed	0	0	0	0	0	0	0
Total Zinc	Least-disturbed	100	100	100	100	100	100	100
	Most-disturbed	0	0	0	0	0	0	0
Total Selenium	Least-disturbed	100	100	100	100	100	100	100
	Most-disturbed	0	0	0	0	0	0	0

Table 2 - Stressor condition estimates associated with biological condition for WDEQ/WQD's 2016 Platte survey.

		Platte Superbasin	Platte Superbasin HUC 8 Clusters: Laramie	Lower North Platte & South Platte	Medicine Bow	Middle North Platte	Sweetwater	Upper North Platte
Biological Condition		**% of Stream Miles**	**% of Stream Miles**	**% of Stream Miles**	**% of Stream Miles**	**% of Stream Miles**	**% of Stream Miles**	**% of Stream Miles**
	Least-disturbed	66	47	60	64	69	78	87
	Indeterminate	23	33	40	0	15	22	13
	Most-disturbed	11	20	0	36	16	0	0
Stressor [Indicator]								
Nitrate+Nitrite-N	Least-disturbed	69	63	14	100	77	89	100
	Most-disturbed	31	37	86	0	23	11	0
Total Phosphorus	Least-disturbed	82	100	61	100	68	100	78
	Most-disturbed	18	0	39	0	32	0	22
Total Nitrogen	Least-disturbed	18	12	0	32	0	28	52
	Indeterminate	82	88	100	68	100	72	48
	Most-disturbed	0	0	0	0	0	0	0
Salinity	Least-disturbed	27	0	14	42	32	79	25
	Indeterminate	67	100	70	58	52	21	75
	Most-disturbed	6	0	16	0	16	0	0
TSS	Least-disturbed	54	73	29	57	70	66	33
	Indeterminate	28	27	0	43	30	34	45
	Most-disturbed	18	0	71	0	0	0	22
Chloride	Least-disturbed	100	100	100	100	100	100	100
	Most-disturbed	0	0	0	0	0	0	0
Sulfate	Least-disturbed	100	100	100	100	100	100	100
	Most-disturbed	0	0	0	0	0	0	0
pH	Least-disturbed	98	100	100	100	100	87	100
	Most-disturbed	2	0	0	0	0	13	0
Dissolved Aluminum	Least-disturbed	100	100	100	100	100	100	100
	Most-disturbed	0	0	0	0	0	0	0
Dissolved Arsenic	Least-disturbed	100	100	100	100	100	100	100
	Most-disturbed	0	0	0	0	0	0	0
Dissolved Cadmium	Least-disturbed	100	100	100	100	100	100	100
	Most-disturbed	0	0	0	0	0	0	0
Dissolved Iron	Least-disturbed	100	100	100	100	100	100	100
	Most-disturbed	0	0	0	0	0	0	0
Dissolved Manganese	Least-disturbed	100	100	100	100	100	100	100
	Most-disturbed	0	0	0	0	0	0	0
Dissolved Zinc	Least-disturbed	100	100	100	100	100	100	100
	Most-disturbed	0	0	0	0	0	0	0
Total Selenium	Least-disturbed	98	100	100	100	92	100	100
	Most-disturbed	2	0	0	0	8	0	0
Riparian Disturbance	Least-disturbed	83	93	69	56	92	90	87
	Most-disturbed	17	7	31	44	8	10	13
Channel Instability	Least-disturbed	74	48	76	75	92	100	66
	Most-disturbed	26	52	24	25	8	0	34
Excess Sediment	Least-disturbed	82	54	76	82	100	100	93
	Most-disturbed	18	46	24	18	0	0	7
Accelerated Bank Erosion	Least-disturbed	86	80	100	75	92	100	66
	Most-disturbed	14	20	0	25	8	0	34
Channel Incision	Least-disturbed	96	87	100	100	100	100	93
	Most-disturbed	4	13	0	0	0	0	7

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

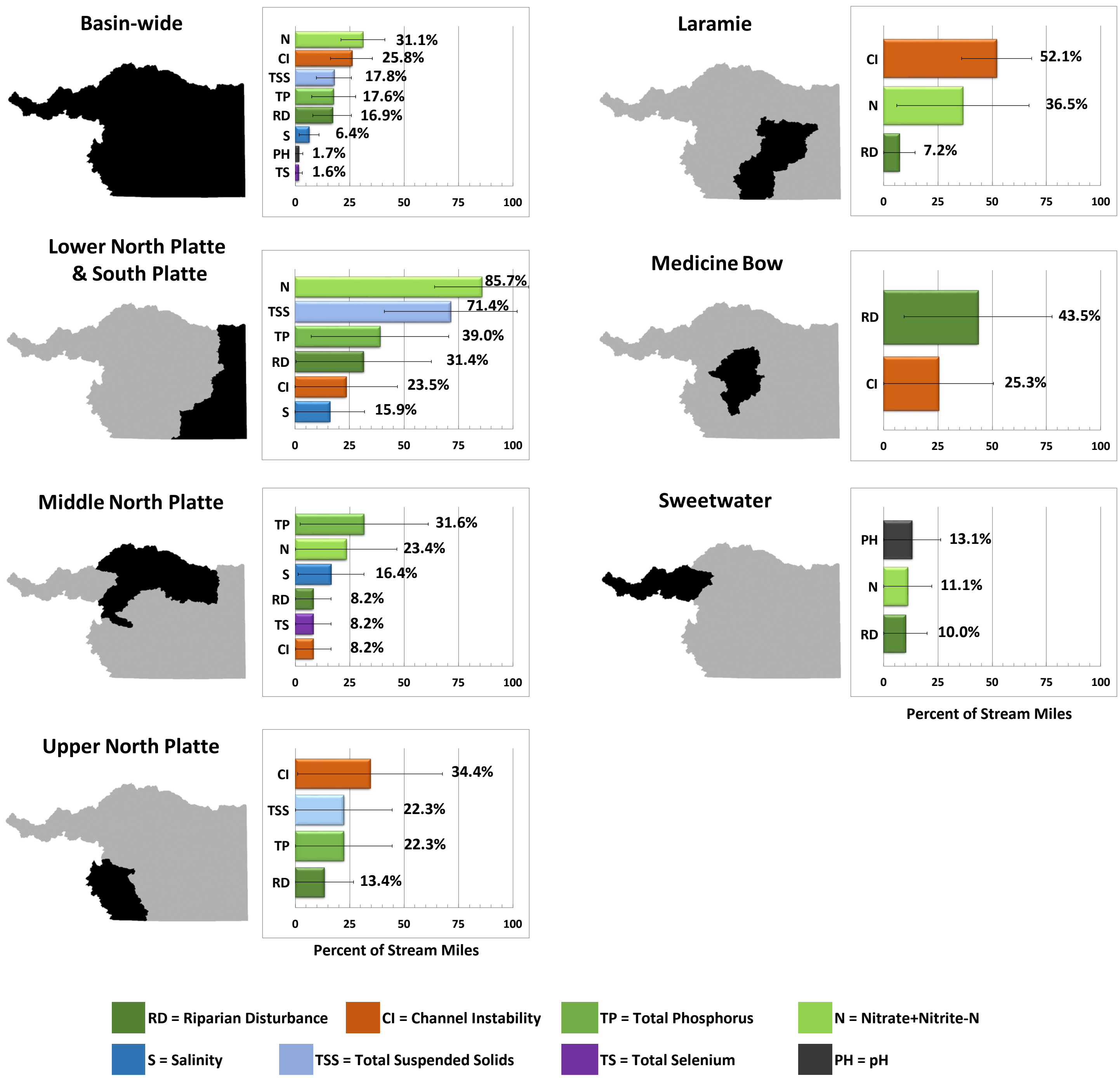
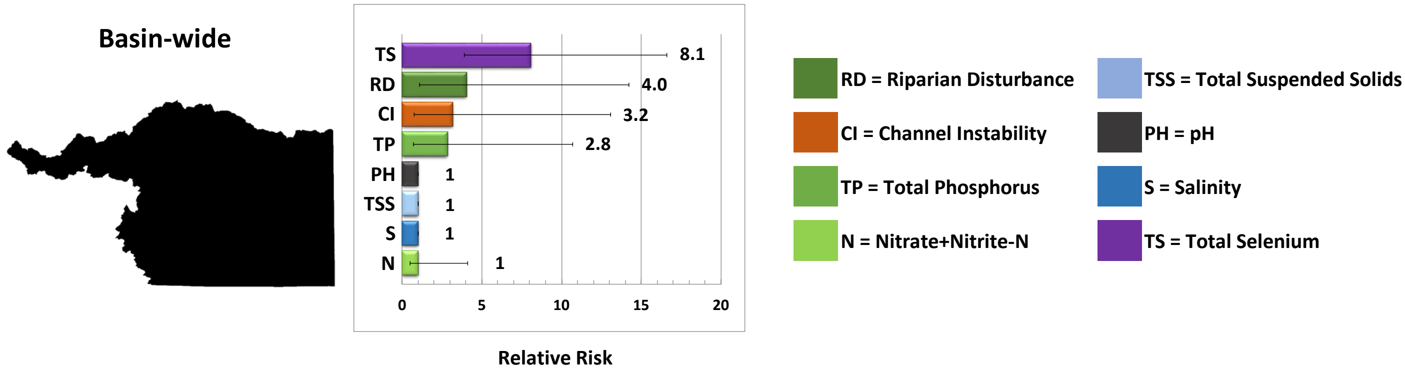


Figure 6 - Relative risk values of chemical and physical stressors to biological condition at the Platte scale. Error bars represent the 95% confidence intervals.



Documented most disturbed selenium conditions occurred only in the Middle North Platte, therefore applicability of selenium relative risk to the remainder of the Platte study area is unknown. Riparian disturbance, channel instability, and total phosphorus exhibit the second-highest risks at 3-4 each (Figure 6).

DISCUSSION

The Platte survey is the first focused and standardized evaluation of the biological and human health condition of streams within the North Platte, South Platte, and Niobrara basins of central and southeast Wyoming. The Platte survey was the fourth of five 'superbasins' monitored as part of WDEQ/WQD's rotating basin probabilistic surveys. The Platte survey provides a representative picture of water quality conditions and identifies chemical and physical stressors to biological and human health condition.

Water quality condition generally exceeds that found in the Bighorn/Yellowstone (Hargett and ZumBerge 2014) and Northeast (Hargett and ZumBerge 2017) probabilistic surveys and similar to the Green probabilistic survey (ZumBerge, Hargett, and Rice 2021) with approximately two-thirds (67%) of perennial streams currently considered in the least-disturbed biological condition and only 11% in the most-disturbed condition. Among the six HUC 8 clusters, the Sweetwater and Upper North Platte are in better biological condition relative to those in the Medicine Bow and Laramie.

The most extensive stressor in the Platte is nitrate+nitrite-N, affecting approximately 31% of perennial streams. Channel instability, TSS, total phosphorus and riparian disturbance are also top stressors, with 17 to 26% of perennial streams in the most-disturbed condition. The prevalence of most disturbed nitrate conditions in the Platte is, in large part, a reflection of the very high relative extent of most-disturbed nitrate+nitrite-N conditions in the Lower North Platte and South Platte.

