Recommendations for a Macroinvertebrate Index of Biotic Integrity (M-IBI) for the San Juan Metropolitan Area

A WPI Ineractive Qualifying Project

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Sponsored by The Conservation Trust of Puerto Rico

Recommendations for a Macroinvertebrate Index of Biotic Integrity (M-IBI) for the San Juan Metropolitan Area

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This report is the product of an education program, and is intended to serve as partial documentation for the evaluation of academic achievement. The report should not be construed as a working document by the reader.

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Abstract

This project, prepared for the Conservation Trust of Puerto Rico (the Trust), outlines the initial development of an Index of Biotic Integrity (IBI) for the San Juan metropolitan area of Puerto Rico. It adapts methodologies developed in rural areas of the mainland United States to the tropical urban streams in San Juan and recommends updates to the Trust's Mapa de Vida stream assessment protocols. Stream flow data, water quality data, and macroinvertebrate samples were collected at nine sites in a set of six streams representing a gradient of environmental quality throughout the San Juan area to form a data set on biological communities of urban streams. Statistical data analysis supported recommendations for eight indices that comprise an IBI for the streams of San Juan.

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Authorship

This report was a joint effort between all team members, in both primary writing and editing.

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Executive Summary

This project was sponsored by the Conservation Trust of Puerto Rico, also referred to as "the Trust" or Fideicomiso, in order to better evaluate stream ecosystem health in the San Juan metropolitan area of Puerto Rico. The Trust is a private corporation that exists to protect and conserve lands of historical and geographical significance to Puerto Rico, many of which contain streams in various ecological conditions. Currently, the Trust evaluates streams using traditional methods developed in the continental forty-eight United States. These methods were originally developed by the United States Department of Agriculture (USDA) and the United States Environmental Protection Agency (EPA) for rural wadeable streams in the temperate and subtropical climates of the mainland US. Though these metrics have been adopted by the Trust for a citizen-science program called Mapa de Vida, the current assessments are insensitive to many environmental conditions found in urban tropical streams.

In order to better classify the health of stream ecosystems in the San Juan metropolitan area, the Trust requested that the research team perform initial steps in implementing biological monitoring as well as recommendations to modify the Mapa de Vida protocol to be more sensitive to urban and tropical conditions. The primary goal of this project was thus to perform the initial steps in the development of an Index of Biotic Integrity (IBI). Through this work, the Trust provided a stage to achieve the secondary goal of developing recommendations to enhance the protocol used in Mapa de Vida for the tropical ecosystems of Puerto Rico.

An IBI uses characteristics of the biological communities found in streams to assess stream ecosystem health. This method of assessment is far more sensitive to environmental conditions than traditional methods of ecosystem health monitoring because the stream biota responds to small changes in environmental condition whereas observations of researchers and water chemistry parameters are insensitive to small changes. For the IBI, the Trust requested the evaluation of macroinvertebrate communities. Macroinvertebrates are diverse and abundant in almost all streams, thus location and collection is a simple process that can be performed with little training, a situation ideal for the research team that spent only two months on site.

Comparing aspects of the biological community to other assessments of ecosystem is a vital component of the IBI methodology. It is critical that the ecosystem health of each site be quantitatively established so that two sets of data, one for parameters of the macroinvertebrate community and one for the quantitative stream health exist. In order to build this data set, a dispersion of sampling sites that establish a gradient of environmental conditions is necessary; the work of site selection was performed by knowledgeable experts in the Trust so that the project team would have a solid background on which to take the initial steps of IBI development. In this case, the assessment used to quantitatively establish ecosystem health was the Mapa de Vida protocol, thus providing the experience to evaluate the program and make recommendations for its improvement.

Initially, the project team proposed that samples be collected from thirty sites in the San Juan metropolitan area in the project time frame. This goal was rapidly changed to ten sites subsequent to meetings with ecologists at the Trust. At the end of the sampling time frame, samples had been collected from nine different sites in six different streams across the project area, only one site short of the revised goal. Experts at the Trust agreed that nine sites were adequate to perform the analyses of the biological communities necessary for initial steps in the development of an IBI.

At each of the nine sites, a series of procedures was performed in a standardized and repeatable fashion. The Mapa de Vida assessment documents were filled out according to the printed guidelines and all procedures of the Mapa de Vida program were performed. The Stream Visual Assessment (SVA) used involved assessments of several physical characteristics of the stream water, substrate, banks, and surrounding vegetation. In addition to the standard SVA, two additional categories of evaluation were added by the research team to help account for conditions of the urban and tropical environment.

In conjunction with the SVA, the Mapa de Vida protocol involves measurements of stream discharge, water quality for several common parameters, and physical descriptions and drawings of every site evaluated. Notes were taken in a field journal along with the Mapa de Vida protocol to assist in site identification and maintain a log of issues experienced. Common issues included inclement weather, difficult or dangerous access to streams, and several issues with insensitivities to environmental qualities of the SVA. Other issues encountered in the process involved identification and counting of macroinvertebrates collected by the research team, all of whom were untrained in macroinvertebrate taxonomy.

The data collected was entered into a standardized Microsoft Excel workbook that was created for the project. Data was accumulated from component sheets into a summary spreadsheet in order to facilitate analysis. The data analysis was performed using the built-in

ToolPak, which is capable of performing a variety of statistical analyses. Each data set was checked for normality using a skewness test and transformed to approximate a normal distribution if necessary. Most attributes of a biological community do not follow normal distributions, so the majority of biological data sets were transformed. After normalization, a correlation analysis was performed between the different biological indices (33 separate indices) and the SVA final value as well as water quality parameters.

A total of eight indices had significant statistical correlation to the SVA final value. Five of these indices describe aspects of the biological community including pollution tolerances and abundance of certain taxa of macroinvertebrates. The remaining three indices were water quality parameters that have also been previously used as metrics of ecosystem health. The selection criteria used for indices was an absolute value of the correlation coefficient R between each index and the SVA final value, with selection for R>0.5. These eight indices provide an excellent foundation upon which an IBI may be established with further work, achieving the primary project goal of performing the initial steps in the development of an IBI.

In addition to the work regarding IBIs, use of the Mapa de Vida protocol for site scoring permitted achievement of the secondary project goal. Several recommendations were presented to the Trust for modification of the Mapa de Vida program to account for conditions that were observed in the field. These recommendations included removal of two of the fifteen SVA component indices, a merger of two indices, an addition of two new indices, and modification of three indices. Additional recommendations were made to the Trust for future work in IBIs to improve macroinvertebrate identification procedures, reallocate field time to shorten field days, standardize the collection procedure to improve the quality of results, and account for seasonality and the nocturnal lifestyle of some rare macroinvertebrates.

While this project fulfilled both of its goals, it is only a preliminary study. Although the results are useful for a wide variety of applications, there are also cases where biological monitoring techniques such as the IBI are not useful. For instance, the indices that this study has suggested are viable for an IBI are sensitive to pollution and changes in environmental conditions, but have no ability to detect the source of changes in ecosystem health. Ultimately, the product of this study has provided the Trust with the foundation for an excellent tool to assess the ecosystem health of streams in the San Juan metropolitan area.

Chapter 1: Introduction

Populous islands place increased demands on natural resources, leading to the destruction of many natural habitats that protect valuable aquatic systems. This is especially true of freshwater sources, which suffer from urban encroachment, contamination from industrial and agricultural chemical run-off, and drought from overuse. Often one considers pollution on a local scale, but one rarely remembers to consider the impact of pollution on watersheds in extended zones. The limited size and availability of island watersheds, essential for sustaining natural habitats and providing potable water, amplifies the stresses imposed by human activity. Hence, severe pollution is of even more concern to an island watershed than to a watershed on a larger landmass because the effects of pollutants are magnified through smaller watershed systems.

Puerto Rico is a small, densely populated island with significant concerns of watershed health. Recent research indicates that Puerto Rico has considerably more damaged estuary systems than any other major region of the United States, leading to general concerns for watershed health (Borja et al., 2008). The poor ecosystem health in Puerto Rico is largely a result of limited conservation on the island and low public awareness of environmental health. Currently, a mere 7.2% of the land and water of Puerto Rico is actively protected. This is minimal in comparison to other Caribbean countries such as Costa Rica with 34% of the land protected, the Dominican Republic with 42% of the land protected, and the U.S. Virgin Islands with 54% of the land protected (The Conservation Trust of Puerto Rico, 2007). Therefore, it is critical that efforts be made to conserve and restore water sources in Puerto Rico, and to implement adequate monitoring.

The Río Piedras, flowing through the capital city of San Juan, is one river that represents the negative impacts of urban human activity in its watershed. The First Aqueduct in Puerto Rico is located on the Río Piedras and previously provided fresh drinking water to the area. Unfortunately, increasing urbanization in the 1960s polluted the river, which has since been surrounded by urban features and significantly eroded. These damages ultimately led to closure of the aqueduct to the public for any use (The Conservation Trust of Puerto Rico, 2007).

The Conservation Trust of Puerto Rico, also known as Fideicomiso or simply “the Trust”, is an organization that has obtained and protects over 18,000 acres of land that has historical, cultural, environmental, or geological significance to Puerto Rico. Fideicomiso has worked to save and restore the splendor of the island, and since its creation in 1970 has begun the restoration of vital environments across the island of Puerto Rico. The properties the Trust manages and resotres include but are not limited to Las Cabezas de San Juan which surrounds the bioluminescent bay in Fajardo, Hacienda Buena Vista in Ponce, Servidumbre de Conservación de Montes Oscuros in the Cloudy Mountains, and Antiguo Acueducto de San Juan (The First Aqueduct of the Río Piedras). Currently, the First Aqueduct restoration process is a model for restorations of streams the Trust intends to emulate in other properties it manages in the future.

The Conservation Trust currently lacks metrics specific to Puerto Rico that accurately describe the health of watersheds in their possession or that Fideicomiso seeks to acquire in the future. Past assessments of watershed health have studied the prominence of flora in the vicinity of the First Aqueduct and have also carried out basic chemical testing of water at a small number of sites. These studies ultimately resulted in a conservation management plan for the First Aqueduct of the Río Piedras and were a significant step towards the restoration of that property (Zabinski et al., 2009). However, Fideicomiso has not been able to describe the quality of the water and aquatic species in any area that it currently owns. Therefore, the Trust is currently unable to properly evaluate the effects of the organization's restorations on watershed health.

The goal of this project was to provide the initial steps in the design of a multimetric index that measures the integrity of water sources in the San Juan metropolitan area of Puerto Rico and accurately reflects anthropogenic stresses on watersheds. This investigation suggests components of an Index of Biotic Integrity (IBI) that the research team found relevant through data analysis of biological surveys performed on streams in the San Juan area. Although the use of several forms of biological monitoring is important, IBIs have been popular methods for assessing the health of bodies of water since their conception in the 1980s by Dr. James Karr, Professor of Biology at the University of Washington (J. R. Karr, 1981). The underlying concept of this index is that all parts within a given ecosystem are interconnected, so the presence of certain species serves as a useful indicator for the overall health of the region. These species include fish, algae, plankton, and invertebrates. The abundance, diversity, and condition of these indicator species are used to classify the state of the watershed (U.S. Environmental Protection Agency, 2009).

Data that the team collected was used to select indices for a Macroinvertebrate Index to Biotic Integrity (M-IBI) for Fideicomiso. The technique of modifying an IBI is very common, but it is unacceptable to use when the ecosystem of study differs even slightly from the original ecosystem used to develop the IBI (Bedoya, Novotny, & Manolakos, 2009; Chainho, Costa, Chaves, Dauer, & Costa, 2007; Kerans & Karr, 1994; Seegert, 2000). The process used for this project both established a process that can be used and repeated for Puerto Rico as well as developed suggestions for future ventures. To date, no IBI has been developed for Puerto Rico; thus, we have selected our indices directly from the accumulated data. From analysis of this data, significant correlations between Stream Visual Assessment values and several indices of the biological population were discovered. Development of a M-IBI provides a tool to accurately correlate the state of the macroinvertebrate system of a given river with the amount and severity of anthropogenic disturbances upstream and in the surrounding region. Ultimately, this tool will allow The Conservation Trust to determine the areas of highest priority for conservation and restoration in Puerto Rico. With an Index of Biotic Integrity, the Trust is in a better position to understand the health of watersheds and to protect the aquatic systems of Puerto Rico.

Chapter 2: Literature Review

This section presents information pertinent to this study, including aspects of the ecosystem and fauna that the Interactive Qualifying Project team studied in Puerto Rico. This section also details other relevant research performed by biologists, ecologists, and consultants to more firmly establish the scientific principles and commonly accepted techniques in designing an IBI. Additionally, special attention is given to the manner in which the studies described are conducted in order to illustrate more fully the steps that the IQP team needed to take to correctly develop an IBI.

2.1 Puerto Rican Ecosystem Management

In conjunction with spreading urbanization, the lack of effective water conservation plans in Puerto Rico has led to necessary updates in water preservation. Since the 1940s, Puerto Rico has developed and industrialized rapidly, mostly due to a combination of migrations to urban areas and the downfall of a once thriving agriculture based economy. At one point, 90% of the 8,900 square kilometers of Puerto Rico had been deforested (Ramirez, De Jesus-Crespo, Martino-Cardona, Martinez-Rivera, & Burgos-Caraballo, 2009). Conservation efforts have since furthered appreciation of natural environments, though a deeper understanding by the public and scientific community is imperative for their protection.

2.1.1 Trust History

The environmental degradation mentioned above and the pollution resulting from urbanization and industrialization led to the creation of The Conservation Trust of Puerto Rico (also known as Fideicomiso) in 1970 in an effort to effectively conserve important areas of Puerto Rico. Since its inception, the Trust has acquired twenty different sites totaling approximately 18,000 acres of land. One of these areas includes the First Aqueduct of the Río Piedras, which is located in San Juan (The Conservation Trust of Puerto Rico, 2007).

The health of the Río Piedras is shaped by both natural and anthropogenic factors in the San Juan metropolitan area. Negative urban impacts such as poor sewage removal and point-source pollutants have proved harmful to water systems in many locations (Walton, Salling, Wyles, & Wolin, 2007). The influences of urban environments surrounding the watersheds explain to a certain extent the degradation of these streams, but these areas are also affected by natural influences. Variations in rainfall, elevation, and temperature throughout Puerto Rico are examples of naturally occurring environmental interactions that impact these ecosystems. For example, higher elevation combined with lower average temperatures throughout the year tends to result in more rainfall, as in the Luquillo Mountains of Puerto Rico, notably home to the El Yunque national rain forest. San Juan, however, is located on the coast, with higher average temperatures and an elevation close to sea level (Daly, Helmer, & Quinones, 2003). The effect of these features is less rainfall than in much of Puerto Rico as well as little variance in rainfall throughout the year.

It can be shown that several factors influence the health of streams, both metropolitan and rural. Unfortunately, the continuous urbanization of the San Juan area has surpassed the management efforts of freshwater sources, causing recurrent problems with wastewater, drinking water, and overall ecological degradation of the environment (The Conservation Trust of Puerto Rico, 2007). To better understand the health of streams in the area, a more complete understanding of stream ecology in the region is essential.

In order to further the understand of ecosystem health in the San Juan metropolitan area, the Trust has developed the Mapa de Vida program, a citizen-science initiative in Puerto Rico which allows community volunteers to assist in the upkeep and monitoring of the island's watersheds. Volunteers of the Conservation Trust of Puerto Rico work in the field to perform tests such as water quality and visual assessments of wadeable streams. The Trust hopes that involvement of the community will raise awareness of watershed quality issues, which in turn would prevent degradation (Fevold, 2010).

2.1.2 General Stream Terminology

To accurately describe many concepts related to the structure of a stream, one must understand a set of stream characteristics describing stream features, often referenced in ecological literature as streambed morphology. As all aspects of stream flow and ecology are directly related to the stream morphology, it is necessary to fully understand morphology to assess stream qualities. In this section, several key terms that describe aspects of stream morphology will be explained and further depicted through visual representations. All definitions presented are adaptations from glossaries presented in the USDA Stream Visual Assessment Protocol and the Fluvial Geomorphology training website created by COMET, NWS NERFC, and SUNY-ESF. All images in this section are adapted from the Fluvial Geomorphology training website. Additional terms used throughout this report are listed in the glossary, which can be found in Appendix A (COMET, NWS NERFC, and SUNY-ESF).

Watersheds

A ***watershed*** is a geographical term referring to an area defined by a set of ridges and highlands that divide areas that drain water to different stream systems. All the land within a watershed flows to the same main stream system that empties into a larger body of water. Within a watershed, a ***stream*** is commonly defined as a body of water confined to a narrow topographic depression, down which water flows and transports rock particles, sediment, and dissolved particles. Rivers, creeks, brooks, and runs are all types of streams.

Stream flow naturally has several levels corresponding to local and upstream precipitation as well as the age of the stream. The first set of terms presented here describes flow characteristics at set points in time. These terms are frequently used in field evaluations of streams such as those created by the EPA and United States Department of Agriculture (USDA).

Stream Physical Descriptors

Stream ***reach*** defines the length of a stream over which samples and measurements are taken. The reach is the basic area used for measurements in stream ecology. The length of a specific reach is selected such that each reach gives an accurate representation of the characteristics of the entire stream in that geographic area. Many reaches are defined in terms of the bankfull width, ranging in length from 10 times to 20 times the bankfull width. For streams with highly variable bankfull widths or unstable streams, the reach for a specific stream may simply be defined as a specific length.

A ***channel*** is a natural or artificial waterway of perceptible extent that periodically or continuously contains moving water. A channel has a definite bed and banks that serve to confine the water; almost all flowing water runs through a channel. ***Channelization*** refers to the erosive and deposition processes by which a channel straightens to increase average flow velocity. In young streams and some urban streams, areas with confined channels may exist. The term ***confined channel*** refers to a channel without access to a floodplain.

The ***thalweg*** of a stream identifies a single line running through a channel at which the stream depth is at a maximum for each stream cross section. The thalweg is the line of maximum depth running the full length of a stream. Many depths are commonly measured in relation to the thalweg.

Flow Descriptors

The base flow, bankfull, active channel width, and floodplain terms are all used to describe river stage and width of a specific stream. ***Base flow*** refers to the low flow stage at which the river is fed from ground water. Correspondingly, the ***base flow width*** refers to the average stream width when standard flow is fed from groundwater upstream (not dependent upon rain in the immediate vicinity of the stream). The term ***bankfull*** refers to the river stage where the flow reaches the height at which perennial vegetation grows; it is denoted by the river depth at which incipient flooding begins to occur. The ***bankfull width***, often abbreviated ***Wbkf***, is thus the river width at the bankfull stage. Thus, the ***depth at bankfull***, referenced as ***dbkf***, is also defined as the average depth at the bankfull stage. In the same sense as the base flow width and bankfull width, the ***Active Channel Width***, termed ***ACW*** is defined as the average stream width at bankfull. The ACW and Wbkf are used interchangeably and depend strictly upon the preferences of the author of the document. The ***floodplain*** of a stream is a broad, gradually sloping area that is flooded when the stream depth increases beyond bankfull depth. A floodplain is generally bounded by a terrace or abandoned floodplain. Figure 1 presents graphical representations of flow descriptors.

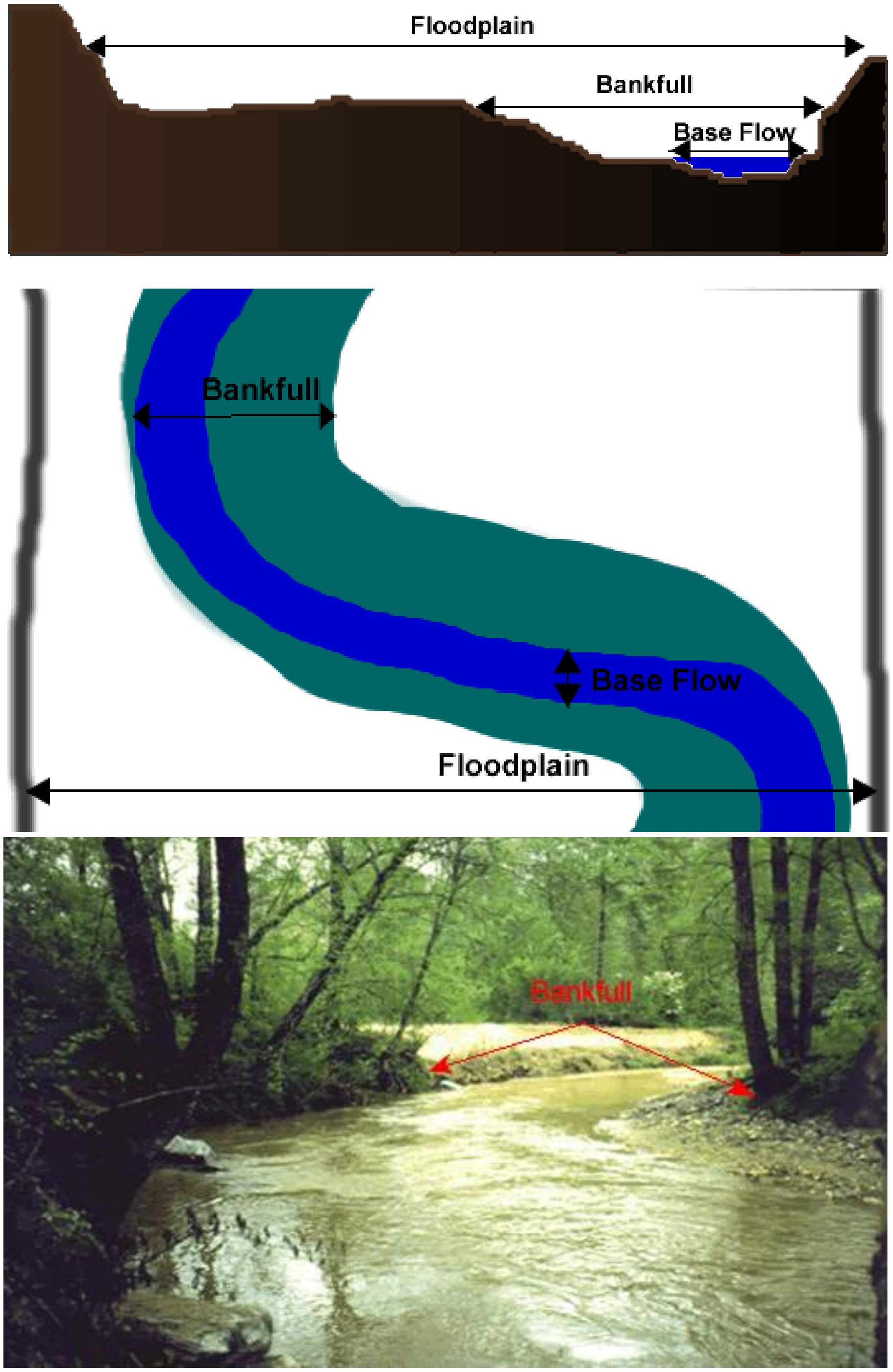


Figure 1: Baseflow, Bankfull, ACW, and Floodplain (COMET, NWS NERFC, and SUNY-ESF)

Erosive and Deposition Processes

The following terms describe processes or systems by which streams change. ***Erosion*** is the general process by which elements of the stream are worn down or removed from their original place due to water flow or other environmental conditions such as wind. In most circumstances, streams undergo a specific type of erosion referred to as ***scouring***, wherein stream flow actively erodes stream banks and the stream bottom. The terms that follow all explain specific processes. ***Downcutting***, or ***degradation***, is the process by which a stream's gradient becomes less steep due to erosion of the substrate. In most cases, downcutting may be accomplished through nickpoints. ***Nickpoints*** are stream features where downcutting is actively occurring as the stream erodes down to a new base level. Nickpoints can be seen as rapid and abrupt drops in the substrate. Nickpoints always migrate upstream as sediments are removed and washed downstream. Following erosive processes, ***deposition*** refers to the process by which eroded sediments are deposited in other formations along the course of a stream. The deposition process is responsible for the formation of geographic features such as the alluvial.

An ***incised stream*** refers to a stream in which downcutting has lowered the stream elevation to the point where separate channel geographies and new floodplains begin to emerge. Incised channels tend to have high banks with some noticeable breaks where downcutting and scouring has occurred in separate stages. Figure 2 shows a sequence where downcutting and scouring create an incised channel.

