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Ecological Condition of Streams in Eastern and Southern Nevada

EPA R-EMAP Muddy-Virgin River Project

Photo: Las Vegas Valley Wash

RESEARCH AND DEVELOPMENT

Ecological Condition of Streams in Eastern and Southern Nevada

EPA R-EMAP Muddy-Virgin River Project

Prepared by

Leah Hare[1], Daniel Heggem[1], Robert Hall[2], Peter Husby[3]

[1]U.S. Environmental Protection Agency
Office of Research and Development
National Exposure Research Laboratory
Environmental Sciences Division
Las Vegas, NV 89119

[2]U.S. Environmental Protection Agency
Region 9 WTR2
San Francisco, CA 94105

[3]U.S. Environmental Protection Agency
Region 9 Laboratory
Richmond, CA 94804

U.S. Environmental Protection Agency
Office of Research and Development
Washington, DC 20460

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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 Muddy-Virgin River Project Area. 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, Reviewer Steve Gardner and Reviewer Richard Tippit.

Notice

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Executive Summary

This report summarizes data collected from the wadeable streams in the Muddy-Virgin River Project Area 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 Muddy-Virgin River Project Area. 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 Muddy-Virgin River Project was to assess the water quality and biotic integrity of perennial and intermittent streams over a one year sampling period for the Muddy-Virgin River Project Area, using a combination of macroinvertebrates, physical habitat measurements, water and sediment chemistry, and sediment metabolism. The objectives of the Muddy-Virgin River Project Area R-EMAP were to describe the condition of surface waters, relate ecological conditions to ecological stressors and examine relative risks to streams within the Area.

The report presents data collected during a one year study period beginning in May of 2000. 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 37 sites were sampled.

This study has provided a substantial baseline data set for the Basin. While the percentage of impacted streams varied, many 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 as related to 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 Muddy-Virgin River Project Area.

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Acronyms and Abbreviations

ACEC Area of Critical Environmental Concern

AFDM Ash Free Dry Mass

BLM Bureau of Land Management

BOD Biochemical Oxygen Demand

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

R-EMAP Regional Environmental Monitoring and Assessment Program.

SpC Specific Conductance

SEC Sediment Effect Concentration

UNR University of Nevada, Reno

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 water bodies.

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 0.05 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.

Foreword

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 Muddy-Virgin River Project Area in southern 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.

Today, all of Nevada's major population centers are either situated near or bisected by one of its major rivers. The cities and towns utilize the life giving water of those rivers; the vast reaches of dryness demand this relationship. Las Vegas derives its water from the Colorado River via Lake Mead. The rivers in the Muddy-Virgin River Project Area also drain into Lake Mead, supplying additional water needs for a thirsty city. The water relied upon today will be used for future generations. Though the assessment of Nevada's rivers and streams has gotten off to a slow start, decisions made today regarding water management in the Great Basin region will be important for years to come.

I. Introduction

“Water! It’s about water.”

Wallace Stegner, western author and lifelong resident of the arid regions of western North America, was asked what a newcomer to the American West should know. The above statement was his terse reply. In fact, life does not exist without water. This fact is nowhere more pertinent than in the Nevada Great Basin where rivers are the flowing arteries in the midst of huge, arid, and often desolate western landscape. These streams and rivers have been a critical resource to both humans and wildlife for many thousands of years.

This report summarizes data collected from the wadeable streams in the Muddy-Virgin River Project Area 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 Muddy-Virgin River Project Area.

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

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II. Basin Description

The Muddy-Virgin R-EMAP project area encompassed eastern and southern Nevada (NV). The study area extended from Ely, NV, in east-central Nevada, south to Las Vegas, NV, to southeastern Utah (Washington County), and the Lake Mead National Recreation Area of Arizona. The study area encompassed 32,856 square miles in Nevada, 5,400 square miles in Arizona and 2,400 square miles in Utah. Arizona and Utah were included to incorporate the lower Virgin River Basin. All major drainages in this system with flowing surface water, during the index period of May/June, were sampled for this study. These included the White River, Pahranagat River, Beaver Dam Wash, Meadow Valley Wash, Muddy River, Las Vegas Valley Wash, and Lower Virgin River (Figure 1).

The eastern and southern portion of Nevada is in Ecoregion III (Omernik, 1987), subecoregions 13 (Central Basin and Range) and 14 (Mojave Basin and Range) with a small portion of Arizona and Nevada in subecoregion 22 (Arizona/New Mexico Plateau). The portion of the lower Central Basin and upper Mojave Basin is comprised of north-south trending fault-bounded horst and graben geomorphology. The Mojave Basin and Range physiography is a creosote bush-dominated shrub community (Figure 2). This is distinct from the saltbush-greasewood and sagebrush-grass associations that occur to the north in the Central Basin and Range. Major vegetation communities include montane, pinyon-juniper, western juniper, sagebrush/grassland, shadscale, and Mojavean (Mac et al., 1998). 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. Fan deposits in the Mojave Basin and Range ecoregion are predominantly composed of debris flows.

The Virgin River is the largest contributor to the Colorado River in Nevada. During low-flow periods, most of the flow in the Virgin River originates from a highly saline, major spring system in Littlefield, Arizona, located approximately 10 miles upstream of Mesquite (ADWR, 2009). Precipitation is low (e.g., <15 cm/year in subecoregion 14) in this region whose elevation ranges from 367 to 3626 m. Surface water resources in the drainage basin are primary spring fed with the Virgin River receiving drainage from snowmelt in central and eastern Utah. The Las Vegas Valley Wash is currently an urban drainage system with few naturally flowing springs, but does receive spring or autumnal monsoon rainfall. Flash flooding is an important ecological event in eastern and southern Nevada. However, flash flooding does not occur with its historical frequency or severity due to regulation of all streams and rivers.

The wadeable streams of eastern and southern Nevada do not represent a broad range of basin areas and gradients. Most high elevation streams are dry throughout most of the year, with flow alternating between the surface and hyporheic zone and returning to valley streams. Basin streams, which have flowing water for most of the year, do not lend themselves to conventional stream order, which classifies stream size based on a hierarchy of tributaries. It is important to acknowledge that the basin morphology does influence stream processes. Unfortunately, how basin morphology interacts with stream processes for eastern and southern Nevada is unknown. The results of this study imply that paradigms of the relationships between stream order and basin morphology are not applicable to desert, spring-fed stream systems. This is most likely a result of the sensitive nature of the desert environment to anthropogenic stressors. Because this relationship is unknown, it is difficult to determine if the interpretation of stream condition is confounded.

Figure 1. Location of Major Rivers and Sampling Sites.

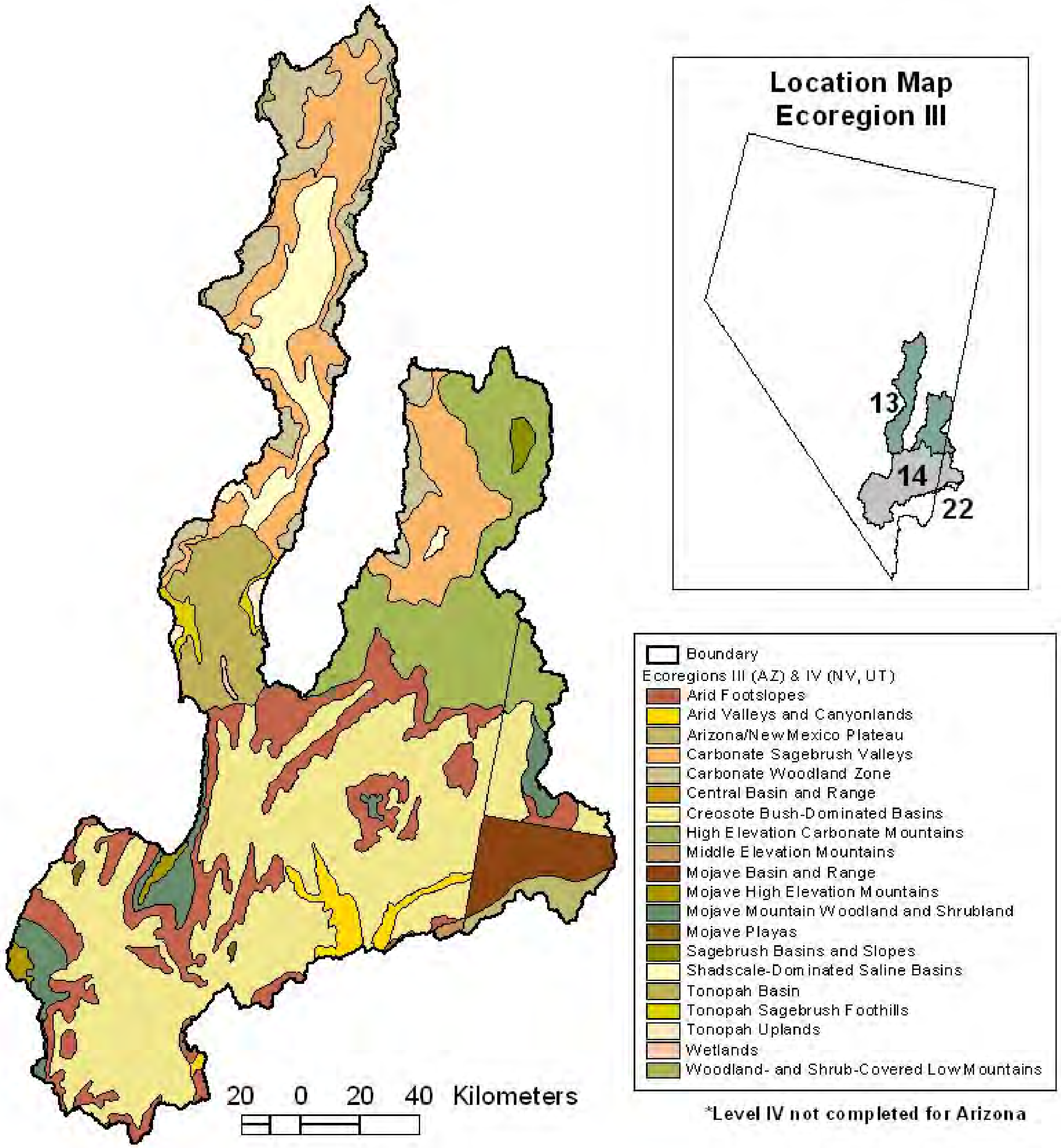


Figure 2. Ecoregions of the Muddy-Virgin River Project Area.

Heavy water use, approximately 75%, of existing flowing water and pumping of aquifers further decreases the extent of river flow in the Muddy-Virgin project area. The Pahranagat and White rivers are highly manipulated, and large portions of the rivers exist in straight ditches rather than natural, meandering channels. The Meadow Valley Wash is an intermittent stream system, which has primarily hyporheic flow in its lower-middle portion and only during flash floods will flow into the Muddy and Virgin rivers. The Muddy and Virgin Rivers are also highly disturbed being moderately channelized and having regulated flow. These rivers are under pressure from agricultural practices, ranching, dairy farming, a coal-fired power station (Muddy River), mining, water treatment facilities, and urban influences. Additionally, the Las Vegas Valley Water Authority plans to pump the aquifers at the head of the Muddy River, the effects of which are yet unknown.

Streams in eastern and southern Nevada are home to several endemic and listed species. The Muddy River has the endangered Moapa Dace (*Moapa coriacea*) and several endemic snails. The Pahranagat roundtail chub (*Gila robusta jordani*) is endemic to the Pahranagat River, and the Virgin River chub (*Gila robusta seminude*) to the Virgin River. Threats to these biotic endemics include invasive organisms, [e.g., fish (*Tilapia spp*.) and plants (*Tamarix sp*.)], water withdrawal, sedimentation and chemical and thermal pollution.

With the vast majority of the land in northeast Clark County under federal management, private land is predominantly located along the Muddy and Virgin River flood plain corridors. Agricultural irrigation is the primary water use. Pollutants of concern are total phosphorus and metals including boron, iron and arsenic. Several dairy farms and feedlots identified in the vicinity of the Muddy River can be key contributors of BOD loading, nitrates and bacteria in downstream receiving waters. The only significant industrial operation in the lower Muddy River is NV Energy’s Reid Gardner Power Plant near the unincorporated area of Hidden Valley. While runoff from a large stockpile of coal at this site is intercepted in a containment ditch, it has been reported that during large discharge events, flow from the site may reach the Muddy River (Clark County, 2008).

Soil erosion from agricultural lands can contribute significant amounts of nutrients, trace metals and pesticides to receiving waters. Forms of nitrogen and phosphorus are associated with either irrigation return flows or storm runoff. Along the lower reaches of the Muddy-Virgin River system, the soils are highly susceptible to erosion (Clark County, 2000). As of 2000, Moapa Valley, encompassing the lower part of the Muddy River, has 5,182 acres of agricultural lands, of which 4,982 acres are irrigated. Virgin Valley, in the lower portion surrounding the Virgin River, has 3,531 acres of agricultural lands, of which 3,068 acres are irrigated. Irrigation, along with the effects of evapotranspiration, results in an increased salt concentration in irrigation return flows. Fertilizers applied to agricultural areas can impact residual nitrogen and phosphorus transported to receiving waters.

The Virgin River is designated as an Area of Critical Environmental Concern (ACEC) in the BLM’s Proposed Las Vegas Resource Management Plan (1998). The U.S. Fish and Wildlife Service has established two fish recovery teams, one for the entire length of the Virgin River and the other specifically in the lower Virgin River for the recovery of the federally endangered woundfin *(Plagopterus argentissimus)*, Virgin River chub (*Gila robusta seminude*), and three additional species of special concern.

Originally, the Muddy River was bordered by willow *(Salix sp.)* and screwbean mesquite *(Prosopis Pubescens)* (Longwell, 1928). Now the dominant trees along the spring systems in the Warm Springs area are non-native palms and tamarisk (*Tamarix sp*.), which is the most common riparian species along the middle and lower Muddy River (Clark County, 2008).

Except for the immediate riparian corridor, the southern desert shrub is the dominant vegetation community mapped by BLM (1998). Riparian vegetation along the river includes rushes, cattails, inland salt grass and stands of mesquite and greasewood (City of Mesquite, 2009). See Figure 3 for land cover in the Muddy-Virgin River Project Area.

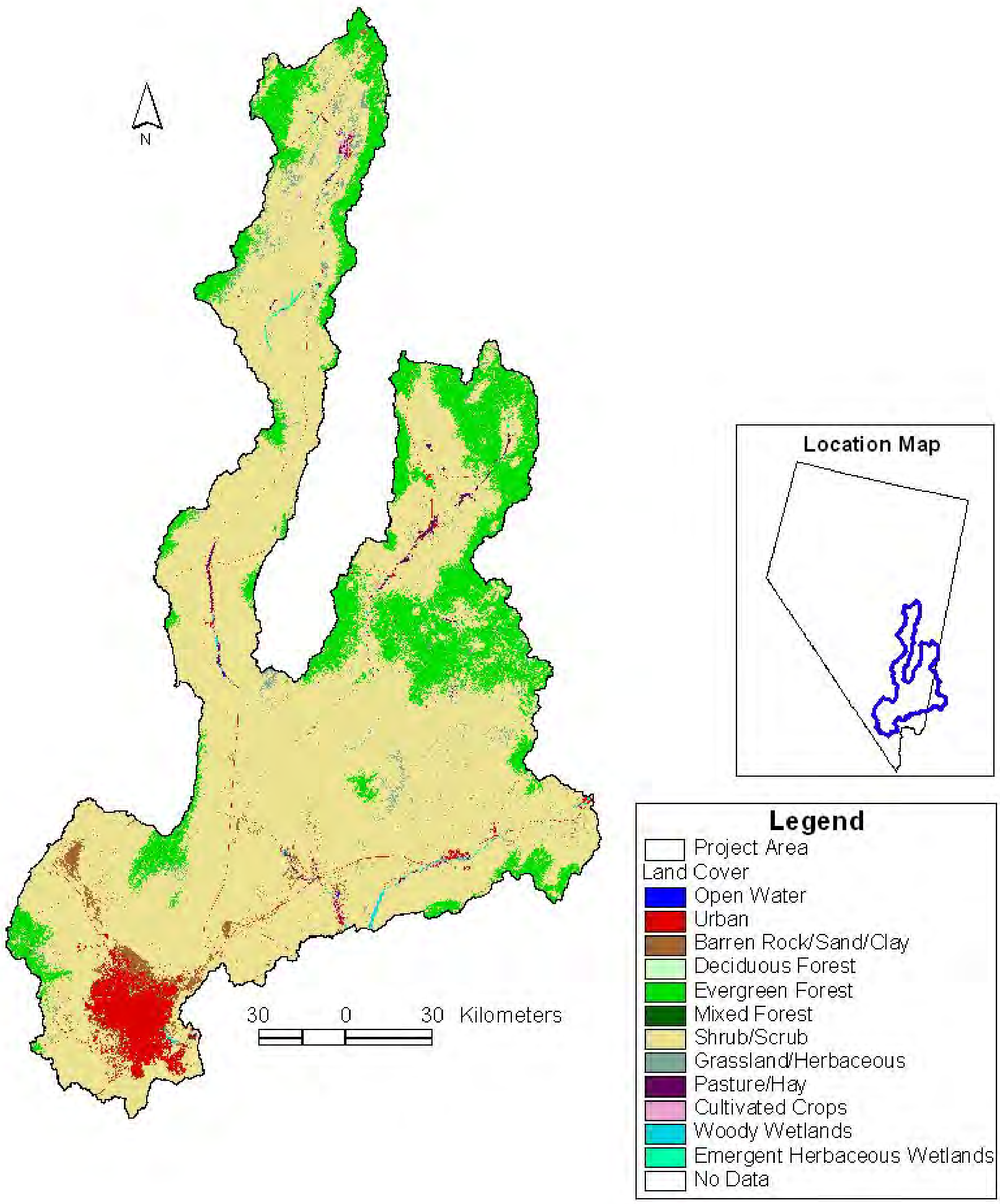


Figure 3. NLCD 2000 Land Cover for Muddy-Virgin River Project Area.

III. Project Description

This report summarizes data collected from the wadeable streams in the Muddy-Virgin River Project Area. The determination of current status is a critical step in the future management of stream resources such as water quality, 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 Muddy-Virgin River Project Area. 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, 1998).

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

- Describe the ecological condition of surface waters in the Muddy-Virgin River Project Area.
- 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 Muddy-Virgin River Project Area.

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 Muddy-Virgin River Project Area, sites (Figure 1) were assessed for accessibility based upon the knowledge of local experts with field experience in the Muddy-Virgin River Project Area, 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, 1999, 2004) over the Muddy-Virgin River Project Area. 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 Muddy-Virgin River Project Area 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 Muddy-Virgin River Project Area
- Equal representation of stream courses
- Equal representation of one year, 2000
- Detection of trends in a set of indicators by revisiting at least 10% of the sites sampled the previous year (Stevens & Olson, 1999)

Optimal statistical representation of aquatic resources in the Muddy-Virgin River Project Area 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 statistical extent of the Muddy-Virgin River Project Area resource was estimated at 12,427 km stream length.

The sampling index period for this study was May-June, 2000. The southern Great Basin and Mojave Basin ecoregions receive approximately five to seven inches of rain per year with most of the rainfall occurs during winter and summer. Tributaries to the Muddy River and Virgin River are predominantly ephemeral. Because of the arid nature of the southern Great Basin and Mojave Basin, to obtain a statically significant number of sampleable sites (~40) during the index period, 1500 sites were randomly selected.

Reconnaissance of random site locations was conducted from December 1999 to May 2000. The objective during the site selection process was to maximize the number of sites with flowing water, limit the number of sites with no water, and to gain an understanding of the hydrographic region as a whole. Sites were initially mapped onto DeLorme's Atlas and Gazetteer. Sites in Utah and Arizona were reconnaissanced (and sampled) only if they were located on the Virgin River. In the field, sites were located using 7.5" USGS and BLM topographical maps and a

Garmin III Global Positioning System Unit. Actual site coordinates were recorded on the USEPA R-EMAP datasheet.
In addition to reconnaissance by UNR field staff, to acquire local background knowledge on the sites, possible R-EMAP sites were mapped onto USGS topographic maps and sent to the local BLM office in Caliente, NV, and the U.S. Fish and Wildlife Service office in Las Vegas, NV. Of the 1500 randomly generated sites, status of surface water (i.e., flowing water present) was determined by ground verification of USEPA site coordinates with a GPS unit for 116 random sites, and comparison of mapped location with field observations for 243 sites. Status of surface water for all other sites were determined by comparing detailed field notes with mapped location of each site. Only 37 sites had flowing surface water and thus were able to be sampled (Appendix 1).

In relation to site accessibility, land ownership proved not to be an issue in this area. Twenty-seven percent of sampled sites were on federal land (BLM, national parks, state parks, etc.), 12% owned by the state of Nevada, and 61% privately owned. Private ownership was determined by comparing sites mapped onto 1:60,000 USGS topographic maps to land ownership maps in respective county assessor offices.

Landowners were contacted via telephone for access to sites on private lands and explained that UNR is conducting an aquatic assessment project involving sampling water quality and biotic parameters. It was clearly explained to the landowners the goal of this project is to develop a baseline understanding of the current status of the watersheds surface waters. The objectives of this study did not include identification of federally listed or endemic species. Of all sites with flowing water, four sites were not physically able to be sampled and one site was not granted access from private land owners.

The original site location was shifted when the site was not able to be sampled due to morphological changes in location of the channel, channels with large hyporheic zones, or vegetation or land use conflicts where the original site could not be reached. Seven percent of original site locations were shifted up or downstream to accommodate land ownership. A problem exists with the R-EMAP protocol of choosing random locations for sampling for eastern and southern Nevada. Most areas mapped as surface water on USGS and BLM topographical maps are actually dry washes that flow intermittently with heavy rainfalls. In these intermittent stream channels, flow generally consists of flashflood events, which would not be samplable.

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 1997; 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.

Periphyton:

Periphyton samples were collected at the nine cross-sections at erosional and depositional habitats of each sample reach. In erosional habitats, a sample of substrate was scrubbed within a 15 cm diameter to remove the periphyton, and placed in a funnel which then drained into a bottle. In depositional habitats, the top 1 cm of a 12 cm^2 area of soft sediments was vacuumed into a syringe. The syringe was then emptied into a plastic bottle.

Four types of laboratory samples were prepared. An ID/enumeration sample determines composition and abundance. Chlorophyll and acid/alkaline phosphatase activity (APA) samples were analyzed for their relation to biomass and structure. A biomass sample was also taken. This is a measurement of the organic matter of a sample, measured by weighing the difference in mass after drying and incinerating the matter. The remains are ash free dry mass (AFDM). The sample was then weighed against its dry mass to determine the biomass. This was done to discount against any silt or other inorganic matter.

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).

Photo: Pahranagat River south of Upper Lake

IV. Analysis and Results

Using the R-EMAP protocols described, data was collected from 37 sites in the Muddy-Virgin project area. Data quality assurance procedures followed those outlined in USEPA bioassessment guidelines. For this report, because of the large volume of data/information collected, only indicators of significant interest are reported on. Additional indicators are summarized in Appendix 3. In the project area, stream order, which classifies stream size based on a hierarchy of tributaries, consisted of first, third, forth and fifth order streams, with the majority of samples taken in the fifth order streams (Table 3).

Table 3. Streams in the Muddy-Virgin Project Area by Stream Order.

Stream Order	No. of Samples	% Total
1	1	1.6
3	13	23.4
4	6	10.1
5	17	64.9

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 Muddy-Virgin River Project stream reach had a value greater than or equal to the value selected on the x-axis. For example, Figure 4 shows that approximately 95% of the stream length has a measurement of Total Phosphorus of $\leq$ 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. The "population" in this report is the stream reaches in the Muddy-Virgin project area.

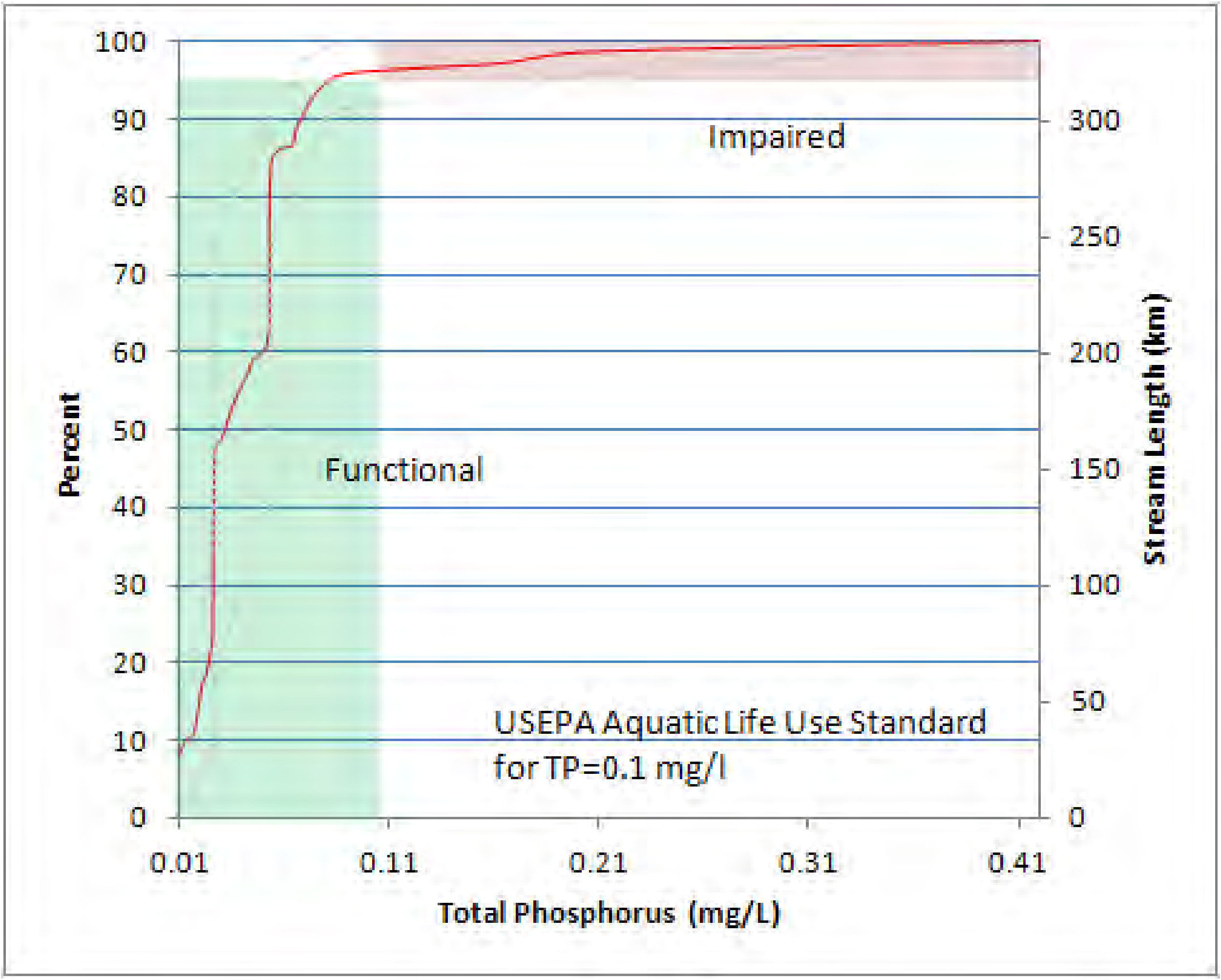


Figure 4. Cumulative Distribution Frequency of Stream Total Phosphorus.

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 11 water column indicators were collected from 37 sites (Appendix 2). 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. Stream location values were graphed using the data from the 22 sampling sites located on the Virgin River and Muddy River. Cumulative Distribution Frequency and Condition Estimate were done with data from all 37 sites collected in the Muddy-Virgin River Project Area.

Temperature

Water temperature is temporally variable and can vary daily and seasonally, thus a single measure of water temperature is limited in determining stream conditions. However, during the sampling period (May-June) water temperature ranged from 13.1 to 32.8°C over all sites with a mean temperature of 23.1°C. High stream temperatures were expected here as most of the study streams are warm-spring fed. There was no relationship between temperature and latitude or between water temperature and mid-channel shading (Figure 5). Using Nevada State criteria as a reference, at the time of sampling, fifteen samples exceeded the 24°C standard and twenty-five sites exceeded the 20°C standard. Figure 6 shows the CDF and condition estimate using 20°C as the condition standard.

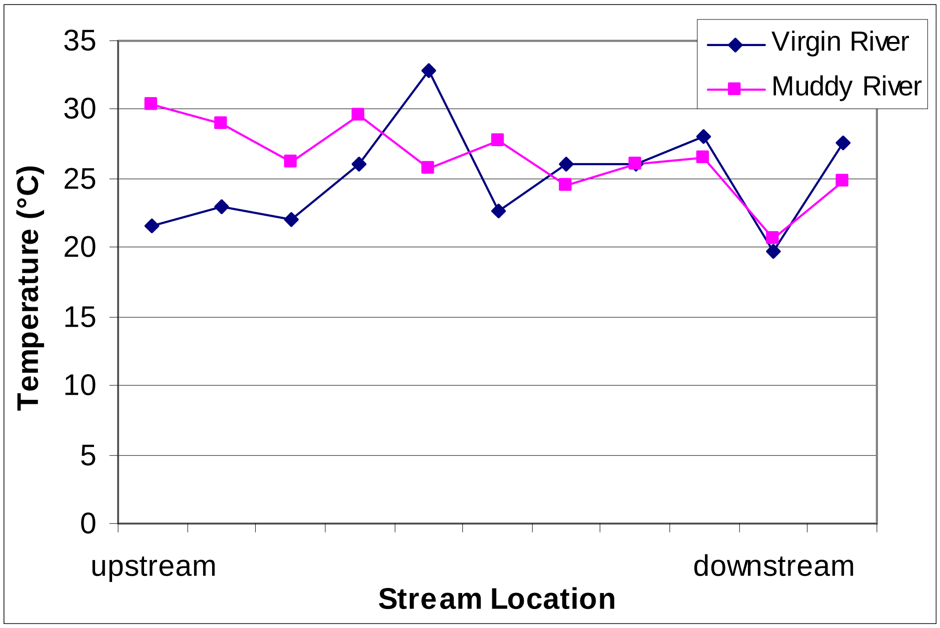


Figure 5. Temperature and Latitude Graphed Separately for Muddy and Virgin River Drainages, n= 22.