Nutrients (nitrate+nitrite-N and total phosphorus) were most prevalent in the Laramie, Middle North Platte, and the Lower North Platte and South Platte, whereas physical stressors were more prevalent in the Laramie, Medicine Bow, and Upper North Platte. All stressors considered, the Laramie and Lower North Platte and South Platte HUC clusters have the poorest chemical and physical stressor conditions.

Nutrients such as nitrate+nitrite-N, total nitrogen, and total phosphorus are not directly toxic to aquatic life. In fact, streams of the Platte have low relative risk of a most-disturbed biological condition when elevated nitrate+nitrite-N is present and moderate relative risk when elevated total phosphorus is present. This may be slightly misleading, however, as the Lower North Platte and South Platte has 40% of stream miles in indeterminate biological condition. While this region may not have the greatest extent of most-disturbed biological conditions among HUC8 clusters, the presence of widespread flow alterations precluded development of expected biological conditions. Many Lower North Platte and South Platte perennial streams were categorized indeterminate by default, possibly underrepresenting most-disturbed biological conditions. In addition, the processes that control metabolism and nutrient cycling in streams, their influences to parameters such as dissolved oxygen and pH, and the critical thresholds where negative effects to aquatic life (e.g., fishes versus benthic macroinvertebrates) begin can vary considerably in streams, and may not affect biological condition to the point of being in a most-disturbed condition. Total nitrogen, contrary to total phosphorus and nitrate+nitrite-N, is low across the Platte with very low relative extent and relative risk.

Channel instability is a composite physical stressor that includes excess sediment, accelerated stream bank erosion, and channel incision. Excess sediment and accelerated stream bank erosion are the dominant channel instability sub-stressors in the Platte (14-18%) and among the five HUC8 clusters other than Sweetwater. Low mean percentage riparian vegetative bank cover (<70%) usually corresponded with accelerated bank erosion and channel bed aggradation/degradation. Also corresponding to a low percentage of riparian vegetative bank cover are limited overhead cover and riparian woody vegetation and high percent upland or facultative vegetation on banks. Channel instability is the most extensive stressor in the Upper North Platte (34%) and Laramie (52%). Presence, density, and condition of riparian vegetation greatly influence rates of bank erosion (which contribute to channel instability). Historic or legacy disturbances such as flow alterations, channelization, riparian vegetation removal, historic grazing management, and tie drives all influence present day channel stability.

Flow alterations are one of the most pervasive stressors statewide. Flow reductions facilitate excess sedimentation via a reduction in sediment transport capacity of the channel or in the case of flow augmentation, accelerated bank erosion, and/or incision due to increased shear stresses from above normal flows. Dams store sediment produced in the watershed causing sediment deficiency immediately downstream that promotes incision, reduces thermal amplitude, and tempers peak sediment flushing flows farther downstream from the dam. Varying degrees of flow alterations affect almost 82% of perennial stream miles in the Platte.

Together, anthropogenic disturbances that influence physical attributes of the channel are the most important factors driving channel instability stressors that influence biological condition of perennial streams. The extent of channel instability in the Platte and its potential effect on aquatic life is apparent in that perennial streams are 3 to 4 times more likely to be in a most-disturbed biological condition when riparian disturbance or channel instability are present as when they are not present.

TSS is the third most extensive stressor basin-wide, with 18% of stream miles in the most-disturbed condition. Elevated TSS is very extensive in the Lower North Platte and South Platte, with 71% of stream miles in the most disturbed condition. TSS consists of both organic and inorganic suspended materials and is naturally greater during runoff from snowmelt or thunderstorms. TSS sample collection occurred during baseflow or near baseflow conditions, minimizing flow-dependent increases in TSS as a possible cause of elevated TSS. Elevated TSS in some streams in the Platte can occur naturally, as their watersheds may contain highly erodible silt/clay bearing geology and soils combined with naturally sparse vegetation cover. However, in areas without these overriding natural influences, human activities associated with irrigation drainage and flow augmentation may be chronic contributors to the Platte and, particularly, Lower North Platte and South Platte streams with a most-disturbed TSS condition.

Anthropogenic contributions of inorganic TSS (silts and clays) are a transport mechanism for other pollutants. Silt and clay are often chemically active and pollutants such as nutrients, metals, pesticides or their breakdown products can bind to these particles. There does not appear to be a clear linkage between TSS and nutrients in the Platte, as only half the streams with a most-disturbed TSS condition are in a most-disturbed condition for total phosphorus, which is the most likely nutrient to adsorb to sediment. Most streams with a most-disturbed TSS condition also have a most-disturbed nitrate+nitrite-N condition. From a relative risk perspective, a most-disturbed TSS condition apparently poses no greater risk to aquatic life when present in Platte streams.

The next most extensive stressor is riparian disturbance where the most-disturbed condition relative extent is approximately 17% of stream miles. There is a 4.0 times greater risk of having a most-disturbed biological condition when a most-disturbed riparian disturbance condition is present.

Salinity is the only other stressor where relative extent exceeded 5% in the Platte. All of the stream miles in the most disturbed condition for salinity are in the Middle North Platte and Lower North Platte and South Platte. Chloride, which is one component of salinity, was not elevated in any streams of the Platte. From a relative risk perspective, a most-disturbed salinity condition apparently poses no greater risk to aquatic life when present in Platte streams.

Dissolved fractions of aluminum, arsenic, cadmium, iron, manganese, and zinc as well as sulfate and total selenium are detrimental to aquatic life at elevated concentrations.

However, only 2% or less of stream miles basin-wide are in the most-disturbed condition for these compounds. Stream miles in the most-disturbed total selenium condition exhibit concentrations that were influenced by natural seleniferous-bearing soils and marine shale geology.

The extent of most-disturbed *E. coli* concentrations (an indicator of human health condition for recreational uses) in the Platte is 33%. Relative extents of the most-disturbed *E. coli* condition vary widely among all three regions of the Platte (8-69%) with the Lower North Platte and South Platte having the greatest extent of most-disturbed *E. coli* condition. All streams are in the least-disturbed condition for drinking water suitability with respect to total cadmium, nitrate+nitrite-N, total selenium, and total zinc. Most stream miles in the Platte are in the least-disturbed condition for drinking water suitability with regard to iron (99%), arsenic (94%), and manganese (89%). Most disturbed conditions for arsenic were confined to the Lower North Platte and South Platte, where arsenic concentrations in surface water currently are being studied due to the Platte survey. Potential sources of the elevated manganese, a cause of unpleasant odor and flavor in drinking water, are predominantly associated with the local geology. The combined information suggests that waters within the Platte would require minimal treatment for these parameters to be suitable as drinking water supplies.

Sampled herbicides and pesticides, with one exception, were below reportable concentrations. Threshold values for human health or biological condition were not established for these parameters since most lacked numeric water quality criteria that were the basis for thresholds for many other chemical parameters, and a reference approach was not appropriate. The expected condition would be non-detectable concentrations but, on the other hand, a detection does not necessarily imply impacts to human health or biological condition. The logic applied is that non-reportable concentrations are assumed to be least-disturbed for human health and biological condition, and reportable concentrations without a corresponding water quality criterion are indeterminate. It's important to keep in mind that the timing of sampling may not coincide with moments of high chemical usage.

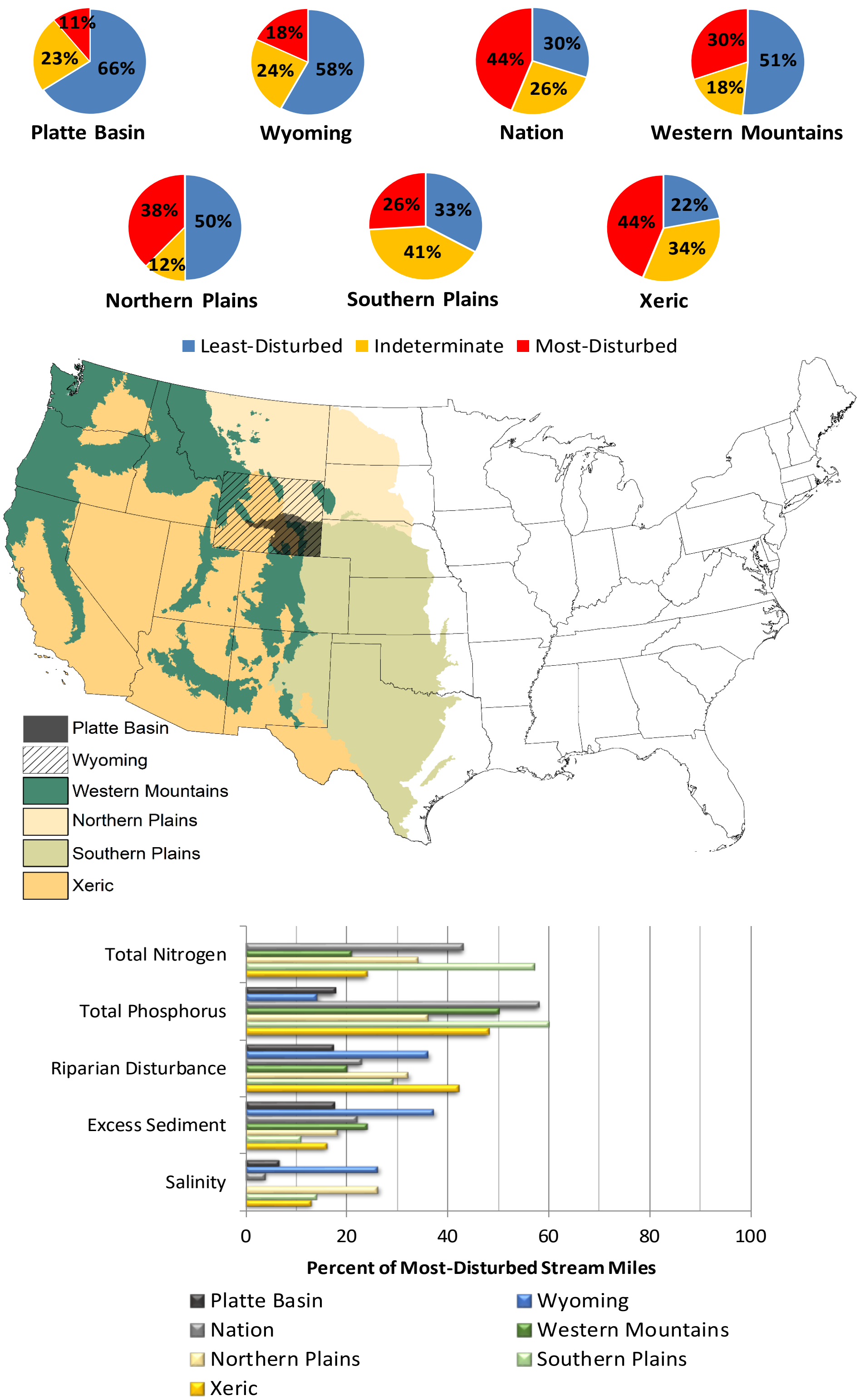
The study was designed at the Platte scale thus sample sizes in each HUC8 cluster are smaller than needed to reach similar levels of statistical confidence at the Platte scale. As such, confidence intervals for biological, human health condition, and stressor relative extents indicate less precise estimates than for the Platte scale. HUC8 clusters aided our confidence in getting more uniform spatial distribution of sites across the Platte than potentially would otherwise be realized. Results are presented at the HUC8 scale to show how biological and human health condition and associated stressor relative extents might vary across the Platte.

