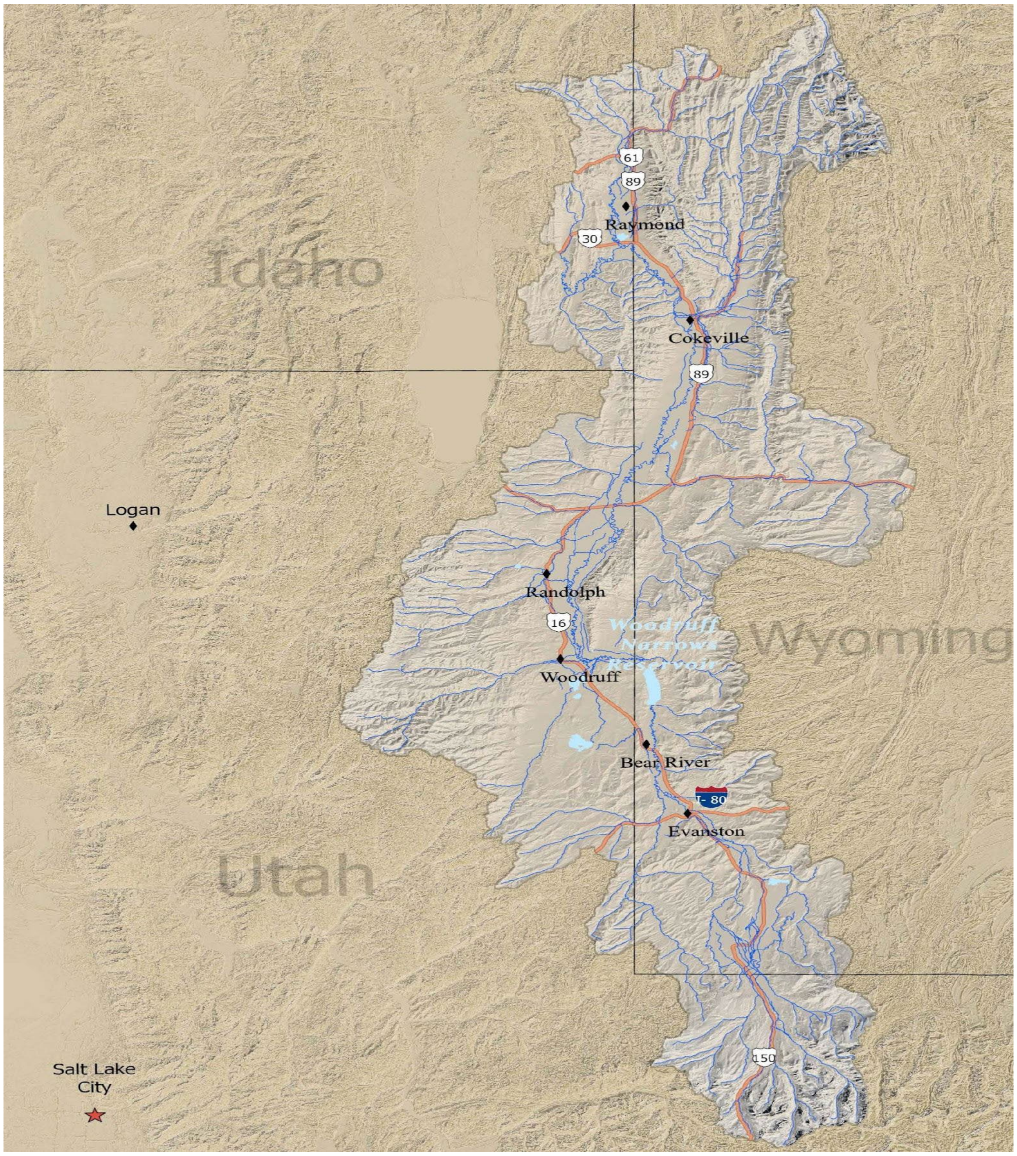
Biological Condition of Streams and Rivers in the Upper and Central Bear River Basin, Wyoming, Utah, Idaho

Results of the 2021 Upper and Central Bear River Basin Probabilistic Survey



Wyoming Department of Environmental Quality – Water Quality Division

Utah Division of Water Quality

Idaho Department of Environmental Quality

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EXECUTIVE SUMMARY

The Wyoming Department of Environmental Quality - Water Quality Division (WDEQ/WQD), Idaho Department of Environmental Quality - Surface and Wastewater Division (IDEQ/SWD), and Utah Department of Environmental Quality - Division of Water Quality (UDEQ/DWQ) jointly conducted a probabilistic survey of perennial streams and rivers in the Upper and Central Bear River Basin (hereinafter the Tri-State Bear Survey, or TBS) in 2021. Results from this survey provide an objective representation of the biological condition of perennial streams and rivers in the TBS. This study also identifies the most common stressors and their relative impact to biological condition. Additional drink water and human health parameters were evaluated at sites in Wyoming and Idaho.

The survey included all non-headwater (>1st Strahler order), perennial streams within the Upper and Central Bear sub-basins (8-digit HUCs). The survey encompassed 3,738 of the 9,578 (39%) perennial stream miles initially considered for the survey. Of the 9,578 total perennial stream miles, the remaining 5,840 stream miles were identified as ephemeral, intermittent, human constructed, wetlands, inaccessible or access was denied.

Findings from this study indicate that 37% of the perennial streams in the TBS are in the least-disturbed biological condition. Approximately 41% of perennial streams are considered most-disturbed, implying an appreciable deviation from reference expectations associated with anthropogenic stressors. The remaining 22% of perennial stream miles were deemed to be of indeterminate biological condition.

Of the eleven stressors investigated, riparian disturbance (42% of stream miles), channel instability (34% of stream miles), and total suspended solids (23% of stream miles) were the three most common stressors influencing biological condition in the TBS. Riparian disturbance was typically comprised of a collection of indicators — low overhead cover, minimal woody vegetation, hoof shear/trampling along river or stream banks, and dominant upland/ facultative vegetation encroachment on the banks. Of the perennial stream miles experiencing channel instability, accelerated bank erosion and excess sediment were the most extensive substressors.

Perennial streams were 2.14 times more susceptible to being in the most-disturbed biological condition when total phosphorus was present and 2.04 times more likely when channel instability was present. Following total phosphorus and channel instability, excess sediment presented a 1.99 times greater risk of having a most-disturbed biological condition when present.

Results were put into a national perspective by comparing findings from the most recent National Rivers and Stream Assessment (NRSA). Slightly better biological and stressor conditions occurred in the TBS than NRSA. For the TBS, 37% of perennial streams were in the least-disturbed biological condition, compared to 28% for NRSA. Likewise, the TBS showed 41% of perennial streams in the most-disturbed biological condition, compared to 47% for the NRSA. Far fewer streams were in the most-disturbed condition for total nitrogen (5%) and total phosphorus (17%) compared to the Nation (44% and 42%, respectively).

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.

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).

- 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

Wyoming's Bear/Snake survey was an opportunity for the Bear River Water Quality Committee and Task Force to leverage an existing project to support the Committee's strategic goals and objectives. The Committee designed a probabilistic survey of two 8-digit hydrologic units (HUCs) of the Bear River Basin shared by the three states (Upper and Central Bear). The study design used existing Wyoming Bear/Snake survey sites within these HUCs, supplemented with Utah and Idaho sites and several supplemental Wyoming sites in a spatially representative 50-site probabilistic survey of the TBS.

The objectives of the TBS were to 1) determine the biological condition of perennial streams and rivers (hereafter referred to as 'perennial streams') within the Upper and Central Bear combined study area, 2) determine the most extensive selected stressors likely to influence biological condition, 3) determine the relative risk of selected stressors to biological condition, and 4) provide recommendations on focus pollutants and areas where additional investigation could be conducted to determine whether aquatic life uses are being supported.

STUDY AREA

Originating in Utah within the Uinta Mountains, the Bear River flows northward along an arc-shaped path, crossing the Utah- Wyoming state line three times prior to flowing into Idaho, then turning south back and returning to Utah to ultimately deposit into the Great Salt Lake. The Bear River Basin spans roughly 7,300 mi² (~4,800,000 acres) (USGS, 1987). The Bear River Basin is located within the Great Basin Region and is comprised of two HUC 6 sub-basins —the Upper Bear River Basin (160101), and the Lower Bear (160102). Within the Upper Bear River HUC 6, there are two HUC 8 watersheds—Upper (16010101) and Central (16010102). The study area of the TBS encompasses these two HUC 8's and account for 2,804 mi² (1,794,560 acres) and support approximately 3,800 miles of rivers and streams of which ~ 226 miles are the Bear River proper. Hereinafter, the Upper and Central Bear HUCs are the "study area".

Land ownership within the study area is a heterogenous composition of federal, state, and private lands—the Upper Bear Basin is dominantly federal land with private ownership being the next largest ownership category (USFWS, 2013). The Central Bear River Basin has a majority makeup of private lands with federal land being the next largest category (USFWS, 2013). State-owned lands in the study area fall into the lowest category.

The TBS study area is dominated by three bioregions—Wyoming Basin, Sedimentary Mountains, and Southern Rockies—where the Wyoming Basin bioregion encompasses a vast 69% (Figure 1). Bioregions, a Wyoming Department of Environmental Quality geographical classification based on ecoregions (Chapman et al. 2003) and watershed characteristics, describe terrains with similarities in habitat, chemical, and biological attributes (Hargett, 2011). The Wyoming Basin bioregion is derived of a high elevation, arid desert shrubland with geographic features that include escarpments, mesas, rolling hills, and alkaline depressions all of which are surrounded by forested mountains (Hargett, 2011). Within the TBS, the Wyoming Basin spans all three states, from north of Raymond, Idaho, south past Wyoming's southern border into Utah, and from the eastern border of the greater Bear River Basin westerly well into Utah. The Sedimentary Mountains are characterized with pronounced bedrock geological formations with increased elevations. The

Sedimentary Mountains make up 22% of the Bear River Basin. This bioregion is in the most western portion of the study area in Utah, a small island within Utah near the southwestern corner of Wyoming, and within the most northern section of the basin in Idaho and Wyoming. The Southern Rockies bioregion within the study area is characterized by the Uinta Mountains (Hargett, 2011). This bioregion is concentrated in the southernmost section of the basin in the eastern part of Utah and the southeasternmost section of southwestern Wyoming (Figure 1). The Southern Rockies bioregion only accounts for 9% of the total bioregion coverage in the study area.

The greater Bear River Basin offers unique terrain, geography, and vegetation. The precipitation within the basin supports a diverse, natural and anthropogenic vegetation community (USFWS, 2013). Privately owned land, present in the lower elevation areas of the study area, prioritizes land use for agricultural activities such as alfalfa and grain cultivation, and ranchland activities such as grazing. Other parts of the lower elevation plains are dominated by grass and shrublands consisting of diverse native rangeland grasses and shrub species. Forested lands occur within their species niche (aspect, elevation, soil composition, etc.). Broadly, higher elevations support coniferous spruce, lodgepole, and subalpine pine while middle elevations support coniferous species and aspens. Lastly, lower elevations and riparian areas support more temperate, deciduous tree species (USFWS, 2013).

The greater Bear River Basin's climate is heavily influenced by local elevations (Taboga et al. 2014). Across the three states, the study area elevation ranges from approximately 6,000 to 12,700 feet. Humidity within the Wyoming Basin provides a more semi-arid climate. As elevations increase in the Southern Rockies and Sedimentary Mountain bioregions, local mountainous orographic effects contribute to increased humidity and precipitation (Taboga et al. 2014). However, in 2021, the study area was presented with severe to extreme drought conditions at the time of sampling and throughout the year (Figure 2 and Appendix 4). The greater Bear River Basin's annual precipitation ranges from 10 inches in lower elevations to 65 inches in higher, headwater elevations in the Uinta Mountains (Utah Division of Water Resources 2005b as cited by USFWS 2013). Inversely, lower elevations see a higher temperature average (53ºF) and higher elevations see lower annual temperature averages (37ºF) (USFWS, 2013).

The greater Bear River community and economy rely heavily on water. However, as the basin is presented with an increase in population, water use follows. Consistent with provisions of the Bear River Compact, depletion estimates from 1976 to 2009 were calculated for the Upper Division (above Stewart Dam) and Lower Division (below Stewart Dam). In the upper division, Utah saw an increase of 5,935 acre-feet (AF) in agriculture water depletions, 841 AF in reservoir evaporation, and a decrease of -5 AF in municipal and industrial depletions (Bear River Commission, 2014). Wyoming saw an increase in all three categories—2,407 AF, 197 AF, and 401 AF accordingly. Idaho was estimated to see an increase in all categories and those estimates are as follows—1,310 AF, 0 AF, and 3 AF. In the lower division, Idaho was estimated to see an increase in all three categories—8,667 AF, 11 AF, and 300 AF. Lastly, Utah's lower division was estimated to see a decrease in agricultural depletions at -5,771 AF, 0 AF in reservoir evaporation, but a large increase of 5,978 AF in municipality and industrial use (Bear River Commission, 2014).

Water in the west generates revenue from a variety of sectors. The greater Bear Basin promotes many revenue opportunities that derive from primary uses — agriculture (crops and livestock), natural resource recreation and tourism, and hydropower. These primary uses generate nearly $1 billion in market revenue annually (Hjerpe et al. 2023). However, the greater Bear River Basin additionally fuels revenue generated from Great Salt Lake as the lake is an important source for minerals and the world's leading brine shrimp harvest effort that supports the global aquaculture industry (Hjerpe et al. 2023).

Additionally, the greater Bear River Basin offers many ecosystem services that do not have a monetary value, but rather positive benefits to human activity and ecological resistance and resilience. The greater Bear Basin supports regulatory, supporting, provisioning, and cultural ecosystem services. Regulatory services consist of gas and disturbance regulation and soil erosion control—supporting services include nutrient and water cycling—provisioning includes biomass and freshwater for consumption—cultural includes recreation (wildlife viewing, hiking, fishing, and hunting) and tourism that occurs within the basin (USFWS, 2013). The very limited supply of water for private landowners (grazing and agriculture), future oil, gas, mining, residential development, and reoccurring drought events may ultimately be reflected upon river and stream health without conservation efforts.