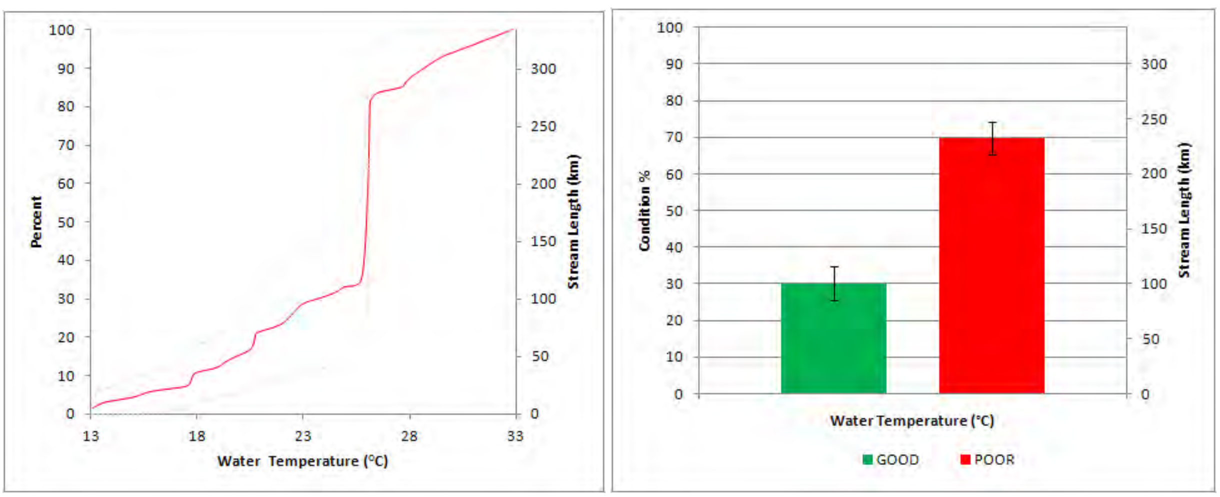


Figure 6. Cumulative Distribution Function and Condition Estimate for Stream Water Temperature.

pH

Another important water column variable, hydrogen ion activity (pH), is a numerical measure of the concentration of the constituents determining water acidity. It is measured on a logarithmic scale of 1.0 (acidic) to 14.0 (basic) and 7.0 is neutral. As seen in Figure 7, the pH values in the upstream portions of the Virgin River range from 7.9 to 8.4, which is indicative of increased alkalinity from the carbonate rock units which underlay the Basin. 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 pH of the Muddy-Virgin area ranged from 7.2 to 8.6 with an average of 8.0 (Figure 8). All of the sampled stream reaches were within the state of Nevada's pH standard of 6.0 to 9.0. The condition estimate was not determined for pH as all the sample sites fell into the good category. This study indicated that pH was not a sensitive indicator of anthropogenic stress within the basin.

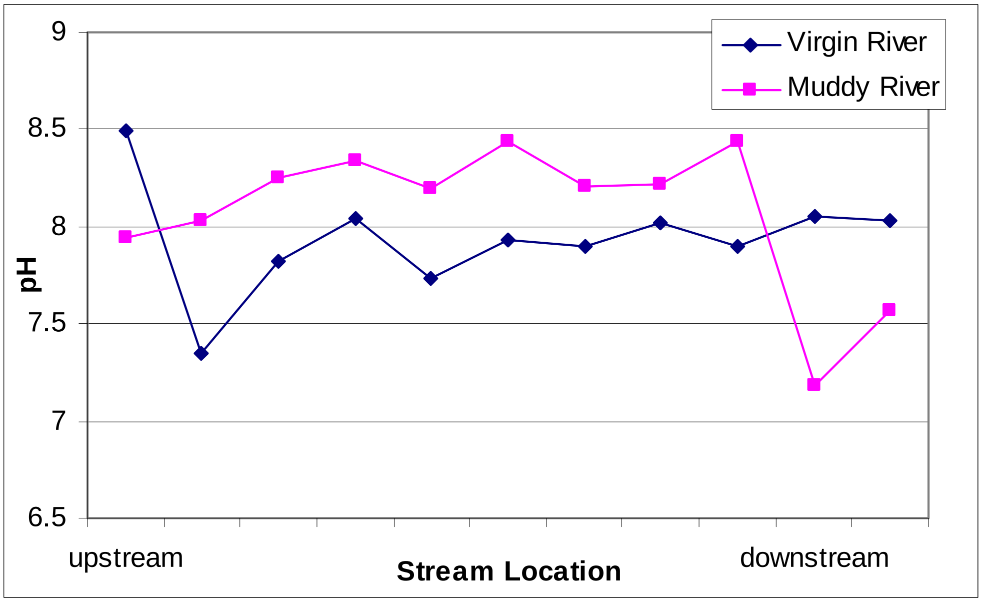


Figure 7. pH Values Graphed in Relation to Sampling Location in the Muddy and Virgin Rivers, n=22.

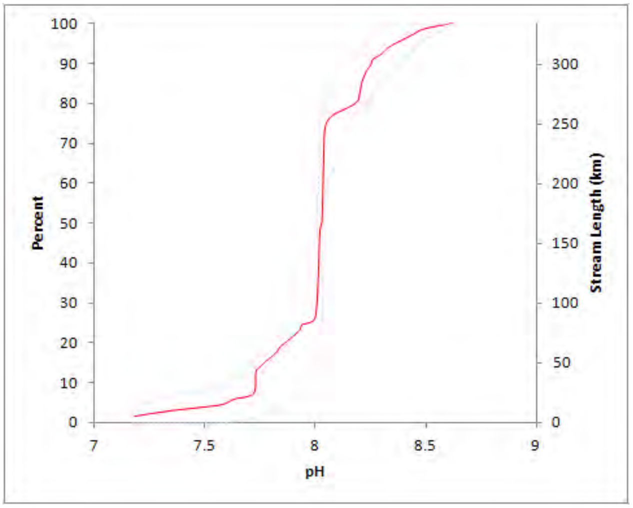


Figure 8. Cumulative Distribution Frequency of pH of Streams.

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 specific conductance standard is 800 µS/cm. The net increase from upstream to downstream for both the Muddy River and Virgin River (Figure 9) was most likely a result of cumulative increase of salts in the downstream direction resulting from the river systems draining carbonate rocks sequences (Eakin, 1964) and agriculture return flows in the lower reaches. Conductivity in the Muddy-

Virgin area ranged from 793 to 3800 µS/cm with a mean of 1704 µS/cm (Figure 10). In the Muddy-Virgin River Basin, 80% of the samples exceeded this standard. This is most likely a result of the natural background saline nature of the valley soil chemistry

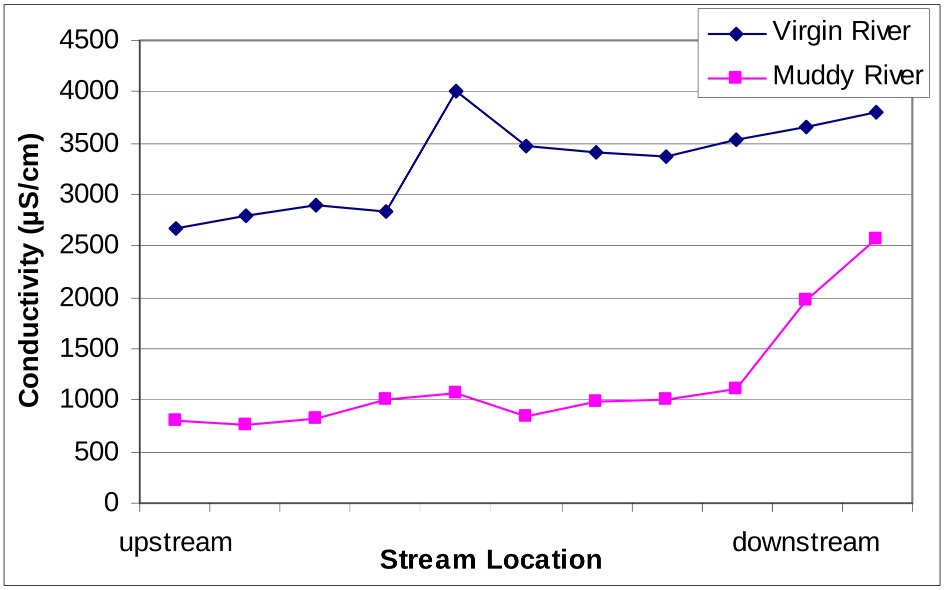


Figure 9. Conductivity Values Graphed in Relation to Sampling Location in the Muddy and Virgin Rivers, n=22.

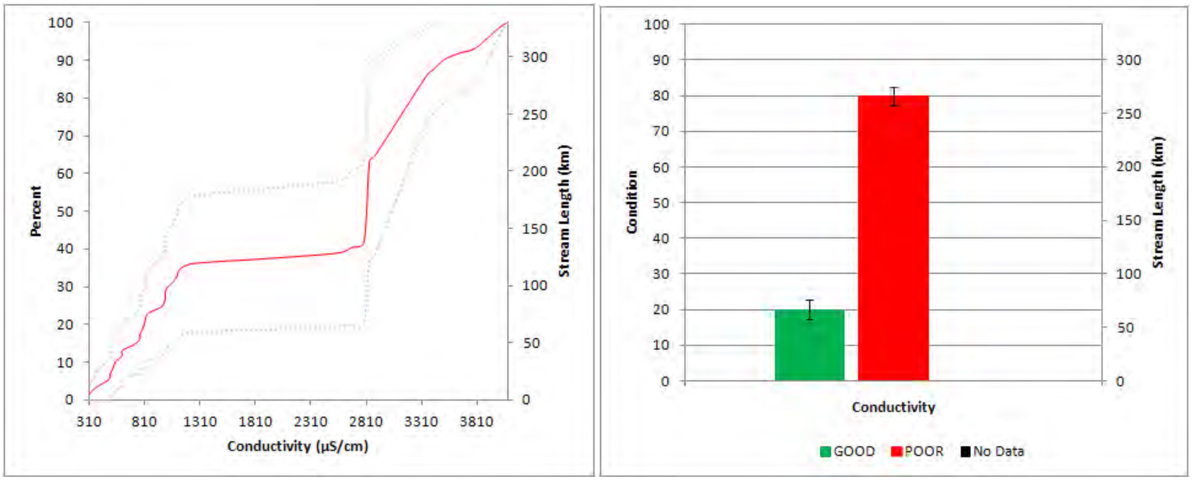


Figure 10. Cumulative Distribution Frequency and Condition Estimate of Stream Conductivity.

Dissolved Oxygen (DO)

Dissolved oxygen is 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. The higher latitude sites tended to have higher DO values for the Virgin River, but the relationship between DO and latitude was not significant (R=0.114, P=0.724). In the Muddy River, DO levels were slightly higher downstream (R=-0.402, P=0.195) (Figure 11). DO values ranged from 5.1 to 12.8 mg/L with a mean of 8.3 mg/L among sampling sites (Figure 12). All sites had DO values exceeding 5 mg/L, with two sites below the 6 mg/L standard representing the lower limits determined suitable by Nevada state standards. The condition estimate was not determined for DO as all the sample sites fell into the good category.

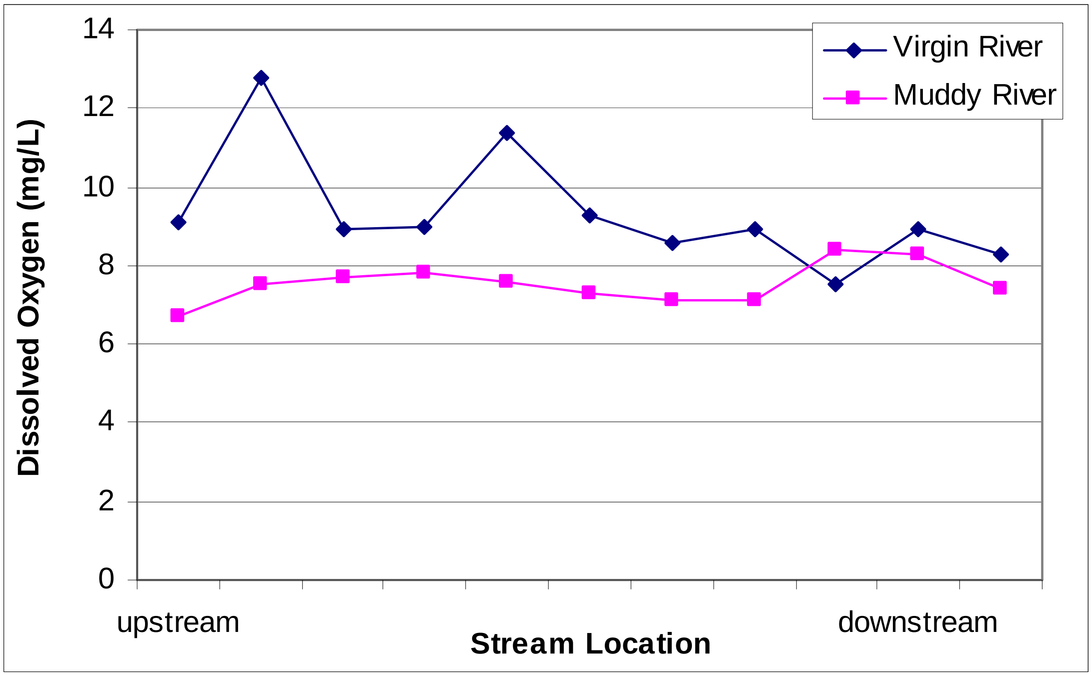


Figure 11. Dissolved Oxygen Values Graphed in Relation to Sampling Location in the Muddy and Virgin Rivers, n=22.

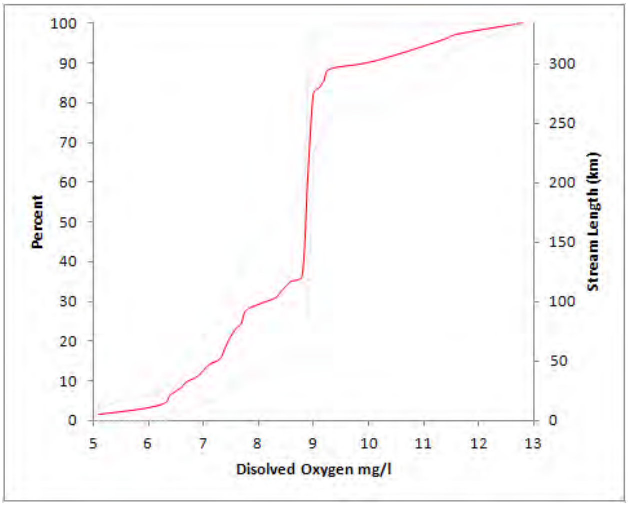


Figure 12 Cumulative Distribution Frequency of Stream Dissolved Oxygen.

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 six water nutrient parameters were collected at all sites. Water samples were analyzed for chloride, ammonia, nitrite/nitrate, total Kjeldahl nitrogen, total phosphorous (TP), and sulfate. Total nitrogen was calculated. Sulfate summary statistics can be found in appendix 2. Five nutrients were selected for condition analysis and are shown in Table 5.

Table 5. Nutrients in the Muddy-Virgin Area, Expressed as mg/L.

Indicator	Mean	Min	Max
Total Phosphorus	0.06	0.01	0.43
Total Nitrogen	0.68	0.09	4.02
Nitrate/Nitrite	0.36	0.00	3.11
Total Kjeldahl Nitrogen	0.29	0.06	0.88
Ammonia	0.03	0.01	0.09
Chloride	173.08	1.0	675.00

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. The state of Nevada water quality standard for total phosphorus (TP) is 0.1 mg/L, except for the reach from Glendale to Lake Mead which has a water quality standard of 0.3 mg/L. Total phosphorus in eastern and southern Nevada streams ranged from <0.01 to 0.43 mg/L with a mean of 0.06 mg/L (Table 5). As seen in Figure 13, very low phosphorus concentrations had an impact on macroinvertebrate taxa richness. As concentrations increased, taxa richness increased until the water quality standard was exceeded. As phosphorus concentrations increased above the standard, there was a net impact to aquatic organisms. The condition estimate level was set at 0.1 mg/l for total phosphorus. Figure 14 shows that in the Muddy-Virgin area the ecological condition for total phosphorus is good in 95 percent of the Basin and in poor condition in 5 percent.

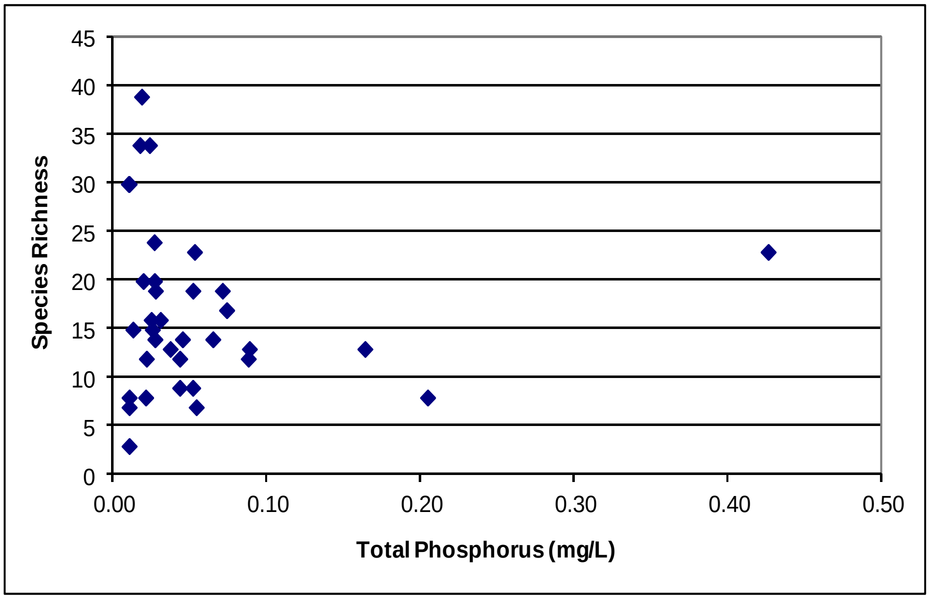


Figure 13. Total Phosphorus in Relation to Species Richness in all Sampling Sites Included in the Study, R=-0.048, P=0.783, n=35.

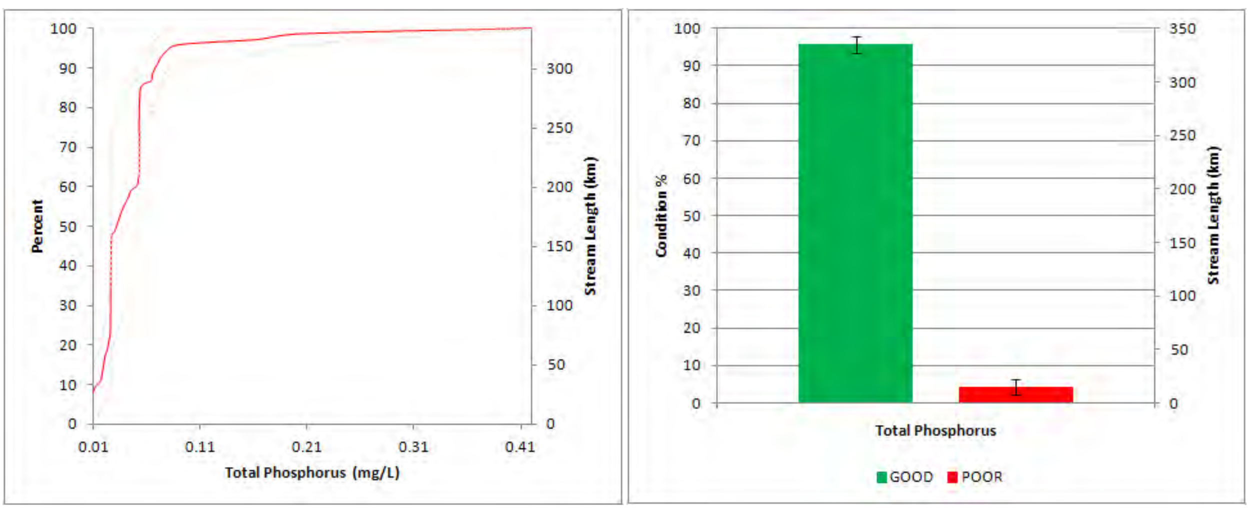


Figure 14. Cumulative Distribution Frequency and Condition Estimate of Total Phosphorus.

Total Nitrogen

Nitrogen is a necessary life nutrient. In excess it becomes a pollutant which can cause gross imbalances in ecosystem function. It is a primary cause of eutrophication of surface waters, in which excess nutrients, usually nitrogen and phosphorus, stimulate algal growth. Total Nitrogen (TN) is the sum of nitrate/nitrite-nitrogen, ammonia and organically bonded nitrogen. Samples for the Muddy Virgin Area ranged from 0.09 mg/l to 4.02 mg/l with a mean of 0.68 mg/l. The condition estimate level (Figure 15) was set at 0.38 mg/l in accordance with USEPA Ambient Water Quality Criteria Recommendations (USEPA December 2000).

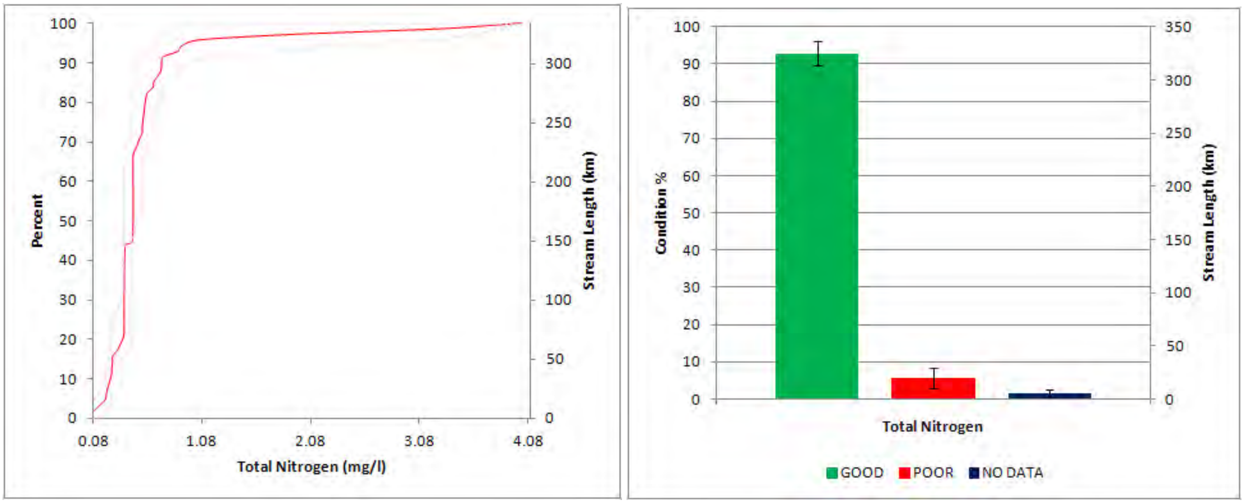


Figure 15. Cumulative Distribution Frequency and Condition Estimate of Total Nitrogen.

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. Nitrite/nitrate in the Muddy-Virgin area ranged from <0.01 to 3.11 mg/L. As seen in Figure 16, there was an overall decreasing trend of nitrite/nitrate downstream. This would indicate the state of the stream riparian function, which is the interaction of the hydrologic, geomorphic and biotic processes within the riparian zone, had an impact on the nitrogen fixation, thus impacting benthic community structure. Yet, there was not a significant relationship between nitrite/nitrate and species richness (Figure 17). The nitrate/nitrite level for condition determination was set at 0.3 mg/l Figure 18. Eighty-two percent of the stream length was found to be in good ecological condition for nitrate and 18 percent was found to be in poor condition.

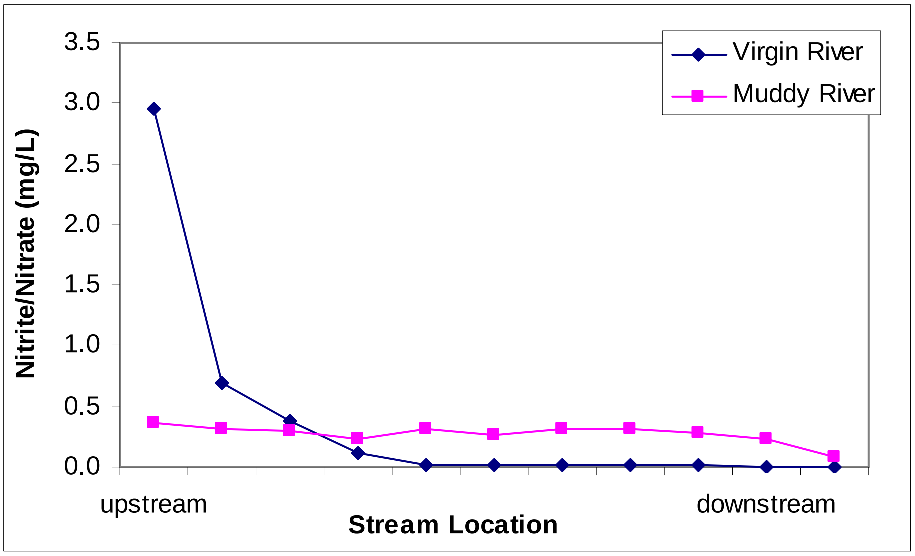


Figure 16. Comparison of Nitrate/Nitrite in the Muddy and Virgin Rivers, n=22.

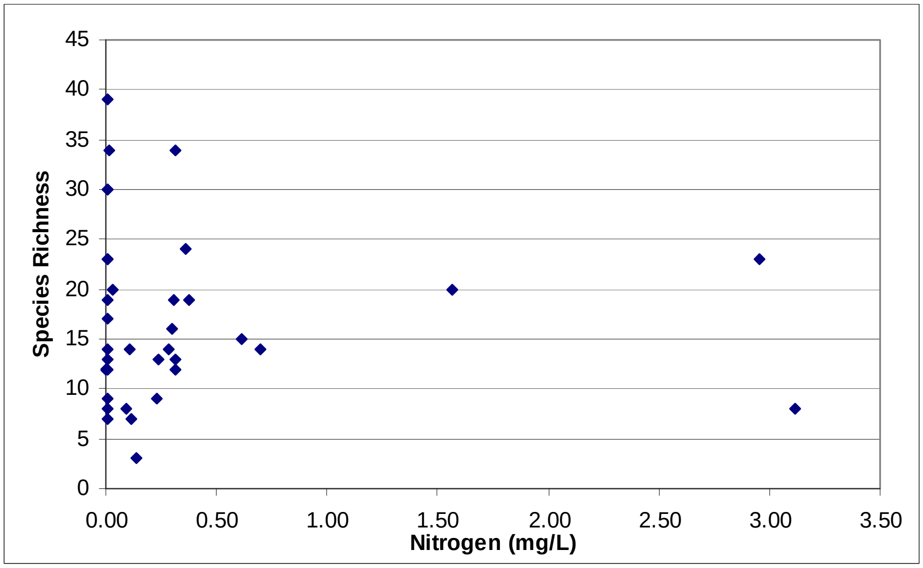


Figure 17. Nitrate/Nitrite Verses Species Richness for all Sampling Sites in the Study Area R=-0.048. P=0.786, n=35.

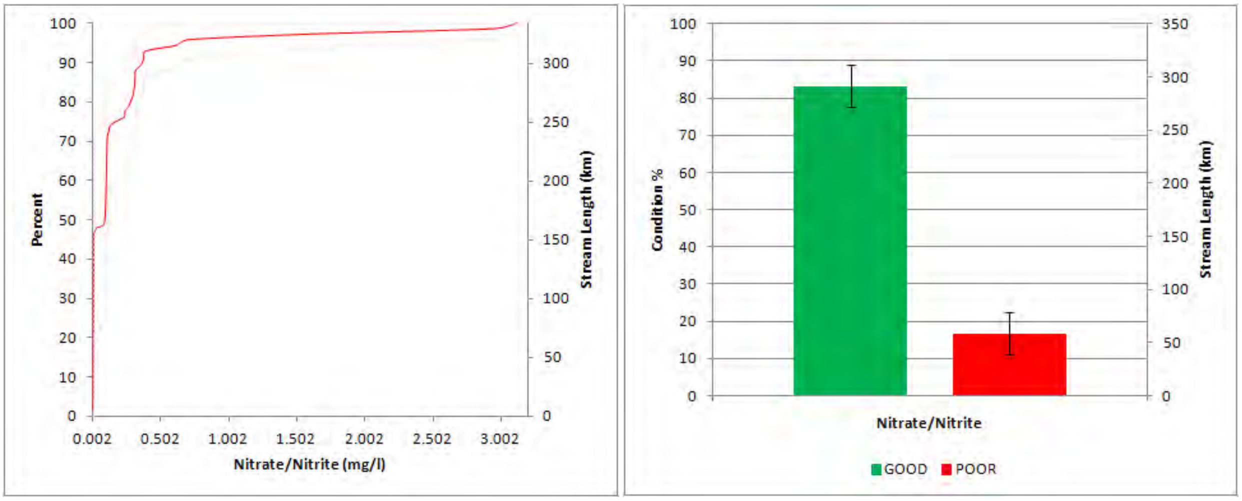


Figure 18. Cumulative Distribution Frequency and Condition Estimate of Nitrate/Nitrite.

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 19 shows that the TKN condition estimate for the Muddy-Virgin area is about 32 percent below that level which is considered in good condition and that 68 percent is above that level and is considered in ecologically poor condition.