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

Nationally (lower 48 contiguous states), the percentage of stream miles in the least-disturbed biological condition (30%) is much less relative to the Platte (66%) (USEPA 2020) (Figure 7). Likewise, the percentage of national stream miles in the most-disturbed biological condition is 44% - much greater than the Platte estimate of 11%.

When compared to the three previous rotating basin probabilistic surveys, the Platte (66% least-disturbed) is in better biological condition than the Bighorn/Yellowstone (38%) and Northeast (52%), and similar to the Green (63%). With regard to stressor extents, all four superbasins had channel instability and riparian disturbance as dominant stressors to biological condition. Channel instability is a top two stressor in all four regions,

Figure 7 - Biological condition (top) of perennial streams and rivers (by percentage of respective stream length) and relative extents (bottom) of stressors common to the Green, Wyoming (Hargett and ZumBerge 2013), Mountains/Basins and Plains/Lowlands regions of the United States (USEPA 2015) and national (USEPA 2015) probabilistic surveys.



although channel instability is more extensive in the Bighorn/Yellowstone and Northeast (~35% of stream miles) than in the Green (20%), and Platte (26%). Riparian disturbance is prevalent in the Green and Northeast (24-26% of stream miles), but less so in the Platte and Bighorn/Yellowstone (~17%). These comparisons show that physical impacts to stream channels and riparian zones are important factors for biological conditions across much of Wyoming.

Nutrients (nitrate+nitrite-N and total phosphorus) emerged as top stressors in the Platte. These parameters affected 18% and 31% of perennial streams in the Platte, respectively, whereas the Green (8% and 9%) and NE (14% and 7%) exhibited lesser relative extents of these parameters. The Bighorn-Yellowstone was intermediate with 23% and 21% of perennial streams affected by these parameters. The greater extent of irrigated crops in the Platte and Bighorn-Yellowstone may partially explain the greater relative extent of nutrients in these basins, though site-specific non-human factors must be considered.

The Platte is slightly better than the entire state of Wyoming with regard to the percentage of stream miles in the least-disturbed biological condition (66% Platte vs. 58% Wyoming). The Platte also has fewer miles in the most-disturbed biological condition (11% Platte vs. 18% Wyoming) (Figure 7) (Hargett and ZumBerge 2013). The Platte fairs better than the Western Mountains, Northern and Southern Plains, and Xeric regions of the United States with regard to least-disturbed (66% Platte vs. 51% Western Mountains 50% Northern Plains, 33% Southern Plains, and 22% Xeric) and most-disturbed (11% Platte vs. 30% Western Mountains, 38% Northern Plains, 26% Southern Plains, and 44% Xeric) biological conditions (USEPA 2020) (Figure 7).

Among the five stressors evaluated at different geographic scales, riparian disturbance, excess sediment, and total phosphorus are the most extensive stressors in the Platte (17-18%), with excess sediment and riparian disturbance the most common throughout Wyoming (36-37%) (Figure 7). Total phosphorus is the fourth most extensive throughout Wyoming (14% of stream miles). Interestingly, total phosphorus is the most extensive stressor nationwide (58%) and in the Western Mountains of the western US (50%). Total nitrogen is an inconsequential stressor to streams in the Platte but is an extensive stressor across the Nation (43%).

RECOMMENDATIONS

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

Results from this survey do not account for the synergistic effects of multiple stressors nor do they identify all the potential environmental stressors that may be limiting the biological condition of particular streams. Survey results indicate that nitrate+nitrite-N and channel instability are the most common stressors in the Platte, followed by TSS, total phosphorus, and riparian disturbance. The commonality of channel instability and riparian disturbance combined with their moderate to high relative risks suggest that efforts aimed at reducing these two stressors in would benefit biological conditions in the Platte. The probable linkage between these two stressors indicate that efforts to address one will likely benefit the other. Accelerated bank erosion and excess sediment are the most prominent of the three sub-stressors that comprised channel instability. Efforts to reduce accelerated bank erosion will not only help to address channel instability, but also reduce TSS and consequently phosphorus loading to streams in the Platte since sediment can function as a nutrient transport mechanism. Total phosphorus, the fourth most common stressor, was elevated in 18% of stream miles in the Platte, and had notable relative risk to biological condition. Elevated total phosphorus attained the greatest relative extents within the Middle North Platte and Lower North Platte and South Platte. Total phosphorus reduction efforts could have greater benefit in these regions than the remainder of the Platte.

Applying the relative risk values derived at the Platte scale, and considering the relative extents of stressors within each HUC 8 cluster, the Lower North Platte and South Platte emerges as an area with the greatest potential need for additional investigation into support of aquatic life uses and eventual point and nonpoint- source pollution reduction. Individual and combined influences of channel instability, riparian disturbance and elevated concentrations of total phosphorus, nitrate-nitrite, and TSS degrade water quality. Among the six HUC 8 clusters, the highest relative extent for most of the aforementioned stressors and the greatest extent of most-disturbed *E. coli* conditions occur within the Lower North Platte and South Platte. While this region may not have the greatest extent of most-disturbed biological conditions among HUC8 clusters, the presence of widespread flow alterations precluded development of expected biological conditions, thus many Lower North Platte and South Platte perennial streams were categorized indeterminate by default. The large proportion of perennial streams categorized as having indeterminate biological condition may underrepresent the true impact of these stressors on biological condition.

ACKNOWLEDGMENTS

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

Particular gratitude is extended to the field crews, comprised of both full time and temporary WDEQ staff, who logged many hours both in the office and in the field to successfully implement this project.

WDEQ/WQD Monitoring Program field crews consisted of Lanny Goyn, Eric Hargett, and Logan Harsh (Cheyenne crew); Tavis Eddy, Michael Wachtendonk, and Kayla Huey (Lander crew); Jason Martineau, Chad Rieger, and Ben Wollenzien (Sheridan crew); and Jeremy ZumBerge (Program Supervisor). Other WDEQ staff include David Waterstreet, Cathy Norris, and Michael Thomas.

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Appendix 1 – Biological condition stressor thresholds used to establish condition categories for streams and rivers within bioregions of the Platte 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="8">Bioregion</th></tr>
<tr><th>Granitic Mountains</th><th>Sedimentary Mountains</th><th>Southern Rockies</th><th>High Valleys</th><th>Wyoming Basin</th><th>Southern Foothills & Laramie Range</th><th>NE Plains</th><th>SE Plains</th></tr>
<tr><td rowspan="15">Water Chemistry</td><td>Chloride (mg/L)</td><td colspan="8">< 230 / ≥ 230</td></tr>
<tr><td>Conductivity (µS/cm)</td><td>< 39 / ≥ 226</td><td>< 219 / ≥ 451</td><td>< 43 / ≥ 255</td><td>< 174 / ≥ 596</td><td>< 260 / ≥ 1552</td><td>< 70 / ≥ 459</td><td>< 1456 / ≥ 2493</td><td>< 352 / ≥ 769</td></tr>
<tr><td>Dissolved Aluminum (µg/L)</td><td colspan="8">< 87 (when pH< 7.00 and Total Hardness as mg/L CaCO3 < 50 mg/L) or < 750 (when pH ≥ 7.00 and Total Hardness as mg/L CaCO3 ≥ 50 mg/L)</td></tr>
<tr><td>Dissolved Arsenic (µg/L)</td><td colspan="8">< 150 / ≥ 150</td></tr>
<tr><td>Dissolved Cadmium (µg/L)</td><td colspan="8">$< e^{(0.7409[\ln(\text{Total Hardness as mg/L CaCO3})]-4.719)(1.101672-[\ln(\text{Total Hardness as mg/L CaCO3})]*0.041838)} / \geq e^{(0.7409[\ln(\text{Total Hardness as mg/L CaCO3})]-4.719)(1.101672-[\ln(\text{Total Hardness as mg/L CaCO3})]*0.041838)}$</td></tr>
<tr><td>Dissolved Iron (µg/L)</td><td colspan="8">< 1000 / ≥ 1000</td></tr>
<tr><td>Dissolved Manganese (µg/L)</td><td colspan="8">$< e^{(0.5434[\ln(\text{Total Hardness as mg/L CaCO3})]+4.7850)} / \geq e^{(0.5434[\ln(\text{Total Hardness as mg/L CaCO3})]+4.7850)}$</td></tr>
<tr><td>Dissolved Zinc (µg/L)</td><td colspan="8">$< e^{(0.8473[\ln(\text{Total Hardness as mg/L CaCO3})]+0.884)(0.986)} / \geq e^{(0.8473[\ln(\text{Total Hardness as mg/L CaCO3})]+0.884)(0.986)}$</td></tr>
<tr><td>Nitrate+Nitrite-N (mg/L)</td><td colspan="8">< 0.100 / ≥ 0.100</td></tr>
<tr><td>TSS (mg/L)</td><td colspan="2">< 3 / ≥ 7</td><td>< 3 / ≥ 6</td><td>< 3 / ≥ 10</td><td>< 3 / ≥ 64</td><td>< 3 / ≥ 9</td><td>< 3 / ≥ 33</td><td>< 3 / ≥ 11</td></tr>
<tr><td>Total Phosphorus (mg/L)</td><td colspan="8">< 0.100 / ≥ 0.100</td></tr>
<tr><td>Total Nitrogen (mg/L)</td><td>< 0.100 / ≥ 0.500</td><td>< 0.100 / ≥ 0.700</td><td>< 0.100 / ≥ 0.539</td><td>< 0.100 / ≥ 0.640</td><td>< 0.140 / ≥ 1.063</td><td>< 0.100 / ≥ 0.754</td><td colspan="2">< 0.180 / ≥ 1.098</td></tr>
<tr><td>Total Selenium (µg/L)</td><td colspan="8">< 5 / ≥ 5</td></tr>
<tr><td>Sulfate (mg/L)</td><td colspan="8"><table><tr><th></th><th>Cl < 5 mg/L</th><th>5 ≤ Cl < 25 mg/L</th><th>25 mg/L ≤ Cl</th></tr><tr><td>HD < 100 mg/L</td><td>500 mg/L</td><td>500 mg/L</td><td>500 mg/L</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></tr><tr><td>HD > 500 mg/L</td><td>500 mg/L</td><td>2000 mg/L</td><td>2000 mg/L</td></tr></table>Cl = Chloride
HD = Hardness</td></tr>
<tr><td>pH</td><td colspan="8">> 6.5 and < 9.0 / < 6.5 or > 9.0</td></tr>
<tr><td rowspan="2">Biological Cond</td><td>WSII</td><td>> 60.3 / < 40.2</td><td>> 52.3 / < 34.8</td><td>> 48.8 / < 32.6</td><td>> 48.8 / < 32.5</td><td>> 39.9 / < 26.2</td><td>> 66.7 / < 44.5</td><td>> 58.4 / < 38.9</td><td>> 55.1 / < 36.7</td></tr>
<tr><td>WY RIVPACS</td><td>> 0.88 / < 0.65</td><td>> 0.82 / < 0.68</td><td>> 0.89 / < 0.62</td><td>> 0.86 / < 0.69</td><td>> 0.82 / < 0.64</td><td>> 0.88 / < 0.68</td><td>> 0.75 / < 0.51</td><td>> 0.78 / < 0.51</td></tr>
<tr><td>Riparian Disturbance</td><td>Riparian Disturbance</td><td colspan="8">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="8">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="8">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="8">Most-disturbed when either either active channel incision (e.g. evident headcuts or unexpected shifts in channel gradient) or recent (within the past 10 years) channelization is present.</td></tr>
</table>