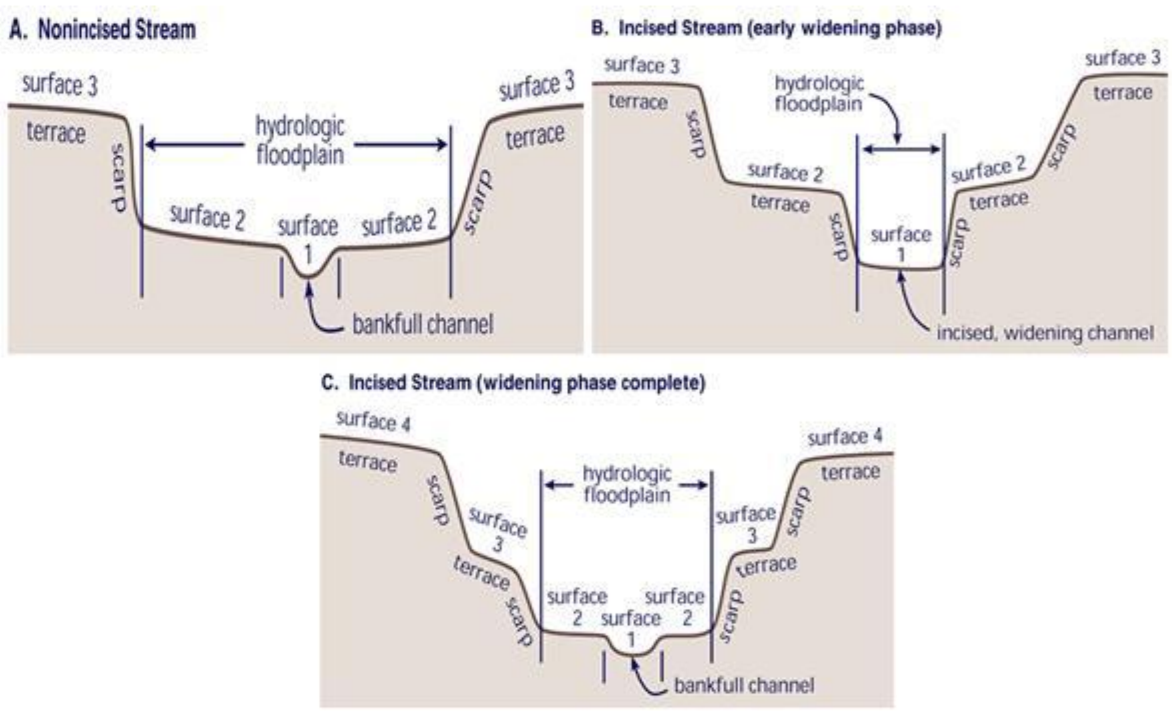


Figure 2: Channel Incision (COMET, NWS NERFC, and SUNY-ESF)

Additional terminology may be found in the full glossary in Appendix A.

2.1.3 Physical Stream Assessment

In 1972, the Clean Water Act (CWA) was passed to help protect the crucial water resources within the United States. One suggestion from the CWA was to gather yearly information on protection and restoration efforts to show to the American people. Data has been collected and compiled over the years by the Environmental Protection Agency (EPA) and other agencies, but has been considered to be inadequate with regard to the health of the nation's freshwater systems (U.S. Environmental Protection Agency, 2006).

To gain better information and insight, the EPA and other governmental agencies have been working together on water assessments over the past two decades. These collaborations have resulted in multiple assessments such as three different national water quality evaluations and multiple visual stream assessments. The Wadeable Streams Assessment (WSA) is the first nationally consistent, statistically valid study of the nation's wadeable streams and marks the continuation of a commitment to produce statistically valid scientific assessments of the nation's fresh waters. Using very complete and standardized methods explained within the appendices, the agencies were able to produce scientifically credible information on the condition and health of the nation's wadeable streams. The WSA also helped to supply funding and expertise to enhance monitoring capabilities (U.S. Environmental Protection Agency, 2006).

One partner involved in these developments with the EPA is the United States Department of Agriculture (USDA). The USDA has created a Visual Stream Assessment Protocol that is a commonly accepted manual used to offer a fundamental level of stream health evaluation. The protocol does not require expertise in the field and can be completed by any level of ecologist. The protocol uses over 15 different factors that are measured on a ten point scale using one's personal judgment of the physical conditions within a specific reach. These factors are listed below and are described in length within Appendix C (Newton, Pringle, & Bjorkland, 1998).

- Channel condition
- Hydrologic alteration
- Riparian zone
- Bank stability
- Water appearance
- Nutrient enrichment
- Barriers to fish movement
- Instream fish cover
- Pools
- Insect/invertebrate habitat
- Coldwater fishery
- Warmwater fishery
- Manure presence
- Salinity
- Riffle embeddedness
- Macroinvertebrates observed
- Stream Invertebrates

As described in the manual, "changes in any one characteristic or process have cascading effects throughout the system and result in changes to many aspects of the system…Often several factors can combine to cause profound changes. For example, increased nutrient loads alone might not cause a change to a forested stream. But when combined with tree removal and channel widening, the result is to shift the energy dynamics from an aquatic biological community based on leaf litter inputs to one based on algae and macrophytes. The resulting chemical changes caused by algal photosynthesis and respiration and elevated temperatures may further contribute to a completely different biological community (Newton et al., 1998)." The protocol provides a practical assessment method for the immediate area, but it struggles in identifying problems outside the assessment area. To reflect health of the entire watershed, biological monitoring tools such as the Index of Biotic Integrity may be used, which is described in Section 2.2.

2.1.4 Stream Flow

An essential metric in the determination of stream health and stream characteristics is the stream discharge, or volume of water that flows through a stream cross section in a given amount of time. The stream discharge affects the overall health and type of organisms the system can support. Another important measure is flow velocity; since stagnant waters provide little water stirring, low flow velocities result in low Dissolved Oxygen (DO). Low DO can prohibit the survival of larger organisms in the water and is also a limiting factor in the establishment of aquatic trophic structure. Not only does flow velocity affect the dissolved oxygen, but it also affects the number of particles present. Concurrently, pollutants will not be transferred through areas with low stream flow as readily as through those with higher flow velocities. In order to assess the health of each stream, measurements of its ability to remove pollutants from water entering the stream through the watershed must be taken (U.S. Environmental Protection Agency, 2004; U.S. Environmental Protection Agency, 2006).

2.1.5 Chemical Monitoring

In addition to biological monitoring and physical assessments, chemical measurements are valuable in the evaluation of the health of stream systems. While chemical characteristics have historically been used to determine stream health, chemical monitoring does not always provide accurate, complete descriptions of the streams being studied (Bedoya, Novotny, & Manolakos, 2009). Thus, methods focusing on the biological aspects of a system should integrate chemical descriptions and compare biological, physical, and chemical data. Since pollution affects stream ecosystem health, identifying chemical composition is useful when determining water quality. Commonly measured parameters are DO, pH, total dissolved solids (TDS), salinity, nitrates, phosphates, and conductivity. Because these analytes are influenced by temperature, they must be measured in specific ways. Detailed analysis of complex chemicals must be performed in a lab, which extends the time length of a given project. As a result, the following analyses were viable based on their reliability as indicators of stream health and the availability of quick, portable measuring tools.

Temperature regulates biological activity, the metabolic rate, and growth of aquatic organisms, so variations in temperature promote different biotic features (Zabinski et al., 2009). Temperature also influences the solubility of gases dissolved in the water; at higher temperatures, less gas, such as oxygen or carbon dioxide, can dissolve in the stream. Common factors that affect temperature are the amount of canopy cover and shading, temperature of pollutant discharges into the stream, flow and depth of water, time of day, season, and geographical position. Commonly available thermometers are used to measure temperature, which should be determined at the center of the stream reach of interest (U.S. Environmental Protection Agency, 2004).

Dissolved oxygen denotes the oxygen content of the water. Low oxygen concentration is indicative of unhealthy organic material, nitrate-rich fertilizers, or phosphate-based detergents. Bacteria and fungi process nonliving organic matter, and algae grow in the presence of nitrate or phosphate compounds; respiration rate and oxygen consumption increase in the presence of a larger biomass. Excess algae can block sunlight from penetrating into the water, reducing their photosynthetic capabilities (Quiñones, 2005).

Certain aquatic insects are dependent upon the dissolved oxygen (Ephemeroptera, Diptera, and Odonata) while others acquire gaseous oxygen from the surface (Hemiptera and Coleoptera). In addition, while dissolved oxygen levels in the water are primarily controlled by the water temperature, they are also affected by turbulence and aeration, the population and identity of organisms present, salinity, photosynthetic activity, level of nutrient-enrichment, and amount of organic material (Quiñones, 2005).

The pH of a stream is defined as $\mathrm{pH} = -\log[\mathrm{H}^+]$, where $[\mathrm{H}^+]$ is the concentration of hydrogen ions, and indicates the acidic $(\mathrm{pH} < 7)$, neutral $(\mathrm{pH} = 7)$, or basic $(\mathrm{pH} > 7)$ character of the stream. Photosynthesis and respiration cycles of algae, high organic content, eutrophification, and salinity influence variations in pH. Acidification may have little effect on insects like damselflies but others, such as mayflies, are much more acid-sensitive.

Nitrate and phosphate are forms of nitrogen and phosphorus commonly found in aquatic environments and serve as nutrients for plant and algal growth. High concentrations are indicative of pollution from untreated sewage, industrial waste, urban activities, agriculture, and fertilizer runoff, along with other point-source and nonpoint-source pollution (Carpenter et al., 1998). Eutrophication is the enrichment of streams from an increase in nitrogen and phosphorus nutrients. Increased levels in these nutrients result in algal growth; dead and decaying algae subsequently reduce levels of dissolved oxygen in water close to the streambed, inducing stresses on aquatic insects. Higher nitrate and phosphate levels influence invertebrate diversity and abundance by decreasing food availability, altering the algal and macrophyte community, and diminution of DO (Quiñones, 2005; Zabinski et al., 2009).

Total dissolved solids, salinity, and conductivity indicate the level of inorganic and organic matter, salt, and ionic substances present in the stream. The concentration of total dissolved solids measures the content of inorganic and organic substances in a solution; high TDS levels are associated with hard water. High flows erode materials that become suspended in streams; in addition, agricultural, urban, and surface runoffs contribute to levels of total dissolved solids. Low salinity is associated with freshwater, while brackish waters have high salinity. Stream water with high salinity can be classified as brine while water of lower salinity can be termed as saline water, brackish water, or freshwater. Various aquatic insects have differing tolerances to salinity levels. Conductivity measures the ability of stream water to conduct electricity; it is related to the TDS and salinity of that stream.

2.2 Index of Biotic Integrity

2.2.1 Background

The Index of Biotic Integrity (IBI) was invented in 1981 by Dr. James Karr as a means for quantitatively assessing the health of ecosystems by using indicator species to derermine health. Karr used fish as the indicator species of the system in the original IBI, since which many adaptations have arisen (J. R. Karr, 1981). The IBI is defined by the Watershed Science Institute to be an "indexing procedure commonly used…to assess watershed condition… [and] the effect of human disturbance on streams and watersheds" (United States Department of Agriculture Natural Resources Conservation Service, 2007). Those systems not affected by humans contain the most diverse amounts of species, including those which are very susceptible to harm from the environments. Originally, twelve aspects of the fish population were observed. These twelve were given scores ranging from one to five, where five was considered to be least affected by humans, and one was the most impacted (U.S. Environmental Protection Agency, 2009). The lowest scoring regions contained few and abnormal fish, most of which were not vulnerable to the environment (J.

R. Karr, 1981). This determination of water system health has since been updated and adapted to different locations around the world. Fish species are no longer the sole indicators of health, but others, such as benthic macroinvertebrates and algae, have since been included (U.S. Environmental Protection Agency, 2009).

For this study, only macroinvertebrates were used as indicators of the health of freshwater systems. Macroinvertebrates are excellent health indicators in freshwater systems because of their crucial role in the food chain, as they are a necessary source of nourishment for other organisms to survive. Certain indicators of macroinvertebrate populations, such as abundance, diversity, and overall health, correlate to the health of the water source in which the macroinvertebrates live. These indicators can be measured comparatively against similar freshwater streams with the same ecological parameters to determine the overall health of one system relative to the other. The symposium of several comparisons as described above is commonly termed a multimetric index. A biological multimetric index, incorporating comparisons between various aspects of the macroinvertebrate population of streams in Puerto Rico could help the Trust evaluate the physical condition of each of its sites.

2.2.2 Data Collection

The results of macroinvertebrate samplings depend significantly upon how researchers collect, store, and analyze samples as the final outcome of any biological study is influenced by the manner in which data is collected. Greg Seegert, chief ichthyologist and senior scientist at EA Engineering, states that “with regard to data collection, a degree of standardization is necessary. Procedures should be developed that tell an investigator when, where, and how to sample. A suite of standard methods that covers the range of conditions and stream sizes likely to be encountered in the area being investigated should be established. Round-robin testing should then be used to establish the variability and reproducibility of each method. The applicability of each metric should be established for the geographic area in question and each metric should be carefully calibrated (Seegert, 2000).”

One common method for collecting measurements in freshwater streams involves a process commonly referred to as “kick sampling,” which provides the degree of standardization suggested by Seegert. In kick sampling, the recorder enters the stream with a mesh hand net and uses his/her feet to kick up debris from the streambed to collect the samples. It is important for the person recording to examine and sample different microhabitats that exist within the stream system itself. To acquire the best sample possible, the collection net is held downstream from the kicking, where the river current propels the samples into the net. When near grasses and roots, the data collector should run the net through the plant matter to ensure maximum collection. While gathering specimens, especially in plant matter, foreign debris enters the sample and the larger samples may need to be broken down into subsets of smaller samples in order to remove it. To standardize the collection process, set collection time intervals should be used for each separate sample (Freshwater Biological Association, 2008).

2.2.3 Data Analysis

Once the data is collected and cataloged, analysis is necessary to quantitatively score the overall health of the different streams and regions. The use of statistical analysis has simplified the handling of the large amounts of data collected in several IBI studies, and quantitative backing for qualitative observations facilitates the elimination of outliers and identification of the most relevant information. Most data has inherent units attached to it (counts, percentages, etc.), so index normalizations have been used for comparison between different types of data in the past. This data analysis technique allowed researchers to select indices for the final IBI that show strong correlations to environmental conditions while reducing researcher bias (Barbour et al., 1996; Kerans & Karr, 1994; Weigel, Henne, & Martinez-Rivera, 2002). Some statistical models of importance are those presented in the case studies discussed in Section 2.3.

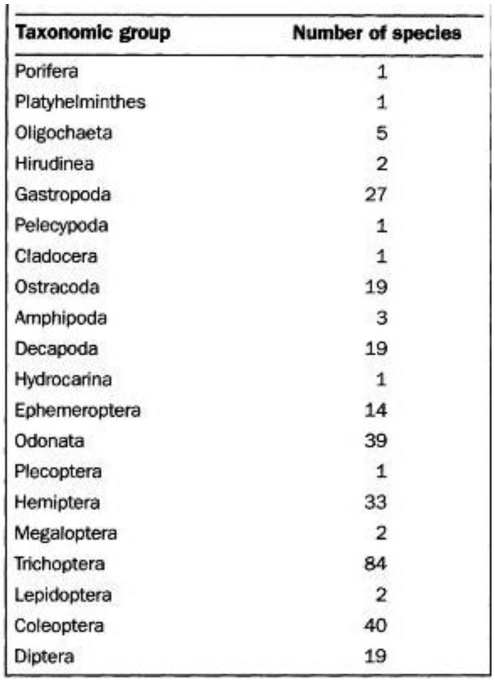
2.2.4 IBI Critics

There are many challenges associated with the development of an IBI. Strict guidelines are in place, including the use of indicator species that reflect the ecosystem of the specific geographical area studied. Data that researchers have previously collected, however, may not have followed the same guidelines that are currently used when acquiring data for an IBI. When researchers use past information, there may also be a disparity between current environmental conditions and the conditions at the time in which data was collected. It is considered better to have small sets of complete, accurate data, rather than having large quantities of low quality data (Seegert, 2000). Another developmental problem is borrowing metrics and grading procedures created from preexisting indices to generate a completely different IBI, without accounting for variations within each specific environment.

It is important to develop the proper metrics according to the geographical location (Seegert, 2000). Conclusions should not be based upon supposed accepted values, but rather upon site-specific data “because of differences in factors such as invertebrate taxa, climate, water chemistry, soil types, and management regimes” (Davis & Bidwell, 2008). As Seegert states, “Biological expectations should be reasonable and attainable, and therefore the limitations of each system must be taken into account. Expectations are sometimes set unreasonably high by resource/regulatory agencies, particularly in urban settings” (Seegert, 2000).

Multimetric techniques such as the IBI are excellent for identifying impaired sites and for comparing environmental health among sites. However, the IBI is of limited use in establishing the causes of impairment. When environmental degradation is identified, follow-up studies of the impaired area will likely be necessary to determine the cause of the impairment. Thus an IBI should not be used to determine relationships of causality, but simply as a tool for monitoring environmental health.

IBI’s developed in Caribbean nations provide helpful building blocks to the development of a Puerto Rican IBI. These indices have tracked all of the different taxonomic groups living within the Caribbean islands. With this knowledge, researchers may prescreen common indices for practicality with the expected population. The known Caribbean macroinvertebrates, for example, are shown in Table 1 below.



Taxonomic group	Number of species
Porifera	1
Platyhelminthes	1
Oligochaeta	5
Hirudinea	2
Gastropoda	27
Pelecypoda	1
Cladocera	1
Ostracoda	19
Amphipoda	3
Decapoda	19
Hydrocarina	1
Ephemeroptera	14
Odonata	39
Plecoptera	1
Hemiptera	33
Megaloptera	2
Trichoptera	84
Lepidoptera	2
Coleoptera	40
Diptera	19

Table 1: Caribbean Macroinvertebrate Species (Bass, 2003)

In order to further examine the techniques described to develop an IBI, we review the design of similar multimetric indices. Specifically, the following section describes several case studies involving the use of benthic invertebrates. The techniques of data collection and analysis as well as the final results of each study are presented in order to exhibit techniques that have led to successful formation of IBIs.

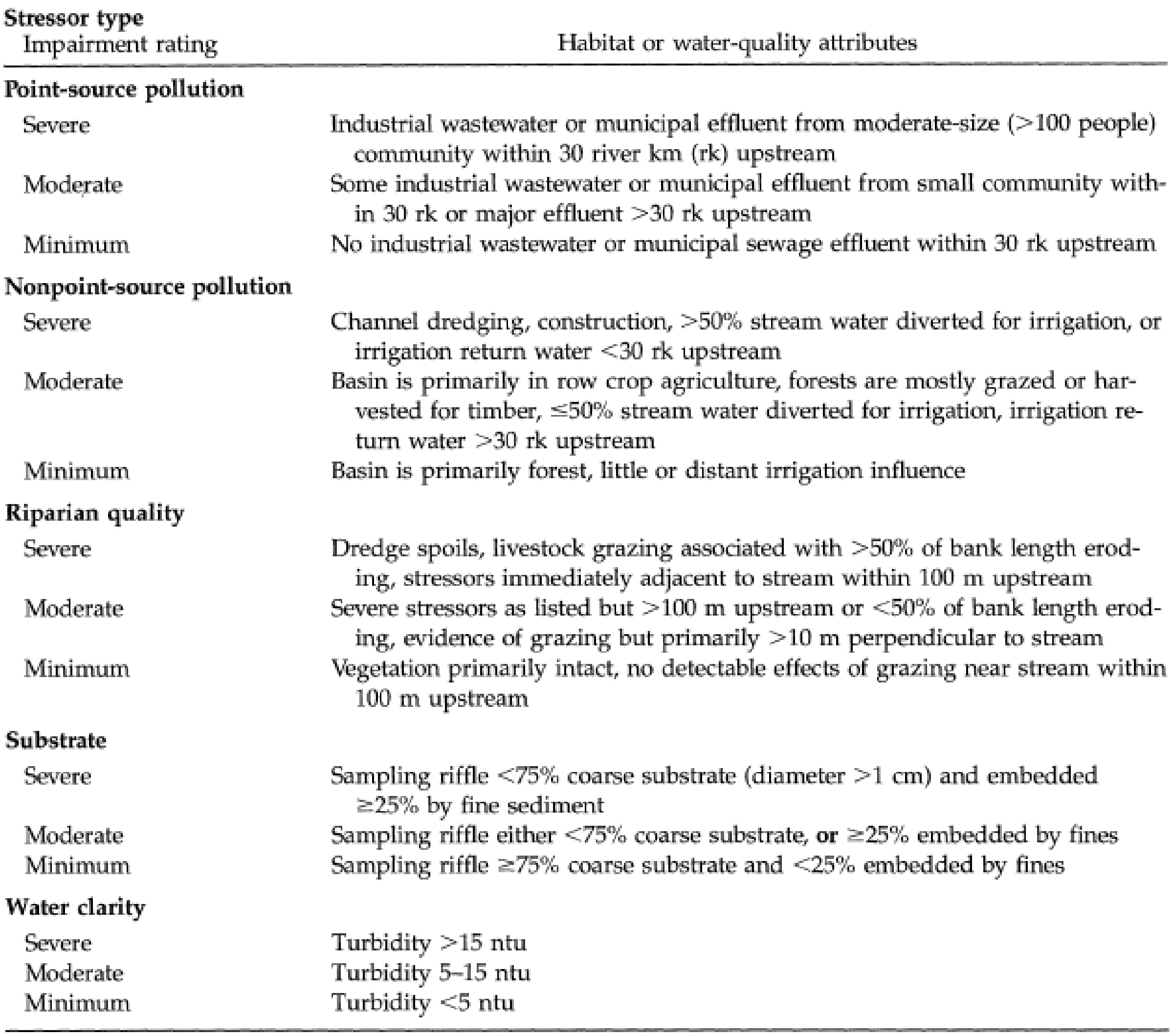
2.3 IBI Case Studies

Three case studies are explored in the following sections to illustrate methods that are helpful in the determination of Indices of Biotic Integrity. The first case is an IBI performed for watersheds in West-central Mexico. These watersheds face many of the same problems as the Trust has encountered in Puerto Rico and have similar climates and geographic features. The Sierra de Manantlán Biosphere Reserve is aware of environmental degradation, but lacks methods to determine the extent and perpetuation of environmental destruction. The lack of these standards motivated a study to develop a macroinvertebrate IBI (M-IBI) to better understand ecological integrity in the area. In designing the M-IBI, the researchers sought to select indices that accurately reflected environmental conditions observed in initial site surveys (Weigel et al., 2002). The second case study is an IBI performed for the rivers of the Tennessee Valley. This area has experienced severe anthropogenic stress through the works of the Tennessee Valley Authority, which has also monitored the water quality for many consecutive years in numerous sites. The research team validated the IBI performed through use of this extensive set of measurements. The final IBI reviewed was performed for fresh water sources of Florida. This IBI highlights statistical analyses techniques used to eliminate researcher bias in the selection of final indices for a macroinvertebrate index of biotic integrity. These three case studies build a picture of the foundations for developing an IBI.

2.3.1 A Macroinvertebrate IBI in West-central Mexico

Researchers investigated initial metrics that would accurately assess the Sierra de Manantlán Biosphere Reserve ecosystem by measuring several key functions of watershed health. The initial selection included macroinvertebrate trophic structure, breadth of species, and function of population. To more accurately capture environmental variation in the study, a large number of sites were sampled both inside and out of the Sierra de Manantlán Biosphere Reserve, totaling 33 sites on 21 streams within 6 major river basins in the area at which data was accumulated (Weigel et al., 2002). Although this is a significant number and included a good variety of sampling sites, it falls slightly short of the range of 35-40 sampling sites suggested by Seegert. Additionally, streams of similar sizes that go through similar climate zones were selected as the targets of the sampling, a practice that is necessary for developing an accurate IBI. Research indicates that selection methods based on similarities in slope of the river and type of river section also ensure consistency of results (J. R. Karr, 1981; Seegert, 2000; U.S. Environmental Protection Agency, 2009).

The researchers quantified ecosystem health prior to macroinvertebrate sampling to better select indices for the M-IBI. Producing initial data on ecosystem health in this way provided the researchers with comparison data to determine whether the final IBI accurately reflected known environmental conditions. The environmental pollution at each site was graded as severe, moderate, or minimum, corresponding to values of 0, .5, and 1 for each evaluation category (Weigel et al., 2002). Prior mapping was beneficial because it allowed verification of the IBI developed through the initial conditions observed. However, this specific technique also exhibits a notable drawback: the researchers introduce a large degree of bias upon initial quantification of ecosystem health (J. R. Karr, 1981; Seegert, 2000; Soldner et al., 2004). Five different anthropogenic stressors were quantified in the initial evaluation, including point-source pollution, nonpoint-source pollution, riparian quality, substrate, and water clarity resulting for a maximum total environmental grade rating of five and a minimum grade of zero. The highest quality sites were used as the reference sites. Clearly, those sites exhibiting environmental stress cannot be used as a reference (Soldner et al., 2004; Weigel et al., 2002). These five categories accurately evaluate all types of pollution encountered in watersheds. The evaluation categories may be seen in Table 2.

