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Ecological Condition of Streams in Northern Nevada

EPA R-EMAP Humboldt Basin Project

Photo: Humboldt River Basin

RESEARCH AND DEVELOPMENT

Ecological Condition of Streams in Northern Nevada

EPA R-EMAP Humboldt Basin Project

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Forward

The U.S. Environmental Protection Agency (USEPA) is charged by Congress to protect the nation's natural resources. Under the mandate of national environmental laws, the USEPA strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, the USEPA's Office of Research and Development (ORD) provides data and scientific support that can be used to solve environmental problems, build the scientific knowledge base needed to manage ecological resources wisely, understand how pollutants affect public health, and prevent or reduce environmental risks.

The National Exposure Research Laboratory (NERL) is the Agency's center for investigation of technical and management approaches for identifying and quantifying stressor exposures to humans and the environment. Goals of the laboratory's research program are to: 1) develop and evaluate methods and technologies for characterizing and monitoring air, soil, and water; 2) support regulatory and policy decisions; and 3) provide the scientific support needed to ensure effective implementation of environmental regulations and strategies.

The USEPA initiated the Environmental Monitoring and Assessment Program (EMAP) to assess the current condition and trends of the ecological resources throughout the United States. Within this context, the USEPA developed the Regional Environmental Monitoring and Assessment Program (R-EMAP) to conduct studies on a smaller geographic and temporal scale.

This report presents stream data on the Humboldt River Basin in northern Nevada using the R-EMAP Program. Water is of primary importance to both the economy and the ecology of the region. Many of the waters of Nevada have previously received relatively little attention in regards to systematic bioassessment and this study is intended to address a lack of adequate historical baseline data for the region.

Acknowledgements

The authors would like to apologize for the delay of this report relative to the sample collection. We feel that this data will be of value as a baseline for the Humboldt River Basin. We strongly believe that reporting this data will greatly aid in the understanding of this unique river system. We want to fully acknowledge the late Dr. Gary Vinyard for his vision and leadership and we wish to dedicate this report to his memory. We are also grateful to those who help us with this report in their time and effort including, Angela Hammond, Phil Kaufman, David Peck, Tony Olsen, Heather Powell, Kuen Huang-Farmer, Pamela Grossmann, Tad Harris, Richard Snell, David Bradford and Sherman Swanson.

Notice

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Executive Summary

This report summarizes data collected from the wadeable streams in the Humboldt River Basin of Nevada. The determination of current status is a critical step in the future management of these stream resources, and, to that end, this study focuses on providing "baseline" data for the systems studied. To provide the information needed to assess these streams, the USEPA's Regional Environmental Monitoring and Assessment Program (R-EMAP) protocols were used for sampling stream reaches within the Humboldt River Basin. This work was done by personnel from the University of Nevada Biological Resources Research Center (BRRC), in cooperation with US Environmental Protection Agency (USEPA) Region 9 and the USEPA office of Research and Development (ORD).

The goal of the this project was to assess the water quality and biotic integrity of perennial and intermittent streams over a three year sampling period for the Humboldt River Basin, using a combination of macroinvertebrates, physical habitat measurements, water and sediment chemistry, and sediment metabolism. The objectives of the Humboldt River R-EMAP were to describe the condition of surface waters, relate ecological conditions to ecological stressors and examine relative risks to streams within the Basin.

The report presents data collected during a three year study period beginning in 1998. Sampling sites were selected using a probability-based design (as opposed to subjectively selected sites) using the USEPA River Reach File version 3 (RF3). About 69 sample sites were sampled and ten of the 1998 sites were revisited to capture seasonal variations.

This study has provided a substantial baseline data set for the Basin. While the percentage of impacted streams varied, 38% of stream reaches studied in the Basin were assessed to be in a "most-disturbed" condition. We recommend that a next step for ecological condition analysis should be a landscape ecology approach which would focus on the spatial relationships and the ecological processes of the landscape, and which should provide a comprehensive basis for identifying and evaluating current and historical land use practices.

Further, because riparian function is heavily influenced by the condition of adjacent and upland ecosystems, we recommend that riparian Proper Functioning Condition (PFC) assessments be considered in environmental and water management decisions for a more sustainable ecosystem for the Humboldt River Basin.

Acronyms and Abbreviations

AFDM	Ash Free Dry Mass
BLM	Bureau of Land Management.
BRRC	Biological Resources Research Center
EMAP	Environmental Monitoring and Assessment Program.
CCC	Critical Continuous Concentration
CDF	Cumulative Distribution Frequency
CMC	Critical Maximum Concentration
HUC	Hydrologic Unit Code
LWD	Large Woody Debris
NDEP	Nevada Division of Environmental Protection
NLCD	National Land Cover Data
R-EMAP	Regional Environmental Monitoring and Assessment Program.
SpC	Specific Conductance
SEC	Sediment Effect Concentration
UNR	University of Nevada, Reno
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey

Glossary

Allochthonous - In limnology, organic matter derived from a source outside the aquatic system, such as plant and soil material.

Benthic - Pertaining to the bottom (bed) of a water body.

Channel - The section of the stream containing the main flow.

Cobble - Substrate particles 64-256 mm in diameter.

Abiotic - Non-living characteristic of the environment.

Confidence interval - An interval defined by two values, called confidence limits, calculated from sample data with a procedure which ensures that the unknown true value of the quantity of interest falls between such calculated values in a specified percentage of samples.

Detritus - Non-living organic material.

Dissolved oxygen (DO) - Oxygen dissolved in water and available for organisms to use for respiration.

Ecological indicator - Objective, well-defined, and quantifiable surrogate for an environmental value.

Ecoregion - A relatively homogeneous area defined by similarity of vegetation, landform, soil, geology, hydrology, and land use. Ecoregions help define designated use classifications of specific waterbodies.

Ephemeral river - A river that only flows when there is rain or snow has melted. The rest of the year there is just a dry river bed with no water.

Embeddedness - The degree to which boulders, cobble or gravel in the stream bed are surrounded by fine sediment.

Fine - Silt or clay less than 0.06 mm in diameter.

Functional groups - Groups of organisms that obtain energy in similar ways.

Glide - Slow, relatively shallow stream section with little or no surface turbulence.

Gravel - Substrate particles between 2 and 64 mm in diameter.

Headwaters - The origins of a stream.

Laminar flow - A smooth flow with no disruption between its layers.

Macroinvertebrate - Organisms that lack a backbone and can be seen with the naked eye.

Non-native species - A species that is not native to a particular location.

pH - A numerical measure of the concentration of the constituents that determine water acidity (H+). Measured on a scale of 1.0 (acidic) to 14.0 (basic); 7.0 is neutral.

Rapid - Water movement is rapid and turbulent with intermittent white-water surface with breaking waves.

Glossary (cont.)

Riffle - An area of the stream with relatively fast currents and cobble/gravel substrate.

Sand - Small but visible particles between 0.06 to 2 mm in diameter.

Stream order - A ranking of streams based on the presence and rank of its tributaries.

Stream reach - Section of stream between two specific points.

Stressor - Any physical, chemical or biological entity that can induce an adverse response.

Substrate - The composition of the stream or river bottom ranging from rocks to mud.

Taxon (plural taxa) - A level of classification within a scientific system that categorizes living organisms based on their physical characteristics.

Tolerance - The ability to withstand a particular condition, e.g., pollution-tolerant indicates the ability to live in polluted waters.

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I. Introduction

Nevada's landscape is comprised primarily of arid and montane ecosystems (Omernik, 1987), and water is of primary importance in both the economy and ecology of the region. Although most regions in the United States have well established stream monitoring programs, many of the waters of Nevada have received little attention in regards to systematic bioassessment prior to this study. The Humboldt River Basin is of interest to water quality managers due to potential human impacts, and/or lack of adequate historical baseline data.

The Humboldt Drainage Area is sparsely populated with only one town (Elko) having a population of over 15,000 (Figure 3). Fewer than 70,000 persons reside within the Humboldt Drainage. Sixty-six percent of the basin is owned by the Federal Government and managed by the National Forest Service. Thirty-two percent is privately owned and the remainder is held by Native Americans, State lands and other Federal holdings.

There are a number of potential water quality impacts from anthropogenic sources in the Humboldt Basin, including mining, cattle grazing, irrigated agriculture, and recreation. In the late 1800s, heavy grazing led ranchers to supplement feed with water dependant hay crops, creating water conflicts. By the 1900s, grazing-induced vegetation destruction and subsequent erosion was apparent. To date, all federal lands are still used for grazing, creating pressures on the drainage system. Substantial effects on riparian and in-stream resources have occurred, including streambank trampling, channel straightening and channel incision. Rye Patch Dam, located 22 miles upstream of the Humboldt Sink, is one of the basin's reservoirs. Because most of this water is diverted for irrigation for farmers, the Humboldt River only reaches the sink during high water years (Glennen, 2002).

The Nevada silver boom began in the late 1800s and depended heavily on large amounts of wood for fuel. Deforestation became evident near local mining towns. In the early 1900s gold mining was becoming more prevalent, and today Nevada is the third largest producer of gold globally. Much of this gold is mined in the Carlin Trend, which is a 50-by-5 mile belt within the Humboldt Basin. The belt is characterized by very small gold particles, requiring extensive methods of removal. In 2000, numerous gold mines were in operation, some over two thousand feet deep. These open pit mines are often below the water table making it necessary to remove groundwater in order to facilitate mining activities. Pumped waters are frequently discharged to surface-receiving water, creating the possibility for chemical and/or thermal pollution or they are more recently used for agriculture.

Additionally, the groundwater resources being depleted are drawing down the water table. Questions have arisen concerning the impacts of this extensive pumping. Pit lakes, one probable effect, form in the void left once a mining project and groundwater pumping ceases and have the potential to create long-term impacts. If the water is contaminated, it may flow to down-gradient groundwater or evaporate to become a hazard for surrounding wildlife (Solnit, 2000).

Abandoned mines also pose issues relating to water quality in the region. In the state of Nevada, there are over 150,000 known abandoned hardrock mines, many within the Humboldt River Basin (Nash, 2000). Mine waste is known to impact water quality by increasing suspended solids, metal content and acidity. Other impacts could include effects from chemicals used from mine processes, trash, and the erosion of mine waste into stream channels.

For future management of the Humboldt River Basin stream sources, water managers and environmental managers will need comprehensive historical data to address the above potential issues. The goal of this report is to provide a sound set of baseline data to support those management efforts.

II. Basin Description

The Humboldt River Basin study area is mainly within subecoregion (i.e., ecoregion Level III) 13 (Central Basin and Range), which is generally characterized by a wide variety of habitats ranging from salt flats and sagebrush (*Artemesia* spp.) dominated basins to subalpine zones in montane environments (Figure 1). The northern portion of the basin is a part of subecoregion 80 (Northern Basin and Range). The lower elevation basin areas of subecoregion 13 receive low amounts of rainfall, but are characterized as semi-desert, as they receive more than 15 cm of precipitation per year. The low annual precipitation for this subecoregion is both a function of distance from the Pacific Ocean and the rain-shadow effects of the Sierra Nevada mountain range.

Despite the characterization of the Central Basin and Range subecoregion as having ponderosa pine (*Pinus pondersosa*) forests, few if any Ponderosa forests exist in the Humboldt River Basin. Forests in the Humboldt River Basin are generally Pinyon Pine (*Pinus edulis*) and Juniper (*Juniperus osteosperma and occidentalis*) dominated with upper elevations consisting of aspen (*Populus tremuloides*), bristlecone pine (*Pinus longaeva*), white fir (*Abies concolor*), Limber pine (*Pinus flexilis*), and white bark pine (*Pinus albicaulis*). The low altitude plains and valleys, which comprise most of the watershed, have sagebrush (*Artemisia sp.*), bunch grasses and invasive nonnative cheatgrass (*Bromus tectorum*). The lower basin is dominated by shadscale (*Atriplex confertifolia*) and black greasewood (*Sarcobatus vermiculatus*) (Benke and Cushing, 2005). Figure 2 shows the general land cover for the Humboldt River Basin.

The Humboldt River Basin drainage covers an area of approximately 27,359 square kilometers (17,000 square miles) in the Great Basin, between Latitude 41^{o}50' in the north and 38^{o} 45' in the south. The system generally drains northeast to southwest, with several major tributaries draining from the south or north into the main stem (Figure 3). The snowmelt from the Jarbidge, Independence and Ruby Mountain ranges are the primary source of water in the basin. The mountains are steep and deeply incised with alluvial/colluvial deposits in the canyons with fine sediments becoming the dominant substrate in the broad valleys. Volcanic rocks dominate the basin which can influence water chemistry.

The main tributaries to the Humboldt are the Reese, Marys, South, North and East Fork of the Humboldt, and the Little Humboldt Rivers. Marys River originates in the Jarbidge Mountain range, and is considered to be the headwaters of the Humboldt River. The mainstem of the Humboldt River is one of the longest rivers in the Great Basin having an aerial extent of 483 kilometers (300 miles), 1610 meandering kilometers (1000 meandering miles), from the headwaters to its terminus within the Humboldt Sink, south of Lovelock, at an elevation of 1185 meters. Stream flow is at a maximum at Palisade Canyon with streams downriver occasionally or often stopping before entry into the mainstem. As a function of this, environmental conditions within and between lotic systems in this drainage are highly variable.

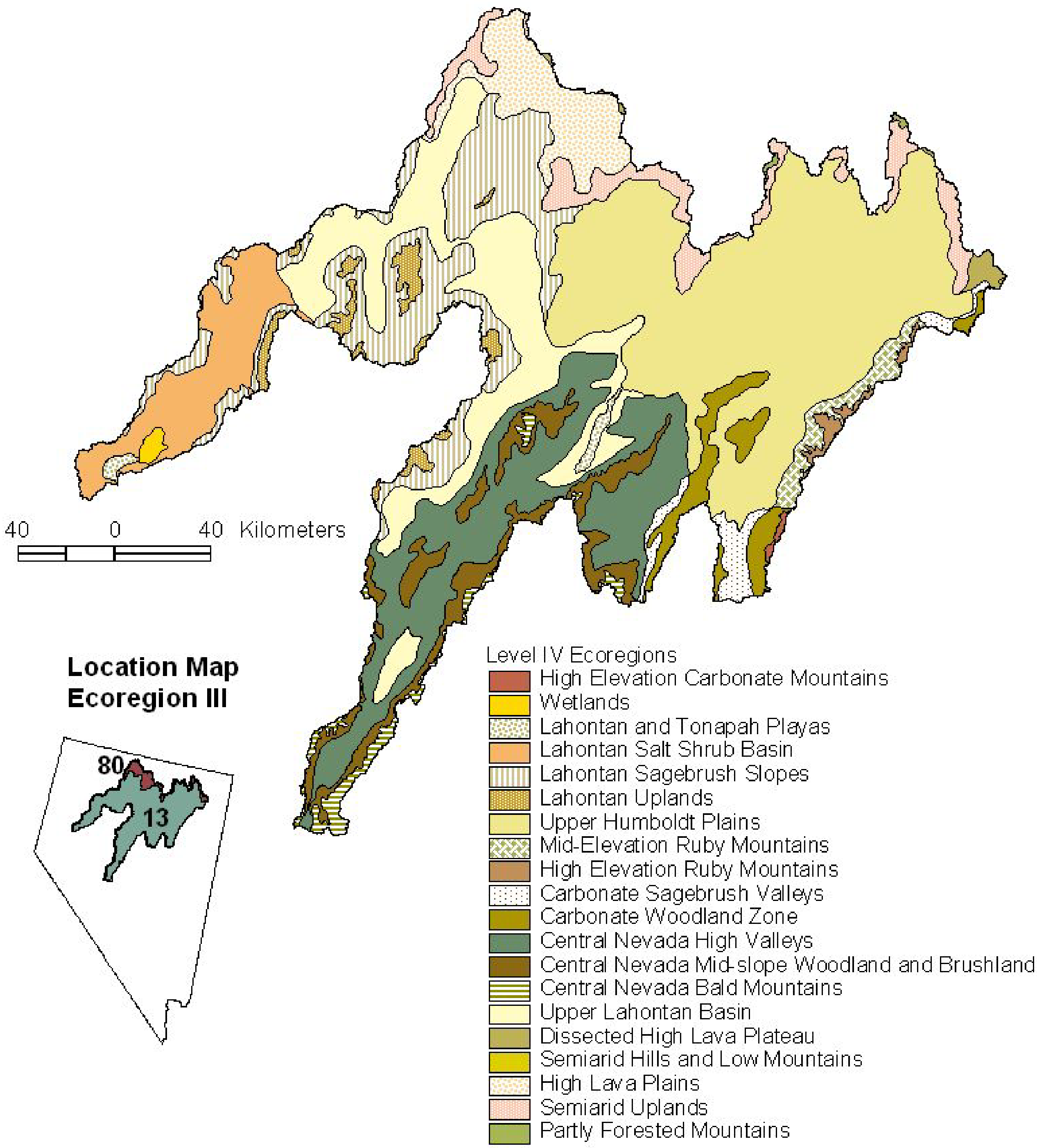


Figure 1. Ecoregions of the Humboldt River Basin (Omernik, 1987).

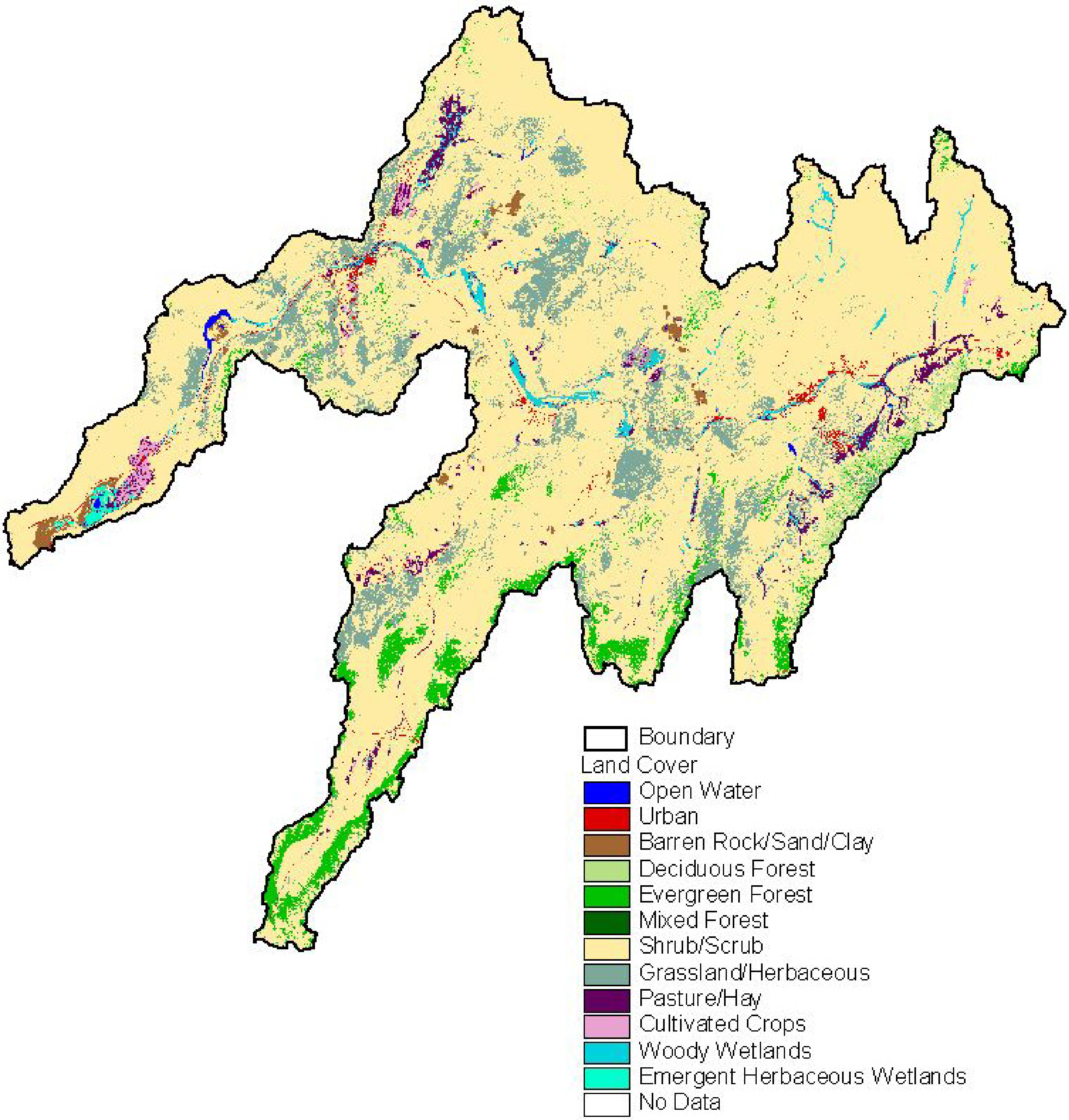


Figure 2. National Land Cover Data 2001 for Humboldt River Basin (Homer, Dewitz, Fry, Coan, Hossain, Larson, Herold, McKerrow, VanDriel, Wickham, 2007).

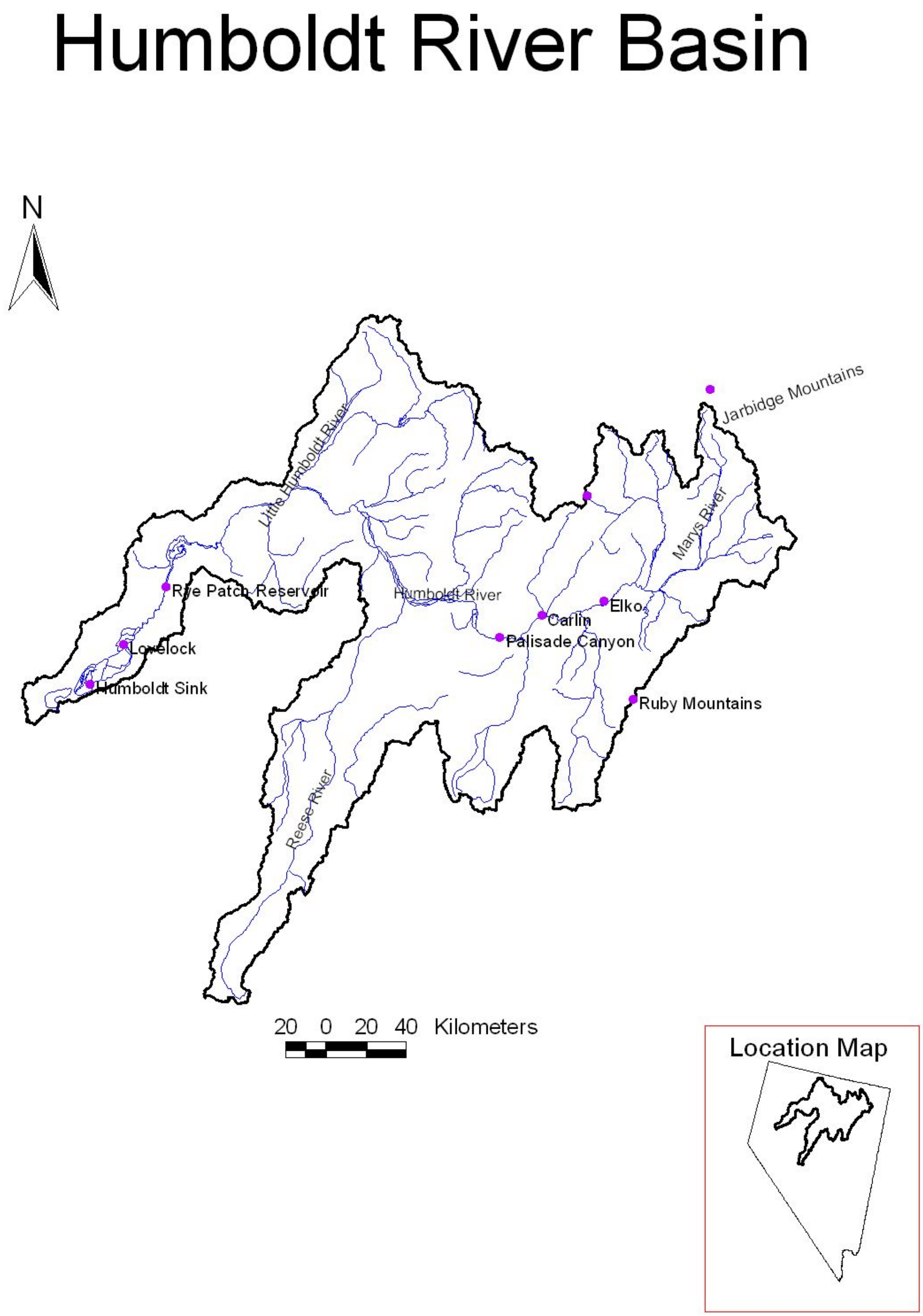


Figure 3. Location of the Humboldt Rivers and Main Tributaries.

III. Project Description

This report summarizes data collected from the wadeable streams in the Humboldt River Basin Watershed. The determination of current status is a critical step in the future management of this stream resources, and, to that end, this study focuses on providing "baseline" data for the systems studied. To provide the information needed to assess these streams, the USEPA's Regional Environmental Monitoring and Assessment Program (R-EMAP) protocols were used for sampling stream reaches within the Humboldt River Basin. This work was done by personnel from the University of Nevada Biological Resources Research Center (BRRC), in cooperation with USEPA Region 9 and the USEPA Office of Research and Development (ORD).

The USEPA initiated the Environmental Monitoring and Assessment Program (EMAP) to assess the current condition and trends in the ecological resources in the United States. Within this context, the USEPA developed the Regional Environmental Monitoring and Assessment Program (R-EMAP) to conduct studies on smaller geographic and temporal scales within the United States. The goal of R-EMAP is to provide environmental managers with statistically valid analyses of stream ecosystems condition (Whittier & Paulsen, 1992). Three main objectives direct the R-EMAP projects: (1) estimate the current status and trends in indicators of condition, (2) define associations between human-induced stresses and ecological condition, and (3) provide statistical reports to environmental managers and the public (Lazorchak & Klemm, 1997).

The goal of the this project was to assess the water quality and biotic integrity of perennial and intermittent streams over a three year sampling period for the Humboldt River Basin, using a combination of macroinvertebrates, physical habitat measurements, water and sediment chemistry, and sediment metabolism. The objectives of the Humboldt River R-EMAP were to:

- Describe the ecological condition of surface waters in the Humboldt Basin.
- Examine the relationship between indicators of ecological condition and indicators of ecological stressors in these streams.
- Examine the relative risk of wadeable streams within the Humboldt Basin.

A. DESIGN - Selection of Stream Sites

Environmental monitoring and assessments are typically based on subjectively selected stream reaches. Peterson et al. (1999) compared subjectively selected localized lake data with probability-based sample selection and showed the results for the same area to be substantially different. The primary reason for these differences was lack of regional sample representativeness of subjectively selected sites. Stream studies have been plagued by the same problem.

A more objective approach is needed to assess stream quality on a regional scale. Therefore, sampling sites were selected using a probability-based design using the USEPA River Reach File version 3 (RF3) 1:100,000 scale Digital Line Graph (DLG) as a sample frame to represent the wadeable streams.

For the Humboldt River Basin Study, sites (Figure 4) were assessed for accessibility based upon the knowledge of Dr. Gary Vinyard, who had more than 20 years of field experience in the Humboldt River Basin, combined with land ownership patterns, as represented on 1:100,000 maps. The monitoring network was established by overlaying the national EMAP 40 km^2 hexagonal frame (Stevens, 1994) over the Humboldt River Watershed. Sites were selected using a probability-based, or random, design to represent the first to sixth order streams (i.e., nominally wadeable streams) within the Humboldt River Basin. The selection was weighted by stream length where more sites were selected for higher order streams because of the larger representation of stream miles, and the potential of these streams being dry. The site selection requirements were:

- Equal area sampling representation of the Humboldt River Watershed
- Equal representation of stream courses
- Equal representation by year for the two study years of 1998 and 1999
- Detection of trends in a set of indicators by revisiting at least 10% of the sites sampled the previous year (Stevens & Olson, 1991)

Optimal statistical representation of aquatic resources in the Humboldt Watershed is best achieved with a sampling of at least 40 sites. It is difficult to discern from RF3 whether line segments will in fact contain water, be accessible, and wadeable. In addition, it was anticipated some landowners would refuse permission to enter sampling locations. Therefore, the number of prospective sampling sites selected was increased to compensate for these discrepancies. As a result, in 1998, 120 sites were initially selected to reach the statistical target of 40 sampled sites. Due to the high number of dry sampling sites , only 35 sites were sampled in 1998. In 1999, 160 were initially selected, but only 34 sites were sampled. In addition, to assess inter-seasonal variability, ten sites from 1998 were randomly selected and revisited. For this report, water quality and physical habitat data were averaged for revisit sites. The stastical extent of the Humboldt River Basin resource was estimated at 12,427 km stream length.

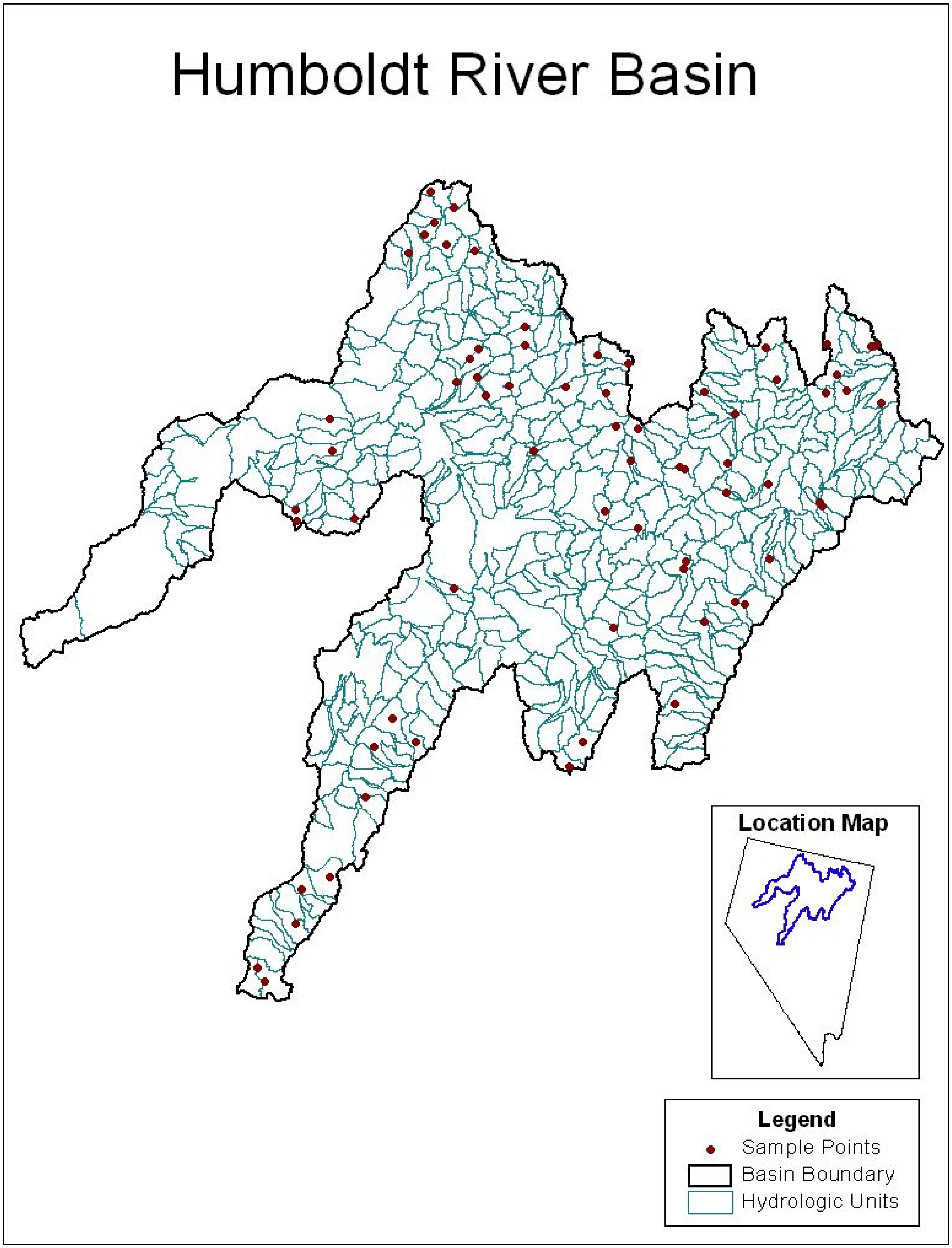


Figure 4. Humboldt River Basin Sample Sites.

B. INDICATORS - What to Measure at Each Selected Site?

The objective of the Clean Water Act is to restore and maintain the chemical, physical and biological integrity of the Nation's waters. In order to assess the Nation's waters, it is important to measure water quality (water column parameters), physical habitat (watershed and instream measurements) and biological (macroinvertebrates communities) condition as well as sediment respiration and water and sediment chemistry (metals).

EMAP uses ecological indicators to quantify these conditions. Indicators are simply measurable characteristics of the environment, both abiotic and biotic, that can provide information on ecological resources. Table 1 is a general list of the indicator categories used in EMAP to detect stress in stream ecosystems. The following section describes EMAP measurements in each of these indicator categories.

Table 1. General EMAP Indicators.

Indicator	Rationale
Water column chemistry	Water chemistry affects stream biota. Numeric standards are available to evaluate some water quality parameters.
Watershed condition	Disturbance related to land use affects biota and water quality.
In-stream physical habitat and riparian condition	Instream and riparian alterations affect stream biota and water quality. Physical habitat in streams includes all physical attributes that influence organisms.
Biological-Benthic macroinvertebrates	Benthic macroinvertebrates live on the bottom of streams and reflect the overall biological integrity of the stream. Monitoring benthic invertebrates is useful in assessing the condition of the stream.
Sediment Metabolism	Measures functionality of ecosystems by changes in dissolved oxygen, and can be used to indicate ecosystem stress.

Reach Identification

In a stream assessment, the sampling reach length has to be long enough to ensure the collection of representative samples. Proper functioning stream systems have repeating morphological patterns (Rosgen 1996). Kaufmann et al., 1999, indicate that the sample reach needs to incorporate this cyclic variation. Depending on the objective of the stream bioassessment study and protocol used (Barbour et al. 1999; CDFG 2003; Ohio EPA 1987; OCC 1993; Kaufmann and Robison 1998; Fitzpatrick et al. 1998; Lazorchak et. al. 1998; Meador et al. 1993) reach length can vary from 20 - 40 times wetted or bankfull width. For this study the EMAP protocol of 40 times the wetted width is measured at the center of the reach, or F transect. If the stream wetted width is less than 4 meters, the stream reach length total is 150 meters. If the stream wetted width is greater than 4 meters, the stream reach length total is 40 x wetted width to a maximum of 500 meters or 12.5 meters in width. If the stream wetted width is greater than 12.5 meters the maximum stream reach length will be 500 meters.

Water Column Chemistry

Water chemistry characteristics influence the aquatic community structure. A great deal of information is available on the effects of specific chemicals on aquatic biota. Data for 13 water quality parameters were collected at all sites. Measurements of hydrogen ion activity (pH), dissolved oxygen (DO), stream temperature (^oC), specific conductance (SpC), nitrate (NO_3), nitrite (NO_2), total phosphorus (TP), ammonia (NH_3), chloride (Cl), sulfate, Total Kjeldahl Nitrogen (TKN), Total Suspended Solids (TSS) and Total Dissolved Solids (TDS) were taken. These samples were sent to USEPA Region 9 laboratory (Richmond, CA) or Region 5 laboratory (Cincinnati, OH) for analysis. The rationale behind the selection of some of these water measures is presented in Table 2.

Table 2. Water Column Indicators.