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

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

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

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

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

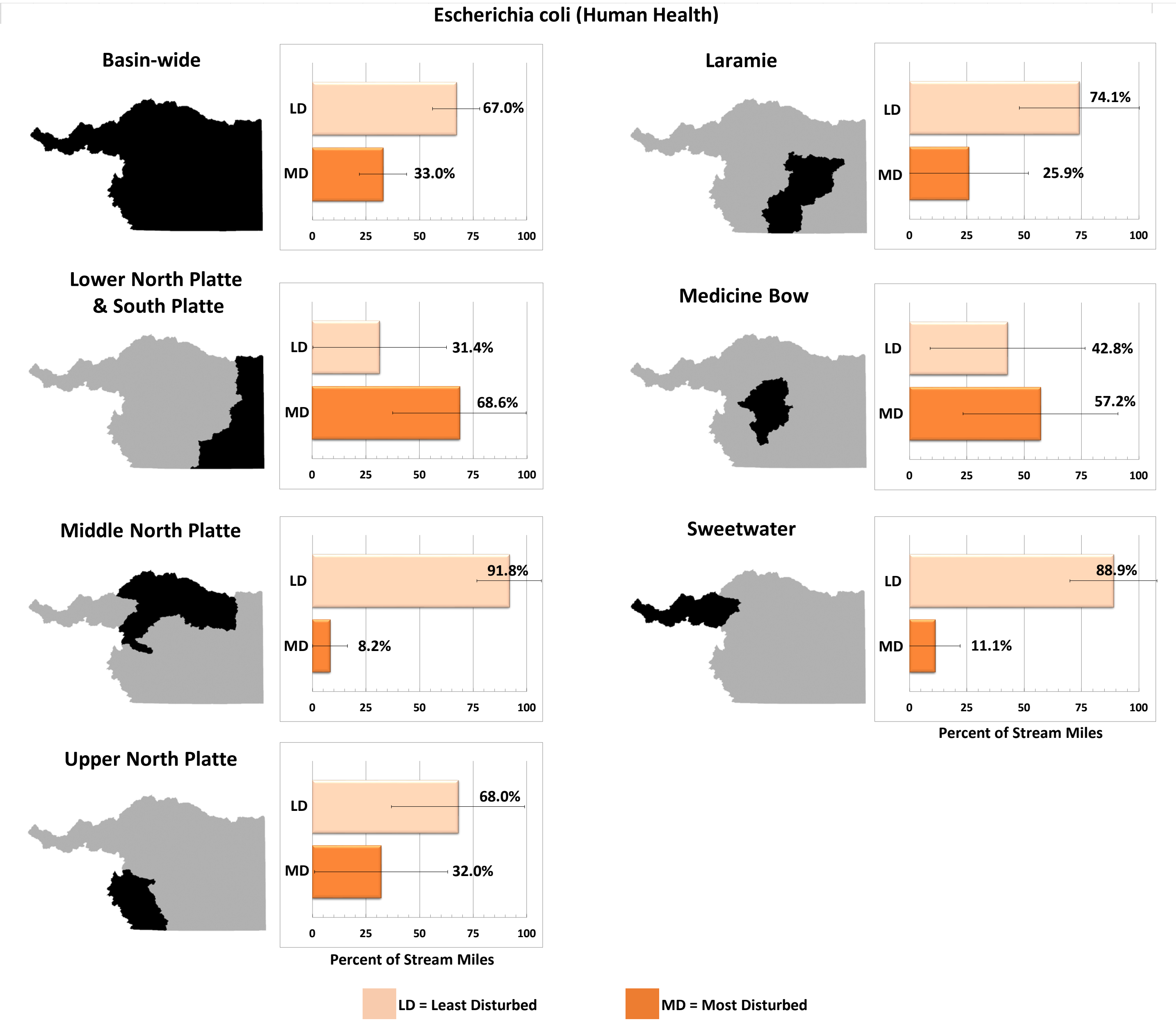
Appendix 3 – Relative departures of 2016 flow statistics from means for the periods of record at selected USGS streams gages within the Platte.

USGS Gage ID	USGS Gage Name	Period of Record	2016 Peak Flow	Mean Peak Flow (cfs) Period of Record	% Departure from Mean Peak Flow for Period of Record	2016 Mean Annual Flow (cfs)	Mean Annual Flow (cfs) for Period of Record	% Departure from Mean Annual Flow for Period of Record
6620000	North Platte River nr. Northgate, CO	1904 & 1915-2020	2,830	3,099.4	-9%	483.9	430.8	12%
6622700	North Brush Creek nr. Saratoga, WY	1961-2020	848	690.5	23%	56.4	50.6	12%
6623800	Encampment River above Hog Park Creek nr. Encampment, WY	1965-2020	1,580	1,136.4	39%	125.1	114.8	9%
6625000	Encampment River at Mouth nr. Encampment, WY	1940-2020	2,820	2,313.1	22%	301.6	249.4	21%
6630000	North Platte River above Seminoe Reservoir nr. Sinclair, WY	1940-2020	9,270	7,678.5	21%	1,498.0	1,143.2	31%
6630465	Medicine Bow River abov East Fork Medicine Bow nr. Elk Mountain, WY	2012-2020	1,100	812.0	36%	69.7	51.2	36%
6632400	Rock Creek above King Canyon Canal nr. Arlington, WY	1955-2020	1,620	1,309.1	24%	91.5	80.7	13%
6634060	Little Medicine Bow River above Sand Creek near Shirley Basin, WY	2015-2020	569	295.5	93%	15.3	16.8	-9%
6634620	Little Medicine Bow River at Boles Spring nr. Medicine Bow, WY	1984-2020	1,090	682.1	60%	44.3	39.7	12%
6635000	Medicine Bow River above Seminoe Reservoir nr. Hanna, WY	1944-2020	1,830	1,760.3	4%	250.5	176.7	42%
6638090	Sweetwater River nr. Sweetwater Station, WY	1974-1992 & 2015-2020	1,400	1,320.2	6%	114.0	125.0	-9%
6646000	Deer Creek in canyon nr. Glenrock, WY	1946-1951 & 1986-2020	4,240	992.7	327%	82.4	56.2	47%
6652000	North Platte River at Orin, WY	1959-2020	10,800	7,006.3	54%	1,946.0	1,604.7	21%
6657000	North Platte River below Whalen Diversion Dam, WY	1917-2020	5,050	4,526.7	12%	1,030.0	692.0	49%
6660000	Laramie River at Laramie, WY	1933-1972 & 2015-2020	1,770	1,072.3	65%	246.1	117.2	110%
6670500	Laramie River nr. Fort Laramie, WY	1915-2020	4,840	1,227.2	294%	493.1	134.8	266%
6674500	North Platte River at Wyoming-Nebraska stateline	1929-2020	8,020	3,614.5	122%	1,586.0	789.3	101%
				Depature Range:	-9% to 327%		Depature Range:	-9% to 266%
				Mean Departure:	70%		Mean Departure:	45%

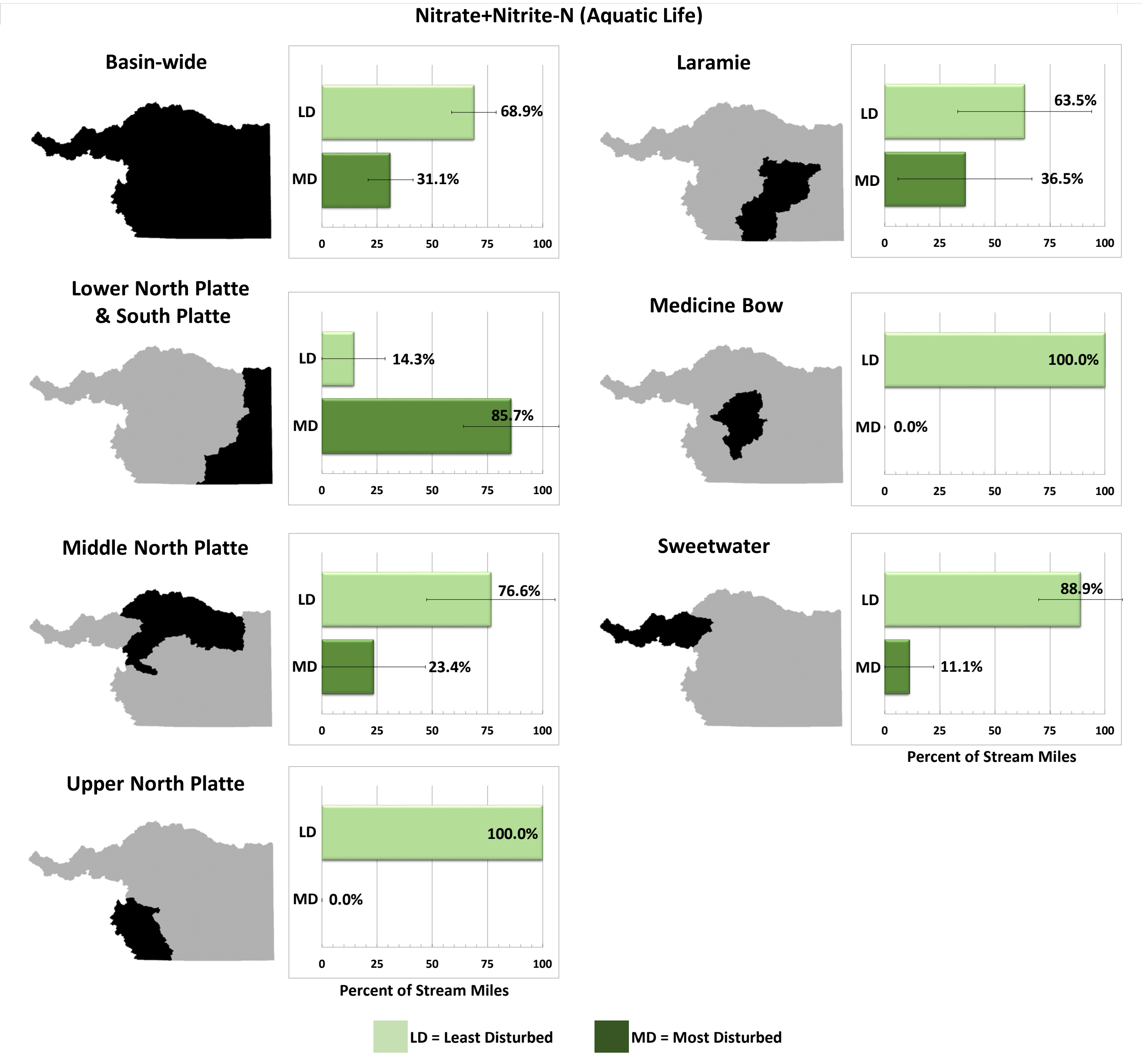
Appendix 4 – Target sites sampled as part of the 2016 Platte survey.