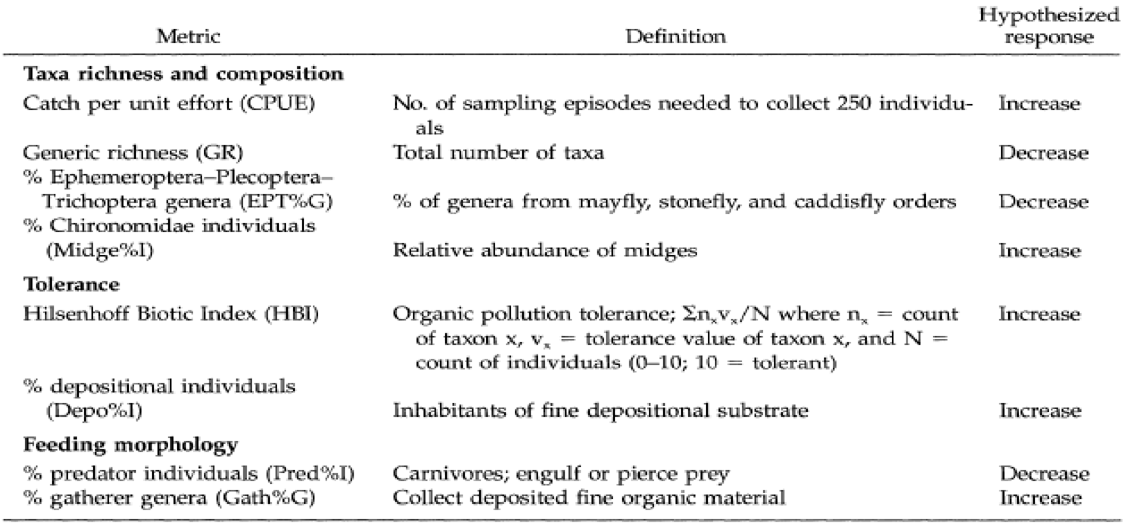


Stressor type Impairment rating	Habitat or water-quality attributes
Point-source pollution	
Severe	Industrial wastewater or municipal effluent from moderate-size (>100 people) community within 30 river km (rk) upstream
Moderate	Some industrial wastewater or municipal effluent from small community within 30 rk or major effluent >30 rk upstream
Minimum	No industrial wastewater or municipal sewage effluent within 30 rk upstream
Nonpoint-source pollution	
Severe	Channel dredging, construction, >50% stream water diverted for irrigation, or irrigation return water <30 rk upstream
Moderate	Basin is primarily in row crop agriculture, forests are mostly grazed or harvested for timber, ≤50% stream water diverted for irrigation, irrigation return water >30 rk upstream
Minimum	Basin is primarily forest, little or distant irrigation influence
Riparian quality	
Severe	Dredge spoils, livestock grazing associated with >50% of bank length eroding, stressors immediately adjacent to stream within 100 m upstream
Moderate	Severe stressors as listed but >100 m upstream or <50% of bank length eroding, evidence of grazing but primarily >10 m perpendicular to stream
Minimum	Vegetation primarily intact, no detectable effects of grazing near stream within 100 m upstream
Substrate	
Severe	Sampling riffle <75% coarse substrate (diameter >1 cm) and embedded ≥25% by fine sediment
Moderate	Sampling riffle either <75% coarse substrate, **or** ≥25% embedded by fines
Minimum	Sampling riffle ≥75% coarse substrate and <25% embedded by fines
Water clarity	
Severe	Turbidity >15 ntu
Moderate	Turbidity 5–15 ntu
Minimum	Turbidity <5 ntu

Table 2: Ratings of Environmental Pollution (Weigel et al., 2002)

For sampling, researchers used D-frame nets and kick-sampling to obtain macroinvertebrates. The kick-sampling method used by the researchers is an established method that is valid for macroinvertebrate samplings (Nerbonne, Ward, Ollila, Williams, & Vondracek, 2008; Soldner et al., 2004). In this case, the number of times the process was performed was used as a Catch Per Unit Effort (CPUE) index, which researchers decided was strongly correlated to abundance. At sites of intense environmental degradation, chronomids were omitted from the CPUE due to their abundance (Weigel et al., 2002). Seegert and Karr have both suggested that CPUE and other measures of abundance are not preferable to use in IBIs. However, under these circumstances, only chronomids could be considered an irruptive or overly abundant species, the primary factors that skew the accuracy of the CPUE index (irruptive species are defined as accounting for >50% of the average catch per sample). Since chronomids were omitted from the CPUE index, this process follows acceptable standards (J. R. Karr, 1981; Seegert, 2000).

After sampling, specimens were put in a sorting pan in the field. Researchers scanned the collection pan for rare taxa and then tabulated individuals starting from the same side of the sampling pan each time to avoid optical bias. The researcher counted the first 250 individuals encountered for the total of that specific sample (Weigel et al., 2002). Researcher bias is eliminated by the tabulating methodology, and rare individual samples are not discounted due to chance. The indices for which data was tabulated can be seen in Table 3.



Metric	Definition	Hypothesized response
Taxa richness and composition		
Catch per unit effort (CPUE)	No. of sampling episodes needed to collect 250 individuals	Increase
Generic richness (GR)	Total number of taxa	Decrease
% Ephemeroptera–Plecoptera–Trichoptera genera (EPT%G)	% of genera from mayfly, stonefly, and caddisfly orders	Decrease
% Chironomidae individuals (Midge%I)	Relative abundance of midges	Increase
Tolerance		
Hilsenhoff Biotic Index (HBI)	Organic pollution tolerance; $\Sigma n_x v_x/N$ where n_x = count of taxon x, v_x = tolerance value of taxon x, and N = count of individuals (0–10; 10 = tolerant)	Increase
% depositional individuals (Depo%I)	Inhabitants of fine depositional substrate	Increase
Feeding morphology		
% predator individuals (Pred%I)	Carnivores; engulf or pierce prey	Decrease
% gatherer genera (Gath%G)	Collect deposited fine organic material	Increase

Table 3: Final Indices Selected for the M-IBI (Weigel et al., 2002)

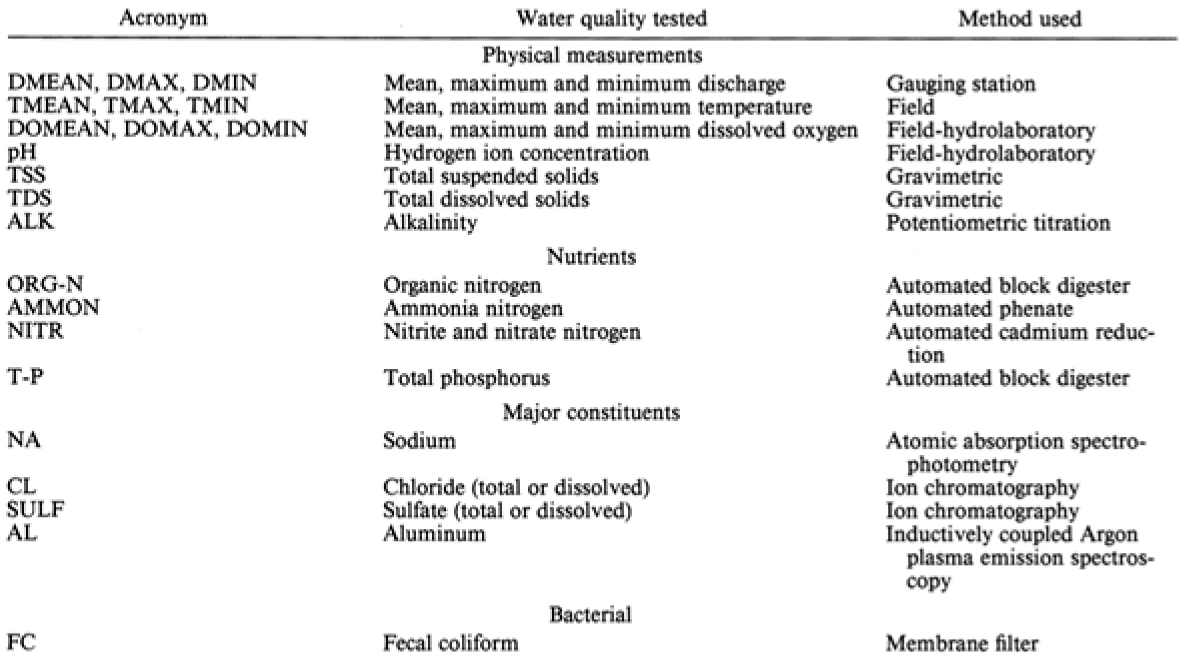
Only one index in this study is of concern. The researchers choose to use percentage Ephemeroptera-Plecoptera-Trichoptera (EPT) as an index because it is has been used historically. In this case, the EPT index correlated to environmental condition, but was not selected to describe a unique aspect of the ecosystem (Weigel et al., 2002). For that reason, further research would be necessary to determine legitimacy of the EPT index (J. R. Karr, 1981; Seegert, 2000; U.S. Environmental Protection Agency, 2009). In addition to the indices used, the researchers performed statistical analyses on all data collected. Many of the analyses required data transformations, but resulted in isolation of outliers and yielded correlations for final indices (Weigel et al., 2002). Abnormalities in the natural world are often captured with relatively small sampling distributions, thus the use of statistical analysis tools insures the integrity of the data (Seegert, 2000; Soldner et al., 2004). The use of statistical tools helped eliminate the total degree of bias in this study.

2.3.2 A Benthic IBI for Rivers of the Tennessee Valley

Industry and human settlements in the Tennessee Valley of the United States subject the environment to various stresses. In 1986, the Tennessee Valley Authority (TVA) implemented a fixed station-monitoring program to observe the effect of human interference on the environment. Recently, researchers used the abundance of data collected to determine indices for a benthic IBI for the area in order to more accurately describe the effects of human stresses on the environment (Kerans & Karr, 1994). The climates and geographies of Tennessee and Puerto Rico are decidedly different. In turn, the landmasses can be expected to have vastly different ecosystems. The watersheds of the Tennessee Valley and Puerto Rico are distant enough that differences in topography prohibit the transference of results and indices (J. R. Karr, 1981; Seegert, 2000). Additionally, the rocky substrates of the Tennessee valley necessitate different sampling methodologies from those that are required on tropical islands, thus sampling methodologies will not be considered in this review (Bass, 2003; Nerbonne et al., 2008; Seegert, 2000). However, this study presents interesting index selection techniques, statistical tools, and validation methods that merit consideration.

As in most watersheds, the streams of the Tennessee Valley originate in the highlands and grow in size as they merge and head downhill. This standard geography of streams generates a relatively consistent set of aquatic features that house different assemblages of benthic invertebrates (Miller et al., 2008; Soldner et al., 2004). Inevitably, the problem is how to determine the significance and weightings of different sub-habitats within a stream's ecosystem. In this study, the researchers opted to use methods of statistical analyses to reduce bias in visual selection techniques of indices. The use of statistics was favorable for the analysis of the large amount of data available to the researchers in advance of their work (Kerans & Karr, 1994).

The TVA amassed a significant dataset of both physical attributes of the water in the Tennessee Valley and of invertebrate populations over a large span of years. The data samplings were performed simultaneously and at regular intervals, providing a piecewise picture of the ecosystem health over time. The large collection of measurements of the physical properties of the water at each site assisted the researchers in evaluating the relevancy of each specific index (Kerans & Karr, 1994). It has been previously determined that accurate measurements of numerous parameters of water quality are essential in determining the correlation between individual indices and ecosystem health, resulting in a well supported index selection. In addition to extensive water quality sampling, these samples must be conducted at the same time as fauna sampling (Bedoya et al., 2009; J. R. Karr, 1981; Novotny, Bartošová, O'Reilly, & Ehlinger, 2005). The water quality parameters tested may be seen in Table 4.



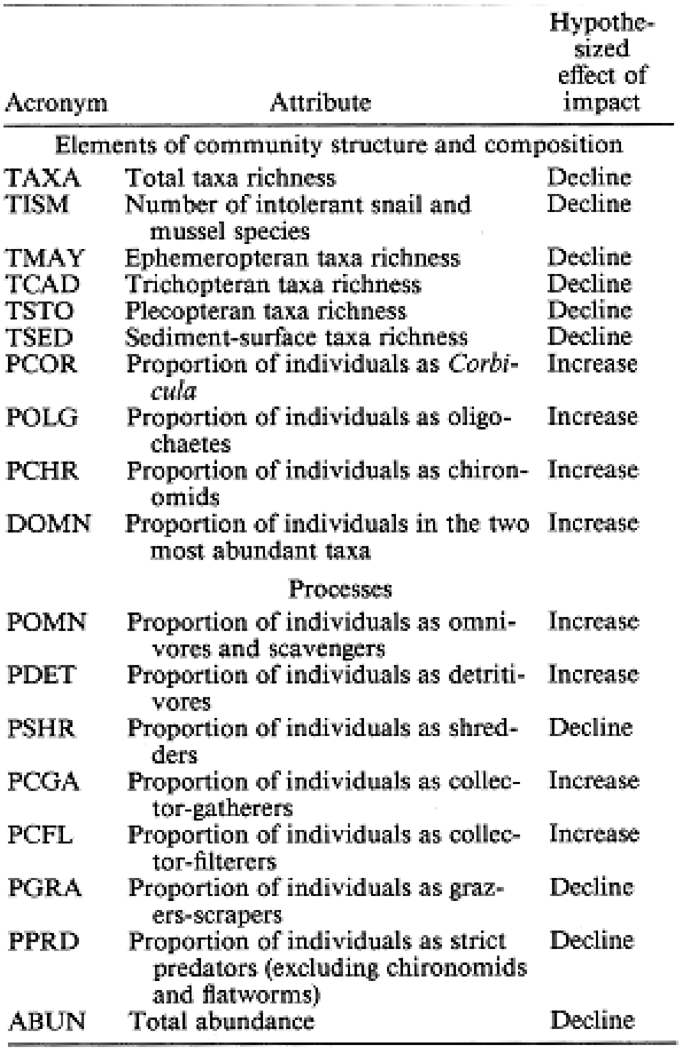
Acronym	Water quality tested	Method used
	Physical measurements	
DMEAN, DMAX, DMIN	Mean, maximum and minimum discharge	Gauging station
TMEAN, TMAX, TMIN	Mean, maximum and minimum temperature	Field
DOMEAN, DOMAX, DOMIN	Mean, maximum and minimum dissolved oxygen	Field-hydrolaboratory
pH	Hydrogen ion concentration	Field-hydrolaboratory
TSS	Total suspended solids	Gravimetric
TDS	Total dissolved solids	Gravimetric
ALK	Alkalinity	Potentiometric titration
	Nutrients	
ORG-N	Organic nitrogen	Automated block digester
AMMON	Ammonia nitrogen	Automated phenate
NITR	Nitrite and nitrate nitrogen	Automated cadmium reduction
T-P	Total phosphorus	Automated block digester
	Major constituents	
NA	Sodium	Atomic absorption spectrophotometry
CL	Chloride (total or dissolved)	Ion chromatography
SULF	Sulfate (total or dissolved)	Ion chromatography
AL	Aluminum	Inductively coupled Argon plasma emission spectroscopy
	Bacterial	
FC	Fecal coliform	Membrane filter

Table 4: Water Quality Parameters (Kerans & Karr, 1994)

Before statistical tests were performed on data, researchers checked the distribution of each data set as desirable indices are often proportional in nature (percent grazers, percent predators, percent scavengers, etc.). Unfortunately, proportional indices do not generally follow a normal distribution and must be normalized. In this case, data transformations were chosen based on the mean and variance of each individual sample needing to be normalized, resulting in logarithmic transformations of all indices involving proportions and the abundance indices (Kerans & Karr, 1994). Statistical transformations of data of this type are necessary to achieve reasonable results. Without the data transformation, few significant comparisons could be drawn (Bedoya et al., 2009; Seegert, 2000; Soldner et al., 2004).

After data normalization, the correlations between attributes and sites were tested using two-way analyses of variance (ANOVA). ANOVA outliers were used to check homogeneity of variance and normality. A small number of ANOVAs displayed small tendencies away from normal distributions, as well as one displaying obvious heterogeneity. Use of ANOVAs allowed for unbiased selection of statistically supported indices (Kerans & Karr, 1994). The use of ANOVAs in determination of IBIs is a new technique and no relevant data supporting the use of ANOVAs in biocriteria has been found, though statistical analysis has become prevalent, as is evidenced above. Without the considerations of statistical techniques, researchers have observed that the selection of indices and determinations of selection criteria are highly subjective. When researchers select these criteria using personal observations as opposed to mathematical models, an enormous amount of researcher bias is introduced in a critical phase of development for the IBI (J. R. Karr, 1981; Kerans, Karr, & Ahlstedt, 1992; Seegert, 2000; Soldner et al., 2004).

After statistical analysis, the resulting indices were evaluated for scientific validity. The final selection of indices was described by the researchers, who stated, "We focus on taxa richness, taxa composition, and surrogates of biological processes (trophic and functional guild structure and total abundance…" (Kerans & Karr, 1994). The ANOVA statistical correlations to sites are also discussed in the study. The final list of indices used in the IBI is shown in Table 5.



Acronym	Attribute	Hypothesized effect of impact
	Elements of community structure and composition	
TAXA	Total taxa richness	Decline
TISM	Number of intolerant snail and mussel species	Decline
TMAY	Ephemeropteran taxa richness	Decline
TCAD	Trichopteran taxa richness	Decline
TSTO	Plecopteran taxa richness	Decline
TSED	Sediment-surface taxa richness	Decline
PCOR	Proportion of individuals as *Corbicula*	Increase
POLG	Proportion of individuals as oligochaetes	Increase
PCHR	Proportion of individuals as chironomids	Increase
DOMN	Proportion of individuals in the two most abundant taxa	Increase
	Processes	
POMN	Proportion of individuals as omnivores and scavengers	Increase
PDET	Proportion of individuals as detritivores	Increase
PSHR	Proportion of individuals as shredders	Decline
PCGA	Proportion of individuals as collector-gatherers	Increase
PCFL	Proportion of individuals as collector-filterers	Increase
PGRA	Proportion of individuals as grazers-scrapers	Decline
PPRD	Proportion of individuals as strict predators (excluding chironomids and flatworms)	Decline
ABUN	Total abundance	Decline

Table 5: Final Indices in the B-IBI (Kerans & Karr, 1994)

Researchers initially used 28 attributes previously determined to be useful indices of benthic macroinvertebrates as the baseline set of attributes to evaluate (Kerans et al., 1992). Through the statistical techniques presented above, 18 indices were selected as the final components of the B-IBI (Kerans & Karr, 1994).

2.3.3 A Benthic Macroinvertebrate IBI for Florida Streams

Identifying their metrics with the general term of biocriteria, M. T. Barbour, et al. (1996) outlined a framework for the development of an index of biotic integrity in Florida. In the process, the team of researchers chose benthic macroinvertebrates to be the basis for their biological assessments. With goals similar to those of Fideicomiso in Puerto Rico, the Florida Department of Environmental Protection sought to reduce water pollution in Florida. To emulate the goals, techniques must be developed to evaluate the current state of the region of interest (Barbour et al., 1996).

Motivation for biological monitoring derives from the inadequacy of traditional chemical testing to assess the complete impact of nonpoint sources of pollution (Novotny et al., 2005; Zhu & Chang, 2008). In addition, the effect of physical disturbances may not be revealed by chemical tests, and as Bedoya points out, healthy biota is not necessarily indicated by “non exceedance for one chemical.” Aquatic systems are multidimensional, with physical, chemical, and biological attributes (Bedoya et al., 2009). Thus, to reveal the effects of transient pollution as well as accumulated legacy pollution, “biological monitoring may be the most appropriate…” because “resident biota in a water body are natural monitors of environmental quality (Barbour et al., 1996).”

A biological index that tracks changes in the integrity of a given ecoregion, relative to a well-defined set of reference sites, should represent the best conditions possible. One must select reference sites that are very similar to the region being studied. The index can then be calibrated to the specific environment and geography. Many authors agree upon the high sensitivity of an index to context (Bedoya et al., 2009; Chainho, Costa, Chaves, Dauer, & Costa, 2007; Miller et al., 2008; Novotny et al., 2005; Seegert, 2000; Zhu & Chang, 2008), so it is crucial that one choose “minimally disturbed streams with small catchments that were representative of and completely within subecoregions (Barbour et al., 1996).” In this study, eighty reference sites were sampled over three years, from 1992 to 1994.

Using a sampling technique analogous to that in Mexico, (Weigel et al., 2002), the researchers used a D-frame dip net to sweep the substrate and take a composite sample from multiple habitats. Preserved in formalin, the samples were processed in the laboratory and organisms were "identified to the lowest taxon possible, usually species (Barbour et al., 1996)." Since candidate metrics vary over regions, streams were classified in small groups based on geographic, hydrologic, and chemical data. Several statistical analysis methods then placed these streams into highly similar ecoregions. Dissimilarity measures between sites was determined by chord distance, but more recent authors with access to more powerful computer software have utilized Euclidean and Mahalanobis distances (Bedoya et al., 2009; Chainho et al., 2007). To evaluate robustness and variations from year to year, the researchers analyzed data from each year separately and data from all three years during the summer. They classified the sites based on their similarity or dissimilarity and created a map detailing the similar ecoregions.

The investigators selected 32 structural or functional biological metrics, mostly based on relative abundance or counts of taxa within the same grouping. Several measures indicate richness and diversity of benthic assemblages, which relate to the health of the biota within the stream ecosystem. The populations of a variety of indicator species change when perturbed due to differing tolerance to pollution. Intolerant taxa tend to disappear at higher levels of pollution, and hence a greater relative abundance of tolerant species correlates to greater pollution (Novotny et al., 2005). Trophic functions, given as relative abundance of specific sensitive organisms, indicate the effects of pollution on the availability and production of food sources (J. R. Karr, Fausch, Angermeier, Yant, & Schlosser, 1986).

The researchers screened each metric and eliminated it if there was high correlation with another in a linear scatterplot, as it would provide redundant information. To account for variance, the sites were the treatments in an ANOVA. The authors tested the sensitivity of each metric, or "its ability to discriminate between reference and impaired sites (Barbour et al., 1996)," by the overlap in box-and-whisker plots. Finally, the researchers normalized the metrics responsive to perturbation in order to eliminate their dimensions (J. R. Karr et al., 1986; Kerans & Karr, 1994). The sum of these normalized scores gave the value of an index that the authors name a Stream Condition Index (SCI). This SCI gives a score to each metric by relative comparison of its value to expectation values based on the reference data set. A high score of 5 is given to a metric within the range of reference values, while a metric outside this range received a low score of 3; a metric was assigned a score of 1 if it highly deviated from the expected value.

In this study of streams in Florida, there appeared to be investigator bias, assumptions of equal weighting in the calculation of the index, and calibration, all of which could be improved upon in future studies. Reference sites in each must be selected to have the least impairment in each region through analysis of land use, pollution sources, and past problems. Without exhaustive investigation, one must rely on one's own judgment to select sites representative of the healthiest streams. When the normalized metrics are aggregated into the index, there is an implicit assumption that each metric has the same weight. This single index is a simplified value used to determine if action is necessary, but the type of action necessary should only be evaluated by analysis of the component metrics. Finally, calibration of the methods in this report could be enhanced through collection of samples from a greater number of reference sites. Samples from as many sites as possible within each ecoregion should be collected in order to better define the site classifications. In addition, samples should be collected from sites suffering from a variety of stressors and from sites with unknown conditions to further test the ability of the index to predict the health of the sites. These new data could further reveal correlations for the tolerance of the benthic assemblages to their stressors (Barbour et al., 1996).

2.3.4 Insight from Case Studies

The case studies above present several useful methods in the development of an index of biotic integrity. Each study involved the identification of reference sites, sampling at impaired sites and reference sites, selection of metrics to be used in the index, and statistical analysis. Each of these steps is critical in the creation of an IBI, and bias or error in any one can impact the final result. The case studies above all demonstrate tactics that lead to the creation of useful IBIs that seemed to accurately reflect the health of the watershed of consideration. This is certainly a result of the incorporation of several valid and successful techniques.

We have found that in the design of our procedures, that it is necessary to minimize researcher bias by carefully designing selection and sampling procedures. Through the research it was also found that kick-sampling is the preferred technique among researchers for macroinvertebrate in-stream sampling. Experts rely heavily on methods of statistical analysis to select the most relevant metrics while simultaneously reducing researcher bias. Statistical analysis also reduces redundancy among indices, allowing a more concise and appropriate IBI to be created. A large number of samples from a wide variety of sites in a relatively broad geographic area must be collected to strengthen the correlations.

Chapter 3: Methodology

In the interest of monitoring the quality of streams in Puerto Rico, the Conservation Trust of Puerto Rico requested the development of an Index of Biotic Integrity (IBI) for stream ecosystems. The overall goal of this project was to perform the initial steps in the design of this IBI. The Trust had selected specific watershed locations in the San Juan area as the sampling sites at which the research team could collect samples for the IBI. The IQP team collected data including water quality tests and macroinvertebrate samples. The team also observed the surroundings of each site to establish the presence of physical stressors in the area. In order to determine the characteristics of the macroinvertebrates that reflected environmental conditions, team members compiled, mapped, and compared the gathered information using various statistical measures. To avoid bias, the project analyzed these comparisons critically in a scientific manner, emphazing the use of statistics.

3.1 Materials

A complete and proper set of materials was obtained to complete all necessary fieldwork. A digital camera was brought to each site to facilitate the documentation of fieldwork and stream reach identification in order to facilitate reviews of the sample collection process and later site identification. Materials listed below were used to acquire samples safely and efficiently.