SURVEY DESIGN

The survey design used NHDPlusHR Beta. For a stream or river to be considered within the study design the river or stream must be contained within HUC 16010101 or 16010102 (Upper or Central Bear), and be non-headwater streams (>1st Strahler order). Stream reaches were selected if they were coded in NHDPlus as StreamRiverPer (perennial streams), StreamRiver, ArtificialPathStreamRiver, ArtificalPath, or StreamRiverInt (intermittent stream), and fell outside of the criterion previously stated.

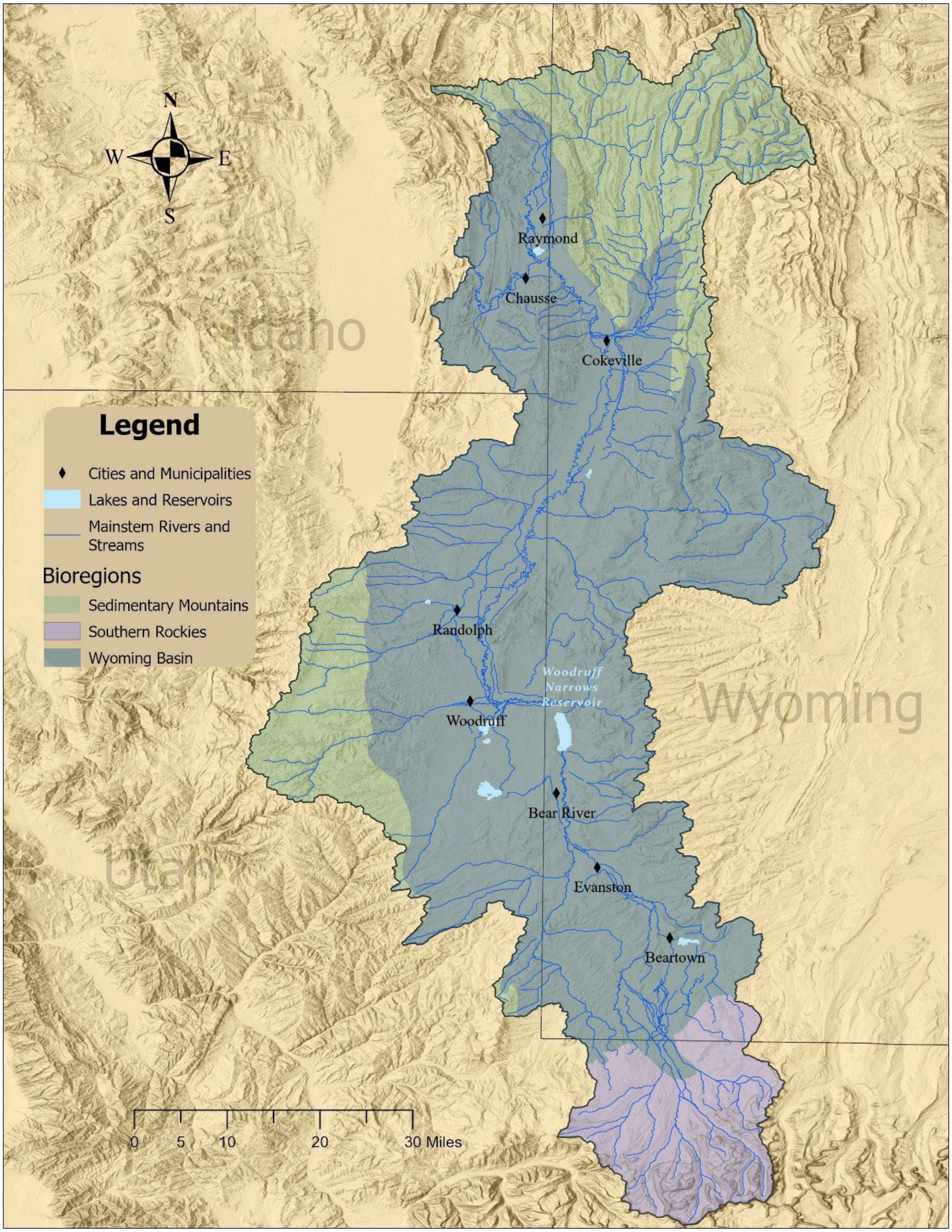
NHDPlusHR indicated the study area has 9,578 total perennial stream miles. After excluding headwater streams (1st Strahler order), approximately 3,738 perennial stream miles (39%) remained. The term 'perennial streams' will be used throughout this report to represent the target population of streams for the TBS.

The survey design is based on the approach developed by Stevens and Olsen (2004 and 1992) and previously implemented in WDEQ/WQD statewide and rotating basin 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 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.

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 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. To ensure spatial uniformity in the design, the 50 sites were allocated equally among the entire basin (Figure 3 and Appendix 5). The same design and stratification generated 301 oversample sites that replaced primary sites not sampled due to access denial, inaccessibility or they were non-target (e.g. ephemeral, canal, wetland, etc.). While 52 sites (two additional) were sampled, two were removed from the analysis due to data quality issues, reducing the sample size to 50 sites.

Figure 1: Bioregions and selected municipalities of the Tri-state Bear Survey (TBS).



DATA COLLECTION

Investigators of this survey followed procedures in the Bear-Snake probabilistic survey sampling analysis plan (WQD/WQD 2021) and all biological data sampling and collection followed Wyoming's standard operating procedures (WDEQ/ WQD 2024). Sites were sampled and in 2021 at typical baseflow or near baseflow conditions. Chlorides, sulfates, nitrate+nitrite-N, total nitrogen, phosphorus, and suspended solids were collected via grab samples in a riffle or run (WDEQ/WQD 2024a). Wyoming and Idaho (36 sites) also collected grab samples for E. coli, total selenium, and dissolved arsenic, cadmium, copper, iron, lead, manganese, silver and zinc. Measurements of water pH, dissolved oxygen and specific conductance occurred in the field (WDEQ/WQD 2024a).

Benthic macroinvertebrates were collected with three different procedures—selection of which were dependent upon stream habitat. The priority sampling procedure for benthic macroinvertebrate collection was to select a representative riffle, where present, within a reach extending 20 times the bankfull width at each monitoring site following standard procedures in WDEQ/WQD (2024a). Eight randomly selected samples (each 1 ft^2) were collected from the representative riffle with a Surber sampler (500-µm mesh collection net), filtered with a 500-µm mesh sieve and combined into a single composite sample. Benthic macroinvertebrate sampling occurred at multiple habitats where riffles were atypical or absent. (WDEQ/WQD 2024a). The multi-habitat sample was a composite of 20 discrete 'jab' samples collected with a dip net, from multiple habitats proportionally weighted based on representation within a 300-foot reach. Additionally, if riffles were not present at a Utah site, an edge habitat-1m sweep procedure was used. This consisted of locating potential habitat along the banks and agitating the identified habitat with hands or feet and performing a one-meter sweep with the net in the direction of the flow (UDEQ/DWQ 2020). Sample processing methods are described in WDEQ/WQD (2024a).

Substrate particle size and mean embeddedness within sampled riffles were estimated by measuring at least 100 randomly selected particles using a modification of the Wolmann pebble count method (WDEQ/WQD 2024a). Mean riffle embeddedness is the degree to which coarse materials are covered or surrounded by very fine gravel, sand, 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) characterized reachwide 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 evaluated at all sites (considering their inherent potential) following approved procedures in WDEQ/WQD (2024a). Samplers noted presence/absence, proximity to the channel and relative influence on 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.

Data analyses were limited to chemical, physical habitat and biological data that attained quality assurance/quality control standards (WDEQ/WQD 2024b).

SETTING EXPECTATIONS OF STREAM AND RIVER CONDITION

INDICATORS OF BIOLOGICAL CONDITION

To assess the biological condition of perennial streams requires establishment of minimum biological condition thresholds applicable to the TBS. Benthic macroinvertebrates are one of the most common indicators used to assess the biological condition of streams across the U.S. Wyoming uses a reference condition approach to develop minimum biological condition thresholds for different regions in the State that are derived from benthic macroinvertebrate data collected at a network of over 200 minimally to most-impacted reference sites. The Wyoming Stream Integrity Index (WSII) and the WY RIVPACS, each of which were developed using Wyoming's reference dataset, including ecoregions common to Wyoming, Utah and Idaho, were used to assess the biological condition of perennial streams for the TBS. Because results from the WSII and WY RIVPACS strongly 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 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 macroinvertebrate-based predictive model that assesses stream biological condition by comparing the riffle-based macroinvertebrate community observed at a site of unknown biological condition with that expected to occur under reference condition (Hargett 2012). The expected macroinvertebrate taxa are derived from an appropriate set of reference sites that are minimally or least-impacted by human disturbance. The deviation of the observed from the expected taxa, a ratio known as the O/E value, is a measure of compositional similarity expressed in units of taxa richness and thus a community level measure of biological condition. O/E values near 1 imply high biological condition while values <1 or >1 imply some degree of biological degradation. O/E values are codified into one of three narrative aquatic life use categories of 'full support', indeterminate' and 'partial/non-support'.

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

Results from the WSII and WY RIVPACS were incorporated into Wyoming's aquatic life use-support decision matrix (WDEQ/WQD 2020). 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 (WY and ID)

Drinking water suitability indicators included dissolved iron, dissolved manganese, dissolved silver, total arsenic, total cadmium, total copper, total lead, nitrate+nitrite-N, total selenium, and total zinc. 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). Data from Wyoming and Idaho sites were compared to thresholds based on Wyoming's human health criteria (fish consumption and drinking water) to evaluate drinking water suitability (WDEQ/WQD 2018)(Appendix 2).

Sample analyses for the TBS included only the dissolved fractions of these analytes. 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 applicable threshold.

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 (WDEQ/WQD 2018).

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, Idaho, and Utah have water quality criteria to protect designated aquatic life uses of streams (WDEQ/WQD 2018, IDEQ 2020, UDWQ 2020). Wyoming's numeric aquatic life pH and chloride chronic criteria were used to evaluate conditions throughout the entire basin (WDEQ/WQD 2018). Each state has the same pH criterion and Wyoming and Idaho share the chloride criterion. The water quality condition was considered least-disturbed when concentrations were less than the numeric criterion. Conversely, water quality condition was considered most-disturbed when the numeric criterion was equaled or exceeded. For dissolved and total metals parameters collected only in Idaho and Wyoming, data was simply reported as the frequency of criteria exceedance.

For parameters without numeric criteria, percentile distributions (25th and 95th percentiles) established stressor-specific least and most-disturbed thresholds for the Wyoming Basin, Southern Rockies, and Sedimentary Mountain bioregions utilizing reference site values from the Bear River Basin and Green River Basin of Wyoming. This percentile-based methodology for establishing least and most-disturbed thresholds is similar to the approach used for EMAP-West (Stoddard et al. 2005) and the NRSA (USEPA 2015). Since Utah has established numeric criteria for total phosphorus, total nitrogen, and nitrates, the specific criteria take precedent for establishing the thresholds of low, moderate, or high for sites in Utah.

Stressors collected and analyzed in this report, their descriptions, and the established expectations are described below.

CHEMICAL STRESSORS

NUTRIENTS – Parameters such as nitrate+nitrite-N (commonly referred to as nitrate), total nitrogen and total phosphorus are essential nutrients to the biological productivity of streams, though are generally found in low concentrations naturally and are therefore considered limiting to plant and algal growth. However, excess contributions of nutrients associated with human activities, otherwise known as nutrient enrichment, can cause problems that range from annoyances to serious effects to aquatic life (USEPA 2000). Nutrient concentrations in streams may 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). The 2018-2019 USEPA summary of the National Rivers and Stream Assessment portrayed total nitrogen and total phosphorus as the top stressors to streams and presented elevated risk to the biological condition of the Nation's waters (USEPA 2023). 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 (NH_3), 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. Wyoming and Idaho currently do not possess protective numeric criteria for aquatic life for total phosphorus, total nitrogen or nitrates; however, Utah possesses specific total phosphorus and total nitrogen numeric criteria for category 1 and 2 waters (USEPA 2023a). Category 1 and 2 waters have a numeric criterion of 0.035 mg/ L of total phosphorus and 0.040 mg/L of total nitrogen, whereas category 2 waters have criteria of 0.08 mg/L total phosphorus and 0.8 mg/L of total nitrogen. All waters have a nitrate criterion of 4 mg/L and all other waters (excluding category 1 and 2) have a numeric criterion of 0.05 mg/ L of total phosphorus and no criteria for total nitrogen (USEPA 2023a). Therefore, nitrate thresholds were derived using conservative 95th and 25th percentiles of nitrate concentrations among all Bear River and Green River Basin reference sites combined to determine the least and most-disturbed conditions, respectively (Appendix 1). Reference-based nitrate, total nitrogen, and total phosphorus data were gathered from the Bear and Green River basins due to the quantity of non-detectable reporting limits within the Bear River Basin. A total phosphorus condition of 0.100 mg/L is generally considered unacceptably high for the maintenance of aquatic life (Dodds et al. 2002, Peterson et al. 2004, Vollenweider 1971) in perennial streams. Bioregion specific thresholds for the TBS were much more stringent than the accepted value of 0.100 mg/L except for streams located within the Wyoming Basin bioregion ($\leq$ 0.01mg/L / $\geq$ 0.13 mg/L) (Appendix 1).

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 may affect aquatic life through alterations to feeding mechanisms, reduced photosynthesis by

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

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. There is no federal or state criterion for TSS protective of aquatic life in Wyoming, Idaho, or Utah.

Therefore, least and most-disturbed TSS thresholds for each bioregion were derived from the 95th and 25th 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 soil erosion can also increase the salinity of streams. There is no federal or state criterion for specific conductance protective of aquatic life. Therefore, least and most-disturbed salinity expectations were derived from the 95th and 25th percentiles of specific conductance measurements among reference sites for each bioregion, respectively (Appendix 1).