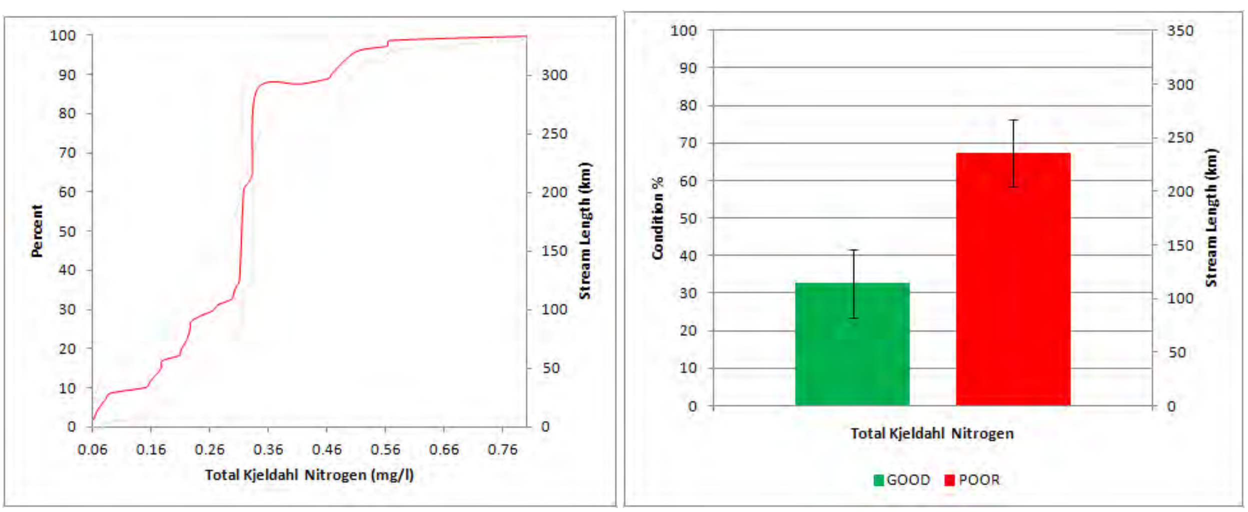


Figure 19. Cumulative Distribution Frequency and Condition Estimate of Total Kjeldahl Nitrogen.

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 20) to be in good condition throughout the Muddy-Virgin area. No condition estimate was done as all the sample sites fell into the good category.

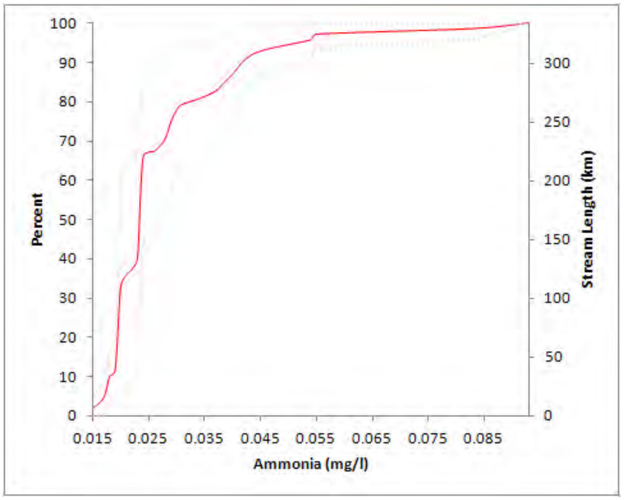
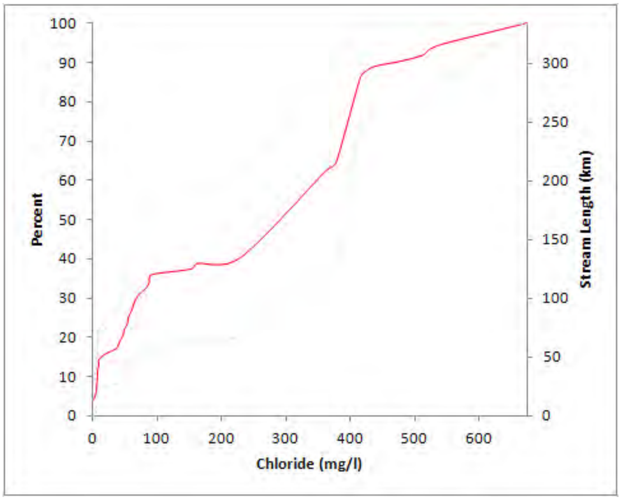


Figure 20. Cumulative Distribution Frequency of Ammonia.

Chloride

Chloride, present in all natural waters at low concentrations, is considered a good water quality tracer because 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 state of Nevada water quality standard for chloride in the Muddy-Virgin River system is 250 mg/L with a range from <1 to 675 mg/L. While the variation in chloride concentrations in Nevada streams appears large, care should be taken to account for solute input from spring sources. Where several sample sites were on one river, only sites with elevated chloride levels, relative to other sites on the same river, should be considered for further research. Using a level of 250 mg/l, Figure 21 shows that the chloride condition estimate for the Muddy-Virgin area is about 40 percent below that level which is considered in good condition and that 60 percent is above that level and is considered in ecologically poor condition.



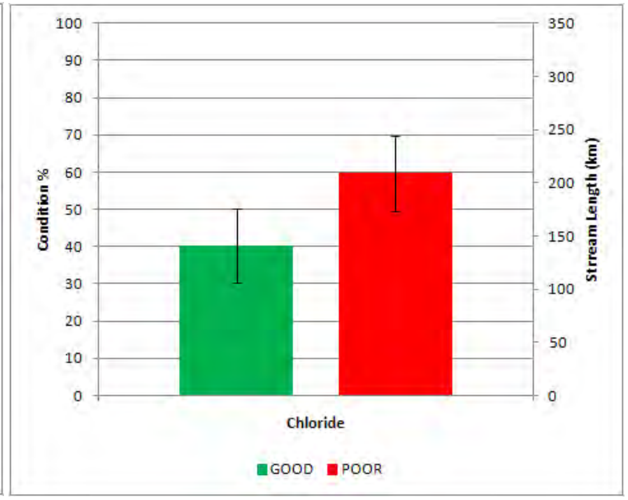


Figure 21. Cumulative Distribution Frequency and Condition Estimate of Chloride.

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 22). Stream orders for sampling sites are listed in Appendix 1.

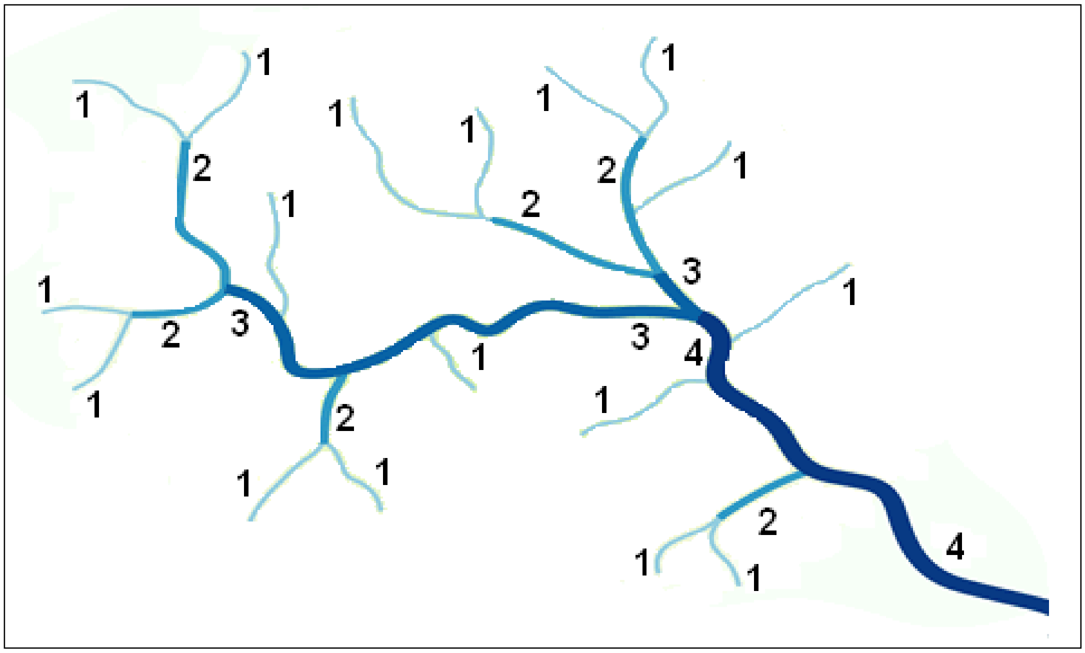


Figure 22. Strahler Stream Order (FISRWG, 1998).

In the Muddy-Virgin project area within the Great Basin, this type of stream classification is not appropriate. Many of the streams are ephemeral washes having flowing water only during summer monsoonal thunderstorms. Most dry channels do not receive snowmelt runoff in eastern and southern Nevada. Streams with flowing water are located in the valley floor and are fed primarily from spring sources. Another contributing factor includes mid-summer monsoons with flash flooding. Stream organization also shows no relationship to the spatial area of the basin (R=-0.123, P=0.617) (Figure 23).

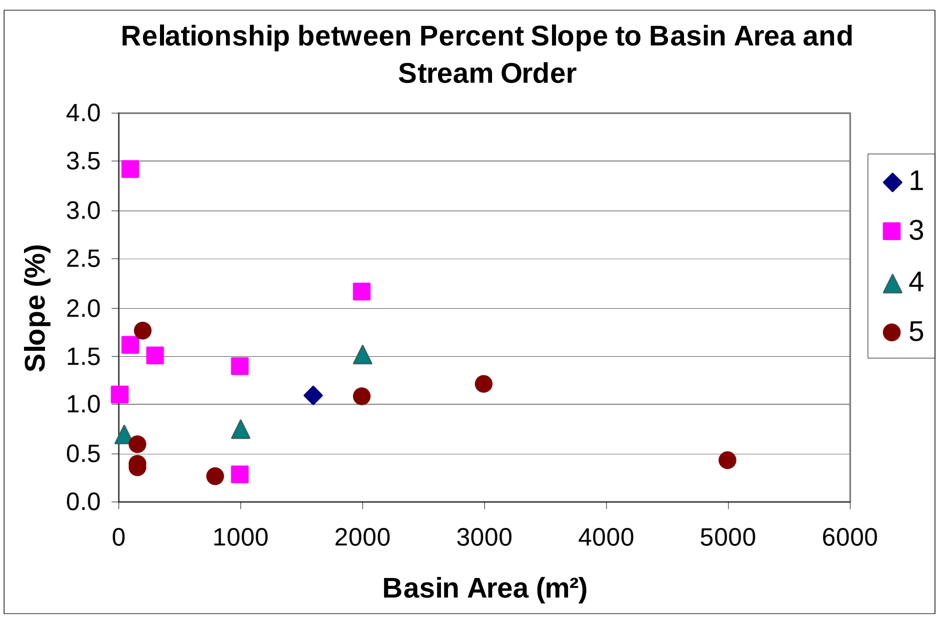


Figure 23. Relationship between Percent Slope to Basin Area and Stream Order, R=-0.123, P=0.617, n=19.

Likewise, stream order was not related to stream wetted width and thalweg depth for all stream orders (R=-0.049) (Figure 24). The first order stream of this study was narrow, shallow and topographically constrained. The third (R=0.756) and fourth (R=0.934) order streams exhibited a positive correlation to thalweg depth, and wetted width. This positive correlation indicated that most of these streams were also constrained in their channels. Fifth order streams did not have a significant correlation (R=-0.148). For all stream orders, mean stream wetted width ranged from 0.0 to 26.6 m and averaged 6.6 m. Mean thalweg depth ranges from 4.3 to 88.6 cm with a mean of 43.3cm.

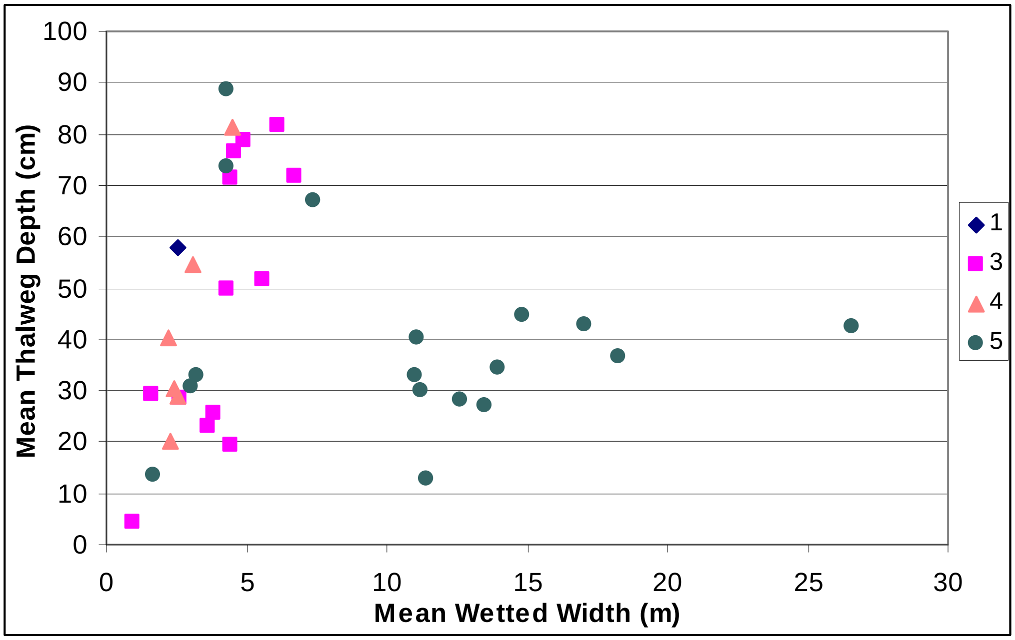


Figure 24. Relationship between Mean Thalweg Depth and Mean Wetted Width by Stream Order, R=-0.049, P=0.771, n=37.

In eastern and southern Nevada, stream flow does not scour alternating banks resulting in a sequence of bars, pools, and riffles. Rather, streams are nearly straight channels with homogenous laminar flow. In direct contradiction to the predicted pool-riffle channel morphology typical of low gradient streams (Montgomery & Buffington, 1998), most of the channels in eastern and southern Nevada have a glide morphology (Figure 25). A total of 92.7% of stream samples were glide, while riffles comprised only 6.7%.

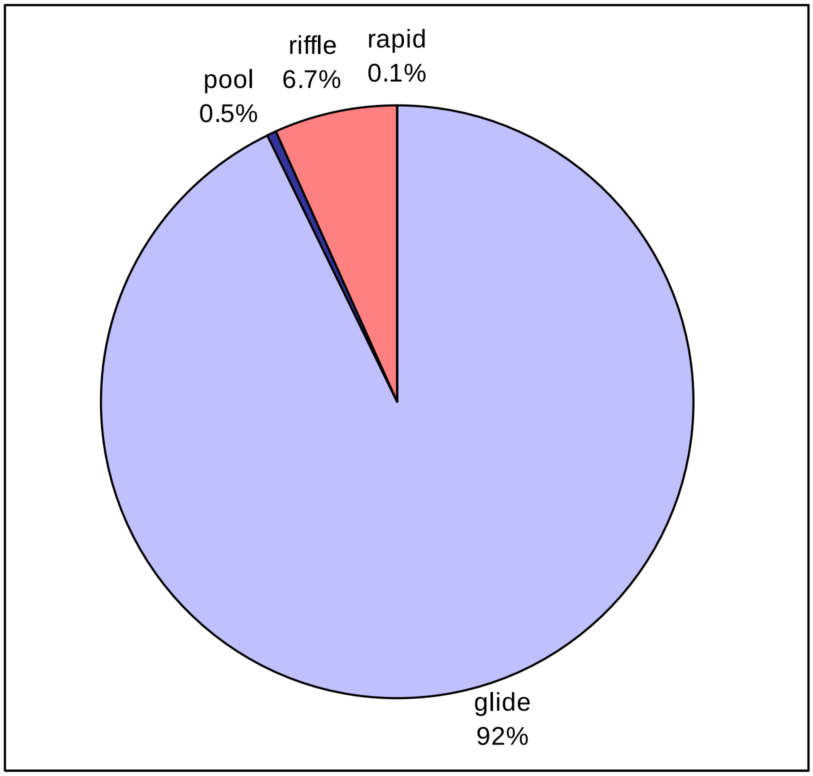


Figure 25. Percent of Stream Samples within each Channel Type.

The wadeable streams of eastern and southern Nevada do not represent a broad range of basin areas and gradients. Most high elevation streams are dry throughout most of the year, and the relationship of dry channels to permanent water sources is unknown. Basin streams, which have flowing water for most of the year, do not lend themselves to conventional stream order. The basin morphology does influence stream processes and this is important to acknowledge. Unfortunately, how basin morphology interacts with stream processes for eastern and southern Nevada is unknown.

Substrate

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

Sand and fine sediment (< 2 mm) was the most common substrate size, comprising 72.6% of all surface stream substrates (Figure 26). Gravel was the next dominant size, comprising 16.4% of all surface stream substrates. Cobble, boulder, hardpan, and other substrate types comprised a limited portion of dominant substrate type (Table 6).

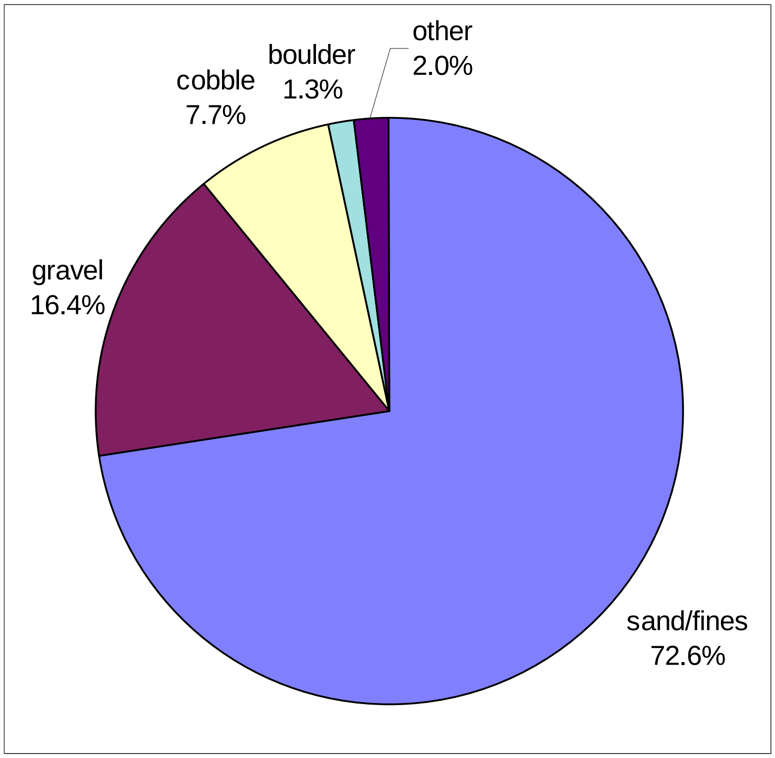


Figure 26. Total Percent of Streambed with Dominant Substrate Class.

Table 6. Percent of Stream Substrate Sample Dominated by Major Substrate Classes.

Description	1st Order	3rd Order	4th Order	5th Order	Total
Sand/Fines	98.18	69.5	81.27	70.5	72.63
Gravel	1.81	19.86	16.2	14.7	16.41
Cobble	0.00	6.38	1.59	11.38	7.73
Boulder	0.00	1.28	0.63	1.55	1.26
Wood/Other	0.00	1.00	0.32	1.66	1.16
Hardpan	0.00	1.99	0.00	0.00	0.71
Bedrock	0.00	0.00	0.00	0.22	0.10

Classifying the data by Strahler stream order did not further elucidate the data other than to indicate the primary source material is fines (Figure 27). The sand and fine substrate size class dominated stream substrate from each stream order. Fourth order streams had slightly more variety in dominant substrate type. Gravel was less than 20% of dominant substrate in all sampled streams. The dominance of fine grained material appears to be indicative of desert stream systems which are subject to flooding. Sparse terrestrial vegetation makes fine grained material readily available.

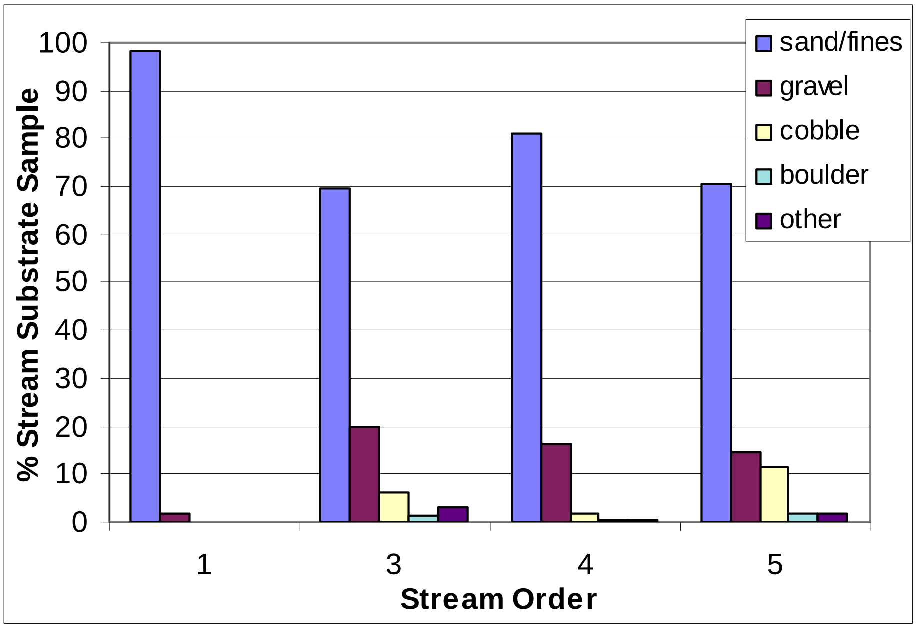


Figure 27. Percent of Stream Samples Dominated by Different Substrate Classes in Relation to Stream Order.

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. LWD also plays a major role in temperature dependent stream processes such as benthic respiration or fish movement. The quantity, type and size of LWD recruited from the riparian zone and from hill slopes are important to stream function in channels influenced by LWD. 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 of sorting spawning-sized gravel.

LWD is compiled into classes based on the length and diameter of each piece (Table 7). Although field data was collected for the stream reaches, the data is not reported on here because of the overall low amount of LWD. See Appendix 3 for a complete summary.

Table 7. Definition of LWD Classes Based of Length and Diameter Per 100m of Stream Sample.

	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

Most streams in eastern and northern Nevada do not support large fish species, for which LWD is very important. Native fish species are adapted to warm water, higher salt and trace metal concentrations, and higher turbidity. Little to no research on the benefits of LWD in desert, warm, spring-fed streams is available.

Riparian Vegetation

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

- influences channel form and bank stability through root strength;
- is a source of recruitment for LWD 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 are collected for three vegetation heights as expressed in Table 8.

Table 8. Riparian Vegetation Category and Associated Height.

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

Typical vegetation comprising each class is list in Table 9. The “Tree” category is primarily composed of vegetation not native to this area.

Studies on the effects of nonnative vegetation on desert stream processes are limited to ephemeral streams of the desert southwest and the Colorado system. While the results of research from these areas may be applicable to eastern and southern Nevada streams, they are not applicable to the warm, spring-fed streams of the Muddy-Virgin project area.

Table 9. Vegetation Category and Associated Vegetation Community of Muddy-Virgin Project Area.

Vegetation Type	Typical Vegetation Community
Tree	*Washingtonia filifera, Tamarix sp.,* Cottonwood, Ash, Alder, *Salix, Prosopis*
Understory	*Pluchea sp., Baccharis sp.,*
Ground cover	*Distichylus sp., Bromus sp*., mint, fords, herbs, flowering plants.

Vegetation cover from trees was relatively sparse, whereas, understory and ground cover were more common (Figure 28). The first order stream had less vegetation cover and less variation in type of cover compared to third to fifth order streams (Figure 29).

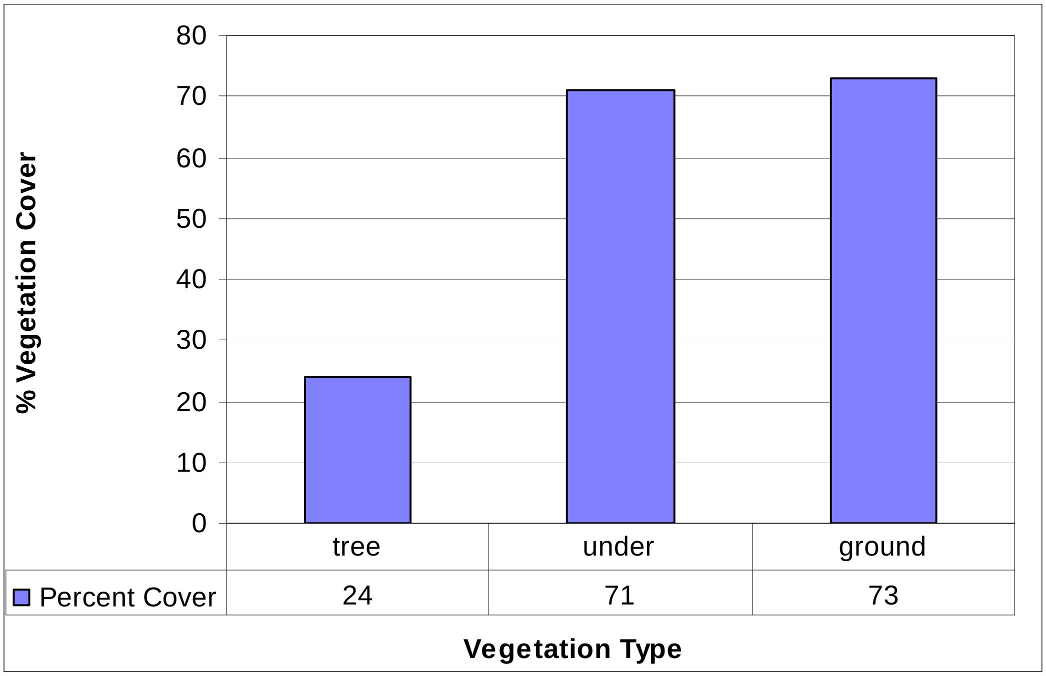


Figure 28. Percent Vegetation Cover by Vegetation Class.

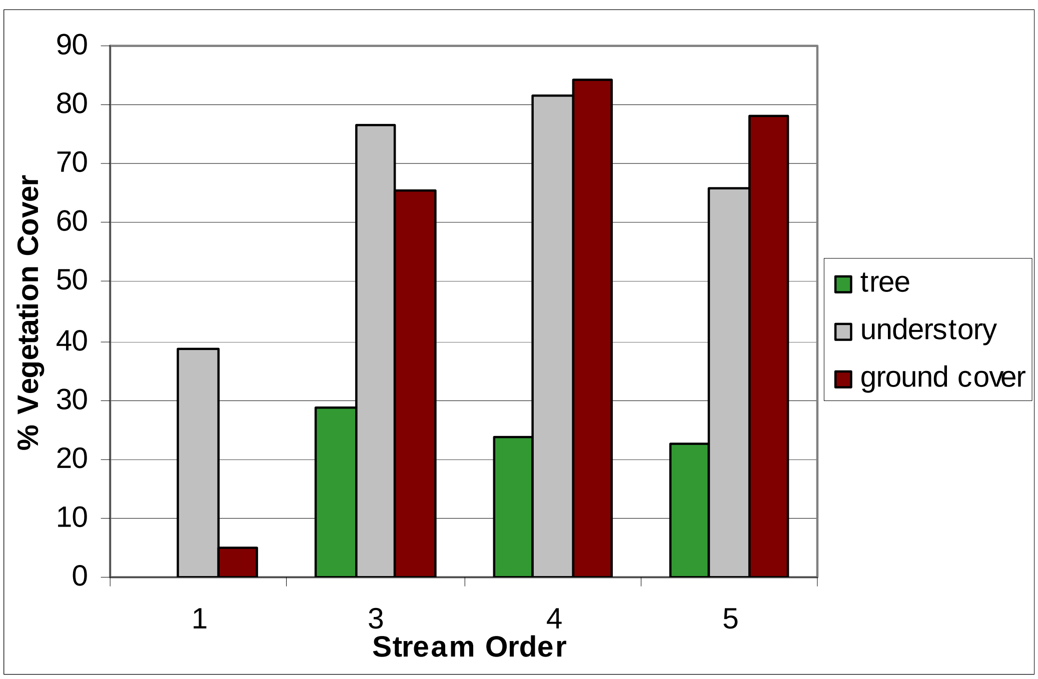


Figure 29. Percent Samples with Vegetation Cover by Class in Relation to Stream Order.

Stream shading is determined from average densiometer readings for each sample site. Shading was moderate with an average 31.7% of stream mid-channels shaded (Figure 30) and an average 56.3% of stream banks shaded. Figure 31 shows percent mid-channel and bank shade by stream order. While it is expected that shade will decrease as one moves from headwaters downstream to the valley floor, this pattern was not illustrated in data collected in eastern and southern Nevada streams.

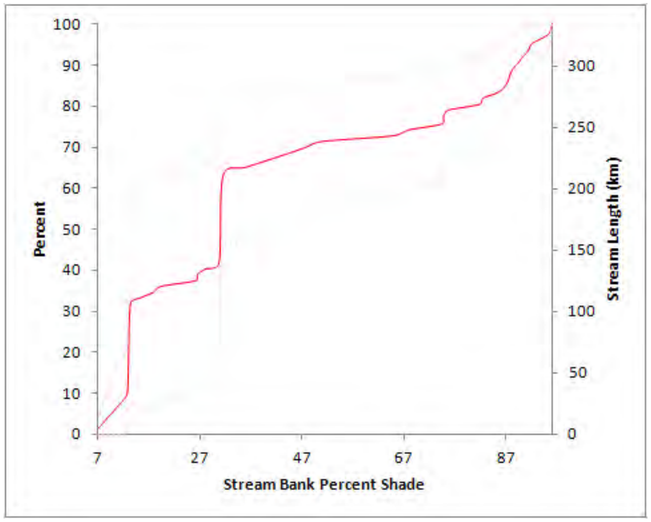


Figure 30. Cumulative Distribution Function of Bank Shade.

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 56.3% of stream banks shaded and an average of 31.7% of stream mid-channels shaded (Figure 32). Given the types of vegetation found in the range and basin ecoregions which comprise the Muddy-Virgin area, 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.