Personal Equipment:

- Chest waders
- Change of clothing
- Non-waterproof hiking boots
- Safety log and/or personal safety information for each team member
- First Aid kit and extra drinking water
- Cellular phone and emergency contact numbers
- Vehicle emergency kit (battery charger, flashlight, first-aid kit, basic tools, duct tape)

Water Quality Testing Equipment:

- Nitrate and phosphate testing kits
- Water chemistry 300 ml chemically clean sample jar
- Completed water chemistry sample jar labels and clear tape to cover labels
- Multi-parameter Tester35 (including calibration solutions plus extra batteries)

- DO meter kit (including calibration solutions plus extra batteries)
- pH meter kit (including calibration solutions plus extra batteries)
- Gallon buckets (3)

Sampling and Cataloging Equipment:

- Water-resistant, container-type clipboard
- Site maps, dataforms and protocol instructions
- GPS receiver (with extra batteries) and analog compass
- Current velocity (stream gauge) meter kit (plus extra battery)
- D-frame kick net for macroinvertebrate sampling (4)
- 5-gallon white buckets w/lid (4)
- 50 meter surveyor's tape (1)
- Stream transect stakes (2) and 2lb. hammer
- 50 meter poly rope (1/2 inch or less diam.)
- Sorting trays, sample screens and ethanol for processing invertebrate specimens
- Macroinvertebrate 300 ml composite sample jar
- Tweezers (4)
- Backpack
- Microscope
- Storage Vials and labels
- Magnifying glass
- Brunton ADC Pro Weather Meter

3.2 IBI Design Method

Research presented in Chapter 2 lead to the IBI methodology presented here. Initially, the research team selected the individual process steps to develop a reliable IBI. A significant part of the IBI process was in the selection of sites that provided a gradient of environmental conditions: reference sites that represented optimal conditions and lower quality sites that corresponded to degraded environmental conditions. The selection of sites that represented such conditions was a complicated process that required trained experts with knowledge of local geography and environmental conditions. For this study, sites were selected by ecologists at Fideicomiso using a detailed process that is described in the following section, Section 3.3. The research team treated this aspect of site selection as a black box in the design of the IBI methodology, assuming that the site selection was performed in a way favorable to the design of an IBI.

To evaluate which aspects of a biological community were affected by ecological health across the sites, the ecological health was established for each site in a quantitative manner using traditional measures. For this to be accomplished, the area of evaluation was consistently determined for each site; the Trust suggested the use of a directional buffer for each site to determine the stream reach for evaluation. For each site, a central cross section of the stream was selected at which to perform measurements of stream flows based upon the characteristics of the stream; this cross section was called the “X site.” The reach was determined to extend 100m upstream and downstream of the X site, for a total reach of length 200m. Quantitative measures of reach health for the sites were determined using adaptations of protocols developed by the US Department of Agriculture and the US EPA. The protocol used for initial site evaluations, detailed in Section 3.4, evaluated a comprehensive set of ecosystem characteristics for each stream reach that were graded using a scoring guide to ensure consistency of results.

In addition to quantitative site scorings, water chemistry testing was used to determine the indices of water quality that also reflected stream reach health and macroinvertebrate population characteristics. Certain indices of water quality are known to reflect good and poor ecosystem health, and use of these characteristics as an additional evaluation helped to further pinpoint ecosystem health in conjunction with the quantitative evaluation. Several aspects of water chemistry were measured at each site reflecting anthropogenic stress and low flow water quality for each stream. These indices also help to identify the suitability of an aquatic habitat for different species, providing a set of data that may be used to validate the results of collection at each site. The use of water quality as a metric of stream reach health is further detailed in Section 3.5 below.

Since the validity and relevancy of the IBI also depends upon taxa counts at each site, consistent methods and timing of macroinvertebrate collections are essential in developing an IBI that accurately reflects environmental conditions. To keep the results of collection consistent, the same five people, four WPI students and a Nature Interpreter from Fideicomiso, Omar Monzón, collected samples at each site using the same method. The techniques used in collection and the efforts made to standardize this process are described in full detail in Section 3.6.

Once collected at each site, the macroinvertebrates were identified, counted, and preserved for further analysis. This step requires the knowledge of an expert in the field of macroinvertebrate taxonomy as many macroinvertebrates are extremely similar, and the taxa to which each animal was identified depended upon the tolerance of that class of invertebrate to environmental pollution. The taxa to which each animal was identified was selected primarily by Omar Monzón, an expert in the area of macroinvertebrate taxonomy. The cataloging process and methods of identification, both in stream and at the field base used by the researchers, are discussed in Section 3.7. It should be noted that this process often took place across several days, pending the availability of experts and facilities at different Fideicomiso sites to aid the research team in identification.

After the quantitative scoring of each site and macroinvertebrate cataloging, data was entered into Microsoft Excel for analysis. Data transformations were applied to data sets that did not follow normal distributions, after which analyses were performed to determine which indices correlated to water quality and quantitative site scores. Though this step is important and is a step where bias can be introduced, errors introduced in this process have less significant effects upon the outcome of the IBI than errors in the prior steps site selection, quantitative site assessment, macroinvertebrate collection, and macroinvertebrate cataloguing. Errors in these previous steps could render the study biased, skewed, or inconclusive whereas errors in the analysis of data may quickly be changed and bias can only be introduced through the interpretation of the results. A discussion of the data analysis techniques is presented in Section 3.9.

The weaknesses of the study and areas where the IBI did not accurately reflect actual circumstances were critical in understanding the utility of the IBI as a tool in ecosystem health monitoring. Some of the limiting characteristics were common to other biological monitoring techniques, whereas others were not. Identifications of the limiting characteristics were made using data presented in the literature as well as suggestions and knowledge of Fideicomiso experts. The limitations, strengths, and prominent uses of the study will all be discussed in detail in the results chapter.

3.3 Site Selection

In site selection, it was necessary to choose sites that were representative of the entire watershed that was examined. In the case of this study, the area of interest was the San Juan metropolitan area due to transportation limitations. Using ArcGIS and Google Earth, experts at the Trust defined a limited project area that allowed travel time to the site to be a maximum of one hour. The site area selected is shown as the solid red box in Figure 3: Map of Total Project Area. Within the limited project area, sixty sites were chosen that were dispersed equally through three main watersheds; the Río Bayamón, the Río Piedras, and the Río Grande de Loíza. Each separate point is represented by a yellow dot within Figure 3: Map of Total Project Area. These sites were chosen by an expert at the Trust using Google Earth and National Hydrologic Data (NHD) sets already loaded within GIS to help locate present annual streams in which there was observable flow.

This site selection technique involves a degree of bias. Sites were only chosen if there was reasonable access into the stream observable. As many of the neighborhoods in Puerto Rico surrounding these streams were gated communities, accessing desired sites was occasionally restricted. In order to establish an even gradient from less impacted sites to highly impacted sites, Trust experts chose sites that were close to developed areas, as well as those sites that were within the urban region but had less developed surroundings. These sites were stratified based upon their degree of urbanization, and three sites along the same stream were chosen in close proximity (within one mile) to give access options within each region. To standardize the process, the middle site was the first site to which the team attempted to gain access. If no access was available to this site, then the next choice was the upstream site. This made the process more systematic and helped to avoid bias in selecting sites for convenience of access, as easily accessible sites may have had higher anthropogenic stresses. Lastly, specific sites such as streams near major factories were purposefully avoided, as these streams would most likely have a greater effect on the overall health of the stream system and possibly pose a threat to the research team.

The naming convention used in defining sites was provided by the Trust. Each site ID has three parts, a project code (WPI), a point code (RP for Río Piedras or WP for Way Point), and a site ID number. These three components are combined in the order listed with hyphens inbetween each part to form the site names that were used for the project. In this project, sixty sites were identified, so site ID numbers range from one to sixty. For instance, one site visited was site number 27, which had a site ID that reads WPI-WP-27.

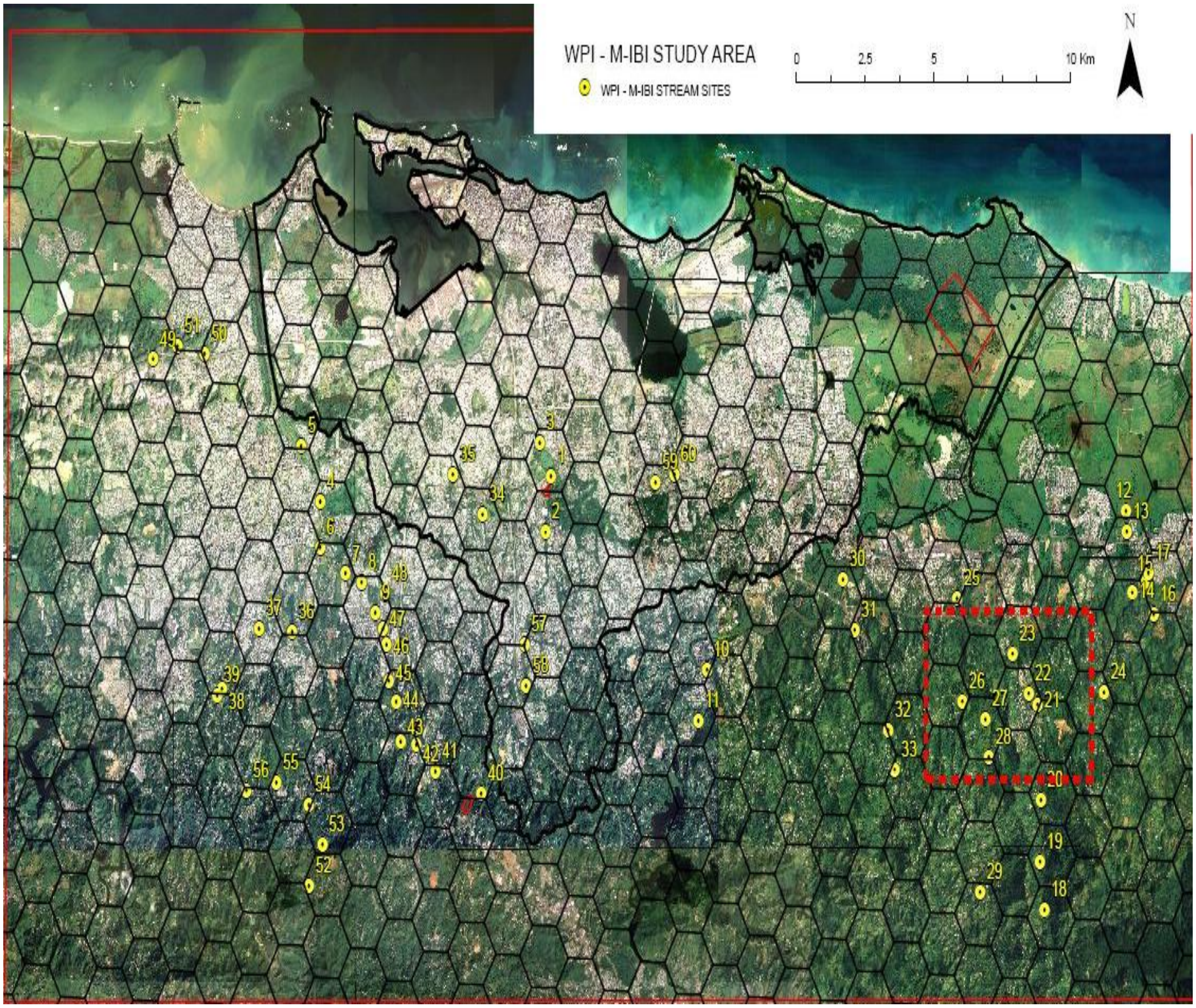


Figure 3: Map of Total Project Area

3.4 Land Cover Classification

ESRI's ArcGIS (version 9.3) was used to conduct the land-cover classification of the study sites (ID: 1, 2, 3, 21, 27, 38, 44, 48, and 54). Digital orthophoto quarter quads (DOQQs) from 2007 supported the visual digitalization at a scale of 1:6,000. Four classes guided the classification: developed, agriculture, non-forest, and forest. Developed areas include any type of impervious cover (streets, residential, commercial, public areas, etc). Areas classified as agricultural showed clearly defined crop lines. Forest areas presented a closed canopy of trees, whereas non-forest areas were all those areas that were not forests, including rivers, pasture, and sparse trees. After completing the digitalization, the area of each class was calculated (M. Torrado, Personal Communication, April 26, 2010).

3.5 Stream Reach Assessment

An initial quantitative rating of each assessment site is a key component in all IBIs that do not have a recorded history of environmental conditions for all sites. Initial surveys have been designed in many contexts for varying reasons: some are designed for speed of assessment, some are designed to cover the largest number of environmental factors possible, and yet others are designed for use by untrained volunteers. Regardless of design, all initial surveys aim to gauge environmental pollution that affects the health of the ecosystem at each individual site, and many aspects of the stream must be quantitatively evaluated. The number of aspects of the ecosystem evaluated and the importance of each aspect in overall ecosystem health directly determine the degree to which an initial evaluation of the site accurately reflects the ecosystem health of the site.

Several renditions of quick visual stream assessments have already been produced by major organizations interested in stream ecology. Unfortunately, no assessment exists as of yet for island streams or urban streams, thus relegating background protocols to those produced in other areas for larger landmasses. The two most prominent of these evaluations have already been mentioned in this report due to their use in the Trust. The USDA Stream Visual Assessment Protocol and the EPA Wadeable Stream Assessment Protocol both weighed heavily in the development of a Wadeable Stream Assessment used by Fideicomiso in the Mapa de Vida program. The Wadeable Stream Assessment used by the Mapa de Vida program was selected for use in this project due to the inclusion of assessments of the key factors determining environmental health and in part due to recommendations by the Trust's scientific coordinator Brick Fevold. The Mapa de Vida Assessment used by the research team can be found in Appendix B, whereas the USDA and EPA protocols may be found in Appendices C and D.

Both the USDA and EPA documents have existed for several years, and have been used by multiple organizations for various studies. These documents were designed for the evaluation of wadeable streams, as are the streams encountered in this study. As these protocols were developed explicitly for rural streams in the 48 continental states of the US, the factors evaluated in the Mapa de Vida visual assessment, designed primarily from the USDA document but with some influences from the EPA protocol, heavily reflect techniques used in the evaluation of rural streams in the continental United States. As such, the Trust requested recommendations on how to modify the Mapa de Vida visual stream assessment as a secondary deliverable for the project.

In conjunction with notes taken in the allotted areas in the Mapa de Vida document, a field journal was kept by the team to record observations of problems encountered in the field and situations where the Mapa de Vida assessment failed to account for ecological factors encountered in the urban streams of the San Juan metropolitan area. Problematic situations were encountered quite frequently, even in reference sites selected to represent the highest ecological conditions. For this reason, the field journal and write in spaces in field data forms were used extensively.

Similar to the USDA protocol, the Mapa de Vida assessment derives a score from an average of ten base factors for each site and up to an additional five optional factors where applicable. In addition to those characteristics graded by the Mapa de Vida assessment, an additional two categories were added to be averaged into the final score for the site. These two additional values were selected by the research team to compensate for observed factors that the assessment does not currently take into account. The first additional category is based on the land use in the area near the site. The scoring for this category directly corresponded to the percentage of land in its natural state (not used for agriculture, roads, or development) divided by 10, with the minimum score given being 1, even for values calculated below 1. The calculation of this value is described in Section 3.4. The area of evaluation for characterizing land use was a circle centered on the stream reach being evaluated with a radius of 564m. The area encompassed by such a circle corresponds 100 hectares, or $1km^2$, an area great enough to evaluate the surrounding environment but small enough so that the evaluation areas of sites did not overlap. The second added category was used to account for immediate area environmental pollution according to the scale given in Table 6 below.

Score	Descriptor
10	No visible pollutants in evaluation area
8	Some trash on banks at the bankfull depth (resulting from transit in flooding)
6	Some trash on banks at the bankfull depth (resulting from transit in flooding) and some other small visible pollutants such as garden hoses visible
4	Smaller metallic and plastic trash present on banks and in river can be observed, but is not abundant, no chemical pollutants
2	Mid-sized (larger than a hand) metal or plastic trash can be observed over a significant area from a single point, small containers containing pollutants may be present
0	Reebar, steel wires, other construction equipment or small tools and mechanical devices (power saws, drills)
-2	Construction equipment, mechanical devices, and/or chemical pollutants observed
-4	Large pieces of cars, appliances
-6	Whole cars or other mechanical apparatuses
-8	Batteries, oil drums, and other chemical containers are present
-10	Trash dump in evaluation area

Table 6: Description of Scores for Local Environmental Pollution within 1 km^2

Each site can achieve an overall maximum score of 10 and a minimum score of 1. The scoring system and scale upon which factors are graded is adapted directly from the USDA Stream Visual Assessment Protocol, and further details on scoring can be found in the attached protocol in Appendix C. This scoring is by no means comprehensive, and will be a point of discussion in later chapters along with other modifications proposed to the Mapa de Vida assessment document.

3.6 Water Quality Testing

Once the X site was established along the stream reach of interest, water chemistry measurements were taken. Stream water samples were collected near the left bank, at the center of the stream, and near the right bank. Preferably, these were taken one meter upstream from the X site. However, if stream morphology or presence of river features such as riffles made this impractical, a site further upstream, but still within the reach was chosen. To avoid collection of unrepresentative samples, the group avoided collecting water samples near riffles, which aerated the water changing dissolved oxygen, and downstream of others' activities, which kicked up sediment and debris. A team member used three different small buckets to collect samples from the left side, center, and right side of the stream.

Starting at the left side, the sampler positioned the bucket upstream of his or her body and away from leaves and stream debris, angled it so the opening faced downstream, and slowly lowered it into the water. As the water flowed gently into the bucket, the team member waited one minute to allow the sample to equilibrate with the surrounding stream water and to ensure that no bubbles or debris remained within the bucket. The bucket was then carefully carried to the stream edge and placed near the water-testing equipment; samples were then collected in buckets from the center and right side of the stream and placed in order next to the sample from the left side. The buckets were placed on flat surfaces, and measurements were quickly taken by two team members to achieve the most accurate values.

Following the instructions for each respective instrument, given in Appendix E, the water chemistry parameters investigated in this project were:

- Temperature (°C)
- Dissolved oxygen – DO (mg/L)
- pH
- Total Dissolved Solids- TDS (ppm)

- Salinity – S (ppm)
- Nitrate – N (ppm)
- Phosphate – P (ppm)
- Conductivity – Con (µS)

These analytes are listed in the order in which they were obtained. On the advice of the scientific coordinator at Fideicomiso, Brick Fevold, this ranking reflected the significance of how collection from the stream, metabolic processes of microorganisms, and lack of water flow in the bucket impacted their values over time. A given parameter was measured in the left bucket, then the center bucket, and finally the right bucket by one team member; the second team member assisted by taking out and storing the instruments and recording the results in the appropriate fields on the data form for that site. Upon completing the water chemistry measurements, the water samples were disposed of onto gravel, dirt, or grass away from banks of the river.

Figure 4: Team Members (left to right): collecting water sample, testing water sample, recording results

3.7 Macroinvertebrate Collection

The collection of macroinvertebrates differed in each microhabitat. The most common places macroinvertebrates were collected included deep pools, riffles, and banks. These areas provided good starting points when gathering the macroinvertebrates at each site. The different microhabitats possible within each location are listed below.

- Woody Debris
- Submerged Logs

- Leaf Packs
- Undercut Banks
- Boulders/Cobble
- Surface Water
- Substrate
- Overhanging vegetation
- Artificial

Kick sampling, as described in Section 2.2.2 Data Collection, offered exceptional results when sampling within bottom substrates such as sand, leaf pack, and clay, but was not a reasonable collection technique for every habitat. All extraneous material that was within the net was sorted out and removed before emptying the net into the collection buckets, as this saved time when cataloging the macroinvertebrates. When sampling submerged logs, woody debris, and different rock types team members picked up the object, brushed off the excess matter, and moved the animals into the collection buckets. Many small worms, snails, and insect larvae were firmly attached to these logs and rocks and were very difficult to collect only by kick sampling. Often, tweezers were used to remove various macroinvertebrates from rocks or other debris. To get the best results when sampling overhanging vegetation and undercut banks, the D-net was used to push upwards and brush up against the material of the habitat, which knocked off the macroinvertebrates into the net. Many macroinvertebrates, especially shrimp, were very agile and sensed movements within the water, so sampling procedures often required significant patience in holding the collection net steady.

3.8 Macroinvertebrate Cataloging

As the creation of an IBI demanded accurate counts, the collected macroinvertebrates were counted than stored and preserved in vials containing 70% ethanol solution. Each specimen was removed from the collection container, identified, added to the site tallies, and then stored in a vial specifically for that creature's taxa (see Figure 5). Each vial contained a label which identified the collection site, time, date, and specimen name.

A different technique was used for capture of each taxon, including damselfly and dragonfly larvae, shrimp, water striders, snails, etc. Damselfly larvae tended to hold tightly to leaves or other available debris in the water. The larva needed to be shaken off and removed with tweezers to be placed in the appropriately labeled vial. Shrimp hid under available debris, moved quickly, and jumped when out of water. Therefore, most shrimp had to be removed by hand and promptly placed in ethanol in a lidded container. Water striders "ran" on top of the water and could be removed in groups from the bucket using small jars or available screens. Once caught, the water was drained and the striders were placed in the ethanol solution. Finally, snails could be easily removed from the bucket by hand or with tweezers and placed in the appropriate vial. All other taxa caught moved slowly or only marginally, and could be removed in a similar fashion.

In several instances, the organisms that were captured were too small to identify with the naked eye. In this case, the team used several different methods to identify the organisms. Foremost, the organisms were examined under a 5x hand magnifying glass while alive. The manner in which many organisms moved helped to easily identify them to the proper taxa. However, some could still not be identified in the field. When this was the case, the organisms were placed in a jar filled with ethanol and transported to the Fideicomiso office in Old San Juan where they were examined and identified by Omar Monzón under a higher magnification microscope.

Figure 5: (Clockwise from top left): Placement of specimen in jar, cataloging of sample, shrimp specimen in vial, vials containing samples, and label inside shrimp vial

Macroinvertebrates were catalogued at the Fideicomiso tree nursery (“Viveros”) in the UPR Botanical Gardens. This location was convenient because of its proximity to the Río Piedras stream sites and its location in the Río Piedras area. Viveros was used as a field base where all equipment necessary for cataloging and for field work was stored in a safe area. The large outdoor space available and running water and electricity aided in the cataloging process. Unfortunately, this required the team to travel to Viveros at the beginning and end of every field day to pick up and stow equipment as well as catalog the macroinvertebrates.

3.9 Sample Project Time

Precise repeatable sampling demanded a systematic collection process that accomplished all tasks in the same fashion. The sampling process of each site can be seen in a step-by-step manner in Figure 6. The process was broken down into a specific distribution with responsibilities for each team member (labeled as Team Member 1: TM1 through Team Member 4: TM4) in the overall process of the sampling. At each site, the team members rotated positions. In this way, each team member filled every role in four samplings, thus minimizing the bias introduced from having one team member repeat the same role every time. Consequently, this same technique may increase the variability of the results between sites due to different motions and techniques of each member of the four-person team. The actions of Omar Monzón (the team’s driver and field advisor) are not included in the diagrammed process. Omar spent the time at the sites advising the team on how procedures should be carried out and performing other miscellaneous tasks to help streamline the process. Omar contributed 10 minutes to sampling at every site in order to maintain consistent procedures.