Indicator	Importance to Biota	Examples of human activities that influence this indicator
Stream Temperature	-Influences biological activity -Growth and survival of biota	-Riparian shade reduction -Altered stream morphology
Dissolved Oxygen (DO)	-Growth and survival of fish -Sustains sensitive benthic invertebrates -Organic material processing	-Erosion -Addition of organic matter -Riparian shade reduction -Industrial and municipal waste
pH	-Fish production -Benthic invertebrate survival	-Mining -Addition of organic matter
Conductivity	-Indicator of dissolved ions	-Agricultural returns, industrial input and mining
Nutrients-Total Kjeldahl Nitrogen, Ammonia, and Total Phosphorus	-Simulates primary production -Accumulation can result in nutrient enrichment	-Erosion -Recreation and septic tanks -Stormwater runoff -Fertilization from agriculture, livestock waste and sewage
Chloride	-A surrogate for human disturbance (Herlihy et al. 1998)	-Industrial discharge, fertilizer use, livestock waste, and sewage

Physical Habitat Observations and Indicators

Physical habitat in streams includes all structural characteristics that influence the organisms within the stream. Physical habitat parameters were measured in order to quantify and provide an understanding of the stream's ecological functioning.

Some Useful Definitions - Habitat:

Bankfull Width – The stream width measured at the average flood water mark.

Canopy – A layer of foliage in a forest stand. This most often refers to the uppermost layer of foliage, but it can be used to describe lower layers in a multistoried stand.

Channel – An area that contains continuously or periodically flowing water that is confined by banks and a stream bed.

Large Woody Debris – Pieces of wood larger than five feet long and four inches in diameter, in a stream channel.

Riparian Area – An area of land and vegetation adjacent to a stream that has a direct effect on the stream. This includes woodlands, vegetation and floodplains.

Substrate Size – The composition of the grain size of the sediments in the stream or river bottom, ranging from rocks to mud.

Thalweg – The deepest part of the stream.

All indicators vary naturally, thus expectations differ even in the absence of human caused disturbance. The following three types of habitat variable are measured or estimated:

Continuous Parameters

Thalweg profile (a survey of depth along the stream channel), and presence/absence of fine sediments were collected at points along the stream reach. Crews also tally large woody debris along the reach.

Transect Parameters

Measures/observations of bankfull width, wetted width, depth, canopy closure, and fish cover were taken at ten evenly spaced transects in each reach. Slope measurements and compass bearing between each of the 10 transects were collected to calculate reach gradient. This category includes measures and/or visual estimates of riparian vegetation structure, human disturbance, and stream bank angle, incision and undercut.

Reach Parameters

Total stream discharge was also measured at or near the x-site, which is defined as the center segment of the stream reach, using 15 to 20 individual velocity measurements, spaced at equal widths across the stream. All velocity measurements were taken at 60% of the total stream depth for each point sampled.

Biological Indicators

Due to the fact that many of the streams in the Great Basin do not support fish communities, it was decided that biological sampling efforts should focus on macroinvertebrates and sediment metabolism. In addition, a full suite of in-stream and riparian physical habitat data was taken, as a means of correlating the biologic condition of the in-stream community to the condition of the riparian and upland environments.

Taxonomy of benthic macroinvertebrates was done by BRRC personnel, U.C. Berkeley personnel, and Bioassessment services, Folsom CA. Chemical analysis was done by the USEPA's Cincinnati lab. Data compilation involved the quality assurance methods designed by USEPA's Office of Science and Technology, Corvallis office (Kauffman et al., 1999).

Benthic Invertebrate Assemblage:

Benthic invertebrates inhabit the sediment or surface substrates of streams. The benthic macroinvertebrate assemblages in streams reflect overall biological integrity of the benthic community. Monitoring these assemblages is useful for assessing the status of the water body, and for monitoring trends. Benthic communities respond to a wide array of stressors in different ways, thus, it is often possible to determine the type of stress that has affected a macroinverebrate community (Klemm et al., 1990). Because many macroinvertebrates have relatively long life cycles, of a year or more, and are relatively immobile, macroinvertebrate community structures are a function of past conditions.

Benthic samples of substrate surface area were taken using a Surber sampler from riffle habitat only, unless no riffle existed. If no riffle existed, samples were taken from glides at that site. Riffles or glides used for benthic sampling were chosen randomly among the potential appropriate sampling locations at each transect. Each chosen riffle was then divided into ten equal lengths, and three sampling sites were determined randomly based on these ten segments. All samples were preserved in 90% ethanol and transported to the UNR aquatic ecology lab. In the laboratory, macroinvertebrates were sorted from the detritus by spreading the sample out evenly in a large tray, which was divided into a grid with numbered squares. Detritus from randomly chosen squares were moved to a smaller tray. With a microscope, macroinvertebrates were then sorted from the detritus, placed into small, plastic vial and filled with ethanol. Invertebrates were identified to lowest possible taxonomic unit.

Sediment Metabolism

Sediment samples were collected from throughout the stream reach, using the top two centimeters of sediment, until a volume of 1 liter was obtained. Sediment metabolism measurements were taken by incubating 15 ml of sediment in 35 ml stream water (50 ml vials), with five replicates plus two blank controls, at ambient stream temperature for two hours, and determining the difference in dissolved oxygen between start and finish (details provided in Section 3).

IV. Analysis and Results

Using the R-EMAP protocols described, data was collected from 69 sites in the Humboldt River Basin, of which five did not have continuous water flow. Site 101 is outside the designated Humboldt River Basin, it is still reported on here for analysis. Physical habitat parameters were collected from all sites, and water quality samples were collected from the 66 sites with adequate water flow. Benthic invertebrates were collected from the 64 sites with continuous water flow. In the Humboldt River Basin, stream order, which classifies stream size based on a hierarchy of tributaries, ranged from first to sixth order streams, with the majority of samples taken in the second, third and fourth order streams (Table 3).

Table 3. Streams in the Humboldt River Basin by Stream Order.

Stream Order	# of Samples	% Total
1	2	2.9
2	18	26.1
3	21	30.4
4	22	31.9
5	4	5.8
6	2	2.9

Data Analysis and Interpretation

In this report, the primary method for evaluating indicators was cumulative distribution functions (CDFs). The statistical design of the EMAP dataset allows for the extrapolation of results from sampled sites to the greater target population. Any of the data metrics can be quantitatively described using cumulative distribution functions (CDF's), which show the stream length represented in the target population (or proportion of length) that has values for an indicator at or below some specific value of interest. CDF graphs show the complete data population above or below a particular value as shown by the red line**.** The grey dotted lines are the upper and lower confidence boundaries of the data. To read a CDF graph, chose a particular value along the x-axis. Draw a line straight up to the CDF line. Then, read over to the y-axis to determine what percentage of Humboldt River Basin had a value greater than or equal to the value selected on the x-axis. For example, Figure 5 shows that approximately 78% of the stream length has a measurement of Total Phosphorus of ≤ 0.1mg/l and is considered functional. This is an effective way to show the extent of functionality (good) or impairment (poor) based on a particular metric for the entire population. Once this distribution is established, thresholds can be drawn at any point in the distribution.

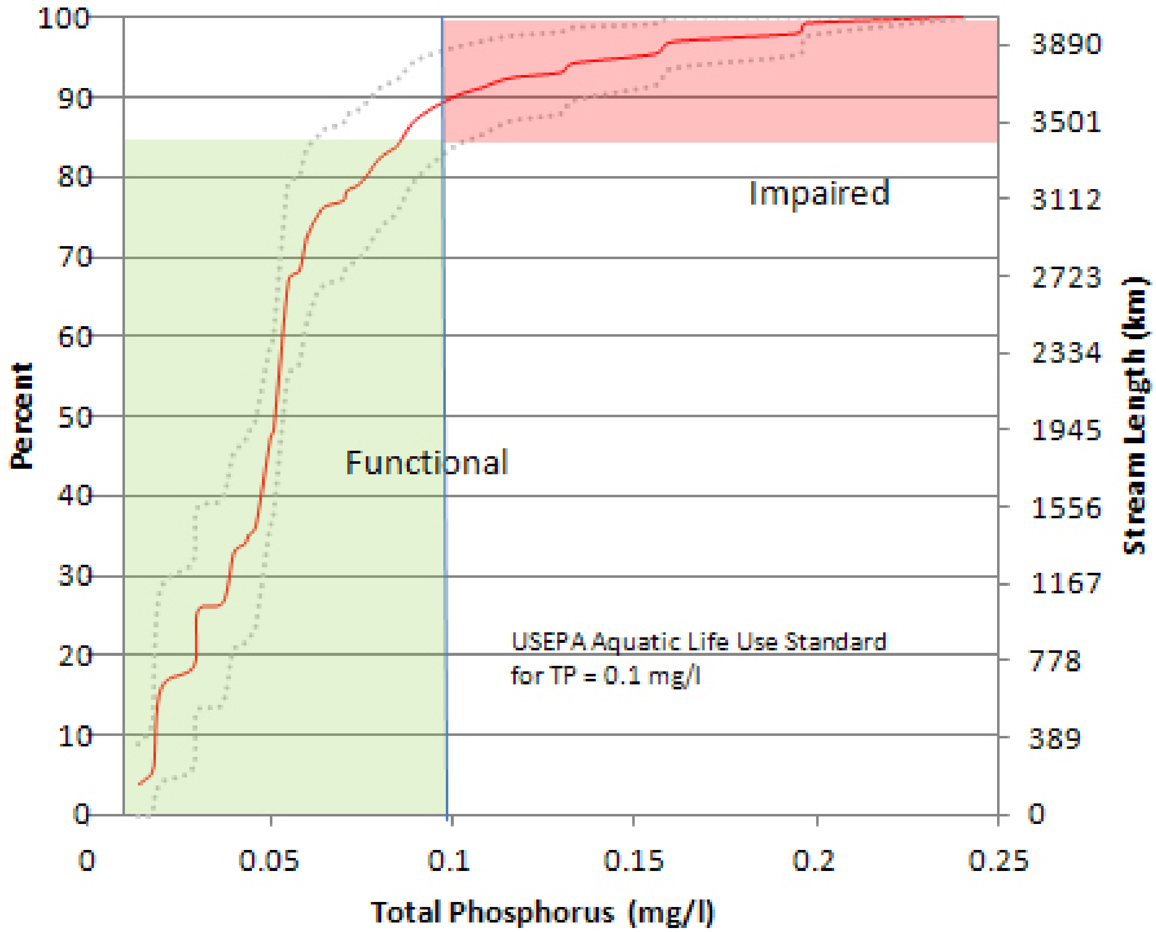


Figure 5. Example of a Cumulative Distribution Function (CDF) Showing a Threshold (0.1 mg/l) between Impaired and Functional Condition for Total Phosphorus and the Associated Proportion of Stream Length Sampled (left Y axis) and Extent of Stream Length Sampled (right Y axis) in each Category.

A. Water Column Chemistry

In general terms, a water quality standard defines the goals for a body of water by designating the use or uses to be made of the water, setting criteria necessary to protect those uses, and preventing degradation of water quality through anti-degradation provisions. Water quality standards apply to surface water of the United States, including rivers, streams, lakes, oceans, estuaries and wetlands. Under the Clean Water Act, each state establishes water quality standards which are approved by the USEPA. The State of Nevada has established water quality standards that include water quality criteria representing maximum concentration of pollutants that are acceptable, if State waters are to meet their designated uses, such as use for irrigation, watering of livestock, industrial supply and recreation (Table 4).

Table 4. Water Quality Standards for Nevada.

Indicator	Standards for Nevada
Water Temperature	≤24°C (non-trout waters) ≤20°C (trout waters)
pH	6.5-9.0
Specific Conductivity	≤800 µS/cm
Dissolved Oxygen	≥5 mg/L (non-trout waters) ≥6 mg/L (trout waters)

Data for water column indicators were collected from 66 sites in 1998 and 1999. Sites 139, 230 and 257 did not have adequate water for analysis. There were also nine revisit sites for water quality in 1999 which were averaged. The results reported below are for only those variables that have applicable criteria and/or those that influence the biota. See Appendix 2 for complete list of variables and summary statistics. Sites were not continuously sampled and timing of sampling was not intended to capture the peak concentration of chemical indicators. Data interpretation reflects a single view in time at these representative locations.

Temperature

Water temperature is temporally variable and can vary daily and seasonally and by elevation, thus a single measure of water temperature is limited in determining stream conditions. However, over the sampling period, water temperature ranged from 8.2 to 27.7°C over all samples with a mean temperature of 17.7°C (see Figure 6). Using Nevada State criteria as a reference, at the time of sampling, five samples exceeded the 24°C standard and 22 sites exceeded the 20°C standard. Figure 6 shows the CDF and condition estimate using 20°C as the condition standard.

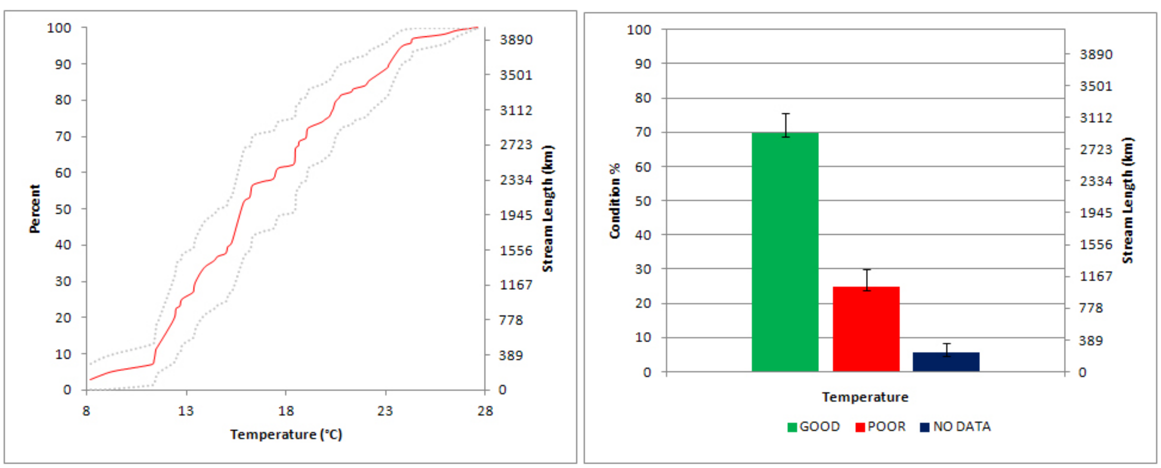


Figure 6. Cumulative Distribution Function and Condition Estimate for Stream Water Temperature.

pH

Another important water column variable, hydrogen ion activity (pH), is a numerical measure of the concentration of the constituents that determine water acidity. It is measured on a logarithmic scale of 1.0 (acidic) to 14.0 (basic) with 7.0 being neutral. The pH of the sampled sites ranged from 6.6 to 11.7 with a mean of 8.3 (Figure 7). Three samples were greater than the standards for Nevada. Measurements of pH collected during the day are typically elevated as CO_2 is depleted due to photosynthesis which effectively shifts the pH up. The condition standard determined by the authors using the standards and best judgement for this pH analysis was: 0 to 6.5, poor; 6.6 to 8.9, good; 9 and above, poor.

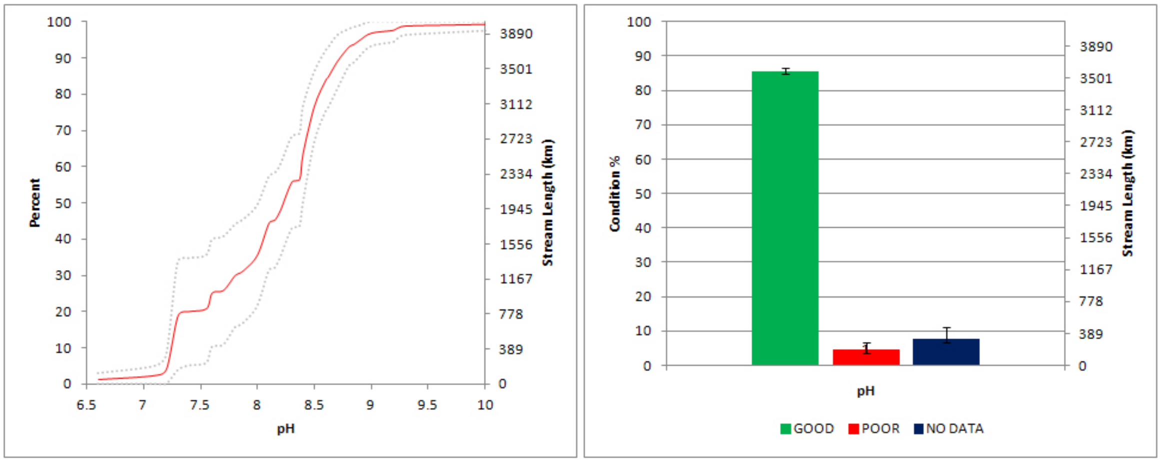


Figure 7. Cumulative Distribution Frequency and Condition Estimate of pH of Streams.

Specific Conductance

Conductivity, a measure of the ion concentration of water, is useful in determining contamination from mining and agricultural practices. The state of Nevada's standard for specific conductance is 800 µS/cm. Five samples exceeded this standard. Conductivity ranged from 53 to 1514 µS/cm with a mean of 328 µS/cm. Figure 8 shows the CDF and condition estimate. 800 µS/cm was used as the condition estimate standard.

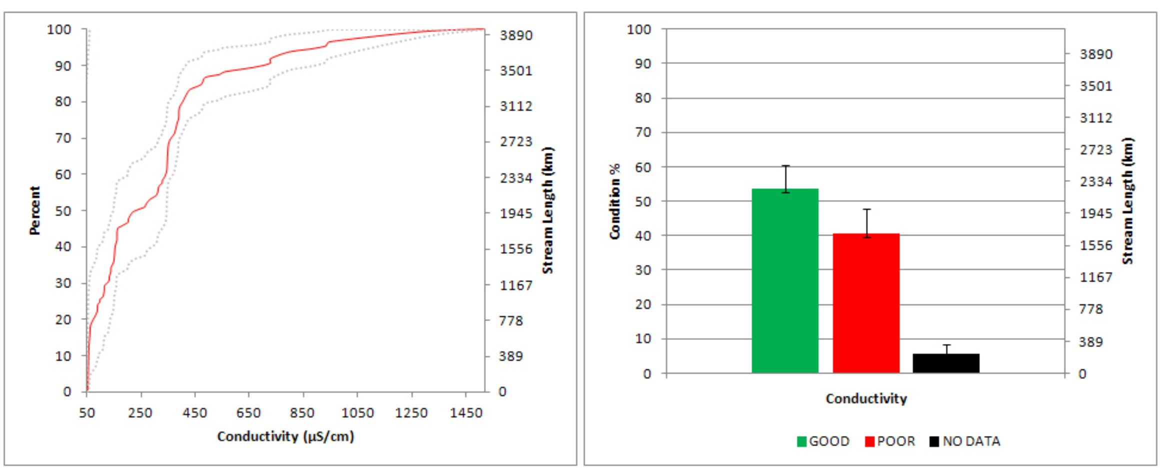


Figure 8. Cumulative Distribution Frequency and Condition Estimate of Stream Conductivity.

Dissolved Oxygen

Dissolved oxygen (DO) is simply the amount of gaseous oxygen (O_2) dissolved in water and available for organism respiration. Dissolved oxygen can decrease with increased turbidity and temperature. Increases in both of these parameters can reflect impacts of human disturbance. Decreases in DO can be associated with inputs of organic matter, increased temperature, a reduction in stream flow, and increased sedimentation. DO, like temperature, is highly spatially and temporally variable. Thus, single point-in-time DO measurements may not reflect important diel patterns. DO values ranged from 2.4 to 15.5 mg/L with a mean of 8.1 mg/L among samples (Figure 9). The condition estimate used for DO as determined by the authors using the standards and best judgement was below 5 poor, between 5 and 9 good, and above 9 poor.

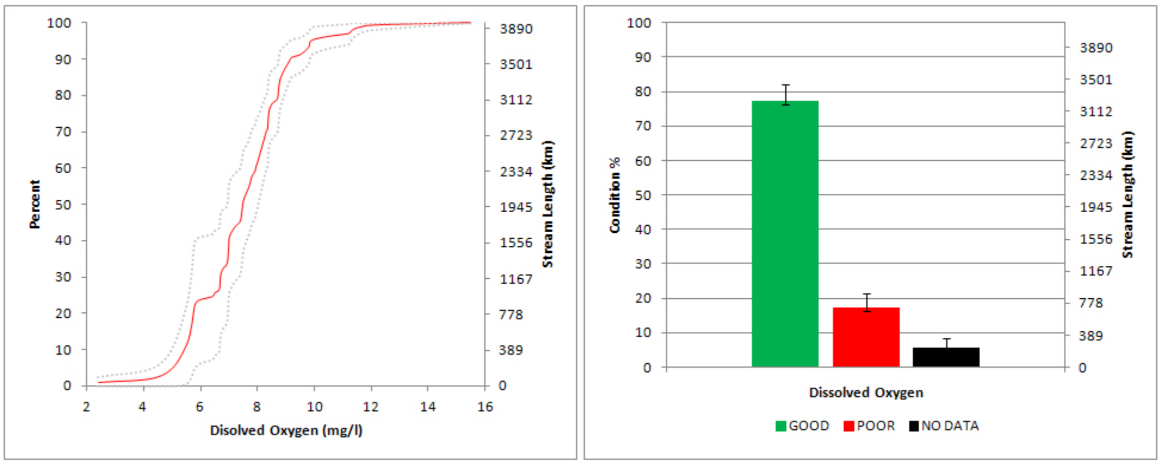


Figure 9. Cumulative Distribution Frequency and Condition Estimate of Stream Dissolved Oxygen.

Nutrients

Nutrients are essential to life and nutrient balance in streams is important to maintain a properly functioning ecological condition. Abnormal inputs from anthropogenic sources can result in increased algal growth (eutrophication) which can upset the ecological balance of the stream. Likewise, loss of nutrients from human activities can reduce stream productivity. Historic land use practices of mining, dairy, cattle grazing and landfills within the area could affect the balance. Data for eight water nutrient parameters were collected at all sites but not for all years. Water samples were analyzed for chloride, ammonia, nitrite, nitrate, total Kjeldahl nitrogen, phosphorus, total phosphorous (TP), and sulfate. Five nutrients were selected for condition analysis and are shown in Table 5.

Table 5. Nutrients in the Humboldt River Basin, Expressed as mg/L.

Indicator	Mean	Min	Max
Total Phosphorus	0.07	0.01	0.20
Nitrate	0.05	0.02	0.65
Total Kjeldahl Nitrogen	0.23	0.06	1.2
Ammonia	0.04	0.01	0.1
Chloride	17.58	0.2	204.2

Total Phosphorus

Phosphorus, along with nitrogen, is often a limiting factor in growth of aquatic vegetation. An increase in phosphorus, which could be the result of nutrient input from agriculture, is reflected in increased growth of algae. Samples for total phosphorus (TP) in the Humboldt River Basin ranged from 0.01 to 0.20 mg/L with a mean of 0.07 mg/L (Table 5). The state of Nevada water quality standard for TP is 0.1 mg/L. Ten sites had TP levels above the Nevada water quality standard. The condition estimate level was set at 0.1 mg/l for total phosphorus. Figure 10 shows that in the Humboldt River Basin the ecological condition for total phosphorus is good in 84 percent of the Basin and in poor condition in 12 percent.

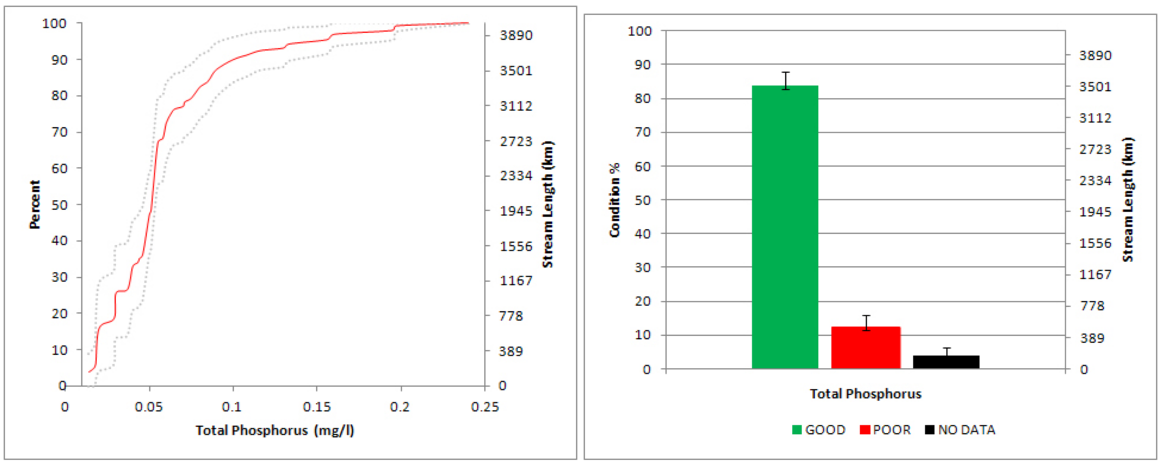


Figure 10. Cumulative Distribution Frequency and Condition Estimate of Stream Total Phosphorus.

Phosphorus is an essential nutrient for plant and bacterial activity. Yet, an excess of phosphorus may reduce habitat, disrupting ecological cycles and affecting macroinvertebrate communities. In the Humboldt River Basin, there was no apparent correlation between TP level and macroinvertebrate species richness (Figure 11).

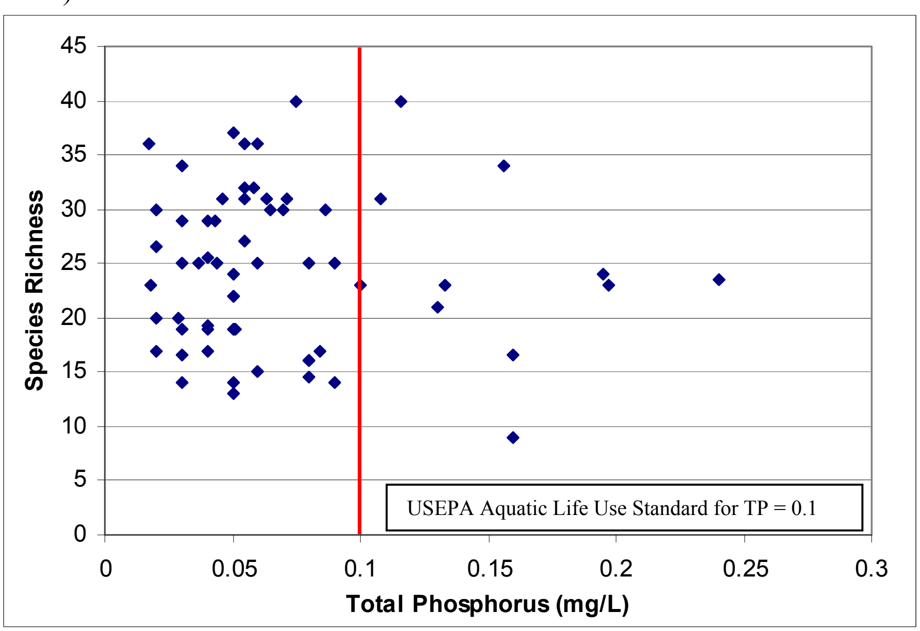


Figure 11. Total Phosphorus in Relation to Macroinvertebrate Species Richness in Sampling Sites.

Nitrite/Nitrate

Inorganic nitrogen (nitrite and nitrate) is the major form of nitrogen in lotic systems available to plants (Welch et al., 1998). As stated by MacDonald et al. (1991), concentrations of <0.3 mg/L would probably prevent eutrophication. Water standards for beneficial uses for nitrite is <1 mg/L and 10 mg/L for nitrate. In the Humboldt River Basin, nitrite and nitrate samples were only taken in the 1998 sampling period. All nitrite values were at or below the detection limit of 0.02 mg/L. Total Nitrogen was not calculated for this study because nitrite and nitrate measurements were only made the first year. The analysis of the first year survey data for nitrate can be found in Figure 12. The nitrate level for condition determination was set at 0.3 mg/l Figure 12. Ninety-one percent of the stream length was found to be in good ecological condition for nitrate and 8 percent was found to be in poor condition.

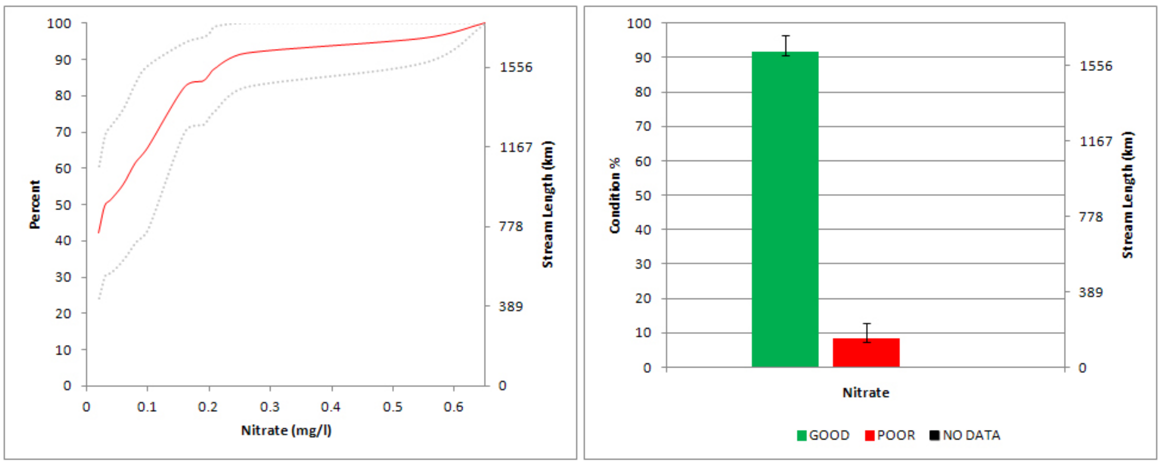


Figure 12. Cumulative Distribution Frequency and Condition Estimate of Stream Nitrate Levels for 1998.

Nitrogen is another nutrient that can affect macroinvertebrate communities, yet there was no apparent correlation between nitrate and species richness (Figure 13).

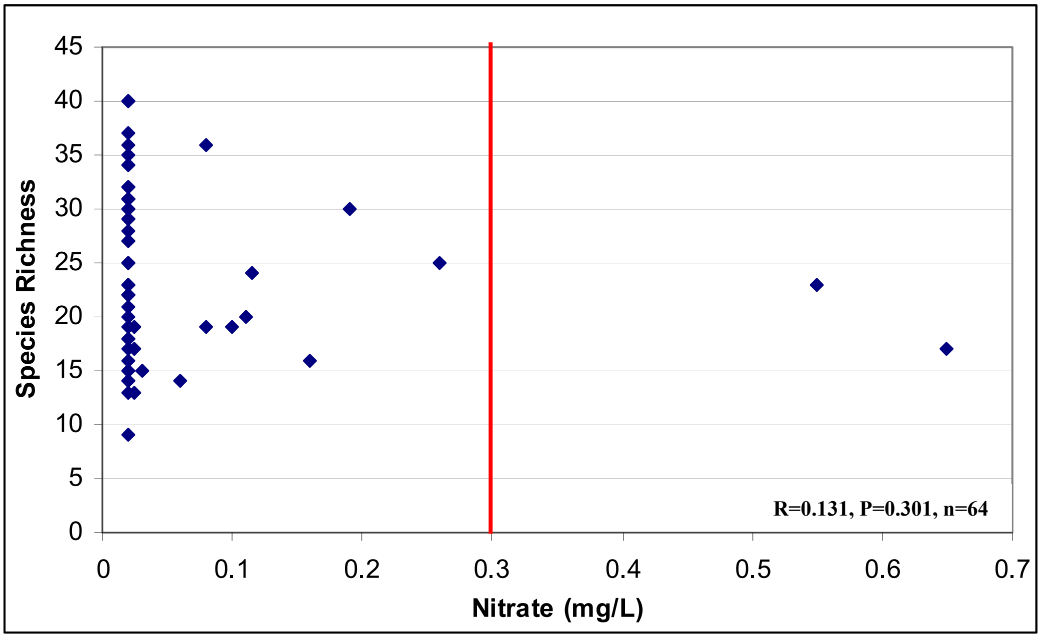


Figure 13. Nitrate in Relation to Macroinvertebrate Species Richness in Sampling Sites.

Total Kjeldahl Nitrogen

Total Kjeldahl Nitrogen (TKN) is the sum of organic nitrogen, ammonium and ammonia in a waterbody. It is measured in milligrams per liter (mg/l). High measurements of TKN indicate possible sewage and animal manure discharge into the water. Levels of 0.3 mg/l or more may indicate that pollution is present. Using that level of TKN (Figure 14) shows that the TKN condition estimate for the Humboldt River Basin is about 84 percent below that level which is considered in good condition and that 12 percent is above that level and is considered in ecologically poor condition.

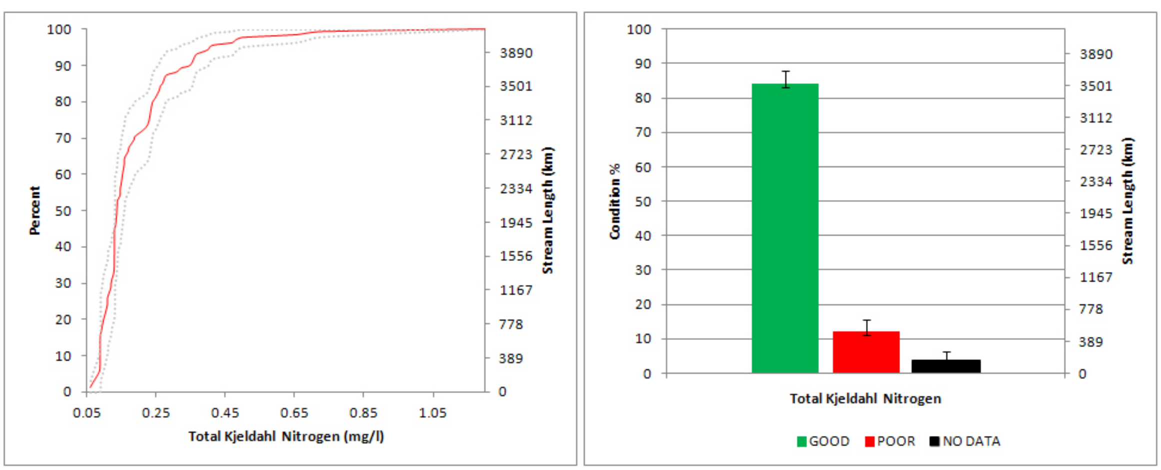


Figure 14. Cumulative Distribution Frequency and Condition Estimate of Stream Total Kjeldahl Nitrogen.

Ammonia

Abnormal levels of nitrogenous compounds found in water generally indicate pollution. Most of the nitrogen in functional (i.e., not impaired) water bodies originates from the decay of the remains of plants and animals. Ammonia nitrogen is the most common form of nitrogen in a water bodies involving the biological breakdown of animal waste products. High pH and warmer temperatures can increase the toxicity of a given ammonia concentration. The ammonia level of 1.8 mg/l was used for this condition analysis and was taken from the USEPA's National Recommended Water Quality Criteria – Aquatic Life Criteria. Ammonia levels were shown (Figure 15) to be in good condition in 96 percent of the Humboldt River Basin samples.