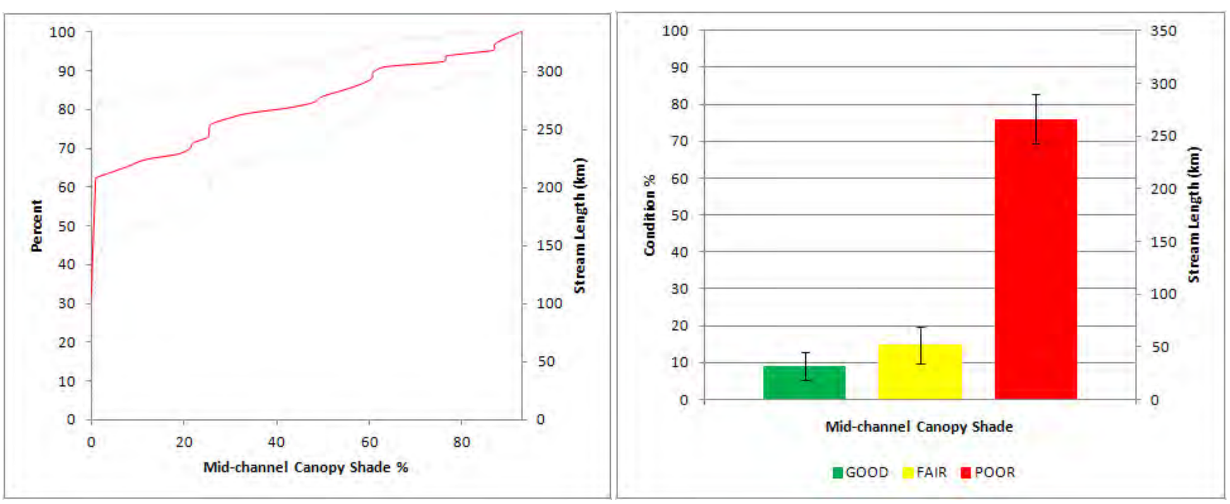


Figure 31. Cumulative Distribution Function and Condition Estimate of Mid-channel Canopy Shade.

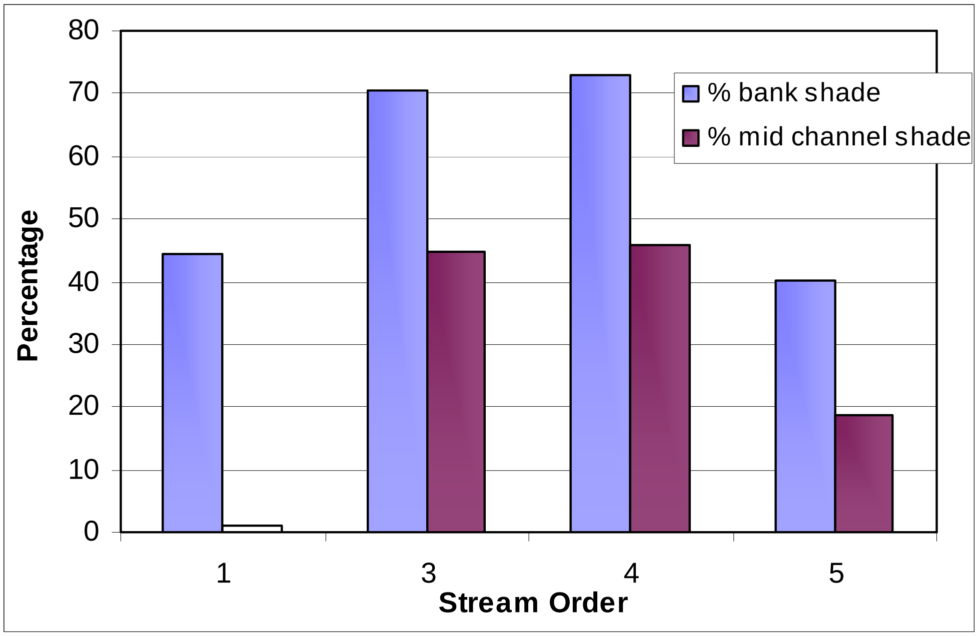


Figure 32. Cumulative Distribution Function of Bank Shade.

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 indicative of the overall complexity of the channel, which is likely to be beneficial to other organisms.

In the Muddy-Virgin project area, fish cover was analyzed according to its level of presence as described in Table 10. Overall fish cover was sparse. The most common form of averaged fish cover was overhanging vegetation, with a score of 1.26, followed by aquatic macrophytes (algae mats provide cover), with a score of 0.78 (Figure 33).

Level of Presence	Description	Score
Absent	None	0
Sparse	<10%	1
Moderate	10-40%	2
Heavy	40-75%	3
Very Heavy	>75%	4

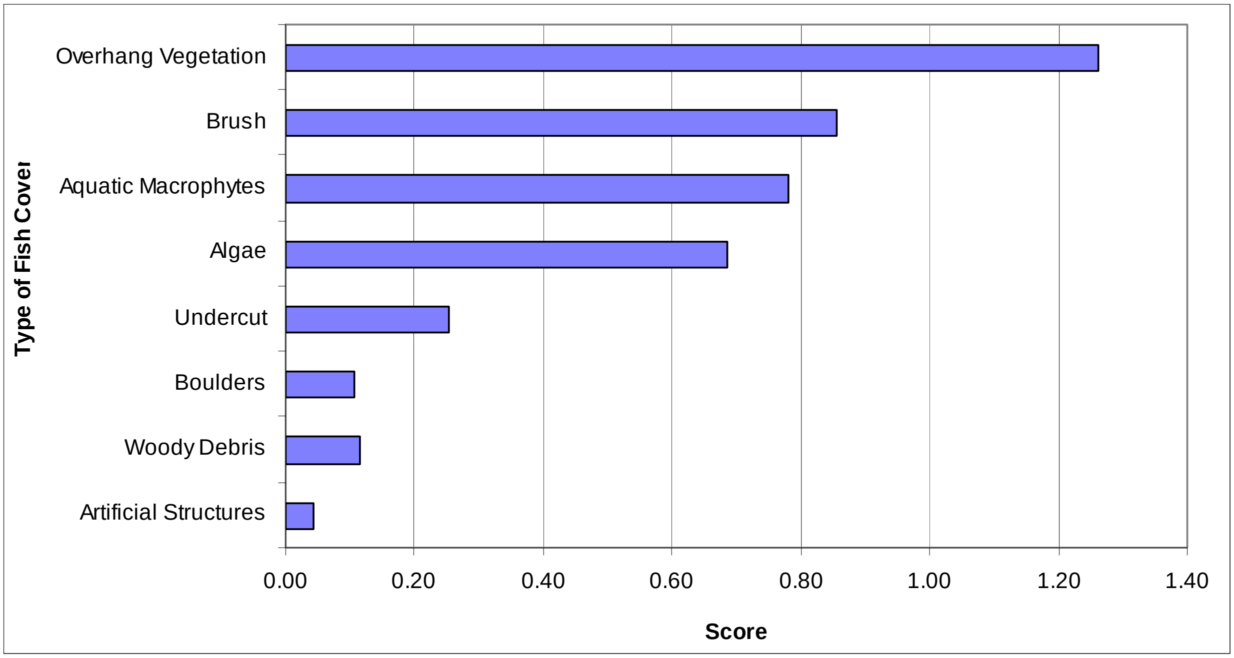


Figure 33. Level of Fish Cover.

Riparian Disturbance Indicators

Removal or alteration of riparian vegetation reduces habitat quality and can result in negative impacts on stream biota. Riparian disturbance data were collected by examining the channel, bank and riparian area on both sides of the stream at each of transect, and visually estimating the presence and proximity of disturbance (Hayslip et al., 1994). Eleven different categories of disturbance were evaluated. Each disturbance category was assigned a value based on 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 found. Row crops, logging, and mining were not observed in the streams of the Muddy-Virgin area. Shown in Figure 34, the most common form of riparian disturbance was pastures (31%), followed by roads (28%) and landfills (22%). In general, the level of human influence was low for all forms of riparian disturbances, as the averaged scores for all indicators were <0.67 (see Figure 35).

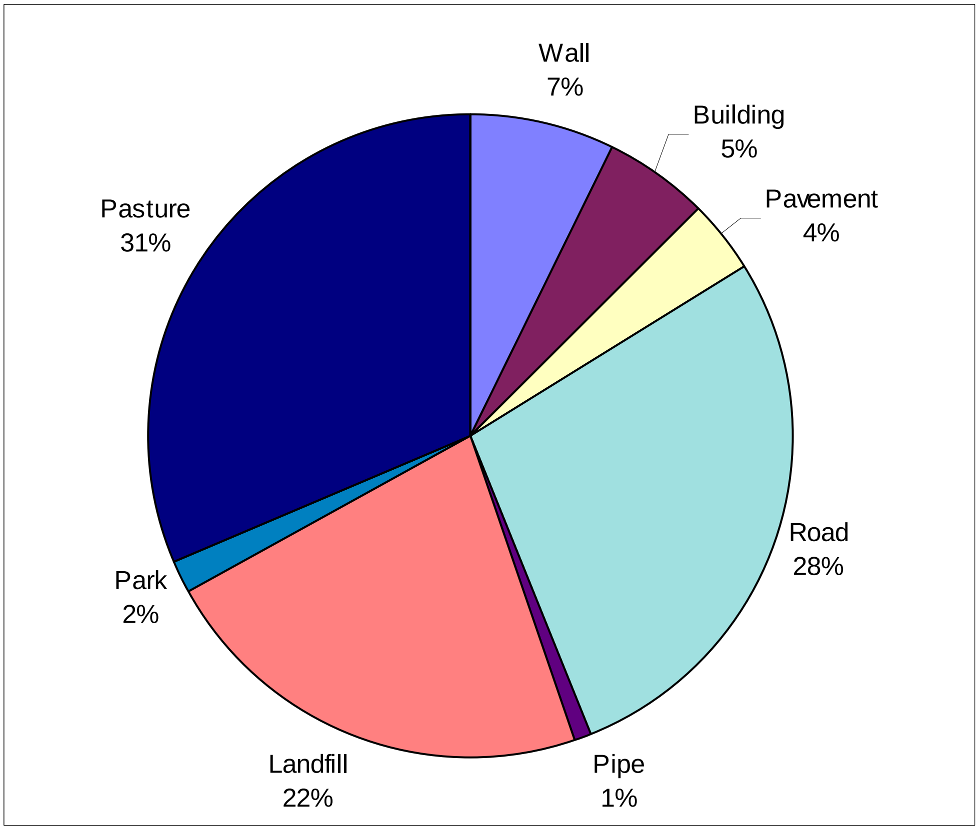


Figure 34. Percentage of Riparian Zone Human Influence, by Type, on Stream Reaches.

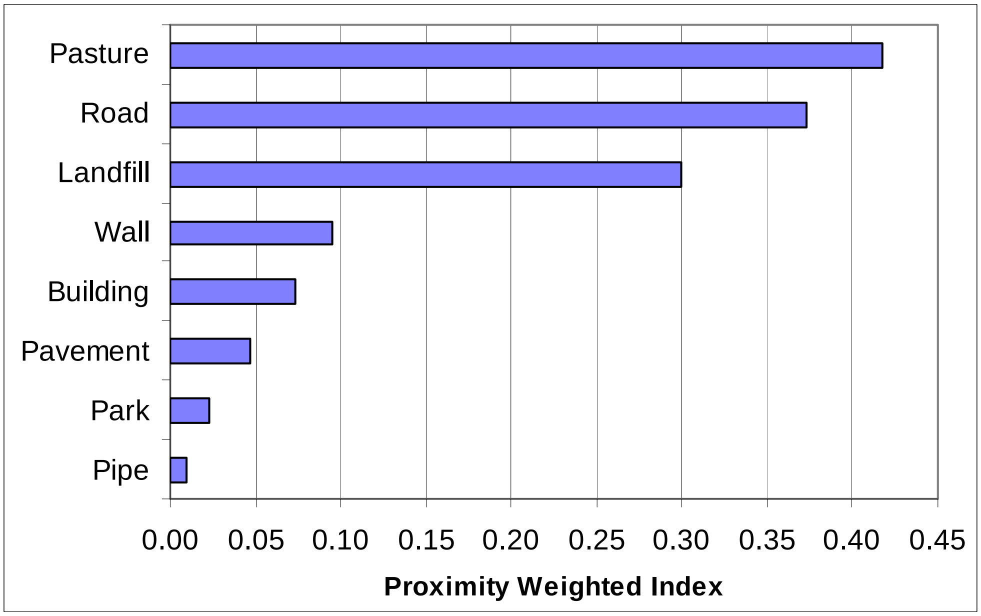


Figure 35. Mean Riparian Zone Human Influence by Type.

C. Biological Indicators

Benthic Invertebrates

Benthic macroinvertebrate assemblages indicate the overall biological integrity of the stream. Monitoring these assemblages is useful in assessing the current status of the water body and long-term changes that have occurred (Plafkin et al., 1989). Temporal and spatially infrequent surface flows in desert ecosystems can create microhabitats which are chemically and biologically distinct. Fragmentation will alter the function of these microhabitats resulting in differing taxa composition of the benthic aquatic community. Ecological response to hydrologic extremes will exhibit a response alternating between gradual change to a swift transition when a habitat disappears or is fragmented (Boulton, 2003). Benthic macroinvertebrate data were available from all sample reaches and collected at each transect using modified Serber samplers. These samples were combined into three composite samples for each reach. Since riffles were uncommon in the project area, a subset of each composite sample was identified. The following three metrics were used in the analysis: taxa richness, EPT taxa richness, intolerant taxa richness (Table 12).

Table 12. Description of Benthic Macroinvertebrate Indicator Metrics (Resh and Jackson, 1993 and Resh, 1995).

Metric	Description	Rationale
Taxa Richness	The total number of different taxa describes the overall variety of the macro-invertebrate assemblage. Useful measure of diversity of variety 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**phemeroptera (mayflies), **P**lecoptera (stoneflies), and **T**richoptera (caddis flies).	In general, these taxa are sensitive to human disturbance.
Percent Intolerant Taxa	Percent taxa of those organisms considered to be sensitive to disturbances.	Taxa intolerant to pollution based on classification from Wisseman (1996).

The metric 'Taxa Richness' gives an indication of variability of macroinvertebrate communities throughout eastern and southern Nevada. Total number of taxa ranged from 3 to 39 species (Figure 36). 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 Muddy-Virgin project area shows that there are many (72.7%) poor condition locations. As determined by the authors using the existing 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 4.

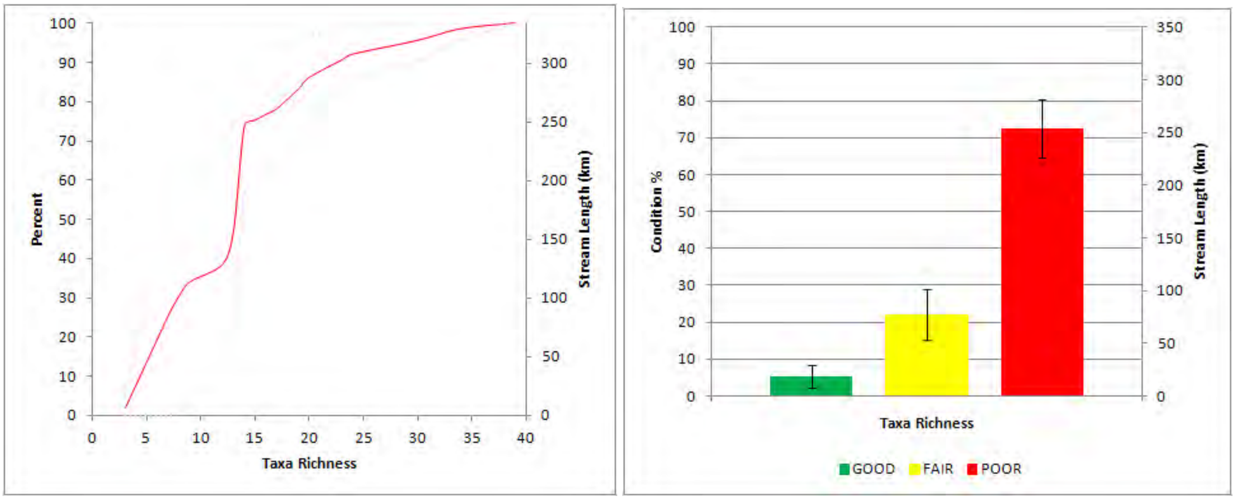


Figure 36. Cumulative Distribution Function and Condition Estimate of Total Invertebrate Taxa Richness.

EPT taxa ranged from 0 to 16 species (Figure 37). EPT taxa richness is the number of mayflies, stoneflies and caddis flies found and in general these taxa are sensitive to human disturbance. The condition analysis estimate of taxa richness measurement over the Muddy-Virgin area shows that there are very few (7%) good condition locations. Condition estimate values were set at: 0-7 poor, 8-17 fair and 18-25 good. Summary statistics are presented in Appendix 4.

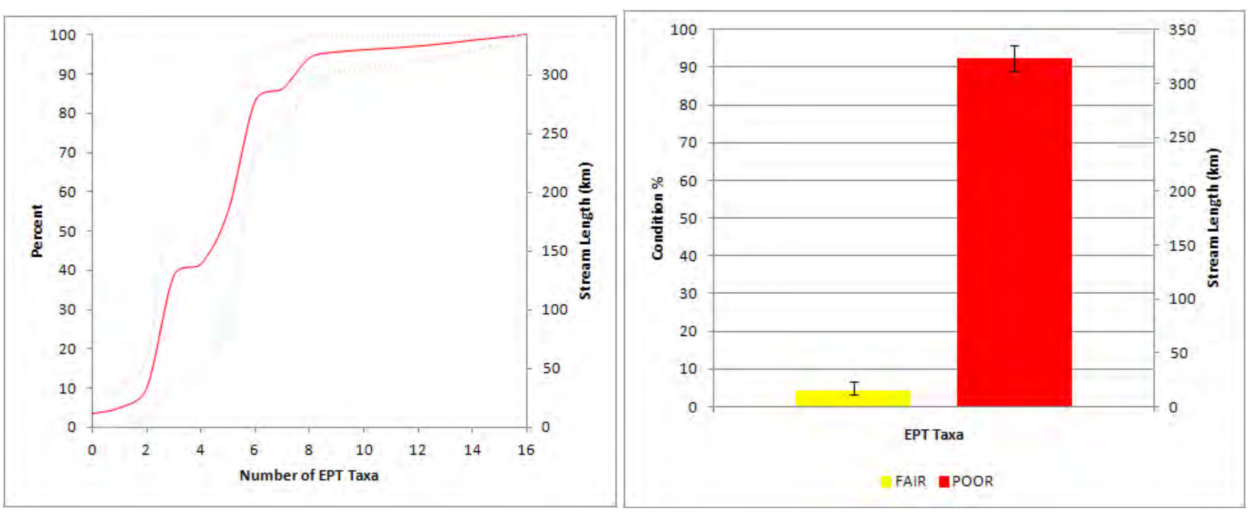


Figure 37. Cumulative Distribution Function and Condition Estimate of EPT Taxa Richness.

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, 91 percent of the Basin is in a poor ecological condition as determined by intolerant taxa (Figure 38).

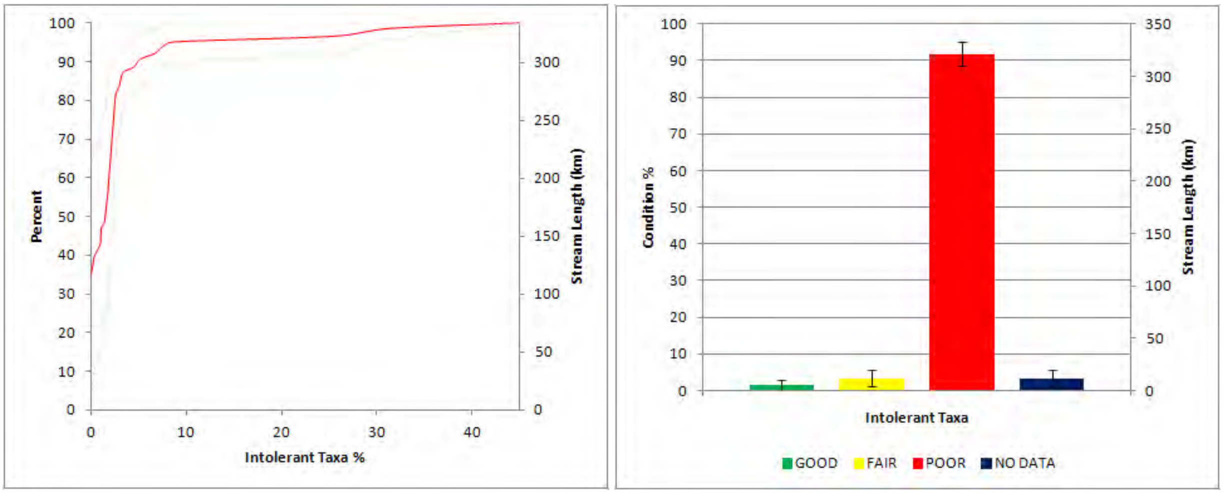


Figure 38. Cumulative Distribution Function and Condition Estimate of Intolerant Taxa.

A total of 17 metrics were analyzed and are summarized in Table 13 (Appendix 4). Biotic indices such as taxa richness, because of its high variability, may not be sufficient to determine functional changes in a warm water, fine substrate stream system. Functional feeding groups provide an indication on 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.

Predators comprised 13.9% of the population. Scrapers, piercers, and shredders, are the more sensitive organisms, and are considered to represent a healthy stream system. The mean shredder (0.7%) and grazer (4.4%) densities 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 generalist (collectors and filterers) more tolerant in stressed environments.

Table 13. Summary Statistics for Macroinvertebrate Metrics, Muddy-Virgin Project 2000.

Metric	Mean	Min	Max
Total Taxa	16.83	3.00	39.00
% EPT	41.79	0.00	81.19
EPT Taxa	5.51	0.00	16.00
% Ephemeroptera	26.72	0.00	75.89
Ephemoptera Taxa	2.86	0.00	7.00
% Plecoptera	0.02	0.00	0.68
Plecoptera Taxa	0.06	0.00	2.00
% Trichoptera	15.06	0.00	70.42
Trichoptera Taxa	2.60	0.00	9.00
Shannon H	1.73	0.53	2.73
% Collector	58.79	7.63	95.32
% Filterer	22.02	0.00	71.95
% Predator	13.90	0.78	87.94
% Grazers	4.42	0.00	39.42
% Shredders	0.66	0.00	12.45
% Burrower	19.32	0.66	68.35
% Climber	0.50	0.00	3.67
% Clinger	1.75	0.00	19.92
% Sprawler	7.29	0.00	28.09
% Swimmer	13.98	0.00	53.00
Community Tolerance (HBI)	5.36	4.21	8.18
% Intolerance (<4)	4.77	0.00	46.06
% Tolerance (≥7)	15.31	0.00	85.41

Table 14 shows that collectors and filterers were dominant through all stream types. Grazers and predators were evenly distributed throughout the different stream types within the Muddy-Virgin River system. Shedders were highly variable throughout the system and were more abundant in shaded small streams, indicating a more functional riparian system. Shredder population decreased as streams became wider and riparian systems moved to a more non-functional status. As seen Table 15, predators were most dominant in shaded small streams and open small streams. Collectors-filterers increased in dominance in open medium streams, and open large streams.

Table 14. Examples of Expected Functional Feeding Group Rations from Resh (1995).

Metric	Shaded Small Streams	Open Small Streams	Open Medium Streams
% Collectors- Filterers	>50%	>40%	>50%
%Grazers	<25%	>25%	>25%
% Predators	~10%	~10%	~10%
% Shredders	>25%	>10%	<5%

Table 15. Mean Percent of Functional Feeding Groups from the Muddy-Virgin Project.

Metric	Shaded Small Streams	Open Small Streams	Open Medium Streams
% Collectors- Filterers	72.25	77.69	91.08
% Grazers	7.45	3.86	3.34
% Predators	18.35	17.59	5.38
% Shredders	1.92	0.55	0.03

The Muddy-Virgin River study area was dominated by the collector-filterers (72.3%). Dominance of a particular group (i.e., collector-filterers) is an indication the Muddy-Virgin system was reflecting stressed conditions.

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 (MMI) is an approach used in the United States to analyze BMI assemblage data. This method evaluates 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). 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 was 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 Muddy-Virgin River Project Area, sixty-eight metrics were calculated from the data collected at thirty-five sites. 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 kinds 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, signifying lower water quality

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 chooses 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 (Omernik, 1987) the Muddy-Virgin Area utilized the criteria set for the South Xeric basin, which encompasses the Central Basin and Range (ecoregion 13) and the Mojave Basin and Range (ecoregion 14) (Appendix 5). For the Muddy-Virgin Area, five least-disturbed sites (8, 10, 95, 128, 258) and five most-disturbed sites (232, 289, 669, 720, 1009) were chosen (Figure 1 and Appendix 1).

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 the same.
- Richness metrics with a range less than four were not included in the next test (Appendix 6).
- 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 7).
- 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 8).

Once the representative from each metric class has been determined, each needs to be scored using a 0 to 10 scale. Scoring is needed since metrics respond differently. With increased perturbation, total taxa decreases while percent tolerant organisms increase. For positive metrics (those whose values are highest in least-disturbed sites), ceiling and floor values were set at the 5th and 95th percentile (Table 16). Values less than the 5th percentile were given a score of 0, while those with values greater than the 95th percentile were given a score of 10. Values in between were score linearly. Negative metrics were scored similarly with the floor at the 95th percentile and the ceiling at the 5th percentile.

Table 16. Final Metrics and Ceiling/Floor Values

	Ceiling	Floor
DipPct	6.9	66.3
PredPct	71.0	1.0
SwmmrTax	3	0
TotalTax	34	7
Hyd2TriPct	0	100

Metric Descriptions can be found in Appendix 6

Scores were summed for each site for a total score of 50. Scores were multiplied by 2.0 for a maximum IBI score of 100 (Appendix 9). In the Muddy-Virgin River project area, the total scores for macroinvertebrate IBI ranged from 4 to 84 (Figure 39). The condition estimate values used for the IBI measurement are as follows: 100-70 good, 69-50 fair, and 40 -0 poor. See Figure 40 for location of relative IBI scores.

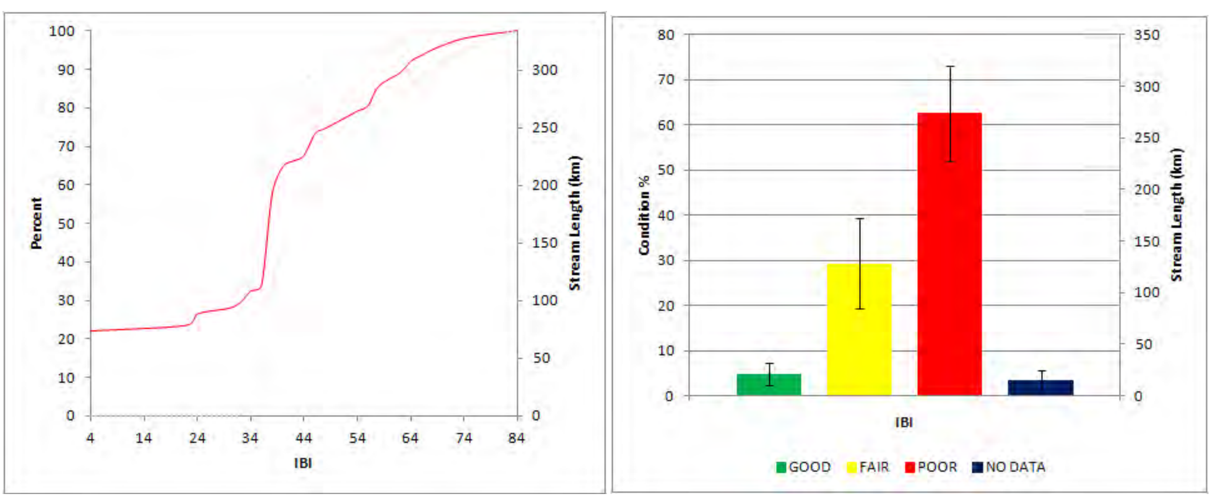


Figure 39. Cumulative Distribution Function and Condition Estimate of Macroinvertebrate IBI.

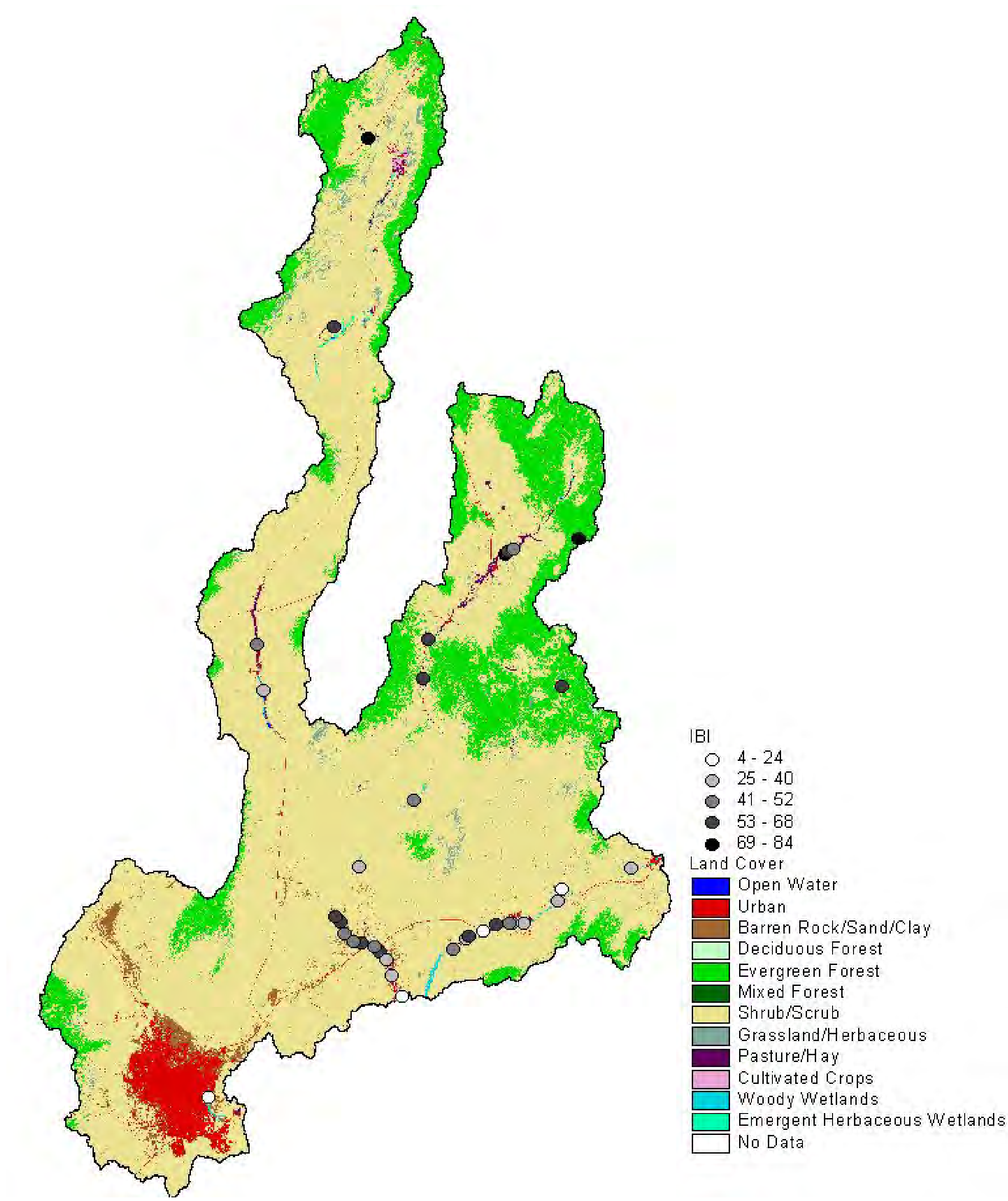


Figure 40. Relative IBI Scores for Muddy-Virgin River Project Area Sampling Sites.