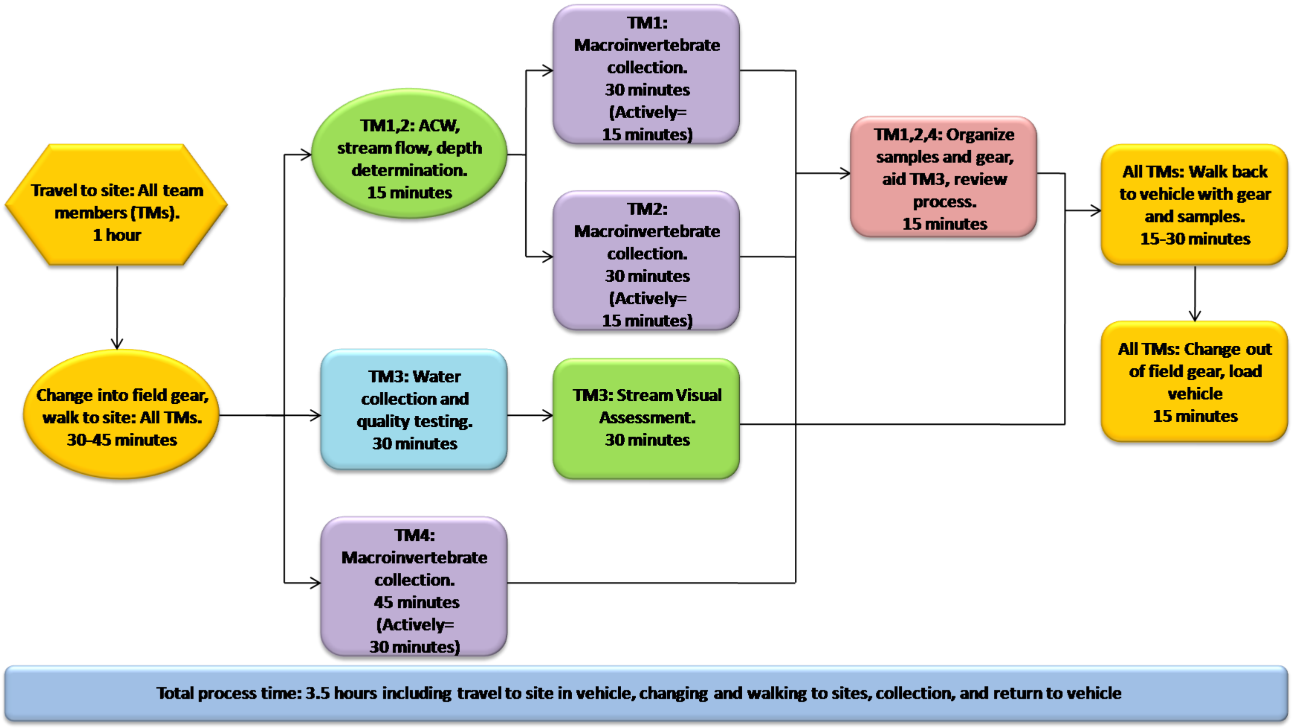


Figure 6: Site Sampling Procedure Timeline

Figure 6 estimates the amount of time the procedures took at each site. This time estimate was critical as the number of sites at which the team could effectively collect samples in each day of fieldwork was based on this estimate, and the total number of days needed to collect samples for all sites was dependent upon the estimation of the number of days of field work. Ranges were used to account for variability that naturally occured and the team employed conservative estimates to assure that the project would be completed.

At the outset each sampling day, all team members traveled to the site to be examined. In addition to the four-person team, Omar Monzón, a Fideicomiso ecologist, traveled to all sites providing transportation and oversight. Transportation took approximately one hour, depending on the distance of the site from the field base at The First Aqueduct complex and traffic conditions. After arrival on site, all team members changed into the appropriate field clothing and walked to the actual sampling location, which took up to 45 minutes, depending on the distance of the site from available parking and the willingness of property owners to allow access to the streams.

Each team member fulfilled a role in the collection of data at each site as shown in Figure 7, with team members rotating positions at each new site. Team Members (TMs) 1 and 2 completed the active channel width (ACW), stream flow, and stream depth measurements. Simultaneously, TM3 collected and tested the water from three parts of the stream: left bank, middle, and right bank. TM4 gathered macroinvertebrate samples via kick sampling and other sampling techniques. Gathering samples from within each microhabitat that existed in each stream, such as riffles, shallow waterbeds, algae beds, and other habitats ensured a diverse range of specimens would be observed.

Figure 7: (Clockwise from top left): Team member determining ACW, assessing physical features, kick sampling, collecting water samples

After the ACW and physical features of the stream were determined, TMs 1 and 2 joined TM4 in macroinvertebrate sample collection. The total time TMs actively collected samples was for one hour per site in order to standardize procedures and maintain a consistent data set. Active sample collection involved searching for and attempting to catch the macroinvertebrates, and did not include removal of debris from the samples or moving the specimens from nets to buckets, both of which took a significant amount of time. At each site, this process was performed in a standardized fashion. During this time, TM3 completed the different water quality tests, which took roughly 30 minutes while TM2 simultaneously recorded water quality and stream gauge values. TM3 then moved on to completing the visual stream assessment forms for the site, which can be found in Appendix B. The water quality testing kits provided by the Trust were capable of testing temperature, pH, dissolved oxygen (DO), phosphate (P), nitrate (N), salinity (S), total dissolved solids (TDS) and conductivity levels (Con). Many of these water qualities that have been tested and used as indicators in previous IBI studies (Kerans & Karr, 1994).

Equipment such as D-frame nets and plastic buckets with lids was used to capture and separate the macroinvertebrates. The samples were composite and thus all specimens were collected from observed microhabitats and stored for transit in the same buckets. Nets were essential in sample collection in the freshwater streams because water currents displaced sample matter quickly. When collecting from certain microhabitats, each team member held the net downstream of their own body position, providing the maximum amount of free current to pass through the net and thus the maximum amount of sample to be collected within one attempt. Other microhabitats, such as leaf packs, needed to be sorted through by hand. Placing the samples in the plastic buckets enabled transportation to the Trust's facilities at The Tree Nursery in the UPR Botanical Garden for identification.

After collecting samples, TMs 1, 2, and 4 aided TM3 in completing the visual stream assessment as well as organizing and consolidating the samples. Before leaving the site, all team members assembled and reviewed the process to ensure that all microhabitats were sampled, all processes were completed, and all samples were successfully collected. The team then took all of the samples and gear to the vehicle and changed out of field clothing.

The team estimated that on average it took three and half hours to travel to a site, collect samples, and perform all tests and analyses. Assuming that the sites were near each other and all procedures were carried out without interruption, the time required to travel to each site and collect all data was at least two hours. In adverse conditions, the whole process took as long as four and a half hours due to traffic, access difficulties, and unanticipated weather conditions. An overall process timeline is provided in Appendix I.

3.10 Statistical Analyses of Data

After completion of field work, the team compiled the results recorded on the data forms and entered the data into a Microsoft Office Excel 2007 workbook. A standard spreadsheet was created for each individual site, and another spreadsheet compiled the data from each site into a summary table. The Analysis ToolPak provided in Excel was used to generate descriptive statistics, histograms, and correlation coefficient matrices; scatterplots were also generated through Excel's charting features. Here, the term "variable" refers to a macroinvertebrate count, macroinvertebrate relative abundance (expressed as a percentage), stream visual assessment score, or water quality parameter.

Stream flow data was used to calculate discharge for each site by multiplying discretized average flow velocities by component cross-sectional areas (U.S. Environmental Protection Agency, 2004). However, the team decided that the stream gauge protocol did not reliably produce accurate results due to iron buildup on its rotating magnet and difficulty measuring the current velocity at a specific depth. Discharge was not considered further.

The stream visual assessment (SVA) component scores were averaged and the total number of taxa identified at each site was determined. Based on the Mapa de Vida protocol pollution classification scheme and information on invertebrate pollution tolerance (Voshell, 2002), totals were calculated for the group 1, group 2, and group 3 taxa. The project team discarded variables for which values of zero were recorded at four or more sites as significant correlations were difficult to establish.

With the descriptive statistics tool in the Analysis ToolPak, the mean, standard deviation, and skewness of each variable across all sites were determined. In addition, histograms were generated with the ToolPak. The data for each variable did not always follow a normal distribution. Most statistical analyses rely on the variables of interest being normal, so transformations were applied if necessary after inspecting histograms for normality and skewness numbers determined by the ToolPak. For each variable with a skewness greater than 0.5, a log(X+1) transformation was applied; if the skewness was less than -0.5, the variable was $(X+1)^{-1}$ transformed in order to adjust the skewness towards zero (MacDonald, 2009).

With the correlation tool, a correlation coefficient matrix was generated to establish R values between all the variables. Due to the limited time of the project and limited number of sites visited, the team used a basic guideline suggested by a thesis published at the University of Puerto Rico (Quiñones, 2005); if the R value was greater than 0.5 or less than -0.5, the correlation was considered to be strong.

From information presented in the literature, the Index of Biotic Integrity should integrate only the parameters that are the most relevant reflections of ecosystem health. To establish the selection of appropriate indices for the IBI, correlations between the SVA average and the other variables were inspected. For the variables with a strong correlation to the SVA, scatterplots were generated for visual inspection. As discussed in Chapter 4, indices were subsequently selected based on the correlation coefficient R.

3.11 Summary

The team designed a methodology for testing and sampling that would develop an IBI for the Conservation Trust of Puerto Rico to assess stream health in the San Juan area. The results will be able to determine which indicators should be used for the creation of an accurate IBI as well as the water quality of the sites.

The project team identified important personal protective equipment in addition to the field equipment needed for sample collection with assistance from ecologists at the Trust. The method detailed here was a precise sampling method based on standard techniques found in the literature that resulted in satisfactory catches from each site. From the sampling time, the project team created a timeline to identify the scope of the work. This timeline was a very dynamic entity throughout the course of the project, having been revised on a daily basis. This timeline allowed the team to coordinate and manage the efforts between sample collection, cataloging, data analysis, and writing through the duration of the project.

Following sampling processes and the project timeline, this section describes statistical analyses that were used to discern correlations between data sets. Due to the short timeline for project completion and the team's lack of experience with biological monitoring and ecological statistical analyses, the team chose simple, straight-forward procedures that were commonly accepted in the literature. The integration of all the techniques presented here have been made with the intent to provide the foundations of an IBI that reflects environmental conditions with a low degree of bias.

Chapter 4: Results and Analysis

This chapter presents observations for each of the nine sampled sites. Section 4.2 provides results and preliminary analysis of the data collected. Finally, from experiences in the field, the team prepared several recommendations for improving future work.

4.1 Site Descriptions

This section describes each of the nine sites sampled. Six streams were studied. The sites are given the number they were assigned during the site selection process and are listed by the chronological order in which they were sampled. Pictures presented at the end of each description are a view upstream on the left and a view downstream on the right. Additional information can be found in the appendices. For each study site, Appendix F lists the stream name and the GPS coordinates of the X site. Supplementary pictures documenting obstacles and pollution at each site can be found in Appendix G, and Appendix H presents images of collected macroinvertebrates.

4.1.1 Site 1 – Río Piedras

At Site 1, an extraordinary amount of algae along the streambed was observed. Several fallen bamboo dams were encountered along the route to the X site, most likely created by flooding. Sheet metal, pipes, garden hoses were only some of the debris noticed within the river. There was also a full sized vehicle flipped upside down underwater in the stream. A previous attempt at sampling Site 1 occurred the week before, but could not be performed due to the removal of a large bamboo dam by a hydraulic crane upstream from the X site.

At the X site, a drainage pipe stuck out of the left bank of the stream. The drainage pipe, though, was not in use and was deemed not harmful to the stream system. Several corporate buildings and roads ran parallel to the left bank. The right bank, however, was mostly undeveloped. Both banks were high, ranging from 15 to 20 feet, and were quite eroded. There was little overhanging vegetation and undercut banks, but some riffles and several deep pools were observed.

At the site, seven different taxa groups of macroinvertebrates were collected.

Figure 8: Site 1 on the Río Piedras

4.1.2 Site 2 – Río Piedras

This was the first site in which the team sampled. The original plan was to complete Site 1 beforehand, but a large bamboo dam which developed near the First Aqueduct lead to Site 2 being sampled first. The original entry point was inaccessible due to surrounding gated communities. Eventually, a road bridge was found and provided entry. Though an access path was found, the team needed to climb down an approximately twenty-foot right bank to access the X site. The underside of the bridge was inhabited by a large flock of pigeons, which most likely added unwanted waste into the system. From there, the team walked upstream to the X site, which was set up in between two riffles.

After reaching the X site, large amounts of green algae were observed on both the streambed and the rocks within the water. The streambed itself consisted of mostly sand, mixed in with various clay patches near the banks. The only two microhabitats noticed were the riffles and the overhanging vegetation, both of which were sampled. The vegetation on the banks consisted of tall grasses and a few trees, providing limited canopy cover and exposing the stream to the hot tropical sun. Pollutants such as large pieces of rusted metal, an electric drill, garden hoses, and household trash were seen within the stream.

A total of five separate taxa groups was identified and cataloged from Site 2.

Figure 9: Site 2 on the Río Piedras

4.1.3 Site 3 – Río Piedras

Access to Site 3 was relatively easy, as there was a road directly on each side of the stream banks. The riparian zone along the 25-foot high banks was composed of tall grasses with different trees scattered throughout, providing little canopy cover. Erosion was clearly visible on each bank.

The X site was set up in a run between two small riffles. There were several small rock islands scattered throughout the stream. Algae were heavily present, especially on the sand and gravel streambed. Sampling spots included riffles, overhanging vegetation, leaf packs, and small pools. Trash, metal cans, pipes, tires, hoses and small car parts were also observed throughout the sampling location.

There were seven different taxa groups collected and cataloged from Site 3.

Figure 10: Site 3 on the Río Piedras

4.1.4 Site 21 – Río Canóvanas

Site 21 was accessed, with permission from a landowner, through a yard and barbed wire fence. Entry to the X site was through the stream's left bank riparian zone, which was made up of several different trees, grasses, and bamboo groupings. The right bank consisted of some trees, but was mostly comprised of grazing pasture, as there was a horse and stable along the bank. Partial erosion was visible, especially on the right bank.

Several different microhabitats such as riffles, deep pools, overhanging vegetation, undercut banks, leaf packs, large boulders, and wooden debris gave the macroinvertebrates multiple places to thrive. A plethora of shrimp were seen jumping out of the water in an attempt to move upstream, for mating purposes, according to Omar Monzón. Pieces of human garbage, such as large tarps, garden hoses, metal cans, and rebar, were found along the banks and in the water.

Overall, seven taxa groups were cataloged in the macroinvertebrate samplings.

Figure 11: Site 21 on the Río Canóvanas

4.1.5 Site 27 – Río Canovanillas

Accessing Site 27 required walking about a half mile through the woods. Once at the stream bank, it became apparent that the X site would have to be moved because of a large 25-foot waterfall within the stream reach. The next closest accessible point was 300 meters upstream. The X site was set up in a channelized part of the stream just after riffles created by medium sized boulders. Upstream from the riffles, the stream opened up into a wide and slow moving section.

The right bank had a lush and stable riparian zone, comprised of trees and grasses with little bamboo present. On the left bank, there was an open field with plenty of grass and hills. Horses and cows were observed grazing and roaming throughout the fields. Towards the end of the field, there were rows of crops being grown and cultivated.

Little human impact on the area was observed. The only indication of human presence was that of a rope swing tied to a half fallen tree that was hanging over the river. The team found minimal pollutants, such as manure, garden hoses, and some paper products.

There were many microhabitats encountered within the stream, such as multiple leaf packs, riffles, deep and shallow pools, boulders, undercut banks, and wooden debris. The main streambed substrate consisted of sand and gravel.

The total number of different taxa collected and cataloged at this site was eight.

Figure 12: Site 27 on the Río Canovanillas

4.1.6 Site 38 – Río Minillas

Site 38 was located behind a church and the stream was accessed with permission from a church employee. The parking lot of the church was very close to the edge of the right bank, about 12-feet high. The left bank had a better riparian zone, with more trees stretching back for a longer distance than the length of the right-side riparian zone. There were also a few dilapidated houses within view on the left bank. Both banks were quite eroded, with exposed tree roots.

The X site was established below small riffles and before a small waterfall that ran through bedrock and emptied into calmer waters. In addition to these riffles and waterfall, many different microhabitats were observed and sampled, including overhanging vegetation, undercut banks, a few leaf packs, large rocks, pools, and tree debris. Shrimp were seen swimming upstream and many crab holes were located in the clay of the left bank. The few pollutants spotted included a steering wheel, wooden planks, and sheet metal.

A total of eight different taxa groups was collected from Site 38.

Figure 13: Site 38 on the Río Minillas

4.1.7 Site 44 – Río Guaynabo

Site 44 was accessed through the backyard with permission of the homeowner on a dead end street. The stream was located behind a barbed wire fence, on top of 10 foot banks. Canopy cover shaded most the stream. A healthy riparian zone including many trees on the right bank was noticed, even though a fence along the left bank was also present. Behind the fence was mostly bare land with the trees showing some exposed roots.

The X site was established downstream of two stream channels. The wider left channel contained fast-flowing water and several riffles. Stagnant waters and a narrow pathway defined the right channel. The combination of these two features created a somewhat fast-flowing reach. The streambed substrate was uniformly composed of cobble, and several types of microhabitats were observed and sampled: undercut banks, riffles, and little overhanging vegetation. Pollutants observed included rusted scrap metal, cinderblocks, a number of hoses, a car tire, clothing, an embedded saw, minimal household garbage, and a pipe which drained into the stream.

A total of ten separate taxa groups was identified and cataloged from Site 44.

Figure 14: Site 44 on the Río Guaynabo

4.1.8 Site 48 – Río Guaynabo

Entry to Site 48 was difficult due to tall grasses, steep slopes, and man-made debris. The team observed a truck frame, several tires, garden hoses, and shopping carts upon arriving to the site. There were several industrial buildings to the left of the site as well as a cemetery upstream of the X site. While walking to the X site, an extreme amount of trash such as diapers, Styrofoam, paper and plastic products, and electronics were noted. An excessive amount of rusted sheet metal, rebar, and a propane tank were also observed within the stream. This was also the only stream with a noticeably bad odor.

Sampling was performed in microhabitats such as leaf packs, shallow pools, and undercut banks. The water appeared to have a murky color, but this could have been due to the previous day's rain. The streambed was comprised of mostly sand with mud near the banks. The banks were eroded and likely affected the amount of run-off into the stream. The large groups of bamboo trees on the bank could have also been a factor in bank erosion.

Overall, there was a total of five different taxa of macroinvertebrates collected.

Figure 15: Site 48 on the Río Guaynabo

4.1.9 Site 54 – Río Bayamón

This site was directly parallel to a main residential road. Entry into the site involved walking through an area of trees that opened into the stream; little shade was offered the stream due to sparse canopy cover. On the right side of the bank was a landfill or trash dump. Other pollutants such as garbage bags, diapers, motor oil, and large chunks of car debris were also observed. In order to avoid the immediate local pollution of the landfill and obtain a more representative study of the stream system, the X site was placed upstream of the landfill.

Although it had rained the day before, the water seemed clear enough to take water quality samples. Stream flow measurements were not taken because some equipment was accidentally left at the Viveros, but depth measurements were still performed. There were numerous trees along the left side of the bank, providing stability to the riparian zone. The right bank, however, consisted of grasses and a large stretch of sand and mud. The stream possibly received some sedimentation from the run-off of this bank. Site 54 also had many large boulders within the stream system, causing small channel-like areas. Several microhabitats such as riffles, pools, leaf packs, overhanging vegetation, and undercut banks were sampled.

There were eleven different taxa collected and indentified from the site.

Figure 16: Site 54 on the Río Bayamón

4. 2 Stream Quality Assessment

In traditional analyses of stream health, water quality measurements combined with Stream Visual Assessments (SVAs) are used to qualify (and more recently quantify) the health of a stream ecosystem (Newton et al., 1998). In this study, data for both traditional analyses and biological monitoring were collected, enabling the use of both traditional measures and biological measures in a multimetric index. The SVA final value was the baseline measure for analysis; thus correlation to the SVA final value determined the viability of traditional and biological indices for a final multimetric index to assess stream quality.

4.2.1 Traditional Measures of Stream Quality

In order to build a comprehensive multimetric index, several traditional measures were employed. These measures included measurements of water chemistry and a Stream Visual Assessment applied in the Mapa de Vida program and adapted as described in the methodology. In order to incorporate water chemistry indices, a correlation analysis was performed between water chemistry data and the SVA final value. Table 7 presents results from the correlation analysis; for each water quality parameter measured, its correlation to the SVA value is determined as a correlation coefficient (R value).

WQ Parameter	R Value to Transformed SVA
Temp	-0.68
DO	-0.061
pH	0.56
TDS	0.080
S	0.054
N	N/A
P	0.59
Con	0.098

Table 7: Correlations between the SVA final value and WQ parameters

As seen in Table 7: Correlations between the SVA final value and WQ parametersTable 7 above, several water quality parameters are correlated to the final SVA value. In particular, the water temperature, pH, and phosphate concentrations (P), which are known from the literature to reflect environmental condition, have observable correlations to the SVA value. Additionally, there is very little scattering of correlation values: either a water quality parameter has notable correlation to the SVA value or it is decidedly uncorrelated. Unfortunately, the measurement technique used for phosphates was highly inaccurate because it employed qualitative colormetrics, which did not result in numerical values. Consequently, further studies will be necessary to more firmly establish the correlation between numerical measurements for phosphates and the SVA final value. For this study, the phosphate index was still considered to be viable using the measurement technique presented in the methodology. Thus the water quality parameters correlated to the SVA final valuable that were viable for use in a multimetric index were water temperature, pH, and phosphate measures.

Though TDS, salinity (S), and conductivity (Con) are all compared in Table 7, it is known that these values are all directly related to each other and follow the same trends between sites. This is due to the nature of these three measurements: all are directly dependent upon ion concentration in the water tested. Because of this relationship, only one of these values is necessary if a comparison to biological indices is desired. In this case, the project team utilized TDS as a comparative index to determine if aspects of the biota are dependent upon ion concentration in the water. The relationship between TDS, S, and Con parameters can be seen in Figure 17.

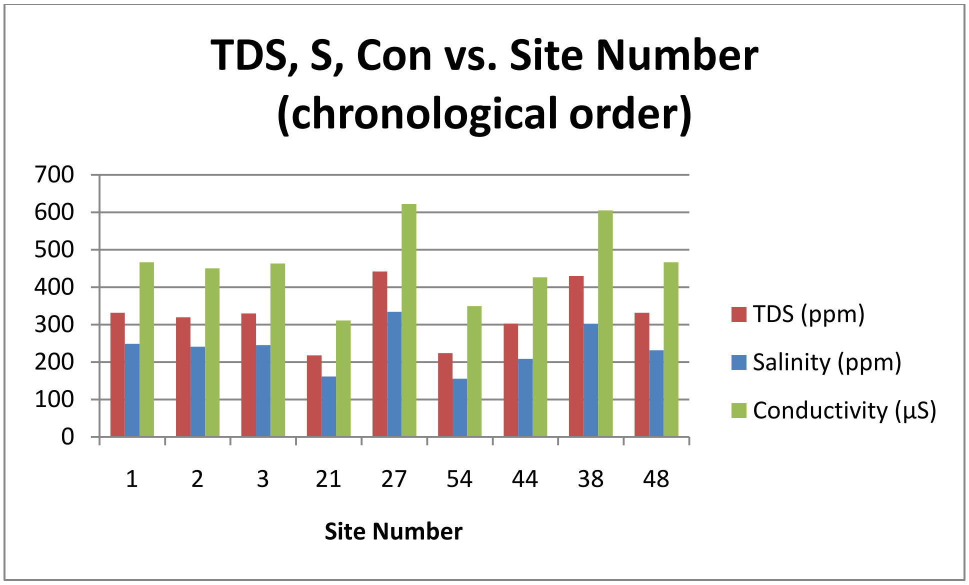


Figure 17: Relationship between TDS, Salinity, and Conductivity

From the data presented in Table 7 above and knowledge of water chemistry measurement, it can be seen that there are three different groups of water quality indices. First, there is a group that involves the water temperature, pH, and phosphates that is correlated to the SVA final value. Second, there is a group involving TDS, salinity, and conductivity, which are all chemically related but not notably correlated to the SVA final value. Finally, there is a group including only DO which has no relation to the other two groups. This is reasonable because DO is primarily a function of flow features upstream of the X site, namely the presence of riffles, falls, and rapids. Using an analysis of correlation, these three groups were examined in comparison to biological indices to determine relations among them; the results are presented in Section 4.2.3

4.2.2 Results of Normalization

Each water quality parameter considered displayed normal distributions and skewness of magnitude less than 0.5 and did not require data transformation. Figure 18 shows the distribution of other indices for which data was available at every or almost every site. Figure 18(a) and (e) do not appear to display a normalized distribution, but this is likely because the bin range selected by Excel does not accurately reflect normality. Shrimp and damselfly larva were not collected at every site, so the zero value shows frequency that impacts the shape of Figure 18(b) and (c). Based on the descriptive statistics generated by the Analysis ToolPak in Excel, the magnitude of the skewness of each untransformed and transformed variable was determined, as shown in Table 8. Skewness measures the asymmetry of the tails in a distribution of a variable; a nonzero skewness indicates deviation from a normal distribution (Weisstein, 2010). The transformation reduced the skewness for each variable, and the team accepted it.