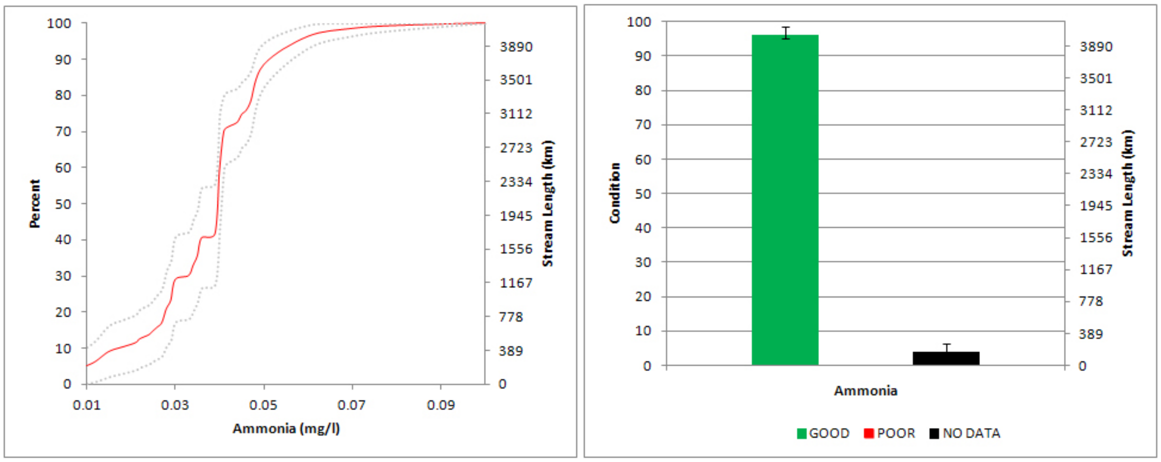
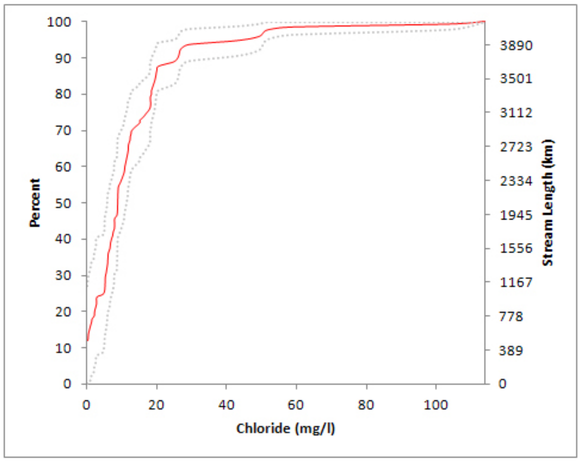


Figure 15. Cumulative Distribution Frequency and Condition Estimate of Stream Ammonia.

Chloride

Chloride, present in all natural waters at low levels, is considered a good indicator as it is involved in few reactions relative to other ions (Feth, 1981). The worldwide chloride mean concentration in rivers is 7.8 mg/l, with a range from 1 to 280,000 mg/L (Hem, 1985). Found to be an indicator of human disturbance, anthropogenic sources can be ascribed to urban and agricultural runoff. The recommended USEPA standards for beneficial uses in the Humboldt River Basin is ≤250.0 mg/L. Chloride samples ranged from <0.2 to 204.2 mg/L in the Humboldt River Basin, with a mean of 17.6 mg/L. The condition level for chloride in water was set at 250 mg/l. As found in Figure 16, none of the stream condition for chloride was shown to be in poor ecological condition.



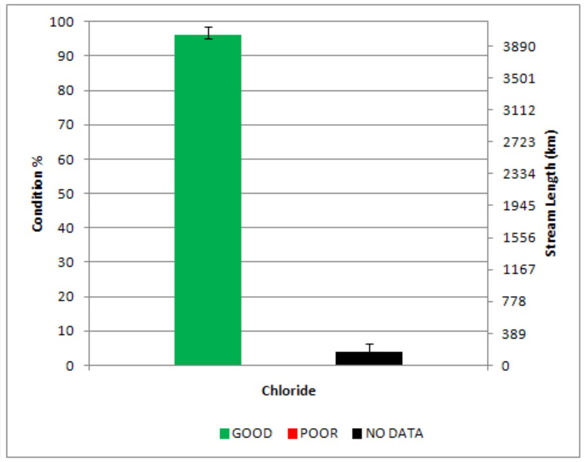


Figure 16. Cumulative Distribution Frequency and Condition Estimate of Stream Chloride Levels.

B. Physical Habitat Indicators

While there are currently no water quality criteria for physical habitat variables, they are very important for supporting designated uses and directly support the goal of the Clean Water Act. Physical habitat is described from measures taken at two scales: watershed and individual stream. Physical habitat characteristics define how streams process inputs and respond to disturbance. There can be much variation in physical habitat characteristics at either scale. This section describes watershed scale features (basin size and slope), physical stream characteristics (substrate, habitat units, fish cover), and riparian characteristics.

Channel Form

Strahler stream order describes the location of a stream in the watershed. A first order stream has no tributaries, representing source streams. Two first order streams come together to create a second order stream. Two second order streams come together to create a third order stream, and so on. If two streams of different orders combine, the united stream takes on the larger of the two sizes (Strahler, 1957) (Figure 17). Stream orders for sampling sites are listed in Appendix 1.

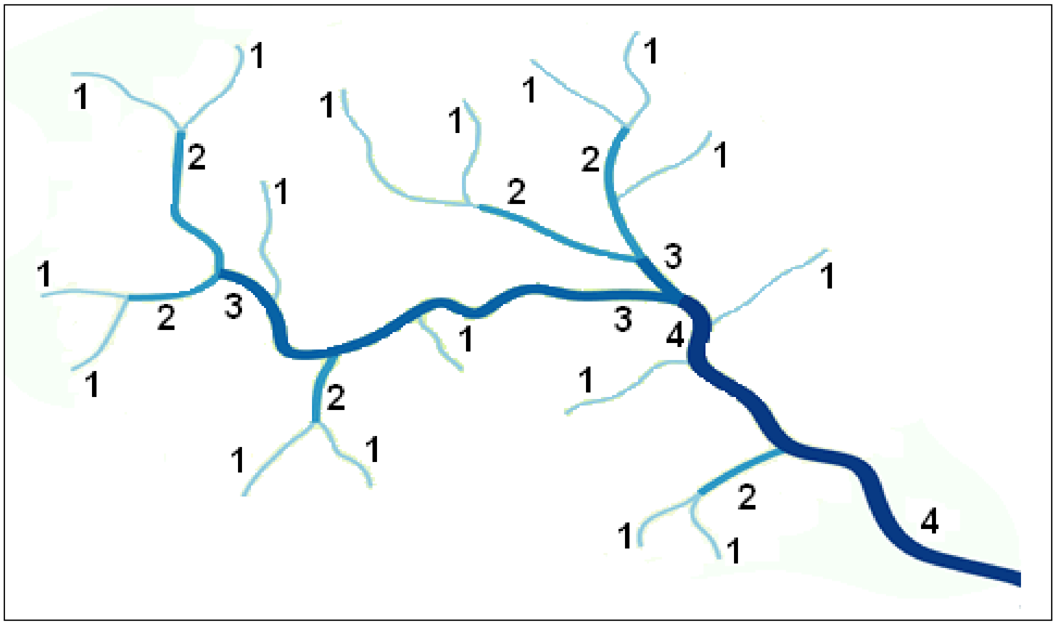


Figure 17. Example of Strahler Stream Order (FISRWG 1998).

Stream order was related to stream wetted width and depth for all stream orders combined (R=0.678, P=0.000) (Figure 18). The two first order streams were shallow and narrow. The second (R=0.770), third (R=0.780), four (R=0.756) and fifth (0.444) order streams exhibited a positive correlation between depth and wetted width. There were two, sixth order streams that were relative in size. Because data were collected over a period of many weeks, observed values do not reflect a constant channel measurement. Water width/depth ratio would be expected to vary at each site and data do not usually reflect bankfull width/depth ratios.

For all stream orders, mean stream wetted width ranged from 0.00 m (dry stream beds) to 16.68 m and averaged 3.03 m. Mean depth ranged from 0.00 cm to 110.49 cm with a mean of 23.79 cm.

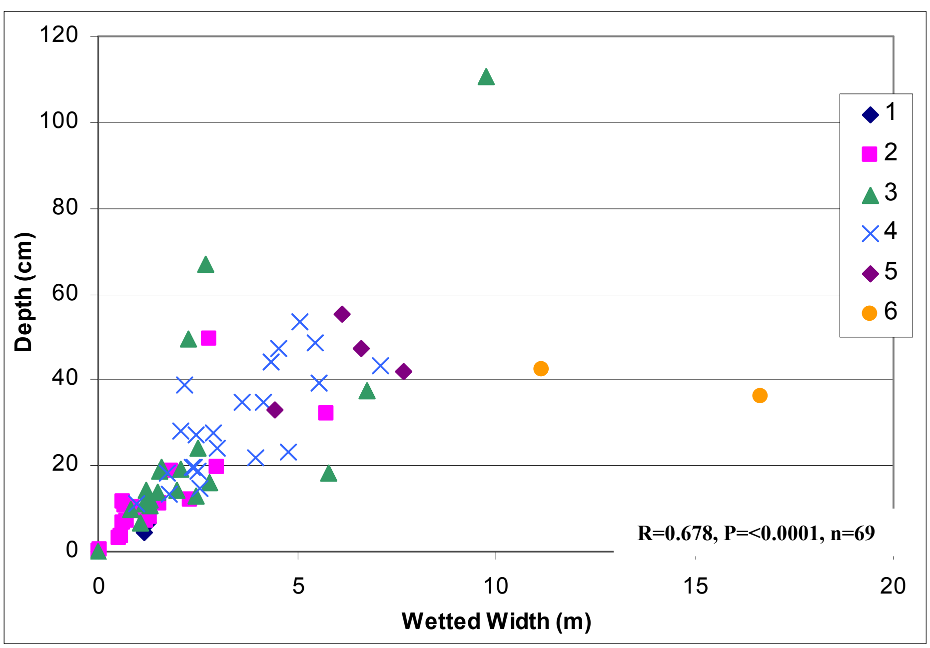


Figure 18. Relationship between Thalweg Water Depth and Wetted Width for Each Stream Order (1-6).

Large Woody Debris

Large woody debris (LWD), as single pieces or in accumulations (i.e. log jams), alters flow and traps sediment, thus influencing channel form and related habitat features. The quantity, type and size of LWD recruited to channel from the riparian zone and from hillslopes are important to stream function in channels that are influenced by LWD of various sizes. Loss of LWD without a recruitment source can result in long-term alteration of channel form as well as loss of habitat complexity in the form of pools, overhead cover, flow velocity variations, and retention and sorting of spawning-sized gravel.

LWD data were only collected during the 1998 sampling period. The data were then compiled into classes based on length and diameter of each piece (Table 6). No medium or large class pieces were identified and counted (Table 7). Most small and very small LWD were found at site 92, a second order stream located east of Rye Patch Reservoir at the base of Humboldt Mountain Range.

Table 6. Definition of LWD Classes Based on Length and Diameter (Kaufmann, 1999).

	Length (m)		
Diameter (m)	**1.5-5**	**>5-15**	**>15**
0.1-0.3	Very small	Small	Medium
>0.3-0.6	Small	Medium	Large
>0.6-0.8	Small	Large	Large

Table 7. Mean LWD Quantity Per 100m by Size Class and Streams Order.

Size Class		Stream Order					
	All	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**
Very small	35.58	0	35.30	0.28	0	0	0
Small	8.67	0	8.67	0.00	0	0	0

Substrate

Substrate describes the grain size of particles on the stream bottom and ranges from boulders to mud. Stream substrate is influenced by many factors including geology, transport capacity and channel characteristics.

Gravel (2 to 64 mm) was the most common substrate size, comprising 41.2% of all surface stream substrates (Figure 19). Sand and fine sediment (<0.06 to 2 mm) was the next dominant size, comprising 33.7% of all surface stream substrates, followed by cobble (64 to 250 mm) at 20.6%. Hardpan, boulders, bedrock and wood comprised a limited portion of dominant substrate type.

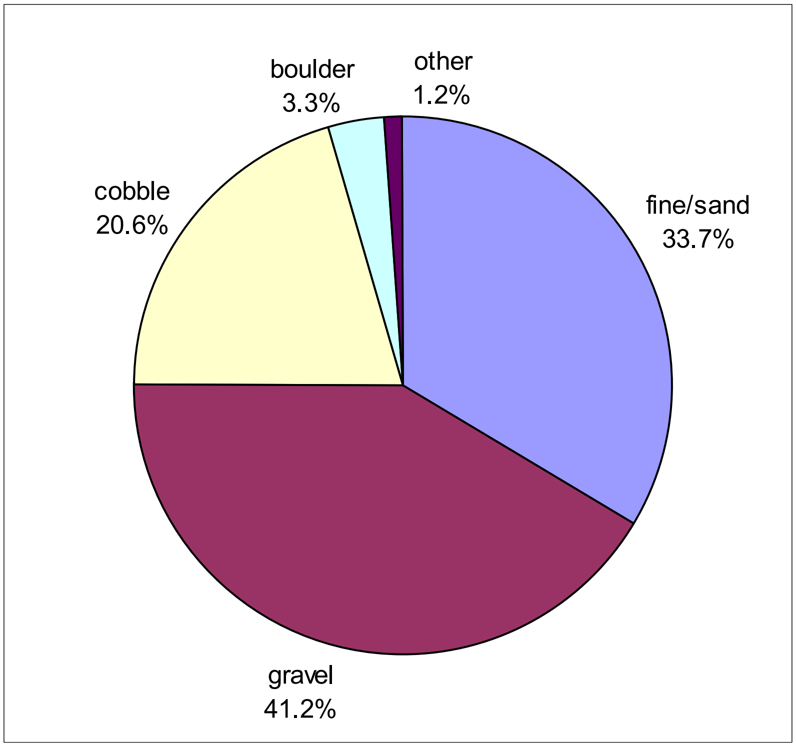


Figure 19. Percent of Streambed with Dominant Particle Size.

Table 8. Percent of Stream Substrate Types for each Stream Order.

Strahler Order	1st Order	2nd Order	3rd Order	4th Order	5th Order	6th Order	All Streams
Fine/Sand	3.64	31.42	44.53	46.90	33.86	41.82	33.70
Gravel	61.82	41.67	30.36	30.72	42.50	40.00	41.18
Cobble	29.09	22.76	16.91	14.66	21.82	18.18	20.57
Boulder	1.82	3.49	7.04	6.73	0.91	0.00	3.33
Other	3.64	0.66	1.17	0.99	0.91	0.00	1.23

Classifying the data by Strahler stream order, gravel dominates first order streams (Table 8; Figure 20). Second through sixth order streams have a higher mix of gravel and sand and fine substrates. Third and fourth order streams have similar substrate diversity with sand and fine substrate as the dominant type. The surficial composition of the Humboldt Basin, consisting of thin alluvium (young sediment or freshly eroded rock particles), intrusives (slowly cooled rocks originating from shallow magma having small to medium sized grains), and tertiary sediments (river sediment, gravel), may provide some explanation for the high percentage of gravel (Maxey & Shamberger, 1961).

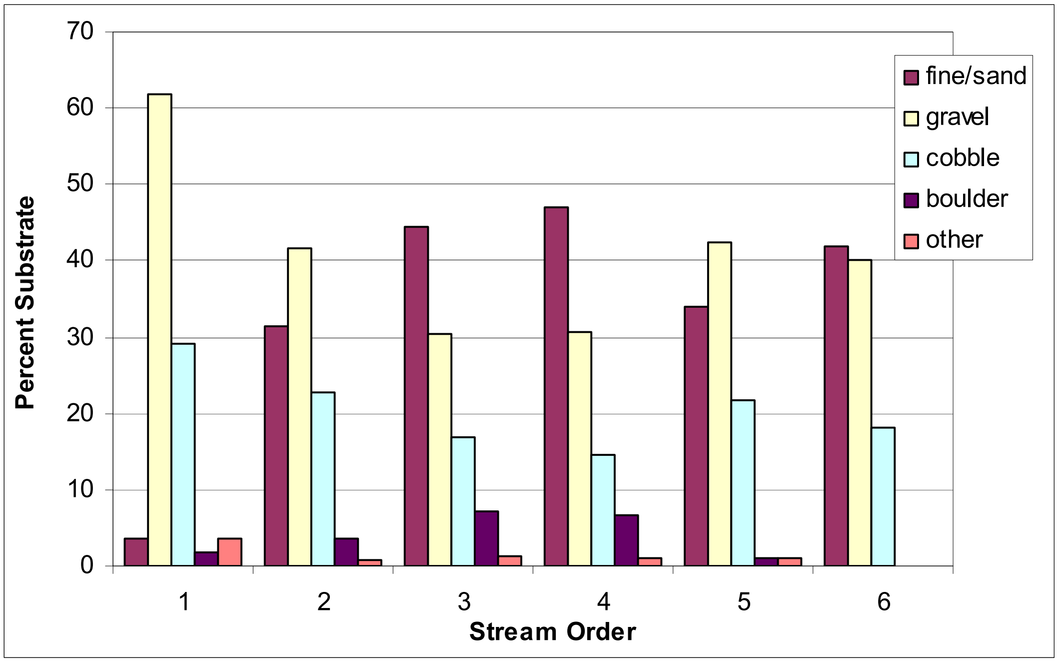


Figure 20. Substrate Size by Stream Order.

Relative Streambed Stability

Disturbances to the landscape can contribute large amounts of sediment to a stream. The stream must maintain a balance between sediment deposit and transport. Too much fine sediment can reduce habitat availability and water circulation, both of which are necessary for aquatic invertebrates and benthic organisms (Kaufmann et. al., 2004). Relative streambed stability (LRBS) measures the ability of a stream to transport sediment and is calculated utilizing bankfull channel dimensions, thalweg depth profiles, slope, woody debris, and systematic pebble counts (Kaufmann et al., 2008).

Of the 69 sites, thalweg depth profiles were gathered for 59 of them. Sites that were inaccessible or did not have data available do not have corresponding LRBS values. To account for stream "roughness" or variables that impact stream flow, woody debris counts and the amounts of different sediments present in the stream are factored in the LRBS calculation. Hardpan and bedrock measurements were not included due to insignificant amounts present within the sampled areas (Faustini & Kaufmann, 2007). See Appendix 4 for a full summary of calculations.

A large negative LRBS value indicates more fine sediments were present than expected, while a large positive LRBS value indicates more coarse sediments present than expected. Either instance suggests ecological disturbance/stress (Herger et. al., 2007).

Streambed stability values ranged from -5.615 to 1.320 with a mean of -0.325 (see Figure 21). The streambed stability values used for the ecological condition analysis were; -5 to -3 poor, -2.9 to -0.5 good, -0.49 to 2 poor. The most disturbed sites in terms of fines and the most disturbed sites in terms of coarse substrate resulted in a 61 percent poor ecological condition for the stream length represented. This analysis should be considered very preliminary. More information concerning streambed characteristics to help refine the condition values in the Humboldt River Basin are needed.

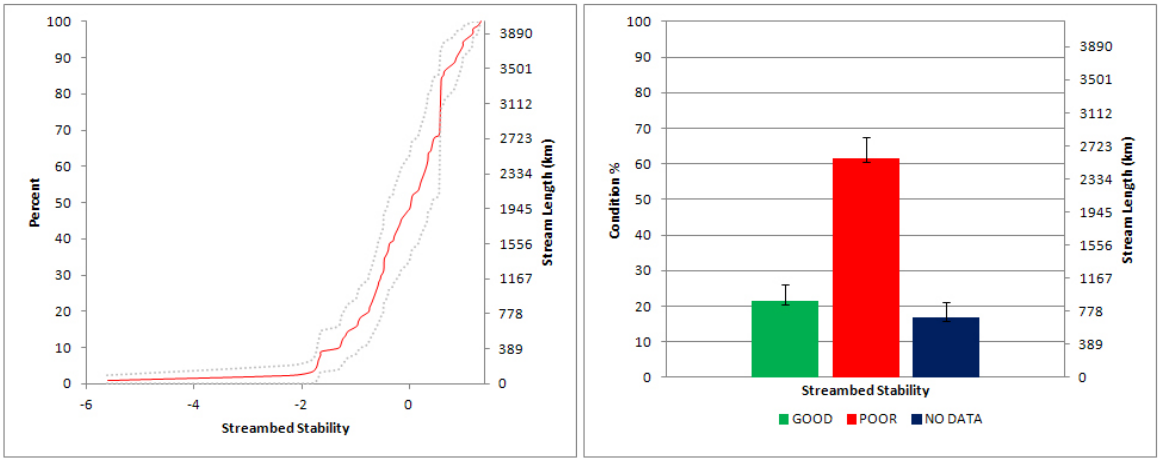


Figure 21. Cumulative Distribution Function and Condition Estimate of Streambed Stability.

Pools

In streams, pools are areas of deeper, slower flowing water that are important habitat features for fish. The abundance of pools and their size and depth depends on the stream's power and channel complexity. Stream size, substrate size and abundance, and larger roughness element (e.g. LWD) availability all contribute to the frequency and quality of pools. An estimated 6.5% percent of stream reaches were pools which had a mean depth of 8.79 cm and a mean volume of 0.71 m^3. Over 90% of the pools were less than 50 cm deep and there were no pools over 100 cm deep (Figure 22).

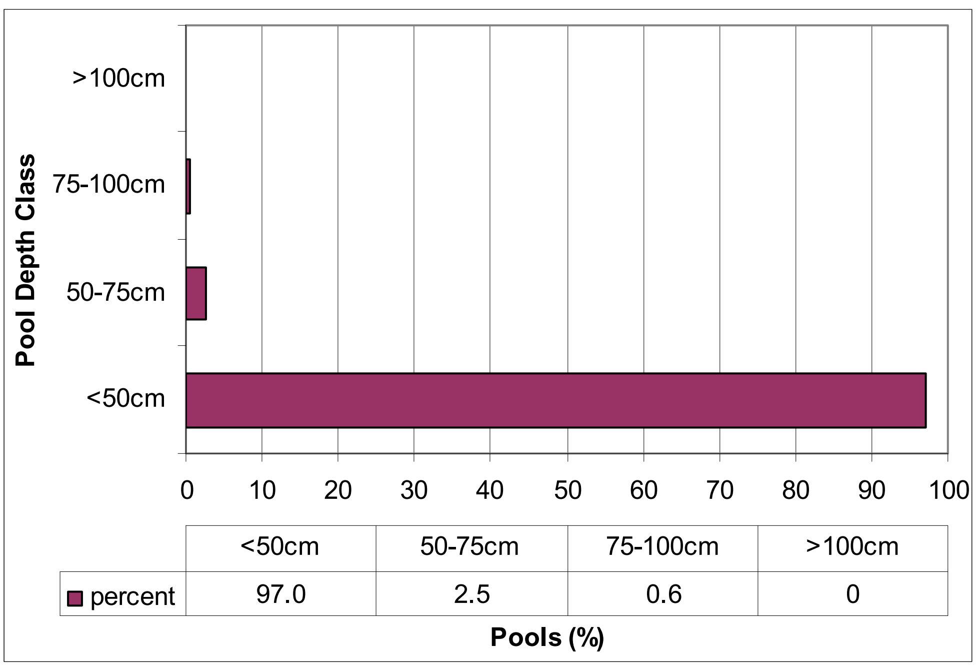


Figure 22. Frequency of Pools by Depth Class.

Riparian Vegetation

Riparian (stream bank) vegetation is important for several reasons:

- influences channel form and bank stability through root strength;
- source of recruitment for LWD that influences channel complexity;
- provides inputs of organic matter such as leaves, and shades the stream which influences water temperature;
- provides allochthonous energy to the system.

Expressed as a proportion of the reach, riparian cover data were collected for three vegetation heights as expressed in Table 9.

Table 9. Riparian Vegetation Category and Associated Height.

Vegetation Cover Type	Height
Tree or canopy layer	>5m
Understory	0.5-5m
Ground cover	<0.5m

Visual estimates of cover density and general structural/species vegetation classes (e.g. coniferous, deciduous) of each layer were recorded. Overall, riparian vegetation was dense and most streams had abundant riparian vegetation (Figure 23).

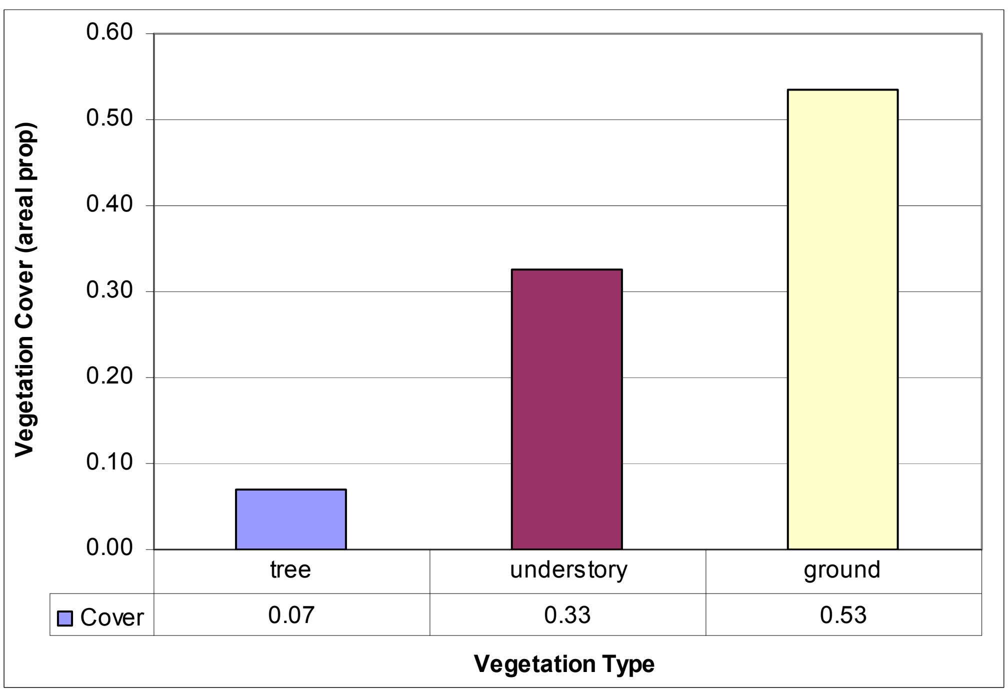


Figure 23. Percent Vegetation Cover by Vegetation Class.

Vegetation from trees was relatively sparse with the greatest percentage in second order streams. There was no tree cover at all in the fifth and sixth order streams. Ground cover was the dominant vegetation type for all stream orders (Figure 24).

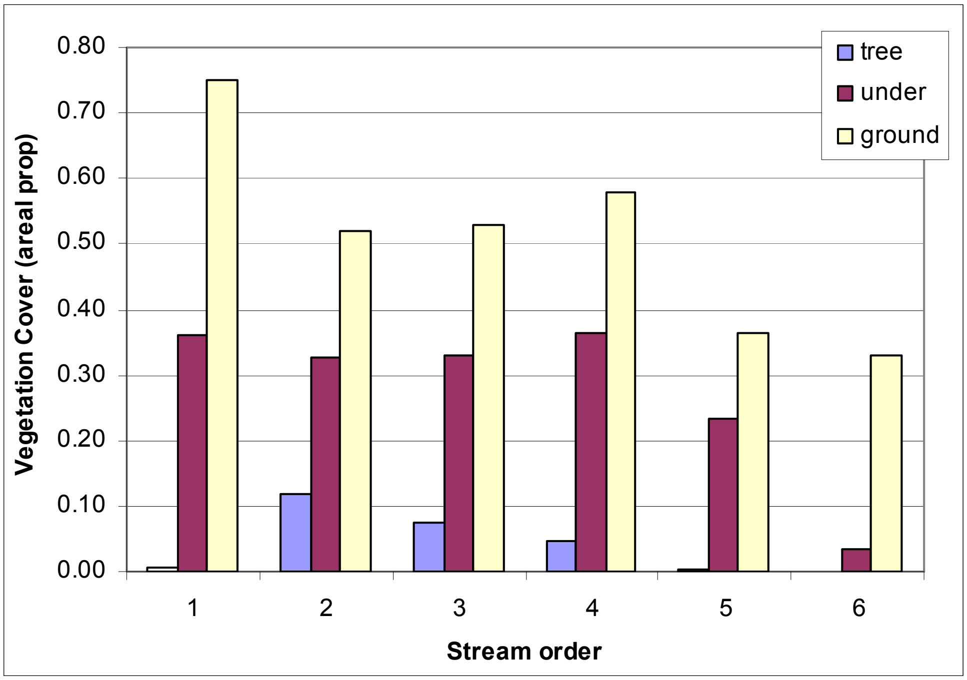


Figure 24. Percent Samples with Vegetation Cover by Class in Relation to Stream Order.

Three types of riparian canopy cover types were considered: coniferous, deciduous, and mixed coniferous and deciduous cover. The riparian tree canopy of most streams is composed of deciduous species (Figure 25).

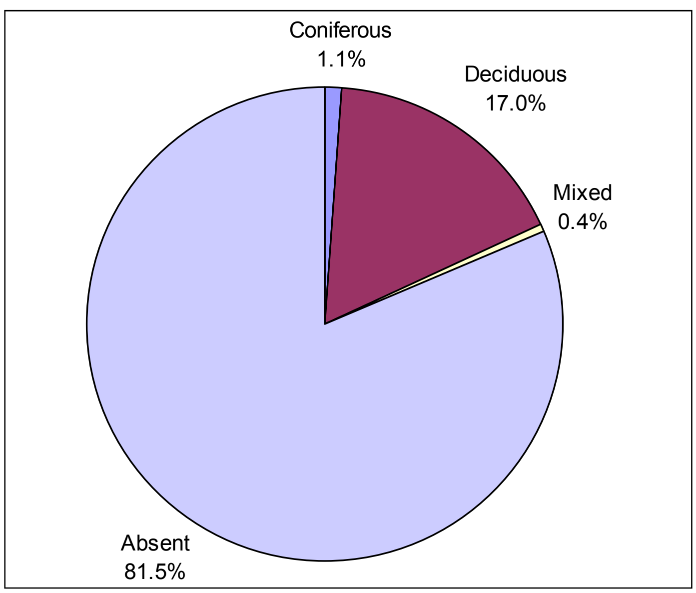


Figure 25. Mean Percent Riparian Canopy Cover by Vegetation Type.

In addition to riparian vegetation presence, stream shading from riparian canopy was assessed at each transect. Stream shading is determined from average densiometer readings for each sampling site. Separate calculations from the bank and mid-channel were made. Shading was low with an average of 45.6% of stream banks shaded (Figure 26) and an average of 18.8% of stream mid-channels shaded (Figure 27). Given the types of vegetation found in the range and basin ecoregions which comprise the Humboldt River Basin, the condition estimate should be used for comparison purposes. The values of both shade condition measurements were poor 0 – 30, fair 31 – 70, and good, 71 – 100.

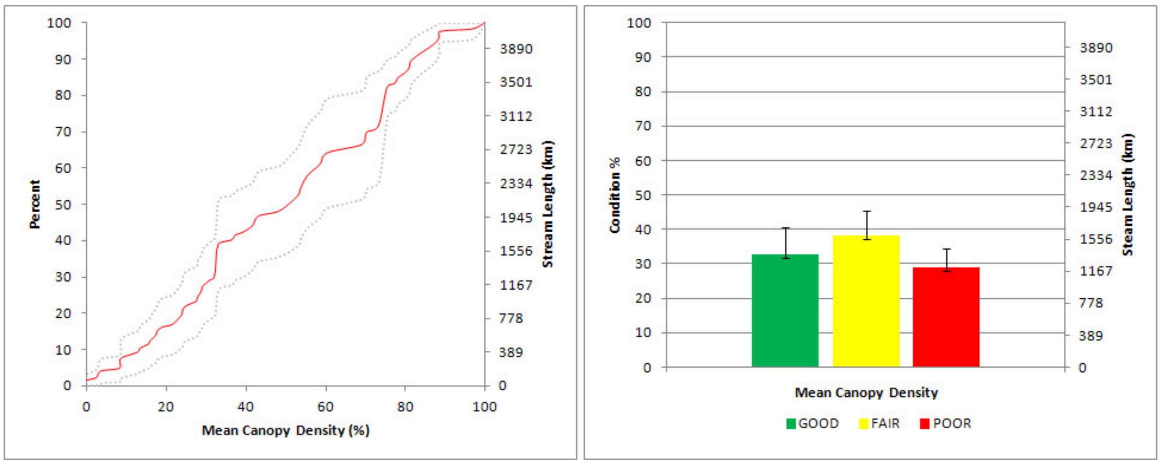


Figure 26. Cumulative Distribution Function and Condition Estimate of Mean Canopy Shade on Bank.

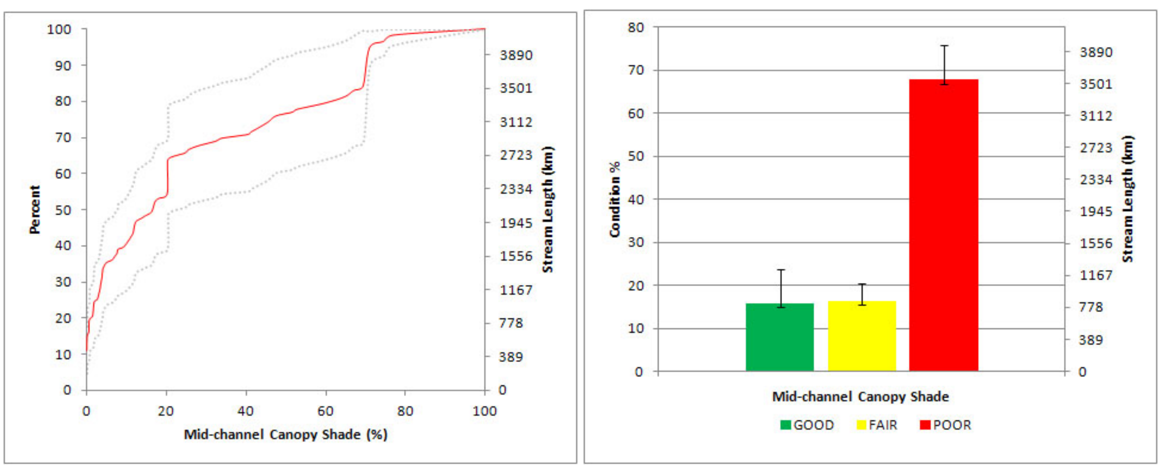


Figure 27. Cumulative Distribution Function and Condition Estimate of Mid-Channel Canopy Shade.

The accepted paradigm provides dynamics for stream characteristics relative to stream order. According to Poole and Berman (2001) it is expected that shade will decrease as stream order increases. The Humboldt River Basin exemplifies this. Mid-channel shade decreased fairly linearly as stream order increased (Figure 28). Mean canopy shade varied with the lowest density for sixth order streams.

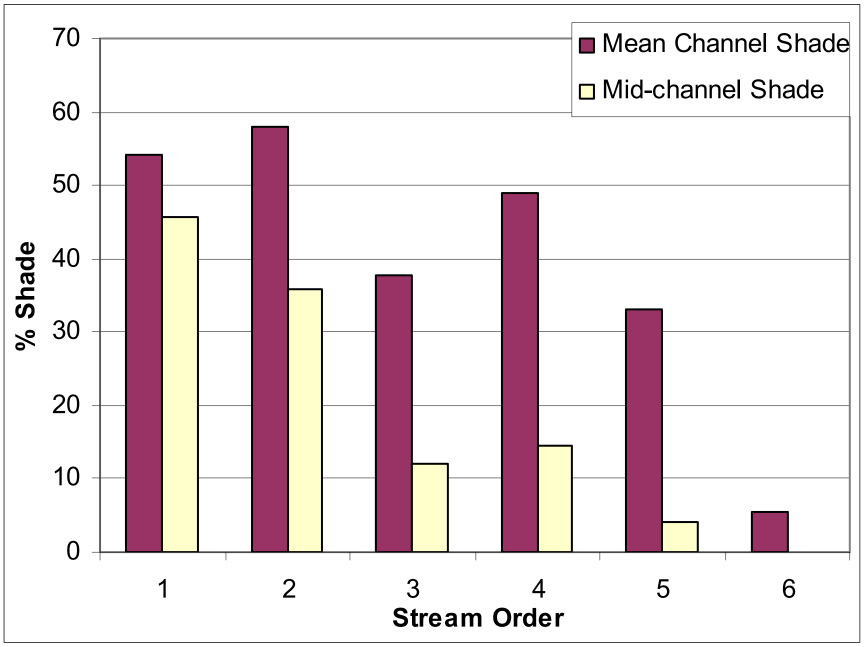


Figure 28. Percent Mid-Channel and Bank Shade by Stream Order.