Periphyton

Periphyton consists of algae, fungi, bacteria, protozoa, and detritus found on or within moist substrate in a stream channel. Periphyton can be used as indicators of environmental stress because they are highly susceptible to disturbances. The main factor for accumulation of periphyton is the level of resources, primarily nutrients and temperature, which influences metabolism and growth. There has also been close correlations found between quantities of periphyton and the type of substrate and flow of a stream reach. Water movement restores necessary materials and removes metabolic byproducts. This action may select for and against certain organisms, correlating to low periphyton development. It has also been established that concentrations of metals may have effects on certain species (Weitzel, 1979).

Periphyton samples were collected at the nine cross-sections of each sample reach at erosional and depositional habitats. From those samples, four types of laboratory samples were prepared: an ID/enumeration sample, chlorophyll and acid/alkaline phosphatase activity (APA) samples, and a biomass sample. Biomass is a measurement of the organic matter of a sample, measured by weighing the difference in mass after drying and incinerating the matter. The remains are ash free dry mass (AFDM). The sample is then weighed against its dry mass to determine the biomass. This is done to discount against any silt or other inorganic matter (see Appendix 10 for a complete list of periphyton samples). The cumulative distribution function and condition estimate are not reported for periphyton in the report.

Ratios between chlorophyll and AFDM have been used to indicate community structure. The autotrophic index (AI), which is the ratio between biomass and chlorophyll, has been used to indicate organically polluted conditions. In theory, higher numbers reflect more polluted waters. In the Muddy-Virgin River project area, site 8 had the highest AI value of 22740. Site 215 had the lowest AI value of 112. The CDF for the Muddy-Virgin River project area is shown in Figure 41.

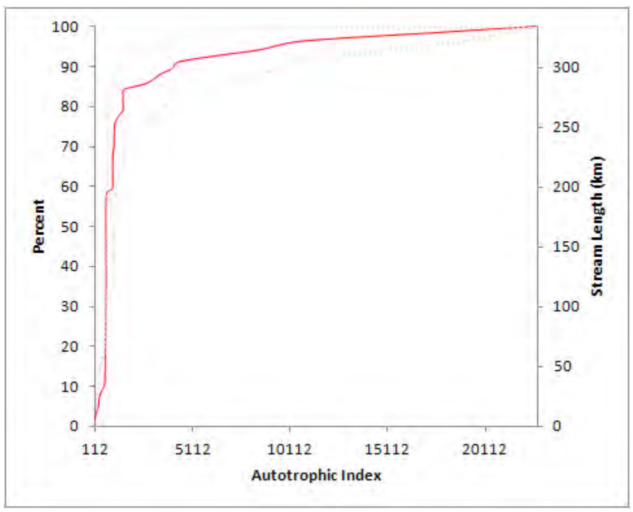


Figure 41. Cumulative Distribution Function of the Autotrophic Index.

Figure 42 shows the Muddy-Virgin River project area CDF and condition estimate for chlorophyll-a. The condition estimate level for chlorophyll-a was determined as, good was less than 10 µg/cm² and poor was greater than 10 µg/cm². Chlorophylla-a (chl-a) was selected as an indicator of water quality because it is an indicator of phytoplankton biomass, with concentrations reflecting the integrated effect of many of the water quality factors that may be altered by restoration activities. Studies have examined chlorophyll-a (chl-a) to determine that levels above 10 µg/cm^2 (up to 15 µg/cm^2) can indicate areas with higher levels (>20%) of filamentous algae, or pond scum, coverage (Barbour, 1999). In the project area, sites 289 and 669 exceeded the 10 µg/cm²chl-a level (Figure 43, Table 17).

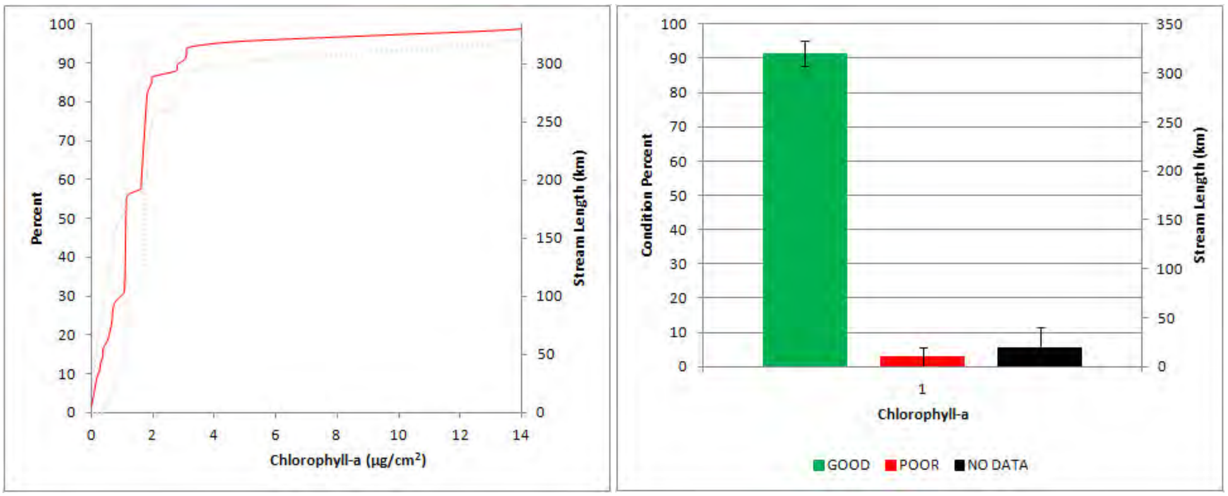


Figure 42. Cumulative Distribution Function and Condition Estimate of Chlorophyll-a.

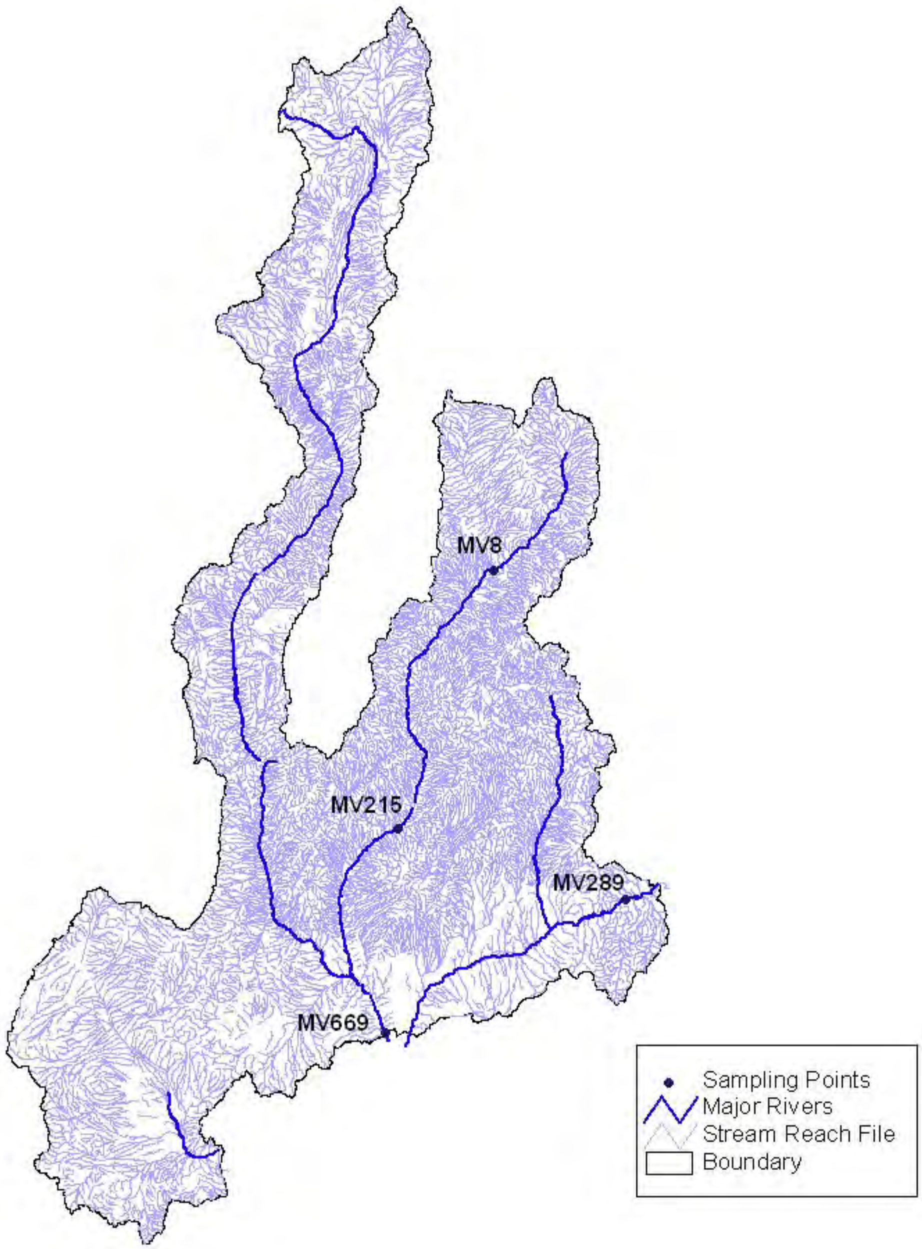


Figure 43. Location of Muddy-Virgin R-EMAP Sample Sites with High Chl-a Levels and Highest and Lowest AI Levels.

Table 17. Sampling Sites with High chl-a Levels and Highest and Lowest AI Levels.

Site ID	Chl-a	AI
MV8	--	22740
MV215	--	112
MV289	15.08µg/cm^2	--
MV669	13.68µg/cm^2	--

Figure 44 is the project-wide CDF of the Biomass parameter in mg/cm^2. Figure 45 shows a map of biomass values within the Muddy-Virgin project area. Within the Muddy River, the trend indicated that biomass increased downstream. The inverse occurred within the Virgin River (Figure 46). This may be due to differences in agricultural land use intensities between the two river basins.

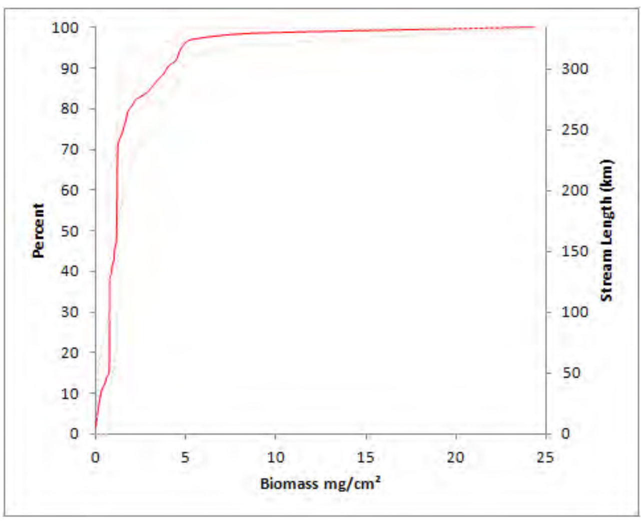


Figure 44. Cumulative Distribution Function of Biomass.

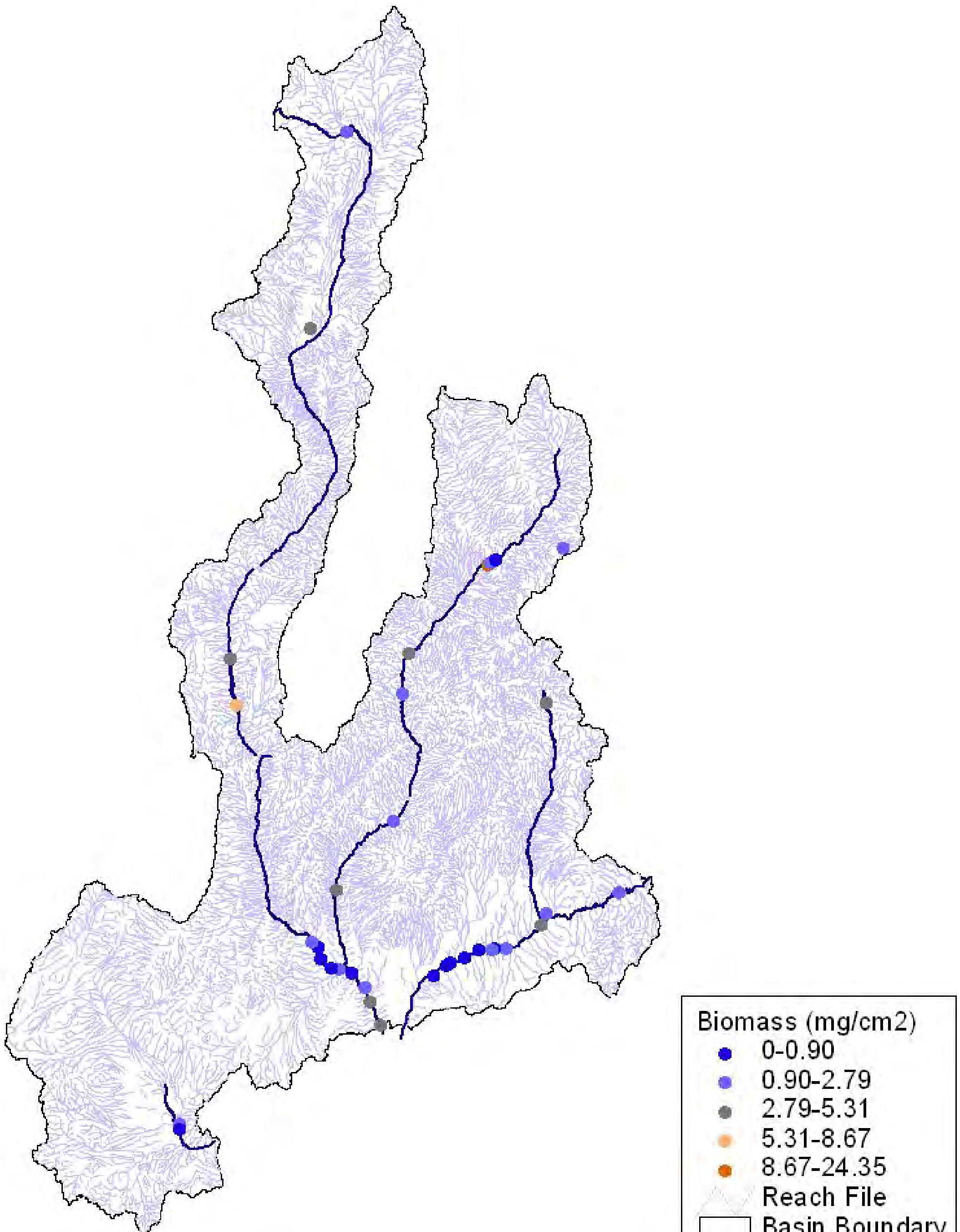


Figure 45. Map of Biomass (AFDM/cm²) in the Muddy-Virgin Project Area.

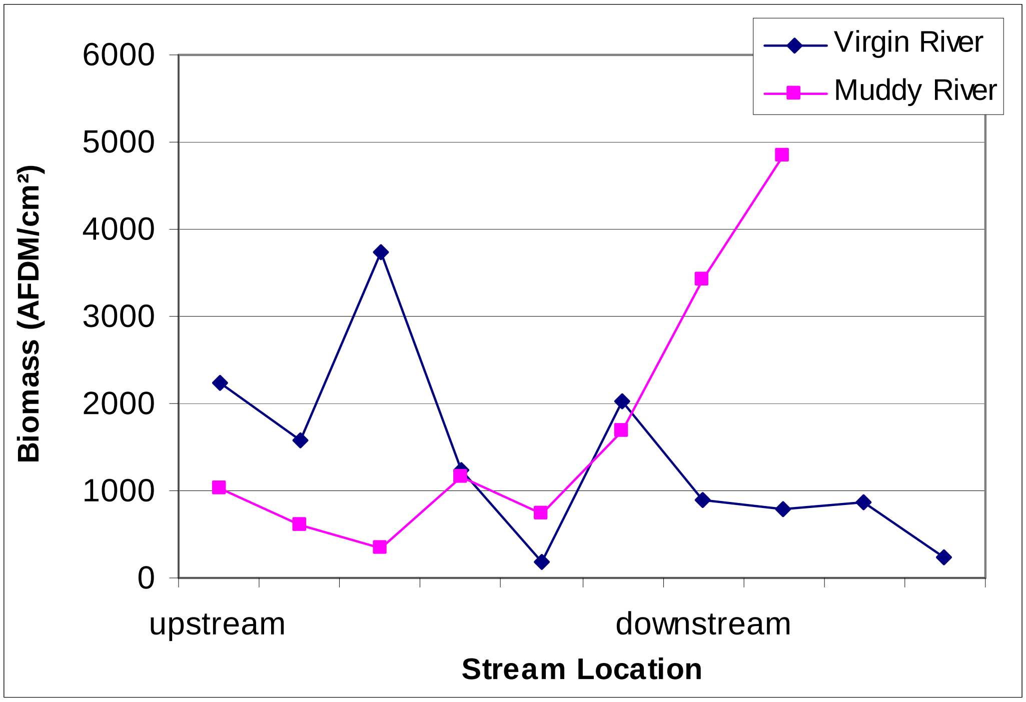


Figure 46. Biomass Values Graphed in Relation to Sampling Locations in the Muddy and Virgin Rivers, n=18.

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 was 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. Nutrient availability 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 several factors such as extent of floodplains and flow variability.

Respiration values ranged from 1.53 (site 1310) to 36.51 (site 19) 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 47 shows the cumulative distribution function of sediment respiration for the Virgin-Muddy project area. Levels ranging for 1.5 mg/g/h to 21.5 mg/g/h are likely to be encountered over 90% of the stream reach. The condition estimate was not reported as estimates of condition for this measure in dry desert stream could not be found in the literature.

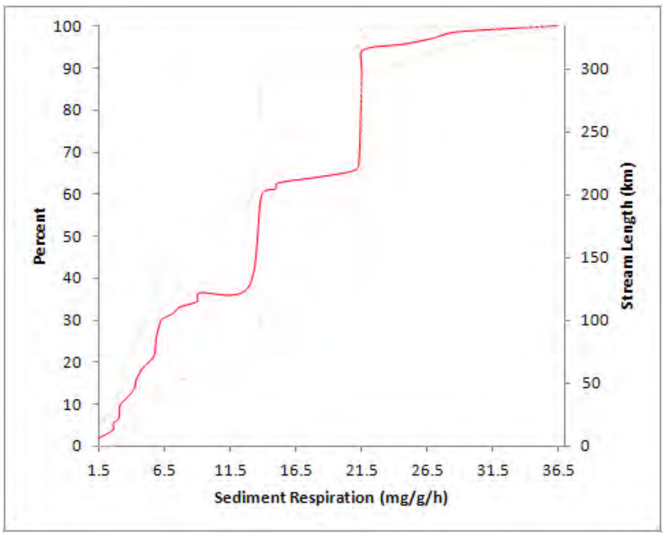


Figure 47. Cumulative Distribution Function of Sediment Respiration.

One factor that may affect levels of community respiration is the location of agricultural land use along a river (Figure 48). In the Muddy River, respiration increased downstream. In the Virgin River, values varied, but had an overall downward trend downstream (Figure 49). It is interesting to note that higher sediment respirations rates are located along the Virgin River as it exits the Zion National Park in southern Utah (Figure 48) and flows by high density agricultural land use areas.

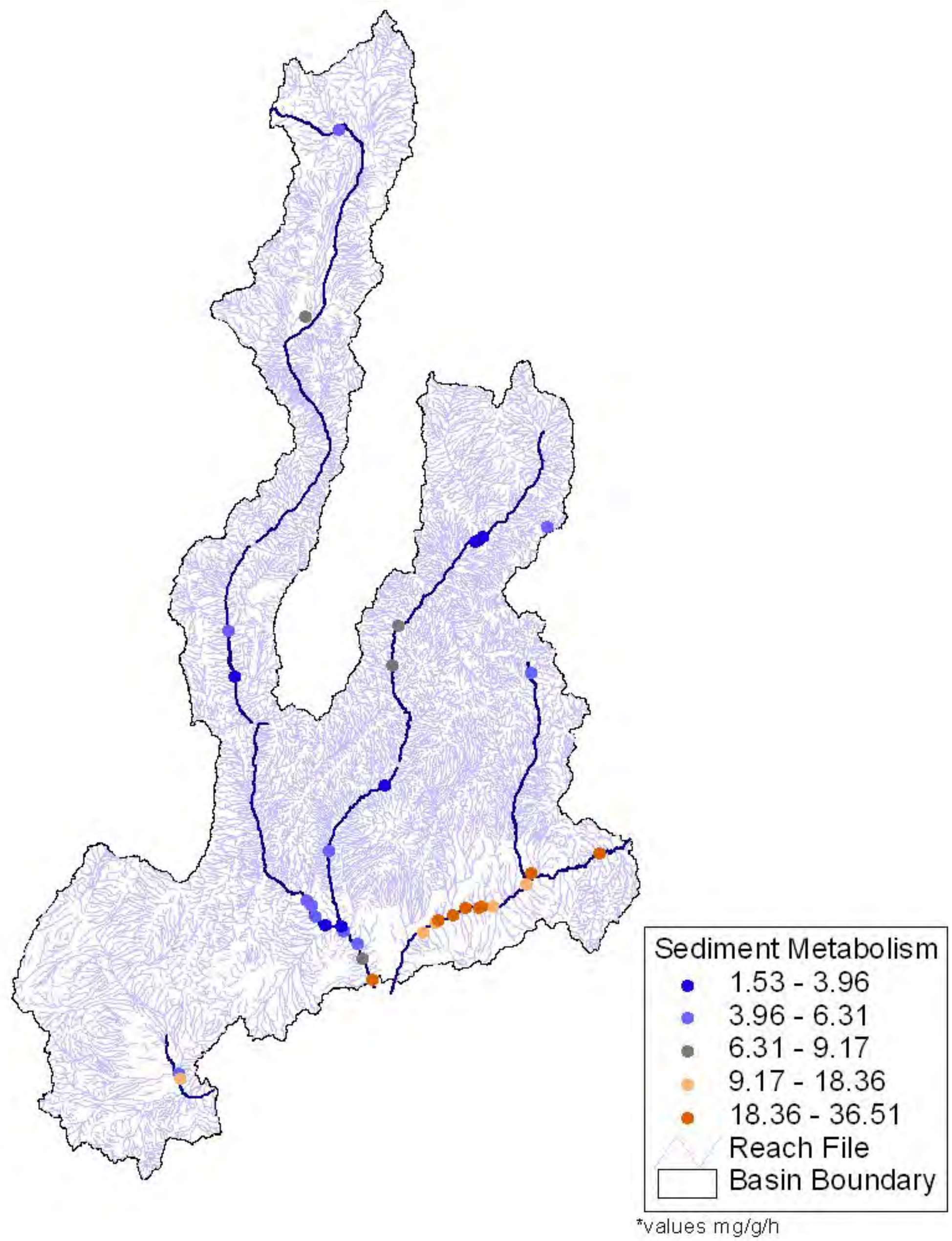


Figure 48. Map of Sediment Metabolism in the Muddy-Virgin Project Area.

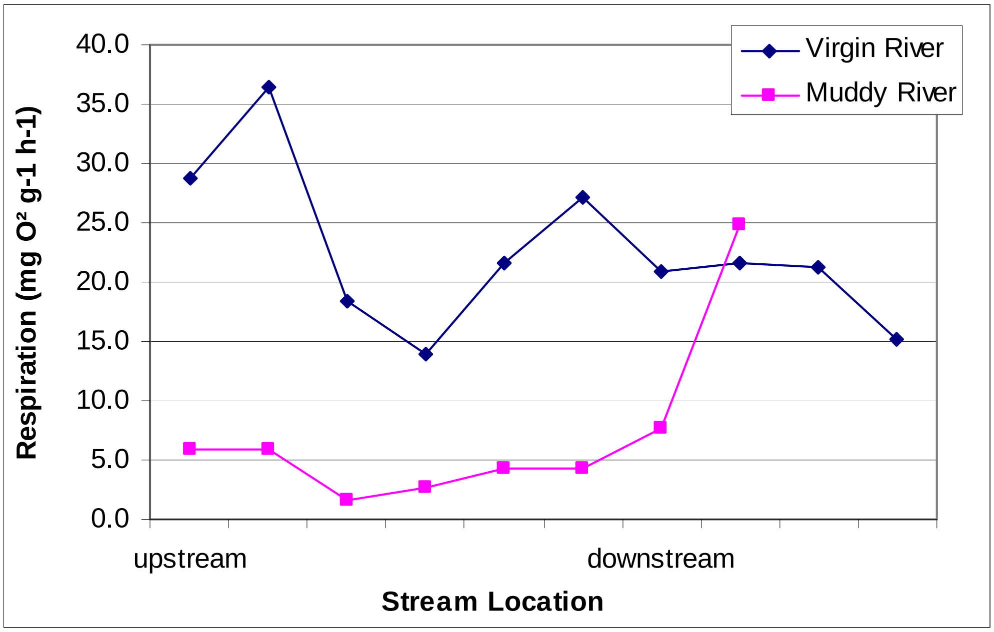


Figure 49. Sediment Metabolism Values Graphed in Relation to Sampling Location in the Muddy and Virgin Rivers, n=21.

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 15) reveal arsenic, mercury, manganese and nickel were at levels of concern at a number of sites. A total of 37 sites were sampled at least once for water and sediment.

Water

In the Muddy-Virgin project area, a total of 37 samples were taken for analysis of water quality pollutants. The USEPA National Ambient Water Quality Criteria (GOLD BOOK) (Office of Water, 1986) was used in this report to determine whether the concentration of a pollutant exceeded standards. Specifically, the three pollutant standards used in the report are the Federal drinking water standard, the Criteria Continuous Concentration (CCC), and the Critical Maximum Concentration (CMC). (Table 18). The CCC is designed as a benchmark to determine if a particular body of water is safe for aquatic life over a chronic period of exposure (based on a four day average concentration chronic limit). The CMC is designed to set a maximum allowable concentration of a contaminant for aquatic life (one hour average acute limit). Standards have not been set for all contaminants. Available USEPA's National Recommended Water Quality Criteria – Aquatic Life Criteria were used for both acute and chronic effects (USEPA, Office of water, 2014). See Appendix 11 for a complete list of data for each sampling point.

Table 18. 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 (2nd)
Lead	HD	HD	15
Manganese	--	--	50 (2nd)
Mercury	--	0.012	2
Nickel	HD	HD	--
Selenium	--	5	50
Silver	HD	HD	100 (2nd)
Zinc	HD	HD	5000 (2nd)

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

Sediment

Using these benchmarks, the data from the Muddy-Virgin River project area were 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 taken into an organism upon ingestion. For these reasons, metals concentrations in sediment are of concern in the streams of the Muddy-Virgin River project area. Sediment was collected at least once at 37 sampling points.

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 report, 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* commonly 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)(Buchman, M.F., 1999) and Florida Department of Environmental Protection (FDEP)(MacDonald, D.D. et al., 2003).

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 (Table 19), 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 was then selected based on these results. Table 19 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 19. 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 20). A basin-wide condition estimate was not determined for hardness because only one year was measured.

Table 20. 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. Aluminum levels in water ranged from a minimum of 200 µg/l to a maximum of 500 µg/l with a mean of 208 µg/l. The cumulative distribution frequency and condition estimate for aluminum in water is not given in this report. The cumulative distribution frequency for aluminum in sediment is given in Figure 50.
The criterion for aluminum in fresh water sediment was not found so the condition estimate was not calculated.

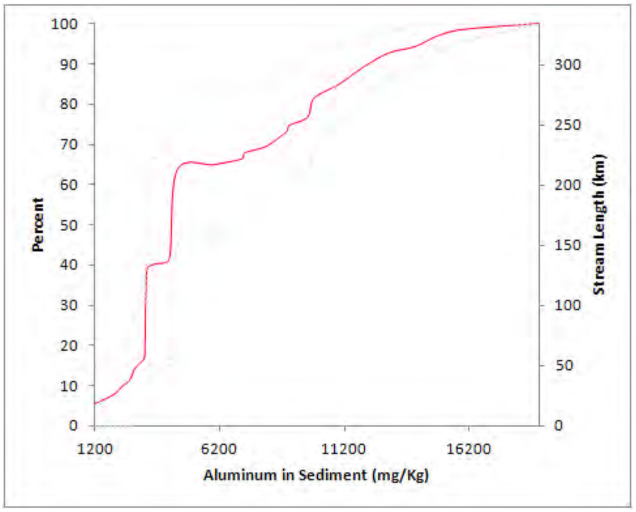


Figure 50. Cumulative Distribution Frequency and Condition Estimate of Aluminum in Sediment.

Antimony:

The analytical quantification limit for 33 of the sampling sites was 5 µg/L. The quantification limit is the lowest limit at which values can be determined. Sites 119, 232, 289 and 310 had an analysis limit of 10 µg/L. With a drinking water standard of 6 µg/L, it was unable to be determined whether the four sites with a higher quantification limit were over the standard. All sites were below the CCC standard of 30 µg/L. There is no CMC standard.

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 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 below 10 µg/l in water as good and below as poor. The condition estimate of arsenic in sediment is below 10 mg/Kg as good, between 10 and 15 as fair and above 15 as poor. The results are shown in Figure 51. 90 % of the stream length for arsenic in water is in poor condition and 69 % of the stream length for arsenic in sediment is in good condition, 27% fair condition and 4% in poor condition.