	Skewness, Untransformed	Skewness, Transformed
Group 1 total organisms	1.62	-1.50
Shrimp total organisms	1.57	-0.65
Damselfly larva total organisms	1.79	0.37
Water strider total organisms	2.36	0.06
Total taxa diversity	0.53	-0.03

Table 8: Comparison of skewness before and after transformation of selected indices

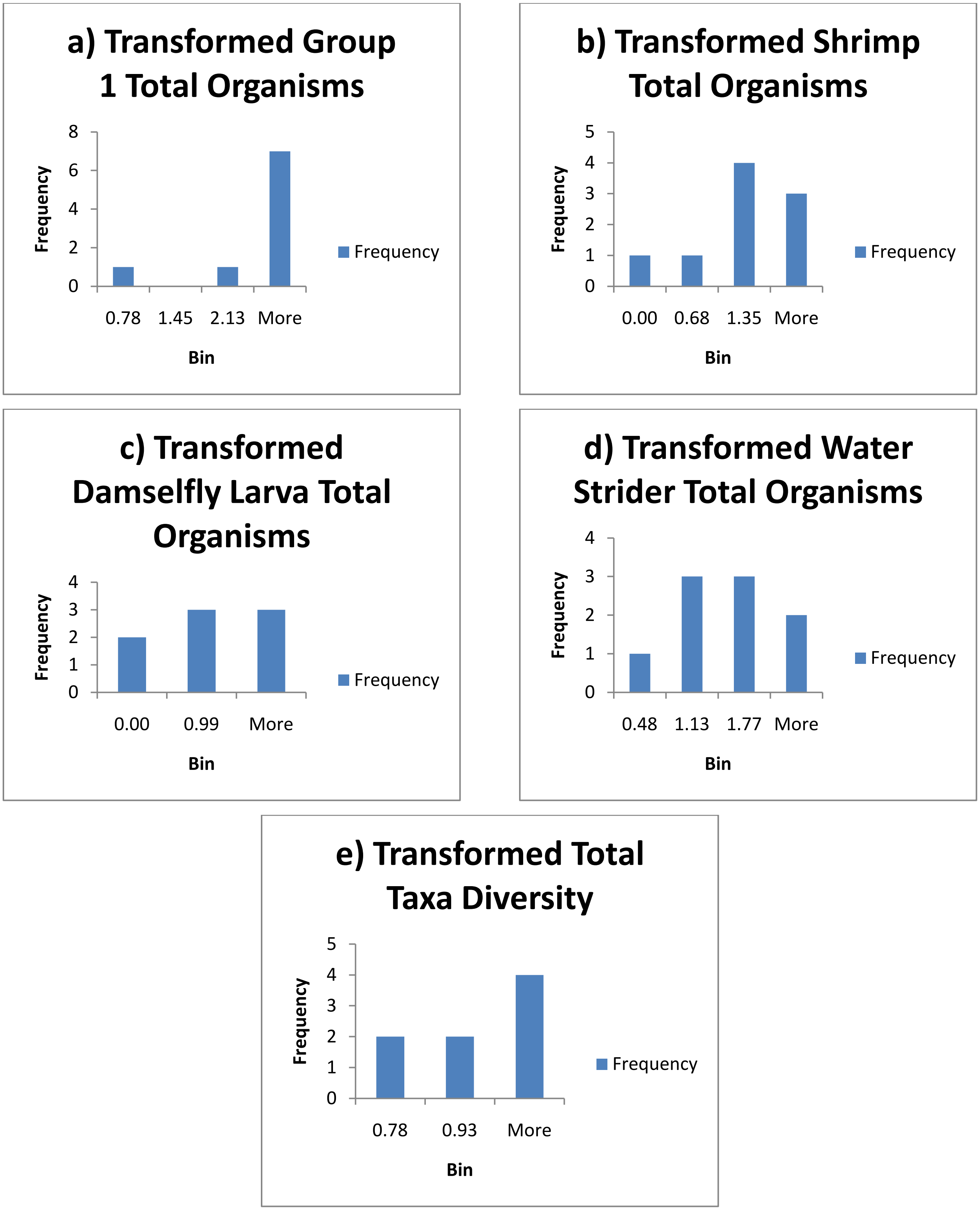


Figure 18: Histograms for transformed data sets for (a) group 1 total organisms index, (b) shrimp total organisms index, (c) damselfly larva total organisms index, (d) water strider total organisms index, (e) total taxa diversity index

4.2.3 Biological Monitoring as a Measure of Stream Quality

The final correlation analysis was based on the assumptions about the data sets of interest detailed in Section 4.2.2. Biological indices were compared to the three groups of traditional measures with representative indices of SVA final value, TDS, and DO. This selection was based upon the analysis of correlation between the Stream Visual Assessment (SVA) final value and water quality parameters as previously presented. Data normalization and correlation analyses were conducted in the fashion presented in the methodology and organized into tables for comparison. The indices compared were normalized biological indices of individual species and tolerance groups as well as normalized biological relative abundances of individual species and tolerance groups. The results of this comparison are presented in Table 9.

	Biological Index	SVA	DO	TDS	Index Relative Abundance	SVA	DO	TDS
Group 1 Indices	Caddisfly	0.35	-0.39	0.07	Caddisfly %	0.38	-0.43	0.18
	Riffle Beetle	0.61	0.22	-0.40	Riffle Beetle %	0.64	0.17	-0.04
	Mayfly	0.56	-0.43	0.13	Mayfly %	0.46	-0.48	0.20
	Gilled Snail	0.58	0.13	-0.41	Gilled Snail %	0.25	0.14	-0.48
	GROUP 1 TOTAL	**0.61**	**0.08**	**-0.36**	**GROUP 1 TOTAL %**	**0.33**	**0.06**	**-0.43**
Group 2 Indices	Shrimp	0.76	-0.23	-0.06	Shrimp %	0.27	-0.37	0.14
	Crab	0.60	-0.28	0.38	Crab %	0.55	-0.19	0.25
	Damselfly	-0.83	0.54	-0.30	Damselfly %	-0.74	0.31	0.06
	Dragon Fly	-0.78	0.55	0.08	Dragon Fly %	-0.75	0.51	0.08
	Water Strider	0.58	0.01	0.25	Water Strider %	0.39	-0.34	0.54
	GROUP 2 TOTAL	**0.37**	**0.10**	**0.28**	**GROUP 2 TOTAL %**	**-0.25**	**-0.15**	**0.52**
Group 3 Indices	Midge Fly	0.43	-0.13	-0.32	Midge Fly %	0.45	-0.12	-0.24
	Pouch Snail	-0.08	0.51	-0.42	Pouch Snail %	-0.17	0.32	-0.10
	Other Snail	0.10	-0.69	0.12	Other Snail %	-0.19	-0.89	0.22
	Aquatic Worm	-0.33	0.25	0.03	Aquatic Worm %	-0.45	0.28	0.05
	GROUP 3 TOTAL	**0.02**	**0.14**	**-0.29**	**GROUP 3 TOTAL %**	**-0.33**	**0.11**	**-0.01**
	Total	0.65	0.01	-0.21				

Table 9: Correlation Analysis between biological indices and the SVA final value

In Table 9 above, negative correlations with R value less than -0.5 are highlighted in red and R values greater than 0.5 are highlighted in green. For the case of biological correlations, those having R values of absolute magnitude greater than 0.5 are statistically significant (Quiñones, 2005). For the case presented above, some of these correlation values are invalidated from use in a multimetric index by small taxa counts. For instance, crabs and riffle beetles were caught only at two or three sites and not in significant enough numbers to be considered as valid statistical measures. A greater number of samples would need to be gathered in order to validate the correlation for these two indices. The indices for dragon fly larva, pouch snail, and other snails were also all comprised of low counts of invertebrates at a small number of sites, so although these indices show significant correlations to the SVA or DO, the research team deemed the data sets for these indices too small to consider these as valid measures for this study.

In the case of group one taxa, certain indices show correlations that are part of a larger tolerance group: the indices of riffle beetle, mayfly, and gilled snail all show strong positive correlations to the SVA value, as does the index for group one taxa including all of these. In this case, the research team elected to use the group one taxa index to represent these groups as opposed to individual component indices that comprise the group one taxa in order to avoid redundancy. Additionally, all biological indices showed higher correlations in the taxa count transformed data set than in the relative abundance transformed data set. For this reason, no indices of relative abundance were selected for use over corresponding taxa count indices.

The final indices of the stream biota that have statistical correlations to the SVA final value are the group 1 total organisms, shrimp total organisms, water strider total organisms, and total species diversity. All of these indices have a correlation coefficient R of nearly 0.6 or above, denoting significant correlation to the SVA final value and thus stream quality. It is interesting to note that although the total number of intolerant organisms was highly correlated to the SVA final value, the total number of tolerant organisms and the number of any individual taxa of tolerant organisms did not correlate to the SVA final value.

4.2.4 Suggestions for a Multimetric Index: IBI

After eliminations for all invalid data, the biological indices that have strong correlations to the SVA final value suggesting possible use as indicators are the group 1 total organisms index, shrimp total organisms index, damselfly larva total organisms index, water strider total organisms index, total taxa diversity index, water temperature, pH, and phosphates. All of the biological indicators as well as the SVA final value data set were normalized, whereas water quality parameters initially had normal distributions. A table presenting all the indices the research team suggests for use in an Index of Biological Integrity can be seen Table 10.

Suggested Index	Correlation Coefficient R (to SVA final value)
Shrimp total organisms	0.76
Total taxa diversity	0.65
Group 1 total organisms	0.61
Phosphates	0.59
Water strider total organisms	0.58
pH	0.56
Water temperature	-0.68
Damselfly larva total organisms	-0.83

Table 10: Suggested Indices for an IBI, listed in descending order of R value

Although correlations between DO and TDS do not have any significance to the multimetric index, the Trust requested that a correlation analysis be performed on these values as well since they represent significant aspects of the ecosystem. Three correlated values were discovered as a result of this analysis, though none of them with the strength of correlations seen between the SVA final value and other indices. There was a correlation observed between DO and damselfly larva, but upon review of notes taken by the team in field documents it is probable that this is a result of errors in the three Río Piedras stream reaches. On the field day when two of these sites were visited, RP-1 and RP-3, the DO meter was not calibrated and could not be used, thus the value for DO from RP-2 was used. This value in turn was quite high due to a large series of riffles upstream, which may have skewed the results of this DO correlation analysis. The sites RP-1 and RP-3 were not observed to have numerous riffles upstream, and thus a lower DO would be expected. Therefore, the team feels that this correlation is inconclusive and needs to be verified with further data. The TDS correlation analysis returned two values that were of interest, both of which were relative abundances. The transformed data sets for relative abundance of water striders and the relative abundance of group 2 total organisms were both weakly correlated to the TDS index. This could indicate some form of interdependence between group 2 macroinvertebrates and dissolved solids, but once again further data and research into this area would be needed to support any hypotheses.

When the correlation analysis is viewed as a whole, it is evident that more biological indices are correlated to the SVA than to any other parameter. This indicates that the SVA is likely a good representation of the biological community and vice versa. In this study, the SVA is assumed to be an accurate measure of ecosystem health, as is suggested by the EPA and USDA of their visual assessment documents (Newton et al., 1998; U.S. Environmental Protection Agency, 2004). Since the Mapa de Vida program is adapted directly from these documents, the SVA used in this study should also be a reasonable representation of ecosystem health. Transitive logic then implies that the attributes of the biological community suggested for use as an IBI also represent stream ecosystem health. In effect, the data collection and analysis process has thus achieved the ultimate goal of this study in preliminary findings that several attributes of the biological community reflect ecosystem health as determined by metrics already accepted in the scientific community.

4.3 Recommendations for Future Work

After receiving hands-on experience in the field, the project team prepared several recommendations for future studies to provide help and standardization within the IBI process. Ideally, all parts of the process should be completed by a biological expert or with the help of one, as understanding the reasons for performing the IBI and the overall process is essential.

4.3.1 Cataloging

Knowledge of the microhabitats in which the macroinvertebrates live and the ability to identify each macroinvertebrate collected is important. Not being experts in the field, the team encountered difficulty in these areas and required the help of one such expert. In this study, the project team had no prior training or experience in the field of macroinvertebrate identification and was only capable of identifying organisms to order or class. This presented a challenge in evaluating many indices that have traditionally been used as bioindicators that necessitate identification to lower biological taxonomic rank (Weigel et al., 2002). Identification of macroinvertebrates to family and species would significantly strengthen results by enabling analyses of trophic function and species diversity. In addition to these added groups of evaluation, many species have slightly different pollution tolerances. Identifying each organism to the species rank also allows grouping into a more sophisticated hierarchy of pollution tolerances, such as the five-tier system used in *A Guide to Common Freshwater Invertebrates of North America* (Voshell, 2002). An increase in the number of indices available for evaluation adds breadth and credibility to the results of analyses. For this reason, trained macroinvertebrate taxonomists should be employed for all cataloging in future studies.

If no expertise is available, one should make sure that multiple practice runs are attempted before collecting true results from the streams. After many hours of practice, the team was able to cut time at the site from 3 hours to a little over 1 hour. Laying out each person's duties, as described in the sampling timeline, prior to arriving at the site is an effective way of saving time and standardizing the process through exchange of roles. Proper teamwork and field experience makes for a much easier and enjoyable time in the field.

4.3.2 Site Access

Locating the access and X sites ahead of time and mapping the areas are also highly recommended practices. In urban areas, access can be limited and difficult due to the many obstacles such as gated communities, bamboo blockages, fencing, roads, and access through personal properties. Most obstacles can be avoided through finding new access points or asking for permission from landowners to enter the stream; however, others cannot be, and a backup site may need to be used. Time should be set aside prior to collection dates for travelling to each of the sites and marking a place for entry as well as the X site. This will save multiple hours within the day when out on collection days. This recommendation stems from the team experiencing such issues because on several days, up to two hours were spent searching for access to a single site.

4.3.3 Standardizing Collection

To aid in the development of more accurate metrics, high quality measuring devices should be used. Although the nitrate and phosphate tablets used do recognize the presence of these nutrients in the stream, they do not supply data as precise as the DO and pH devices currently used. With the small timeframe available to complete the study, testing for nitrates, phosphates, ammonia, and other heavy metals could not be performed as they take up to three weeks to complete analysis from outside laboratories.

To assist in creating more accurate and reliable results, a set of more standardized methods should also be produced and followed. When sampling at each stream, collection times should be the same at each separate site. Collection time accounts for the total time spent actively searching for the macroinvertebrates. It does not include the time spent sorting out leaves, transferring animals into the collection buckets, or the like. The amount of time sampled for each microhabitat should also be regulated, as collecting too much from one microhabitat may skew data. One way to normalize this process is to identify six different microhabitats and sample each for ten minutes. Using equipment such as a stopwatch can also ensure that time parameters are followed correctly.

Another factor which must be considered is the difference of sampling during the day and at night. Some macroinvertebrates are nocturnal, leading to minimal collection during the day. Nocturnal animals in Puerto Rico include freshwater crab and certain species of shrimp. For the best results, sampling should be performed during both day and night. This recommendation arose from a lack in collection of nocturnal species such as the freshwater crab from solely day sampling.

4.3.4 Seasonality

There are also differences in collection counts due to seasonality. Certain species reproduce or die more at different times throughout the year. During these times, the species may be abundant or lacking. Additionally, during the rainy season, a higher number of sediments may be present in the streams from run-off, as many of the streams sampled in this project showed bank erosion. Seasonality also affects the amount of pollination created by trees and other plants. This adds nutrients to the water, affecting water quality result. Migration patterns also change throughout the year so the amount of birds present within the stream systems also changes. Several bird species thrive by eating these macroinvertebrates, so their presence will affect species counts as well. Due to time restraints, sampling for this project occurred during only one season, but it is important to collect information throughout the entire year for an accurate overall view. Sampling throughout the year will compensate for biological variability that occurs from season to season within a stream system.

The weather is one of the most vital concerns for accurate results. This includes the weather at the X site and upstream of the site. It is important to realize that rain may cause water quality tests to stray from the normal features of the stream and performing these tests at such times may lead to unrepresentative results. Upstream weather also affects the water quality results as rain upstream can easily travel downstream to the X site and influence the test results.

Not only does rain affect the water quality tests, but also the macroinvertebrate counts. Rain leads to rushing water and even flooding, which can wash many samples downstream. Fast moving water can also be dangerous for the sampling team, especially in streams which flood quickly and to high levels. Rain on the previous day or day of sampling also seemed to cause high levels of phosphates when tested. Several sites could not be sampled when first planned because of rushing, dangerous waters and threats of flooding.   With reliable transportation, it could be useful to wait an extra day to allow for more accurate data collection. It is highly recommended that the sampling team be able to track weather conditions several days before arriving to the sampling site. If this is not possible, it is recommended that the sampling team interview the people living within the area to gain a better sense of recent weather conditions.

4.3.5 Mapa da Vida

The Stream Visual Assessment used for this study and the Mapa de Vida program for the Trust allows one to make many qualitative measurements of the stream system, but does not specifically describe factors that exist within urban tropical streams. First, the SVA does not account for the amount of pollutants and trash seen within these streams. Many of the streams were full of garbage, cars, household appliances, chemicals, or even located next to a trash dump. A section should be added to the SVA describing localized pollution within the area. Research could be conducted to determine the extent at which localized pollution should affect the final SVA value and to determine a corresponding scale for the pollution component index.

Several categories within the SVA do account for differences that can occur on either side of the stream banks. There were several streams that would have a lush riparian zone on one bank, while the other bank was completely eroded and blank due to roads, housing, or structural differences. Scoring for channel condition, riparian zone, and bank stability should be adapted to allow differences within each bank to be identified. This could be done by simply grading each bank separately and then averaging the two scores.

The research team found that the qualitative measurements of “salinity” and “macroinvertebrates observed” used within the SVA were not applicable to the study. Salinity did not need to be scored because it was quantitatively measured as a parameter in water chemistry testing. The number of macroinvertebrates observed was also ignored, as this was one of the major components of the study. It is also suggested that the scoring element “barriers to fish movement” also be eliminated and transformed as part of the “hydrologic alteration” scoring parameter.

The area of evaluation used in the Stream Reach Description Form adapted from the Mapa de Vida program to measure percent land use along the stream should also be reexamined. Although the 100 hectares used for this study does supply some information on the effects of different land covers, it does not give an overall view of the watershed system as a whole. Tropical streams tend to flood often carrying rainwater, nutrients, and pollutants from areas much further than 100 hectares. This holds true for Puerto Rican streams as water is carried from high in the mountains and will run all the way to the coast. Understanding the watershed in which the streams are located, will provide a better overall outlook on the effects of development within each stream system.

To further improve the Mapa de Vida protocol, the project team suggests modifications to the stream gauging technique used in this study. The stream gauging method used was unreliable and only provided results at some sites, due both to complexity of technique and inaccuracy in the stream gauge used. Other methods of measuring stream discharge should be evaluated for practicality before a decision is made upon which method to use. If resources are limited and only a stream gauge such as the one used in this study is available, the technique for measurement should be significantly revised. This is the case for the Mapa de Vida protocol, where equipment has already been acquired. With this equipment, stream flow measurements should be taken on definite and consistent intervals as opposed to intervals that are a function of the ACW. The interval the research team suggests is a 0.5 meter interval starting 0.25 meters from the left bank and progressing across to the right bank. In this method, the number of intervals for streams of different ACW will vary, but the error introduced inherently by choosing measurement intervals is consistent across all streams. In addition to using this revised interval system, the stream gauge should be used to measure the flow in a very specific technique at each interval. The gauge should be placed on the bottom and should be lifted slowly to the surface at a constant rate while the meter takes an average. This method would then result in the average flow across the depth of the stream at each interval. From these measurements, the stream discharge may be calculated in a discretized fashion. At each interval, the stream depth at that point may be multiplied by 0.5m to obtain a component cross sectional area (in m^2). This cross sectional area would then be multiplied by the recorded average flow speed (converted to m/s) for that interval resulting in an average discharge (m^3/s) for that cross sectional component. The average discharge for every cross sectional component of the river can then be summed in order to obtain an average discharge for the stream. This method minimizes errors across both the width and depth of the stream by taking averages across both.

Chapter 5: Conclusion

The Conservation Trust of Puerto Rico exists to protect elements of the Puerto Rican landscape that have cultural and environmental importance to the island's inhabitants. A great part of the Trust's goals include the procurement and maintenance of land reserves. Puerto Rico contains many habitats that protect the diversity in species that exists in the tropical climate and regions that have cultural significance due to the heritage of the island. However, one unifying element of conservation in Puerto Rico is the island's freshwater sources. Important uses of freshwater sources include drinking water and water for agriculture, both of which are encountered daily in human life. Consequently, the quality of freshwater sources is integral in the sustainability of life on the island due to the limited size and number of watersheds available.

The Trust is currently seeking a metric specifically tailored to the ecology of Puerto Rico that can accurately assess the health of fresh water ecosystems on the island. Per the Trust's request, the steps proposed in this document will lead to the formulation of a Macroinvertebrate Index of Biotic Integrity (M-IBI). The M-IBI provides an accurate and reliable indication of ecosystem health based on the feeding structure, quantity, and order of macroinvertebrates found in the streams and rivers of the San Juan metropolitan area. Multimetric indices based on aquatic organisms such as the M-IBI can accurately reflect ecosystem health by comparing these indices along with water quality measurements due to the sensitivity of invertebrates to complex environmental interactions. The Trust can use the M-IBI developed to assess the health of watersheds it currently owns as well as to evaluate other watersheds it intends to acquire in the future.

The formulation of an Index of Biotic Integrity is a scientific and systematic process. In its basic components, an IBI is designed through a straightforward scientific technique. With help from professionals in the field, an accurate analysis of the data collected provided for an M-IBI that reflects many environmental conditions. Our team has designed the process for development of the IBI based on successful IBIs performed in multiple ecosystems by experts in the field, as well as based on several critical reviews of the IBI process by prominent ecologists and biologists. Since no prior data exists and no other IBIs have been performed in Puerto Rico to date, the IBI developed is entirely original work and not based on other studies. This study is the first work in the development of an IBI in Puerto Rico and an important step for conservation and environmental restoration efforts.

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Appendices

Appendix A: Glossary

A

Active Channel Width (ACW)

ACW is the width of the stream at the bankfull discharge. Permanent vegetation generally does not become established in the active channel.

Aggradation

Aggradation is the process by which a stream's gradient steepens due to increased deposition of sediment from flow and geographic characteristics of the stream. In other words, the stream bottom or floodplain is raised in elevation due to increased deposition.

Alluvial

An alluvial is a feature where sediments are transported and deposited chiefly by water and are sorted in the process.

Alluvial Fans

Alluvial fans are triangular alluvial deposits of sediment left by a stream that has lost velocity upon entering a broad, relatively flat valley.

Alluvium

Alluvium refers to sediments that are transported chiefly by water and form alluvial deposits.

B

Bankfull

This flow stage is delineated by the elevation point of incipient flooding, indicated by deposits of sand or silt at the active scour mark, breaks in stream bank slope, perennial vegetation limit, rock discoloration, or root hair exposure.

Bankfull Depth (dbkf)

This is the average depth measured at bankfull discharge.

Bankfull Discharge (Qbkf)

The bankfull discharge is the dominant channel forming flow with a recurrence interval seldom outside the 1 to 2 year range. This term refers to the river flow when at the bankfull stage.

Bankfull Stage (Sbkf)

This is the stage at which water starts to flow over the floodplain. The elevation corresponds to the bankfull depth. These terms are highly interrelated.

Bankfull Width (Wbkf)

Bankfull width is defined as the channel width at bankfull discharge.

Baseflow

Baseflow is commonly defined as the stage at average Low Flow.

Baseflow Width

Baseflow width is defined as the wetted width at baseflow, and is critical in fisheries passage and other biotic processes.

Benthic

Benthic is a term that refers to the lowest layer or form of something: the benthic layer of a stream is the streambed and substrate.

Boulders

Here boulders are defined as large rocks measuring over 10” diameter.

C

Channel

A channel is a natural or artificial waterway of perceptible extent that periodically or continuously contains moving water. It has a definite bed and banks that serve to confine the water.

Channelization

Straightening of a stream channel to increase average flow velocity.

Channel Length

The channel length is the curvilinear distance measurement along the center of the channel. It is the distance traveled following the midline of the stream through a certain channel.

Channel Roughness

This term is used to describe the amount of energy the flow expends overcoming coarseness and texture of bed material, curvature of the channel, and variation in profile.

Channel Slope

The slope is defined as the change in elevation divided by the length of channel along a channel distance of 20-30 riffle/pool sequences or 2 meander lengths.

$$\text{Channel Slope} = \frac{\text{Valley Slope}}{\text{Sinuosity}}$$

Cobbles

Cobbles are defined as medium sized rocks that measure 2.5 to 10 inches in diameter.

Colluvial

This is a process where colluviums are transported chiefly by gravity and form sedimentary deposits.

Colluvium

This term refers to sediments that are transported chiefly by gravity and are unsorted. Colluvium may travel within water.

Competence

This is a term that describes a stream's ability to transport sediment. Competence also refers to the diameter of the largest sediment grain transported.

Confined Channel

A confined channel is a channel that does not have access to a floodplain.

D

Datum

The datum is defined as an arbitrary elevation from which all vertical measurements are taken in a design.

Degradation

This is the process by which a stream's gradient becomes less steep, due to the erosion of sediment from the streambed. The streambed elevation is lowered due to a net loss of substrate. This process is also called downcutting.

Delta

This geographic formation is an alluvial fan having its apex at the mouth of a stream.

Deposition

Deposition is the terminus of erosion, where the settling of sediments occurs.

Downcutting

See degradation.

E

Ecoregion

A geographic area defined by similarity of climate, landform, soil, potential natural vegetation, hydrology, or other ecologically relevant variables.

Elevation

Elevation is a relative measure of vertical height relative to a prescribed datum.

Embeddedness

Embeddedness is the degree to which an object is buried in steam sediment.

Emergent plants

Plants classified as emergent are aquatic plants that extend out of the water.