Fish Cover

Many structural components of streams are used by fish as concealment from predators and as hydraulic refugia (e.g. bank undercuts, LWD, boulders). Although this metric is defined by fish use, fish cover is also indicative of the overall complexity of the channel which is likely to be beneficial to other organisms. Fish cover was analyzed according to its level of presence, as described in Table 10. Overall fish cover was moderate. The mean area covered by all types but algae was estimated to have an areal proportion of 0.415, area covered by natural objects (includes overhanging vegetation, undercut banks, LWD, brush and boulders) was 0.412, and area covered by large objects was 0.156 (see Figure 29).

Table 10. Index of Fish Cover Presence.

Level of Presence	Description
Absent	None
Sparse	<10%
Moderate	10-40%
Heavy	40-75%
Very Heavy	>75%

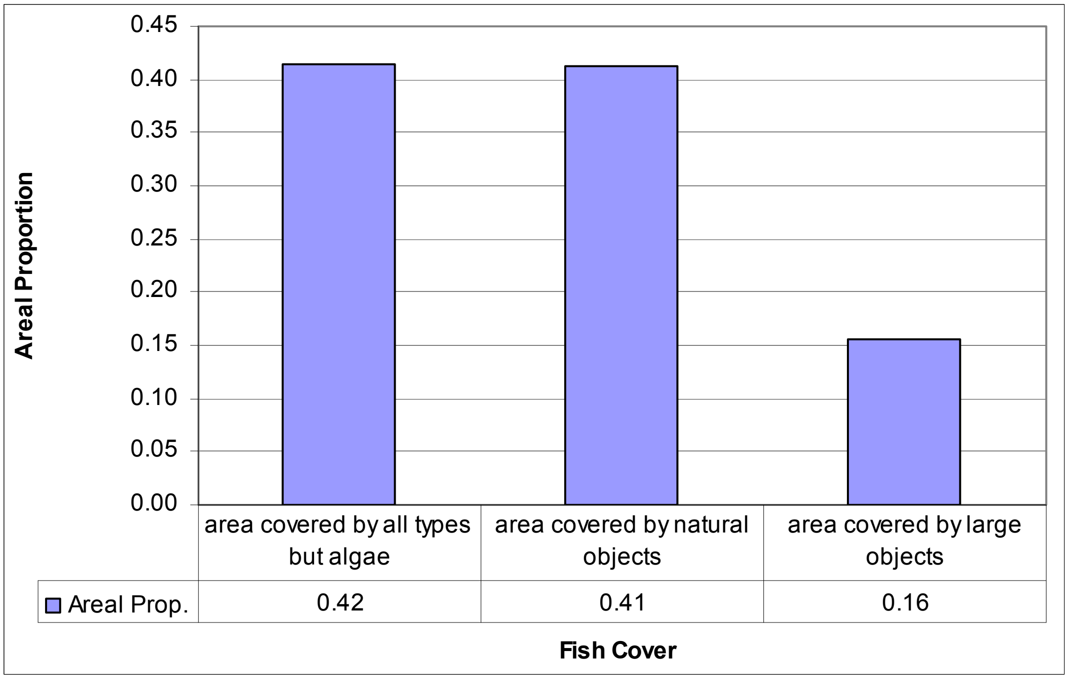


Figure 29. Natural Fish Cover.

Riparian Disturbance Indicators

Removal or alteration of riparian vegetation reduces habitat quality and can result in negative effects to the stream biota. Riparian disturbance data were collected by examining the channel, bank and riparian area on both sides of the stream at each of the transects, and visually estimating the presence and proximity of disturbance (Hayslip et al., 1994). Eleven categories of disturbance were evaluated. Each disturbance category is assigned a value based on its presence and proximity to the stream (Table 11).

Table 11. Riparian Disturbance Proximity to Stream and Associated Score.

Criteria	Score
In channel or on bank	1.67
Within 10m of stream	1.0
Beyond 10m from stream	0.67
Not present	0

Not all types of disturbance were observed in the riparian zone of the Humboldt Basin Streams. Piping and lawns/parks were not observed in the riparian zone of any of the streams. Shown in Figure 30, the most common form of riparian disturbance is pastures/hayfields (81.7%), followed by roads/railroads (13.3%).

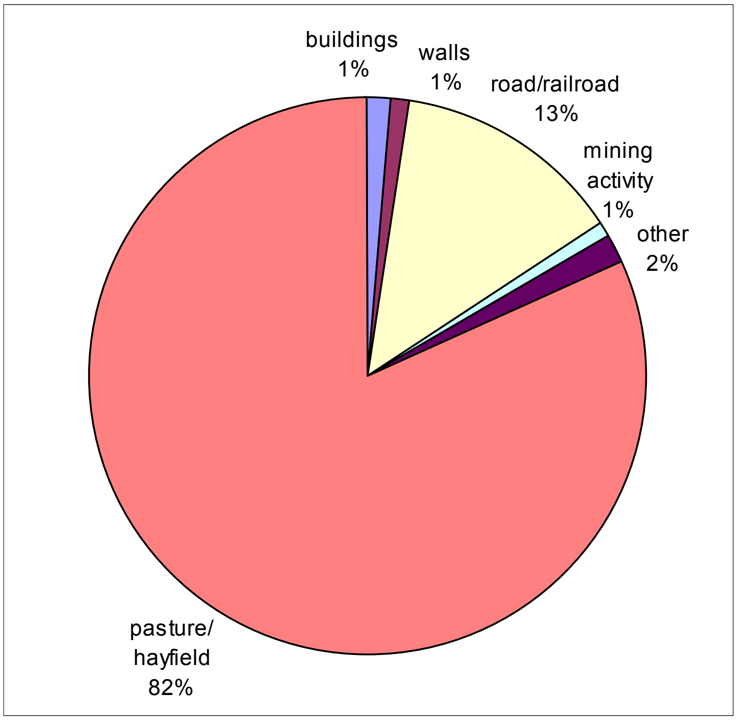


Figure 30. Percentage of Riparian Zone Human Influences on Stream Reaches.

Data were expanded to calculate a proximity-weight disturbance index for each reach (Kaufmann et al., 1999). This index combines the extent of disturbance (based on presence or absence) as well as the proximity of the disturbance to the stream. Categories of disturbances were defined using quartile ranges of the data (Table 12).

Table 12. Levels of Human Influence.

Data Range	Level of Human Influence
0-0.6	Low
>0.6-1.3	Medium
>1.3-1.9	High
>1.9	Very High

Generally the level of human influence was low for all the separate categories, except for pastures/ hayfields which was medium (1.20) and accounted for the greatest percentage of riparian disturbance (Figure 31). For all disturbance categories combined, the majority of sites have a high level of human influence (1.5). See Appendix 3 for a full summary.

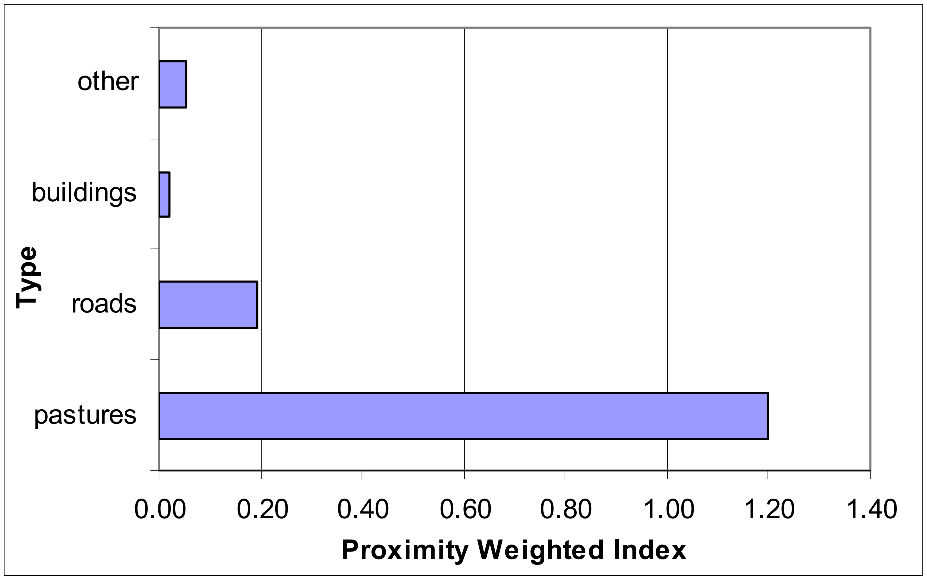


Figure 31. Mean Riparian Zone Human Influence by Type.

C. Biological Indicators

Benthic Invertebrates

Benthic macroinvertebrate assemblages reflect overall biological integrity of the stream because of their sensitivity to numerous stream characteristics. Monitoring these assemblages is useful in assessing the current status of the water body, as well as long-term changes (Plafkin et al., 1989). For example, these communities are vulnerable to changes in temperature, which is in part regulated by the riparian vegetation. Nutrients, such as phosphorus and nitrogen, are essential, but in excess, may become toxic, reducing the amount of habitat available and disrupting biological communities.

Benthic macroinvertebrate data were available from 64 sample reaches and collected at each transect using modified Serber samplers. The following three metrics were used in the analysis: taxa richness, EPT taxa richness, and percent intolerant taxa (Table 13).

Table 13. Description of Benthic Macroinvertebrate Indicator Metrics (Resh and Jackson, 1993 and Resh, 1995).

Metric	Description	Rationale
Taxa richness	The total number of taxa describes the overall variety of the macroinvertebrate assemblage. Useful measure of diversity of the assemblage.	Decreases with low water quality associated with increasing human influence. Sensitive to most human disturbance.
EPT taxa richness	Number of taxa in the orders **E**phmeroptera (mayflies), **P**lecoptera (stoneflies), and **T**richoptera (caddis flies).	In general, these taxa are sensitive to human disturbance.
Percent intolerant taxa	Percent taxa of considered to be sensitive to disturbances.	Taxa that are intolerant to pollution based on classification from Wisseman 1996.

The metric ‘Taxa Richness’ gives an indication of variability of macroinvertebrate communities in the Humboldt Basin. The total number of taxa ranged from 9 to 40 species (Figure 32). Variability of taxa richness may be a result of difference in spatial location, flow regimes, habitat, chemistry and/or temperature where the invertebrate fauna becomes dominated by a few taxa. The condition analysis estimate of taxa richness measurement over the Basin shows that there are very few (7%) poor condition locations. As determined by the authors using the standards and best judgement the values used for the condition estimate were: 1-15 poor, 16-25 fair, and 26-40 good. Summary statistics are presented in Appendix 3.

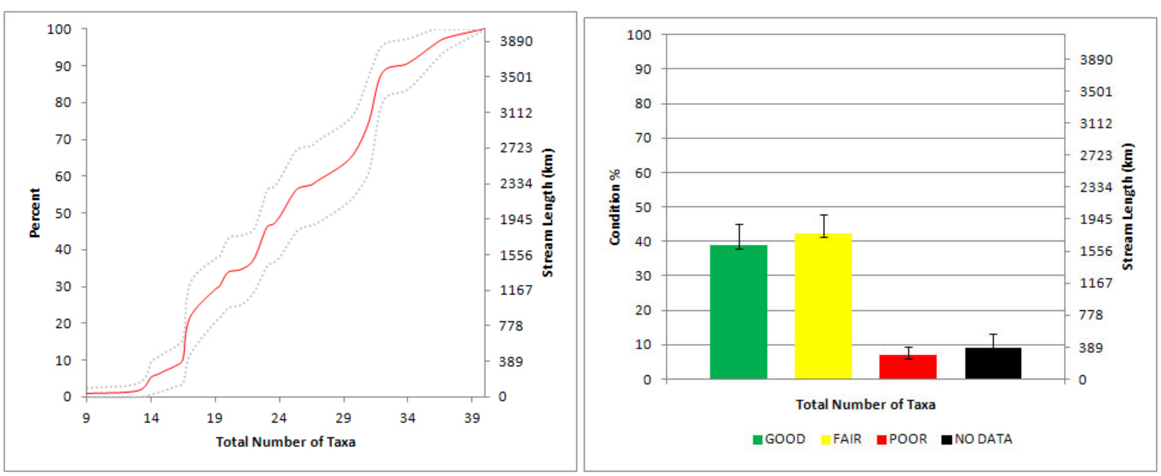


Figure 32. Cumulative Distribution Function and Condition Estimate of Total Taxa Richness.

EPT taxa ranged from 2 to 24 (Figure 33) and percent intolerant taxa ranged from 0% to 57.2% (Figure 30). Condition estimate values were set at: 0-7 poor, 8-17 fair and 18-25 good.

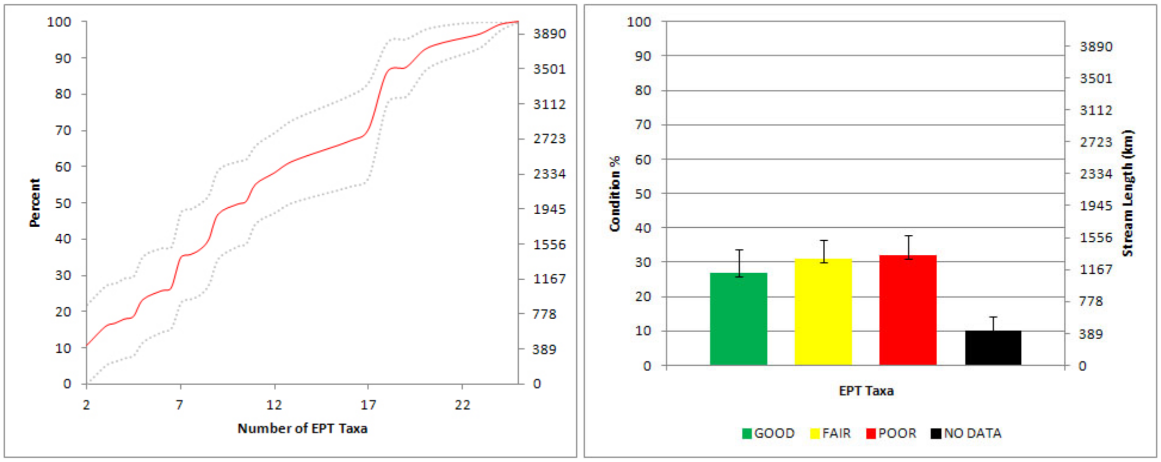


Figure 33. Cumulative Distribution Function and Condition Estimate of EPT Taxa Richness.

Intolerant taxa are used as an indicator of disturbance. A high number of intolerant taxa indicates a low amount of disturbance. The condition estimate values were; 1-20 poor, 21-40 fair, and 41 to 60 good. Given this set of estimate values, 57 percent of the Basin is in a poor ecological condition as determined by intolerant taxa (Figure 34).

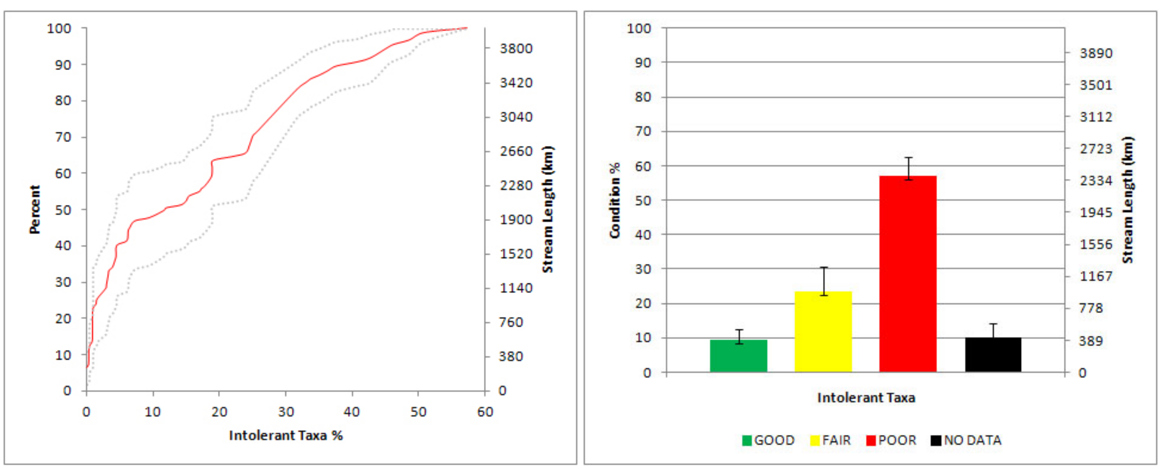


Figure 34. Cumulative Distribution Function and Condition Estimate of Percent Intolerant Taxa.

A total of 24 metrics were analyzed and are summarized in Table 14 (Appendix 5). Biotic indices such as taxa richness may not be sufficient to determine functional changes in a substrate system. Functional feeding groups provide an indication of the available feeding strategies in the benthic assemblage**.** Functional feeding groups across divergent stream systems can be successful in characterizing variability in resource utilization (Karr et al., 1986; Karr & Chu, 1999; Resh, 1995). Without relatively stable food dynamics, an imbalance in functional feeding groups will result.

Table 14. Summary Statistics for Macroinvertebrate Metrics.

Indicator	Mean	Min	Max	Standard Deviation
Taxa Richness	24.6	9.0	40.0	7.7
HBI	4.7	2.3	7.8	1.1
Shannon H	2.0	0.7	2.7	0.4
% EPT	42.9	1.8	86.5	22.2
EPT Taxa	10.9	2.0	24.0	6.3
% Ephemeroptera	25.5	0.9	81.6	19.0
Ephemeroptera Taxa	4.3	1.0	10.0	2.3
% Plecoptera	5.3	0.0	33.5	8.2
Plecoptera Taxa	2.3	0.0	7.0	2.1
% Trichoptera	12.0	0.0	62.8	15.3
Trichoptera Taxa	4.3	0.0	13.0	2.9
% Collector	46.9	7.3	87.2	19.6
% Filterer	24.5	0.4	69.8	18.3
% Predator	14.2	1.9	58.1	11.8
% Grazer	12.1	0.2	56.4	13.7
% Shredder	2.3	0.0	27.6	4.6
% Dominant Taxa	37.6	13.9	81.6	15.9
% Intolerant	16.3	0.0	57.2	16.5
% Tolerant	10.0	0.0	73.2	16.9

Predators comprised 14.2% of the population. Shredders are the more sensitive organisms to disturbance? and are considered to represent a healthy stream system. In the Humboldt River Basin, shredder densities (2.3%) were low. Cummins and Klug (1979) indicate collectors and filterers (generalists) have a broader range of acceptable food materials than specialists (scrapers, shedders, etc.). This makes collectors and filterers more tolerant in stressed environments. The Humboldt River Basin is dominated by the collector (46.9%) and filterer (24.5%) feeding groups. Dominance of a particular group can be an indication that a stream system is reflecting stressed conditions (Figure 35).

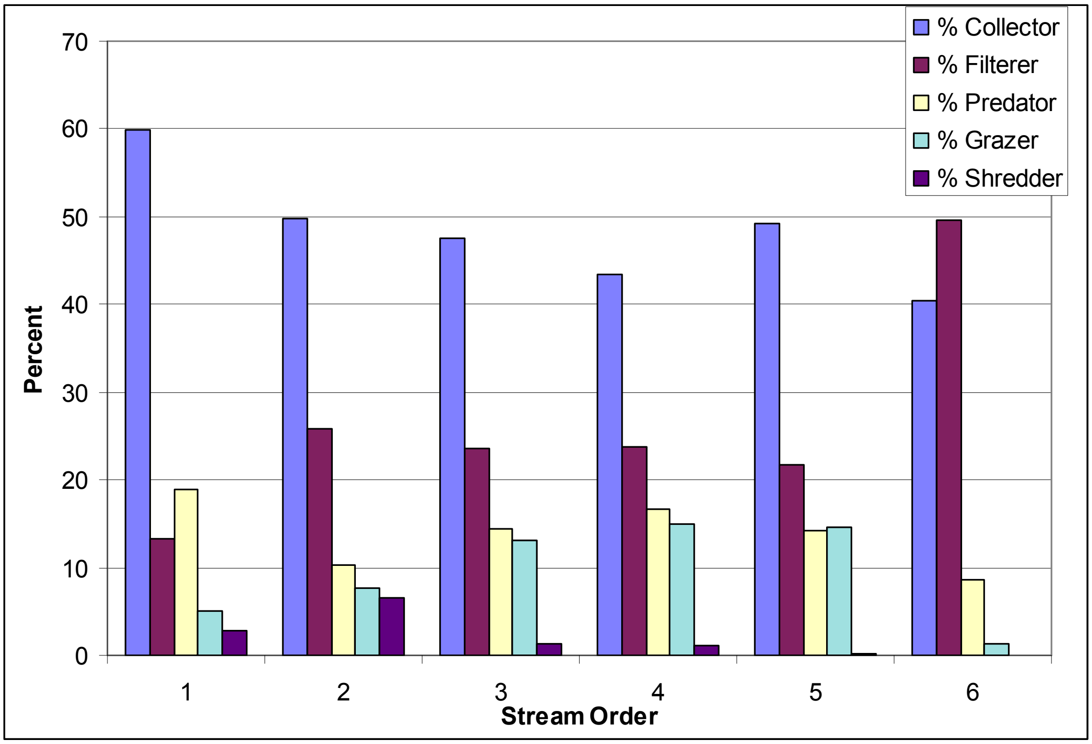


Figure 35. Percent Functional Feeding Groups in Relation to Stream Order.

Macroinvertebrate Assemblages

Benthic Macroinvertebrates (BMI) can be used to understand how human influence affects the ecological condition of streams and rivers. One method to understand the function of the BMI assemblages is to compare the sites with low human disturbance (least-disturbed sites) with the condition of the entire area. Using these reference sites as a benchmark, the BMI is evaluated by comparing sites of unknown condition against this standard. The Multi-Metric Index is used to analyze biological variables using a number of criteria, and a subset of the five best performing metrics are then combined into a single, unitless index, often called an Index of Biotic Integrity (IBI)(Karr, 1991). These final variables, or metrics, should be sensitive to stressors, represent diverse aspects of the biota and be able to discriminate between reference and stressed conditions. Multiple variables are used to provide a solid, predictable analysis of the biological condition.

BMI assemblage data were attained using the Ecological Data Application System (EDAS). This program, created by Tetra Tech, Inc manages, integrates and analyzes data, such as benthic macroinvertebrate information, through the use of Microsoft Access. The Master Taxa Table contains information about each taxon, including feeding habits, tolerance, habit and their individual Taxonomic Serial Number (TSN). Taxa information not found in the Master Taxa Table was input using Barbour et al (1999) and the Integrated Taxonomic Information System as references. For the Humboldt Basin, sixty-six metrics were calculated from the data collected at sixty-four sites, not including revisit samples. Each metric was assigned one of five classes demonstrating a separate element of biotic integrity:

- Richness- the number of different kinds of taxa
- Composition- the relative abundance of different species of taxa
- Functional Feeding Groups- primary method by which the BMI feed
- Habit- predominant BMI behavior

- Tolerance- a general tolerance to stressors, scores range from zero to 10, with higher numbers representative of organisms more tolerant to organic waste.

Reference Conditions

Setting expectations for assessing ecological condition require a reference, or benchmark, for comparison. Since pristine conditions are rare, this report uses the concept of the “Least-Disturbed Condition” as reference. This type of reference condition selects sites through numerous chemical and physical criteria verified through a GIS screening process achieving the best conditions, or least-disturbed by human activities. Since reference conditions vary among geographic regions, the Humboldt Basin utilized the criteria from Stoddard et al (2005) set for the Southern Xeric Basin and Range, which encompasses the Central Basin and Range (ecoregion 13) and the Mojave Basin and Range (ecoregion 14) (Appendix 6). For the Humboldt Basin, six least-disturbed sites (29, 70, 108, 120, 166, 280) and six most-disturbed sites (6, 11, 12, 96, 103, 245) were chosen.

Index for Biotic Integrity

To create the IBI, a number of steps were taken to choose one metric from each class with the best behavior in terms of the tests described below. Any metric that failed a test was not considered for further evaluation and not subjected to subsequent tests.

- Range: If the values of a metric are similar with little range, it is doubtful that the metric will be able to differentiate between most-disturbed and least-disturbed sites. Metrics were eliminated if more than 75% of the values were the same. In addition, richness metrics with a range less than four eliminated (Appendix 7).
- Responsiveness: Metrics were examined in response to key stressors by evaluating scatter plots of each metric versus stressor variables. F-tests, a statistically precise method to determine the ability of metrics to detect any change, were performed to test the ability of metrics to distinguish between least-disturbed and most-disturbed sites (Appendix 8).
- Redundancy: Redundant metrics do not provide additional information to the IBI. Thus, only metrics not containing redundant information were included. A correlation matrix was used to include only metrics with an r^2 value less than 0.5. Metrics with the highest F-test values were considered for inclusion first, but replaced with the next non-redundant metric of the same class as needed (Appendix 9).

Once the representative metric from each metric class had been determined, each needed to be scored using a 0 to 10 scale. Scoring is needed since metrics respond differently to disturbance and the scales differ among metrics. For example, with increased perturbation, total taxa tends to decrease while percent tolerant organisms tends to increase. For positive metrics (those whose values are highest in least-disturbed sites), ceiling and floor values were set at the 5^{th} and 95^{th} percentile (Table 15). Values less than the 5^{th} percentile were given a score of 0, while those with values greater than the 95^{th} percentile were given a score of 10. Values in between were scored linearly. Negative metrics (those whose values are highest in the most-disturbed sites) were scored similarly with the floor at the 95^{th} percentile and the ceiling at the 5^{th} percentile.

Table 15. Final Metrics and Ceiling/Floor Values[1]

	Ceiling	Floor
Tnyt2ChiPct	69.1	0.0
FiltrTax	0.5	40.9
ClngrTax	0.0	8.0
ChiroTax	5.0	2.0
TolerPct	53.0	0.1

[1] Metrics are defined in Appendix 7.

Scores were summed for each site for a total score of 50, then multiplied by 2 for a maximum IBI score of 100, with 100 signifying the best attainable condition (Appendix 10). In the Humboldt River Basin, the total scores for macroinvertebrate IBI ranged from 10 to 96 (Figure 36). The condition estimate values used for the IBI measurement are as follows: 100-70 good, 69-50 fair, and 40 -0 poor.

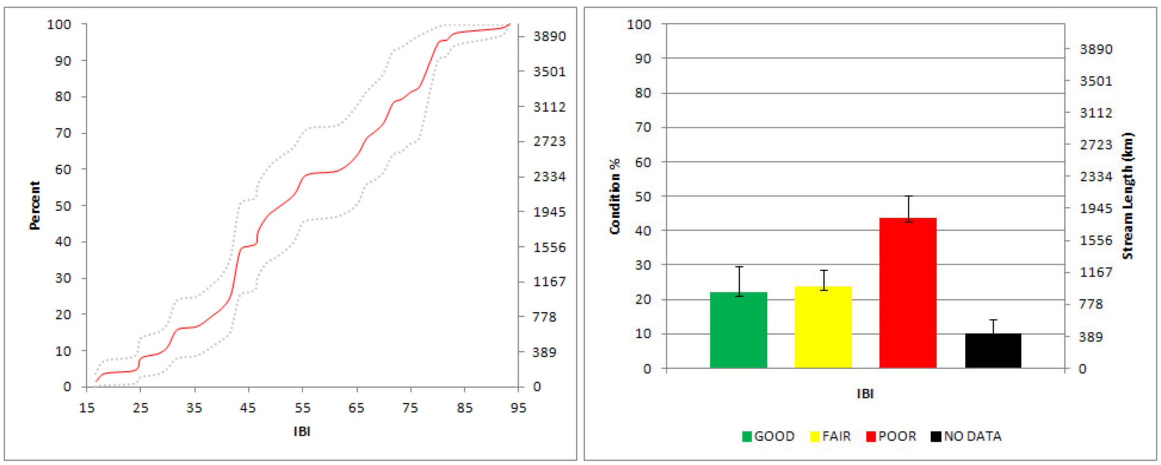


Figure 36. Cumulative Distribution Function and Condition Estimate of Macroinvertebrate IBI.

D. Sediment Respiration

Sediment respiration measures functionality of ecosystems and can be used to indicate ecosystem stress. To assess benthic microbial community activity, stream water containing a given amount of sediment were measured for changes in dissolved oxygen (DO) concentration. Using EMAP protocol, along each stream reach, the top 2 cm of soft surface sediment were collected from depositional areas of the nine cross-section transects. Any visible organisms were removed. All nine samples were combined to prepare one composite sample for each individual stream reach. Initial temperature and DO measurements were taken and recorded. The sample was then incubated for two hours in a small cooler filled with stream water, at which time the final DO concentration was determined. The sediment is frozen until it can be analyzed to determine the ash free dry mass (AFDM).

The respiration rate is the change in DO concentration per hour adjusted for AFDM. The end result is a measure of sediment respiration for AFDM (See Appendix 11 for a summary list of sediment respiration). Respiration, which is the oxidation of organic matter to CO_2, provides heterotrophs with energy for growth and is a step in the mineralization of organic matter.

Scientists have been studying the relationships between stream metabolism and other ecosystem processes as a means to measure ecosystem health. Nutrient availability can limit algal growth. Flow or stream discharge determines the amount of time available for settling. This and other physical habitat parameters, such as riparian vegetation, substrate and amount of pools, may all be important explanatory factors in evaluating and explaining respiration. Models have been developed to compare different types of stream systems, but application is limited due to factors such as extent of floodplains and flow variability.

A total of 79 samples were taken, including 9 revisited sites in 1999 (Figure 37). For this report, revisit sites were averaged. Respiration values ranged from -0.59 (site 52) to 13.43 (site 34) mg/g/h. Increased algal growth can be stimulated by elevated anthropogenic input of nutrients. The sedimentation of algal material has been found to increase benthic oxygen demand for benthic respiration production. In this stage, high respiration values would be apparent. Oxygen-depleted bottom water, thus low respiration values, is often the end result. (Hansen & Blackburn, 1992).

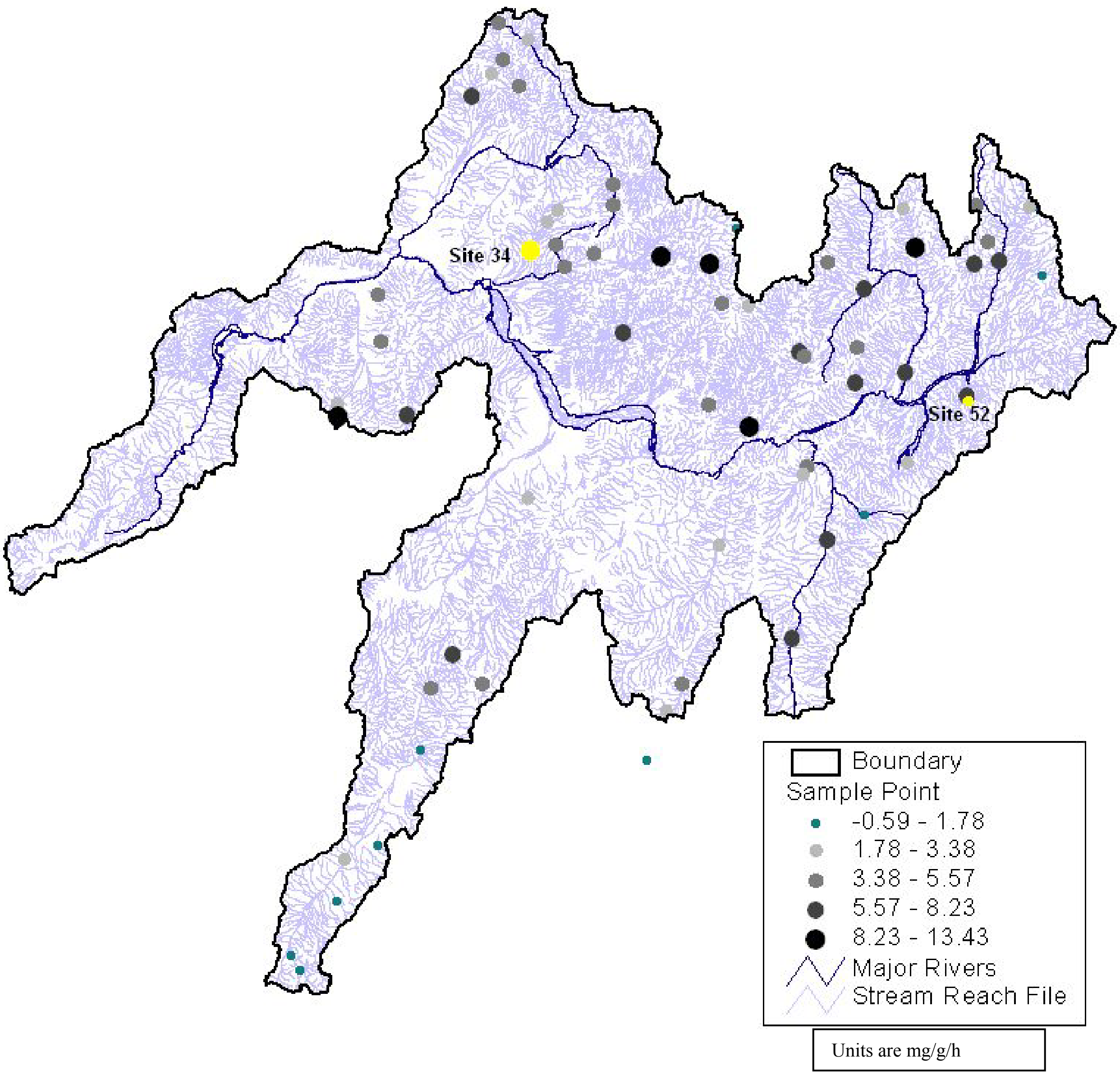


Figure 37. Map of Sediment Respiration Levels in the Humboldt Basin.

E. Metals

In 1998, the mining industry was required by the USEPA to list all toxics released that exceeded the Toxic Release Inventory reporting levels. Consequently, it was recognized that mining industries were one of the greatest producers of toxic pollutants in the country. Of the 57 facilities in USEPA Region 9 reporting toxic releases, the majority of them (63%) were in the State of Nevada. A number of sites exceeded criteria for aquatic life. Comparison of trace metal levels in the water and sediment to established USEPA criteria (Appendix 16) reveal arsenic, mercury, manganese and nickel were at levels of concern at a number of sites. A total of 68 sites were sampled at least once for water and sediment. Ten of these sites were sampled a second time for assessment of inter-annual variability.

Water

A total of 75 samples were taken for water quality pollutants at 66 sites. Three sites (6, 139, and 259) were not sampled in either 1998 or 1999. Nine sites were revisited (R) in 1999. Revisit sites were not averaged because of changes in detected levels. See Appendix 12 for summary statistics. The USEPA National Ambient Water Quality Criteria (GOLD BOOK) is used in this report as the means of determining whether a particular pollutant exceeds standards. Specifically, the three pollutant standards used in this report are the Federal drinking water standard, the Criteria Continuous Concentration (CCC), and the Critical Maximum Concentration (CMC). The CCC is designed as a benchmark by which to determine whether a particular body of water is safe for aquatic life over a chronic exposure, based on a four-day average concentration. The CMC is designed to be a maximum allowable concentration of a contaminant over a one-hour average exposure period for aquatic life. Standards have not been set for all contaminants. Available USEPA's National Recommended Water Quality Criteria – Aquatic Life Criteria (Table 16) were used for both acute and chronic effects.

Table 16. National Recommended Water Quality Criteria for Toxic Pollutants.

Chemical Name	CMC (µg/L)	CCC (µg/L)	Drinking Water Standard (µg/L)
Antimony	--	30	6
Cadmium	HD	HD	5
Chromium	HD	HD	100
Copper	HD	HD	--
Iron	--	--	300 (2^{nd})
Lead	HD	HD	15
Manganese	--	--	50 (2^{nd})
Mercury	--	0.012	2
Nickel	HD	HD	--
Selenium	--	5	50
Silver	HD	HD	100 (2^{nd})
Zinc	HD	HD	5000 (2^{nd})

*(A secondary (2^{nd}) Drinking Water Standard is not Mandatory. It is for Aesthetics or Voluntary Basis.) *HD= Hardness Dependent*

Sediment

Using these benchmarks, the data from the Humboldt Basin was analyzed and compared to the established benchmarks. See Appendix 13 for a complete list of data for each sampling point. The ten revisit sites were included, but not averaged. Aluminum and chromium concentrations in sediment did not exceed any benchmark standard. CDFs, condition estimates and discussion are given in the following section (Results for Metals in Water and Sediment).