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

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

SULFATE – As with chloride, sulfate occurs naturally in aquatic systems and generally originates from the decomposition of organic matter, atmospheric deposition or geologic weathering. Depending on the background concentrations of chloride and hardness, elevated concentrations of sulfate may be toxic to aquatic life (Soucek and Kennedy 2005). Anthropogenic sources of sulfate include sewage and industrial effluent (coal mines and oil treaters in particular), irrigation induced leaching of sulfate rich soils and agricultural runoff. There are currently no national or Wyoming, Idaho, or Utah 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.

PHYSICAL STRESSORS

RIPARIAN DISTURBANCE - The riparian zone, or the interface between a stream and surrounding uplands, assists in the natural ability to protect streams from both natural and human disturbances when adequate vegetation is present. In many streams, this vegetation is vital to stream bank integrity, allowing stream banks to withstand the erosive forces of water at high flows. The vegetation also captures surface flows, which facilitates groundwater recharge and reduces flooding while filtering sediment, nutrients and other constituents (Gregory et al. 1991). Aquatic life depends on riparian vegetation for habitat (e.g. roots and large woody debris) and shading which helps maintain cooler stream temperatures in smaller streams. Vegetation also 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. The degree of riparian disturbance was evaluated in this study by 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 documented as most-disturbed when at least four of seventeen indicators noted in Appendix 1 were present in the reach within 30 feet of the channel. The 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.

Riparian disturbance can impact aquatic life through alterations to habitat.

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 web and food resources, in-stream cover; increased temperatures and ultimately a diminished and less diverse aquatic life community comprised of generalist, short-lived taxa tolerant to elevated levels of environmental stressors.

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

Excess Sediment - Excess sediment may be the most important pollutant in United States streams (Waters 1995). Excess sediment creates unstable physical conditions including channel aggradation or degradation and consequently degradation of habitat for aquatic life. This pollutant also smothers fish eggs and fills interstitial spaces in stream beds and scours those beds where benthic organisms live, thereby severely impacting growth, reproduction, recruitment and survival. Direct abrasion to aquatic life also occurs. Excess sediment may clog surface water diversions and reduce channel capacity; increase flood stage and flood hazard through aggradation and accelerate reservoir sedimentation and reduce storage. In addition to riparian disturbance, alterations to a natural flow regime that reduce sediment transport competency or capacity may result in an accumulation of sediment.

Excess sediment often results in the development of 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 may be suitable for detection of channel aggradation in cobble-bed streams (Sylte and Fischenich 2002). The mean riffle embeddedness that corresponded to the 95th percentile of the reference site distribution in Wyoming was 38%. Considering this information and accounting for the diversity of substrate composition among reference sites in Wyoming and a margin of sampling error, a conservative mean riffle embeddedness of ≥50% may be a reasonable threshold for detection of channel aggradation. Excess sediment was noted as present when 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 energy at high flows, minimizing alterations to channel dimension, pattern or profile while also capturing sediment and other pollutants (Waters 1995).

Accelerated bank erosion generally occurs when riparian areas and stream banks are lacking adequate vegetation with well-developed root structures due to riparian vegetation removal, trampling, hoof shear, or recreational traffic and thus cannot retain soil and stabilize streambanks during high flows. Accelerated bank erosion may occur when stream banks exhibit high bank-height ratios where much of the bank surface is exposed above bankfull elevation and thus the bank is at greater risk for surface erosion, bank slumping and failure and mass erosion processes (Rosgen 2006). Accelerated bank erosion is a form of channel degradation that reduces in-stream aquatic habitat along the banks and

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

contributes excess sediment to a channel. Cowley (2002) suggests that 70% unaltered stream banks appear to be the minimum level that would maintain stable conditions. In addition, Rosgen F and G channels are deeply entrenched, highly susceptible to changes in dimension, profile and planform and are general indicators of channel bed or bank instability in valley types where they are unexpected (Rosgen 1996). Therefore, accelerated bank erosion was noted as present when either mean streambank stability was < 70% or Rosgen F or G channels were present in valley types where they are unexpected (Appendix 1).

Channel Incision - Accelerated stream bank erosion and excess sediment are sometimes associated with channel incision. Channel incision is abandonment of an active floodplain and a lowering of the channel bed with concomitant lowering of the water table. Channel incision is triggered by a variety of causes, though is often associated with channel enlargement or straightening (channelization).

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

Other causes of channel incision include reduced sediment load due to upstream dams, increased peak flows caused by anthropogenic activities and land use changes (Fischenich and Morrow 2000, Galay 1983). Channel incision was noted as present when evidence of active channel incision (e.g. evident headcuts or unexpected shifts in channel gradient) or recent (within the past 10 years) channelization was documented within the reach (Appendix1).

RANKING OF STRESSORS

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

RELATIVE EXTENT

Relative extent (as a percentage) quantifies how extensive the most-disturbed stressor condition is among perennial streams of the TBS. 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, stressors are ranked according to their relative extents at the basin wide scale

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) for the TBS 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* is the most-disturbed stressor condition and *lds* is 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.

DATA ANALYSIS

All probabilistic survey analyses were performed using modifications of the 'spsurvey.analysis' scripts developed in the R programming language (Version 4.3.3) by the USEPA's Office of Research and Development in Corvallis, Oregon or with STATISTICA (Version 10) (Statsoft 2011). The statistical procedures used in 'spsurvey.analysis' to extrapolate estimates of evaluated and assessed stream lengths and biological condition, stressor relative extents and stressor relative risks from collected data are fully described in Paulsen et al. (2008), Van Sickle and Paulsen (2008) and Van Sickle et al. (2006).

2021 STREAM FLOWS

The Bear River Basin probabilistic survey occurred during a year of below average precipitation and snowpack and drought conditions (NRCS 2024 and University of Nebraska-Lincoln).

Data collected at ten USGS stream gage stations present within or proximate to the study area show below average peak and mean annual flows in 2021 (Appendix 4). At the basin scale, peak flows in 2021 were on average -55% (range: -82% to +3%) below the mean peak flow for the unique period of record for each gage, and the mean annual flows were -57% (range: -76% to +-30%) below the average mean annual flow.

RESULTS

EXTENT OF RESOURCE

The TBS had 3,738 perennial stream miles, which is the target stream length. Approximately 60% (2,243 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 (Figure 3 and Figure 4). Non-target sites were those identified as completely ephemeral or intermittent, wetlands or human constructed channels such as irrigation canals. Approximately 19% (710 miles) of the target stream length was not assessed based on the proportion of survey sites where the landowner denied access, could not be contacted, or the site was inaccessible. The remainder of the sampling frame represented the assessed targeted stream length for the TBS – 822 miles (Figure 3-Figure 4, Appendix 5). This assessed targeted length represents 22% of the target perennial stream miles for the TBS and only 9% of the 9,578 perennial stream miles from the GRTS modified sample frame.

BIOLOGICAL CONDITION

Approximately 37% of the assessed perennial stream miles were in the 'least-disturbed' condition, whereas 41% were in the 'most-disturbed' condition, and 22% of streams within the 'indeterminate' condition (Figure 5).

DRINKING WATER SUITABILITY AND HUMAN HEALTH CONDITION (WY AND ID)

Drinking water and human health thresholds are outlined in Appendix 3. Of 36 stream sites (Wyoming and Idaho only) investigated for drinking water suitability and human health condition, 13 sites exceeded the threshold for *E.Coli* (Table 3). Of the 36 sites, zero exceeded arsenic, cadmium, copper, lead, selenium, silver, and zinc thresholds (Table 3). Two of 36 samples exceeded the iron threshold and one exceeded manganese threshold (Table 3).

PHYSICOCHEMICAL STRESSORS TO BIOLOGICAL CONDITION

NUTRIENTS

Nitrate+nitrite-N was not in the most-disturbed condition within any streams of the TBS (Appendix 6, Table 1). Nitrate-nitrite-N was, however, in the indeterminate condition in 11% of stream miles with the remaining 89% in the least-disturbed condition.

Approximately 52% of stream miles were in the least-disturbed total phosphorus condition (Appendix 7, Table 1). The most-disturbed total phosphorus condition was present in 20% of stream miles and 28% in the indeterminate condition. (Appendix 7, Table 1).

The percentage stream miles in the least-disturbed total nitrogen condition was 67%, indeterminate (26%) and only 6% in the most-disturbed condition (Appendix 8, Table 1).

SALINITY

Least-disturbed salinity conditions occurred in 32% of stream miles in the TBS (Appendix 9, Table 1). Approximately 22% of stream miles were in the most-disturbed condition and 46% in the indeterminate condition (Appendix 9, Table 1).

TOTAL SUSPENDED SOLIDS

Forty-nine percent of stream miles were in the least-disturbed condition for total suspended solids, 23% in the most-disturbed condition, and 29% in the indeterminate condition (Appendix 10, Table 1).

CHLORIDE, pH and SULFATE

Most stream miles were in the least-disturbed condition for chloride at 99% and a minimal 1% of streams were in the most-disturbed condition (Appendix 11). For sulfates, 100% of stream miles were in the least-disturbed condition (Table 1). Similarly, pH had 96% of streams in the least-disturbed condition and only 4% of streams deemed as most-disturbed (Appendix 12, Table 1).

ALUMINUM, ARSENIC, CADMIUM, COPPER, IRON, LEAD, MANGANESE, SELENIUM, SILVER, ZINC (WY AND ID)

Additional chemical aquatic life stressors were collected at 36 sites in Wyoming and Idaho as part of the TBS. Results were compared to thresholds shown in Appendix 2. All 36 samples in Wyoming and Idaho within the Bear River Basin were less than biological condition thresholds for aluminum, arsenic, cadmium, copper, iron, lead, manganese, silver and zinc (Table 2).

PHYSICAL STRESSORS TO BIOLOGICAL CONDITION

RIPARIAN DISTURBANCE

Riparian disturbance was in the most-disturbed condition in 42% of perennial stream miles whereas 58% were in the least-disturbed condition (Appendix 13, Table 1). Riparian disturbance was often associated with sparse overhanging cover, minimal woody vegetation, bare ground coverage, and hoof shearing/ trampling on the banks.

CHANNEL INSTABILITY

For the TBS, 34% of stream miles exhibited indicators of channel instability (excess sediment, accelerated bank erosion and/or active channel incision) in the most-disturbed condition and 66% in the least-disturbed condition (Appendix 13, Table 1).

Channel instability consists of three component substressors—accelerated bank erosion, excess sediment, and channel incision. Streams having channel instability were more affected by accelerated bank erosion and excess sediment (each having ~20% of cumulative 34%) than active channel incision (5.2%) (Appendix 14, Table 1).

RANKING OF STRESSORS

Relative Extent – Stressors were ranked according to the proportion of target stream miles that were in the most-disturbed condition for a particular stressor (Figure 6). Riparian disturbance was the most common stressor (42%) that has the potential to affect aquatic life in the study area (Figure 6). Channel instability was the second most common stressor affecting 34% of stream miles, followed by total suspended solids (23%), salinity (22%), excess sediment (20%), accelerated bank erosion (20%), and total phosphorus (20%). Channel incision, total nitrogen, pH, and total chlorides were the least common stressors, each affecting approximately 6% or less of TBS stream miles (Figure 6).

Relative Risk – Total phosphorus presents the greatest relative risk (2.14) to the biological condition of targeted streams as measured with benthic macroinvertebrates. (Figure 7). In other words, the most disturbed biological condition is 2.14 times more likely to occur in streams having the most disturbed total phosphorus condition than streams with the least-disturbed total phosphorus condition. Channel incision is the second highest risk at 2.04 (Figure 7). Excess sediment presents the third-highest relative risk to biological condition at 1.99 (Figure 7).

DISCUSSION

TBS provided a focused and standardized evaluation of the biological condition of streams within the upper and central Bear River basin of southwest Wyoming, northeastern Utah, and southeastern Idaho. TBS provided a representative picture of current biological conditions and identifies stressors affecting biological health without a complete census of all streams in the study area.

The most extensive stressors of the TBS were riparian disturbance, channel instability, and total suspended solids affecting approximately 42%, 34%, and 23% of perennial stream miles, respectively (Figure 6).

Figure 2: Drought timeline during sampling events within the Bear River Basin.

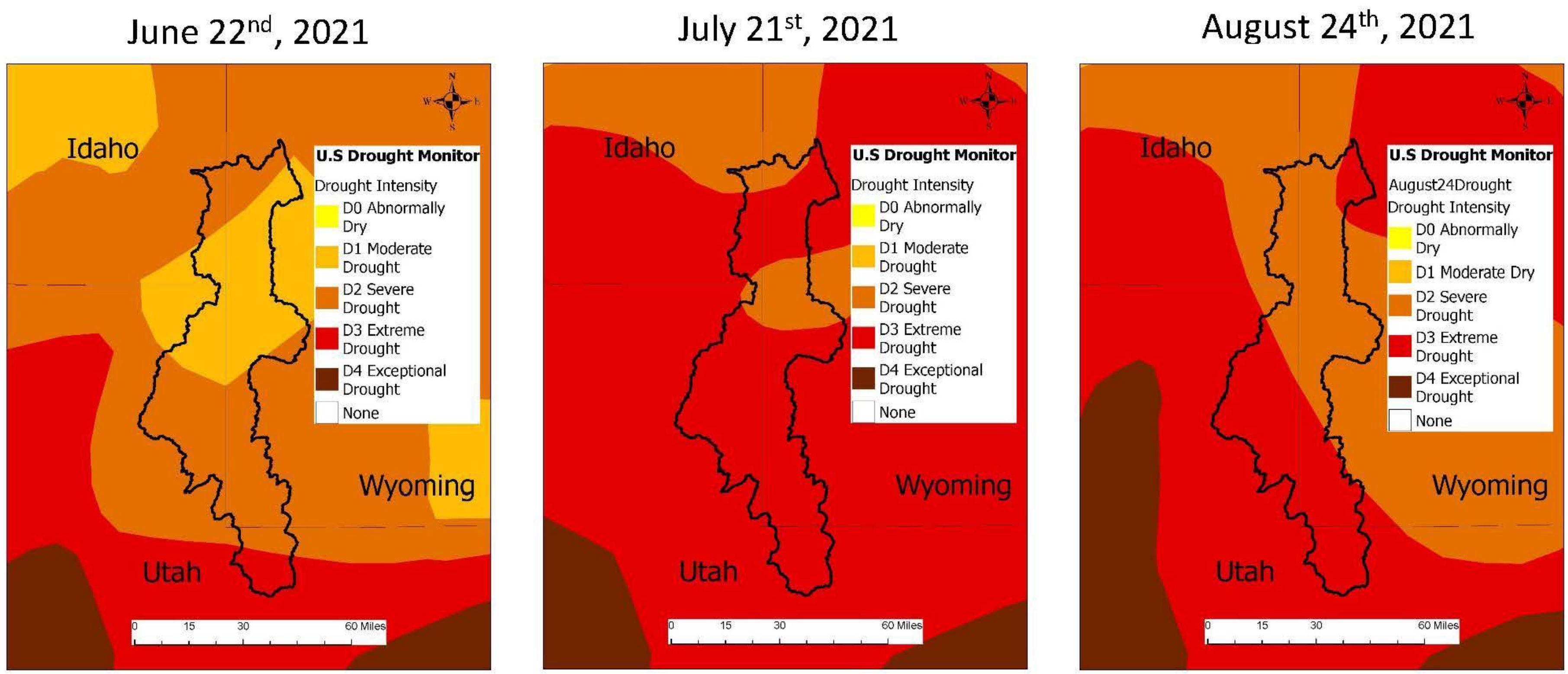


Figure 3: Target, non-target, access denied, and inaccessible sites evaluated as a part of the Tri-state Bear Survey (TBS).