Entrenchment Ratio (ER)

The ER is mathematically defined as the channel width at two times
the bankfull depth divided by the channel width at bankfull.

$$\mathrm{ER} = \frac{\mathrm{CW(2*dbkf)}}{\mathrm{CW(Wbkf)}}$$

Erosion

In this process particles of rock and soil are loosened, as by weathering, and then transported elsewhere, as by wind, water, ice, or gravity.

F

FGM

Fluvial Geomorphology

Flood-Prone Area

These areas are relatively flat lowlands that border a stream and are covered by its waters at flood stage of twice the maximum bankfull depth.

Flood-Prone Width (WFP)

The stream width at a discharge level defined as twice the maximum bankfull depth.

Floodplain

A floodplain is land that is actively flooded beyond bankfull once every 1-2 years, generally broad, gently sloping valley floor, often bounded by a terrace (abandoned floodplain) or encroaching side slope.

G

Gabions

Gabions are wire baskets filled with rocks; they are used to stabilize stream banks and to control erosion.

Geologic Material

Solid inorganic substratum of the earth and all possible derivatives is referred to as geologic material.

Geomorphology

This is the study of the evolution and configuration of landforms.

Glide

A glide is a fast water habitat type that has low to moderate velocities, no surface agitation, no defined thalweg, and a U-shaped, smooth, wide bottom.

Gradient

The gradient is the slope calculated as the amount of vertical rise over horizontal run expressed as ft/ft or as percent (ft/ft * 100).

Grass

This is a general term referring to an annual to perennial herb, generally with round erect stems and swollen nodes; leaves are alternate and two-ranked; flowers are in spikelets each subtended by two bracts.

Gravel

Gravel refers to small rocks measuring 0.25 to 2.5 inches across.

H

Habitat

Habitat refers to the area or environment in which an organism lives. There are multiple microhabitats in each stream.

Hydrology

Hydrology is the study of the properties, distribution, and effects of water on the Earth's surface, soil, and atmosphere.

I

Incised Channel

A channel with a streambed lower in elevation than its historic elevation in relation to the flood plain is termed an incised channel.

Intermittent Stream

An intermittent stream is one in contact with the ground water table that flows only certain times of the year, such as when the ground water table is high or when it receives water from surface sources.

K

Kick Sampling

Kick Sampling is a technique used by ecologists to collect aquatic organisms from the substrate of a river. The technique involves holding a net downstream of a substrate which is disturbed by gentle kicks in order to release organisms that will then be captured in the net downstream.

L

Landforms

Landforms are natural features of a landscape.

Low Flow

Low Flow is defined as groundwater fed flow.

M

Macroinvertebrate

A macroinvertebrate is a spineless animal visible to the naked eye or larger than 0.5 millimeters.

Macrophyte Bed

This bed is a section of stream covered by a dense mat of aquatic plants.

Meander

A meander is a stream curve deviating from a linear course. Components of meander geometry include length, amplitude, and belt width.

Meander Width Ratio

Meander Width Ratio is mathematically defined as Meander Belt Width divided by the Bankfull Width.

$$\mathrm{MWR} = \frac{\mathrm{MBW}}{\mathrm{Wbkf}}$$

N

Nickpoint

A nickpoint is the point where a stream is actively eroding (downcutting) to a new base elevation. Nickpoints migrate upstream (through a process called headcutting as a result of erosive activity).

Nonpoint-source pollution

Nonpoint-source pollution is any water pollution that is not point source and may involve diffuse and ill-defined transport of polluted runoff, leaching of chemicals through soil, or atmospheric deposition.

P

Perennial stream

A perennial steam flows continuously throughout the year.

Point bar

A point bar is a gravel or sand deposit on the inside of a meander; it is an actively mobile river feature.

Point-source pollution

Point-source pollution involves the transport of pollutants, at a single location, directly from the source to the water, where the source can be directly identified.

Pool

Pools are deeper areas of a stream with slow-moving water.

R

Reach

A reach is a channel-type unit length with the same channel type existing for a length of a certain number of bankfull channel widths. A reach is characterized as a length of a channel for which a single gauge affords a satisfactory measure of the stage and discharge.

Riffle

Riffles are shallow sections in a stream where water is breaking over rocks, wood, or other partly submerged debris and producing surface agitation.

Riparian Zone

This zone is adjacent to a stream or any other body of water (from the Latin word ripa, pertaining to the bank of a river, pond, or lake).

Riprap

This is a term used to refer to rock material of varying size used to stabilize stream banks and other slopes.

Run

Runs are fast-moving sections of a stream with a defined thalweg and little surface agitation.

S

Scouring

Scouring refers to erosive removal of material from the stream bottom and banks.

Sinuosity

The sinuosity can be defined as either the ratio of Channel Length to Valley Length or the ratio of Valley Slope to Channel slope.

$$\text{Sinuosity} = \frac{\text{Channel Length}}{\text{Valley Length}} = \frac{\text{Valley Slope}}{\text{Channel Slope}}$$

Stream

A body of water confined to a narrow topographic depression, down which it flows and transports rock particles, sediment, and dissolved particles. Rivers, creeks, brooks, and runs are all streams.

T

Taxon

Taxon (plural: taxa) refers to a general category or rank in the hierarchical classification system of kingdom, phylum, class, order, family, genus, and species. (Voshell, 2002)

Terrace

A terrace is an abandoned floodplain, due to river incision, downcutting, etc.

Thalweg

A thalweg is a longitudinal outline, trace, or survey of the deepest part of a riverbed from source to mouth (upstream/downstream). It may also be defined as the line of steepest descent along the stream.

Turbidity

The murkiness or cloudiness of water caused by particles, such as fine sediment (silts, clays) and algae is described as turbidity. Turbidity can be measured with scientific instruments and commonly has the unit NTU.

V

Valley

This geological feature is a depression on the earth surface between two adjacent uplands, drained by and whose form is changed by water movement resulting from gravity.

Valley Length

The valley length is the horizontal distance measured in the thalweg of two cross sections in a linear depression between two adjacent uplands.

Valley Slope

Valley slope is the slope for a given reach such that valley and reach intersect for some longer distance (several meanders or step pools).

W

Watershed

A watershed is a common geographical term referring to an area that is defined by a set of ridges and highlands that divide areas that drain to different river systems. All the land within a watershed flows to the same main river system that empties into a larger body of water.

Wetted Width

This term describes the width of the wetted stream at the time of the survey. Wetted width is generally less than bankfull width and is also referred to as "low flow channel width".

Appendix B: Mapa de Vida Protocol and Data Forms

MAPA DE VIDA

A Template to Watershed Quality Assessment

This manual contains procedures for collecting information on the biotic and abiotic components of streams in Puerto Rico. It is adapted from the Wadeable Streams Assessment Field Operations Manual, and is a work in progress. The protocols described here are designed for use by volunteer groups participating in the Watershed Quality Assessment of Mapa de Vida, a citizen-science program sponsored and coordinated by the Conservation Trust of Puerto Rico.

The procedures described in this document reflect a simplification of the methods presented in the WSA Field Operations Manual, in order to enable a crew of 6-10 persons to effectively sample sites located on wadeable streams in Puerto Rico during a ½-day field activity. Each crew consists of at least two individuals trained in the necessary techniques and protocols described in this document, and are assisted by 4 to 8 untrained volunteers. Crew safety and health considerations and guidelines related to field operations are provided.

Stream sampling points were chosen from stream networks visible on USACE 2007 DOQQ aerial photography at a 1:100,000 scale. No systematic or randomized selection process was used in the process to select sample streams, however sample streams were selected based on the representation of Puerto Rico's watersheds defined by the U.S. Geological Service. Stream access points, and subsequent mid-stream reach sampling locations (X-site) were selected primarily based on stream access and safety. However, efforts were made to minimize effects at a local scale due to the presence of confluences and other hydrologic anomalies identified in the WSA Field Operations Manual.

Mapa de Vida's Watershed Quality Assessment is a stream-based approach to engage the citizen's of Puerto Rico in activities and discussion relating to the importance of watershed management, the protection of healthy drinking water, ecosystem function and services, biological diversity, and spiritual and recreational opportunity.

1.0 Safety and Health

Personnel participating in field activities on a regular or infrequent basis should be in sound physical condition. Appropriate safety apparel such as waders, gloves, life-vests, etc. must be available and used when necessary. Bright colored (e.g., orange) vests should be worn during field activities. First aid kits and blankets must be readily available in the field. Cellular or satellite telephones and/or portable radios should be provided to field teams working in remote areas for use in case of an emergency. Facilities and supplies must be available for cleaning of exposed body parts that may have been contaminated by pollutants in the water. Anti-bacterial soap and an adequate supply of clean water or ethyl alcohol, or equivalent, should be suitable for this purpose. All surface waters and sediments should be considered potential health hazards due to toxic substances or pathogens. Persons must become familiar with the health hazards associated with using chemical fixing and/or preserving agents. Chemical wastes can cause various hazards due to flammability, explosiveness, toxicity, causticity, or chemical reactivity. During the course of field research activities, field teams may observe violations of environmental regulations, may discover improperly disposed hazardous materials, or may observe or be involved with an accidental spill or release of hazardous materials. In such cases it is important that the proper actions be taken and that field personnel do not expose themselves to something harmful.

1.1 General Safety Guidelines for Field Activity:

- *Two or more persons must be present during all sample collection activities, and no one should be left alone while in the field.*
- *Exposure to stream water and sediments should be minimized as much as possible. Use gloves if necessary, and clean exposed body parts as soon as possible after contact.*
- *Use appropriate protective equipment (e.g., gloves, safety glasses) when handling stream substrate material and using hazardous chemicals*
- *Any person allergic to bee stings, other insect bites, or plants must take proper precautions and have any needed medications handy.*
- *Field personnel should also protect themselves against the bite of mosquitos because of the potential risk of acquiring pathogens that cause Dengue Fever and transmission of other communicable diseases.*
- *All field personnel should be familiar with the symptoms of hypothermia and know what to do in case symptoms occur. Hypothermia can kill a person at temperatures much above freezing (up to 10oC or 50oF) if he or she is exposed to wind or becomes wet.*
- *Field personnel should be familiar with the symptoms of heat/sun stroke and be prepared to move a suffering individual into cooler surroundings and hydrate immediately.*

2.0 Overview of Field Activity

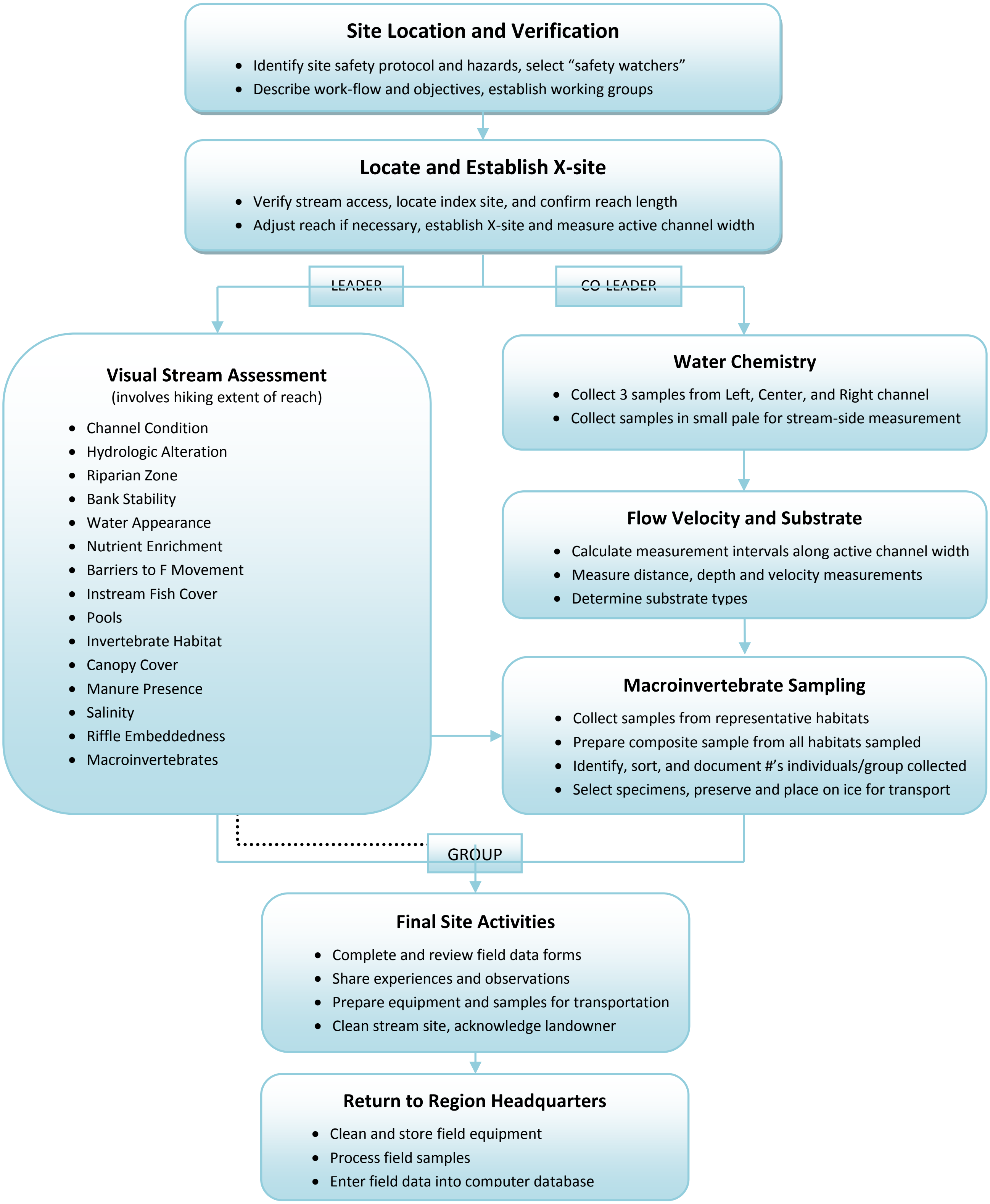
This section presents a general overview of the activities that a 6-10 person field team conducts during a typical ½-day sampling visit to a stream site. General guidelines for recording data and use of standardized field data forms and sample labels are also presented. Table 2 provides an estimated time available to conduct the various field activities described here for wadeable streams less than 25 meters in width. Figure 2 illustrates the general organization of activities conducted for each stream reach. For streams larger than 25 meters in width (active channel *width), additional time beyond that presented in Table 2 may be necessary to complete all required activities.*

Upon arrival at a pre-selected stream site, each team must confirm that they are at the correct site and locate the specific stream section shown on the Reach Map that will serve as the stream reach sample index-site (X-site). The X-site is important since it is used to determine the length of stream both down-stream and up-stream to be assessed using the methods described here. The X-site is also the location within the reach where flow velocity, stream discharge, and field measurements for water chemistry are to be measured.

Once the X-site has been identified and the transect established across the stream channel, the team splits into separate groups; one team remains at the X-site to complete the water chemistry measurements and estimation of stream discharge, and the other group proceeds to conduct a walking transect along first the lower then upper portions of the stream reach to visually assess stream quality indicators as described in the USDA Stream Visual Assessment Protocol. Both groups may collect samples of benthos and other macroinvertebrates. After all data collection activities have been completed, both groups re-unite in a common area along the river to organize and review data forms, process any field samples collected, and to share experiences and observations prior to departing the steam site.

TABLE 2. ESTIMATED TIMES AND DIVISION OF TASKS FOR FIELD ACTIVITIES			
Leader		Co-leader	
Task	Estimated Time Required	Task	Estimated Time Required
Confirm site location and safety, identify location of the "index-site"			0.5 hr
Measure active channel width and determine reach sample length			0.5 hr
Water chemistry measurements and sampling	0.5 hr	Visual Assessment (down stream)	0.5 hr
Measurement of water depth and stream discharge	0.5 hr	Visual Assessment (up stream)	0.5 hr
Collecting and processing benthos samples	0.5 hr	Collecting and processing benthos samples	0.5 hr
Data form review, group discussion and steam exit			0.5 hr
SUMMARY			3 hrs per team[a]
[a] **For wider wadeable streams (e.g., > 30 m, it may require 1 day to complete all required activities.**			

Figure 2. Field Activity Work Flow



Site Location and Verification

- Identify site safety protocol and hazards, select "safety watchers"
- Describe work-flow and objectives, establish working groups

Locate and Establish X-site

- Verify stream access, locate index site, and confirm reach length
- Adjust reach if necessary, establish X-site and measure active channel width

Visual Stream Assessment
(involves hiking extent of reach)

- Channel Condition
- Hydrologic Alteration
- Riparian Zone
- Bank Stability
- Water Appearance
- Nutrient Enrichment
- Barriers to F Movement
- Instream Fish Cover
- Pools
- Invertebrate Habitat
- Canopy Cover
- Manure Presence
- Salinity
- Riffle Embeddedness
- Macroinvertebrates

Water Chemistry

- Collect 3 samples from Left, Center, and Right channel
- Collect samples in small pale for stream-side measurement

Flow Velocity and Substrate

- Calculate measurement intervals along active channel width
- Measure distance, depth and velocity measurements
- Determine substrate types

Macroinvertebrate Sampling

- Collect samples from representative habitats
- Prepare composite sample from all habitats sampled
- Identify, sort, and document #'s individuals/group collected
- Select specimens, preserve and place on ice for transport

Final Site Activities

- Complete and review field data forms
- Share experiences and observations
- Prepare equipment and samples for transportation
- Clean stream site, acknowledge landowner

Return to Region Headquarters

- Clean and store field equipment
- Process field samples
- Enter field data into computer database

3.0 Base Station Activities

Activities Before Each Stream Visit

Confirming Site Access:

Regional staff should assemble a stream visit project file containing important location and access information for the stream they are scheduled to visit. Before visiting the stream, the field crew must review the contents of the project file. The landowner listed in the project file should be contacted to confirm site access permission and obtain a current description of the stream condition as it relates to weather hazards (i.e., risk of flash flooding).

Stream Visit Itinerary:

Team leaders are responsible for reviewing the project file in order to develop a stream visit itinerary for the day's field activity. Review each stream project file to ensure that it contains the appropriate maps, contact information, copies of permission letters, and access instructions. Determine the best access routes, call the landowners or local contacts to confirm access permission, and coordinate rendezvous locations with individuals who must meet with field teams prior to accessing a site.

Instrument Inspections and Performance Tests:

Each field team is required to test and calibrate some instruments prior to departure for the stream site. Required field instruments include a global positioning system (GPS) receiver, a current velocity meter, and water chemistry testing meters. Ideally, backup instruments should be available if instruments fail the performance tests or calibrations described in the following subsections.

Before Departing for Stream:

- ☐ *Project file containing access and other information for scheduled stream site*
- ☐ *Water resistant, container type clip-board*
- ☐ *Site maps, dataforms and protocol instructions*
- ☐ *Safety log and/or personal safety information for each team member*
- ☐ *First Aid kit (including warm blankets) and extra drinking water*
- ☐ *Cellular phone and emergency contact numbers*
- ☐ *GPS receiver (with extra batteries) and analog compass*
- ☐ *DO meter kit (including calibration solutions plus extra batteries)*
- ☐ *pH meter kit (including calibration solutions plus extra batteries)*
- ☐ *Multi-parameter Tester35 (including calibration solutions plus extra batteries)*
- ☐ *Current velocity meter kit (plus extra battery)*
- ☐ *D-frame kick net for benthic macroinvertebrate sampling (ideally 2)*
- ☐ *5-gallon white buckets w/lid (2)*
- ☐ *50 meter surveyor's tape (1)*
- ☐ *Stream transect stakes (2) and 2lb. hammer*
- ☐ *50 meter poly rope (1/2 inch or less diam.)*
- ☐ *Sorting trays, sample screens and ethanol for processing invertebrate specimens*
- ☐ *Completed water chemistry sample jar labels and clear tape to cover labels*
- ☐ *Vehicle emergency kit (battery charger, flashlight, first-aid kit, basic tools, duct tape)*
- ☐ *Water chemistry 300 ml chemically clean sample jar*
- ☐ *Macro-invertebrate 300 ml composite sample jar*

Activities After Each Stream Visit

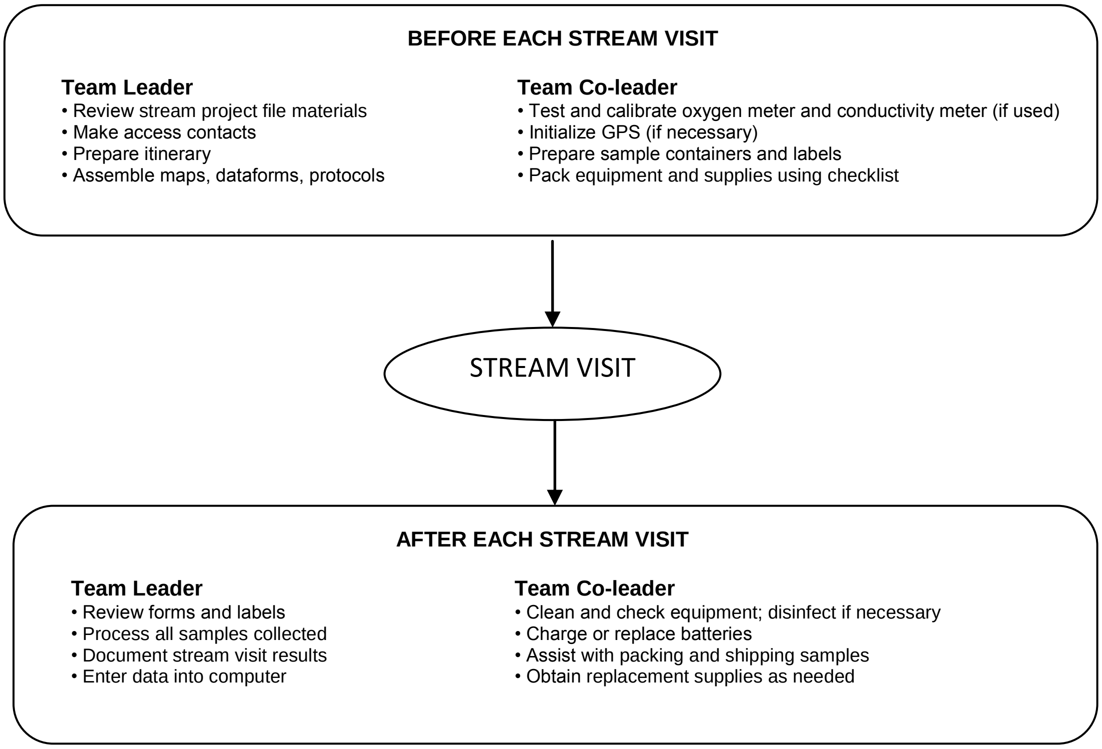
Confirmation of Dataform Completeness and Sample Documentation:

Upon returning to base after sampling a stream, the team repeats the review of all completed data forms and sample labels for accuracy, completeness, and legibility, and makes a final inspection of any samples collected. If information is missing from the forms or labels, the team leader should fill in the missing information as accurately as possible. The team leader initials all data forms after review. The other team member should inspect and clean sampling equipment, check the inventory of supplies, and prepare samples for shipment or archival.

Equipment Care:

Inspect all equipment, including nets, and clean off any plant and animal material. This effort ensures that introductions of nuisance species do not occur between streams, and prevents possible cross- contamination of samples. If nets cannot be cleaned thoroughly using water and detergent, clean and disinfect them with a 10 percent chlorine bleach solution. Use bleach only as a last resort, as repeated use will destroy the net material. Take care to avoid damage to lawns or other property.

Figure 3. Before and After Activity Work Flow



4.0 Site Procedures

When a field team first arrives at a stream site, they must first confirm they are at the correct site. Then they determine if the stream meets certain criteria for sampling and data collection activities to occur. They must decide whether the stream is unduly influenced by rain events which could affect the representativeness of field data and samples. Certain conditions at the time of the visit may warrant the collection of only a subset of field measurements and samples. Finally, if it is determined that the stream is to be sampled, the team lays out a defined reach of the stream within which all subsequent sampling and measurement activities are conducted.

4.1 Determining the Sampling Status of a Stream:

Not all chosen stream sites will turn out to be "wadeable" on any given day. Once the stream location has been confirmed, evaluate the stream section to be assessed (below and above the X-site), and determine if the stream is sampleable. For this protocol, the primary distinction between a "Sampleable" and "Non-Sampleable" stream is based on first the safety for leaders and volunteers to enter the site, and second the level of water flow in the stream. If rain events at the site or upstream from the site present conditions conducive for flash flooding or result in above "base-flow" levels, the stream should be considered non-sampleable. Also, if the stream is significantly below base-flow levels and exhibits isolated pools of non-flowing water, then it should also be considered non-sampleable.