Metal concentrations in water may not adequately reflect all toxic exposure potential, as metal concentrations may be higher in sediment than in water. Benthic macroinvertebrates and some fish may be in close contact with or ingest sediments. The metals are then released into an organism upon ingestion. For these reasons, metals concentrations in sediment are of concern in the streams of the Humboldt Basin Study. Sediment was collected at least once at 68 sampling points. Site 114 was not sampled at all. The ten revisit (R) sites in 1999 were not averaged because of changes in detection limits.

Using numeric criteria to define sediment metals toxicity can be difficult. Toxic response may be an inverse function of organic content because sorption of metals into organic substances may increase bioavailability of the metal to many organisms. There is also variability in toxic response between taxa, with some organisms exhibiting toxic response at much lower concentrations than others. For these reasons, different benchmarks were used, adapted from Jones et al. (1997). Toxicological benchmarks are used in assessing the contaminant levels of organic or inorganic substances in the sediment. Using a number of benchmarks can give stronger support for conclusions. In this paper, three benchmarks were used: the Threshold Effects Concentration (TEC), the Probable Effect Concentration (PEC) and the High No Effect Concentration (NEC).

Sediment effect concentrations (SEC) are laboratory data calculations of the toxicity of sediment samples. The amphipod *Hyalella azteca* and midge *Chironomus riparius are* used as test organisms in observing their reduction in survival or growth. The following methodologies were used to calculate the SECs: National Oceanic Atmospheric Administration (NOAA), apparent effects threshold (AET) and Florida Department of Environmental Protection (FDEP).

NOAA collects and analyzes marine and estuarine sediment samples to create effect based criteria. Concentrations connected with biological effects are then ranked. Above a specified chemical concentration, statistically significant biological effects always occur. This AET concentration is also known as the NEC. The FDEP approach calculates threshold and probable effect levels using the data set by Long et al. (1995). Each SEC was then assessed to establish whether they were able to correctly identify samples as toxic or nontoxic. A subset of the SECs for each chemical is then selected based on these results. Table 17 displays a summary list of benchmarks, which were selected according to a set of requirements, their reliability and conservatism. There is no TEC benchmark for Aluminum. If no benchmark or standard could be found local, State or Canadian criteria were applied.

Table 17. Summary of Selected Screening Level Concentration- Based Sediment Quality Benchmarks for Freshwater Sediments.

Chemical Name	TEC mg/kg	PEC mg/kg	NEC mg/kg
Aluminum	--	58030	73160
Arsenic	12.1	57	92.9
Cadmium	0.592	11.7	41.1
Chromium	56	159	312
Copper	28	77.7	54.8

Manganese	1673	1081	819
Lead	34.2	396	68.7
Nickel	39.6	38.5	37.9
Zinc	159	1532	541

Results for Metals in Water and Sediment

Hardness:

Hardness values, which can also be expressed as calcium carbonate concentration, were determined using the calculation method ([Ca, mg/L]*2.496 + [Mg, mg/L]* 4.118), as described in Standard Methods for Examination of Water and Wastewater (APHA, 1998). This method is the most accurate and is applicable to all waters. Certain metals (e.g. copper, zinc) require that hardness be taken into consideration when determining freshwater aquatic life protection criteria. Depending of the hardness value, these metals can be toxic to aquatic organisms. In general, for CCC standards, which are hardness dependent (HD), toxicity is proportional to hardness; in other words, as hardness decreases, the concentration of metal required to cause toxic effects in the aquatic community increases (Table 18). A basin-wide condition estimate was not determined for hardness because only one year was measured.

Table 18. Formulas to Calculate Specific CMC and CCC Values Based on Hardness. From: USEPA Office of Water, Office of Science and Technology (4304T) 2006 'National Recommended Water Quality Criteria'.

Chemical	m_a	b_a	m_c	b_c	CMC	CCC
Cadmium	1.0166	-3.924	0.7409	-4.719	1.136672-[(ln hardness)(0.041838)]	1.101672-[(ln hardness)(0.041838)]
Copper	0.9422	-1.700	0.8545	-1.702	0.96	0.96
Lead	1.273	-1.460	1.273	-4.705	1.46203-[(ln hardness)(0.145712)]	1.46203-[(ln hardness)(0.145712)]
Nickel	0.8460	2.255	0.8460	0.0584	0.998	0.997
Silver	1.72	-6.59	--	--	0.85	--
Zinc	0.8473	0.884	0.8473	0.884	0.978	0.986

Hardness-dependant metal's criteria may be calculated from the following:

CMC (dissolved) = $\exp\{m_a[\ln(\text{hardness})]+b_a\}(CF)$

CCC (dissolved) = $\exp\{m_c[\ln(\text{hardness})]+b_c\}(CF)$

Aluminum

Aluminum is an abundant element in the earth's crust. It is well tolerated by plants and animals. Aluminum levels in water and sediment can be used to determine stream disturbance due to mining. The USEPA's National Recommended Water Quality Criteria – Aquatic Life Criteria chronic level for aluminum in fresh water is 87 µg/l. This level was used as the condition estimate (Figure 38). The criterion for aluminum in fresh water sediment was not found so the condition estimate was not calculated. The cumulative distribution frequency for aluminum in sediment is given in Figure 38.

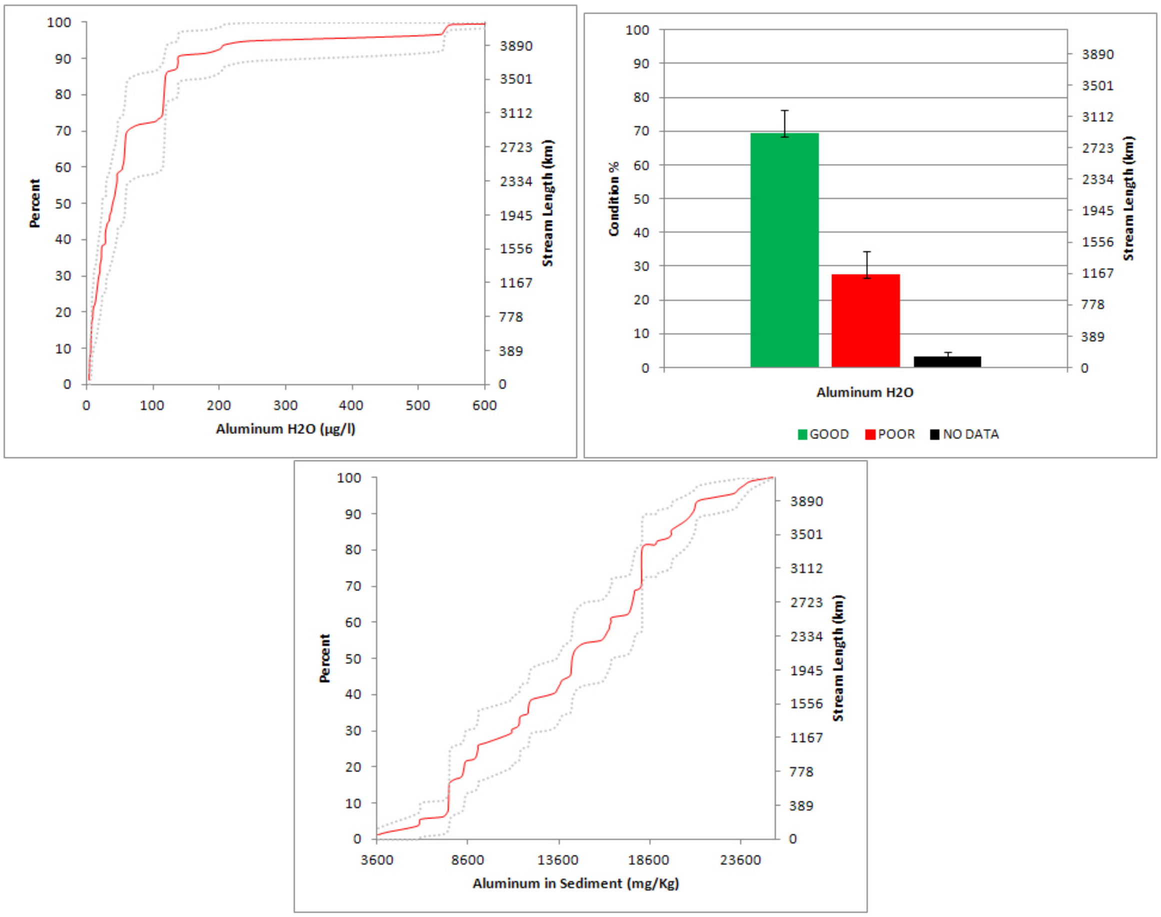


Figure 38. Cumulative Distribution Frequency and Condition Estimate of Aluminum in Stream Water and Sediment.

Arsenic:

Arsenic occurs in many minerals usually in conjunction with sulfur and metals. It is notoriously poisonous to life. Arsenic contamination of groundwater affects millions of people across the world including the western United States. It enters drinking water supplies from natural deposits or from agricultural and industrial practices. Arsenic in surface waters may be associated with mining, especially gold mining. The USEPA's National Recommended Water Quality Criteria – Aquatic Life Criteria chronic level in freshwater for arsenic is 340 µg/l for acute effects and 150 µg/l for chronic effects. The drinking water standard is 10 ppb (µg/l). Freshwater sediment standards or clean-up criteria vary. Washington State Sediment Quality Criteria for arsenic is 57 mg/Kg and Quebec, Canada has established a threshold effect level of 5.9 mg/Kg and a probable effect level of 17 mg/Kg. The condition level for this analysis is 10 µg/l in water and 10 mg/Kg in freshwater sediment. The results are shown in Figure 39.

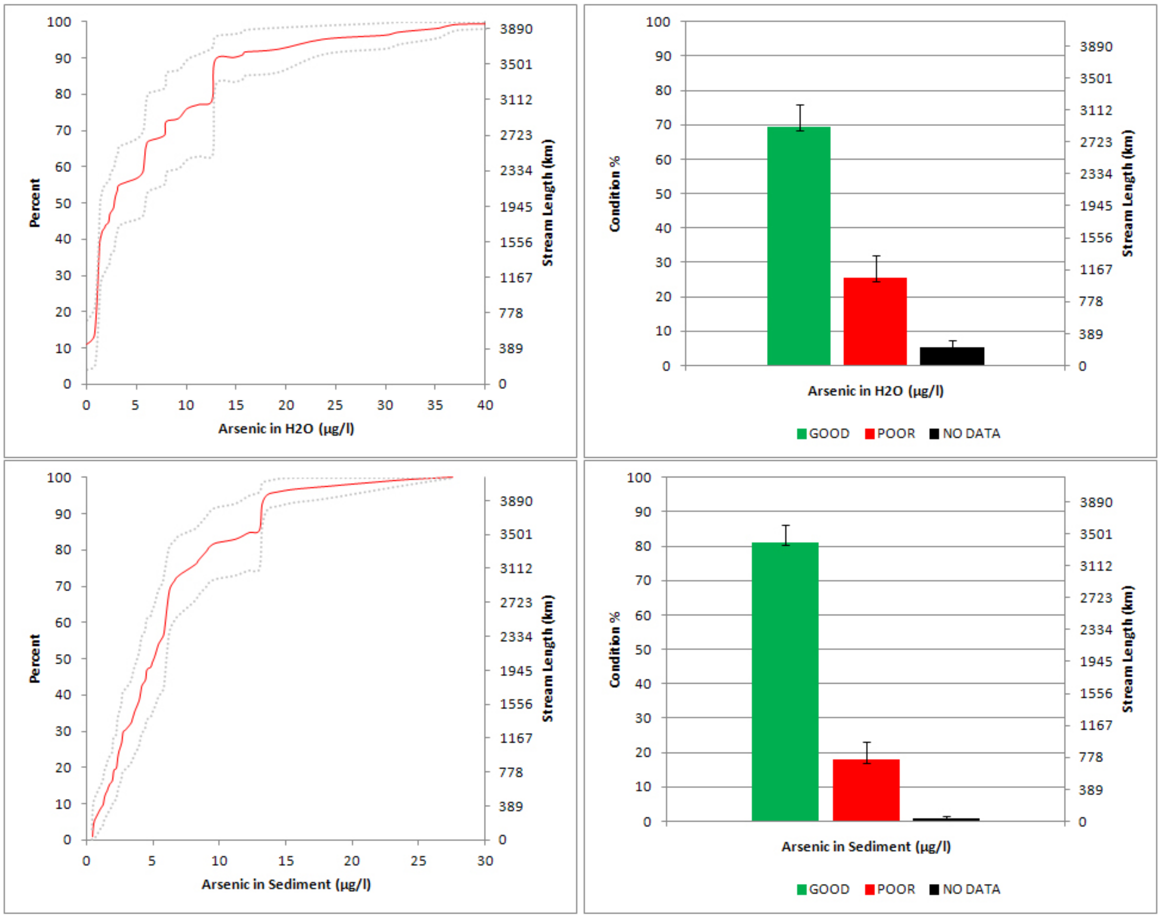


Figure 39. Cumulative Distribution Frequency and Condition Estimate of Arsenic in Stream Water and Sediment.

Antimony:

The detection limit, which is the lowest quantity available to be identified, changed between sampling years. The 1998 detection limit was 32.3 µg/L, while, in 1999, the limit was decreased to 8 µg/L due to a change in methods. With a drinking water standard of 6 µg/L we were unable to determine if most samples exceeded this. Site 133 positively exceeded the drinking water standard in 1999, with an antimony concentration of 9.1 µg/L. We were also unable to determine whether the aquatic CCC level of 30 µg/L was exceeded in 1998 for most samples. Site 82 exceeded both Aquatic CCC levels and drinking water standards for antimony, with a value of 35.9 µg/L. No samples exceeded the CCC for antimony in 1999. There is no CMC standard.

Cadmium:

National ambient water quality criteria for cadmium is dependent on calcium hardness of the water sampled. Detection limits for cadmium changed between 1998 (1.4 µg/L) and 1999 (1.0 µg/L) due to a change of laboratory methods used. Aside from site 82, all samples were below detection limits. Site 82 exhibited a cadmium level of 1.6 µg/L, which, for the calcium hardness of the sampled water (111.1 $CaCO_3$/l), was below federal aquatic life continuous criteria (Marschack, 1998). For CMC standards, 22 samples had standards below the detection limits. All sampling sites had individual CCC standards below the detection limit, thus it was not possible to determine if CCC standards were exceeded. Cadmium concentrations were well below the federal drinking standard of 5 µg/L, for all samples.

Chromium:

National ambient standards for chromium are also dependent on calcium hardness. Chromium detection limits in the analysis used were 2.1 µg/L (1998) and 1.5 µg/L (1999). No samples exceeded CCC levels for this metal. Drinking water standards (100 µg/L) for chromium were likewise not exceeded in any samples.

Copper:

Calculating standards based on hardness, no samples exceeded CCC or CMC values for copper in the Humboldt River Study. There is no drinking water standard for copper. The condition estimate was calculated in freshwater sediment as a possible indicator of mining waste contamination. The condition estimate level was set at 31.6 mg/Kg. Figure 40 shows the results of the analysis.

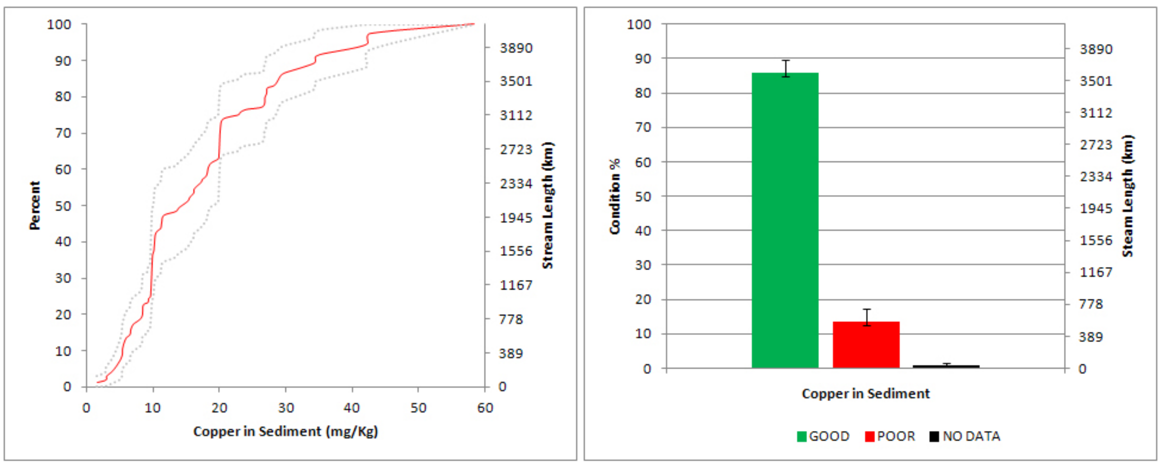


Figure 40. Cumulative Distribution Frequency and Condition Estimate of Copper in stream Water and Sediment.

Iron:

Currently, the USEPA's National Recommended Water Quality Criteria – Aquatic Life Criteria lists iron as a non priority pollutant. The condition estimate for this analysis as set at the chronic effect level of 1000 µg/l for water. No level was set for the freshwater sediment but a cumulative distribution frequency was calculated for future reference. It may be possible to associate high levels of iron with mining practices. The results of the analysis for iron are shown in Figure 41.

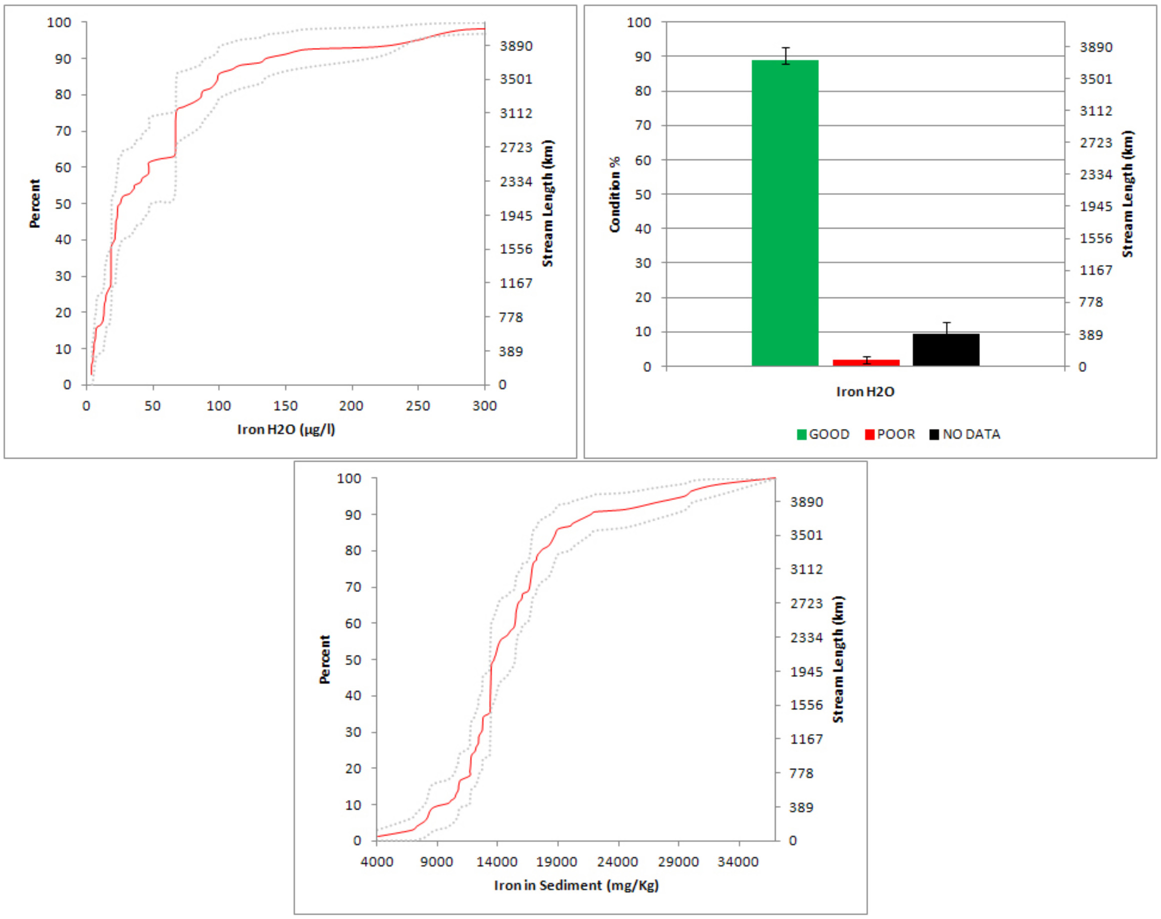


Figure 41. Cumulative Distribution Frequency and Condition Estimate of Iron in Stream Water and Sediment.

Lead:

No samples for surface waters were above the drinking water standard of 15 µg/L. Condition estimates were not done. The condition estimate level for lead in freshwater sediment was set at: good < 35 mg/Kg, fair = 31-91 mg/Kg and poor > 91 mg/Kg. Results are shown in Figure 42.

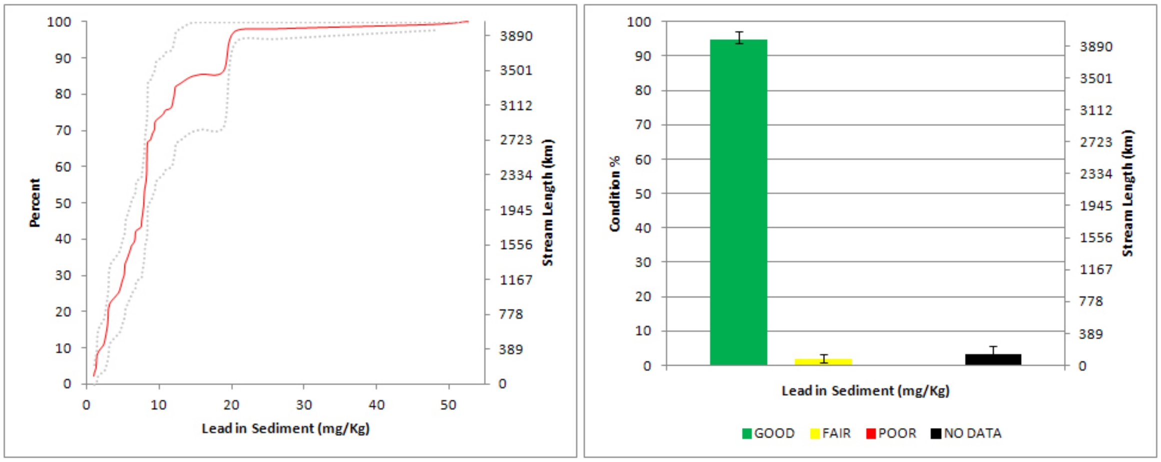


Figure 42. Cumulative Distribution Frequency and Condition Estimate of Lead in Stream Water and Sediment.

Manganese:

There is no aquatic life CCC or CMC standards for manganese. The condition estimates were determined for water and sediment for possible future associations with mining practices. The level for water was set at 4 µg/l which corresponded with a drinking water level of 0.5 mg/l. No level was set for sediment. Results are shown in Figure 43.

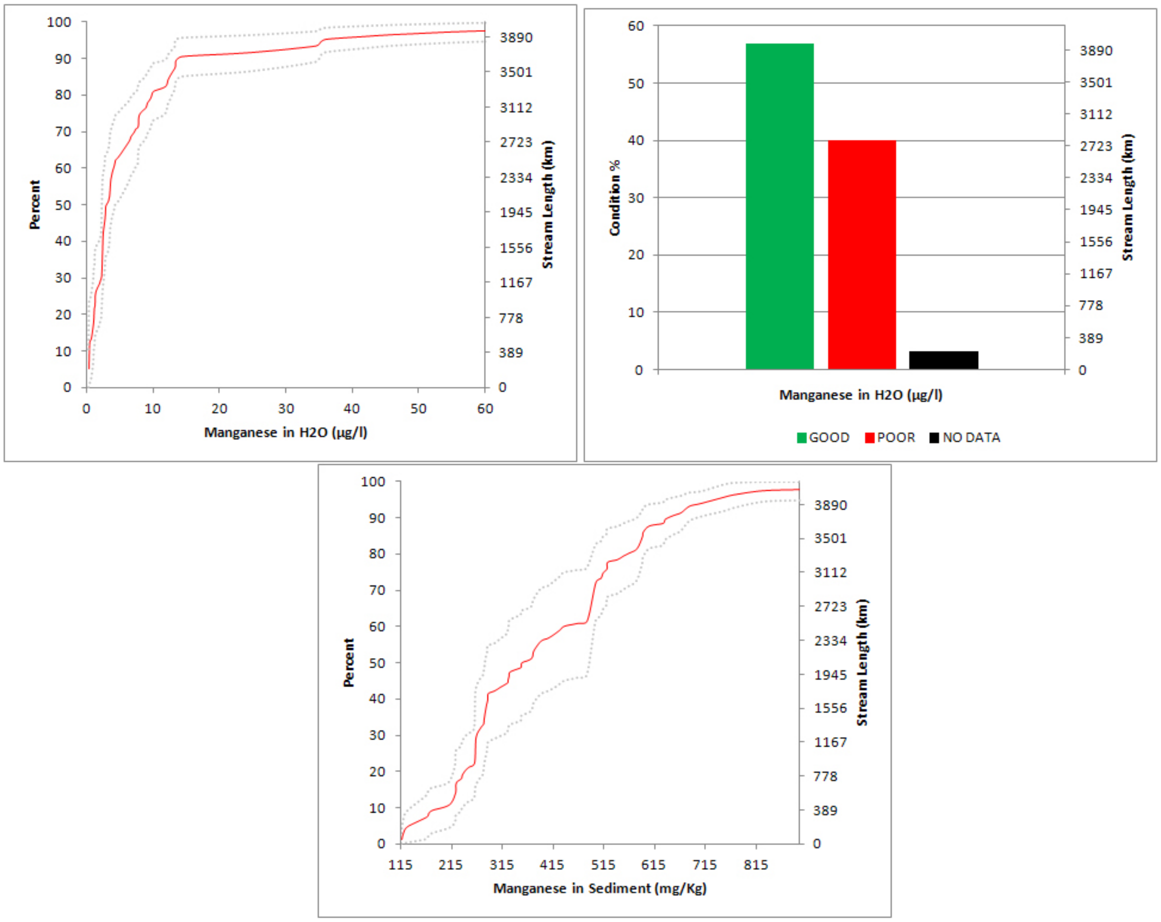


Figure 43. Cumulative Distribution Frequency and Condition Estimate of Manganese in Stream Water and Sediment.

Mercury:

In aquatic systems, mercury and other trace metals are strongly correlated with fine particulate and organic matter. Fine silt and clay particles have a disproportionate amount of surface area and adsorption sites than larger sediment particles (i.e. sand and gravel). Sediment particle size affects the transport of oxygen, minerals and ions, which affects microbial activity and the production of methyl mercury (Jones & Slotton, 1996).

Mercury samples were only collected during the 1998 sampling period. Total mercury concentrations in sediment ranged from 0.1 to 1.5 mg/kg dry weight. In water, all sites were below the 0.1 µg/L detection limit. The Lowest Effect Level (LEL), developed by Persaud et al. (1993) indicates a level of contamination, below which, the majority of benthic organisms will not be affected. The LEL for sediment is 0.2 mg/kg. In the Humboldt River Basin condition estimate (Figure 44) good was given as less than or equal to 0.17 mg/Kg, fair was between 0.17 and 0.49 mg/Kg and poor was greater than or equal to 0.49 mg/Kg.

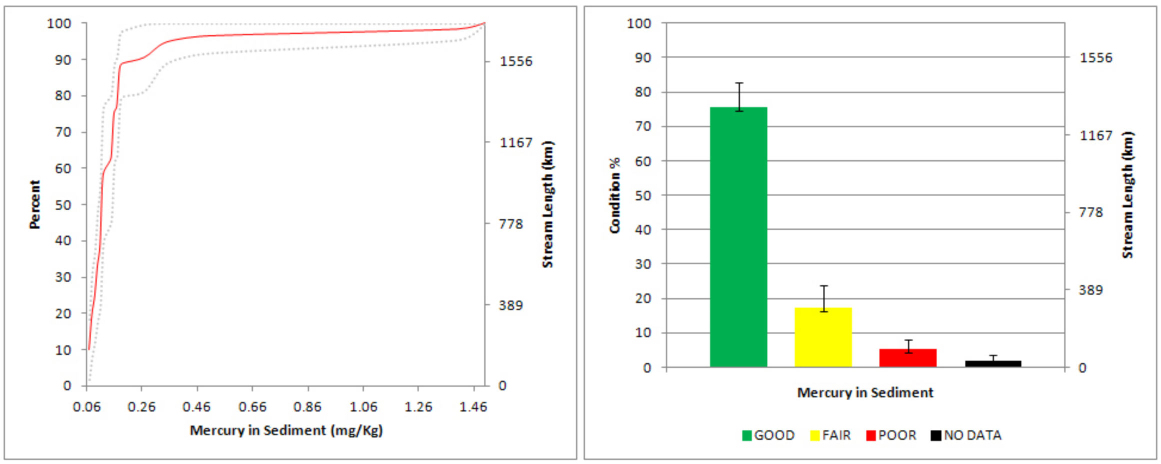


Figure 44. Cumulative Distribution Frequency and Condition Estimate of Mercury in Stream Sediment.

Nickel:

Detection limits for nickel were 15.4 µg/L in 1998, and 6 µg/L in 1999. The nickel aquatic CCC is hardness dependent. All samples were well below the lowest CMC of 52 µg/L for low hardness waters. Sites 4 (13.8 µg/L) and 120 (10.6 µg/L) had CCC levels that were below the detection limit, thus it was unable to be determined if those sites exceeded the standard. There is no drinking water standard for nickel.

Selenium:

The detection limit for selenium changed from 0.5 µg/L (1998) to 14 µg/L (1999). The drinking standard for selenium is 50 µg/L, and the CCC is 5 µg/L. No samples exceeded either the Drinking or CCC standards in 1998. In 1999, six sites (127, 164, 244, 245, 269, 87R) positively exceeded the aquatic life CCC of 5µg/L. The other samples are unreportable/unknown in relation to CCC standards, due to the detection limit being higher than the CCC. There is no CMC standard for selenium.

Silver:

Although no CCC for silver has been established, the CMC standard for this silver is hardness dependent. The detection limits used in the silver analysis were 3 µg/L in 1998 and 0.8 µg/L in 1999. Seven samples from 1999 had detection limits that were above CMC values for silver. Due to the detection limit for silver in 1998, 17 samples have values which are at or below 3 µg/L. These samples are unreportable/unknown in terms of silver concentration relative to CMC values. No samples exceeded the drinking water standard of 100 µg/L.

Zinc:

The CCC for zinc is hardness dependent, and detection limits for this metal were 1.2 µg/L in 1998, and 1.0 µg/l in 1999. The USEPA's National Recommended Water Quality Criteria – Aquatic Life Criteria for zinc in freshwater is 120 µg/l for both acute and chronic effects. The condition estimate levels for this analysis is 120 µg/l for water and sediment. Good being below 120 mg/Kg, fair is between 120 mg/Kg and 310 mg/Kg and over 310 mg/Kg as being poor. Results for this condition estimate for zinc in the Basin are shown in Figure 45.

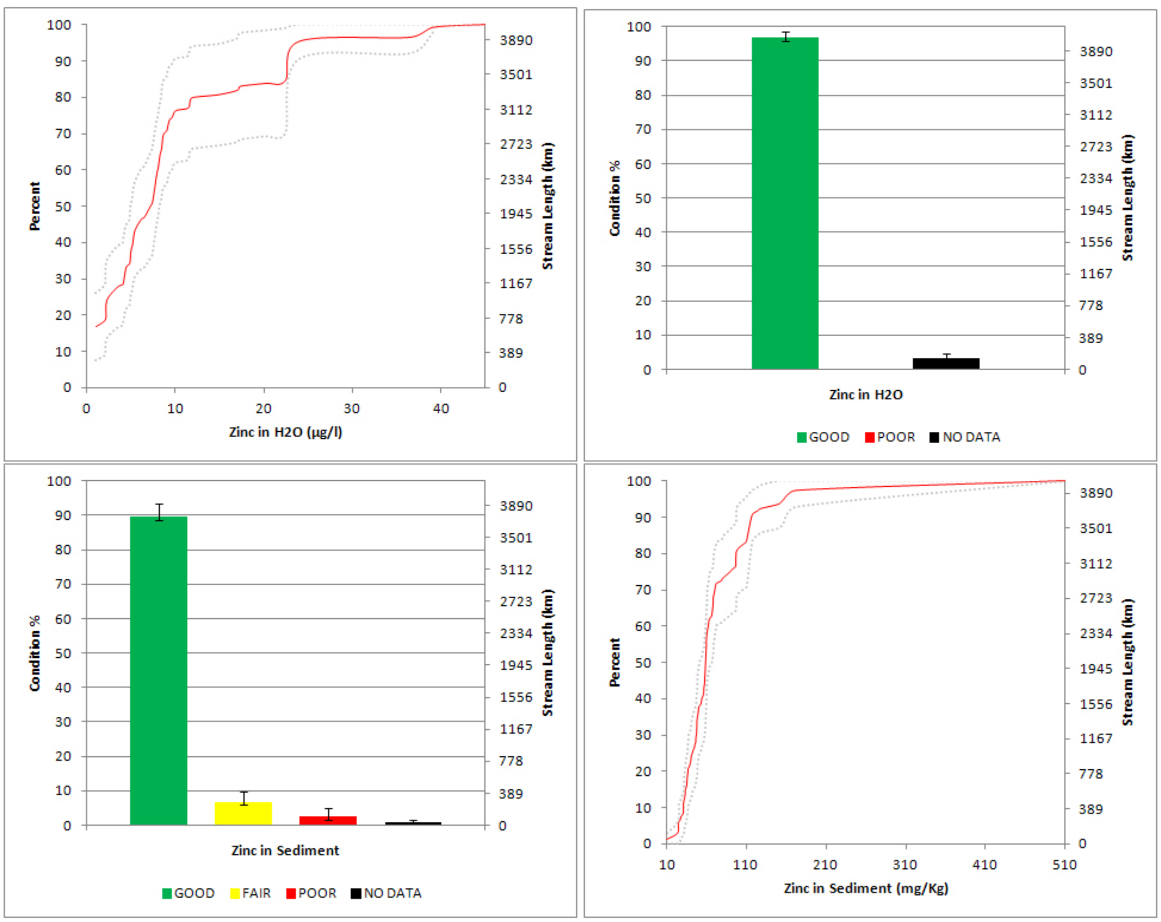


Figure 45. Cumulative Distribution Frequency and Condition Estimate of Zinc in Stream Water and Sediment.

F. Relationships Between Indicators and Stressors

The second objective of this report was to examine the relationship between indicators of ecological condition and indicators of ecological stressors in these streams.

To examine indicator/stressor relationships simple correlations tests (Pearson product-moment, $P<0.05$ significance level) were run on all combinations of indicators (Table 19). Both water chemistry and physical habitat variables can be stressors as well as indicators of stress, depending on the relationship. Although correlations do not imply cause/effect relationships they can provide insight into the ecological processes that may be at work. Significant correlations are termed weak, moderate, or strong where $r<0.50$, $0.50<r<0.75$, and $r>0.75$, respectively.

Table 19. Possible Combinations of Stressors and Indicator Relationships.

	Stressors		
Indicator	**Water Chemistry**	**Physical Habitat**	**Riparian Disturbance**
Benthic Inverts.	X	X	X
Water Chemistry	--	X	X
Physical Habitat	--	--	X
Sediment Respiration	X	X	X

Many significant correlations between indicators and stressors were detected yet many were weak (Appendix 14). The following statements summarize the outcome of correlations between indicators and stressors:

- Benthic invertebrate indicators had only two moderately negative significant correlations. These were between EPT taxa and total dissolved solids (Figure 46) and between EPT txa and absent vegetation in the canopy. All other correlations were weak. Macroinvertebrate IBI assemblages had many weak correlations to stressors. There were two moderate correlations, % fine (Figure 47) and % fast.