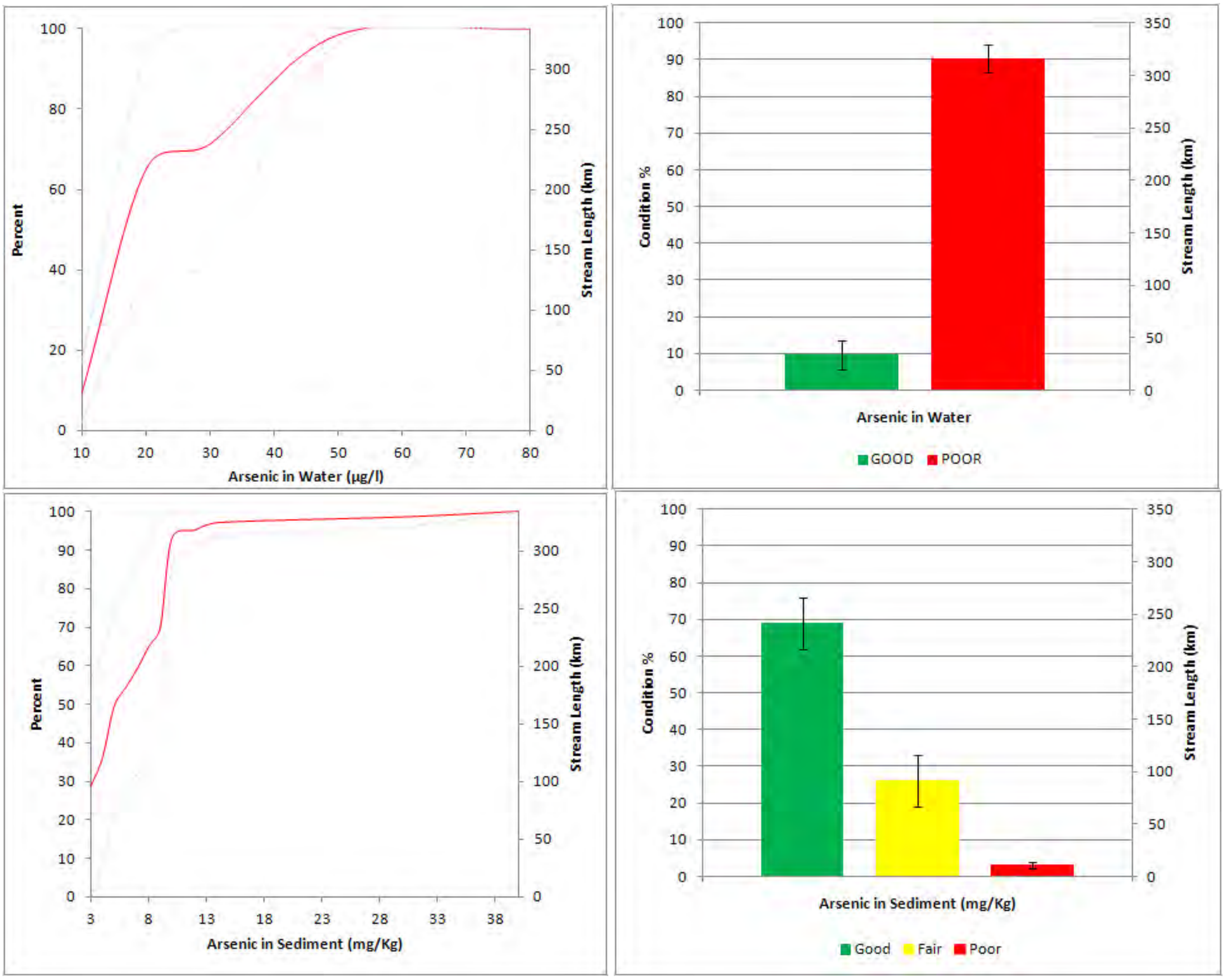


Figure 51. Cumulative Distribution Frequency and Condition Estimate of Arsenic in Stream Water and Sediment.

Cadmium:

National ambient water quality criteria for cadmium is dependent on water hardness. The quantification limit for 33 sites was 5 µg/L. The remaining four sites had a limit of 10 µg/L. Due to high limits, it was not possible to report whether cadmium levels exceeded CCC standards, which had an average of 0.8 µg/L. Similarly, 12 sites had CMC standards that were below the quantification limits. CMC levels ranged from 2.4 to 25.5 µg/L. The drinking water standard for cadmium is 5 µg/L.

Chromium:

National ambient standards for chromium are also dependent on calcium hardness. All chromium samples were at the quantification limit of 10 µg/L. No samples exceeded the drinking water standards of 100 µg/L.

Copper:

Calculating standards based on hardness, no samples exceeded CCC or CMC values for copper in the Muddy-Virgin Project area. With samples ranging from quantification limits of 3 to 20 µg/L, no samples exceeded individual CCC (10.6-111.4 µg/L) or CMC (16.2-216.5 µg/L) values. 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 52 shows the results of the analysis.

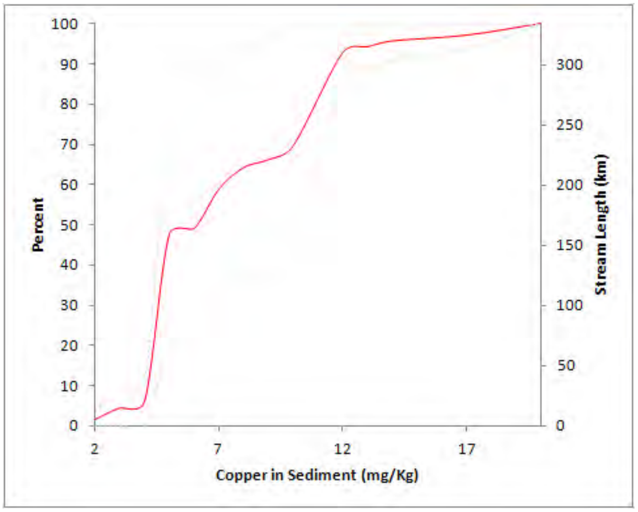


Figure 52. Cumulative Distribution Frequency of Copper in Stream Sediment.

Iron:

Currently, the USEPA's National Recommended Water Quality Criteria – Aquatic Life Criteria lists iron as a non priority pollutant. With a secondary drinking water standard of 300 µg/L, only one site (170) exceeded the standard at 400 µg/L. 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 53.

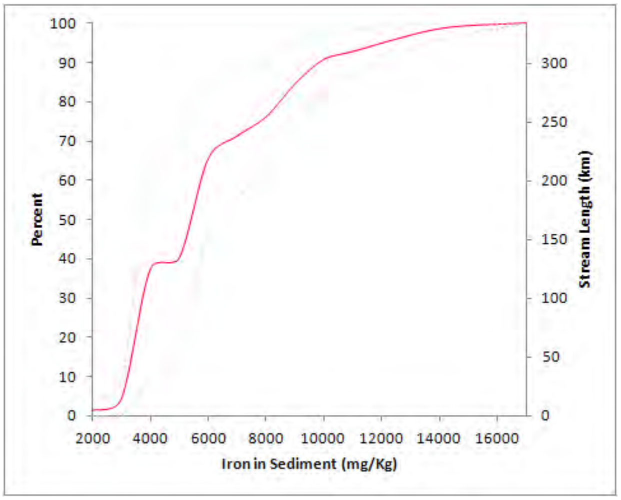


Figure 53. Cumulative Distribution Frequency of Iron in Stream Sediment.

Lead:

National ambient CCC and CMC standards for lead are dependent on hardness. Quantification limits for lead were 5 µg/L for 33 sites and 10 µg/L for the remaining four. All samples were well below the CMC standard. Only one site (258) had a hardness calculated CCC value (3.1 µg/L) below the quantification limit. It could not be determined if that site exceeded the standard. A stream sediment cumulative distribution frequency was calculated for future reference. Results are shown in Figure 54.

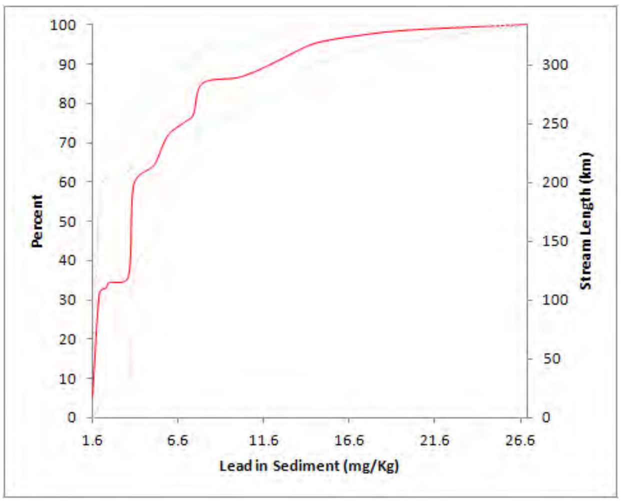


Figure 54. Cumulative Distribution Frequency and Condition Estimate of Lead in Stream Water and Sediment.

Manganese:

There is no aquatic life CCC or CMC standards for manganese. Seven of the thirty-seven samples exceeded the manganese secondary drinking water standard (50 µg/L): 110 (68 µg/L), 669 (120 µg/L), 1100 (130 µg/L), 1009 (160 µg/L), 1190 (250 µg/L), 285 (280 µg/L), and 660 (290 µg/L). Site 720 had a manganese level equal to the drinking water standard (50 µg/L). 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 55.

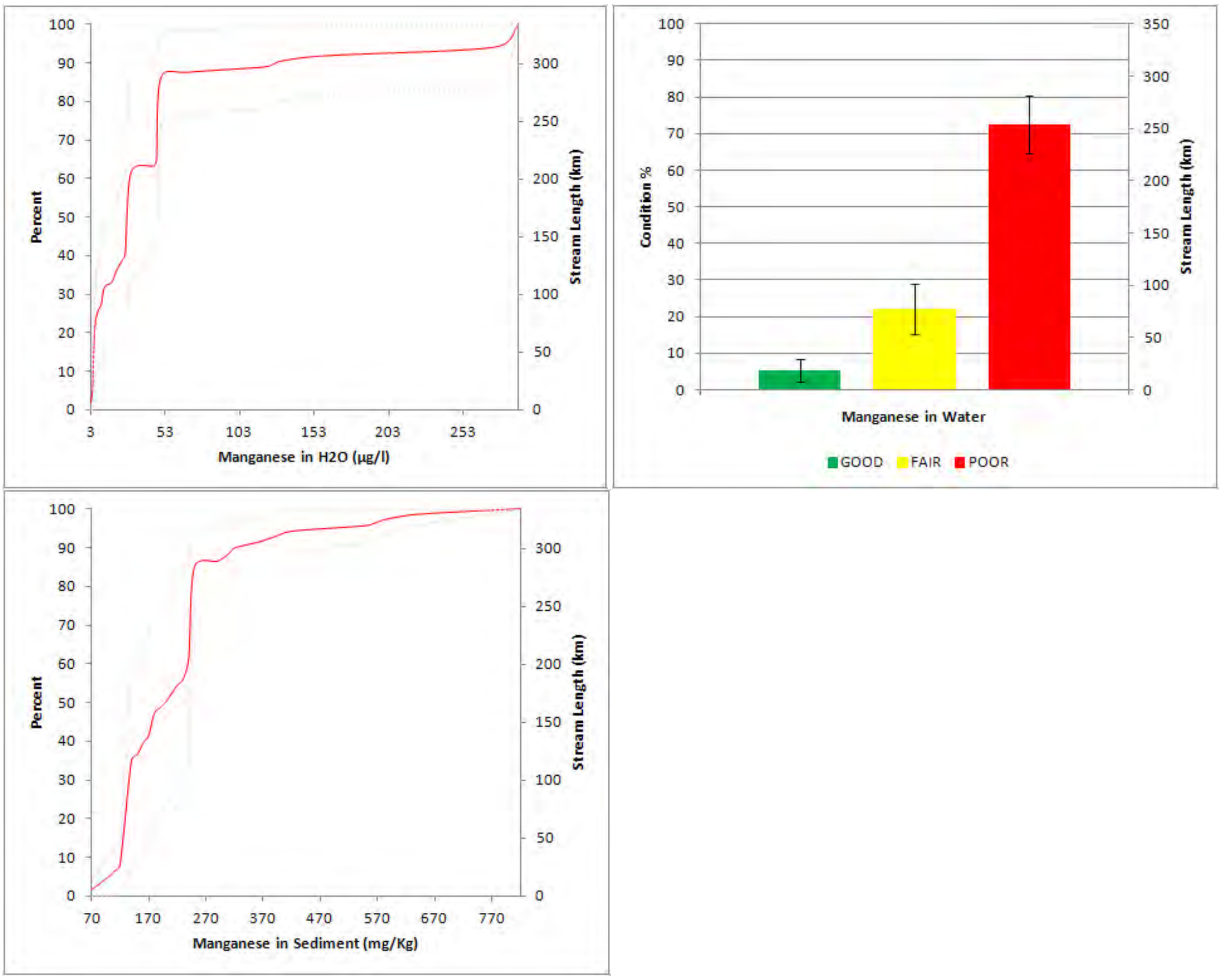


Figure 55. Cumulative Distribution Frequency and Condition Estimate of Manganese in Stream Water and Sediment.

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).

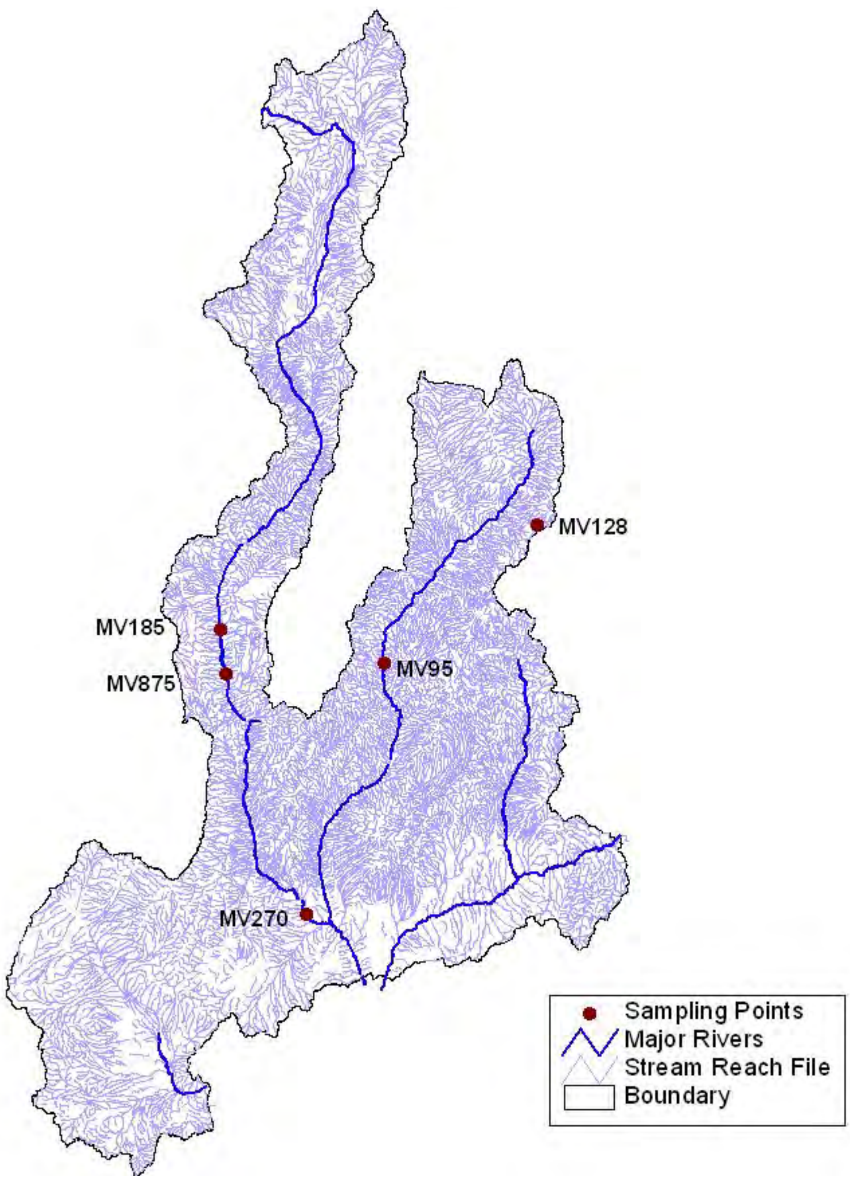


Figure 56. Location of Muddy-Virgin River R-EMAP Sample Sites Containing Mercury in Water and Sediment.

In the Muddy-Virgin River study area, mercury was detected in five of thirty-seven sites, four in sediment with total mercury (HgT) concentrations ranging from 0.08 to 0.80 mg/kg dry weight, and one site with an HgT concentration of 0.41 µg/L (Table 21). Site 95 in Meadow Valley

Wash had an HgT concentration of 0.10 mg/kg dry weight downstream of a few historic mine workings (Figure 56). Site 128, located in Flatnose Wash, in the lower Virgin Watershed, had an HgT concentration of 0.08 mg/kg, and was directly below several abandoned gold mines. Sites 185 and 875, located in the Pahranagat Wash had HgT concentrations of 0.80 mg/kg and 0.20 mg/kg dry weight, respectively. Site 185 and 875 exceed the lowest effect level (LEL) for aquatic life. The LEL, developed by Persaud et al. (1993) indicates a level of contamination, below which, the majority of benthic organisms will not be affected. Site 185 is approximately eight miles further upstream than Site 875. The source of mercury for these two sites was not apparent. There was a historic mine to the west of Site 185, but the drainage entered the Pahranagat Wash between the two sites. Site 270 had an HgT concentration in water of 0.41 µg/L, and had a not detected (ND) for mercury in sediment. Site 270 is located on the Muddy River (Figure 15). Land use upstream of Site 270 consisted of agriculture, dairy and a landfill. Between the landfill and Site 270 was a water impoundment (Damian Higgins, personal communication). Microbial respiration in the impoundment was increasing the solubility of mercury, which was then being released downstream. The source of the mercury in the impoundment could have been deposited in the sediments prior to construction of the impoundment, presently being transported downstream from historic mine sites, and/or resulting from runoff or leaching from the landfill. Possible nutrient enrichment from dairy operations and poor water circulation could be enhancing a potential reducing environment in the impoundment.

Table 21. Total Mercury Concentrations in Water and Sediment for Muddy River Watershed R-EMAP.

***ND=Not Detected**

Site ID	Total Mercury (HgT) µg/L	Total Mercury (HgT) mg/kg dry weight
MV95	ND	0.10
MV128	ND	0.08
MV185	ND	0.80
MV270	0.41	ND
MV875	ND	0.20

With a drinking water standard of 2 µg/L, 36 sites were well below the quantification limits of 0.02 µg/L and 0.03 µg/L. Site 270 was estimated at a mercury level of 0.41µg/L. 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 Muddy-Virgin Project area, the condition estimate (Figure 57) good was given as less than or equal to 0.17 mg/kg and above 0.17 mg/kg was considered poor.

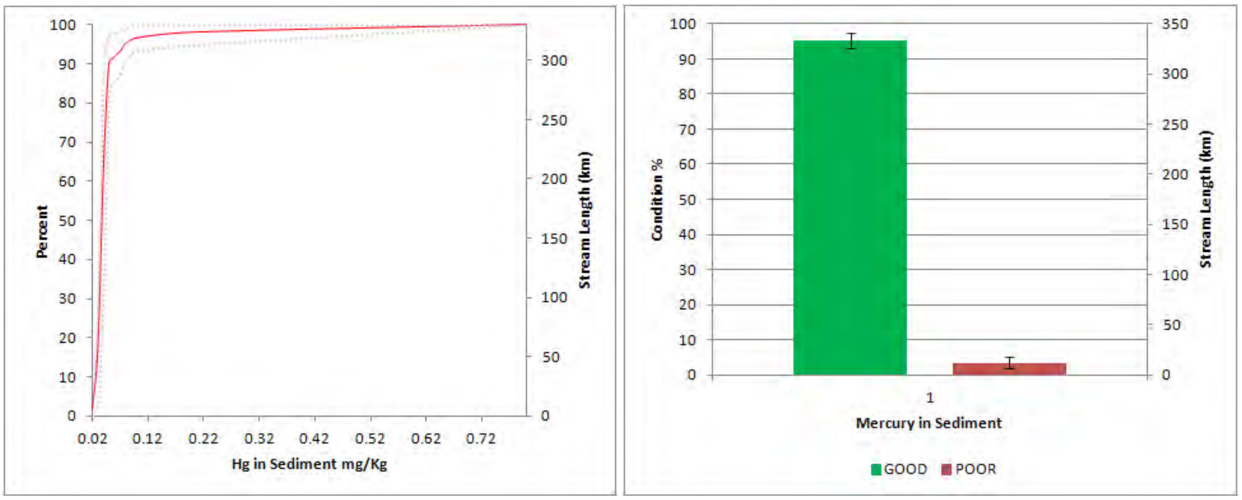


Figure 57. Cumulative Distribution Frequency and Condition Estimate of Mercury in Stream Sediment.

Nickel:

All samples were at or below the quantification limit of 50 µg/L. With hardness dependent CCC and CMC values, all sites were below these standards. There is no drinking water standard for nickel.

Selenium:

All samples were at or below the drinking water standard of 50 µg/L with a quantification limit of 20 or 50 µg/L. With a federal CCC standard of 5 µg/L, it is undetermined whether the samples exceeded this limit.   There is no CMC standard for selenium.

Silver:

Quantification limits of 5 µg/L and 10 µg/L were below the secondary drinking water standard of 100 µg/L. Calculating the hardness dependant CMC value, only one site (258) had a CMC value (4.53 µg/L) below its quantification limit of 5 µg/L.

Zinc:

The CCC and CMC for zinc is hardness dependent. None of the sites exceeded their individual CCC or CMC values. 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 cumulative distribution frequency for zinc in the Muddy-Virgin Project area for water and sediment are shown in Figure 58.

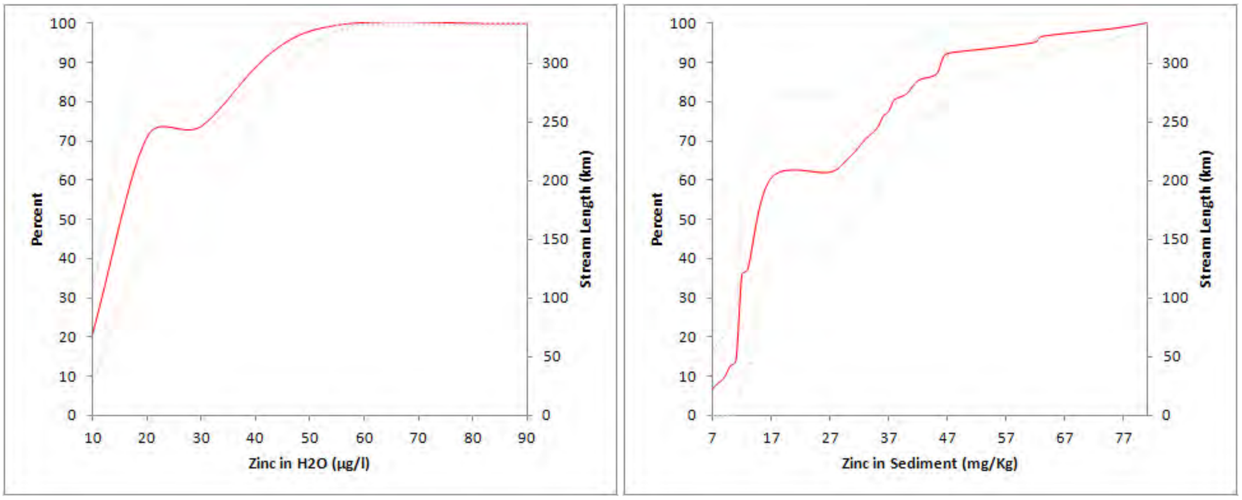


Figure 58. Cumulative Distribution Frequency of Zinc in Stream Water and Sediment.

F. Relationships Between Indicators and Stressors

The second objective of this report is 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 different combinations of indicators (Table 22). Both water chemistry and physical habitat are 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 22. Possible Combinations of Stressors and Indicator Relationships.

	Stressors			
Indicators	**Water Chemistry**	**Physical Habitat**	**Riparian Disturbance**	**Sedimentary Metals**
Water Chemistry	--	X	X	--
Physical Habitat	--	--	X	--
Benthic Inverts.	X	X	X	--
Periphyton	X	X	X	X
Sediment Metabolism	X	X	X	--

Many correlations between indicators were detected as weak (Appendix 14). The following statements summarize the outcome of correlations between indicators:

- Most statistically significant correlations for water chemistry were either weak or moderate, but there were several correlations with high R-values. Water chemistry indicators correlated with riparian disturbance stressors had a moderate correlation between DO and landfills (Figure 59). Water chemistry indicators (conductivity, DO, chloride and sulfate) were all negatively correlated to percent shade and tree cover, while having a positive correlation to average width and width/depth ratio (Figure 60).

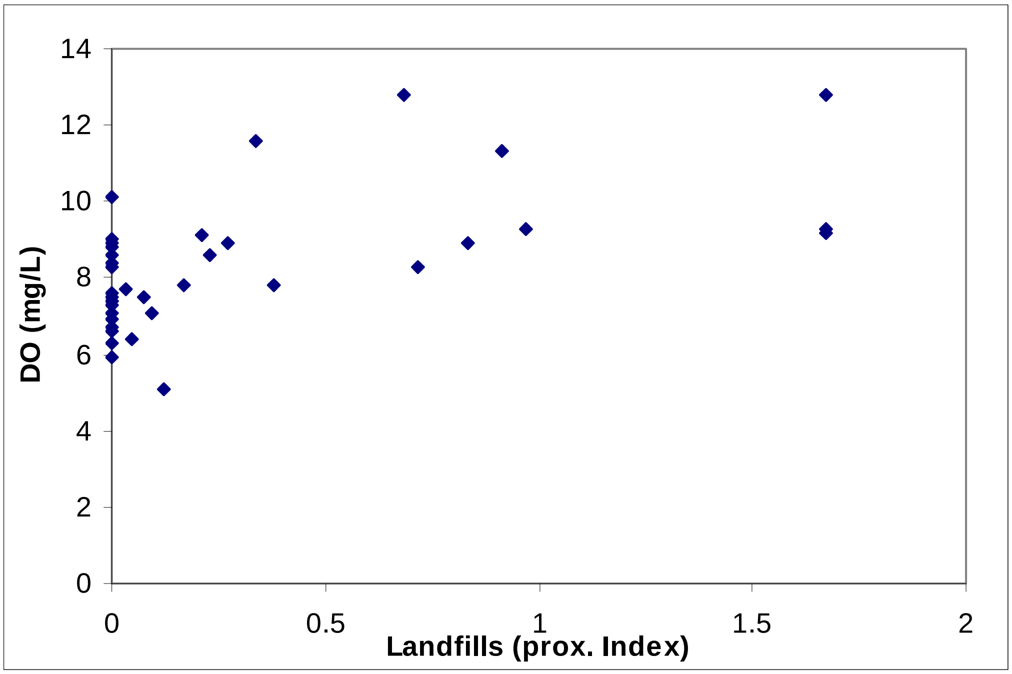


Figure 59. Relationship Between Dissolved Oxygen and Proximity to Landfills. R=0.613 P=0.0001, n=35.

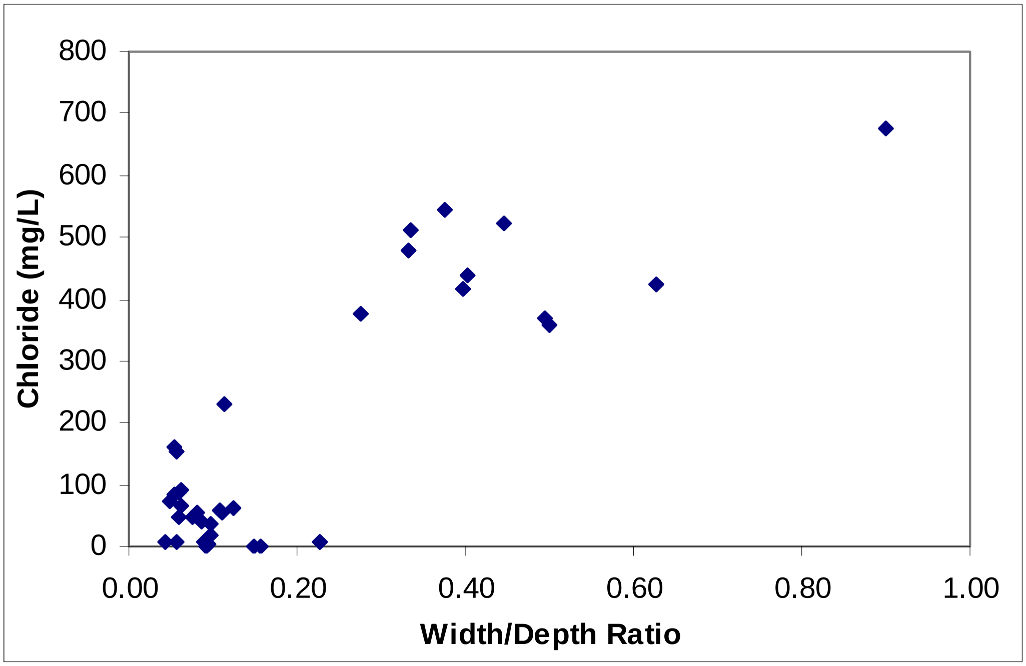


Figure 60. Relationship between Chloride and Width/depth Ratio. R=0.855 P=<0.0001, n=35.

- Four correlations between physical habitat indicators and riparian disturbance stressors were weak. One moderate positive correlation was found between percent pools and the human riparian disturbance indicator proximity to walls (proximity to walls is based on the proximity to the riparian area).

- Individual benthic macroinvertebrate indicators had two weak correlations to water chemistry stressor temperature and TKN. Physical habitat stressors included stream depth, embeddedness, vegetation cover, and percent sand/fine. Taxa richness had two moderately negative correlations to embeddedness and percent sand/fine (Figure 61). Macroinvertebrate IBI assemblage had three weak and two moderate correlations to water chemistry, one weak correlation to physical habitat metric, and two weak correlations to all riparian disturbances.