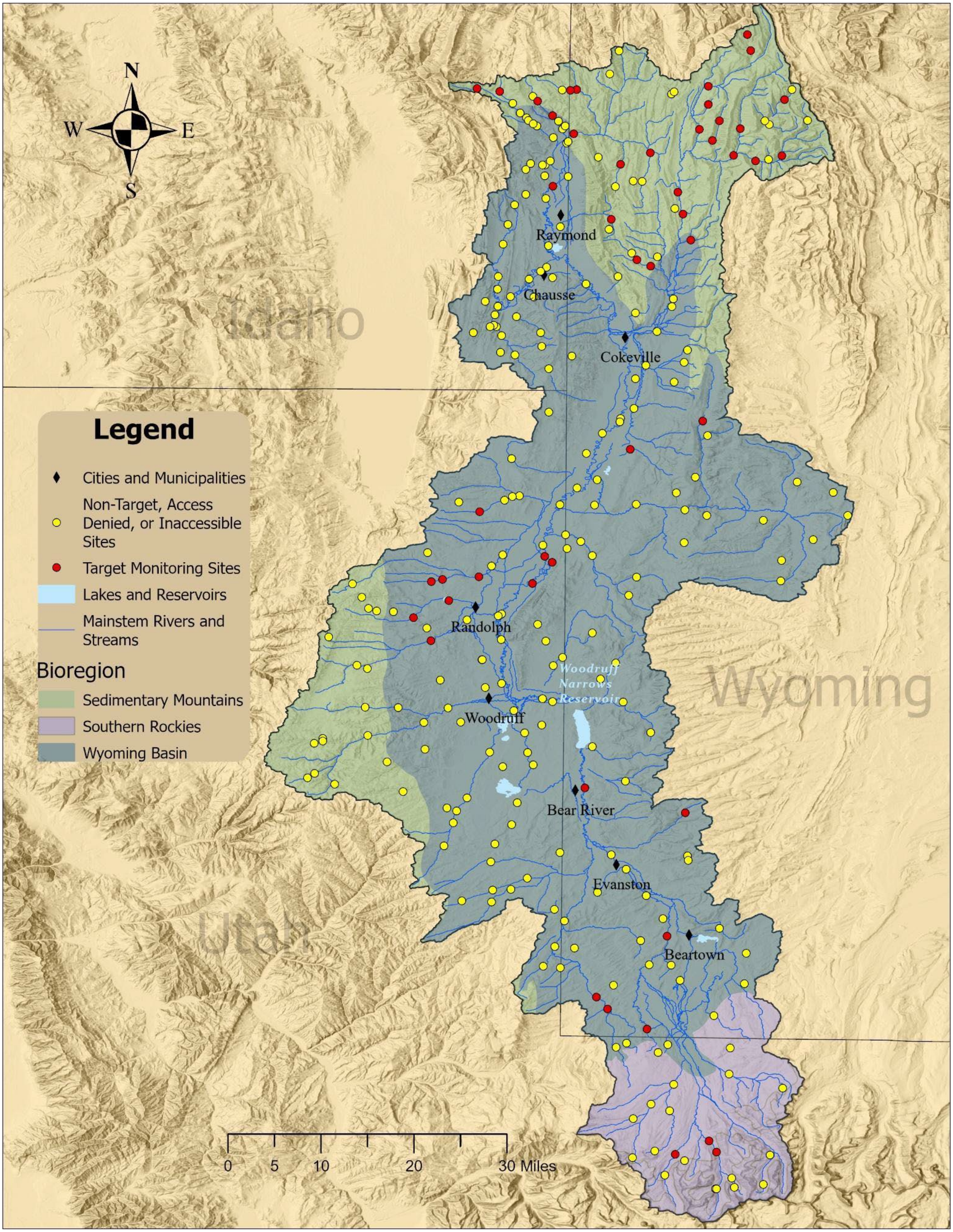


Figure 4: Estimated percentage of target stream miles relative to access denied and non-target miles for the Tri-state Bear Survey (TBS). Error bars represent the 95% confidence interval.

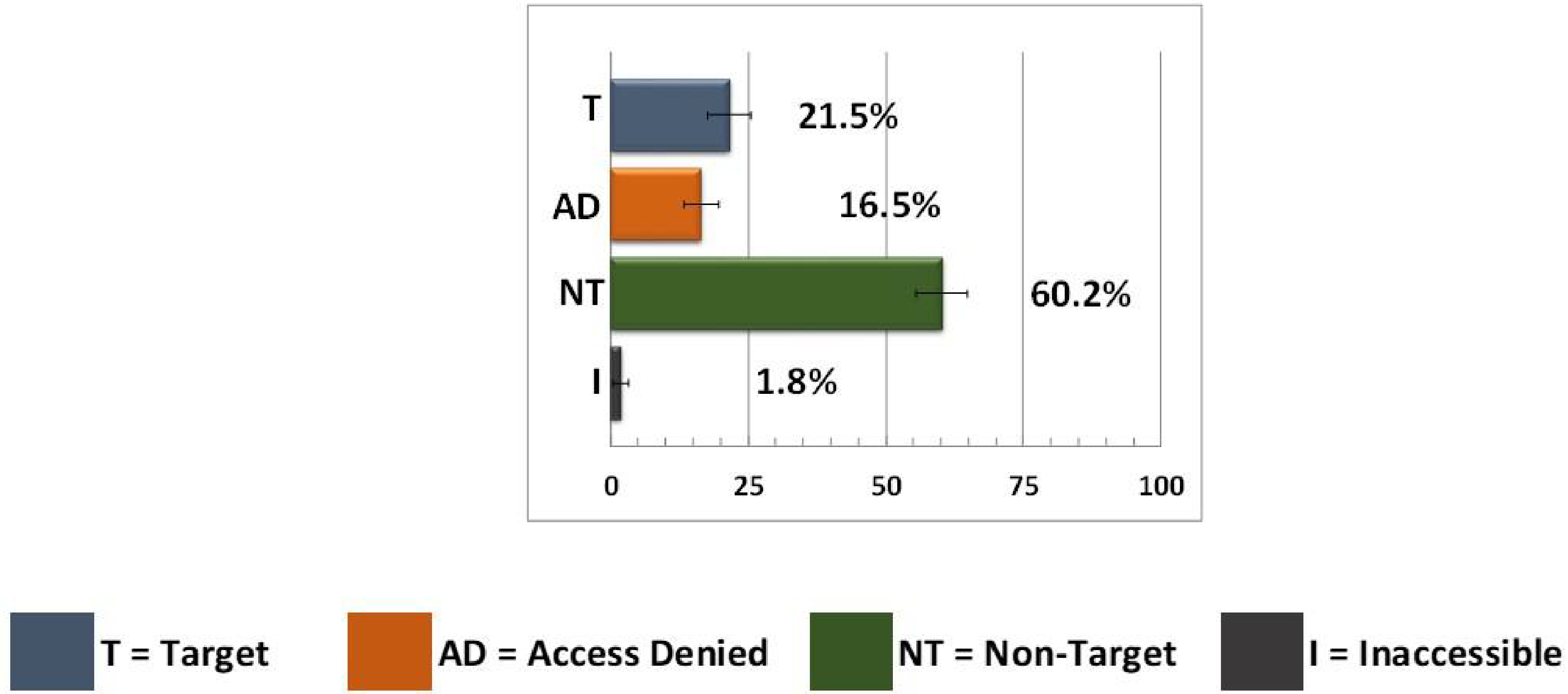


Figure 5: Biological condition of targeted perennial streams for the Tri-state Bear Survey (TBS) based on WDEQ/WQD's aquatic life use matrix. Error bars represent the 95% confidence intervals.

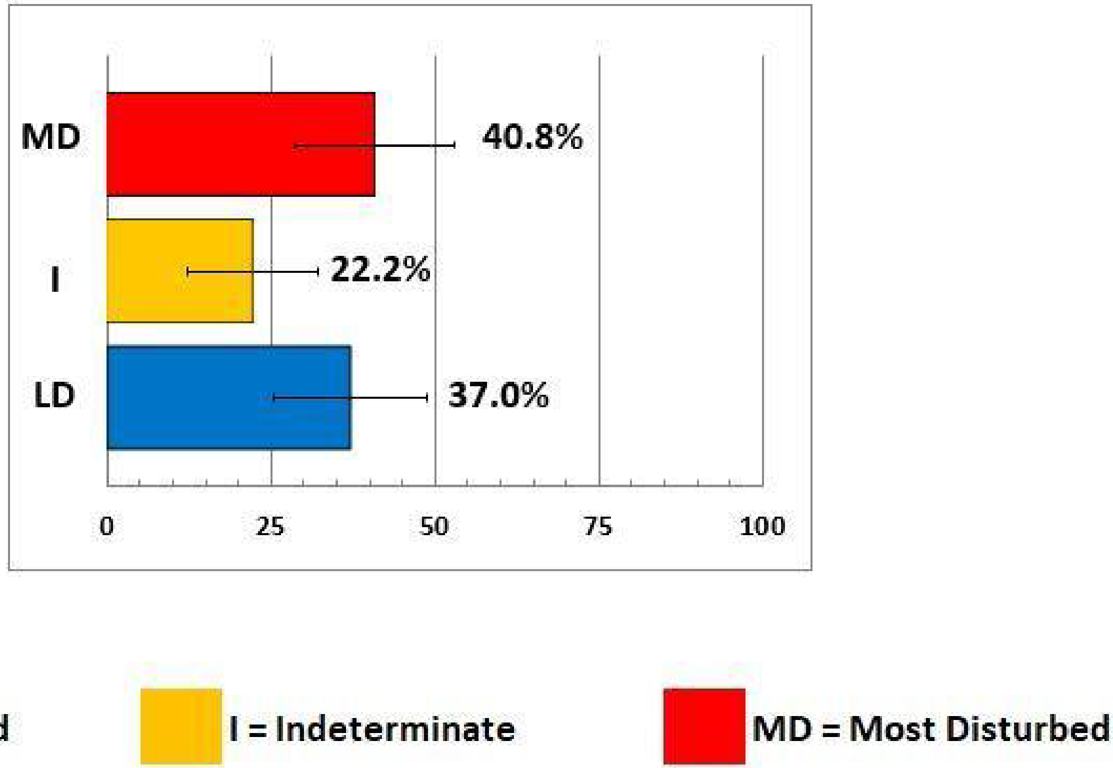


Table 1: Stressor condition estimates associated with biological condition for the Tri-state Bear Survey (TBS).

		Basin Wide
Biological Condition	**Condition Class**	**% of Stream Miles**
	Least-disturbed	37
	Indeterminate	22.2
	Most-disturbed	40.8
Stressor [Indicator]		
Nitrate+Nitrite-N	Least-disturbed	89.2
	Indeterminate	10.8
	Most-disturbed	0.0
Total Phosphorus	Least-disturbed	52.4
	Indeterminate	27.7
	Most-disturbed	19.9
Total Nitrogen	Least-disturbed	67.5
	Indeterminate	26.2
	Most-disturbed	6.3
Salinity	Least-disturbed	31.9
	Indeterminate	46.4
	Most-disturbed	21.7
TSS	Least-disturbed	48.9
	Indeterminate	28.6
	Most-disturbed	22.5
Chloride	Least-disturbed	99.1
	Most-disturbed	0.9
Sulfate	Least-disturbed	100
	Most-disturbed	0.0
pH	Least-disturbed	96.1
	Most-disturbed	3.9
Riparian Disturbance	Least-disturbed	57.7
	Most-disturbed	42.3
Channel Instability	Least-disturbed	66.1
	Most-disturbed	33.9
Excess Sediment	Least-disturbed	79.6
	Most-disturbed	20.4
Accelerated Bank Erosion	Least-disturbed	80.4
	Most-disturbed	19.6
Channel Incision	Least-disturbed	94.8
	Most-disturbed	5.2

Following these most prevalent stressors, salinity, excess sediment, accelerated bank erosion, and total phosphorus were the next most extensive stressors (>15%).

The sampled stressors are a portion of all potential stressors to biological condition. This study excluded an assortment of physical and chemical stressors for which numeric criteria exist in one or more of the three states. Dissolved oxygen and water temperature were not included due to the difficulty capturing the diurnal variability of these parameters with a single measurement. Various parameters having aquatic life and human criteria were excluded from the relative extent analysis due to samples not being collected in every state.

Riparian disturbance characterizes vegetative cover on streambanks and within the riparian zone, and the presence of other human influences adjacent to the stream channel. Channel instability is a composite physical stressor that includes excess sediment, accelerated stream bank erosion and channel incision. Accelerated stream bank erosion and excess sediment were the dominant of the channel instability sub-stressors in the TBS (20%). The percentage of accelerated bank erosion documented during the survey corresponds with riparian disturbance. This inference is supported by evidence that indicates streams in the TBS with accelerated bank erosion and excess sediment often also exhibited indicators of riparian disturbance, predominantly in the form of sparse overhanging vegetation, riparian woody vegetation, upland or facultative vegetation on the bank, and common hoof shear/tramping. Historic or legacy disturbances such as flow alterations, channelization, riparian vegetation removal, historic grazing management, and tie drives influence present day channel stability.