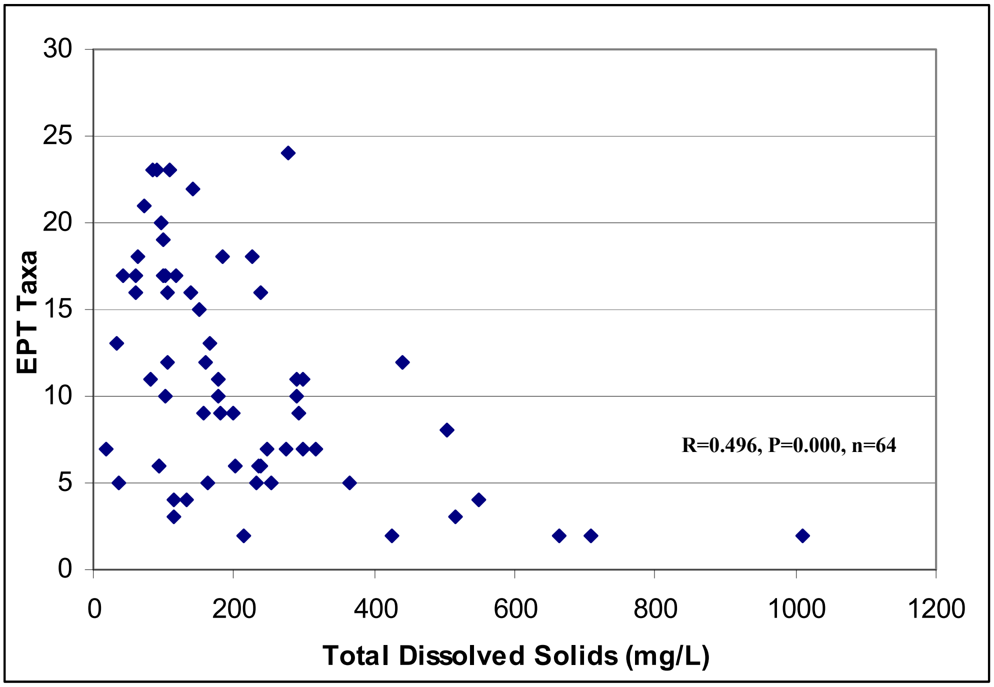


Figure 46. Relationship between Total Dissolved Solids and EPT Taxa.

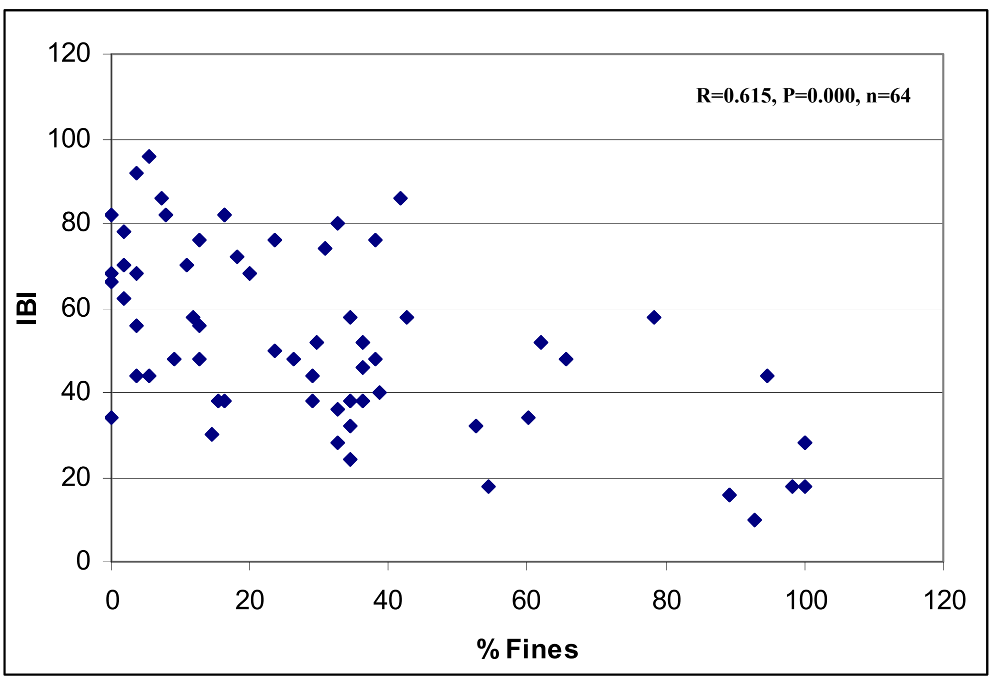


Figure 47. Relationship between Percent Fines and Macroinvertebrate IBI.

- There were five moderately significant correlations for water chemistry indicators. Only one of the moderate correlations existed between total suspended solids and the proximity to building. All other correlations were weak. Many of those were negative correlations between fish cover and several water chemistry indicators.
- All correlations between physical habitat indicators and riparian disturbances were weak. Most of them were negatively correlated to the proximity to pastures. Only percent fine gravel had a positive correlation to the proximity to pastures.
- All correlations for sediment respiration were weak. Only two correlations existed to water chemistry indicators (pH, Temperature) and none existed to riparian disturbances (Figure 48). Physical habitat stressors included mean canopy density, fish cover, and riparian vegetation.

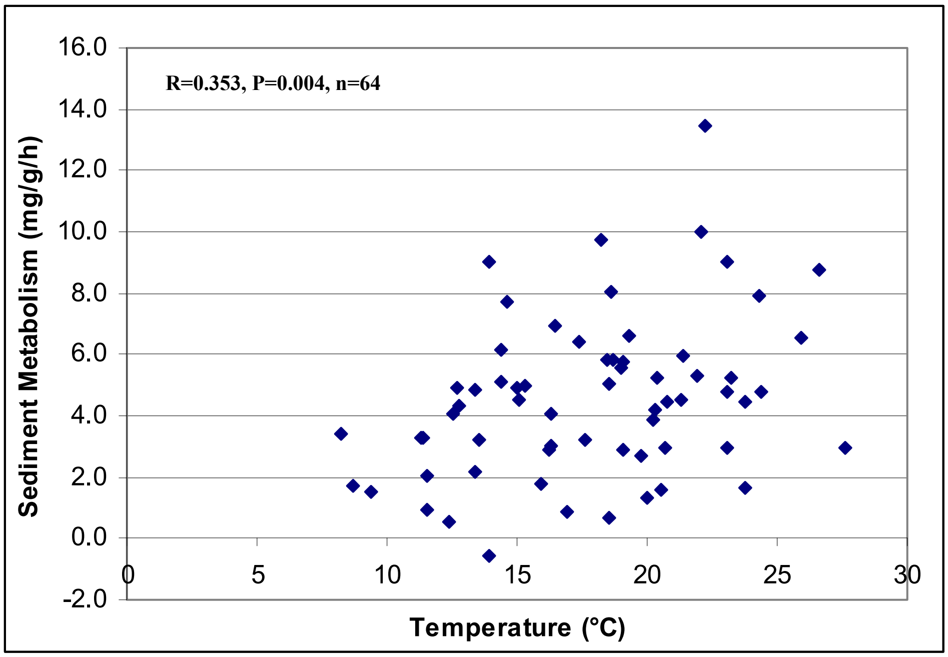


Figure 48. Relationship between Temperature and Sediment Metabolism.

G. Thresholds

Understanding the importance and magnitude of stressors is essential for policy and decision making. In this report, the relative importance of each stressor is defined by comparing the extent of each stressor, expressed in km of stream, to other stressors. To characterize the magnitude of effect, the degree to which each stressor has on biotic integrity, was examined.

Thresholds for condition classes were based on the distribution of sampled values from least-disturbed reference sites. If higher values denoted an improved condition, then scores lower than the fifth percentile were considered in most-disturbed condition. Scores between the fifth the twenty-fifth percentile were considered in intermediate condition, and scores greater than the twenty-fifth percentile were classified as in least-disturbed condition. If the inverse were true, then the least-disturbed, intermediate and most-disturbed classes were set by the seventy-fifth and ninety-fifth percentile (Table 20).

Table 20. Thresholds for Indicators in the Humboldt River Basin.

Indicator	Most-disturbed		Least-disturbed	
	Threshold	%	Threshold	%
Macroinvertebrate IBI	<58	5th	≥73	25th
Sulfate (mg/L)	>23.88	95th	≤6.25	75th
Total Suspended Solids (mg/L)	>27.90	95th	≤18.70	75th
Total Phosphorus (mg/L)	>0.063	95th	≤0.040	75th
Total Nitrogen (mg/L)	>0.478	95th	≤0.388	75th
Conductivity (uS/cm)	>327.25	95th	≤131.50	75th
Residual Pool Area (RP100)	<0.09	5th	≥1.12	25th
% Fast (PCT_FAST)	>87.58	95th	≤58.43	75th
% Slow (PCT_SLOW)	<12.42	5th	≥41.57	25th
Canopoy+Mid+Ground Woody Cover (XCMGW)	<0.22	5th	≥0.42	25th
Mean Mid-Channel Canopy Density (XCDENMID)	<2.87	5th	≥12.10	25th
Fish Cover Area Covered by Natural Objects (XFC_NAT)	<0.72	5th	≥0.79	25th
All Riparian Disturbances	>1.48	95th	≤0.71	75th
Riparian Disturbance from Pastures	>1.17	95th	≤0.62	75th
% Fine	>53.32	95th	≤15.00	75th
% Sand & Fine	>56.50	95th	≤28.18	75th
Mean Mid-Channel Embeddedness (XCEMBED)	>73.62	95th	≤65.50	75th
Streambed Stability (NOR)	<-1.28 or >0.91	5th/95th	≥0.39 & ≤ 0.58	25th/75th

Understanding the relative magnitude or importance of potential stressors is important to making policy decisions. The extent of each stressor in comparison to other stressors (i.e., relative extent) is one aspect to consider in defining the importance of each potential stressor. Another aspect to consider is the severity that each stressor has on biotic integrity relative to other stressors (i.e., relative risk). Each aspect provides important input to policy decisions.

Relative Extent

The total length of the RF3 stream network in Humboldt River Basin is 39,463.2 km. Eighty-six percent of this total was considered non-target, i.e., irrigation canals, pipelines, dry streams. The remaining target stream length (5637.4 km) represents the portion of the sampling frame that meets the criteria for inclusion in the assessment. A stressor's extent is estimated by calculating the proportion of the streams in most or least disturbed condition compared to all stream lengths.

Results of water chemistry indicator metrics varied from 36% (Total Phosphorus) to 71% (Sulfate) for the stream extent in most-disturbed condition. Total Nitrogen had the largest percentage of stream length in least-disturbed condition (57%) (Figure 49). Macroinvertebrate IBI had >50% of the stream length in the most-disturbed condition category.

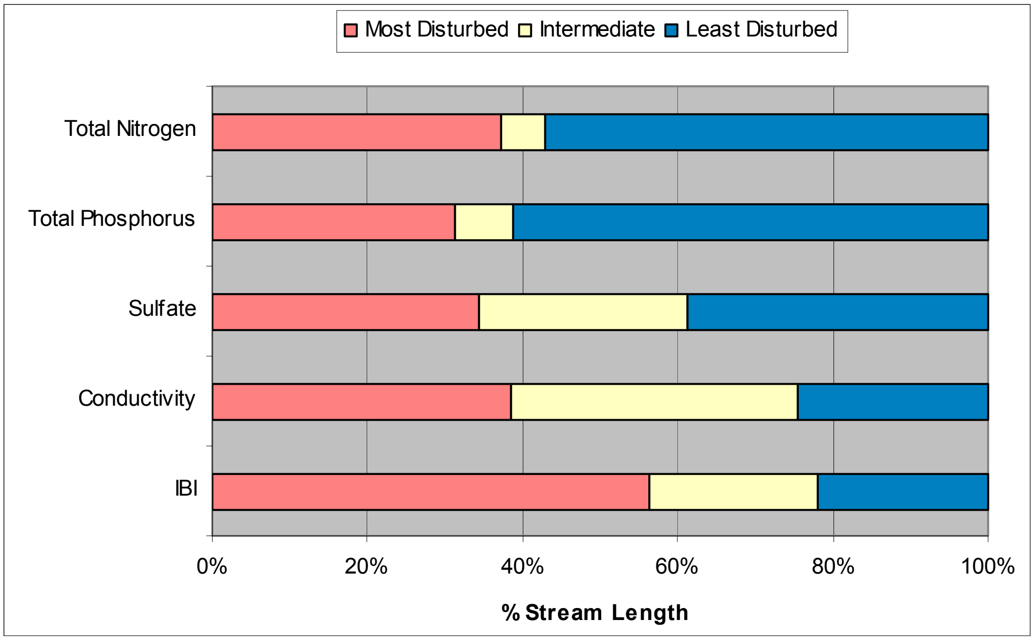


Figure 49. Extent of Stream Length in Most-Disturbed, Intermediate and Least-Disturbed Condition for Selected Water Quality Indicators and Macroinvertebrate IBI.

The relative extents of physical habitat condition stressors were variable (Figure 50). Riparian disturbance stressors were substantial in many streams resulting in >70% of the stream length in most disturbed condition. The extents of riparian vegetation and mid-channel canopy density had evenly distributed condition classes with the largest class in the least-disturbed category. Most stream length assessed for fish cover (78%) was in most-disturbed condition. Channel complexity stressor metrics were fairly consistent with each other with most stream lengths in least-disturbed condition (>70%).

**Sulfate and Total Nitrogen were only Sampled in the 1998 Sampling Period.*

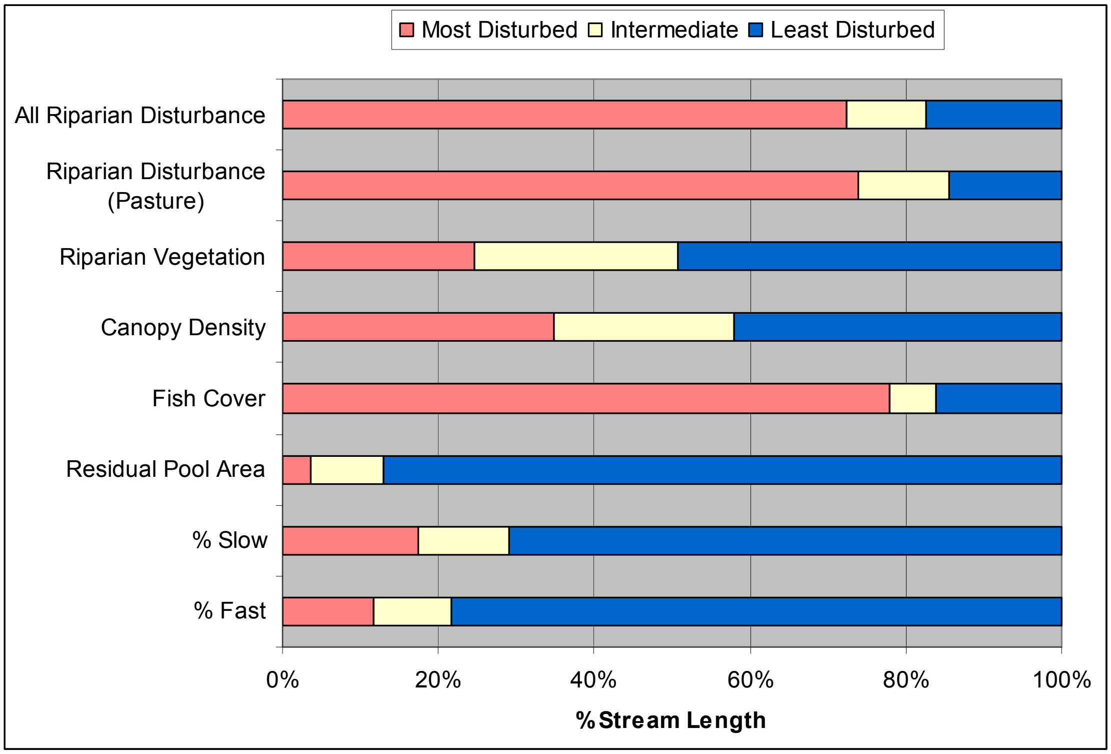


Figure 50. Extent of Stream Length in Most-Disturbed, Intermediate and Least-Disturbed Condition for Selected Physical Habitat Indicators.

Sediment stressor metrics yielded varied results, with the relative extents of stream length in most-disturbed condition ranging from 9 % to 54% (Figure 51). Streambed stability had the majority of extents classified in intermediate condition. Inclusion of the sand fraction of the substrate rather than fines alone resulted in a slightly greater amount of stream length in most-disturbed category (25% versus 19% for fine-sized alone). Figure 52 summarizes all relative extent stressors.

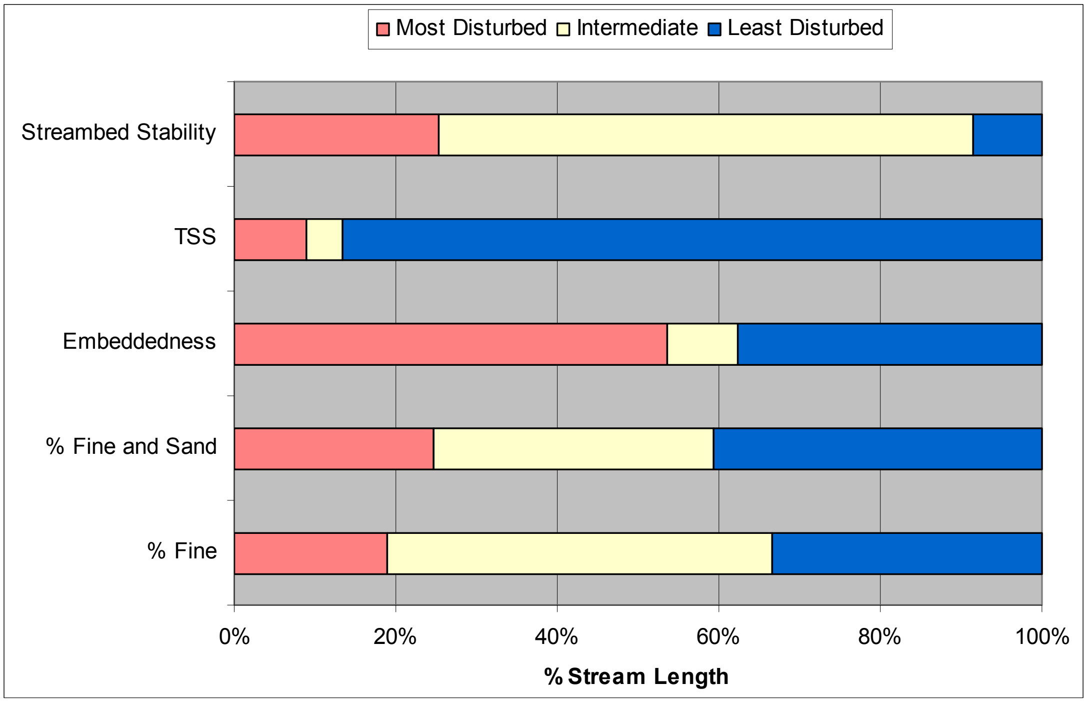


Figure 51. Extent of Stream Length in Most-Disturbed, Intermediate and Least-disturbed condition for Sediment Indicators.

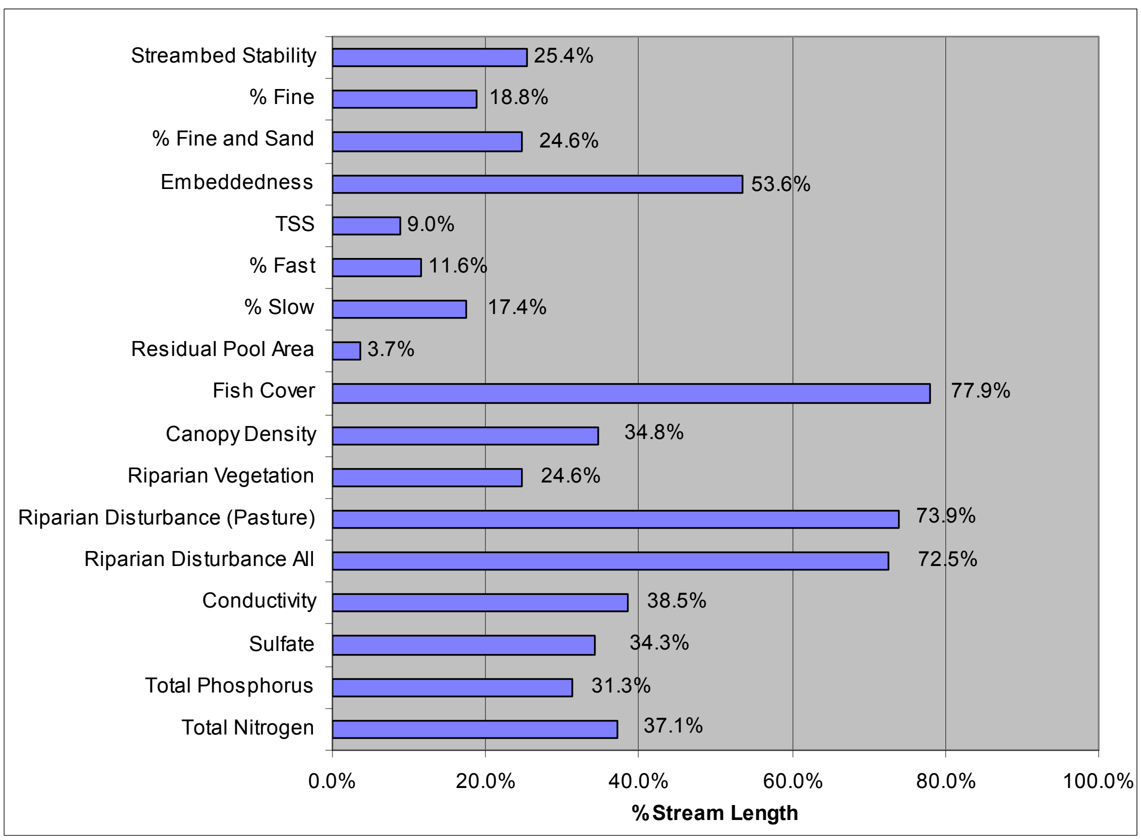


Figure 52. Summary Relative Extent of Stressors (Proportion of Stream Length with Stressors in Most-Disturbed Condition).

Relative Risk

Relative risk, a ratio of two probabilities, assesses the association between stressors and biological indicators. For this report, the two probabilities, or risks, measure the likelihood that a most-disturbed condition of a biological indicator will also occur in a stream with a most-disturbed condition of a particular stressor metric. A risk value of 1.0 or less indicates no association, while values greater than 1.0 represent a relative risk.

$$\text{Relative Risk} = \frac{\text{Risk of poor biological condition, given poor stressor condition}}{\text{Risk of poor biological condition, given good stressor condition}}$$

Stream weights, which are assigned to each stream based on their occurrence of stream order in the reach file, are utilized in probability-based studies to statistically represent the target population. Although using these weights to determine extent is the preferable method to calculate relative risk to present a more accurate assessment, in the Humboldt River Basin, weight data was incomplete. For this study, the calculations are made using the number of sampling sites for the various combinations between biological indicator and stressor conditions. Intermediate conditions were excluded to ensure there was no overlap in conditions classes. The following table is an example of how the data can be arranged and calculated.

Table 21. Relative Risk Analysis.

Number of Sampling Sites		All Riparian Disturbances	
		Least-disturbed	**Most-disturbed**
IBI	**Least-disturbed**	**A: 7**	**C: 15**
	Most-disturbed	**B: 3**	**D: 23**
	Total	**A+B: 10**	**C+D: 38**

The risk of finding a most-disturbed condition for benthic macroinvertebrates in streams that have most-disturbed condition for all riparian disturbances is estimated as:

= D/(C+D)   23/38=0.61

The risk of finding a most-disturbed condition of benthic macroinvertebrates in streams that have a least disturbed condition for riparian disturbance is estimated as:

= B/(A+B) 3/10=0.30

Comparing these two probabilities (0.61/0.30) yields a relative risk of 2.02. In other words, it is 2.02 times more likely to find a most-disturbed condition for benthic macroinvertebrates in streams where riparian disturbance condition is most-disturbed.

Before calculating relative risk, product-moment correlations were calculated between each stressor pair to test for collinearity. If stressors are highly correlated, relative risk assessments may be confounded. Relative risks with a value at or below 1.0 are not considered significant. Variables percent fast, riparian disturbances (pasture), percent fine, percent sand/fine and conductivity were eliminated due to multiple correlations.

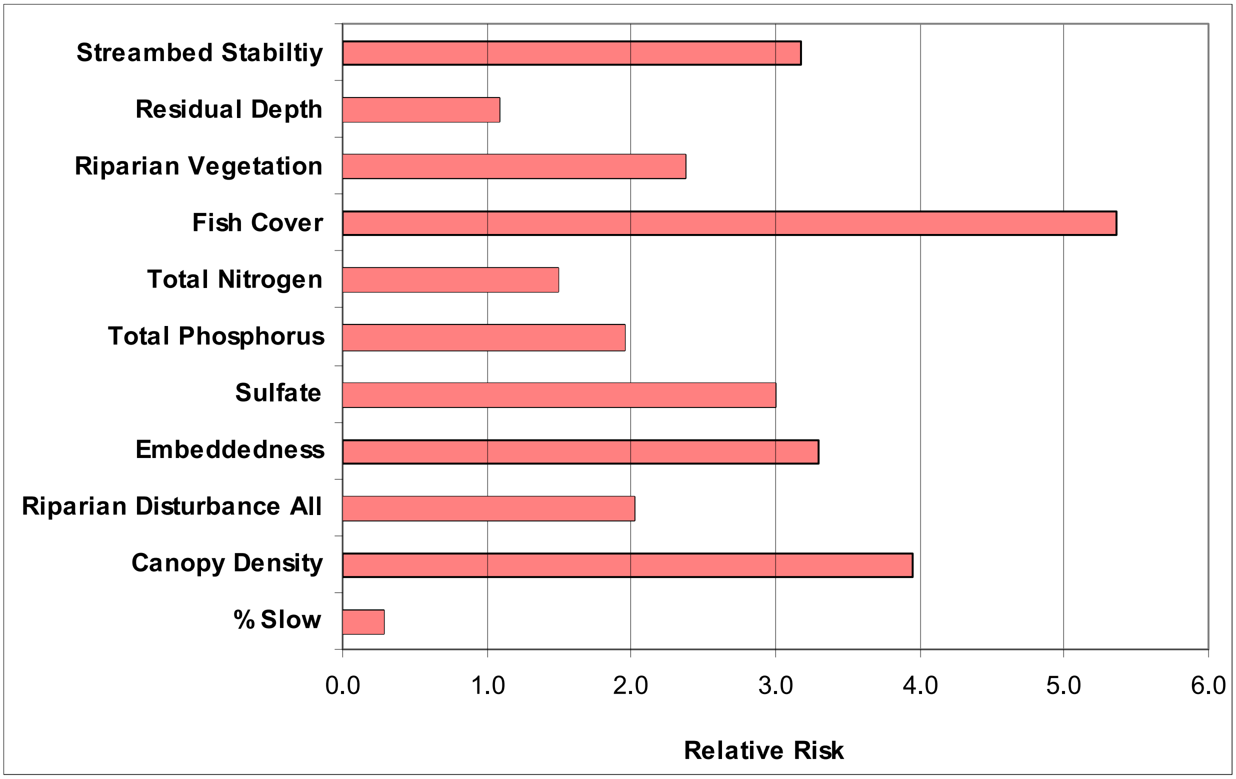


Figure 53. Risk to Benthic Assemblage (IBI) Relative to the Environmental Stressor Condition.

Relative risk assesses the significance of the effects of stressors to stream biota**.** Using multiple species assemblages is preferred as a biological indicator because a stressor that may be very relevant to one assemblage may have less of a signal for another. Yet, for this evaluation, only one biotic assemblage, benthic macroinvertebrate IBI, was used to determine risk to biota. Seventeen stressors were originally used to analyze extent, but only eleven were useable for relative risk estimation due to methods restrictions. Two stressors, percent slow and residual depth had relative risk values and/or confidence intervals significantly less than 1.0 (Figure 53). Fish cover had the highest relative risk value of 5.4. For a complete list of relative risk calculations and results, see Appendix 15.

Combining Extent and Relative Risk

The most comprehensive assessment of the effect of stressors on ecological condition comes from combining the relative extent and relative risk results. Stressors that pose the greatest risk to individual biotic indicators will be those that are both common and whose effects are potentially severe. Viewing the relative risk in relation to the extent of indicators across the stream length assessed, it was found that some indicators with a relative risk greater than one were not found to be widely occurring problems. For example, riparian vegetation was in most-disturbed condition in only an estimated 25% of the stream length, but where this condition occurs the biota is at risk of being in a most-disturbed condition. However, some stressors are both broadly occurring (i.e., high relative extent) and have high relative risk (Figure 54). Primary stressors in terms of both extent and risk to biota are fish cover, riparian disturbance, and embeddedness.

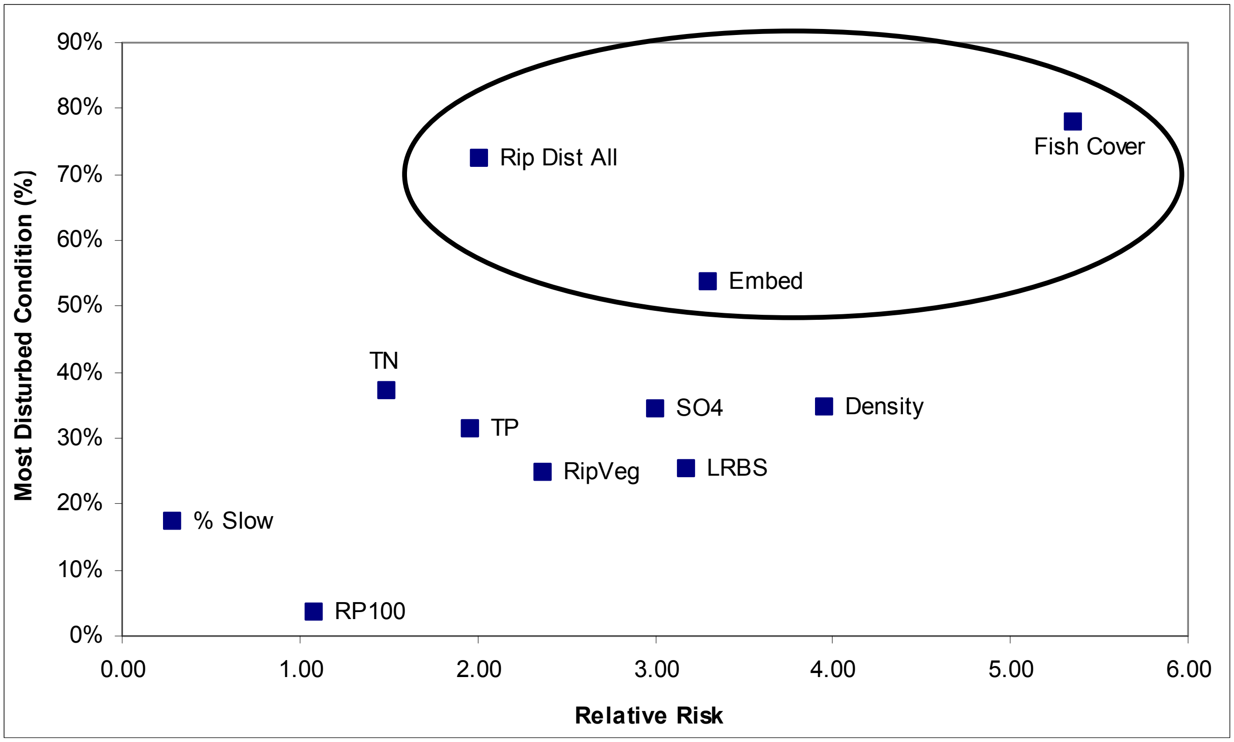


Figure 54. Summary of Extent of Stressors in Most-Disturbed Condition in Relation to Relative Risk*.

V. Conclusion

Physically, ecosystems are always in motion reacting to natural climatic and anthropogenic conditions. These changes, in environmental condition, affect the chemical and biological community structure, which cause further alterations to the environment. Data from this study indicates that the status of many of the streams in the Humboldt River Basin are in less than desirable condition. The percentage of impacted streams varied, with 38% of stream reaches studied in the Humboldt River Basin being in most-disturbed condition. The quality of a stream and wetland riparian ecosystem is directly related to the condition of adjacent uplands. Studies since have shown that improved knowledge of aquatic and upland interactions, at local to watershed scales, is essential in evaluating and designing land management alternatives for stream and wetland resources. Nevada's arid environment, coupled with the fact that much of the biodiversity in this state is associated with riparian or aquatic habitats, makes the management of these systems a matter of particular importance. The baseline data obtained in this study will be of considerable use to local, state, federal and tribal agencies concerned with the future of surface water resources in Nevada. Considerable progress, as a nation, has been made in managing our watersheds. However, much remains to be learned, and studies such as this one play an integral role in helping us meet the Clean Water Act's goal of maintaining the biological and chemical integrity of the nation's waters.

It was beyond the scope of this study to evaluate each stream reach in relation to its own potential and the attributes and processes relevant to that location in the watershed. However, to address the aquatic impacts from environmental stressors it is important to understand the drivers of ecosystem function, and recognize the fundamental changes to the water cycle, water quality, aquatic and terrestrial ecology and stream form and function. By identifying the condition of a watershed and/or ecoregion (i.e., the degree to which interacting stream reaches and wetland riparian areas are functioning properly) and their potential, managers can make the connection between form, function, management and monitoring. Thus they can address the underlying causative factors behind restoration of biological values and ecosystems. A possible next step for ecological condition analysis could be a landscape ecology approach which focuses on the physical processes, spatial arrangements, and connections to ecosystem functions within the watershed. To ecologists and environmental scientists, a landscape is more than a vista, but comprises the features of the physical environment and their influence on environmental resources. Landscape ecology integrates biophysical approaches with human perspectives and activities to study spatial patterns at the landscape level, as well as the functioning of the region. There are many applications of this approach. For example, areas most disturbed by anthropogenic sources can be identified by combining information on population density, roads and land cover with systematic assessments of riparian functionality. Vulnerability of areas can also be identified by looking at the surrounding conditions. Potential erosion control issues can be evaluated as well by considering variables such as precipitation, soils, vegetation, and the steepness of slopes. Ecological processes connect the physical features of the landscape linking seemingly separate watersheds.

[*] The oval emphasizes stressor indicators with both high percent of stream length in most-disturbed condition and with high relative risk. Refer to Appendix 15 for definition of abbreviated indicator names in this figure.

Riparian function is heavily influenced by the condition of adjacent and upland ecosystems. An ecosystem, or landscape, approach will provide a comprehensive basis for identifying and evaluating current and historic land use practices. Riparian proper functioning condition (PFC) assessments, in conjunction with remote sensing, can be used as tools to assist and connect local and regional assessments. Future studies can use remote sensing and geospatial technology in innovative ways to provide needed information on the status and condition of constructed and natural wetland areas. Riparian vegetation is one of the primary ecological attributes affected by human land uses (i.e., grazing, urbanization), and indicates succession to quantify functionality trends. Analyzing spatial relationships and short- and long-term trends determine if goals and objectives are being met. Improved functionality leads toward attainment of water quality standards and many additional environmental services, values, and products, by determining what changes are needed to move the riparian ecosystem towards the desired conditions and helps develop and compare management alternatives. PFC should be considered when making management decisions in the Humboldt River Basin to provide for a more sustainable ecosystem.

VI. References

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VII. Appendecies

Appendix 1. List of Sites.