SurveyID	Type	StationID	WaterbodyName- Reach Name	Latitude	Longitude	HUC 6 Basin	Elevation (ft)	Watershed Area (mi^2)	HUC 8 Cluster	Bioregion
WY09C-151	Base	SR0086	Fox Creek - Abv Squirrel Creek	41.110753	-106.078128	NORTH PLATTE	8,290	9.2	Laramie	SOUTHERN ROCKIES
WY09C-152	Base	SR0089	Nash Fork - Ski Area	41.339045	-106.168810	NORTH PLATTE	8,870	9.8	Laramie	SOUTHERN ROCKIES
WY09C-156	Base	WB0462	Duck Creek - Blw Garrett Rd	42.007255	-105.566685	NORTH PLATTE	7,105	17.2	Laramie	WYOMING BASIN
WY09C-157	Base	WB0466	Little Laramie River - Abv Howell Rd	41.461540	-105.733018	NORTH PLATTE	7,030	357.0	Laramie	WYOMING BASIN
WY09C-159	Base	WB0464	Laramie River - Dodge Ranch	41.936732	-105.558328	NORTH PLATTE	6,875	2,070.0	Laramie	WYOMING BASIN
WY09C-160	Base	SR0088	Lodgepole Creek - Islay Ranch	41.332238	-105.125795	SOUTH PLATTE	6,650	50.3	Lower North Platte & South Platte	SE PLAINS
WY09C-161	Base	WHP0058	Horse Creek - Meriden	41.540633	-104.318133	NORTH PLATTE	4,925	423.5	Lower North Platte & South Platte	SE PLAINS
WY09C-162	Base	WHP0059	Horse Creek - Duroc 2	41.808353	-104.255647	NORTH PLATTE	4,310	1,269.0	Lower North Platte & South Platte	SE PLAINS
WY09C-164	Base	WHP0061	Muddy Creek - Blw Gilland Reservoir	41.135225	-104.286453	SOUTH PLATTE	5,315	68.1	Lower North Platte & South Platte	SE PLAINS
WY09C-166	Base	WHP0055	Bear Creek - Diamond Flat	41.649407	-104.382737	NORTH PLATTE	4,800	320.1	Lower North Platte & South Platte	SE PLAINS
WY09C-173	Base	SR0099	Turpin Creek - Abv Reservoir	41.422582	-106.381601	NORTH PLATTE	9,649	2.3	Medicine Bow	SOUTHERN ROCKIES
WY09C-178	Base	NGP0259	Mill Creek - Abv LaBonte Confluence	42.501388	-105.430455	NORTH PLATTE	5,260	38.0	Middle North Platte	NE PLAINS
WY09C-179	Base	SR0102	Virden Creek - Abv Box Elder Rd	42.644525	-105.887943	NORTH PLATTE	6,660	18.5	Middle North Platte	S. FOOTHILLS & LARAMIE RANGE
WY09C-184	Base	NGP0260	North Platte River - Fort Fetterman	42.847787	-105.463970	NORTH PLATTE	4,823	14,184.0	Middle North Platte	NE PLAINS
WY09C-185	Base	SR0092	North Fork Miner Creek - Abv Copper Creek	41.144555	-106.847892	NORTH PLATTE	7,940	4.5	Upper North Platte	S. FOOTHILLS & LARAMIE RANGE
WY09C-190	Base	WB0474	Rattlesnake Creek - Halleck	41.686115	-106.676059	NORTH PLATTE	6,827	22.0	Upper North Platte	WYOMING BASIN
WY09C-192	Base	SR0085	Big Creek - Big Creek Ranch	41.064283	-106.502649	NORTH PLATTE	7,670	109.7	Upper North Platte	WYOMING BASIN
WY09C-193	Base	WB0473	Pete Creek - 3148	42.362428	-107.251527	NORTH PLATTE	6,341	12.0	Sweetwater	WYOMING BASIN
WY09C-197	Base	MRW0205	Rock Creek - Garfield	42.502195	-108.749309	NORTH PLATTE	7,777	23.0	Sweetwater	WYOMING BASIN
WY09C-200	Base	WB0478	Sweetwater River - Barras	42.490752	-108.307366	NORTH PLATTE	6,569	554.0	Sweetwater	WYOMING BASIN
WY09C-501	OverSample	SR0091	North Fork Little Laramie River - Trailhead	41.339385	-106.159990	NORTH PLATTE	8,925	14.1	Laramie	SOUTHERN ROCKIES
WY09C-502	OverSample	SR0095	North Sybille Creek - Blw Bear Creek	41.729866	-105.455370	NORTH PLATTE	6,455	37.8	Laramie	SE PLAINS
WY09C-512	OverSample	SR0087	Halleck Creek - Yaunt Mountain	41.870790	-105.328408	NORTH PLATTE	5,870	15.5	Laramie	SE PLAINS
WY09C-514	OverSample	WB0463	Laramie River - Bosler Junction	41.551997	-105.684838	NORTH PLATTE	7,035	1,873.0	Laramie	WYOMING BASIN
WY09C-528	OverSample	WHP0057	Horse Creek - Bullwhacker	41.504745	-104.543047	NORTH PLATTE	5,290	321.4	Lower North Platte & South Platte	SE PLAINS
WY09C-532	OverSample	SR0090	North Bear Creek - Hirsig Ranch	41.559507	-105.075843	NORTH PLATTE	6,410	12.0	Lower North Platte & South Platte	SE PLAINS
WY09C-535	OverSample	WHP0060	Horse Creek - Hawk Springs	41.812260	-104.250037	NORTH PLATTE	4,300	1,272.0	Lower North Platte & South Platte	SE PLAINS
WY09C-555	OverSample	SR0098	Medicine Bow River - Stillwater	41.461348	-106.361683	NORTH PLATTE	9,177	22.1	Medicine Bow	SOUTHERN ROCKIES
WY09C-557	OverSample	WB0468	Little Medicine Bow River - Blw Slate	42.247067	-106.119356	NORTH PLATTE	6,803	302.0	Medicine Bow	WYOMING BASIN
WY09C-559	OverSample	WB0480	Wagonhound Creek - Rest Area	41.620920	-106.295056	NORTH PLATTE	7,524	22.5	Medicine Bow	S. FOOTHILLS & LARAMIE RANGE
WY09C-560	OverSample	WB0475	Sheep Creek - Marshall	42.287472	-105.884258	NORTH PLATTE	7,165	45.0	Medicine Bow	WYOMING BASIN
WY09C-563	OverSample	WB0470	Mill Creek - Elk Mountain	41.673990	-106.446968	NORTH PLATTE	7,242	10.0	Medicine Bow	WYOMING BASIN
WY09C-570	OverSample	WB0469	Medicine Bow River - Horne	41.836557	-106.203186	NORTH PLATTE	6,606	313.0	Medicine Bow	WYOMING BASIN
WY09C-571	OverSample	SR0097	East Fork Medicine Bow River - Willow Park	41.505847	-106.337363	NORTH PLATTE	8,830	8.1	Medicine Bow	SOUTHERN ROCKIES
WY09C-577	OverSample	NGP0258	Deer Creek - Glenrock	42.835544	-105.875061	NORTH PLATTE	5,118	182.0	Middle North Platte	NE PLAINS
WY09C-580	OverSample	WB0484	Poison Spider Creek - Clevidence Draw	42.813377	-106.567970	NORTH PLATTE	5,305	444.0	Middle North Platte	WYOMING BASIN
WY09C-581	OverSample	NGP0257	Deer Creek - Abv Deer Creek Rd	42.769180	-105.979982	NORTH PLATTE	5,280	152.0	Middle North Platte	NE PLAINS
WY09C-584	OverSample	WB0482	Bates Creek - Blw 220	42.672998	-106.598468	NORTH PLATTE	5,315	395.0	Middle North Platte	WYOMING BASIN
WY09C-585	OverSample	SR0100	Bates Creek - Blw Chalk Creek	42.529843	-106.319255	NORTH PLATTE	6,420	202.0	Middle North Platte	WYOMING BASIN
WY09C-586	OverSample	SR0101	Little LaPrele Creek - Chamberlain Place	42.579569	-105.710794	NORTH PLATTE	6,240	9.9	Middle North Platte	S. FOOTHILLS & LARAMIE RANGE
WY09C-606	OverSample	WB0461	Brush Creek - Brush Creek Ranch	41.328207	-106.599786	NORTH PLATTE	7,500	87.7	Upper North Platte	WYOMING BASIN
WY09C-607	OverSample	SR0084	Big Creek - Elkhorn Point	41.059612	-106.509676	NORTH PLATTE	7,700	108.3	Upper North Platte	WYOMING BASIN
WY09C-610	OverSample	SR0094	North Platte River - Bennett Peak	41.256270	-106.585517	NORTH PLATTE	7,150	2,052.5	Upper North Platte	WYOMING BASIN
WY09C-611	OverSample	WB0472	Pass Creek - Walcott	41.703018	-106.834818	NORTH PLATTE	6,543	241.0	Upper North Platte	WYOMING BASIN
WY09C-612	OverSample	WB0471	North Platte River - Sanger WGFD	41.551938	-106.904775	NORTH PLATTE	6,635	3,277.0	Upper North Platte	WYOMING BASIN
WY09C-627	OverSample	WB0476	Sweetwater River - Granite Springs	42.416203	-108.501247	NORTH PLATTE	7,062	454.0	Sweetwater	WYOMING BASIN
WY09C-629	OverSample	WB0479	Sweetwater River - Martins Cove	42.444008	-107.217652	NORTH PLATTE	5,907	5,907.0	Sweetwater	WYOMING BASIN
WY09C-630	OverSample	MRW0204	Blair Creek - Sweetwater Needles	42.567525	-109.025567	NORTH PLATTE	8,647	6.3	Sweetwater	GRANITIC MNTS
WY09C-631	OverSample	WB0477	Sweetwater River - Lewiston	42.438621	-108.424770	NORTH PLATTE	6,754	506.0	Sweetwater	WYOMING BASIN
WY09C-634	OverSample	MRW0206	Sweetwater River - Wildcat Butte	42.518734	-109.049354	NORTH PLATTE	7,813	42.0	Sweetwater	HIGH VALLEYS