Within the TBS all stressors except accelerated bank erosion had similar relative risks and confidence intervals, implying there is a higher likelihood of a most-disturbed biological condition occurring when each stressor is present. However, accelerated bank erosion indicates each biological condition class is equally likely to occur when a most-disturbed bank erosion condition is present (Figure 7).

After riparian disturbance and channel instability, the third most extensive stressor was total suspended solids (TSS) where the most-disturbed condition relative extent was approximately 23% of stream miles. TSS consists of both organic and inorganic suspended materials and is naturally greater during runoff from snowmelt or thunderstorms. TSS samples gathered for this study were collected during baseflow or near baseflow conditions, therefore flow-dependent increases in TSS were minimized as a possible cause of elevated TSS. Elevated TSS in some streams in the study area can occur naturally as their watersheds may contain highly erodible silt/clay bearing geology and soils combined with naturally sparse vegetation cover. However, in areas absent such overriding natural influences, human activities associated with irrigation drainage, flow augmentation and industrial effluent may be chronic contributors to TBS streams with a most-disturbed TSS condition.

Anthropogenic contributions of inorganic TSS (silts and clays) may also be a transport mechanism for other pollutants. Silt and clay are often chemically active and pollutants such as nutrients, metals, pesticides or their breakdown products are strongly bound to these particles. There may be a coincidence between TSS and total phosphorus in the TBS as several streams with a most-disturbed TSS condition were also assigned a most-disturbed condition for total phosphorus. Whether TSS-linked detrimental effects to aquatic life occur, they may vary considerably depending on the size, frequency and duration of elevated TSS particles, the mechanisms of influence (e.g. physical abrasion, scouring, reduced visibility, altered feeding dynamics, increased water temperatures), and the influence of bounded pollutants and the aquatic organism(s) affected (i.e. benthic macroinvertebrates, fishes, periphyton). From a relative risk perspective, a most-disturbed TSS condition poses 1.92 times greater risk to aquatic life when present.

Once elevated TSS is deposited, the excess sediment and its influence on aquatic life can be accounted for (in many cases) by the channel instability stressor evaluated as part of this study.

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

Salinity's relative extent was 21.7%. Salinity had similar relative risk (~2.0) as several other stressors. Macroinvertebrate and fish communities of basins and plains streams are adapted to harsh and stochastic environments (Dodds et al. 2004, Fausch and Bestgen 1997, Higgens and Wilde 2005, Matthews 1988, Taylor et al. 1993) such as naturally elevated and wide-ranging salinities dependent on geology and flow regime. The direct influences of elevated salinity may not be as readily observable in communities with such adaptive tolerances; thus salinity narrowly exceeding reference expectations is unlikely to induce observable biological effects.

Total phosphorus (TP) was the seventh most extensive stressor in the TBS with a calculated relative extent of roughly 20% of stream miles being most-disturbed and a 2.14 times greater risk of biological condition being most-disturbed. Considering the indirect and non-toxic effects of elevated total phosphorus on the aquatic community, the degree TP contributed to the most-disturbed biological condition when other biological stressors were present is unknown.

Additionally worth noting, nitrate+nitrite-N had no observed extent (0%) of most-disturbed condition on perennial streams in the TBS. This is likely an underestimate where a larger sample size would identify a small extent of most-disturbed conditions. Nutrients such as nitrate+nitrite-N, total nitrogen and total phosphorus are not directly toxic to aquatic life. However, the processes that control metabolism and nutrient cycling in streams, their influences on parameters such as dissolved oxygen and pH, and the critical thresholds at which different aquatic life (e.g. fishes versus benthic macroinvertebrates) begin to be negatively affected can vary considerably in streams.

Results were put into a national perspective by comparing findings from the most recent National Rivers and Stream Assessment (NRSA).

NRSA ecoregions occurring within the study area were Western Mountains and Xeric regions. Comparisons of the TBS to the most recent NRSA findings hold similarities in design and evaluation.

TBS demonstrated slightly better biological and stressor conditions than NRSA. For the TBS, 37% of perennial streams were in the least-disturbed biological condition, compared to 28% for NRSA. Likewise, the TBS showed 41% of perennial streams in the most-disturbed biological condition, compared to 47% for the NRSA. Far fewer streams were in the most-disturbed condition for total nitrogen (5%) compared to the Nation (44%) (USEPA 2023b and Figure 8). Similarly, TBS had fewer streams in the most-disturbed condition for total phosphorus (17%) than the nation (42%). While indicators of excess sediment were relatively similar between the TBS and the NRSA (17% to 21%), TBS had more perennial streams in the most-disturbed condition for riparian disturbance than the Nation (42% to 22%). Regarding salinity, TBS showed 22% of perennial streams in the most-disturbed condition while only 4% of streams from the Nation were most-disturbed. (Figure 8).

CONCLUSION

The Upper and Central Bear River Basin probabilistic survey results provide an objective representative 'snap-shot' of biological conditions and identified associated stressors in perennial streams and rivers of the Upper and Central Bear River Basin of southwestern Wyoming, southeastern Idaho, and northeastern Utah. While the Upper and Central Bear River Basin probabilistic 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 organized and implemented at the federal, state and local levels. In particular, the probabilistic survey documented the overall fair biological conditions in the study area.

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 a particular stream—each stream is unique and subject to local environments. However, the survey results indicate the study area has more favorable chemical stressor extents compared to the national scale, but physical stressors such as riparian disturbance and channel instability are much more prevalent in the study area. Healthy riparian habitat is vital for maintaining healthy water quality. The riparian zone is defined as the transitional area between a lotic system and land. The riparian zone supports a plethora of ecosystem services such as erosion control, bank stabilization, and microhabitat climate regulation (Capon 2020). Of the seven most abundant stressors, four are physical stressor indications which suggest that benthic macroinvertebrates communities have been degraded by physical stressors.

As a result of the extents of physical stressors in the TBS, there may be a correlation between elevated, most-disturbed conditions for riparian disturbance, channel instability, total suspended solids, salinity, excess sediment, accelerated bank erosion, and total phosphorus. This correlation may warrant the need for additional research of the cascading effects of disturbed riparian and stream habitat within the study area.

ACKNOWLEDGMENTS

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Figure 6: Most disturbed condition relative extent (% stream miles) of chemical and physical stressors for the Tri-state Bear Survey (TBS). Error bars represent the 95% confidence intervals.

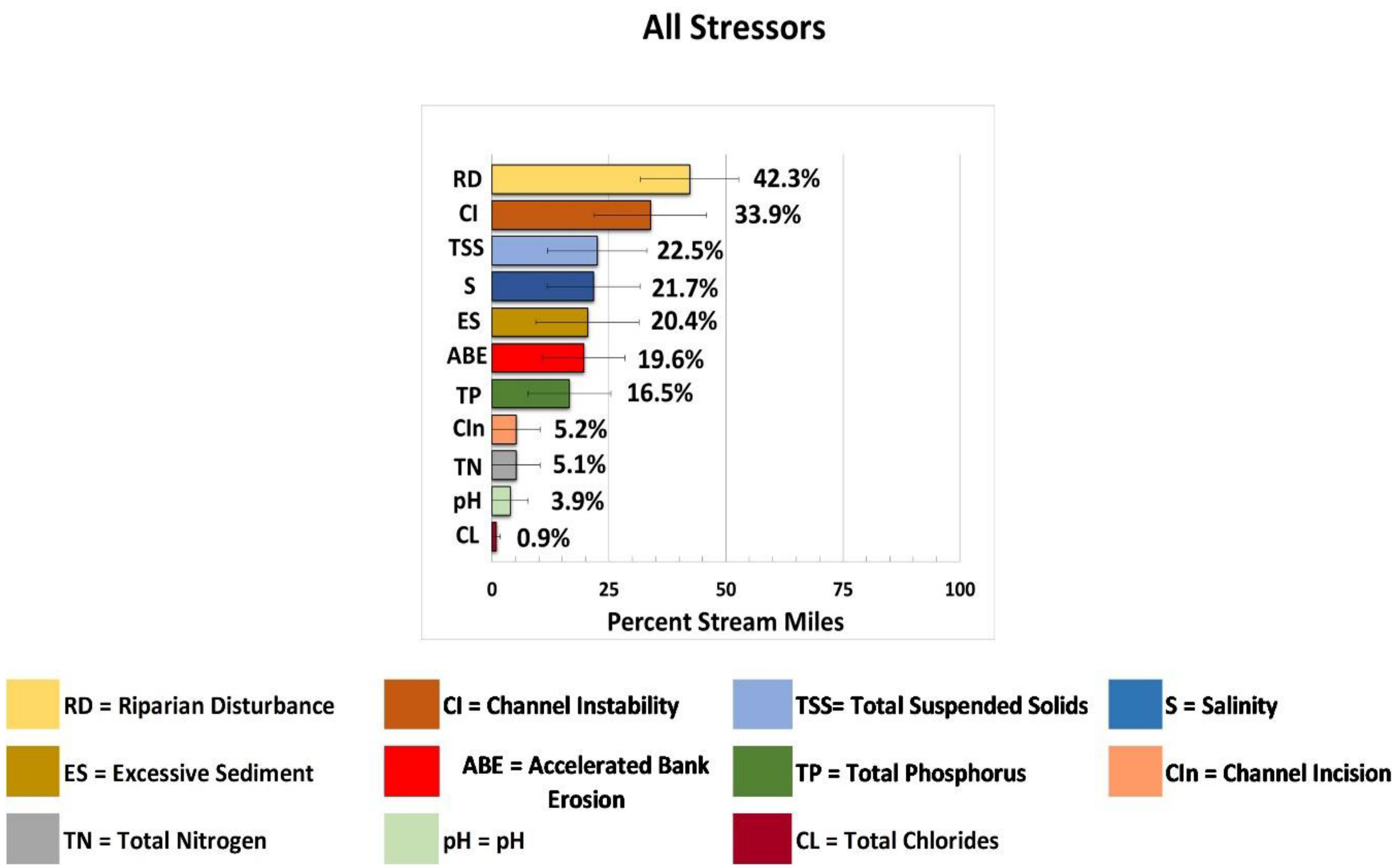

Figure 7: Relative risk values of chemical and physical stressors to biological condition for the Tri-state Bear Survey (TBS). Error bars represent the 95% confidence intervals.

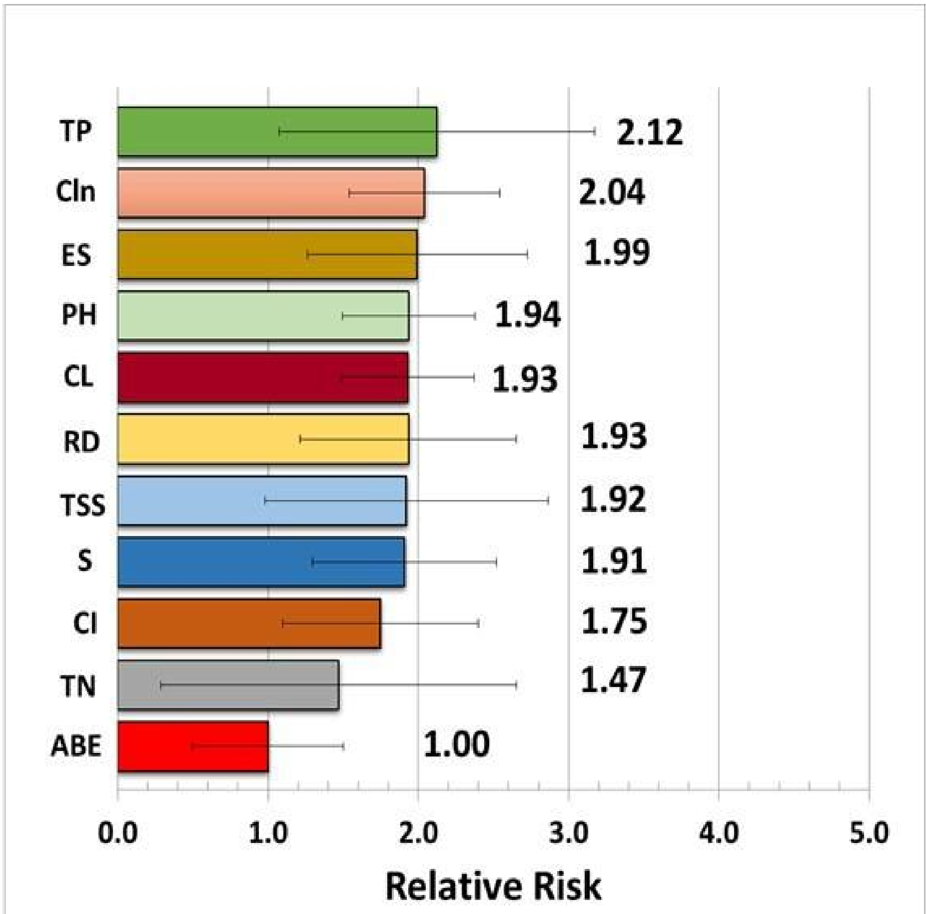

Figure 8: Biological condition (top) of perennial streams (by percentage of respective stream length) and stressor relative extents (bottom) for the Tri-state Bear Survey (TBS) and regional and national scales of the National Rivers and Streams Assessment (USEPA 2023).