Site	Stream Order	Stream Name	Longitude	Latitude
3	5	Middle Reese River	-117.34889	39.17194
4	4	Upper Reese River	-117.47056	38.85000
5	1	Brewer Canyon	-117.23139	39.23861
6	3	Reese River	-117.14417	39.55667
7	3	Millinex	-117.53889	41.56139
11	3	Evans Creek (lower)	-117.00389	41.11083
12	2	Evans Creek (upper)	-116.90056	41.16778
14	2	Boulder Creek	-116.33722	41.10361
15	6	Rock Creek (lower)	-116.70874	40.95036
22	3	Thomas Creek	-117.73333	40.89861
25	2	Elbow Canyon	-117.67833	40.75639
29	4	Oregon	-116.86389	41.32983
34	4	Kelly Creek	-117.15722	41.13611
35	3	Spaulding	-117.79667	40.53972
37	2	Panther	-117.50361	40.55667
49	4	Hank's Creek	-115.34139	41.38556
52	3	Boulder Creek	-115.24528	40.97417
53	3	Dorsey Creek	-115.74972	41.05806
55	6	North Fork Humboldt	-115.53083	41.01278
66	4	Smith Creek	-115.70250	40.46056
69	4	Dixie Creek	-115.85028	40.66750
70	3	Long Canyon Creek	-115.52361	40.55722
71	2	Talbot	-115.44750	40.73861
82	5	Maggie Creek	-116.11500	40.75028
87	3	Blue Basin Creek	-115.97861	41.00750
92	2	Trout Creek	-116.94639	40.38472
96	4	Reese River	-117.16111	38.74917
101	2	Robert's Mountains	-116.23806	39.67500
103	3	Huntington Creek	-115.76139	40.14000
108	2	Chimney Creek	-115.38556	41.56417
109	2	Hot Creek	-115.14278	41.59889
114	3	Gance Creek	-115.94056	41.29917
116	4	Willow Creek	-116.41806	41.21750
118	4	Martin	-117.44722	41.69472
120	2	Buckskin	-117.50083	41.80250
127	2	Welsh Canyon	-116.29778	40.79028
129	3	Beaver Creek	-116.22528	41.11194

Appendix 1. List of Sites (cont.).

Site	Stream Order	Stream Name	Longitute	Latitude
130	3	Marysville Creek	-117.34278	39.04167
133	4	Little Humboldt River	-116.88611	41.39278
134	3	Boulder Creek	-115.25972	40.98333
139	3	Red Hills (dry)	-117.21389	41.62778
140	3	Hot Creek	-115.16639	41.59000
158	4	South Fork	-115.57556	40.55944
161	2	Round Corral Creek	-117.48250	41.64194
164	4	Willow Creek	-116.62500	41.20694
166	2	Iowa Canyon	-116.96250	39.79833
170	1	Rock Creek	-116.34083	41.34250
176	4	Pine Creek	-116.13528	40.37111
181	2	Table Mountain (dry)	-117.78028	40.50167
183	4	Jake Creek	-117.06167	41.17028
184	5	Mary's River	-115.24222	41.41278
190	3	Upper Beaver Creek	-115.68278	41.50528
193	4	Kelly Creek	-117.08917	41.27306
196	4	Reese River	-117.10361	39.86556
199	5	Martin Creek	-117.35778	41.62500
204	4	Hank's Creek	-115.30639	41.46278
215	3	Henderson Creek	-116.16694	39.93139
230	3	Rock Creek (dry)	-116.50056	41.34667
235	2	Robert's Mountains	-116.20639	39.83278
244	2	Pole Creek	-115.05722	41.39222
245	3	Susie Creek	-115.95389	40.99972
247	3	Sherman Creek	-115.72667	40.94944
250	4	Beaver Creek	-115.59361	41.39667
257	2	Coyote Creek (dry)	-116.22389	40.99278
259	3	Gance Creek	-115.76694	41.24083
263	4	Kelly Creek	-117.11861	41.22972
269	4	Upper Little Humboldt	-117.36222	41.76750
278	4	Dixie Creek	-115.85611	40.63750
280	4	Reese River	-117.42583	38.80917

Appendix 2. Summary Statistics for Water Chemistry Indicators for the Humboldt Basin.

Indicator	Units	Mean	Lower 95% Conf.	Upper 95% Conf.	Median	Min	Max	Range	Variance	Standard Deviation	Standard Error
Temperature	°C	17.72	16.60	18.84	18.45	8.20	27.65	19.45	21.32	4.62	0.57
Conductivity	µs/cm	328.40	256.28	400.52	236.00	53.00	1.51E+03	1.46E+03	8.80E+04	296.64	36.79
Dissolved Oxygen	mg/L	8.07	7.61	8.52	7.95	2.40	15.50	13.10	3.48	1.86	0.23
pH	pH units	8.27	8.10	8.45	8.30	6.60	11.70	5.10	0.48	0.70	0.088
Ammonia	mg/L	0.039	0.036	0.043	0.040	0.010	0.08	0.070	0.000	0.015	0.002
Chloride	mg/L	17.58	10.68	24.47	10.82	0.20	204.20	204.00	828.45	28.78	3.52
Nitrate	mg/L	0.050	0.030	0.080	0.020	0.020	0.65	0.63	0.011	0.106	0.013
Sulfate	mg/L	26.74	17.06	36.41	9.56	0.20	259.00	258.80	1.63E+03	40.40	4.94
Total Dissolved Solids	mg/L	221.33	178.71	263.95	179.00	17.20	1.01E+03	992.80	3.24E+04	178.00	21.75
Total Kjeldahl Nitrogen	mg/L	0.22	0.18	0.26	0.17	0.061	1.20	1.14	0.027	0.17	0.020
Total Phosphorus	mg/L	0.066	0.055	0.076	0.055	0.014	0.20	0.18	0.002	0.043	0.005
Total Suspended Solids	mg/L	12.16	7.53	16.80	10.00	0.00	140.00	140.00	374.96	19.36	2.37

Appendix 3. Summary Statistics for Physical Habitat Metrics.

Type	Indicator	Units	Indicator Abbrv.	Mean	Lower 95% Conf.	Upper 95% Conf.	Median	Min	Max	Range	Variance	Standard Deviation	Standard Error
channel	undercut dist	m	XUN	0.013	0.009	0.017	0.006	0.00	0.10	0.10	0.00	0.019	0.00
	bankfull width	m	XBKF_W	5.68	4.42	6.93	4.01	0.87	29.57	28.69	27.98	5.29	0.64
	bankfull height	m	XBKF_H	0.42	0.36	0.48	0.31	0.16	1.35	1.19	0.062	0.25	0.030
	channel slope	%	XSLOPE	3.17	2.55	3.79	2.54	0.30	12.23	11.93	6.74	2.60	0.31
	channel incision height	m	XINC_H	1.01	0.77	1.26	0.66	0.00	6.44	6.44	1.06	1.03	0.13
	bank angle	degree	XBKA	36.76	33.28	40.23	33.64	10.36	86.36	76.00	216.94	14.73	1.77
	wetted width	m	XWIDTH	3.03	2.34	3.71	2.31	0.00	16.68	16.68	8.22	2.87	0.35
	width*depth	m^2	XWXD	1.08	0.68	1.48	0.46	0.00	10.76	10.76	2.84	1.68	0.20
	width/depth	m/m	XWD_RAT	15.86	13.48	18.24	12.99	0.00	57.39	57.39	100.25	10.01	1.21
	depth	cm	XDEPTH	23.79	19.23	28.35	18.74	0.00	110.49	110.49	368.63	19.20	2.33
	reach length	m	REACHLEN	164.73	152.04	177.42	150.00	100.00	380.00	280.00	2.39E+03	48.88	6.47
	sinuosity	unitless	SINU	1.28	1.21	1.36	1.22	1.01	2.47	1.46	0.082	0.29	0.038
	percent fast	%	PCT_FAST	33.30	25.46	41.13	24.00	0.00	100.00	100.00	1.10E+03	33.21	4.00
	percent slow	%	PCT_SLOW	59.82	51.58	68.07	68.67	0.00	100.00	100.00	1.22E+03	34.94	4.21
	percent pools	%	PCT_POOL	6.46	3.58	9.34	0.91	0.00	68.00	68.00	149.03	12.21	1.47
	percent dry/sub	%	PCT_DRS	6.88	1.29	12.47	0.00	0.00	100.00	100.00	560.76	23.68	2.85
	median bank angle†	degree	MEDBK_A	27.46	23.23	31.69	25.50	9.00	79.00	70.00	172.46	13.13	2.16
cover	area covered by all types but algae	areal prop.	XFC_ALL	0.42	0.31	0.52	0.22	0.00	2.02	2.02	0.18	0.43	0.052

Appendix 3. Summary Statistics for Physical Habitat Metrics (cont.).

Type	Indicator	Units	Indicator Abbrv.	Mean	Lower 95% Conf.	Upper 95% Conf.	Median	Min	Max	Range	Variance	Standard Deviation	Standard Error
	area covered by natural objects	areal prop.	XFC_NAT	0.41	0.31	0.51	0.22	0.00	2.02	2.02	0.18	0.43	0.052
	area covered by large objects	areal prop.	XFC_BIG	0.16	0.10	0.21	0.059	0.00	0.96	0.96	0.050	0.22	0.027
	filamentous algae cover	areal prop.	XFC_ALG	0.13	0.092	0.18	0.075	0.00	0.88	0.88	0.032	0.18	0.022
	aquatic macrophyte cover	areal prop.	XFC_AQM	0.13	0.085	0.18	0.043	0.00	0.88	0.88	0.043	0.21	0.025
	area covered by natural objects	areal prop.	XFC_NAT	0.41	0.31	0.51	0.22	0.00	2.02	2.02	0.18	0.43	0.052
	area covered by large objects	areal prop.	XFC_BIG	0.16	0.10	0.21	0.059	0.00	0.96	0.96	0.050	0.22	0.027
	filamentous algae cover	areal prop.	XFC_ALG	0.13	0.092	0.18	0.075	0.00	0.88	0.88	0.032	0.18	0.022
	aquatic macrophyte cover	areal prop.	XFC_AQM	0.13	0.085	0.18	0.043	0.00	0.88	0.88	0.043	0.21	0.025
	large woody debris cover	areal prop.	XFC_LWD	0.010	0.001	0.019	0.00	0.00	0.27	0.27	0.00	0.037	0.005
	brush and small woody debris cover	areal prop.	XFC_BRS	0.074	0.051	0.097	0.049	0.00	0.63	0.63	0.009	0.096	0.012
	overhanging vegetation cover	areal prop.	XFC_OHV	0.19	0.14	0.23	0.094	0.00	0.79	0.79	0.042	0.21	0.025

Appendix 3. Summary Statistics for Physical Habitat Metrics (cont.).

Type	Indicator	Units	Indicator Abbrv.	Mean	Lower 95% Conf.	Upper 95% Conf.	Median	Min	Max	Range	Variance	Standard Deviation	Standard Error
	undercut bank cover	areal prop.	XFC_UCB	0.038	0.021	0.054	0.014	0.00	0.38	0.38	0.005	0.069	0.008
	boulder and rock ledge cover	areal prop.	XFC_RCK	0.10	0.060	0.15	0.018	0.00	0.88	0.88	0.034	0.19	0.023
	artificial structure cover	areal prop.	XFC_HUM	0.003	0.001	0.006	0.00	0.00	0.057	0.057	0.00	0.010	0.001
riparian	canopy present	areal prop.	XPCAN	0.18	0.11	0.26	0.00	0.00	1.00	1.00	0.094	0.31	0.037
	midlayer present	areal prop.	XPMID	0.85	0.79	0.91	1.00	0.00	1.00	1.00	0.071	0.27	0.032
	groundlayer present	areal prop.	XPGVEG	0.98	0.97	1.00	1.00	0.59	1.00	0.41	0.003	0.058	0.007
	canopy+ midlayer present	areal prop.	XPCM	0.18	0.11	0.25	0.00	0.00	1.00	1.00	0.089	0.30	0.036
	3 layers present	areal prop.	XPCMG	0.18	0.11	0.25	0.00	0.00	1.00	1.00	0.088	0.30	0.036
	veg canopy cover	areal prop.	XC	0.069	0.028	0.11	0.00	0.00	0.92	0.92	0.030	0.17	0.021
	veg midlayer cover	areal prop.	XM	0.33	0.28	0.37	0.33	0.00	0.90	0.90	0.042	0.20	0.025
	veg ground cover	areal prop.	XG	0.53	0.48	0.59	0.54	0.030	1.02	0.99	0.050	0.22	0.027
	veg canopy+ midlayer	areal prop.	XCM	0.39	0.32	0.47	0.35	0.00	1.71	1.71	0.10	0.32	0.039
	veg canopy+ mid woody	areal prop.	XCMW	0.29	0.23	0.35	0.23	0.00	1.33	1.33	0.069	0.26	0.032
	canopy+ mid+ ground	areal prop.	XCMG	0.93	0.82	1.04	0.90	0.055	2.74	2.68	0.22	0.47	0.056

Appendix 3. Summary Statistics for Physical Habitat Metrics (cont.).

Type	Indicator	Units	Indicator Abbrv.	Mean	Lower 95% Conf.	Upper 95% Conf.	Median	Min	Max	Range	Variance	Standard Deviation	Standard Error
	canopy+ mid+ ground woody	areal prop.	XCMGW	0.48	0.39	0.57	0.40	0.00	1.86	1.86	0.14	0.37	0.045
	canopy coniferous	areal prop.	PCAN_C	0.011	-0.005	0.026	0.00	0.00	0.55	0.55	0.005	0.068	0.008
	canopy deciduous	areal prop.	PCAN_D	0.17	0.10	0.24	0.00	0.00	1.00	1.00	0.093	0.30	0.037
	canopy mixed (conif+ decid)	areal prop.	PCAN_M	0.004	-0.002	0.010	0.00	0.00	0.20	0.20	0.00	0.026	0.003
	canopy absent	areal prop.	PCAN_N	0.81	0.74	0.89	1.00	0.00	1.00	1.00	0.094	0.31	0.037
	midlayer coniferous	areal prop.	PMID_C	0.00			0.00	0.00	0.00	0.00	0.00	0.00	0.000
	midlayer deciduous	areal prop.	PMID_D	0.28	0.19	0.36	0.00	0.00	1.00	1.00	0.14	0.38	0.046
	midlayer mixed conif+ decid	areal prop.	PMID_M	0.48	0.38	0.58	0.50	0.00	1.00	1.00	0.17	0.42	0.050
	midlayer absent	areal prop.	PMID_N	0.21	0.13	0.28	0.045	0.00	1.00	1.00	0.11	0.33	0.040
	midlayer woody	areal prop.	XMW	0.22	0.18	0.26	0.21	0.00	0.61	0.61	0.026	0.16	0.019
	midlayer herbaceous	areal prop.	XMH	0.10	0.08	0.13	0.062	0.00	0.62	0.62	0.014	0.12	0.014
	ground woody	areal prop.	XGW	0.19	0.15	0.22	0.15	0.00	0.70	0.70	0.023	0.15	0.018
	ground herbaceous	areal prop.	XGH	0.35	0.30	0.39	0.33	0.030	0.85	0.82	0.033	0.18	0.022
	ground barren	areal prop.	XGB	0.22	0.17	0.27	0.17	0.00	0.88	0.88	0.039	0.20	0.024
	riparian canopy cover >0.3m[†]	areal prop.	XCS	0.086	0.025	0.15	0.00	0.00	0.88	0.88	0.036	0.19	0.031

Appendix 3. Summary Statistics for Physical Habitat Metrics (cont.).

Type	Indicator	Units	Indicator Abbrv.	Mean	Lower 95% Conf.	Upper 95% Conf.	Median	Min	Max	Range	Variance	Standard Deviation	Standard Error
	canopy density	%	XCDENBK	45.63	39.06	52.20	41.58	0.00	100.00	100.00	775.44	27.85	3.35
	mid channel canopy density	%	XCDENMID	18.82	13.06	24.59	7.62	0.00	100.00	100.00	596.83	24.43	2.94
human	all human dist	prox.wtd . index	W1_HALL	1.47	1.31	1.62	1.53	0.00	2.50	2.50	0.44	0.66	0.080
	non agric. human	prox.wtd . index	W1_HNOAG	0.27	0.20	0.34	0.17	0.00	1.16	1.16	0.094	0.31	0.037
	agric human dist	prox.wtd . index	W1_HAG	1.20	1.08	1.32	1.50	0.00	1.53	1.53	0.27	0.52	0.062
	building	prox.wtd . index	W1H_BLDG	0.021	0.001	0.041	0.00	0.00	0.42	0.42	0.007	0.084	0.010
	wall	prox.wtd . index	W1H_WALL	0.017	-0.004	0.038	0.00	0.00	0.64	0.64	0.008	0.089	0.011
	pavement	prox.wtd . index	W1H_PVMT	0.002	-0.001	0.004	0.00	0.00	0.068	0.068	0.00	0.009	0.001
	road/railroad	prox.wtd . index	W1H_ROAD	0.19	0.14	0.25	0.030	0.00	0.77	0.77	0.053	0.23	0.028
	pipes	prox.wtd . index	W1H_PIPE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	trash/landfill	prox.wtd . index	W1H_LDFL	0.018	0.005	0.030	0.00	0.00	0.32	0.32	0.003	0.052	0.006
	lawn/park	prox.wtd . index	W1H_PARK	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
	row crop	prox.wtd . index	W1H_CROP	0.001	0.00	0.002	0.00	0.00	0.030	0.030	0.00	0.005	0.001
	pasture/hayfield	prox.wtd . index	W1H_PSTR	1.20	1.08	1.32	1.50	0.00	1.50	1.50	0.27	0.52	0.062
	logging activity	prox.wtd . index	W1H_LOG	0.002	-0.001	0.005	0.00	0.00	0.068	0.068	0.000	0.012	0.001

Appendix 3. Summary Statistics for Physical Habitat Metrics (cont.).

Type	Indicator	Units	Indicator Abbrv.	Mean	Lower 95% Conf.	Upper 95% Conf.	Median	Min	Max	Range	Variance	Standard Deviation	Standard Error
	mining activity	prox.wtd. index	WW1H_MINE	0.014	-0.002	0.031	0.00	0.00	0.33	0.33	0.005	0.068	0.008
lwd	volume class 1	m^3/m^2	V1W_MSQ	0.00	0.00	0.001	0.00	0.00	0.016	0.016	0.00	0.002	0.00
	volume class 2†	$^3/m^2$	V2W_MSQ	0.00	0.00	0.001	0.00	0.00	0.011	0.011	0.00	0.002	0.00
	count class 1† m	#/100m	C1WM100	1.19	-0.854	3.24	0.00	0.00	35.33	35.33	37.12	6.09	1.04
	count class 2†	#/100m	C2WM100	0.25	-0.245	0.75	0.00	0.00	8.67	8.67	2.21	1.49	0.25
pools	number of residual pools in reach	count	NRP	15.31	12.53	18.08	16.00	0.00	39.50	39.50	138.37	11.76	1.42
	number of pools >50cm	count	RPGT50	0.48	0.25	0.71	0.00	0.00	3.00	3.00	0.74	0.86	0.12
	number of pools >75cm	count	RPGT75	0.11	0.027	0.20	0.00	0.00	1.00	1.00	0.10	0.32	0.044
	channel length that forms residual pools†	%	PCTCHARP	55.67	43.46	67.88	56.00	0.00	83.64	83.64	582.43	24.13	6.23
	channel length with sediment present†	%	PCTCHASD	7.68	-1.89	17.26	1.33	0.00	74.67	74.67	358.31	18.93	4.89
	presence of thalweg small sediment % of residual pool length†	%	PCTPSED	12.56	-1.11	26.24	2.97	0.00	100.00	100.00	681.62	26.11	6.98
	pool tail length with sediment†	%	PCTDSED	13.62	-0.11	27.34	6.17	0.00	100.00	100.00	686.47	26.20	7.00
	pool head length with sediment†	%	PCTUSED	12.74	-0.92	26.39	4.85	0.00	100.00	100.00	679.41	26.07	6.97

Appendix 3. Summary Statistics for Physical Habitat Metrics (cont.).

Type	Indicator	Units	Indicator Abbrv.	Mean	Lower 95% Conf.	Upper 95% Conf.	Median	Min	Max	Range	Variance	Standard Deviation	Standard Error
	residual volume per 100 m of reach†	m^3/100m	RPV100R	6.12	1.84	10.39	2.61	0.00	28.20	28.20	71.24	8.44	2.18
	mean residual area per 100 m of channel†	m^2/100m	RP100C	5.75	3.22	8.28	4.23	0.00	15.91	15.91	24.95	5.00	1.29
	number of pools >100cm	count	PRGT100	0.00			0.00	0.00	0.00	0.00	0.00	0.00	0.00
	mean res. depth	cm	RP100	6.36	5.04	7.68	4.89	0.00	20.34	20.34	24.53	4.95	0.67
	mean res. pool width	m	RPXWID	0.87	0.66	1.08	0.69	0.00	4.51	4.51	0.60	0.78	0.11
	mean res. pool depth	cm	RPXDEP	8.79	7.29	10.28	7.12	0.00	25.01	25.01	31.35	5.60	0.76
	mean pool length	m	PRXLEN	5.99	4.73	7.25	5.23	0.00	21.92	21.92	22.22	4.71	0.64
	mean res. pool volume	m^3	RPXVOL	0.71	0.35	1.07	0.21	0.00	8.24	8.24	1.74	1.32	0.18
	mean res. pool area	m^2	RPXAREA	0.70	0.49	0.92	0.37	0.009	3.33	3.33	0.65	0.81	0.11
substrate	percent cobble	%	PCT_CB	18.39	13.94	22.84	10.91	0.00	69.09	69.09	355.39	18.85	2.27
	percent fine	%	PCT_FN	31.83	25.00	38.67	26.42	0.00	100.00	100.00	840.05	28.98	3.49

Appendix 3. Summary Statistics for Physical Habitat Metrics (cont.).

Type	Indicator	Units	Indicator Abbrv.	Mean	Lower 95% Conf.	Upper 95% Conf.	Median	Min	Max	Range	Variance	Standard Deviation	Standard Error
	percent coarse gravel	%	PCT_GC	20.55	16.42	24.67	16.36	0.00	69.09	69.09	305.80	17.49	2.11
	percent fine gravel	%	PCT_GF	14.77	12.19	17.35	12.73	0.00	47.27	47.27	119.76	10.94	1.32
	percent boulder	%	PCT_BL	5.30	2.65	7.96	0.00	0.00	64.00	64.00	126.93	11.27	1.36
	percent sand	%	PCT_SA	8.15	5.24	11.06	1.89	0.00	61.82	61.82	151.82	12.32	1.48
	percent hardpan	%	PCT_HP	0.42	-0.021	0.86	0.00	0.00	12.73	12.73	3.51	1.87	0.23
	percent wood	%	PCT_WD	0.38	0.12	0.64	0.00	0.00	7.27	7.27	1.23	1.11	0.13
	percent bedrock	%	PCT_BR	0.20	-0.094	0.49	0.00	0.00	10.00	10.00	1.53	1.24	0.15
	mean size class†	class 0-6	SUB_X	2.71	2.37	3.05	2.92	1.00	4.73	3.73	1.10	1.05	0.17
	mean embeddedness (channel only)†	%	XCEMBED	58.83	49.21	68.46	65.30	1.21	100.00	98.79	892.08	29.87	4.91
	mean embeddedness (mid-channel and margin)	%	XEMBED	72.44	67.57	77.31	76.27	10.73	100.00	89.27	425.65	20.63	2.48
	streambed stability	unitless	LRBS_NOR	-0.35	-0.63	-0.062	-0.30	-5.61	1.32	6.93	1.24	1.11	0.15

†Samples taken only in the 1998 sampling season.

Appendix 4. Streambed Stability.

Variable Name	Variable Description
XSLOPE	(%) Channel Slope
S	Slope (cm)
RP100	Residual mean depth of reach (cm)
SDDEPTH	Standard deviation of Thalweg depth profile (cm)
XBKF_H	Bankfull height mean (m)
XDEPTH	Depth (cm)
V1W_MSQ	Large woody debris volume in active channel (m3/m2)
Rbf	Bankfull hydraulic radius, also Dbf_th (m)
Rb3	Bankfull hydraulic radius, accounting for channel geometry (m)
R*bf	Bankfull hydraulic radius corrected for roughness (m)
Ct_rpwd	Reach scale hydraulic resistance of residual pool woody debris
Cp3_mill	Particle resistance to submergence
LSub_Dmm_NOR	Sum of weighted substrate proportions, excluding bedrock and hardpan
Cp3Ctrpwd_Rat	Resistance Ratio (resistance to submergence/residual pool reach scale hydraulic resistance)
Reyp3	Reynolds number
Shld_Px3	Shields parameter for incipient motion
Dcbf_NOR	Streambed shear stress of bankfull flows, excluding bedrock and hardpan
LRBS_NOR	Relative streambed stability, excluding bedrock and hardpan
g	Gravity (9.807 m/s2)
v	Kinematic viscosity of water at 20°C (1.02x10**-6m2/s)
rho	Density of fresh water at 20°C (998 kg/m^2)
rhosed	Density of silica (2650 kg m^3)

Equations

[1] **Geometric Diameter Mean**
General Equation: $((x_1)(x_2)(x_3)\ldots)^{(1/n)}$
$_{gm} =$
((Substrate upper limit)
(Substrate lower limit))^$^{(1/2)}$

[2] **Weighted Proportion**
$\bar{D}$(Log$_{10}$ (D_{gm}))(PCT_substrate/100)

[2] **LSub_Dmm_NOR**
= ∑ Site Weighted Proportions

[2] **Slope**
SLOPE (S) = XSLOPE / 100
If XSLOPE = 0, replace value with 0.01 (personal communication)

[2] **Bankfull Hydraulic Radius (Rbf or Dbf_th)**
Rbf = XBKF_H + XDEPTH/100

[2] **Bankfull hydraulic radius, accounting for channel geometry (Rb3)**
Rb3 = (0.65)(Dbf_th)

[1] **Reach scale hydraulic resistance of residual pool woody debris (Ct_rpwd)**
Ct_rpwd =
1.21((RP100/100)$^{1.08}$)((RP100/100) + V1W_msq)$^{0.638}$) /Dbf_th$^{3.32}$

[1, 2] **Keulegan equation, particle resistance to submergence (Cp3_mill)**
Cp3_mill = (1/8) [2.03 Log$_{10}$ (12.2 (Rb3 / ((10$^{(\text{LSub_Dmm_NOR} / 1000)}$)]$^{-2}$
*If Cp3_mill<0.002 then set value = 0.002
**If Cp3_mill>Ct_rpwd THEN Ct_rpwd=Cp3_mill=Ct_rpwd_cl

[2] **Ratio of resistance to submergence (Cp3_mill) to residual pool reach scale hydraulic resistance (Ct_rpwd or Ct_rpwd_cl) (Cp3Ctrpwd_Rat)**
Cp3Ctrpwd_Rat = Cp3_mill / Ct_rpwd or Ct_rpwd_cl
*If Cp3Ctrpwd_rat>1.000000 then Cp3Ctrpwd_rat = 1.00

[1, 2] **Roughness corrected bankfull hydraulic radius (R*bf)**
R*bf = Rb3 (Cp3Ctrpwd_Rat)$^{1/3}$

[1, 2] **Reynolds Number, used in calculating Shields Parameter (Reyp3)**

Reyp3 = (gR*bf(S/100))$^{0.5}$ 10$^{(\text{LSub_Dmm_NOR}/1000)}$ / v
g = 9.807 m/s^2
v = 1.02 x 10$^{-6\text{m2/s}}$

[1, 2] **Shields Parameter for incipient motion (Shld_Px3)**
If Reyp3 > 26 then
Shld_Px3= 0.5{0.22Reyp3$^{-0.6}$ + 0.06 (10 $^{-7.7\text{Reyp3}-0.6}$)}

If Reyp3 ≤ 26 then
Shld_Px3 = 0.04Reyp3$^{-0.24}$

[2] **Streambed sheer stress of bankfull flows (Dcbf_NOR)**
Dcbf_NOR = 1000*((rho g R*bf(S/100)) / (Shld_px3(rhosed - rho)g))

[2] **Stream Bed stability excluding bedrock and hardpan (LRBS_NOR)**

LRBS_NOR = LSUB_dmm_NOR – Log$_{10}$Dcbf_NOR

Appendix 4. Streambed Stability (cont.).

Final Streambed Stability Values

Site ID	LRBS_NOR
3	0.525
4	-
5	-
6	-
7	-0.045
11	-5.615
12	-
14	1.164
15	-
22	-
25	0.336
29	0.388
34	-0.312
35	-1.328
37	0.203
49	0.092
52	0.622
53	0.156
55	0.004
66	-1.200
69	-0.536
70	-
71	-0.380
82	-0.551
87	-0.450
92	0.815
96	-1.838
101	-
103	-1.649
108	-1.702
109	-
114	-
116	1.264
118	0.553
120	0.577
127	-0.190
129	0.860
130	0.652
133	-0.751
134	1.171
139	-0.089
140	-1.661
158	1.320
161	0.282

Appendix 4. Streambed Stability (cont.).

Final Streambed Stability Values (cont.)

Site ID	LRBS_NOR
164	-1.281
166	0.442
170	0.578
176	-0.960
181	-0.480
183	-1.152
184	-0.906
190	-0.989
193	-0.598
196	-1.737
199	0.325
204	-0.714
215	-0.157
230	0.334
235	-0.597
244	0.041
245	-0.485
247	-0.774
250	-0.415
257	0.975
259	-2.202
263	-1.246
269	-0.577
278	-0.287
280	0.989

Appendix 5. Summary Statistics for Macroinvertebrate Metrics.

Indicator	Mean	Lower 95% Conf.	Upper 95% Conf.	Median	Min	Max	Range	Variance	Standard Deviation	Standard Error
Taxa Richness	24.56	22.67	26.46	23.50	9.00	40.00	31.00	59.90	7.74	0.97
HBI	4.73	4.47	5.00	4.62	2.29	7.83	5.54	1.20	1.09	0.14
Shannon H	1.99	1.88	2.10	2.10	0.75	2.74	1.99	0.20	0.45	0.06
% EPT	42.86	37.42	48.29	43.00	1.82	86.53	84.71	491.60	22.17	2.77
EPT Taxa	10.92	9.37	12.47	10.00	2.00	24.00	22.00	40.04	6.33	0.79
% Ephemeroptera Taxa	25.54	20.90	30.19	22.38	0.91	81.56	80.65	359.50	18.96	2.37
Ephemeroptera Taxa	4.34	3.79	4.90	4.00	1.00	10.00	9.00	5.18	2.28	0.28
% Plecoptera Taxa	5.32	3.31	7.34	1.74	0.00	33.49	33.49	67.55	8.22	1.03
Plecoptera Taxa	2.31	1.79	2.83	2.00	0.00	7.00	7.00	4.54	2.13	0.27
% Trichoptera Taxa	11.99	8.24	15.75	5.42	0.00	62.78	62.78	234.83	15.32	1.92
Trichoptera Taxa	4.27	3.56	4.97	4.00	0.00	13.00	13.00	8.23	2.87	0.36
% Collectors	46.90	42.10	51.71	45.48	7.28	87.22	79.94	384.70	19.61	2.45
% Filterers	24.52	20.04	29.01	21.16	0.44	69.76	69.32	335.40	18.31	2.29
% Predators	14.23	11.34	17.12	10.44	1.89	58.11	56.22	139.20	11.80	1.47
% Scrapers	12.07	8.72	15.41	7.24	0.22	56.42	56.20	186.50	13.66	1.71
% Stredders	2.28	1.15	3.41	0.45	0.00	27.59	27.59	21.35	4.62	0.58
% Intolerant (<4)	16.26	12.21	20.30	11.78	0.00	57.21	57.21	272.60	16.51	2.06
% Tolerant Taxa (≥7)	10.02	5.88	14.16	3.01	0.00	73.19	73.19	285.53	16.90	2.11
Dominant Taxa	37.55	33.65	41.45	35.11	13.90	81.56	67.66	253.54	15.92	1.99

Appendix 6. Criteria used to determine least-disturbed and most-disturbed sites.

Criteria Used by Alan Herlihy to Identify Least- and Most-Disturbed Sites

Herlihy Criteria	Total Phosphorus (ug/L)	Total Nitrogen (ug/L)	Chloride (ueq/L)	pH	Riparian Disturbance (W1_HALL)	%Fines	Canopy Density (XCDENBK)
Least	<50	<1500	<1000	<9	<1.5	<50%	>50%
Most	>150	>5000	>5000	<6	>3.0	>90%	<10%

Criteria used by John Stoddard to Identify Least- and Most-Disturbed Sites

Stoddard Criteria	Total Phosphorus (ug/L)	Total Nitrogen (ug/L)	Chloride (ueq/L)	Sulfate (ueq/L)	pH	Riparian Disturbance (W1_HALL)	RBS
Least	<50	<1500	<1000	<10000	<9	<1.5	>-2.0
Most	>300	>4000	>2500	>15000	>9	>3.0	>-2.8

Variables Used in Whittier Ranking to Identify Least- and Most-Disturbed Sites

Chemical	*Habitat*	*Catchment Variables*
TN	%Fines	Road Density
Turbidity	Riparian Disturbances	Population Density
Chloride	Natural Fish Cover	%Urban
Sulfate	Riparian Vegetation	%Agriculture

Appendix 7. Candidate Macroinvertebrate Metrics and Results of Range Test.

Metric ID	Metric Class	Metric Description	Range Test
Shan_e	Composition	Shannon's Evenness Index base e	Pass
AmphPct	Composition	% Amphipoda	**Fail**
BivalPct	Composition	% Bivalvia	Pass
ChiroPct	Composition	% Chironomidae	Pass
ColeoPct	Composition	% Coleoptera	Pass
CorbPct	Composition	% Corbicula	**Fail**
CrCh2ChiPct	Composition	% Cricotopus + Chironomus of Chironomidae	**Fail**
CrMolPct	Composition	% Crustacea Mollusca	Pass
DipPct	Composition	% Diptera	Pass
EphemPct	Composition	% Ephemeroptera	Pass
EPTPct	Composition	% EPT	Pass
GastrPct	Composition	% Gastropoda	Pass
IsoPct	Composition	% Isopoda	**Fail**
NonInPct	Composition	% Non Insect	Pass
OdonPct	Composition	% Odonata	Pass
OligoPct	Composition	% Oligochaeta	Pass
Orth2ChiPct	Composition	% Orthocladiinae of Chironomidae	Pass
PlecoPct	Composition	% Plecoptera	Pass
TanytPct	Composition	% Tanytarsini	Pass
Tnyt2ChiPct	Composition	% Tanytarsini of Chironomidae	Pass
TrichPct	Composition	% Trichoptera	Pass
CllctPct	Feeding	% Collectors	Pass
FiltrPct	Feeding	% Filterers	Pass
PredPct	Feeding	% Predators	Pass
ScrapPct	Feeding	% Scrapers	Pass
ShredPct	Feeding	% Shredders	Pass
CllctTax	Feeding	Collector Taxa Richness	Pass
FiltrTax	Feeding	Filterer Taxa Richness	Pass
PredTax	Feeding	Predator Taxa Richness	Pass
ScrapTax	Feeding	Scraper Taxa Richness	Pass
ShredTax	Feeding	Shredder Taxa Richness	Pass
BrrwrPct	Habit	% Burrowers	Pass
ClmbrPct	Habit	% Climbers	**Fail**
ClngrPct	Habit	% Clingers	Pass
SprwlPct	Habit	% Sprawlers	Pass
SwmmrPct	Habit	% Swimmers	Pass
BrrwrTax	Habit	Burrower Taxa Richness	Pass
ClmbrTax	Habit	Climber Taxa Richness	**Fail**
ClngrTax	Habit	Clinger Taxa Richness	Pass
SprwlTax	Habit	Sprawler Taxa Richness	Pass
SwmmrTax	Habit	Swimmer Taxa Richness	Pass
ChiroTax	Richness	Chironomid Taxa Richness	Pass
ColeoTax	Richness	Coleoptera Taxa Richness	Pass
CrMolTax	Richness	Crustacea Mullusca Taxa Richness	Pass
DipTax	Richness	Diptera Taxa Richness	Pass
EphemTax	Richness	Ephemeroptera Taxa Richness	Pass

Appendix 7. Candidate Macroinvertebrate Metrics and Results of Range Test (cont.).