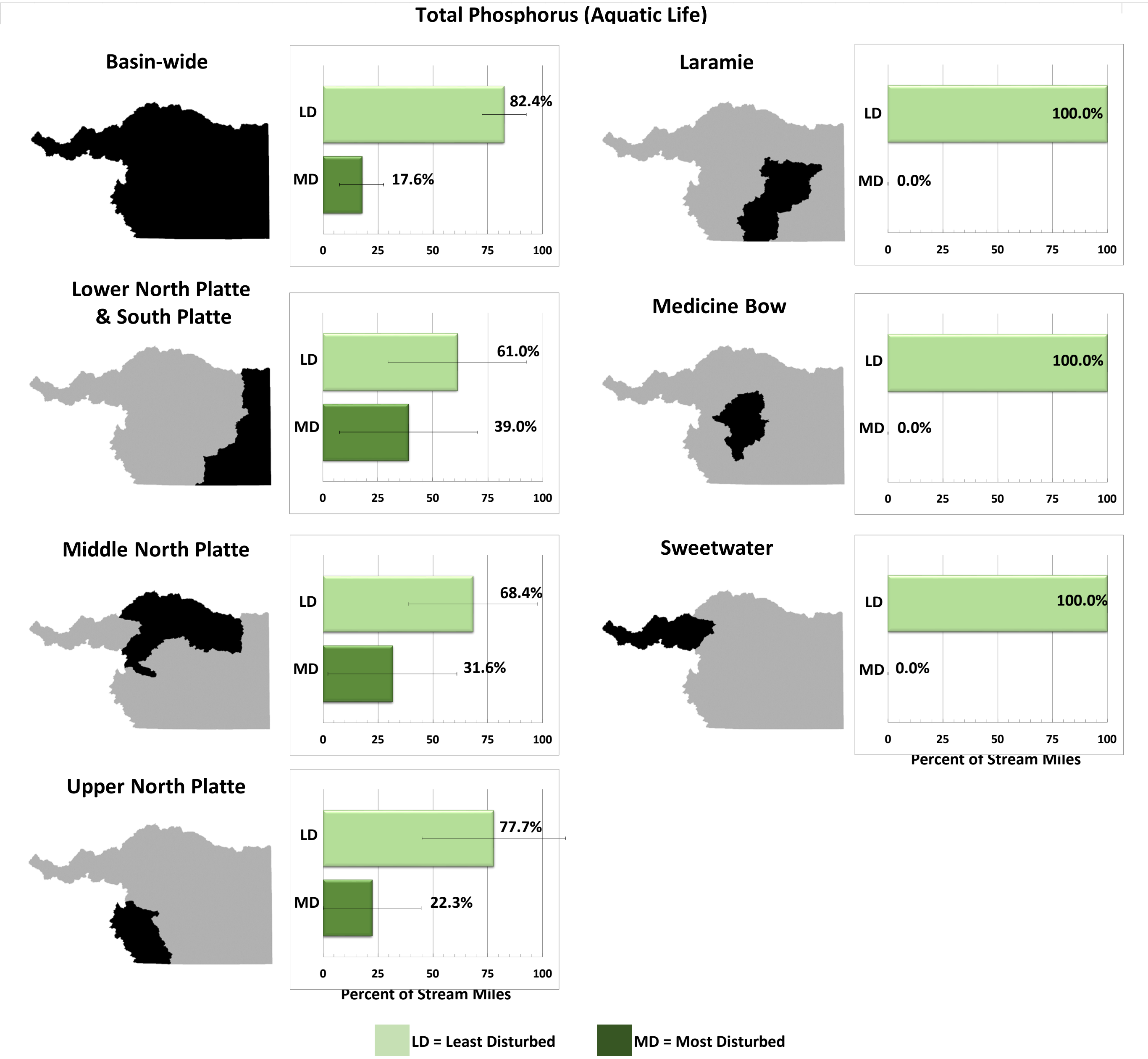
Appendix 5 - Summary of *Escherichia coli* results for the Platte and corresponding HUC 8 Clusters. Error bars represent the 95% confidence intervals.



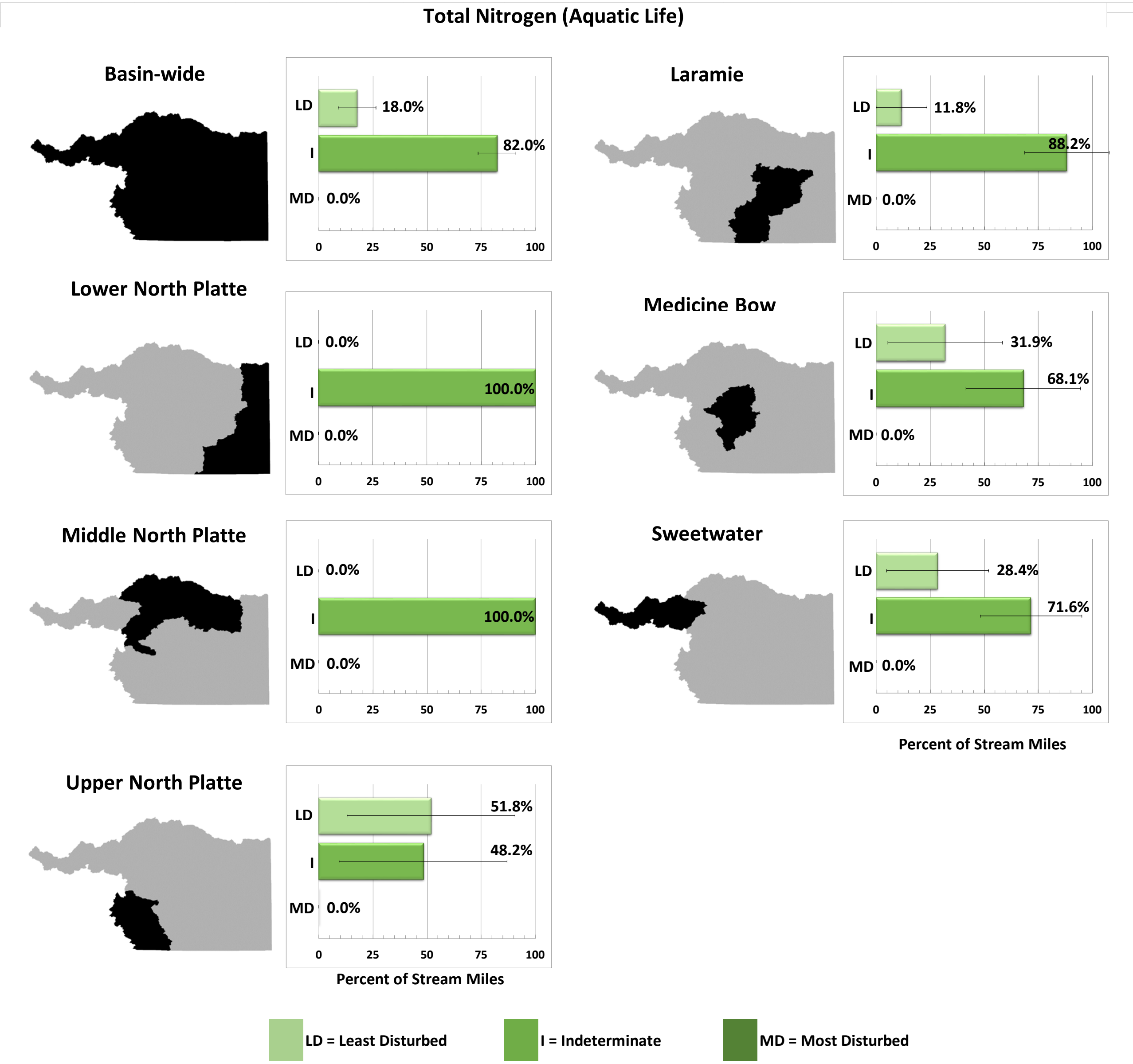
Appendix 6 – Summary of nitrate+nitrite-N results for the Platte and corresponding HUC 8 Clusters. Error bars represent the 95% confidence intervals.



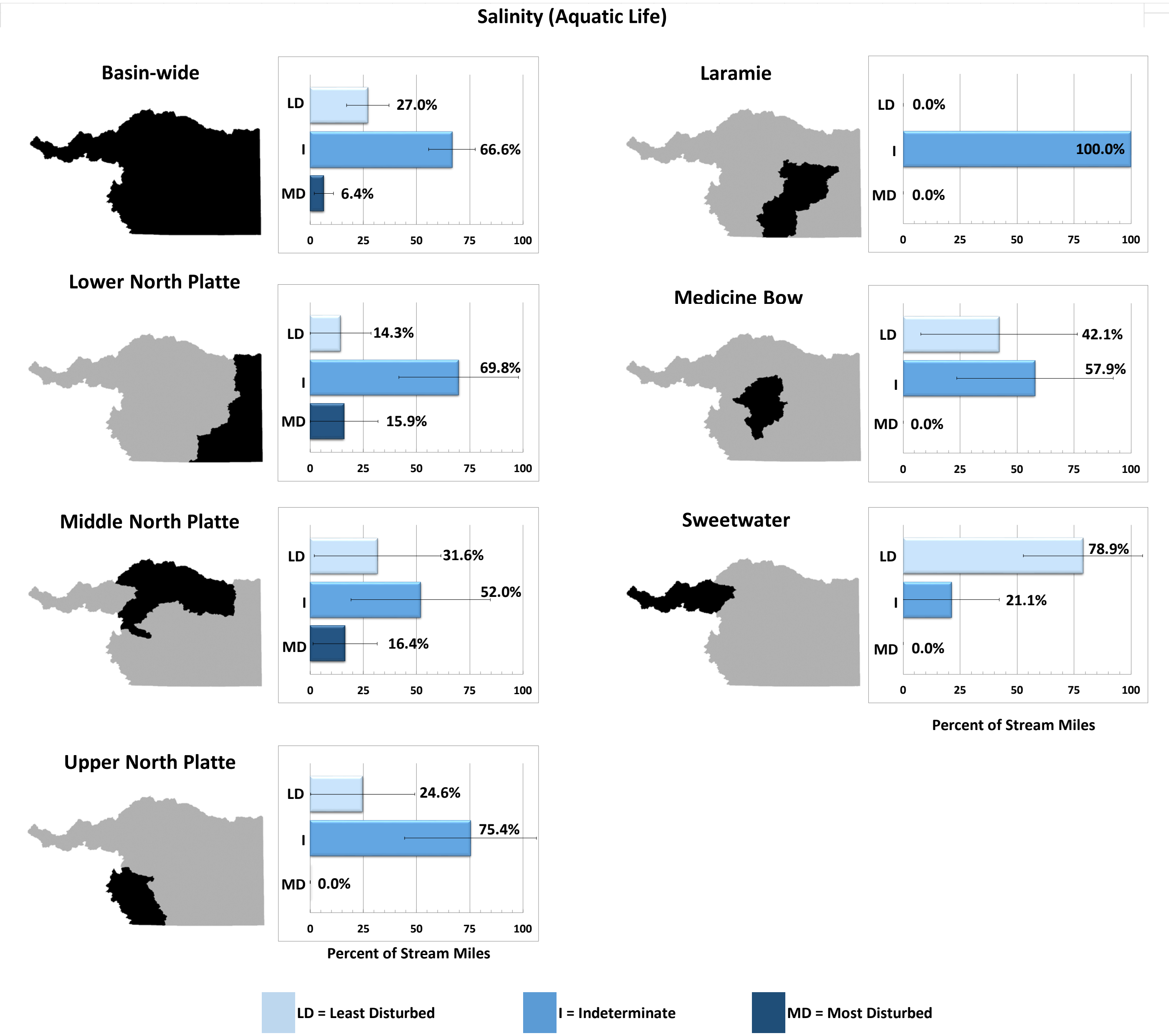
Appendix 7 - Summary of total phosphorus results for the Platte and corresponding HUC 8 Clusters. Error bars represent the 95% confidence intervals.