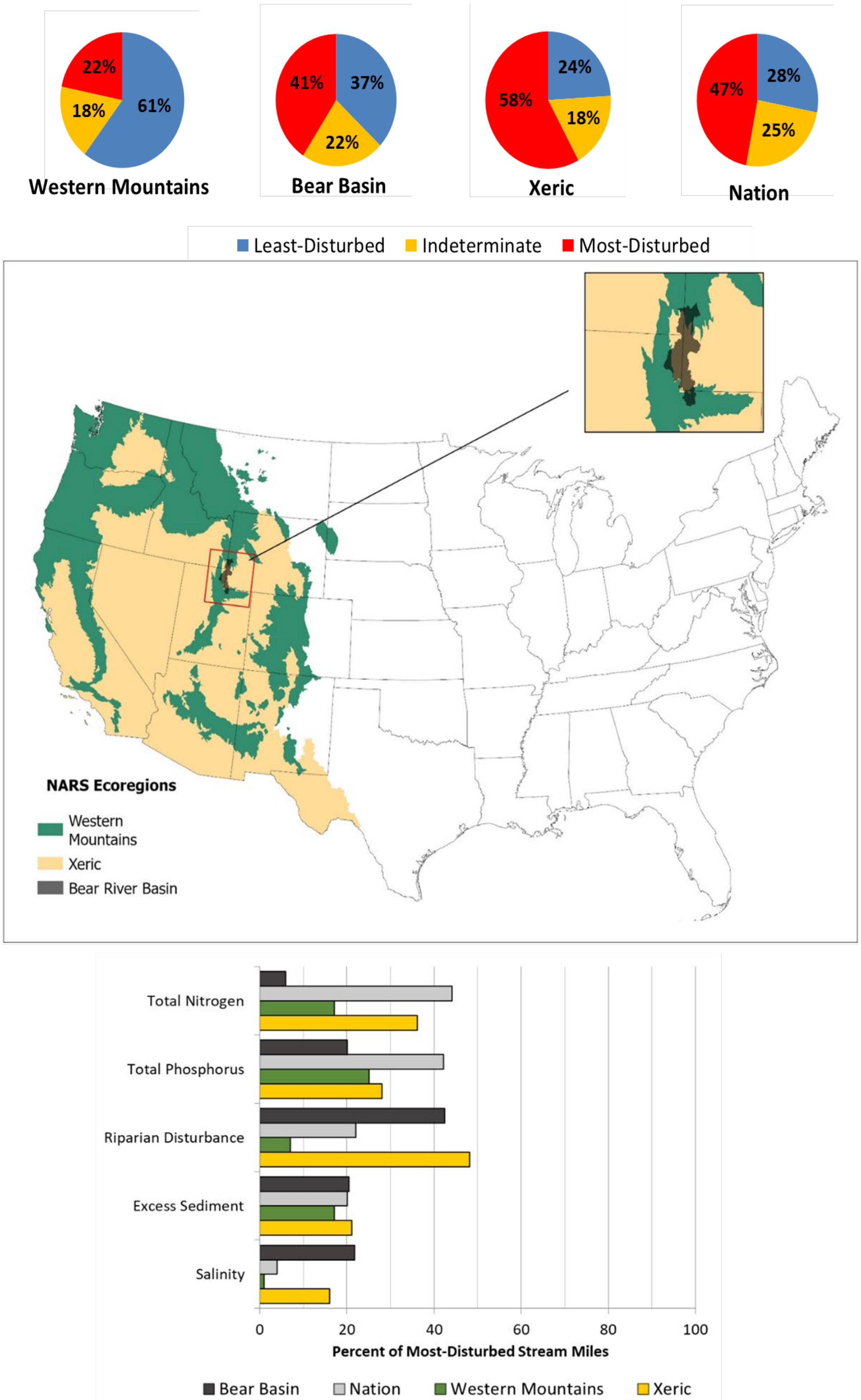

Table 2: Water quality threshold exceedances for selected additional chemical aquatic life stressors of the Tri-state Bear Survey (Wyoming and Idaho only).

Stressor [Biological]	Number of Samples	Number of Criteria Exceedances
Dissolved Aluminum	36	0
Dissolved Arsenic	36	0
Dissolved Cadmium	36	0
Dissolved Copper	36	0
Dissolved Iron	36	0
Dissolved Lead	36	0
Dissolved Manganese	36	0
Total Selenium	36	0
Dissolved Silver	36	0
Dissolved Zinc	36	0

Table 3: Water quality threshold exceedances for selected additional fish and drinking water and recreation condition stressors of the Tri-state Bear Survey (Wyoming and Idaho only).

Stressor [Recreation]	Number of Samples	Number of Criteria Exceedances
Escherichia coli	36	13

Stressor [Drinking Water & Fish Consumption Suitability]		
Total Arsenic	36	0
Total Cadmium	36	0
Total Copper	36	0
Total Iron	36	2
Total Lead	36	0
Dissolved Manganese	36	1
Total Selenium	36	0
Dissolved Silver	36	0
Total Zinc	36	0

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Appendix 1: Biological condition stressor thresholds used to establish condition categories for streams and rivers within bioregions of the Tri-state Bear Survey (TBS). 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.

		Bioregion		
		Sedimentary Mountains	Southern Rockies	Wyoming Basin
Water Chemistry	Chloride (mg/L)	< 230 / ≥ 230		
	Conductivity (µS/cm)	≤ 313 / ≥ 455	≤ 38 / ≥ 199	≤ 410 / ≥ 547
	Nitrate+Nitrite-N (mg/L)	≤ 0.05 / ≥ 0.22[a]	≤ 0.05 / ≥ 0.25[a]	≤ 0.05 / ≥ 0.43[a]
	TSS (mg/L)	≤ 3 / ≥ 6	≤ 2 / ≥ 5	≤ 4 / ≥ 67
	Total Phosphorus (mg/L)	≤ 0.01 / ≥ 0.04[b]	≤ 0.01 / ≥ 0.03[b]	≤ 0.01 / ≥ 0.13[b]
	Total Nitrogen (mg/L)	≤ 0.10 / ≥ 0.41[c]	≤ 0.10 / ≥ 0.25[c]	≤ 0.17 / ≥ 0.64[c]
	pH	> 6.5 and < 9.0 / < 6.5 or > 9.0		
	Sulfate (mg/L)			
Biological Condition	WSII	> 52.2 / < 34.8	> 48.8 / < 32.5	> 39.3 / < 26.2
	WY RIVPACS	> 0.82 / < 0.68	> 0.89 / < 0.62	> 0.81 / < 0.63
Riparian Disturbance	Riparian Disturbance	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.		
Channel Instability	Excess Sediment	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.		
	Accelerated Stream Bank Erosion	Most-disturbed when mean streambank stability < 70% or the channel is classified as an unexpected Rosgen F or G considering its natural valley type.		
	Channel Incision	Most-disturbed when either active channel incision (e.g. evident headcuts or unexpected shifts in channel gradient) or recent (within the past 10 years) channelization is present.		

Sulfate (mg/L):

	Cl < 5 mg/L	5 ≤ Cl < 25 mg/L	25 mg/L ≤ Cl
HD < 100 mg/l	500 mg/l	500 mg/l	500 mg/l
100 ≤ HD ≤ 500 mg/L	500 mg/L	SO4 = [-57.478 + 5.79(HD) + 54.163 (Cl)] * 0.65	SO4 = [1276.7 + 5.508(HD) - 1.457(Cl)] * 0.65
HD > 500 mg/L	500 mg/L	2000 mg/L	2000 mg/L

Cl – Chloride
HD = Hardness

[a]For sites in Utah, thresholds of < 4 / ≥ 4 were applied which correspond to Utah's numeric nitrate criteria protective of aquatic life.
[b]Sites in Utah were evaluated with thresholds of < 0.035 / ≥ 0.035 if they were located on Category 1 or 2 waters, otherwise thresholds of < 0.05 / ≥ 0.05 were applied. These thresholds correspond to Utah's most stringent numeric total phosphorus criteria protective of aquatic life.
[c]Sites in Utah located on Category 1 or 2 waters were evaluated with thresholds of < 0.040 / ≥ 0.040 to correspond with Utah's most stringent numeric total nitrogen criteria protective of aquatic life for these waters. Otherwise, the noted reference-based thresholds within each bioregion were used.

Appendix 2: Water quality criteria for selected additional chemical aquatic life stressors for the Tri-state Bear Survey (Wyoming and Idaho only).

	Criterion
Dissolved Aluminum (µg/L)	< 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)
Dissolved Arsenic (µg/L)	< 150
Dissolved Cadmium (µg/L)	$< e^{(0.7409[\ln(\text{Total Hardness as mg/L CaCO3})]-4.719)}(1.101672-[\ln(\text{Total Hardness as mg/L CaCO3})]*0.041838)$
Dissolved Copper (µg/L)	$< e^{(0.8545[\ln(\text{Total Hardness as mg/L CaCO3})]-1.702)}(0.960)$
Dissolved Iron (µg/L)	< 1000
Dissolved Lead (µg/L)	$< e^{(1.273[\ln(\text{Total Hardness as mg/L CaCO3})]-4.705)}(1.46203-[\ln(\text{Total Hardness as mg/L CaCO3})]*0.145712)$
Dissolved Manganese (µg/L)	$< e^{(0.5434[\ln(\text{Total Hardness as mg/L CaCO3})]+4.7850)}$
Dissolved Silver (µg/L)	$< e^{(1.72[\ln(\text{Total Hardness as mg/L CaCO3})]-6.52)}(0.85)(0.5)$
Total Selenium (µg/L)	< 5
Dissolved Zinc (µg/L)	$< e^{(0.8473[\ln(\text{Total Hardness as mg/L CaCO3})]+0.884)}(0.986)$

Appendix 3: Water quality criteria for selected additional fish and drinking water and recreation condition stressors of the Tri-state Bear Survey (Wyoming and Idaho only)

	Criterion
Total Arsenic (µg/L)	<10
Total Cadmium (µg/L)	<5
Total Copper (µg/L)	<1000
Dissolved Iron (µg/L)	<300
Total Lead (µg/L)	<15
Dissolved Manganese (µg/L)	<50
Dissolved Silver (µg/L)	<100
Total Selenium (µg/L)	<50
Total Zinc (µg/L)	<5000
Nitrate+Nitrite-N (mg/L)	<10
Escherichia coli (cfu/100 mL)	<126

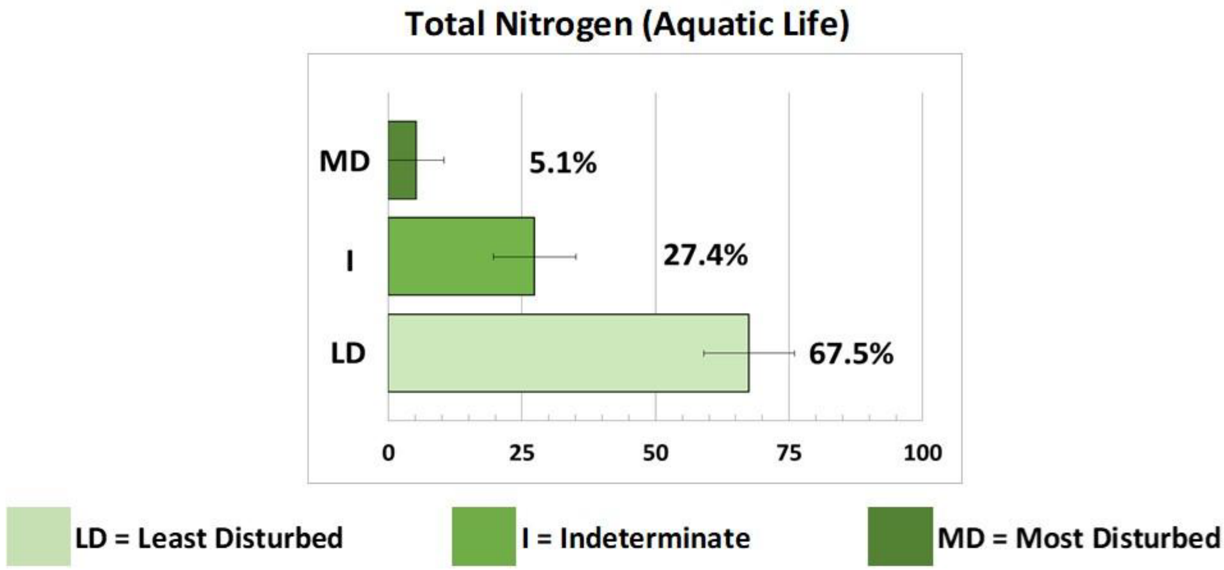
Appendix 4: Relative departures of 2021 flow statistics from means for the periods of record at selected USGS streams gages within Tri-state Bear Survey study area.