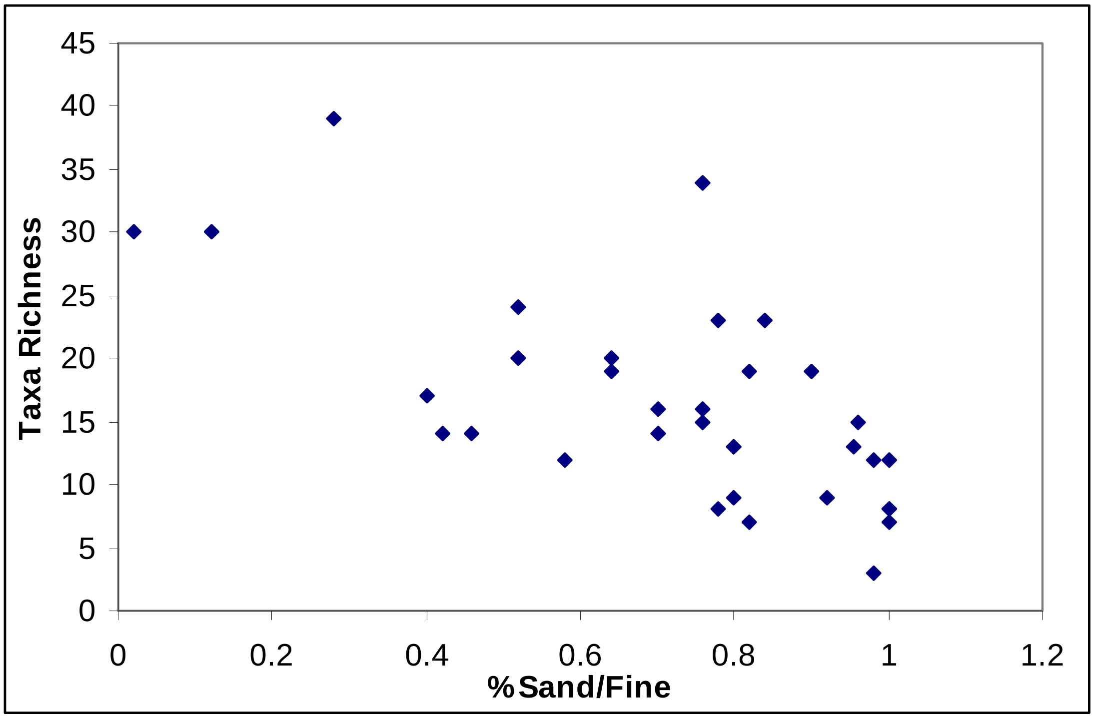


Figure 61. Relationship Between Taxa Richness and % Sand/fine. R=-0.593 P=0.000, n=35.

- Periphyton, defined as AFDM/cm^2, had no correlations to water quality, physical habitat or riparian disturbances. There were only two positive correlations between sedimentary metals: cadmium and lead.

- Sediment metabolism indicators had primarily positively strong and weak correlations to water chemistry. For water chemistry, only pH had a negative weak correlation. A moderate positive correlation existed to width/depth ratio (Figure 62). A moderate negative correlation existed for percent shade. Pipe and landfill riparian disturbances had weak positive correlations.

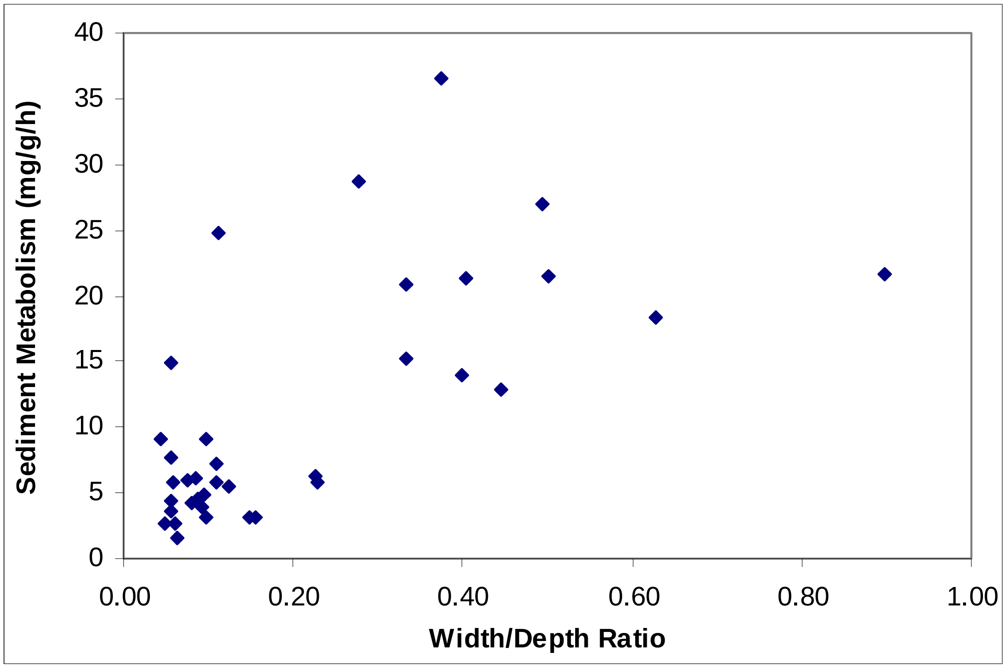


Figure 62. Relationship between Sediment Metabolism and Width/depth Ratio. R=0.651 P=<0.0001, n=35.

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, 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 23).

Table 23. Thresholds for the Muddy-Virgin River Project Area.

Indicator	Most-disturbed		Least-disturbed	
	Threshold	%	Threshold	%
IBI	<56	5th	≥66	25th
Conductivity (µS/cm)	>724	95th	≤550	75th
Total Nitrogen (mg/L)	>0.337	95th	≤0.251	75th
Total Phosphorus (mg/L)	>0.038	95th	≤0.018	75th
Chloride (mg/L)	>16.89	95th	≤8.85	75th
Sulfate (mg/L)	<28	95th	≤27.20	75th
Densiometer (0-17 scale)	<1.07	5th	≥2.62	25th
Fish Cover- Area Covered by Natural Objects	<1.44	5th	≥1.73	25th
Riparian Disturbance Roads (prox. Index)	>0.46	95th	≤0.44	75th
Riparian Disturbance All (prox. Index)	>0.18	95th	≤0.11	75th
% Fine	>0.75	95th	≤0.47	75th
% Sand/Fine	>0.87	95th	≤0.78	75th
Embeddedness (%)	>92.46	95th	≤84.55	75th
% Slow	<0.64	5th	≥0.75	25th

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 is one aspect to consider in defining the importance of each potential stressor. Another issue to consider is the severity to which each stressor has on biotic integrity, assessed by calculating relative risk. Each view provides important input to policy decisions.

Relative Extent

The total length of the RF3 stream network in Project Area is 35015.0 km. Over ninety-nine percent of this total was considered non-target - i.e., many streams within the project area are ephemeral streams and dry for much of the year. The remaining target stream length (705.7 km) represents the portion of the sampling frame that meets the criteria for inclusion in the assessment. A stressor's extent is then estimated by calculating the proportion of the streams in most or least disturbed condition compared to all stream lengths.

Results of water chemistry stressor metrics varied from 46% (total phosphorus) to 78% (sulfate) for the stream extent in most-disturbed condition. Chloride had the largest percentage of stream length in least-disturbed condition (24%) (Figure 63). Macroinvertebrate IBI had 77% of the stream length in the most-disturbed condition category.

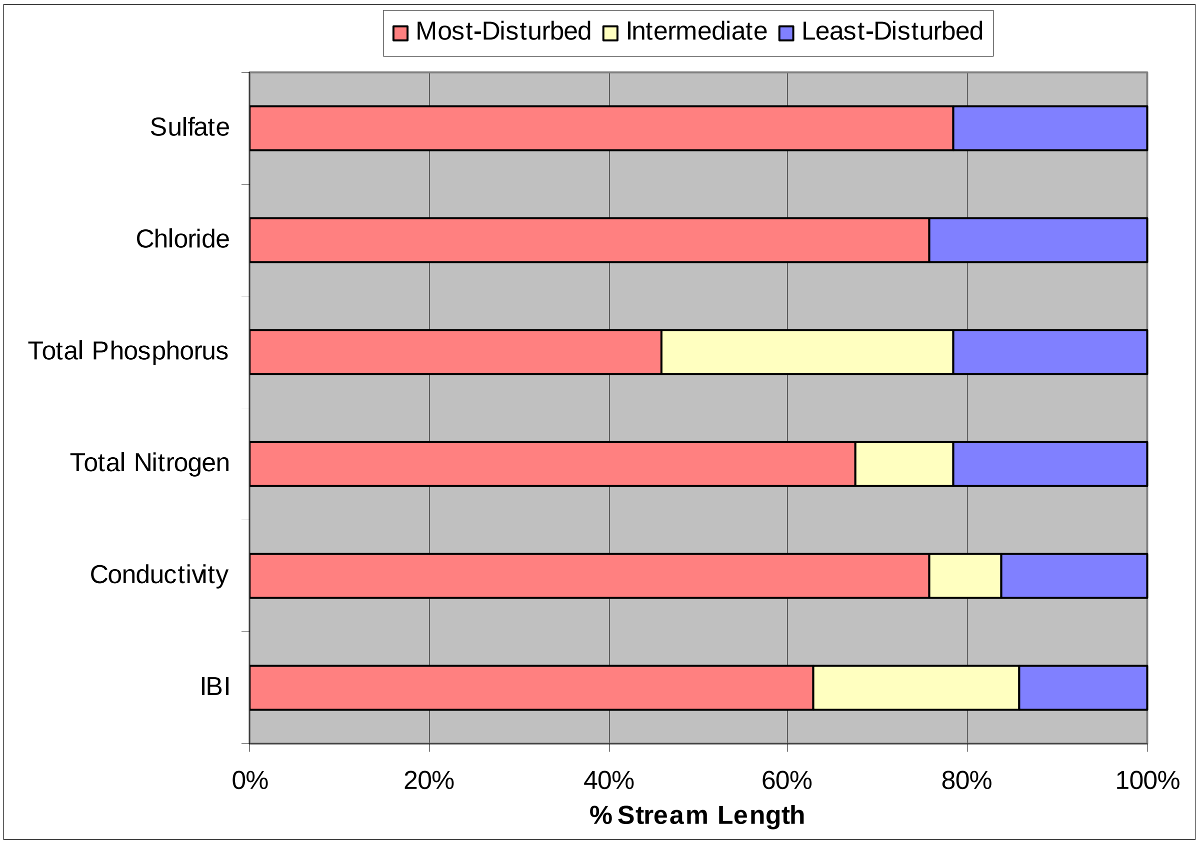


Figure 63. Extent of Stream Length in Most-disturbed, Intermediate and Least-disturbed Condition for Selected Water Quality Indicators and Macroinvertebrate IBI.

Physical habitat condition stressor results were fairly consistent (Figure 64). Sediment stressors metrics had <31% of stream lengths in most-disturbed 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 (30% versus 14% for fine-sized alone). Riparian disturbance from all human causes resulted in 32% of the stream length in most-disturbed condition compared to the reference condition. The results for riparian disturbance from roads only were somewhat less (24%). The metric that varies substantially was slow water habitat (% pools and glides). The large majority of stream length was in the good category (91%) for this stress indicator. Figure 65 gives a summary of the relative extent of stressors.

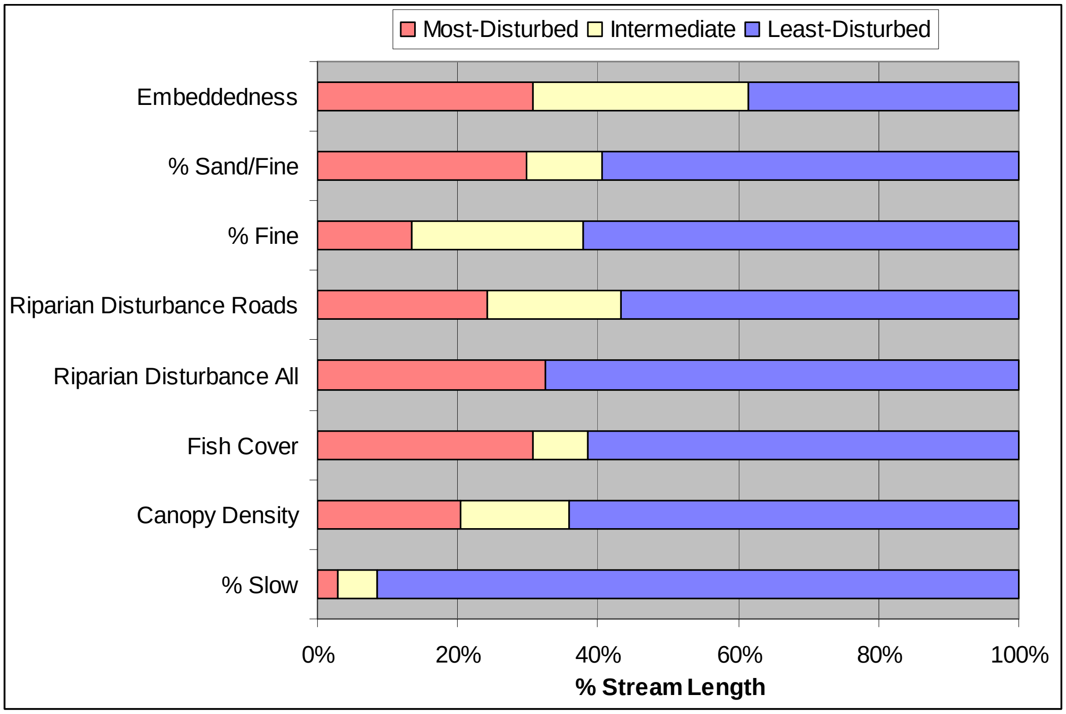


Figure 64. Extent of Stream Length in Most-disturbed, Intermediate and Least-disturbed Condition for Selected Physical Habitat Indicators.

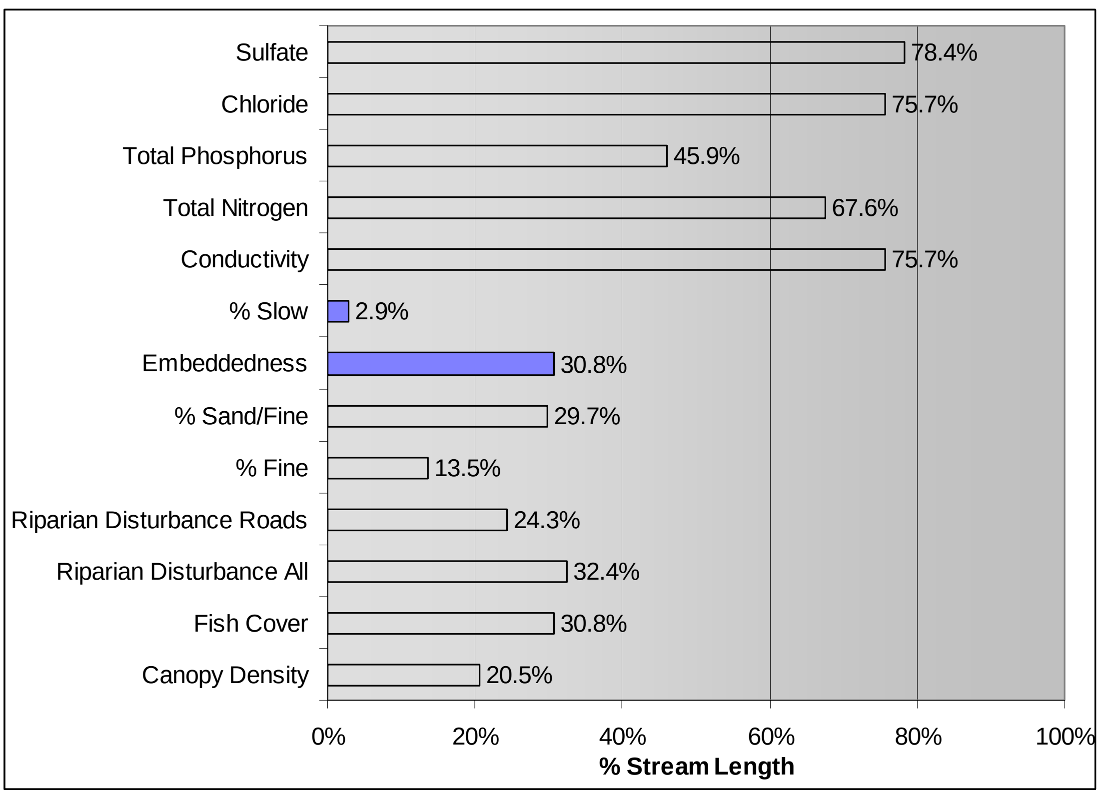


Figure 65. Summary Relative Extent of Stressors (Proportion of Stream Length with Stressors in Most-disturbed Condition).

Relative Risk

Relative risk is a term which assesses the association between stressors and biological indicators. Relative risk is a ratio of two probabilities. For this report, the two probabilities, or risks, measure the likelihood that a most-disturbed condition of a biological indicator will also occur in streams with a most-disturbed condition of a particular stressor. 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 Muddy-Virgin Project area, weight data was incomplete. For this study, the calculations are made from estimating the stream length 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 24) is an example of how the data can be arranged and calculated.

Table 24. Thresholds for the Muddy-Virgin River Project Area.

Number of Sampling Sites		Total Nitrogen	
		Least-disturbed	Most-disturbed
IBI	Good	A: 3	C: 2
	Poor	B: 3	D: 16
	Total	A+B: 6	C+D: 18

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

= D/(C+D)   16/18=0.9

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

= B/(A+B)   3/6=0.5

Comparing these two probabilities (0.9/0.5) yields a relative risk of 1.8. In other words, it is 1.8 times more likely to find a most-disturbed condition for benthic macroinvertebrates in streams where total nitrogen 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 can be confounded. Relative risks at or below 1.0 are not considered significant.

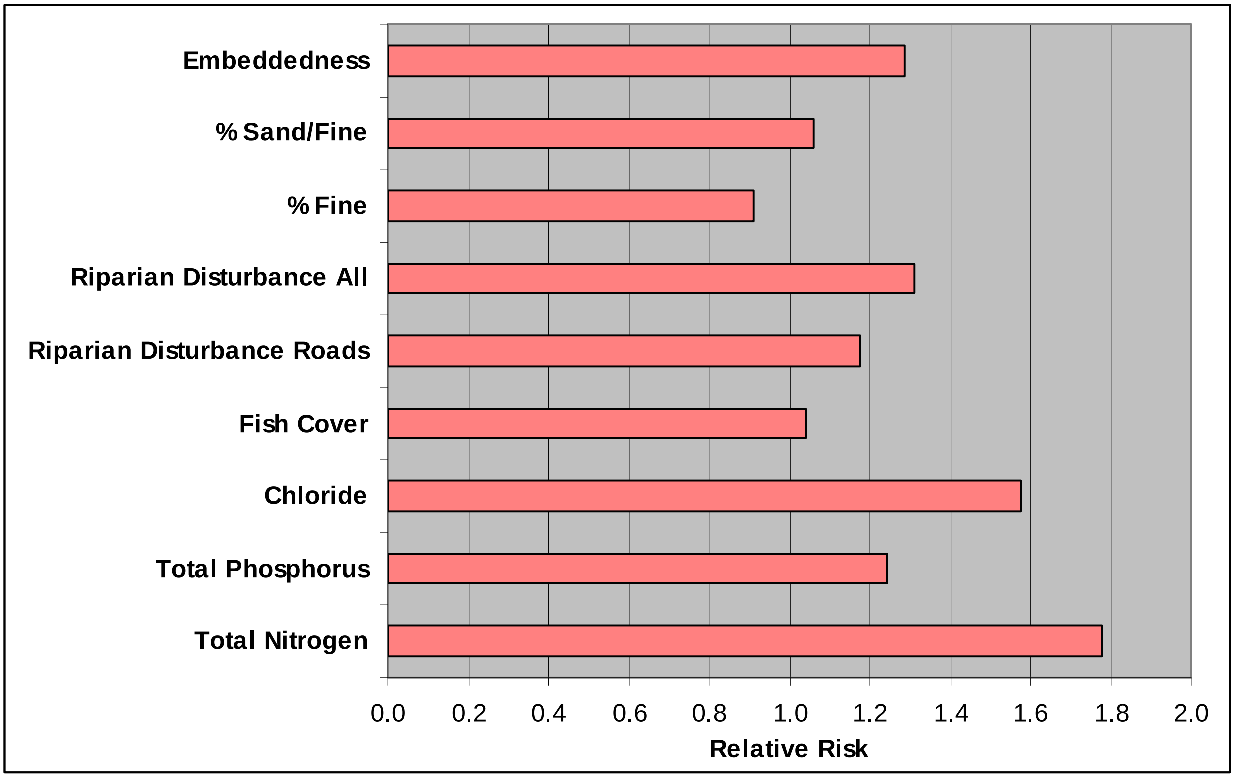


Figure 66. Risk to Benthic Assemblage (IBI) Relative to the Environmental Stressor Condition.

Relative risk assesses the significance of the effects of stressors to stream biota**.** Benthic macroinvertebrate IBI was the biotic indicator for this comparison. Thirteen stressors were originally used to analyze extent. Only nine were useable for relative risk estimation due to methods restrictions (Figure 66). The relationship was only reported for stressors where there was adequate data. Not all stress indicators used in the relative risk analysis exceeded the significance threshold of one (Appendix 14). Percent fine substrate had a relative risk value less than one, while both fish cover and percent sand/fine substrate had values just over 1.0. Total nitrogen and chloride had the highest relative risk values, both at over 1.5.

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 (Figure 67). For example, canopy density was in most-disturbed condition in only an estimated 21% of the stream length, but where this problem does occur the biota is at a high risk of being in a most-disturbed condition. However, some stressors are both broadly occurring and have high relative risk.

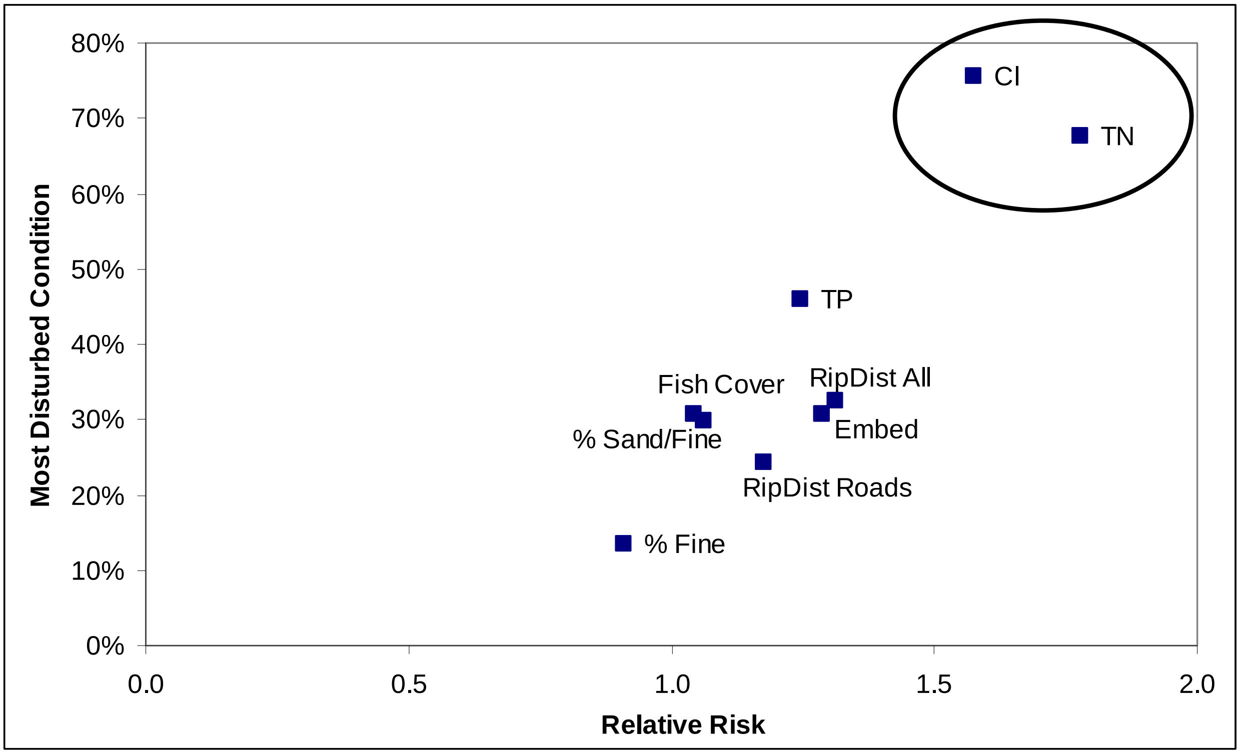


Figure 67. Summary of Extent of Stressors in Most-disturbed Condition in Relation to Relative Risk. The Oval Emphasizes Stressor Indicators with both High Percent of Stream Length in Most-disturbed Condition and with High Relative Risk. Refer to Appendix 14 for Definition of Abbreviated Indicator Names in this Figure.

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 indicate that the statuses of many of the streams in the Muddy-Virgin River project area are in a less than desirable condition. The percentage of impacted streams varied, with 41% of stream reaches studied being in most-disturbed condition. Primary stressors in terms of both extent and risk to biota are conductivity, sulfate, chloride and total nitrogen.

For this evaluation, only benthic macroinvertebrate IBI was used to determine risk to biota. It is preferable to use more assemblages so that the conclusions are more robust. Using multiple assemblages is preferred as a stressor that may be very relevant to one assemblage may have less of a signal for another.

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. Nevada's arid environment, coupled with the fact that most of the biodiversity in this state is associated with riparian or aquatic habitats, makes the management of these systems a matter of particular importance. Although we have made considerable progress as a nation in managing our watersheds, 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

[*] *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.*

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.

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 Muddy-Virgin River Project area to provide for a more sustainable ecosystem.