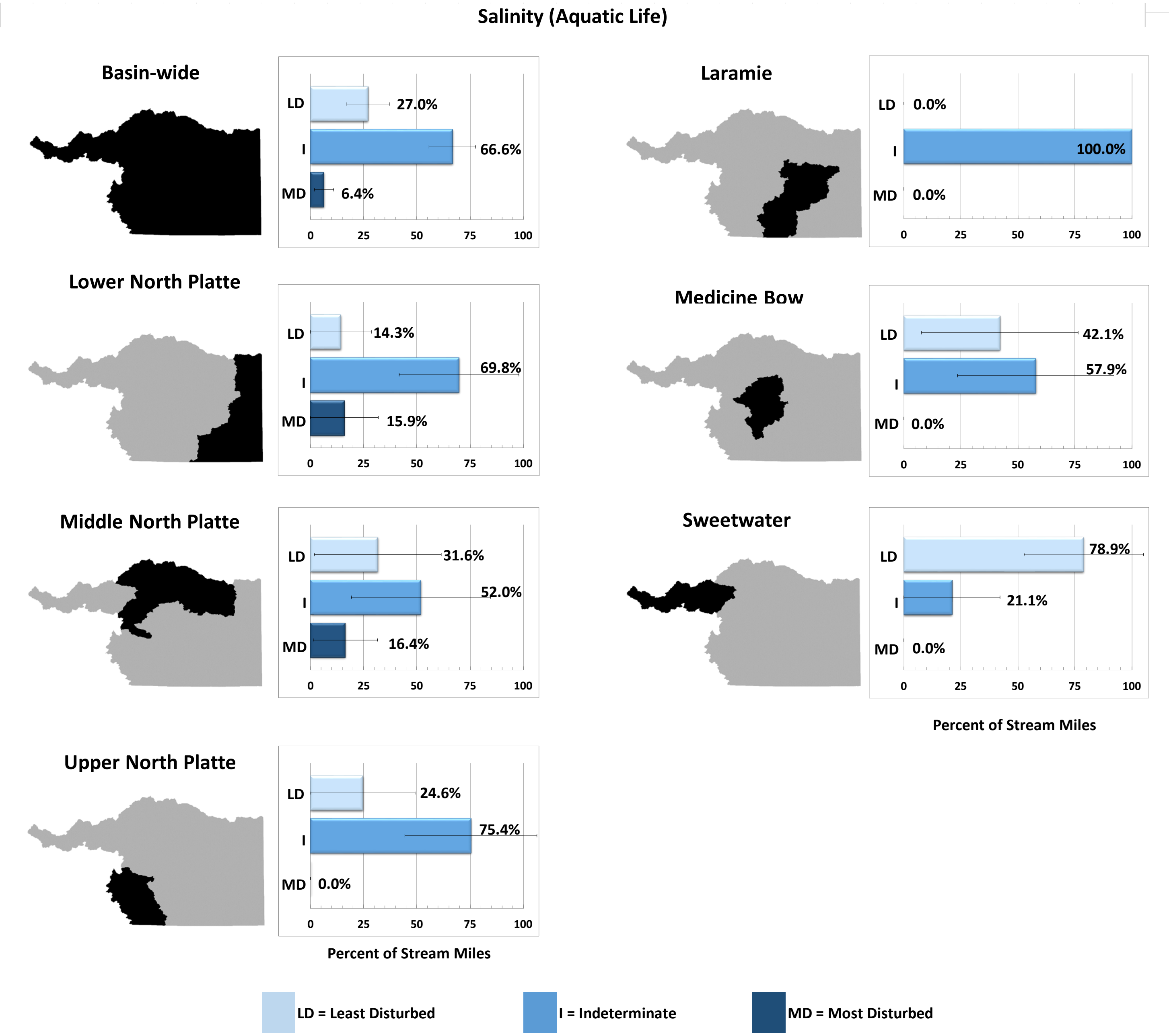
Appendix 8 - Summary of total nitrogen results for the Platte and corresponding HUC 8 Clusters. Error bars represent the 95% confidence intervals.



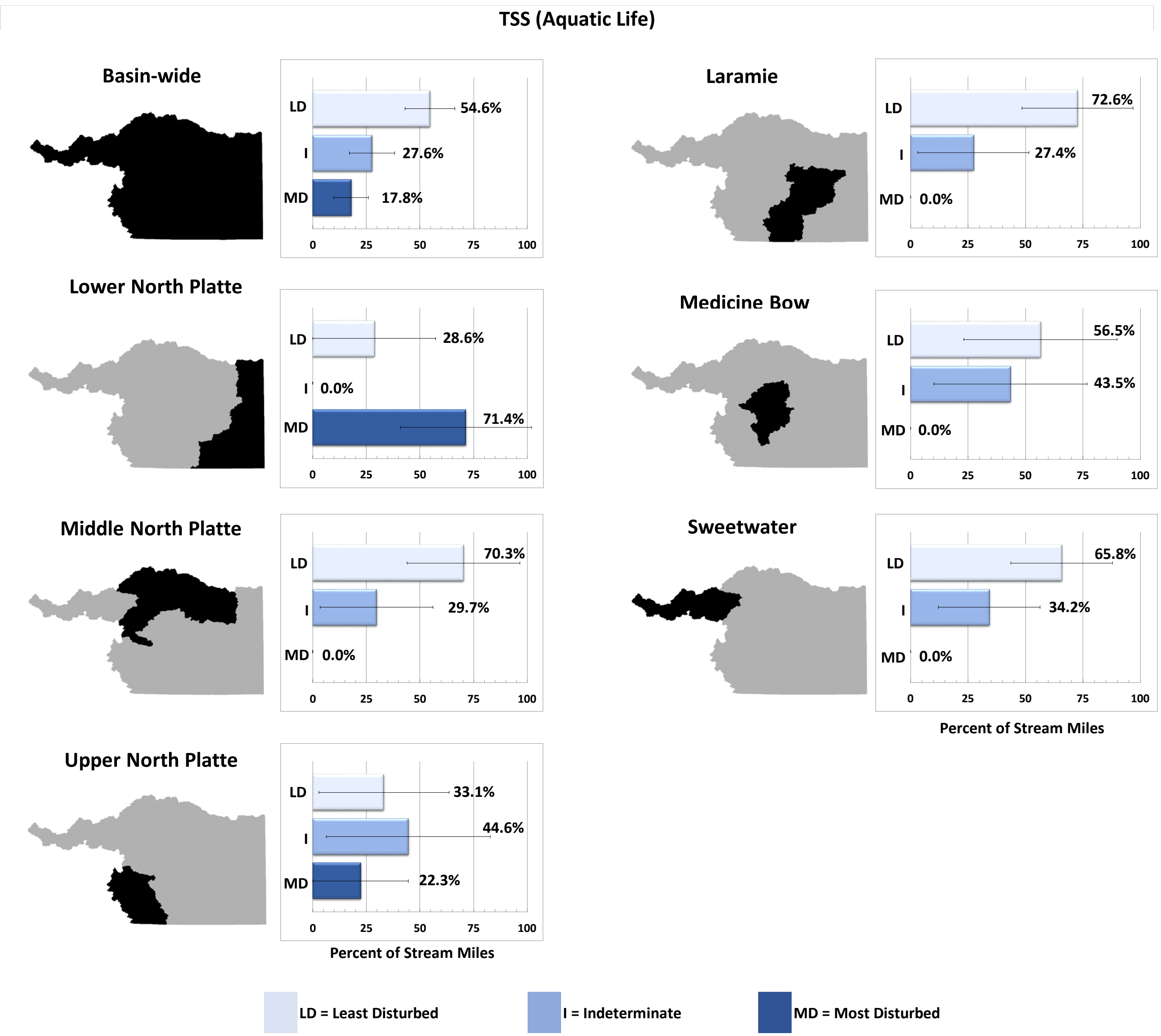
Appendix 9 - Summary of salinity results for the Platte and corresponding HUC 8 Clusters. Error bars represent the 95% confidence intervals.



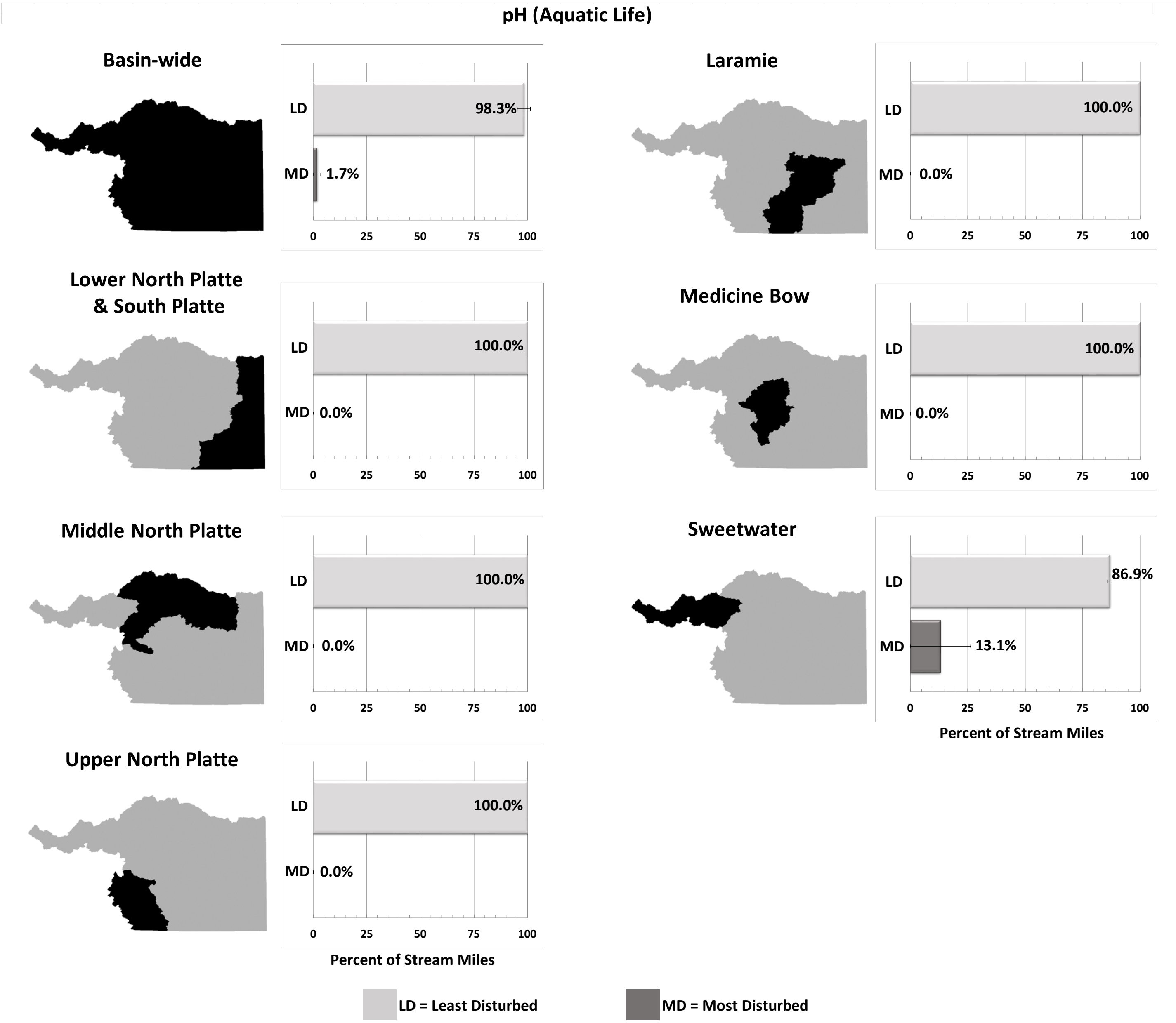
Appendix 10 - Summary of selenium results for the Platte and corresponding HUC 8 Clusters. Error bars represent the 95% confidence intervals.