USGS Gage ID	USGS Gage Name	Period of Record	2021 Peak Flow	Mean Peak Flow (cfs) Period of Record	% Departure from Mean Peak Flow for Period of Record	2021 Mean Annual Flow (cfs)	Mean Annual Flow (cfs) for Period of Record	% Departure from Mean Annual Flow for Period of Record
10011500	BEAR RIVER NEAR UTAH-WYOMING STATE LINE	1943-2021	960	1,897.8	-49%	106.8	191.4	-44%
10016900	BEAR RIVER AT EVANSTON, WY	1984-2021	671a	1,978.3	-66%	83.5	196.6	-58%
10020100	BEAR RIVER ABOVE RESERVOIR, NEAR WOODRUFF, UT	1962-2021	641a	1,873.7	-66%	52.5	214.9	-76%
10020300	BEAR RIVER BELOW RESERVOIR, NEAR WOODRUFF, UT	1962-2021	1270a	1,737.7	-27%	71.5	215.0	-67%
10032000	SMITHS FORK NEAR BORDER, WY	1943-2021	485	941.4	-48%	102.4	188.2	-46%
10038000	BEAR RIVER BELOW SMITHS FORK, NR COKEVILLE, WY	1955-2021	403a	1,813.0	-78%	150.2	413.9	-64%
10039500	BEAR RIVER AT BORDER, WY	1938-2021	336a	1,825.3	-82%	127.8	405.8	-69%
10023000	BIG CREEK NEAR RANDOLPH, UT	1950-2021	13	65.5	-80%	5.2	13.6	-62%
10068500	BEAR RIVER AT PESCADERO, ID	1923-2021	1700a	1,645.3	3%	406.0	578.8	-30%
	#a Discharge affected by Regulation or Diversion			Depature Range:	-82% to 3%		Depature Range:	-76% to -30%
				Mean Departure:	-55%		Mean Departure:	-57%

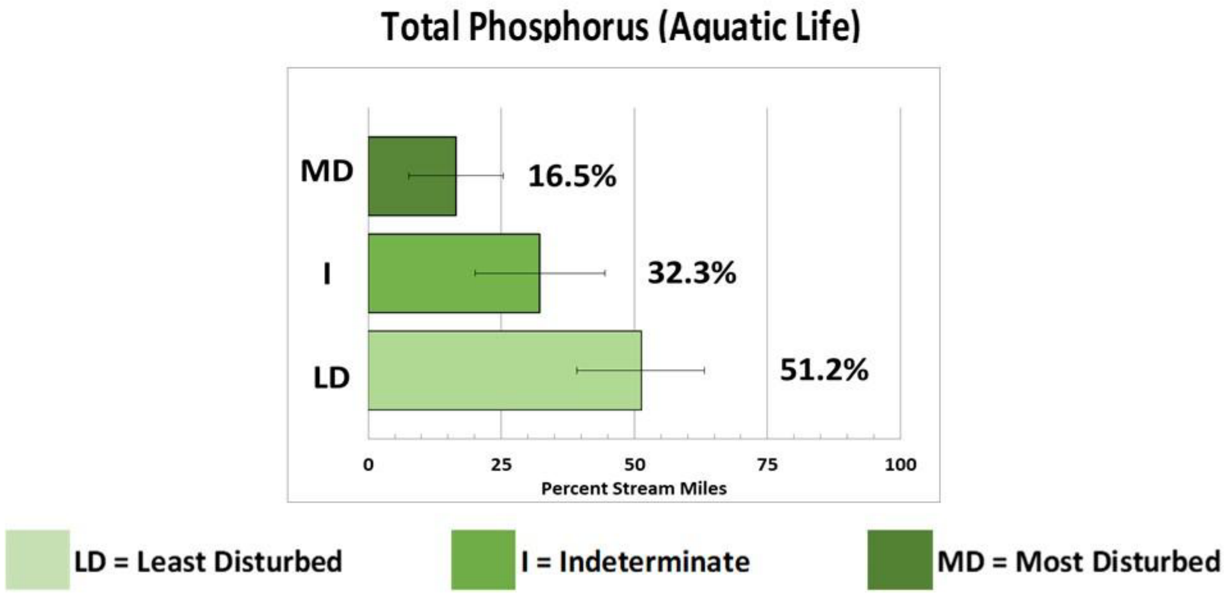
Appendix 5: Sites sampled as part of the Tri-state Bear Survey.

SurveyID	Type	StationID	WaterbodyName- Reach Name	Latitude	Longitude	Elevation (ft)	Watershed Area (mi^2)	HUC 8 Cluster	Bioregion
Bear-016	Base	2628	South Fork Sixmile Creek	41.8119639	-111.18	6,579	2.9	Upper Bear	Wyoming Basin
Bear-017	Base	2631	Otter Creek	41.710893	-111.18005	6,288	36.4	Upper Bear	Wyoming Basin
Bear-036	OverSamp	2618	Bear River	41.7341171	-111.06671	6,220	1,450.0	Upper Bear	Wyoming Basin
Bear-038	OverSamp	2633	Stillwater Fork	40.8194965	-110.80224	8,773	27.3	Upper Bear	Southern Rockies
Bear-052	OverSamp	2619	Bear River	41.7012898	-111.09681	6,230	1,440.0	Upper Bear	Wyoming Basin
Bear-056	OverSamp	2620	South Branch Otter Creek	41.7024035	-111.25394	6,485	4.0	Upper Bear	Wyoming Basin
Bear-066	Base	2569	Smiths Fork	42.40967	-110.84412	7,071	41.9	Central Bear	Sedimentary Mountains
Bear-072	Base	2571	Antelope Creek	41.91117101	-110.94718	6,244	12.2	Upper Bear	Wyoming Basin
Bear-073	Base	2560	Smiths Fork	42.27751	-110.8694	6,668	149.7	Central Bear	Sedimentary Mountains
Bear-077	Base	2587	Salt Creek	42.40103794	-111.03952	6,262	114.4	Central Bear	Sedimentary Mountains
Bear-082	Base	2566	Hobble Creek	42.41263	-110.7804	7,393	17.5	Central Bear	Sedimentary Mountains
Bear-085	Base	2586	Rock Creek	41.95654183	-110.83464	7,064	2.0	Upper Bear	Wyoming Basin
Bear-086	Base	2553	Poker Hollow	42.533284	-110.76552	8,037	5.1	Central Bear	Sedimentary Mountains
Bear-089	Base	2575	Coantag Creek	42.36196345	-110.75663	7,353	27.1	Central Bear	Sedimentary Mountains
Bear-090	Base	2593	South Fork Raymond Creek	42.26898518	-110.98023	6,961	3.8	Central Bear	Sedimentary Mountains
Bear-093	OverSamp	2570	Robinson Creek	42.46985964	-111.03548	7,030	3.7	Central Bear	Sedimentary Mountains
Bear-095	OverSamp	2591	Yellow Creek	41.04063715	-110.97355	7,210	21.8	Upper Bear	Wyoming Basin
Bear-102	OverSamp	2552	Poker Hollow?	42.55803496	-110.77142	8,688	1.0	Central Bear	Sedimentary Mountains
Bear-110	OverSamp	2583	Pleasant Valley Creek	41.34669298	-110.85575	7,191	1.5	Upper Bear	Wyoming Basin
Bear-111	OverSamp	2572	Bear River	41.38422312	-111.01219	6,517	605.9	Upper Bear	Wyoming Basin
Bear-114	OverSamp	2555	Poker Creek	42.457529	-110.71221	8,226	3.2	Central Bear	Sedimentary Mountains
Bear-117	OverSamp	2561	Smiths Fork	42.312547	-110.87733	6,770	140.0	Central Bear	Sedimentary Mountains
Bear-118	OverSamp	2559	Smiths Fork	42.476559	-110.83259	7,400	25.1	Central Bear	Sedimentary Mountains
Bear-119	OverSamp	2573	Bear River	41.15452337	-110.88234	7,104	237.1	Upper Bear	Wyoming Basin
Bear-121	OverSamp	2580	Little Muddy Creek	42.37265585	-110.92035	6,564	11.3	Central Bear	Sedimentary Mountains
Bear-123	OverSamp	2592	Yellow Creek	41.05880453	-110.99122	7,142	28.8	Upper Bear	Wyoming Basin
Bear-125	OverSamp	2590	Trespass Creek	42.44870621	-110.83079	7,726	0.9	Central Bear	Sedimentary Mountains
Bear-133	OverSamp	2585	Porcupine Creek	42.39293697	-110.82397	7,235	5.4	Central Bear	Sedimentary Mountains
Bear-138	OverSamp	2574	Bear River	41.00966676	-110.91179	7,532	155.4	Upper Bear	Wyoming Basin
Bear-141	OverSamp	2589	Sawmill Creek	42.237634	-110.8561	6,644	4.3	Central Bear	Wyoming Basin
Bear-147	OverSamp	2578	Huff Creek	42.35456098	-110.96624	6,641	7.1	Central Bear	Sedimentary Mountains
Bear-153	OverSamp	2584	Porcupine Creek	42.42352248	-110.81302	7,620	2.1	Central Bear	Sedimentary Mountains
Bear-156	OverSamp	2581	Mill Creek	42.1963973	-110.91797	6,627	8.1	Central Bear	Sedimentary Mountains
Bear-157	OverSamp	2576	Coantag Creek	42.37010828	-110.7158	7,585	13.3	Central Bear	Sedimentary Mountains
Bear-169	OverSamp	2567	Hobble Creek	42.370114	-110.79074	7,196	43.6	Central Bear	Sedimentary Mountains
Bear-172	OverSamp	2582	Mill Creek	42.20604726	-110.93959	6,790	4.2	Central Bear	Sedimentary Mountains
Bear-176	OverSamp	2577	Giraffe Creek	42.4687038	-111.04561	7,102	5.1	Central Bear	Sedimentary Mountains
Bear-245	OverSamp	2614	Beaver Creek	42.46608	-111.15528	7,137	2.5	Central Bear	Sedimentary Mountains
Bear-257	OverSamp	2615	Preuss Creek	42.47005	-111.19085	7,323	1.8	Central Bear	Sedimentary Mountains
Bear-271	OverSamp	2613	Thomas Fork	42.31959	-111.07106	6,131	178.4	Central Bear	Wyoming Basin
Bear-273	OverSamp	2612	Dry Creek	42.45151	-111.09611	6,882	4.5	Central Bear	Sedimentary Mountains
Bear-277	OverSamp	2611	Unnamed Tributary	42.42924	-111.07285	6,585	1.0	Central Bear	Wyoming Basin
Bear-290	OverSamp	2621	Little Creek	41.6462241	-111.28111	6,673	8.4	Upper Bear	Wyoming Basin
Bear-301	OverSamp	2622	Bear River	41.7433255	-111.07844	6,218	1,450.0	Upper Bear	Wyoming Basin
Bear-314	OverSamp	2623	Hayden Fork	40.8156653	-110.86627	8,999	15.2	Upper Bear	Southern Rockies
Bear-321	OverSamp	2624	Big Creek	41.6104866	-111.25398	6,414	0.1	Upper Bear	Wyoming Basin
Bear-333	OverSamp	2625	South Branch Otter Creek	41.7058427	-111.23657	6,414	5.5	Upper Bear	Wyoming Basin
Bear-346	OverSamp	2626	Stillwater Fork	40.8367327	-110.81347	8,718	30.4	Upper Bear	Southern Rockies
Bear-349	OverSamp	2627	Little Creek	41.6734875	-111.22653	6,390	33.0	Upper Bear	Wyoming Basin

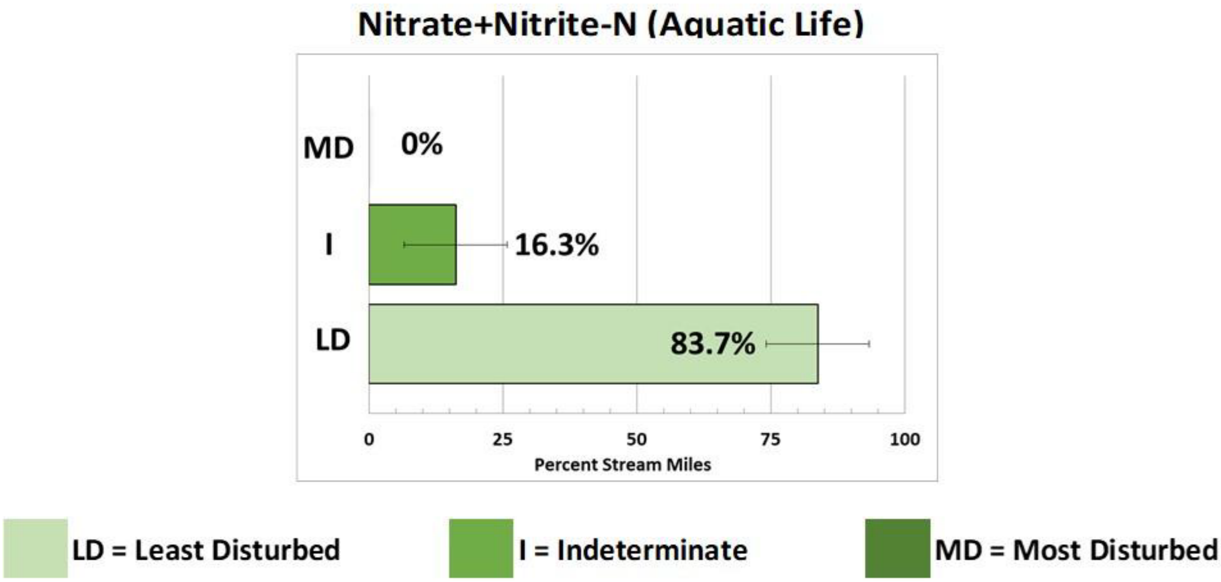
Appendix 6: Summary of nitrate+nitrite-N results for the Tri-state Bear Survey. Error bars represent the 95% confidence intervals.



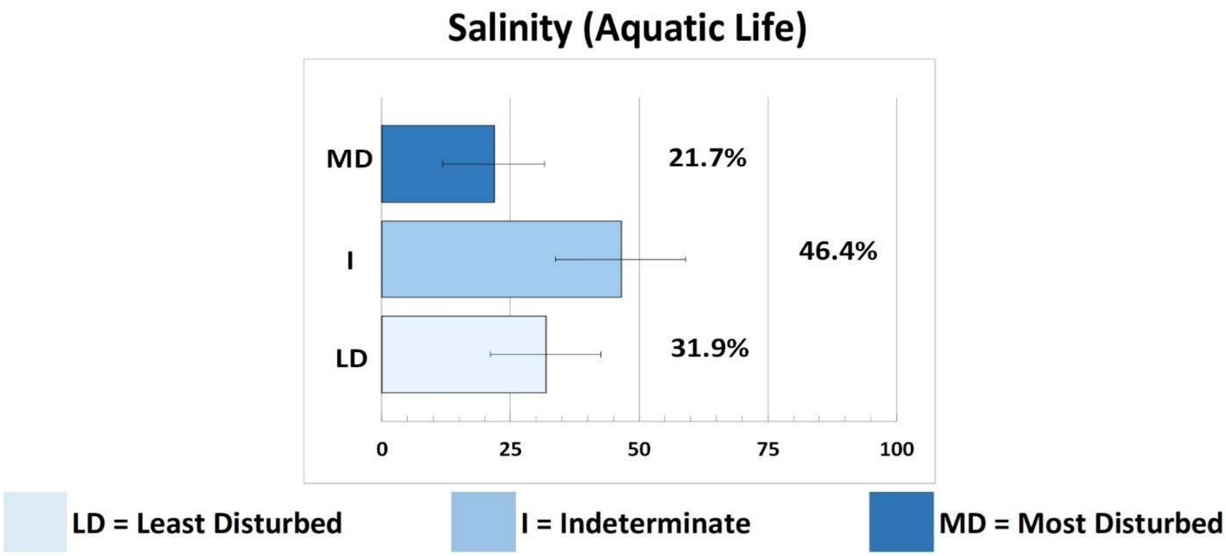
Appendix 7: Summary of total phosphorus results for the Tri-state Bear Survey. Error Bars represent the 95% confidence intervals.