Mertric ID	Metric Class	Metric Description	Range Test
EPTTax	Richness	EPT Taxa Richness	Pass
OligoTax	Richness	Oligochaeta Taxa Richness	**Fail**
OrthoTax	Richness	Orthocladiinae Taxa Richness	**Fail**
PlecoTax	Richness	Plecoptera Taxa Richness	Pass
PteroTax	Richness	Pteronarcys Taxa Richness	**Fail**
TanytPct	Richness	Tanytarsini Taxa Richness	**Fail**
TotalTax	Richness	Total Taxa Richness	Pass
TrichTax	Richness	Trichoptera Taxa Richness	Pass
BeckBI	Tolerance	Beck Biotic Index	Pass
HBI	Tolerance	Hilsenhoff Biotic Index	Pass
NCBI	Tolerance	North Carolina Biotic Index	**Fail**
Dom01Pct	Tolerance	% Dominant 01 Taxa	Pass
Baet2EphPct	Tolerance	% Baetidae of Ephemeroptera	Pass
Hyd2EPTPct	Tolerance	% Hydropsychidae of EPT	Pass
Hyd2TriPct	Tolerance	% Hydropsychidae of Trichoptera	Pass
IntolPct	Tolerance	% Intolerant	Pass
TolerPct	Tolerance	% Tolerant	Pass
IntolTax	Tolerance	Intolerant Taxa Richness	Pass
InMolTax	Tolerance	Intolerant Mollusca Taxa	**Fail**
TolerTax	Tolerance	Tolerant Taxa Richness	Pass

Appendix 8. F-Test Results for Candidate Microinvertebrate Metrics.

	Metric ID	F	P-value
Diversity	Shan_e	1.346	0.273
	Shan_2	1.346	0.273
	Shan_10	1.346	0.273
Composition	Orth2ChiPct	226.342	0.000
	Tanyt2ChiPct	13.089	0.005
	ChiroPct	12.944	0.005
	GastrPct	9.713	0.011
	EPTPct	9.318	0.012
	TanytPct	6.753	0.027
	EphemPct	5.485	0.041
	TrichPct	3.337	0.098
	PlecoPct	2.496	0.145
	DipPct	2.260	0.164
	CrMolPct	1.948	0.193
	OdonPct	1.244	0.291
	OligoPct	1.030	0.334
	ColeoPct	0.897	0.366
	NonInPct	0.611	0.453
	BivalPct	0.410	0.536
Feeding	ScrapPct	5.824	0.036
	FltrTax	4.623	0.057
	ShredTax	2.580	0.139
	ScrapTax	1.856	0.203
	PredTax	1.734	0.217
	ShredPct	1.646	0.228
	CllctTax	0.167	0.692
	FiltrPct	0.809	0.390
	PredPct	0.356	0.564
	CllctPct	0.003	0.959
Habit	ClngrTax	9.375	0.012
	ClngPct	6.866	0.026
	SwmmrPct	2.493	0.145
	SprwlPct	1.561	0.240
	SwmmrTax	1.471	0.253
	BrrwPct	1.431	0.259
	SprwlTax	0.357	0.563
	BrrwTax	0.000	1.000
Richness	ChiroTax	15.625	0.003
	TrichTax	12.755	0.005
	PlecoTax	10.168	0.010
	EPTTax	9.579	0.011
	CrMolTax	7.857	0.019
	EphemTax	2.748	0.128
	TotalTax	2.296	0.161
	DipTax	1.522	0.246

Appendix 8. F-Test Results for Candidate Microinvertebrate Metrics (cont.).

	Metric ID	F	P-value
	ColeoTax	0.220	0.649
Tolerance	TolerTax	15.943	0.003
	IntolTax	14.246	0.004
	HBI	14.172	0.004
	BeckBI	12.414	0.006
	IntolPct	9.982	0.010
	TolPct	6.750	0.027
	Dom01Pct	1.671	0.225
	Hyd2EPTPct	0.575	0.466
	Hyd2TriPct	0.154	0.703
	Baet2EptPct	0.103	0.755

Appendix 9. R^2 Values for Redundancy Test.

	Shan_e	Orth2ChiPct	Tnyt2ChiPct	ChiroPct	GastrPct	EPTPct	TanytPct	EphemPct	FiltrTax	ScrapPct	ClngrTax	ClngrPct
Shan_e	1	0.11	0.30	0.33	0.00	0.51	0.48	0.47	0.46	0.37	0.34	0.41
Orth2ChiPct	0.11	1	0.59	0.66	0.47	0.49	0.47	0.37	0.29	0.30	0.38	0.34
Tnyt2ChiPct	0.30	0.59	1	0.59	0.34	0.24	0.77	0.14	0.24	0.14	0.22	0.17
ChiroPct	0.33	0.66	0.59	1	0.28	0.52	0.84	0.50	0.24	0.18	0.27	0.24
GastrPct	0.00	0.47	0.34	0.28	1	0.10	0.17	0.03	0.00	0.15	0.22	0.19
EPTPct	0.51	0.49	0.24	0.52	0.10	1	0.35	0.91	0.50	0.72	0.57	0.72
TanytPct	0.48	0.47	0.77	0.84	0.17	0.35	1	0.30	0.21	0.12	0.19	0.16
EphemPct	0.47	0.37	0.14	0.50	0.03	0.91	0.30	1	0.53	0.65	0.46	0.61
FiltrTax	0.46	0.29	0.24	0.24	0.00	0.50	0.21	0.53	1	0.31	0.25	0.27
ScrapPct	0.37	0.30	0.14	0.18	0.15	0.72	0.12	0.65	0.31	1	0.73	0.93
ClngrTax	0.34	0.38	0.22	0.27	0.22	0.57	0.19	0.46	0.25	0.73	1	0.88
ClngrPct	0.41	0.34	0.17	0.24	0.19	0.72	0.16	0.61	0.27	0.93	0.88	1
ChiroTax	0.01	0.64	0.30	0.29	0.54	0.14	0.11	0.07	0.10	0.06	0.09	0.06
TrichTax	0.39	0.48	0.45	0.35	0.26	0.67	0.31	0.50	0.33	0.78	0.77	0.79
PlecoTax	0.44	0.45	0.25	0.28	0.22	0.73	0.21	0.51	0.31	0.73	0.77	0.86
EPTTax	0.54	0.41	0.43	0.34	0.22	0.70	0.34	0.48	0.33	0.75	0.79	0.82
CrMolTax	0.03	0.32	0.11	0.02	0.56	0.02	0.00	0.00	0.00	0.11	0.20	0.13
TolerTax	0.00	0.49	0.22	0.10	0.61	0.18	0.03	0.07	0.07	0.27	0.28	0.24
IntolTax	0.48	0.51	0.45	0.39	0.29	0.73	0.36	0.55	0.35	0.82	0.86	0.89
HBI	0.27	0.49	0.29	0.21	0.14	0.68	0.15	0.48	0.46	0.70	0.67	0.70
BeckBI	0.48	0.46	0.42	0.37	0.25	0.69	0.34	0.54	0.35	0.80	0.90	0.88
IntolPct	0.33	0.45	0.28	0.30	0.27	0.71	0.22	0.44	0.22	0.63	0.68	0.73
TolerPct	0.03	0.30	0.12	0.01	0.02	0.22	0.01	0.14	0.36	0.33	0.29	0.27

Appendix 9. R^2 Values for Redundancy Test (cont.).

	ChiroTax	TrichTax	PlecoTax	EPTTax	CrMolTax	TolerTax	IntolTax	HBI	BeckBI	IntolPct	TolerPct
Shan_e	0.01	0.39	0.44	0.54	0.03	0.00	0.48	0.27	0.48	0.33	0.03
Orth2ChiPct	0.64	0.48	0.45	0.41	0.32	0.49	0.51	0.49	0.46	0.45	0.30
Tnyt2ChiPct	0.30	0.45	0.25	0.43	0.11	0.22	0.45	0.29	0.42	0.28	0.12
ChiroPct	0.29	0.35	0.28	0.34	0.02	0.10	0.39	0.21	0.37	0.30	0.01
GastrPct	0.54	0.26	0.22	0.22	0.56	0.61	0.29	0.14	0.25	0.27	0.02
EPTPct	0.14	0.67	0.73	0.70	0.02	0.18	0.73	0.68	0.69	0.71	0.22
TanytPct	0.11	0.31	0.21	0.34	0.00	0.03	0.36	0.15	0.34	0.22	0.01
EphemPct	0.07	0.50	0.51	0.48	0.00	0.07	0.55	0.48	0.54	0.44	0.14
FiltrTax	0.10	0.33	0.31	0.33	0.00	0.07	0.35	0.46	0.35	0.22	0.36
ScrapPct	0.06	0.78	0.73	0.75	0.11	0.27	0.82	0.70	0.80	0.63	0.33
ClngrTax	0.09	0.77	0.77	0.79	0.20	0.28	0.86	0.67	0.90	0.68	0.29
ClngrPct	0.06	0.79	0.86	0.82	0.13	0.24	0.89	0.70	0.88	0.73	0.27
ChiroTax	1	0.18	0.13	0.11	0.37	0.61	0.15	0.23	0.12	0.20	0.15
TrichTax	0.18	1	0.72	0.94	0.18	0.38	0.94	0.82	0.95	0.75	0.40
PlecoTax	0.13	0.72	1	0.85	0.20	0.30	0.86	0.77	0.81	0.91	0.29
EPTTax	0.11	0.94	0.85	1	0.15	0.30	0.96	0.80	0.95	0.86	0.31
CrMolTax	0.37	0.18	0.20	0.15	1	0.76	0.18	0.23	0.16	0.22	0.27
TolerTax	0.61	0.38	0.30	0.30	0.76	1	0.35	0.49	0.32	0.40	0.41
IntolTax	0.15	0.94	0.86	0.96	0.18	0.35	1	0.80	0.99	0.82	0.33
HBI	0.23	0.82	0.77	0.80	0.23	0.49	0.80	1	0.79	0.81	0.67
BeckBI	0.12	0.95	0.81	0.95	0.16	0.32	0.99	0.79	1	0.78	0.34
IntolPct	0.20	0.75	0.91	0.86	0.22	0.40	0.82	0.81	0.78	1	0.28
TolerPct	0.15	0.40	0.29	0.31	0.27	0.41	0.33	0.67	0.34	0.28	1

Appendix 10. Final IBI Scores.

Site ID	**IBI**
3	38.0
4	68.0
5	44.0
6	10.0
7	48.0
11	28.0
12	44.0
14	34.0
15	36.0
22	68.0
25	44.0
29	82.0
34	46.0
35	58.0
37	38.0
49	52.0
52	86.0
53	58.0
55	56.0
66	38.0
69	40.0
70	82.0
71	76.0
82	32.0
87	76.0
92	62.0
96	28.0
101	48.0
103	18.0
108	48.0
109	58.0
114	74.0
116	48.0
118	76.0
120	82.0
127	30.0
129	96.0
130	68.0
133	80.0
134	70.0
140	16.0
158	66.0
161	56.0
164	48.0
166	70.0
170	78.0

Appendix 10. Final IBI Scores (cont.).

Site ID	**IBI**
176	34.0
183	86.0
184	72.0
190	38.0
193	58.0
196	18.0
199	82.0
20	50.0
215	44.0
235	38.0
245	18.0
247	32.0
250	24.0
259	16.0
263	52.0
269	52.0
278	28.0
280	92.0

Appendix 11. Sediment Respiration.

Site Number	Temperature (°C)	DO/AFDM/TIME (mg/g/h)
3	19.8	2.89
4	17.2	0.90
5	12.9	0.57
6	20.5	1.31
7	22.0	5.98
11	21.7	4.52
12	16.1	4.49
14	26.6	4.43
15	26.8	8.23
22	22.5	4.89
25	13.5	4.34
29	18.0	3.89
34	22.8	13.43
35	28.8	2.99
37	17.9	5.76
49	18.0	6.43
52	16.6	-0.59
53	21.9	5.31
55	20.0	6.61
66	16.5	6.94
69	25.7	5.57
71	14.5	3.23
82	18.4	9.72
87	18.7	5.80
92	11.6	3.29
96	21.7	4.45
101	12.0	0.97
103	19.1	8.07
108	14.0	4.85
109	21.4	1.60
114	13.9	4.93
116	22.3	10.03
118	17.0	5.11
120	17.4	4.06
127	12.5	4.06

Appendix 11. Sediment Respiration (cont).

Site Number	Temperature (°C)	DO/AFDM/TIME (mg/g/h)
129	16.7	2.92
130	9.7	1.51
133	18.4	4.96
134	18.7	5.80
140	11.5	2.08
158	18.5	0.70
161	16.7	3.24
164	26.6	8.75
166	18.5	5.03
170	16.2	1.78
176	20.7	2.96
181	31.2	9.02
183	22.8	5.22
184	25.0	7.89
190	13.5	2.18
193	20.2	2.69
196	25.9	6.56
199	20.3	4.22
204	16.0	5.26
215	23.1	4.81
235	8.2	3.38
244	23.8	1.63
245	24.4	4.80
247	14.4	6.17
250	23.2	9.01
259	15.2	7.70
263	23.0	2.99
269	12.0	3.29
278	23.0	3.04
280	8.7	1.73

Appendix 12. Water Metals (µg/L).

Metal	Mean	Lower 95% Conf.	Upper 95% Conf.	Median	Min	Max	Range	Variance	Standard Deviation	Standard Error
Aluminum	76.86	38.34	115.39	30.50	3.70	1.280E+03	1.276E+03	2.90E+04	170.22	19.66
Antimony	19.08	16.31	21.85	8.00	8.00	35.90	27.90	149.47	12.23	1.41
Arsenic	7.47	4.75	10.19	2.90	0.00	75.00	75.00	140.50	11.85	1.39
Barium	79.79	67.37	92.22	69.50	7.30	269.70	262.40	3.01E+03	54.90	6.34
Beryllium	0.15	0.14	0.17	0.20	0.10	0.20	0.10	0.002	0.050	0.006
Boron	90.23	60.70	119.76	49.10	8.30	817.00	808.70	1.70E+04	130.48	15.07
Cadmium	1.18	1.14	1.23	1.00	1.00	1.60	0.60	0.042	0.20	0.024
Calcium	3.10E+04	2.66E+04	3.53E+04	2.80E+04	4.34E+03	7.63E+04	7.20E+04	3.69E+08	1.92E+04	2.22E+03
Chromium	1.77	1.71	1.84	1.50	1.50	2.30	0.80	0.093	0.30	0.035
Cobalt	2.62	2.47	2.78	2.00	2.00	4.20	2.20	0.46	0.68	0.079
Copper	2.33	2.14	2.52	2.00	1.80	5.40	3.60	0.72	0.85	0.098
Iron	77.07	35.95	118.19	23.70	1.30	1.200E+03	1.199E+03	3.30E+04	181.69	20.98
Lead	4.33	3.64	5.01	7.00	0.90	7.30	6.40	9.28	3.05	0.35
Magnesium	1.15E+04	8.95E+03	1.40E+04	6.75E+03	834.00	4.15E+04	4.07E+04	1.26E+08	1.12E+04	1.30E+03
Manganese	27.90	-1.73	57.53	4.30	0.30	1.11E+03	1.11E+03	1.71E+04	130.93	15.12
Mercury†	0.10			0.10	0.10	0.10	0.00	0.00	0.00	0.00
Molybdenum*	2.56	1.91	3.22	2.00	1.10	13.50	12.40	4.59	2.14	0.33
Nickel	10.28	9.21	11.36	6.00	6.00	17.10	11.10	22.47	4.74	0.55
Phosphate*	70.93	58.86	82.99	51.00	37.00	187.35	150.35	1.55E+03	39.41	6.16
Potassium	3.62E+03	2.67E+03	4.58E+03	2.32E+03	459.00	3.08E+04	3.03E+04	1.79E+07	4.24E+03	489.20
Selenium	8.29	6.72	9.86	14.00	0.50	23.15	22.65	48.15	6.94	0.80
Silicon*	1.46E+04	1.27E+04	1.65E+04	1.49E+04	5.01E+03	2.79E+04	2.29E+04	3.78E+07	6.15E+03	960.14
Silver	1.86	1.62	2.10	1.20	0.80	3.30	2.50	1.13	1.06	0.12
Sodium	2.19E+04	1.51E+04	2.87E+04	1.29E+04	1.91E+03	2.21E+05	2.19E+05	9.06E+08	3.01E+04	3.48E+03
Strontium*	176.58	140.99	212.16	145.70	44.20	515.50	471.30	1.35E+04	116.25	18.16
Sulfur*	1.23E+04	6.66E+03	1.80E+04	4.06E+03	1.30E+02	7.49E+04	7.48E+04	3.45E+08	1.86E+04	2.90E+03
Thallium*	9.20	8.93	9.47	9.00	9.00	13.30	4.30	0.78	0.89	0.14
Tin*	8.65	8.19	9.11	8.00	8.00	13.90	5.90	2.26	1.50	0.23
Titanium*	3.55	2.99	4.11	3.00	3.00	12.70	9.70	3.32	1.82	0.28
Vanadium	3.67	3.04	4.31	3.00	0.30	12.60	12.30	7.89	2.81	0.32
Zinc	7.43	5.72	9.14	5.30	1.00	39.10	38.10	57.20	7.56	0.87
Hardness	126.56	106.42	146.69	100.68	15.24	322.17	306.93	7.92E+03	88.97	10.27

†Samples taken only in the 1998 sampling season.

*Samples taken only in the 1999 sampling season.

Appendix 13. Sediment Metals (mg/kg).

Metal	Mean	Lower 95% Conf.	Upper 95% Conf.	Median	Min	Max	Range	Variance	Standard Deviation	Standard Error
Aluminum	1.42E+04	1.30E+04	1.54E+04	1.43E+04	3.20E+03	2.54E+04	2.22E+04	2.86E+07	5.35E+03	605.24
Antimony	6.59	4.95	8.23	1.93	0.50	32.00	31.50	54.66	7.39	0.84
Arsenic	5.50	4.36	6.64	4.06	0.40	27.60	27.20	26.33	5.13	0.58
Barium	313.60	257.94	369.26	264.50	26.51	1.56E+03	1.54E+03	6.29E+04	250.82	28.40
Beryllium	0.69	0.63	0.76	0.63	0.15	1.80	1.65	0.091	0.30	0.034
Boron*	23.94	20.08	27.81	20.05	2.31	51.76	49.45	170.82	13.07	1.97
Cadmium	0.61	0.41	0.81	0.45	0.00	7.74	7.74	0.81	0.90	0.10
Calcium	1.12E+04	7.09E+03	1.53E+04	5.22E+03	637.22	1.23E+05	1.22E+05	3.43E+08	1.85E+04	2.10E+03
Chromium	14.66	12.50	16.81	12.32	1.35	44.90	43.55	94.49	9.72	1.10
Cobalt	6.58	5.86	7.30	5.98	0.92	16.50	15.58	10.52	3.24	0.37
Copper	16.51	13.95	19.08	13.12	0.57	58.30	57.73	133.80	11.57	1.31
Iron	1.53E+04	1.39E+04	1.67E+04	1.41E+04	2.81E+03	3.70E+04	3.42E+04	3.78E+07	6.15E+03	696.00
Lead	8.50	6.63	10.36	7.35	0.97	52.70	51.73	69.78	8.35	0.95
Magnesium	4.29E+03	3.68E+03	4.91E+03	3.52E+03	485.88	1.47E+04	1.42E+04	7.63E+06	2.76E+03	312.86
Manganese	438.58	354.86	522.30	358.62	116.77	3.25E+03	3.13E+03	1.42E+05	377.25	42.72
Mercury†	0.22	0.11	0.33	0.13	0.07	1.50	1.43	0.10	0.32	0.056
Molybdenum*	0.51	0.26	0.76	0.09	0.09	4.39	4.30	0.72	0.85	0.13
Nickel	16.12	13.12	19.12	13.04	1.28	98.82	97.54	182.73	13.52	1.53
Phosphate*	576.80	494.82	658.78	525.75	118.17	1.19E+03	1.07E+03	7.70E+04	277.44	41.83
Potassium	3.46E+03	3.02E+03	3.89E+03	2.87E+03	571.22	9.28E+03	8.71E+03	3.84E+06	1.96E+03	221.81
Selenium	11.00	8.59	13.42	10.92	0.17	40.04	39.87	118.46	10.88	1.23
Silicon*	2.68E+03	2.39E+03	2.97E+03	2.35E+03	1.44E+03	5.43E+03	3.99E+03	9.70E+05	984.71	148.45
Silver	0.60	0.44	0.75	0.069	0.050	3.00	2.95	0.48	0.69	0.079
Sodium	690.73	556.20	825.26	462.50	72.10	2.70E+03	2.63E+03	3.67E+05	606.19	68.64
Strontium*	65.87	51.23	80.52	56.14	5.62	301.48	295.86	2.46E+03	49.58	7.47
Sulfur*	373.53	282.04	465.03	239.67	35.45	1.29E+03	1.25E+03	9.59E+04	309.65	46.68
Thallium*	0.82	0.69	0.96	0.60	0.17	2.76	2.59	0.20	0.45	0.068
Tin*	0.85	-0.035	1.74	0.40	0.40	20.35	19.95	9.05	3.01	0.45
Titanium*	671.29	591.84	750.74	655.92	161.07	1.24E+03	1.08E+03	7.23E+04	268.87	40.53
Vanadium	38.58	32.02	45.15	30.15	3.50	170.98	167.48	874.70	29.58	3.35
Zinc	65.61	52.30	78.91	52.84	10.04	509.42	499.38	3.60E+03	59.96	6.79

†Samples taken only in the 1998 sampling season.

*Samples taken only in the 1999 sampling season.

Appendix 14. R Values of Significant Correlations (P<0.05) between Ecological Indicators and Stressor Indicators. For Riparian Disturbances, Used Three Most Common Forms of Disturbances.

Benthic Invertebrate Indicators and Water Chemistry Stressors							
	pH	SpC	Chloride	Sulfate	TKN	TDS	NH3
Richness		-0.374	-0.329	-0.426	-0.356	-0.442	-0.348
EPT Taxa	-0.320	-0.484	-0.376	-0.430	-0.379	-0.496	-0.332
% Intolerants	-0.420	-0.410		-0.317		-0.387	

Benthic Invertebrate Indicators and Physical Habitat Stressors										
	All Fish cover types but Algae	Fish cover areas by Natural Objects	Fish cover areas by Large Objects	Canopy Present	Midlayer Present	Canopy Absent	Mean Canopy Density	% Fine	% Boulder	Streambed Stability
Richness	0.370	0.371		0.426	0.443	-0.428	0.437			
EPT Taxa	0.432	0.435	0.393	0.553	0.401	-0.556	0.430	-0.421	0.376	0.424
% Intolerants				0.389	0.355	-0.389	0.346	-0.402		0.327

Benthic Invertebrate Indicators and Physical Habitat Stressors		
	All	Pastures/Hayfields
EPT Taxa	-0.383	-0.419
% Intolerants	-0.383	-0.341

Appendix 14. R Values of Significant Correlations (P<0.05) between Ecological Indicators and Stressor Indicators. For Riparian Disturbances, Used Three Most Common Forms of Disturbances (cont.).

Macroinvertebrate IBI Indicator and Physical Habitat Stressors												
	Undercut	Bankfull Height	% Fast	Canopy Present	Midlayer Present	Canopy Absent	Mean Canopy Density	% Cobble	% Fine	% Coarse Gravel	% Boulder	Streambed Stability
IBI	0.301	0.323	0.542	0.439	0.313	-0.442	0.463	0.442	-0.615	0.361	0.462	0.498

Macroinvertebrate IBI Indicator and Physical Habitat and Riparian Disturbance Stressors				
	All Fish cover types but Algae	Fish cover areas by Natural Objects	Fish cover areas by Large Objects	Pasture/Hayfield
IBI	0.417	0.423	0.401	-0.350

Macroinvertebrate IBI indicator and Water Chemistry stressors					
	pH	SpC	Sulfate	TKN	TDS
IBI	-0.319	-0.464	-0.319	-0.379	-0.407

Appendix 14. R Values of Significant Correlations ($P<0.05$) between Ecological Indicators and Stressor Indicators. For Riparian Disturbances, Used Three Most Common Forms of Disturbances (cont.).

Water Chemistry indicators and Physical Habitat stressors												
	Slope	% Fast	All Fish Cover types but Algae	Fish Cover areas by Natural Objects	Fish cover areas by Large Objects	Vegetation Canopy Cover	Vegetation Midlayer Cover	Vegetation Ground Cover	Canopy Absent	Mean Canopy Density	% Fine	Riparian Disturbance Pastures
pH			-0.306	-0.306	-0.287		-0.289			-0.384		0.309
Cond		-0.281	-0.338	-0.339	-0.287		-0.314		0.380	-0.427	0.386	
DO								-0.304				
Temp		-0.314	-0.454	-0.451	-0.337	-0.348	-0.410		0.348	-0.405		
Chloride											0.296	
Sulfate			-0.314	-0.316			-0.328			-0.387	0.359	
TSS								0.312			0.327	
TKN	-0.289	-0.286	-0.299	-0.299			-0.399			-0.385	0.390	
TP		-0.299		-0.277	-0.338							
TDS			-0.361	-0.363	-0.299		-0.291		0.343	-0.480	0.428	
NH3											0.286	

Appendix 14. R Values of Significant Correlations (P<0.05) between Ecological Indicators and Stressor Indicators. For Riparian Disturbances, Used Three Most Common Forms of Disturbances (cont.).

Physical Habitat indicators and Riparian Disturbances				
	All	Buildings	Roads	Pastures
Undercut Distance	-0.261			-0.252
% Pools			-0.284	
All Fish Cover types but Algae				-0.397
Fish Cover area by Natural Objects				-0.393
Fish Cover Areas by Large Objects				-0.368
Vegetation Midlayer Cover				-0.356
Canopy Absent		-0.282		0.388
Mean Canopy Density	-0.256	0.302		-0.407
% Fine Gravel				0.298

Sediment Metabolism Indicator and Physical Habitat Stressors									
	% Fast	All Fish Cover types but Algae	Fish Cover areas by Natural Objects	Fish cover areas by Large Objects	Vegetation Midlayer Cover	Vegetation Ground Cover	Canopy Absent	Midlayer Absent	Mean Canopy Density
Sediment Metabolism	-0.326	-0.371	-0.368	-0.272	-0.389	-0.371	0.312	0.332	-0.381

Sediment Metabolism Indicator and Water Column Stressors		
	pH	Temperature
Sediment Metabolism	0.259	0.353

Appendix 15. Estimating Relative Risk Estimate for Stressors. Data used for Calculation of Relative Risk where A=Least-Disturbed IBI Index and Least-Disturbed Stressor Metric Values, B=Most-Disturbed IBI Index and Least-Disturbed Stressor Metric Values, C=Least-Disturbed IBI Index and Most-Disturbed Stressor Metric Values, D=Most-Disturbed IBI Index and Most-Disturbed Stressor Metric Values. Relative Risk Calculated as =[D/(C+D)]/[B/(A+B)].

Metric	Description	A (# of sites)	B (# of sites)	C (# of sites)	D (# of sites)	Relative Risk	Most Disturbed Condition
%slow	% Pools + Glides	17	23	5	1	0.3	17.4%
density	Canopy Density	19	5	3	14	4.0	34.8%
RipDist All	Riparian Disturbance All	7	3	15	23	2.0	72.5%
Embed	Mean Embeddedness	16	5	6	22	3.3	53.6%
SO_4	Sulfate	14	4	11	22	3.0	34.3%
TP	Total Phosphorus	10	8	5	14	1.7	35.8%
TN	Total Nitrogen	9	8	3	7	1.5	37.1%
Fish Cover	Fish Cover from Natural Features	8	1	17	25	5.4	77.9%
RipVeg	Riparian Vegetation	18	10	2	11	2.4	24.6%
RP100	Mean Residual Depth	21	18	1	1	1.1	3.7%
LRBS_NOR	Streambed Stability	4	1	4	7	3.2	25.4%

Appendix 16 – USEPA Water Quality Criteria for Trace Metals

Aquatic Life Criteria Table

Pollutant	CAS Number	P/NP*	Freshwater CMC[1] (acute) (µg/L)	Freshwater CCC[1] (chronic) (µg/L)	Saltwater CMC[1] (acute) (µg/L)	Saltwater CCC[1] (chronic) (µg/L)	Publication Year
Alkalinity	—	NP		20000 C			1986
Aluminum pH 6.5 – 9.0	7429905	NP	750 I	87 I,S			1988
Ammonia	7664417	NP	FRESHWATER CRITERIA ARE pH, Temperature and Life-stage DEPENDENT SALTWATER CRITERIA ARE pH AND TEMPERATURE DEPENDENT				1999
Arsenic	7440382	P	340 A,D	150 A,D	69 A,D	36 A,D	1995
Bacteria	—	NP	FOR PRIMARY RECREATION AND SHELLFISH USES—SEE DOCUMENT				1986
Boron	—	NP	NARRATIVE STATEMENT—SEE DOCUMENT				1986
Cadmium	7440439	P	2.0 D,E	0.25 D,E	40 D	8.8 D	2001
Chloride	16887006	NP	860000	230000			1986
Chromium (III)	16065831	P	570 D,E	74 D,E			1995
Chromium (VI)	18540299	P	16 D	11 D	1,100 D	50 D	1995
Copper	7440508	P	Freshwater criteria calculated using the BLM mm - See Document		4.8 D,cc	3.1 D,cc	2007
Hardness	—	NP	NARRATIVE STATEMENT—SEE DOCUMENT				1986
Iron	7439896	NP		1000 C			1986
Lead	7439921	P	65 D,E	2.5 D,E	210 D	8.1 D	1980
Mercury	7439976	P	1.4 D,hh	0.77 D,hh	1.8 D,ee,hh	0.94 D,ee,hh	1995
Methylmercury	22967926						
Nickel	7440020	P	470 D,E	52 D,E	74 D	8.2 D	1995
Nutrients	—	NP	See USEPA's Ecoregional criteria for Total Phosphorus, Total Nitrogen, Chlorophyll *a* and Water Clarity (Secchi depth for lakes; turbidity for streams and rivers) (& Level III Ecoregional criteria)				
Oxygen, Dissolved Freshwater	7782447	NP	WARMWATER AND COLDWATER MATRIX—SEE DOCUMENT				1986
pH	—	NP		6.5 – 9 C		6.5 – 8.5 C,P	1986
Phosphorus Elemental	7723140	NP					1986
Selenium	7782492	P	L	5.0	290 D, dd	71 D, dd	1995
Silver	7440224	P	3.2 D,E,G		1.9 D,G		1980
Solids Suspended and Turbidity	—	NP	NARRATIVE STATEMENT—SEE DOCUMENT C				1986
Sulfide-Hydrogen Sulfide	7783064	NP		2.0 C		2.0 C	1986
Temperature	—	NP	SPECIES DEPENDENT CRITERIA—SEE DOCUMENT M				1986
Zinc	7440666	P	120 D,E	120 D,E	90 D	81 D	1995

***P/NP** – Indicates either a Priority Pollutant (P) or a Non Priority Pollutant (NP).*

Human Health Criteria Table

Human Health for the Consumption of

Pollutant	CAS Number	P/NP*	Water + Organism (µg/L)	Organism Only (µg/L)	Publication Year
Alkalinity	—	NP			
Aluminum pH 6.5 – 9.0	7429905	NP			
Antimony	7440360	P	5.6 B	640 B	2002
Arsenic	7440382	P	0.018 C,M,S	0.14 C,M,S	1992
Barium	7440393	NP	1,000 A		1986
Beryllium	7440417	P	Z		
Cadmium	7440439	P	Z		
Chromium (III)	16065831	P	Z Total		
Chromium (VI)	18540299	P	Z Total		
Copper	7440508	P	1,300 U		1992
Manganese	7439965	NP	50 O	100 A	
Mercury Methylmercury	7439976 22967926	P		0.3 mg/kg J	2001
Nickel	7440020	P	610 B	4,600 B	1998
Nitrates	14797558	NP	10,000 A		1986
Nutrients	—	NP	See USEPA's Ecoregional criteria for Total Phosphorus, Total Nitrogen, Chlorophyll *a* and Water Clarity (Secchi depth for lakes; turbidity for streams and rivers) (& Level III Ecoregional criteria)		
pH	—	NP	5 – 9		1986
Selenium	7782492	P	170 Z	4200	2002
Solids Dissolved and Salinity	—	NP	250,000 A		1986
Thallium	7440280	P	0.24	0.47	2003
Zinc	7440666	P	7,400 U	26,000 U	2002

**P/NP – Indicates either a Priority Pollutant (P) or a Non Priority Pollutant (NP).*

Parameter	Criteria	Units
Temperature	17	^{o}C change
pH	6.0-8.5	pH units
Conductivity	800	µS/cm
Dissolved Oxygen	5.0	mg/L
Turbidity	25/3	Stream/Lake NTU
TDS	500	mg/L
TSS	1000	mg/L
Nitrite (NO^-_2)	1	mg/L
Nitrate (NO^-_3)	10	mg/L
Total Kjeldahl Nitrogen(TKN)		mg/L
Ammonia (NH_3)	1.2	mg/L
Total Phosphorus	0.1	mg/L
Orthophosphate	0.05	mg/L
TOC	4.0	mg/L
Sulfate	60	ug/L
Sulfide	2.0	ug/L
Alkalinity	20	mg/L
Hardness		mg/L

Parameters for Calculating Freshwater Dissolved Metals Criteria That Are Hardness-Dependent

Chemical	m_A	b_A	m_C	b_C	Freshwater Conversion Factors (CF) CMC	CCC
Cadmium	1.0166	-3.924	0.7409	-4.719	1.136672-[(*ln*hardness)(0.041838)]	1.101672-[(*ln*hardness)(0.041838)]
Chromium III	0.8190	3.7256	0.8190	0.6848	0.316	0.860
Copper	0.9422	-1.700	0.8545	-1.702	0.960	0.960
Lead	1.273	-1.460	1.273	-4.705	1.46203-[(*ln*hardness)(0.145712)]	1.46203-[(*ln*hardness)(0.145712)]
Nickel	0.8460	2.255	0.8460	0.0584	0.998	0.997
Silver	1.72	-6.59	—	—	0.85	—
Zinc	0.8473	0.884	0.8473	0.884	0.978	0.986

Hardness-dependant metals' criteria may be calculated from the following:

CMC (dissolved) = $exp\{m_A [ln(hardness)]+ b_A\}$ *(CF)*

CCC (dissolved) = $exp\{m_C [ln(hardness)]+ b_C\}$ *(CF)*

Appendix 17 - Calculation of Freshwater Ammonia Criterion

1. The one-hour average concentration of total ammonia nitrogen (in mg N/L) does not exceed, more than once every three years on the average, the CMC (acute criterion) calculated using the following equations:

   - Where salmonid fish are present:
     - $CMC = (0.275/(1 + 10^{7.204\text{-}pH})) + (39.0/(1 + 10^{pH\text{-}7.204}))$
   - Or where salmonid fish are not present:
     - $CMC = (0.411/(1 + 10^{7.204\text{-}pH})) + (58.4/(1 + 10^{pH\text{-}7.204}))$

2.

   A. The thirty-day average concentration of total ammonia nitrogen (in mg N/L) does not exceed, more than once every three years on the average, the CCC (chronic criterion) calculated using the following equations:

   - When fish early life stages are present:
   - $CCC = ((0.0577/(1 + 10^{7.688\text{-}pH})) + (2.487/(1 + 10^{pH\text{-}7.688}))) \times MIN\ (2.85,\ 1.45 \cdot 10^{0.028 \cdot (25\text{-}T)})$
   - When fish early life stages are absent:
   - $CCC = ((0.0577/(1 + 10^{7.688\text{-}pH})) + (2.487/(1 + 10^{pH\text{-}7.688}))) \times 1.45 \cdot 10^{0.028 \cdot (25\text{-}MAX(T,7))}$

   B. In addition, the highest four-day average within the 30-day period should not exceed 2.5 times the CCC.

United States
Environmental Protection
Agency

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