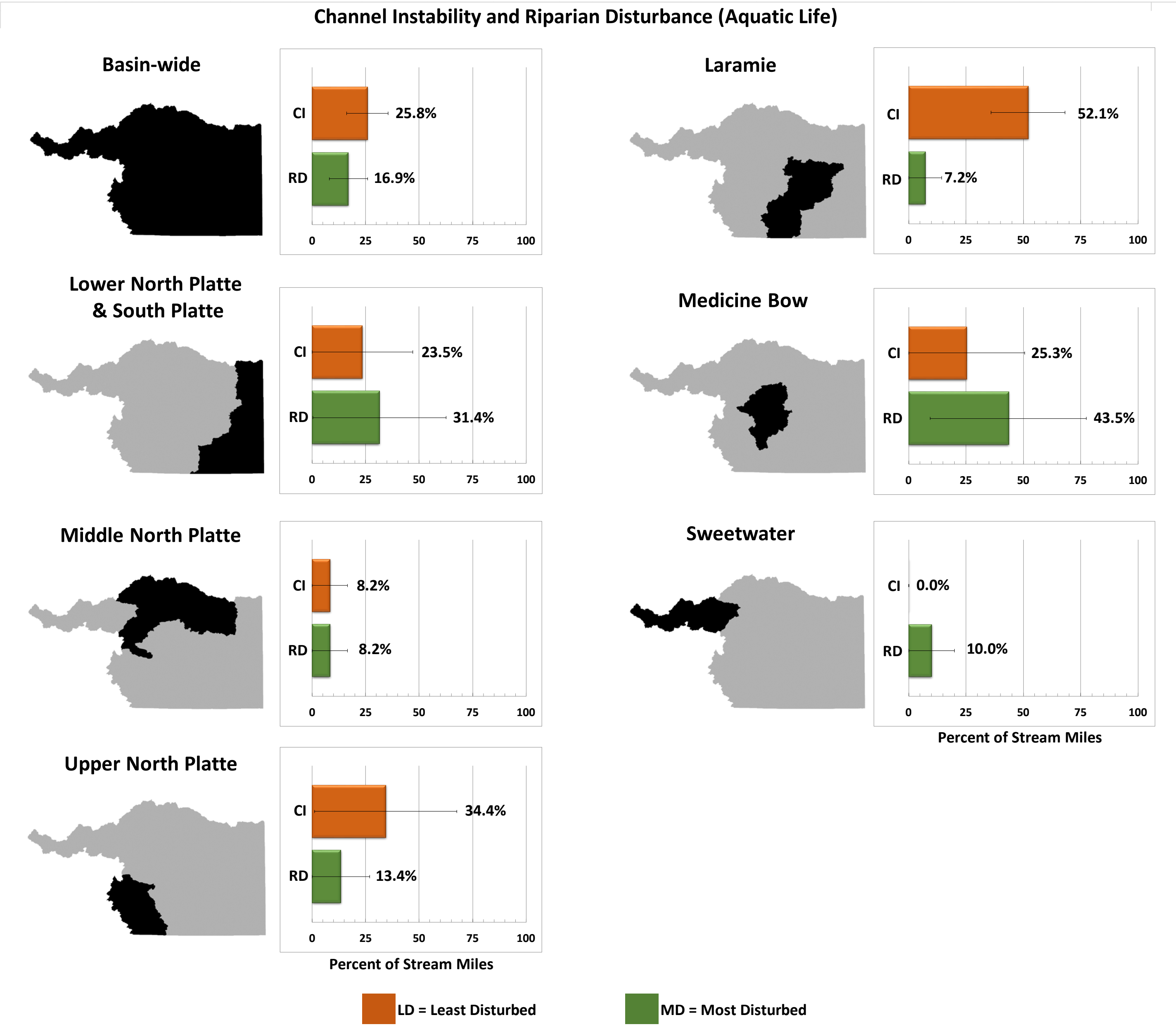
Appendix 11 - Summary of total suspended solids (TSS) results for the Platte and corresponding HUC 8 Clusters. Error bars represent the 95% confidence intervals.



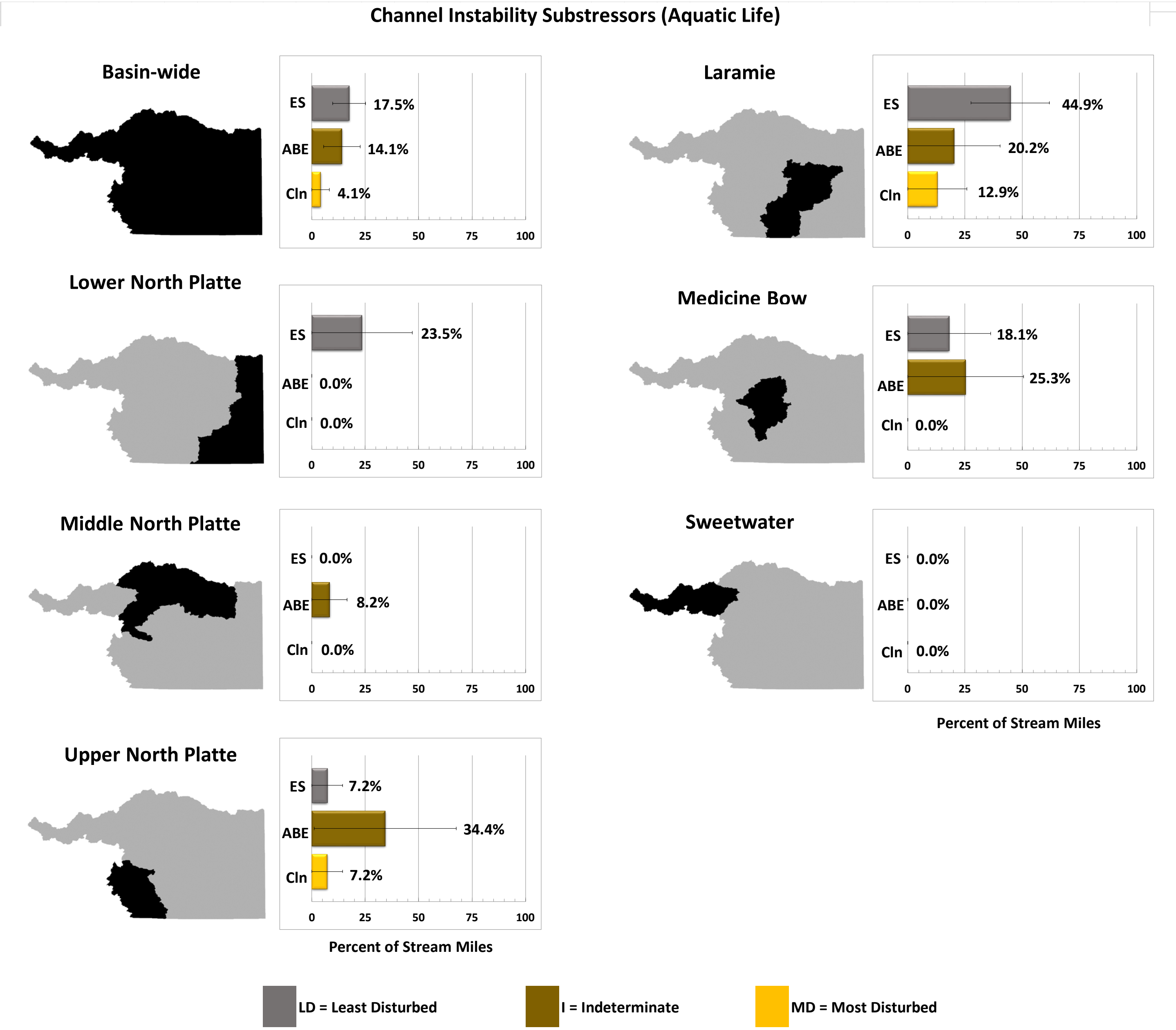
Appendix 12 - Summary of pH results for the Platte and corresponding HUC 8 Clusters. Error bars represent the 95% confidence intervals.



Appendix 13 - Summary of physical stressor results (channel instability and riparian disturbance) for the Platte and corresponding HUC 8 Clusters. Error bars represent the 95% confidence intervals.



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



Appendix 15 - Photos from a subset of the 50 Platte probabilistic survey sites.

Rattlesnake Creek, Carbon County

Horse Creek, Laramie County

Sand Creek

Fox Creek, Goshen County

Nash Fork, Albany County

Douglas Creek, Carbon County

North Platte River, Carbon County

North Sybille Creek, Albany County

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

Cottonwood Creek, Platte County

Deer Creek, Converse County

Blair Creek, Fremont County

Poison Spider Creek, Natrona County

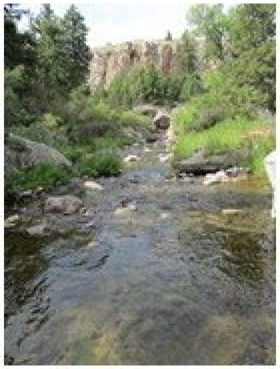
Pass Creek, Carbon County

Virden Creek, Converse County

Poison Spider Creek, Natrona County

Sweetwater River, Fremont County

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



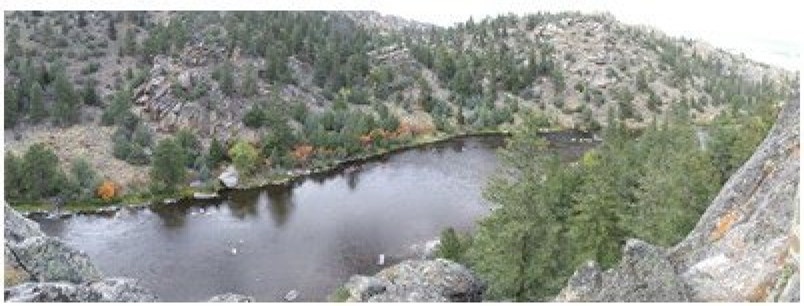
Bates Creek, Natrona County

Bear Creek, Goshen County

Bolton Creek, Natrona County

North Laramie River, Albany County

Medicine Bow River



North Platte River, Carbon County

Laramie River, Albany County