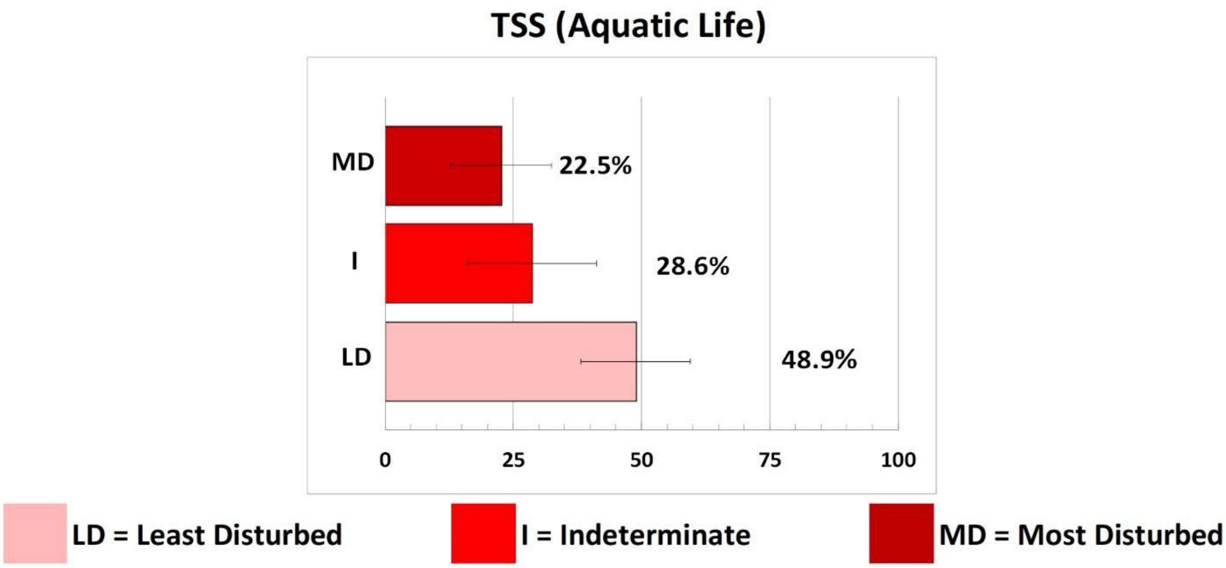
Appendix 8: Summary of total nitrogen results for the Tri-state Bear Survey. Error bars represent the 95% confidence intervals



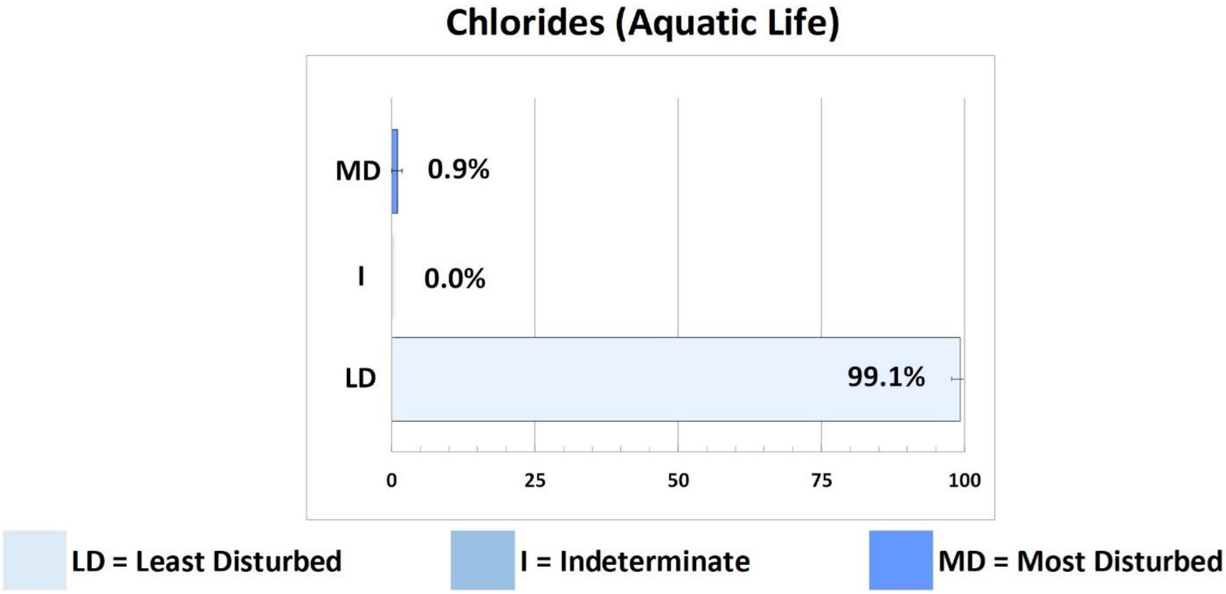
Appendix 9: Summary of salinity results for the Tri-state Bear Survey. Error bars represent the 95% confidence intervals



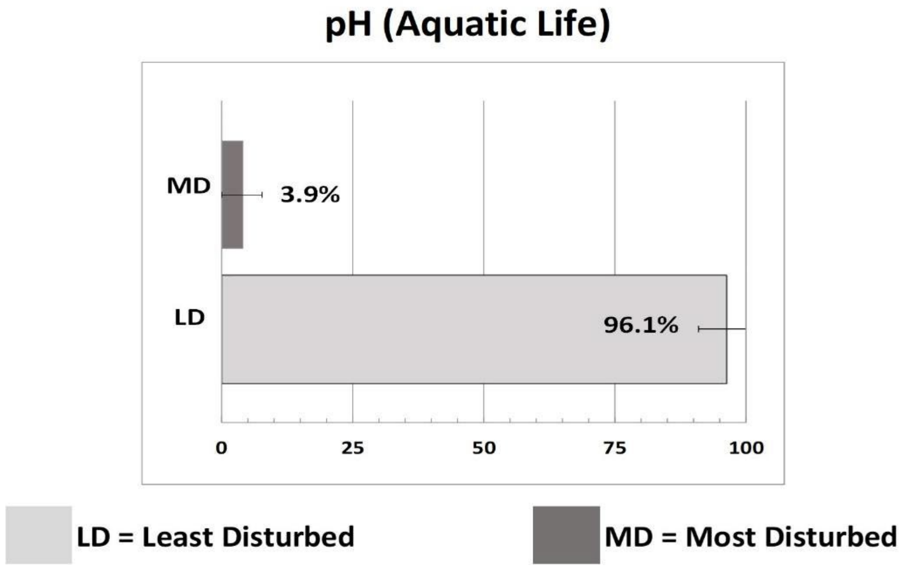
Appendix 10: Summary of total suspended solids (TSS) results for the Tri-state Bear Survey. Error bars represent the 95% confidence intervals.



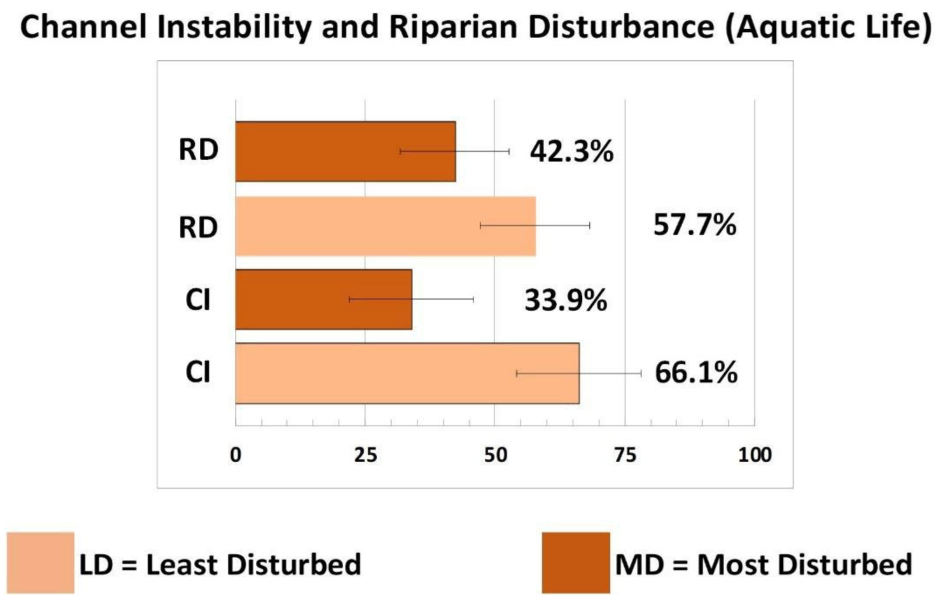
Appendix 11: Summary of chloride results for the Tri-state Bear Survey. Error Bars represent 95% confidence intervals.



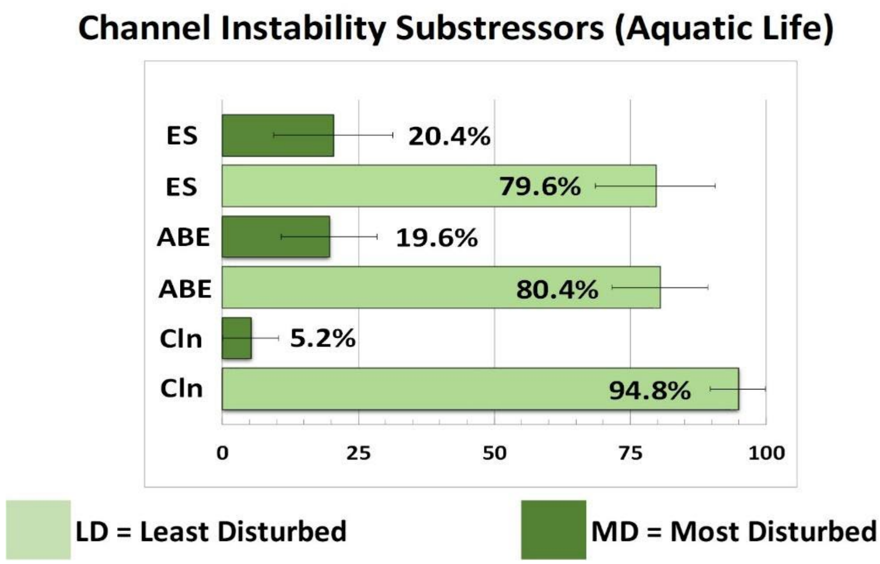
Appendix 12: Summary of pH results for the Tri-State Bear Survey. Error bars represent the 95% confidence intervals.



Appendix 13: Summary of physical stressor results (channel instability and riparian disturbance) for the Tri-state Bear Survey. Error bars represent the 95% confidence intervals.



Appendix 14: Summary of the three component sub-stressors that represent channel instability for the Tri-state Bear Survey. Error bars represent the 95% confidence intervals. ES= Excess Sediment, ABE=Accelerated Bank Erosion, Cin-Channel Incision.



Appendix 15: Photos of Wyoming sites sampled for the Tri-state Bear Survey

Pleasant Valley Creek (Picnic Hollow), Wyoming

Bear River (Town of Bear River), Wyoming

Poker Creek (Mount Isabel), Wyoming

Smiths Fork (Preacher), Wyoming

Smiths Fork (Porcupine Ridge), Wyoming

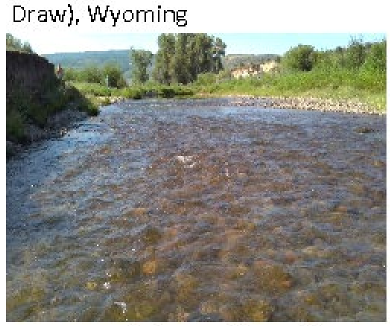
Bear River (Above Booth), Wyoming

Little Muddy Creek (Above Stoner Creek), Wyoming

Yellow Creek (Below Six Section Draw), Wyoming

Trespass Creek (Pine Knoll), Wyoming

Porcupine Creek (Porcupine Ridge), Wyoming



Bear River (Below Bull Creek), Wyoming

Sawmill Creek (Above CCC), Wyoming

Appendix 15 (Cont)- Photos of Wyoming sites sampled for the Tri-state Bear Survey.


Smiths Fork (Above Porcupine), Wyoming


Antelope Creek (NWR), Wyoming


Smiths Fork (Above Twiss), Wyoming


Salt Creek (Canyon Inn), Wyoming


Hobble Creek (Above Spring Lake Creek), Wyoming


Rock Creek (Rockslide), Wyoming


Poker Hollow (8050), Wyoming


Coantag Creek (Below Mistum), Wyoming


South Fork Raymond Creek (Big Bend), Wyoming


Robinson Creek (Above Giraffe Creek), Wyoming


Yellow Creek (above Randall Draw), Wyoming


Poker Hollow Creek (8700), Wyoming

Appendix 15 (Cont)- Photos of Wyoming sites sampled for the Tri-state Bear Survey.


Huff Creek (Below Huff Lake), Wyoming


Porcupine Creek (Wetland), Wyoming


Mill Creek (Above First Creek)


Coantag Creek (Lake Mountain), Wyoming


Hobble Creek (Below Hobble Creek Campground), Wyoming


Mill Creek (By South Fork), Wyoming


Giraffe Creek (Chapo), Wyoming

Appendix 16: Photos of Utah sites sampled for the Tri-state Bear Survey.


South Fork Six Mile Creek, Utah


Otter Creek, Utah


Bear River (BR-036), Utah


Stillwater Fork (BR-038), Utah


Bear River (BR-052), Utah


South Branch Otter Creek, Utah


Little Creek (BR-290), Utah


Bear River (BR-301), Utah


Hayden Creek, Utah


Big Creek, Utah


South Fork Otter Creek, Utah


Stillwater Fork (BR346), Utah


Little Creek (BR-349), Utah

Appendix 17: Photos of Idaho sites sampled for the Tri-state Bear Survey.


Beaver Creek, Idaho


Preuss Creek, Idaho


Thomas Fork, Idaho


Dry Creek, Idaho


Unnamed Tributary to Dry Creek, Idaho