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VII. Appendices

Appendix 1. List of Sites

Site	Stream Order	Stream Name	Longitude	Latitude
8	3	Meadow Valley Wash	-114.3552778	37.834167
10	4	White River	-115.1608333	38.9325
19	5	Virgin River	-113.9191667	36.919167
95	5	Meadow Valley Wash	-114.5672222	37.436944
110	5	Virgin River	-114.2283333	36.723889
119	5	Virgin River	-114.2675	36.689444
128	3	Flatnose Wash	-114.102778	37.919167
144	1	Unnamed	-115.144444	38.379444
170	5	Muddy River	-114.52881	36.641667
173	3	Las Vegas Wash	-115.041944	36.148333
185	3	Pahranagat River	-115.191944	37.439444
207	5	Meadow Valley Wash	-114.664444	36.869444
215	5	Meadow Valley Wash	-114.510278	37.086944
232	4	Las Vegas Wash	-115.036111	36.134137
258	3	Beaver Dam Wash	-114.058056	37.49222
270	3	Muddy River	-114.666944	36.673889
285	5	Meadow Valley Wash	-114.57416	37.551389
289	5	Virgin River	-113.681944	37.013056
298	3	Meadow Valley Wash	-114.346667	37.841667
310	5	Virgin River	-114.033889	36.801667
319	5	Virgin River	-113.928056	36.883056
368	3	Meadow Valley Wash	-114.332778	37.853333
469	4	Muddy River	-114.496389	36.620556
519	3	Muddy River	-114.687222	36.704444
530	4	Muddy River	-114.551389	36.650833
660	5	Virgin River	-114.073611	36.795556
669	4	Muddy River	-114.417222	36.526389
720	5	Virgin River	-114.171667	36.756111
790	5	Virgin River	-114.219444	36.734167
875	3	Pahranagat River	-115.134444	37.314722
1009	4	Muddy River	-114.468333	36.582222
1069	3	Muddy River	-114.708889	36.714444
1100	5	Virgin River	-114.129722	36.782778
1190	5	Virgin River	-114.084167	36.791667
1260	5	Muddy River	-114.566944	36.661944
1300	3	Muddy River	114.598056	36.655556
1310	3	Muddy River	-114.626111	36.654167

Appendix 2. Summary Statistics for Water Chemistry Indicators for the Muddy-Virgin Project Area

Indicator	Units	Mean	Median	Min.	Max.	Range	Variance	Standard Deviation	Standard Error
Water Temp	°C	23.06	23.00	13.10	32.80	19.70	23.90	4.89	0.88
Dissolved O2	mg/L	8.33	8.30	5.10	12.80	7.70	3.01	1.74	0.29
pH	pH units	8.03	8.04	7.18	8.62	1.44	0.09	0.31	0.05
Conductivity	µS/cm	1703.89	1004.00	310.00	4090.00	3780.00	1610325.16	1269.0	208.53
Total Phosphorus	mg/L	0.06	0.03	0.01	0.43	0.42	0.01	0.08	0.01
Total Nitrogen	mg/L	0.68	0.49	0/09	4.02	3.94	0.63	0.80	0.68
Nitrate/Nitrite	mg/L	0.36	0.12	0.00	3.11	3.11	0.51	0.71	0.12
Ammonia	mg/L	0.03	0.03	0.01	0.09	0.08	0.00	0.02	0.00
Chloride	mg/L	173.08	65.93	1.00	675.00	674.00	40861.20	202.1	32.99
Sulfate	mg/L	498.56	246.12	1.00	1854.00	1853.00	269639.20	519.3	85.10
Total Kjeldahl Nitrogen	mg/L	0.29	0.27	0.06	0.88	0.82	0.03	0.17	0.03

Appendix 3. Summary Statistics for Physical Habitat Metrics

Type	Indicator	Units	Indicator	Mean	Lower 95% Conf.	Upper 95% Conf.	Med.	Min.	Max.	Range	Var.	Std. Dev.	Std. Error
channel	stream length	m	reach_length_m	252.89	205.71	300.08	160.00	150.00	500.00	350.00	20028.10	141.52	23.27
& subba	wetted width	m	wt_wid	6.79	4.84	8.73	4.45	0.00	26.18	26.18	35.97	6.00	0.96
	bankfull width	m	bankwid	9.26	6.90	11.63	5.63	1.52	25.60	24.08	53.28	7.30	1.17
	width of mid channel bars	m	barwid	2.06	1.00	3.13	0.00	0.00	10.28	10.28	10.79	3.28	0.53
	ave depth	cm	ave depth	19.17	14.71	23.62	14.20	1.75	47.15	45.4	167.13	12.97	2.19
	thalweg depth	cm	depth	43.34	34.87	50.25	34.61	4.26	88.56	84.30	504.31	22.39	3.78
	% mid channel shade	%	_mid_channel_shade	31.74	21.20	42.29	25.00	0.00	93.05	93.05	1000.45	31.63	5.20
	%bank shade	%	_bank_shade	56.26	45.72	66.80	64.97	7.22	95.99	88.77	999.42	31.61	5.20
	incision height	m	incision height	0.45	0.41	0.49	0.47	0.17	0.72	0.55	0.01	0.12	0.02
	%fast	%	%fast	0.38	-0.25	1.02	0.27	0.00	11.00	11.00	3.42	1.85	0.31
	%slow	%	%slow	0.92	0.89	0.96	0.96	0.61	1.00	0.39	0.01	0.10	0.02
	%pool	%	%pool	0.01	0.00	0.01	0.00	0.00	0.06	0.06	0.00	0.01	0.00
	discharge	m/s	discharge	10.62	6.26	14.98	7.13	0.01	52.23	52.22	161.17	12.70	2.15
	slope of reach	%	slope	1.01	0.76	1.26	0.84	0.23	3.42	3.19	0.50	0.71	0.13
	bearing	degree	bearing	162.36	141.01	183.70	154.24	37.50	307.65	270.15	4336.65	65.85	10.54
	bank angle	degree	angle	41.68	35.24	48.11	33.09	13.64	85.05	71.41	393.70	19.84	3.18
	undercut bank distance	m	undercut	2.16	-1.99	6.31	0.00	0.00	80.00	80.00	163.68	12.79	2.05
	embedded	%	embed	83.49	77.42	89.55	87.36	0.00	100.00	100.00	350.08	18.71	3.00
riparian	canopy layer big trees	%	big trees	8.97	2.06	15.87	0.00	0.00	100.00	100.00	428.70	20.71	3.40
	canopy layer small trees	%	small trees	39.74	28.25	51.24	40.91	0.00	100.00	100.00	1188.48	34.47	5.67
	canopy layer total trees	%	total trees	24.36	16.97	31.74	27.27	0.00	100.00	100.00	490.31	22.14	3.64
	understory woody	%	understory wood	84.77	75.59	93.95	95.45	0.00	100.00	100.00	757.82	27.53	4.53

	understory nonwoody	%	understory nonwood	58.19	45.96	70.42	63.64	0.00	100.00	100.00	1345.07	36.68	6.03
	understory total	%	total understory	71.48	65.11	77.85	70.45	38.64	100.00	61.36	364.86	19.10	3.14
	ground cover woody	%	gcw	66.58	53.72	79.45	86.36	0.00	100.00	100.00	1489.00	38.59	6.34
	ground + canopy woody	%	ground cnw	78.83	68.99	88.67	90.91	0.00	100.00	100.00	870.89	29.51	4.85
	ground barren	%	barren ground	89.82	81.69	97.96	100.00	0.00	100.00	100.00	595.11	24.39	4.01
	ground cover total	%	total ground	72.71	64.80	80.61	79.55	4.55	100.00	95.45	561.88	23.70	3.90
cover	filamentous algae	frac	algae	0.69	0.46	0.91	0.60	0.00	3.09	3.09	0.49	0.70	0.11
	boulders	frac	bouldr	0.11	0.03	0.19	0.00	0.00	1.00	1.00	0.06	0.25	0.04
	brush/woody debris	frac	brush	0.86	0.67	1.04	0.82	0.00	2.27	2.27	0.34	0.58	0.09
	aquatic macrophytes	frac	macphy	0.78	0.45	1.11	0.40	0.00	4.00	4.00	1.02	1.01	0.16
	overhang vegetation	frac	ovrhng	1.26	0.94	1.59	0.91	0.00	3.45	3.45	1.00	1.00	0.16
	artificial structures	frac	struct	0.04	0.00	0.09	0.00	0.00	0.82	0.82	0.02	0.14	0.02
	undercut	frac	undcut	0.25	0.13	0.38	0.00	0.00	1.18	1.18	0.15	0.38	0.06
	woody debris	frac	woody	0.11	0.05	0.18	0.00	0.00	1.00	1.00	0.04	0.21	0.03
woody	bankfull very small	#/100 m	wetsdsl	0.30	0.15	0.46	0.10	0.00	2.10	2.10	0.23	0.48	0.08
	bankfull small	#/100 m	wetsdml	0.06	0.01	0.11	0.00	0.00	0.80	0.80	0.02	0.15	0.02
	bankfull medium	#/100 m	wetsdll	0.00			0.00	0.00	0.00	0.00	0.00	0.00	0.00
	bankfull small	#/100 m	wetmdsl	0.01	0.00	0.02	0.00	0.00	0.20	0.20	0.00	0.04	0.01
	bankfull medium	#/100 m	wetmdml	0.01	0.00	0.02	0.00	0.00	0.20	0.20	0.00	0.04	0.01
	bankfull small	#/100 m	wetldsl	0.00	0.00	0.01	0.00	0.00	0.10	0.10	0.00	0.02	0.00
	bankfull large	#/100 m	wetldml	0.00	0.00	0.01	0.00	0.00	0.10	0.10	0.00	0.02	0.00
	above bankfull very small	#/100 m	drysdsl	0.05	0.00	0.11	0.00	0.00	0.80	0.80	0.03	0.17	0.03

	above bankfull small	#/100 m	drysdml	0.00	0.00	0.01	0.00	0.00	0.10	0.10	0.00	0.02	0.00
	above bankfull medium	#/100 m	drysdll	0.00			0.00	0.00	0.00	0.00	0.00	0.00	0.00
human	wall (prox. index)	frac	wall	0.10	0.00	0.19	0.00	0.00	1.18	1.18	0.08	0.28	0.05
	building (prox. index)	frac	bldg	0.07	0.01	0.13	0.00	0.00	0.67	0.67	0.03	0.18	0.03
	pavement (prox. index)	frac	pvmt	0.05	-0.01	0.10	0.00	0.00	0.70	0.70	0.03	0.16	0.03
	road (prox. index)	frac	road	0.37	0.29	0.46	0.34	0.00	0.84	0.84	0.06	0.25	0.04
	pipe (prox. index)	frac	pipe	0.01	0.00	0.02	0.00	0.00	0.21	0.21	0.00	0.04	0.01
	landfill (prox. index)	frac	landfill	0.30	0.13	0.47	0.03	0.00	1.67	1.67	0.25	0.50	0.08
	park (prox. index)	frac	park	0.02	-0.01	0.06	0.00	0.00	0.67	0.67	0.01	0.11	0.02
	crop (prox.index)	frac	crop	0.00			0.00	0.00	0.00	0.00	0.00	0.00	0.00
	pasture (prox. index)	frac	pasture	0.42	0.21	0.62	0.00	0.00	1.67	1.67	0.37	0.61	0.10
	logging (prox. index)	frac	logging	0.00			0.00	0.00	0.00	0.00	0.00	0.00	0.00
	mining activity(prox. index)	frac	minact	0.00	0.00	0.00	0.00	0.00	0.06	0.06	0.00	0.01	0.00
mesosub	mean substrate size left center	mm	xsublctr	2.47	2.14	2.80	2.67	1.00	4.60	3.60	0.98	0.99	0.16
	mean substrate size right center	mm	xsubrctr	2.45	2.13	2.77	2.22	1.00	4.60	3.60	0.93	0.96	0.16
	mean substrate size center	mm	xsub_ctr	2.69	2.36	3.02	2.60	1.00	5.00	4.00	0.99	0.99	0.16
	mean substrate size left	mm	xsub_lft	1.85	1.52	2.18	1.40	1.00	4.33	3.33	0.96	0.98	0.16
	mean substrate size right	mm	xsub_rgt	1.78	1.48	2.07	1.50	0.88	4.50	3.63	0.78	0.88	0.15

Appendix 4. Summary Statistics for Macroinvertebrate Metrics, Muddy-Virgin Project

Metric	Mean	Upper 95% Conf.	Lower 95% Conf	Median	Min	Max	Range	Variance	Std. Dev.	Std. Err.
Total Taxa	16.83	19.66	14.00	15.00	3.00	39.00	36.00	72.85	8.54	1.44
% EPT	41.79	49.75	33.83	42.58	0.00	81.19	81.19	577.26	24.03	4.06
EPT Taxa	5.51	6.67	4.36	5.00	0.00	16.00	16.00	12.14	3.48	0.59
% Ephemeroptera	26.72	32.97	20.47	25.32	0.00	75.89	75.89	355.74	18.86	3.19
Ephemoptera Taxa	2.86	3.42	2.29	3.00	0.00	7.00	7.00	2.89	1.70	0.29
% Plecoptera	0.02	0.06	-0.02	0.00	0.00	0.68	0.68	0.01	0.12	0.02
Plecoptera Taxa	0.06	0.17	-0.05	0.00	0.00	2.00	2.00	0.11	0.34	0.06
% Trichoptera	15.06	21.59	8.52	5.78	0.00	70.42	70.42	388.84	19.72	3.33
Trichoptera Taxa	2.60	3.29	1.91	2.00	0.00	9.00	9.00	4.36	2.09	0.35
Shannon H	1.73	1.91	1.54	1.71	0.53	2.73	2.19	0.32	0.56	0.09
% Collector	58.79	67.67	49.92	60.45	7.63	95.32	87.69	717.35	26.78	4.53
% Filterer	22.02	29.93	14.10	11.82	0.00	71.95	71.95	570.52	23.89	4.04
% Predator	13.90	21.02	6.78	5.05	0.78	87.94	87.16	461.92	21.49	3.63
% Grazers	4.42	7.13	1.70	1.29	0.00	39.42	39.42	67.22	8.20	1.39
% Shredders	0.66	1.38	-0.06	0.00	0.00	12.45	12.45	4.69	2.17	0.37
% Burrower	19.32	24.69	13.95	15.11	0.66	68.35	67.69	262.49	16.20	2.74
% Climber	0.50	0.80	0.20	0.00	0.00	3.67	3.67	0.82	0.90	0.15
% Clinger	1.75	3.08	0.42	0.22	0.00	19.92	19.92	16.12	4.02	0.68
% Sprawler	7.29	10.17	4.41	4.39	0.00	28.09	28.09	75.77	8.70	1.47
% Swimmer	13.98	18.86	9.10	8.29	0.00	53.00	53.00	216.97	14.73	2.49
HBI	5.36	5.66	5.06	5.08	4.21	8.18	3.97	0.82	0.91	0.15
% Intolerance (<4)	4.77	8.03	1.51	1.39	0.00	46.06	46.06	96.85	9.84	1.66
% Tolerance (≥7)	15.31	21.68	8.94	8.11	0.00	85.41	85.41	369.58	19.22	3.25

Appendix 5. 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 6. Candidate Macroinvertebrate Metrics and Results of Range Test.

Mertric ID	Metric Class	Metric Description	Range Test
Shan_e	Diversity	Shannon's Evenness Index base e	Pass
Shan_2	Diversity	Shannon's Evenness Index base 2	Pass
Shan_10	Diversity	Shannon's Evenness Index base 10	Pass
AmphPct	Composition	% Amphipoda	Pass
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	**Fail**
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	Pass
ClngrPct	Habit	% Clingers	Pass
SprwlPct	Habit	% Sprawlers	Pass
SwmmrPct	Habit	% Swimmers	Pass
BrrwrTax	Habit	Burrower Taxa Richness	Pass
ClmbrTax	Habit	Climber Taxa Richness	Pass
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

Appendix 6. Candidate Macroinvertebrate Metrics and Results of Range Test (cont.).

Metric ID	Metric Class	Metric Description	Range Test
EphemTax	Richness	Ephemeroptera Taxa Richness	Pass
EPTTax	Richness	EPT Taxa Richness	Pass
OligoTax	Richness	Oligochaeta Taxa Richness	**Fail**
OrthoTax	Richness	Orthocladiinae Taxa	**Fail**
PlecoTax	Richness	Plecoptera Taxa Richness	**Fail**
PteroTax	Richness	Pteronarcys Taxa	**Fail**
TanytPct	Richness	Tanytarsini Taxa	**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 7. F-test Results for Candidate Microinvertebrate Metrics.

	Metric ID	F	P-value
Composition	Orth2ChiPct	8.892	0.018
	Shan_e	6.568	0.034
	DipPct	5.098	0.054
	ChiroPct	4.883	0.058
	EphemPct	3.802	0.087
	Tnyt2ChiPct	3.671	0.092
	AmphPct	3.633	0.093
	OdonPct	2.134	0.182
	ColeoPct	2.611	0.145
	BivalPct	2.016	0.193
	GastrPct	1.532	0.251
	TanytPct	0.912	0.368
	EPTPct	0.865	0.380
	TrichPct	0.550	0.480
	NonInPct	0.442	0.525
	OligoPct	0.354	0.568
	CrMolPct	0.002	0.970
Feeding	ShredTax	16.000	0.004
	PredPct	7.791	0.024
	ShredPct	7.570	0.025
	PredTax	7.433	0.026
	CllctTax	5.570	0.046
	ScrapTax	4.840	0.059
	ScrapPct	4.245	0.073
	FiltrPct	3.056	0.119
	FiltrTax	0.640	0.447
	CllctPct	0.022	0.885
Habit	BrrwrPct	6.548	0.034
	SwmmrTax	5.565	0.046
	ClngrTax	4.545	0.066
	BrrwrTax	1.960	0.199
	SprwlTax	1.600	0.242
	SprwlPct	0.435	0.528
	ClmbrPct	0.260	0.624
	SwmmrPct	0.172	0.690
	ClngrPct	0.025	0.879
	ClmbrTax	0.200	0.667
Richness	TotalTax	9.948	0.014
	CrMolTax	7.579	0.025
	DipTax	6.698	0.032
	EPTTax	3.681	0.091
	EphemTax	2.700	0.139
	ChiroTax	2.632	0.143
	ColeoTax	2.592	0.146
	TrichTax	2.262	0.171

Appendix 7. F-test Results for Candidate Microinvertebrate Metrics (cont.).

	Metric ID	F	P-value
Tolerance	TolerTax	19.755	0.002
	Hyd2TriPct	14.761	0.005
	Dom01Pct	6.256	0.037
	IntolPct	3.541	0.097
	Hyd2EPTPct	2.664	0.141
	IntolTax	1.835	0.213
	BeckBI	0.883	0.375
	HBI	0.574	0.470
	Baet2EphPct	0.062	0.810
	TolerPct	0.050	0.829

Appendix 8. R^2 Values for Final Metrics.

Metric ID	Shan_e	ChiroPct	DipPct	Orth2ChiPct	PredPct	ShredPct	CllctTax	PredTax	ScrapTax
Shan_e	1.00	0.11	0.04	0.76	0.05	0.24	0.88	0.76	0.43
ChiroPct	0.11	1.00	0.91	0.12	0.33	0.30	0.06	0.10	0.17
DipPct	0.04	0.91	1.00	0.09	0.35	0.24	0.01	0.08	0.17
Orth2ChiPct	0.76	0.12	0.09	1.00	0.04	0.41	0.70	0.83	0.64
PredPct	0.05	0.33	0.35	0.04	1.00	0.28	0.01	0.04	0.00
ShredPct	0.24	0.30	0.24	0.41	0.28	1.00	0.28	0.20	0.45
CllctTax	0.88	0.06	0.01	0.70	0.01	0.28	1.00	0.59	0.46
PredTax	0.76	0.10	0.08	0.83	0.04	0.20	0.59	1.00	0.52
ScrapTax	0.43	0.17	0.17	0.64	0.00	0.45	0.46	0.52	1.00
ShredTax	0.67	0.23	0.11	0.61	0.29	0.62	0.70	0.46	0.29
BrrwrPct	0.16	0.98	0.92	0.21	0.30	0.37	0.09	0.18	0.27
SwmmrTax	0.19	0.08	0.11	0.33	0.18	0.10	0.11	0.53	0.10
CrMolTax	0.26	0.49	0.41	0.19	0.26	0.33	0.27	0.12	0.26
DipTax	0.81	0.18	0.09	0.82	0.00	0.30	0.86	0.72	0.64
TotalTax	0.89	0.14	0.08	0.91	0.03	0.35	0.87	0.86	0.67
Dom01Pct	0.83	0.26	0.11	0.48	0.20	0.31	0.65	0.56	0.27
Hyd2TriPct	0.36	0.25	0.16	0.27	0.49	0.29	0.35	0.29	0.04
TolerTax	0.71	0.39	0.29	0.75	0.18	0.69	0.68	0.60	0.74

Appendix 8. R^2 Values for Final Metrics (cont.).

Metric ID	ShredTax	BrrwrPct	SwmmrTax	CrMolTax	DipTax	TotalTax	Dom01Pct	Hyd2TriPct	TolerTax
Shan_e	0.67	0.16	0.19	0.26	0.81	0.89	0.83	0.36	0.71
ChiroPct	0.23	0.98	0.08	0.49	0.18	0.14	0.26	0.25	0.39
DipPct	0.11	0.92	0.11	0.41	0.09	0.08	0.11	0.16	0.29
Orth2ChiPct	0.61	0.21	0.33	0.19	0.82	0.91	0.48	0.27	0.75
PredPct	0.29	0.30	0.18	0.26	0.00	0.03	0.20	0.49	0.18
ShredPct	0.62	0.37	0.10	0.33	0.30	0.35	0.31	0.29	0.69
CllctTax	0.70	0.09	0.11	0.27	0.86	0.87	0.65	0.35	0.68
PredTax	0.46	0.18	0.53	0.12	0.72	0.86	0.56	0.29	0.60
ScrapTax	0.29	0.27	0.10	0.26	0.64	0.67	0.27	0.04	0.74
ShredTax	1.00	0.28	0.27	0.32	0.59	0.65	0.71	0.75	0.74
BrrwrPct	0.28	1.00	0.13	0.49	0.26	0.22	0.28	0.25	0.48
SwmmrTax	0.27	0.13	1.00	0.00	0.19	0.28	0.19	0.46	0.18
CrMolTax	0.32	0.49	0.00	1.00	0.32	0.29	0.29	0.20	0.51
DipTax	0.59	0.26	0.19	0.32	1.00	0.94	0.55	0.28	0.74
TotalTax	0.65	0.22	0.28	0.29	0.94	1.00	0.64	0.32	0.81
Dom01Pct	0.71	0.28	0.19	0.29	0.55	0.64	1.00	0.50	0.66
Hyd2TriPct	0.75	0.25	0.46	0.20	0.28	0.32	0.50	1.00	0.37
TolerTax	0.74	0.48	0.18	0.51	0.74	0.81	0.66	0.37	1.00

Appendix 9. Final IBI Scores.

Station ID	IBI
8	74
10	74
19	22
95	66
110	32
119	46
128	84
144	62
170	62
185	46
207	30
215	52
232	24
258	54
270	52
285	58
289	34
298	64
310	38
319	36
368	44
469	38
519	68
530	42
660	40
669	24
720	4
790	56
875	40
1009	34
1069	64
1100	58
1190	48
1300	58
1310	46

Appendix 10. Periphyton

Site Number	Area (cm2)	chl-a (ug/cm2)	Biomass AFDM/cm2 (mg/cm2)	Autotrophic Index (Biomass/chl-a)
8	60	1.07	24.35	22739.58
10	60	0.17	1.06	6276.37
19	48	3.10	1.57	506.96
95	48	2.79	2.79	1000.00
110	0	--	--	--
119	48	0.00	0.24	--
128	72	1.19	1.34	1130.76
144	96	0.38	4.03	10703.46
173	108	0.52	1.77	3424.55
185	96	0.26	4.64	17618.51
207	48	3.04	3.11	1022.44
215	36	9.20	1.03	112.36
232	60	1.87	0.51	275.69
258	36	0.62	5.31	8605.53
270	0	--	--	--
285	24	1.61	4.46	2762.17
289	48	15.08	2.24	148.31
298	24	4.83	1.48	307.05
310	36	1.81	1.22	678.03
319	36	0.91	3.73	4090.41
368	36	1.62	0.00	--
469	60	2.75	1.68	610.52
519	60	0.37	0.60	1605.14
530	108	0.69	0.75	1089.55
660	36	0.17	0.17	1008.35
669	60	13.68	4.85	354.19
720	48	1.13	0.78	687.92
790	36	0.68	0.88	1301.01
875	72	1.99	8.67	4347.24
1009	72	3.15	3.41	1084.26
1069	60	0.66	1.01	1547.99
1100	48	0.58	0.90	1541.14
1190	48	1.96	2.02	1028.48
1300	60	0.75	1.15	1542.71
1310	108	0.30	0.33	1097.26

Appendix 11. Water Metals (µg/L).

Name	Mean	Lower 95% Conf.	Upper 95% Conf.	Median	Min	Max	Range	Variance	Standard Deviation	Standard Error
Aluminum	208.11	191.66	224.55	200	200	500	300	2432.43	49.32	8.11
Antimony	5.54	5.02	6.07	5	5	10	5	2.48	1.57	0.26
Arsenic	25.14	20.13	30.14	20	10	80	70	225.68	15.02	2.47
Barium	48.59	40.92	56.27	42	16	130	114	529.91	23.02	3.78
Beryllium	1.00			1	1	1	0	0.00	0.00	0.00
Cadmium	5.54	5.02	6.07	5	5	10	5	2.48	1.57	0.26
Calcium	146054.05	109038.48	183069.63	80000	39000	350000	311000	1.23E+10	111019.00	18251.41
Chromium	10.00			10	10	10	0	0.00	0.00	0.00
Cobalt	5.27	4.68	5.86	5	3	10	7	3.15	1.77	0.29
Copper	9.08	7.11	11.06	5	3	20	17	35.08	5.92	0.97
Iron	107.03	90.38	123.68	100	60	400	340	2493.69	49.94	8.21
Lead	5.46	4.91	6.01	5	3	10	7	2.70	1.64	0.27
Magnesium	63051.35	43075.45	83027.25	36000	5900	290000	284100	3.59E+09	59912.74	9849.59
Manganese	46.76	20.86	72.65	12	3	290	287	6030.52	77.66	12.77
Mercury	0.04	0.02	0.06	0.03	0.02	0.41	0.39	0.00	0.06	0.01
Nickel	50.00			50	50	50	0	0.00	0.00	0.00
Potassium	17432.43	13748.43	21116.43	13000	3000	46000	43000	1.22E+08	11049.23	1816.48
Selenium	23.24	20.09	26.39	20	20	50	30	89.19	9.44	1.55
Silver	5.54	5.02	6.07	5	5	10	5	2.48	1.57	0.26
Sodium	168378.38	127585.24	209171.52	120000	13000	390000	377000	1.50E+10	122348.85	20114.03
Thallium	5.54	5.02	6.07	5	5	10	5	2.48	1.57	0.26
Vanadium	19.73	19.18	20.28	20	10	20	10	2.70	1.64	0.27
Zinc	21.35	16.07	26.63	20	10	90	80	250.90	15.84	2.60

Appendix 12. Sediment Metals (mg/kg).

Name	Size	Mean	Lower 95% Conf.	Upper 95% Conf.	Median	Min	Max	Range	Variance	Standard Deviation	Standard Error
Aluminum	36	8180.56	6555.95	9805.16	8700	1200	19000	17800	2.31E+07	4801.54	800.26
Antimony	36	32.22	26.67	37.77	30	20	100	80	269.21	16.41	2.73
Arsenic	36	7.83	5.36	10.31	6	3	40	37	53.40	7.31	1.22
Barium	36	110.00	90.45	129.55	100	20	290	270	3337.14	57.77	9.63
Beryllium	36	0.54	0.44	0.65	0.6	0.1	1.1	1	0.09	0.30	0.05
Cadmium	36	1.49	1.13	1.84	1	0.5	6	5.5	1.12	1.06	0.18
Calcium	36	57111.11	45382.25	68839.97	48000	16000	150000	134000	1.20E+09	34664.74	5777.46
Chromium	36	8.72	6.40	11.04	8	2	42	40	47.06	6.86	1.14
Cobalt	36	5.92	4.62	7.21	5	3	20	17	14.71	3.83	0.64
Copper	36	7.81	6.30	9.31	7	2	20	18	19.70	4.44	0.74
Iron	36	7805.56	6566.14	9044.97	7500	2000	17000	15000	1.34E+07	3663.09	610.52
Lead	36	7.95	6.03	9.86	6.5	1.6	27	25.4	32.01	5.66	0.94
Magnesium	36	10908.33	8283.67	13533.00	7600	2800	38000	35200	6.02E+07	7757.22	1292.87
Manganese	36	259.17	203.70	314.63	220	70	820	750	26870.71	163.92	27.32
Mercury	36	0.07	0.02	0.11	0.04	0.02	0.8	0.78	0.02	0.13	0.02
Nickel	36	13.22	9.65	16.79	10	6	60	54	111.26	10.55	1.76
Potassium	36	2308.33	1823.36	2793.31	2000	600	6000	5400	2.05E+06	1433.35	238.89
Selenium	36	5.56	4.78	6.33	5	2	10	8	5.28	2.30	0.38
Silver	36	3.25	2.70	3.80	3	2	10	8	2.65	1.63	0.27
Sodium	36	388.06	319.10	457.01	300	70	900	830	41536.11	203.80	33.97
Thallium	36	12.00	9.99	14.01	10	2	30	28	35.43	5.95	0.99
Vanadium	36	14.44	11.93	16.96	13	4	34	30	55.11	7.42	1.24
Zinc	36	33.44	26.98	39.91	35	7	81	74	364.94	19.10	3.18

Appendix 13. Sediment Metabolism

Site Number	DO/AFDM/TIME (mg/g/h)	Temp (°C)
8	3.06	20.9
10	4.55	13.3
19	36.51	23.8
95	9.04	17.9
110	12.94	20
119	15.16	28.3
128	5.87	18.2
144	9.17	22.4
173	6.13	23.8
185	4.93	28.8
207	5.48	17.3
215	3.12	15.8
232	14.98	27.3
258	6.31	16.2
270	5.76	26.8
285	7.16	21.5
289	28.76	20.9
298	3.12	18
310	13.92	21.9
319	18.36	22.4
368	3.96	13.9
469	4.27	28
519	5.96	29.3
530	4.33	25.1
660	21.62	30.8
669	24.78	25.2
720	21.56	26
790	21.33	28.5
875	3.56	19.4
1009	7.65	20.3
1069	5.83	31.1
1100	20.91	26.1
1190	27.06	23.5
1260	2.61	27.8
1300	2.60	28.8
1310	1.53	29.8

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.

Water Chemistry Indicators and Physical Habitat Stressors:

	Physical Habitat							
	Depth	Wetted Width	Width/Depth	% Bank Shade	% Mid Channel Shade	% Sand/Fine	Discharge	Vegetation Canopy Cover
Water Temperature	0.359					0.371	0.374	
Conductivity	-0.388	0.712	0.733	-0.626	-0.568		0.470	-0.423
DO					-0.446			-0.449
pH			-0.383					
TKN			0.338					
Chloride	-0.409	0.797	0.857	-0.712	-0.597		0.515	-0.353
Sulfate	-0.373	0.754	0.820	-0.616	-0.545		0.494	-0.343

Water Chemistry Indicators and Riparian Disturbance Stressors:

	Riparian Disturbance						
	Wall	Building	Pavement	Pipe	Landfill	Mining	All
Water Temperature						-0.347	
Conductivity					0.420		
DO		0.374	0.342	0.439	0.587		0.373
pH	-0.391			-0.420			
Ammonia							
Nitrate/Nitrite		0.345	0.457				0.358
TKN		0.479	0.397		0.396		
Chloride							
Sulfate							

Physical Habitat Indicators and Riparian Disturbance Stressors:

	Riparian Disturbance			
	Wall	Road	Pasture	Landfill
% Sand and Fine	-0.391			
% Pools	0.614	-0.423		
Discharge			0.476	
Tree Cover				-0.366

Appendix 14. R Values of Significant Correlations (P<0.05) between Ecological Indicators and Stressor Indicators (cont.).

Benthic Invertebrate Indicators and Water Chemistry, Physical Habitat and Riparian Disturbance Stressors:

	Water Chemistry		Physical Habitat			
	Temp	**TKN**	**Depth**	**Embeddedness**	**% Sand/Fine**	**Vegetation Cover-Ground**
Richness	-0.339			-0.550	-0.603	0.481
EPT Taxa					-0.339	0.448
% Intolerant	0.368	-0.379	0.435			

	Water Chemistry					Physical Habitat	Riparian Disturbances	
	SpC	**DO**	**TKN**	**Chloride**	**Sulfate**	**Wetted Width**	**Landfill**	**All**
IBI	-0.587	-0.384	-0.537	-0.481	-0.516	-0.355	-0.441	-0.500

Periphyton Biomass Indicator and Sedimentary Metal Stressors:

	Sedimentary Metals	
	Cd	**Pb**
Biomass (AFDM/cm^2)	0.352	0.548

Community Respiration Indicator and Water Chemistry Stressors:

	Water Chemistry					
	SpC	**pH**	**TP**	**TKN**	**Cl**	**S**
Metabolism	0.791	-0.415	0.403	0.486	0.818	0.740

Community Respiration Indicator and Physical Habitat and Riparian Disturbance Stressors:

	Physical Habitat						Riparian Disturbance	
	Depth	**Wetted Width**	**Width/Depth**	**% Bank Shade**	**% Mid Channel Shade**	**Discharge**	**Pipe**	**Landfill**
Metabolism	-0.435	0.636	0.663	-0.600	-0.517	0.408	0.422	0.359

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)].

Type	Indicator	Units	Indicator	Mean	Lower 95% Conf.	Upper 95% Conf.
TN	Total Nitrogen	3	3	2	16	1.8
TP	Total Phosphorus	2	5	1	8	1.2
SO4	Sulfate	3	4	2	18	1.6
Fish Cover	Area Cover from Natural Features	4	16	1	5	1.0
RipDist Road	Riparian Disturbance from Roads	4	13	1	9	1.2
RipDist All	All Riparian Disturbance	4	8	1	7	1.3
% Fine	% Fine	3	14	1	3	0.9
% Sand/Fine	% Sand/Fine	3	14	1	7	1.1
Embed	Embeddedness	3	7	1	9	1.3

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

Pollutant	CAS Number	P/NP*	Human Health for the Consumption of		Publication Year
			Water + Organism (µg/L)	Organism Only (µg/L)	
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)

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Environmental Protection
Agency

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