Sampling During or After Rain Events:

Avoid sampling during high flow rainstorm events. For one, it is often unsafe to be in the water during such times. In addition, biological and chemical conditions during episodes are often quite different from those during base-flow. On the other hand, sampling cannot be restricted to only strict base-flow conditions. It would be next to impossible to define a strict "base-flow" with any certainty at an unstudied site. Such a restriction would also greatly shorten the index period when sampling activities can be conducted. Thus, some compromise is necessary regarding whether to sample a given stream because of storm events. To a great extent, this decision is based on the judgment of the team leaders. Some guidelines to help make this decision are presented below. The major indicator of the influence of storm events will be the condition of the stream itself. If the team leaders decide a site is unduly influenced by a storm event, do not sample the site that day. Notify the field coordinator or other central contact person to reschedule the stream for another visit on a different date.

Guidelines to determine the influence of rain events:

- *If it is running at bank-full discharge or the water seems much more turbid than typical for the class of stream do not sample it that day.*
- *Do not sample that day if it appears unsafe to wade in the majority of the stream reach. If the majority of the stream reach is permanently unsafe, then document the stream conditions and sample only those portions that can be safely waded.*
- *Keep an eye on the weather reports and rainfall patterns. Do not sample a stream during periods of prolonged heavy rains.*
- *If the stream seems to be close to normal summer flows, and does not seem to be unduly influenced by storm events, go ahead and sample it, even if it has recently rained or is raining.*

Artificial and natural features can also lend a stream reach to be unsampleable. If this is the first time the leaders have been to the stream site, they should scout the sampling reach to make sure it is clear of obstacles that would prohibit sampling and data collection activities. Obstacles that prohibit sampling include artificial structures like large manmade dams, water extraction canals or pipelines, hazardous waste, and any other condition considered unsafe (human or natural). Natural structures that would prohibit sampling include waterfalls greater than 2 meters, *collapsing stream banks with high current, and extensive boulder fields or Karst features where water flows through or under the rocks.*

Establishing the Index Site:
Once the initial stream access point is identified, the X-site should be selected based on the criteria for estimating stream flow velocity and stream discharge (generally straight channel with uniform bottom and stream flow). The stream's Active Channel Width (ACW) is also determined at the X-site and is used to define the length of the total stream reach (length below and above the X-site) that is to be assessed. The X-site is typically the mid-point of the sampling reach and is also the location to conduct stream water chemistry measurements (approx. 1 meter upstream from the X-site transect).

Photo-documenting the Stream Reach and Activity:
Taking site photographs is an important part of the data collection process. Start the photo sequence with one photograph of an 8.5 × 11 inch piece of paper with the site ID, stream name, date, and the word "START" printed in large, thick letters. After the photo of the site ID information, take two photographs at the X-site to represent the Left Bank and Right Bank making sure to capture part of the transect in each. The next photos should be taken from center channel to capture first the downstream direction then the upstream direction. After these 5 photos have been taken, take any additional photos that you determine relevant to documenting stream and bank characteristics and condition that represent effects of hydrology, landuse, as well as to document the vegetation types and animals present. Additional photos should also include photos to represent volunteer and other staff assisting in the stream monitoring activity. End the photo sequence by taking the same 8.5 x 11 inch piece of paper used to Start the sequence and write on the opposite side the same information but use the current time and the word "END". For each photograph, record the camera's photo sequence number and briefly describe each one.

Laying Out the Sampling Reach:
Unlike chemistry, which can be measured at a point, most of the biological and habitat structure measurements require assessing a pre-determined length of the stream to get a representative picture of the overall condition of the ecological community. For this protocol, a "reach map" is provided that marks the general location of the sample-reach's down-stream and upstream end points, and is based on the active channel width at the X-site. This protocol determines the total reach length by multiplying the ACW by twelve (12 times the active channel width) to define the length of the sampling reach that is used to characterize the biotic assemblages and habitat associated with the sampling reach. Measure and record the active channel width used to determine the total reach length, then divide this total by 2 to determine the portions that need to be assessed upstream and downstream of the X-site. Record this information on page 1 of the Stream Description Form. Figures 4 and 5 are provided to illustrate the principal features of the established sampling reach, including the location of the cross-section transect used to measure ACW, determining reach length, flow velocity, and to measure water chemistry.

5.0 Basic Steps to Sample a Stream Reach

1. ***Record the following information on Page 1 of the Stream Reach Description Form.***

    - *Stream name and reach ID, date and start time*
    - *Leaders and volunteer names*
    - *Measure and record relevant weather information*

    The remaining fields on Page 1 are to be completed as part of the stream exit protocol.

2. ***Determine the Sampling Status of the Stream (see text in section 4.1)***

    a. *Sampleable – minimal hazards AND water flow present*

    b. *Non-Sampleable – hazardous OR no water flow present*

    If non-sampleable, record this in the comments on Page 1 of the Stream Reach Description Form.

3. ***Identify and Establish the Index Site:***

    a. *Reference the provided map to locate the pre-determined site that is to serve as the index site (X-site). Fine tune the specific location to represent a reach location characterized by a relatively straight channel and a uniform bottom that demonstrates uniform stream flow suitable to collect measures of stream flow velocity.*

    b. *Suitable sites to establish the X-site include glides and runs that are wadeable across the entire channel.*

4. ***Identify the Active Channel Width (ACW):***

    a. *Identify the general location along each bank that marks the extent of the stream's active channel. Look for a zone that transitions between disturbed stream bed material (or exposed roots) and the presence of permanent vegetation. Include those portions vegetated by annual plants, including wetland associated species that have the ability to re-establish following high flow events. The active channel also marks the location of the "bank-full" discharge level, above which begins to extend into the floodplain. However, bank-full discharge level is not necessarily the "top" of the stream bank and is typically somewhere between the top and the exposed stream bed. See Figure 4.*

5. ***Determine the Active Channel Width (ACW) and base-flow width:***

    a. *Once the location that marks the active channel is determined, install an anchor stake at the active channel mark on the Left bank (determined as one faces downstream). Connect a surveyor's tape (metric) midway on the Left bank stake and roll it out to the right bank, where the second stake is installed to mark the active channel width on the opposite side. Connect the 'reel-end' of the tape to the midway of the second stake. The points where each stake enter the ground should be approximately level to one another. Confirm that the cross-section of the channel crosses a glide or run or similar feature to insure an approximately uniform stream flow.*

        Take care to not disturb the stream bottom just upstream of the X-site prior to collecting water samples for chemistry measurements.

If necessary, as it is for very large streams, connect a rope between both stakes so that it can be used to support a surveyor's measuring tape used to measure the active channel width.

b. *After completing step 4, make sure the surveyor's tape is pulled tightly to minimize tape sag. In other words, pull the tape to be as straight as possible without breaking the tape or pulling free the opposite anchor stake. Measure the active channel width to the nearest one meter using the stake in the Right Bank as the endpoint.*

c. *Record the ACW on page 1 of the Stream Reach Description Form.*

6. ***Determine the Base-flow width:***

a. *The base-flow width is a measure of the width of the "wetted width" of the stream. In other words, using the same surveyor's tape as it is installed, measure the width of the flowing water that is part of the stream. Do not include isolated pools or back water areas.*

b. *Typically, this measure is estimated by subtracting the total distance of dry stream bank visible between the Left Bank anchor stake and the flowing water and the Right Bank and the flowing water on that side.*

c. *Record the base-flow width on page 1 of the Stream Reach Description Form.*

7. ***Defining the Sample Reach:***

a. *For this protocol, refer to the reach map to locate the pre-determined reach boundaries.*

b. *Compare the location with the actual measure of the stream reach to confirm approximate accuracy. This is done by evaluating the stream features, including meanders, pools, large rocks, bridges, etc. to identify your approximate location as it relates to the marks on the reach map.*

c. *The reach boundaries were estimated in a geographic information system (GIS) following similar principles used to determine the ACW in the field. In the field, the ACW is determined by multiplying the actual ACW by 12 to calculate the total length of the sample reach to be assessed. Divide the total sample reach length by 2 to determine the distance to visually assess the reach portions downstream and upstream while walking the length of each portion. For example, if the total reach length is determined to be 150 m, each team would proceed 75 m from the X-site to assess the downstream and upstream portions of the stream sample reach.*

For small streams (<5 meters wide), or those exhibiting channels with "interrupted flow", use 150 m as a minimum sample reach length. Leave the surveyor's tape (and rope if used) in place until all field activities have been completed.

8. ***Conduct the Stream Visual Assessment - Downstream:***

a. *Proceed downstream from the X-site to conduct the Stream Visual Assessment Protocol. Refer to the reach map to track your progress as you walk alongside the stream following the safest route.*

b. Stop approximately half way down the length of the downstream portion of the reach to evaluate the Assessment Element Indicators 1-10 as listed in the USDA Stream Visual Assessment Protocol and the Assessment Scores dataform.

   It may be necessary to continue walking or to cross the channel to gain additional views of different stream features. Refer to the reach map to assist in scoring process.

c. After the first 10 Assessment Elements have been scored, stop conducting the SVA protocol and begin activities described in Step 11 (macroinvertebrates). Once you have completed step 11, return to the X-site to begin the Upstream portion of the SVA protocol. Repeat this step for the upstream portion of the sample reach.

9. ***Measure Stream Water Chemistry:***

   a. Water chemistry measurements are taken from stream water samples collected at 3 different locations approximately 1 meter upstream from the X-site. Use a small pale [sic] to collect samples from each of the left side, center, and right side of the channel. Be sure to angle the pale [sic] opening downstream while gradually allowing water to flow in. The sample should be collected upstream from your body. Do not allow anyone else to be upstream of your efforts. Allow 1 minute to elapse to insure that the sample has equilibrated with the surrounding stream water. Carry the pale [sic] sample over to the stream edge to where the water testing equipment is located to conduct the actual measurements. Be sure to perform this activity quickly but safely to obtain the most accurate measures.

   b. While at the stream side, perform the following stream water tests following the instruction for each instrument:

      - Temperature (0C)
      - Dissolved Oxygen (mg/L)
      - pH (0.0)
      - Total Dissolved Solids (mg/L)
      - Salinity (ppm)
      - Total Nitrogen (mg/L)
      - Total Phosphate (mg/L)

c. *Repeat steps 9a and 9b for the Center and Right sides of the channel. Record the measurements in the appropriate fields on the Chemical and Physical Description dataform. If a calculator is available determine the Mean values for each parameter. Remember to calibrate each meter prior to use.*

10. Water Depth, Substrate Type and Flow Velocity:

a. *Water depth measurements are collected at the X-site using the surveyor's measuring tape that is attached to the anchor stakes. Using the ACW measurement determined in Step 5 to calculate the Interval Width (IW) by dividing the ACW by 20. In other words, the IW should equal 1/20th of the width of the ACW. Measure water depth (WD) in the center of each increment starting from the Left Bank, and continuing along the surveyor's tape until the end of the surveyor's tape anchored at the Right Bank is reached. See Figure 5.*

TIP: Start collecting WD measurements at Point 1 which is determined by:

Pt 1 = ½ (ACW ÷ 20); Then Pt 2 = Pt 1 + IW; Pt 3 = Pt 2 + IW; Etc.

b. *Substrate Type is determined concurrent to collecting water depth measures. Document the substrate type associated with each water depth measurement by identifying what type of substrate material the handle of the D-frame Net (or other measuring device) touches at the stream bottom. Refer to the dataform categories for guidelines on determining substrate type based on size class. Record the substrate type by circling the appropriate category associated with the specific water depth measure.*

c. *Flow velocity (FV) is measured at the exact same locations used to measure water depth. For water depths ≤ 2.5 feet measure flow velocity with the Flow Meter at @ 0.6 x the actual water depth (0.6 x WD). For water depths > 2.5 feet in depth, measure flow velocity at both 0.2 and 0.8 times the water depth, then average the two measures. Proceed to collect flow velocity at each point (Pt 1, Pt 2, etc.) along the active channel. Start water depth from the left bank. Measures need only to occur across the "wetted width" of the stream, and may include at least one 0 depth measurement. Continue for each interval until you reach the right bank (or too deep or dangerous to measure). Follow the instructions for the Flow Meter to accurately measure the flow velocity.*

11. Macro-invertebrate Sampling:

a. *During each Stream Visual Assessment activity (down and upstream), take approximately 30 minutes of time to identify and sample macroinvertebrates at all distinct in-stream invertebrate habitat types observed. Use the D-Net Sampling Net to collect benthic and other invertebrate observed. Record the different species or groups observed and their relative abundance on the Water and Macroinvertebrate Sampling dataform.*

b. *Macroinvertebrate sampling can be conducted using the D-frame kick net in all suitable in-stream habitats present. In addition, also selectively pick up cobbles and other stones as part of the sampling effort to analyze for attached organisms. Do not spend more than 30 minutes effort for each portion of the stream reach.*

c. *When all macroinvertebrate sampling is completed, combine all sampling containers to one bucket and screen out debris and other organic material to produce a* *composite sample. Transfer the composite sample to a 300 mL sample jar, label and cover the label with clear tape. See Figure 6.*

d. *Preserve the sample by adding 50% by volume of 95% ethanol.*

12. Remove the X-site transect:

a. *Following completion of all field measurements, carefully take down the surveyor's tape, rope, and remove the anchor stakes. Prepare all equipment for transporting back to vehicle.*

13. Final Site Activities:

a. *Assemble Teams into one group and confirm all members are accounted for and are not injured.*

b. *Discuss the remaining Assessment Elements (#11-15) if relevant, and finalize a single score for each element on the Assessment Scores Form to combine observations from conducting the downstream and upstream portions of the stream reach.*

c. *Complete the remaining fields of information listed on the Stream Reach Description Form. This includes: end time, evaluation of percent landuse present, sketch of stream reach environment, documentation of photos, including the concluding site ID photo with the words "End."*

d. *Review all dataforms for completion and samples for label accuracy.*

e. *Review the stream visit activity, and ask participants to share their experiences and observations. Conclude collection of any relevant photography, and prepare all members, equipment, and samples for departure from stream site.*

GLOSSARY

Active channel width *–The width of the stream at the bankfull discharge. Permanent vegetation generally does not become established in the active channel.*

Aggradation *– Geologic process by which a stream bottom or flood plain is raised in elevation by the deposition of material.*

Bankfull discharge *– The stream discharge (flow rate, such as cubic feet per second) that forms and controls the shape and size of the active channel and creates the flood plain. This discharge generally occurs once every 1.5 years on average.*

Bankfull stage *– The stage at which water starts to flow over the flood plain; the elevation of the water surface at bankfull discharge.*

Baseflow *– The portion of streamflow that is derived from natural storage; average stream discharge during low flow conditions.*

Benthos Bottom *– dwelling or substrate-oriented organisms.*

Boulders *– Large rocks measuring more than 10 inches across.*

Channel *– A natural or artificial waterway of perceptible extent that periodically or continuously contains moving water. It has a definite bed and banks that serve to confine the water.*

Channel roughness *– Physical elements of a stream channel upon which flow energy is expended including coarseness and texture of bed material, the curvature of the channel, and variation in the longitudinal profile.*

Channelization *– Straightening of a stream channel to make water move faster.*

Cobbles *– Medium-sized rocks which measure 2.5 to 10 inches across.*

Confined channel *– A channel that does not have access to a flood plain.*

Degradation *– Geologic process by which a stream bottom is lowered in elevation due to the net loss of substrate material. Often called downcutting.*

Downcutting *– See Degradation.*

Ecoregion *– A geographic area defined by similarity of climate, landform, soil, potential natural vegetation, hydrology, or other ecologically relevant variables.*

Embeddedness *– The degree to which an object is buried in steam sediment.*

Emergent plants *– Aquatic plants that extend out of the water.*

Flood plain *– The flat area of land adjacent to a stream that is formed by current flood processes.*

Forb *– Any broad-leaved herbaceous plant other than those in the Gramineae (Poceae), Cyperacea, and Juncaceae families (Society for Range Management, 1989).*

Gabions *– A wire basket filled with rocks; used to stabilize streambanks and to control erosion.*

Geomorphology *– The study of the evolution and configuration of landforms.*

Glide *– A fast water habitat type that has low to moderate velocities, no surface agitation, no defined thalweg, and a U-shaped, smooth, wide bottom.*

Gradient *– Slope calculated as the amount of vertical rise over horizontal run expressed as ft/ft or as percent (ft/ft * 100).*

Grass *– An annual to perennial herb, generally with round erect stems and swollen nodes; leaves are alternate and two-ranked; flowers are in spikelets each subtended by two bracts.*

Gravel *– Small rocks measuring 0.25 to 2.5 inches across.*

Habitat *– The area or environment in which an organism lives.*

Herbaceous Plants *– with nonwoody stems.*

Hydrology *– The study of the properties, distribution, and effects of water on the Earth's surface, soil, and atmosphere.*

Incised channel *– A channel with a streambed lower in elevation than its historic elevation in relation to the flood plain.*

Intermittent stream *– A stream in contact with the ground water table that flows only certain times of the year, such as when the ground water table is high or when it receives water from surface sources.*

Macrophyte bed *– A section of stream covered by a dense mat of aquatic plants.*

Meander *– A winding section of stream with many bends that is at least 1.2 times longer, following the channel, than its straight-line distance. A single meander generally comprises two complete opposing bends, starting from the relatively straight section of the channel just before the first bend to the relatively straight section just after the second bend.*

Macroinvertebrate *– A spineless animal visible to the naked eye or larger than 0.5 millimeters.*

Nickpoint *– The point where a stream is actively eroding (downcutting) to a new base elevation. Nickpoints migrate upstream (through a process called headcutting).*

Perennial stream *– A steam that flows continuously throughout the year.*

Point bar *– A gravel or sand deposit on the inside of a meander; an actively mobile river feature.*

Pool *– Deeper area of a stream with slow-moving water.*

Reach *– A section of stream (defined in a variety of ways, such as the section between tributaries or a section with consistent characteristics).*

Riffle *– A shallow section in a stream where water is breaking over rocks, wood, or other partly submerged debris and producing surface agitation.*

Riparian *– The zone adjacent to a stream or any other waterbody (from the Latin word ripa, pertaining to the bank of a river, pond, or lake).*

Riprap *– Rock material of varying size used to stabilize streambanks and other slopes.*

Run *– A fast-moving section of a stream with a defined thalweg and little surface agitation.*

Scouring *– The erosive removal of material from the stream bottom and banks.*

Sedge *– A grasslike, fibrous-rooted herb with a triangular to round stem and leaves that are mostly three-ranked and with close sheaths; flowers are in spikes or spikelets, axillary to single bracts.*

Substrate *– The mineral or organic material that forms the bed of the stream; the surface on which aquatic organisms live.*

Surface fines *– That portion of streambed surface consisting of sand/silt (less than 6 mm).*

Thalweg *– The line followed by the majority of the streamflow. The line connecting the lowest or deepest points along the streambed.*

***Turbidity** – Murkiness or cloudiness of water caused by particles, such as fine sediment (silts, clays) and algae.*

***Watershed** – A ridge of high land dividing two areas that are drained by different river systems. The land area draining to a waterbody or point in a river system; catchment area, drainage basin, drainage area.*

References:

USEPA. 2004. Wadeable Stream Assessment: Field Operations Manual. EPA841-B-04-004. U.S. Environmental Protection Agency, Office of Water and Office of Research and Development, Washington, DC.

USDA. 1998. Stream Visual Assessment Protocol, December 1998. NWCC Technical Note 99–1.

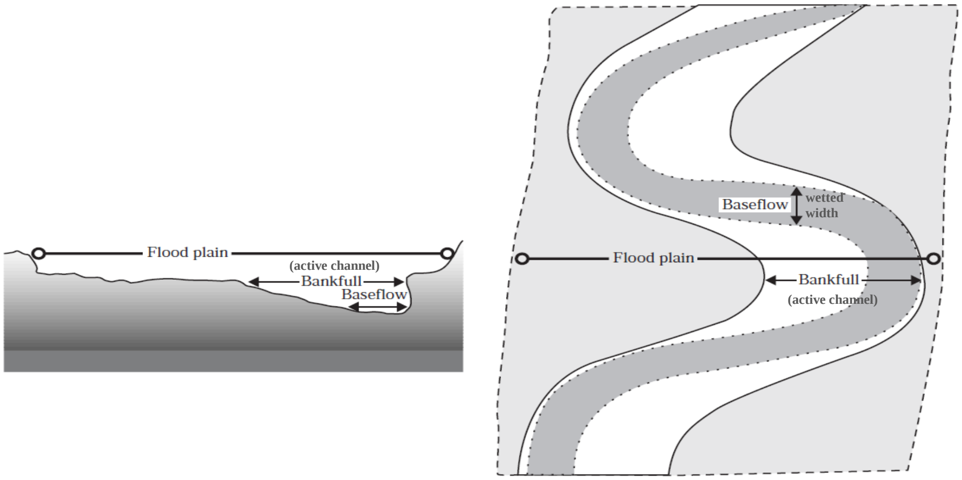


Figure 4. Baseflow, bankfull, and flood plain locations (Rosgen 1996)

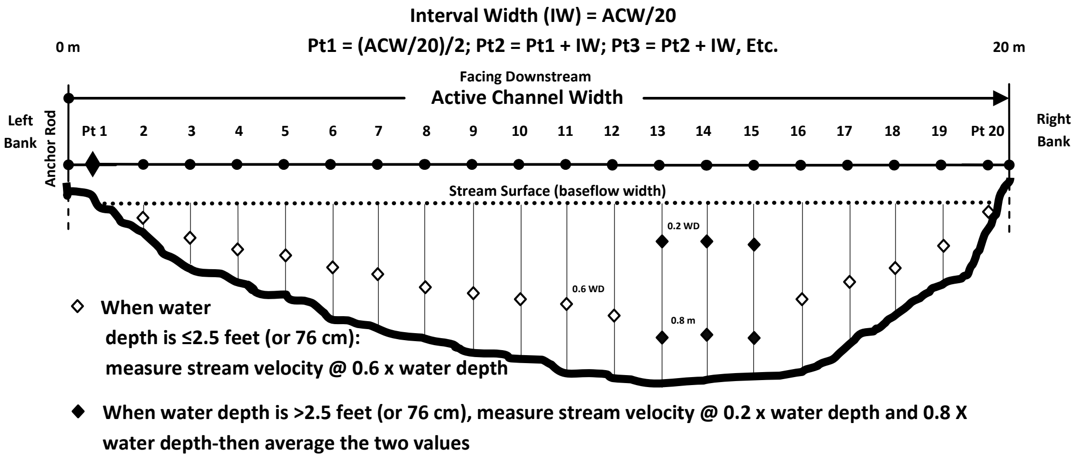


Figure 5. Stream reach cross-sectional view illustrating transect and active channel, water depth, and flow velocity measurement locations

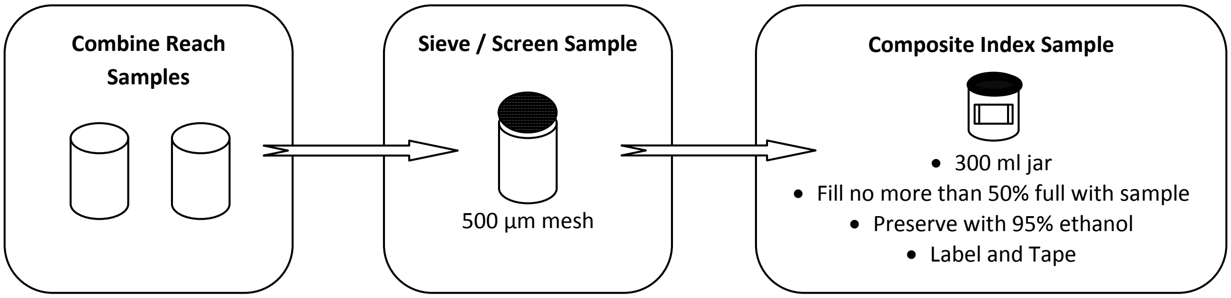


Figure 6. Processing of macroinvertebrate composite sample.

Stream Reach Description Form

Landowner Name:	**Date:**	**Time:** Start ___________ End ___________
Assessment Team:		
Stream Name:	**Reach ID:**	**Hexagon ID:**

Reach Location Description:

Stream Reach: Sampleable ____ Non-sampleable ____	**Elev$^{(m)}$:** down_____, X-site_____, up_____ or Slope ______%
If Non-sampleable, Why: High flow___ Other Hazard___ No Flow___	**GPS Coordinates$^{x\text{-site}}$:** Lat ____ . ________, Lon ____ . _______ (wgs84)

Landuse along Reach (%): (determine for 50m distance from stream AC edge to upland; Estimate to nearest 5 % increment: Total should equal 100%)	agriculture			Forest ________ %	grassland ________ %
	row crop ________ %	Plantation ________ %	grazing/pasture ________ %		
	developed			wetland ________ %	Other: (write-in) _____________ %
	Residential ________ %	Roads ________ %	Industrial ________ %		

Weather Conditions: (current)	air temp _____C	wind speed _____ m/s	wind dir. N / NW / W / SW / S / SE / E	% rel. hum. ______ %	Clouds no / part / full	Precip. no / lght / hvy
Weather Conditions: (recent)	descriptive					

Stream Channel Width (meter)		**Dominant substrate:**	Boulder ___	Gravel ___	Sand ___	Silt ___	Mud ___
AC:	Baseflow:						

Comments:

PhotoID: StreamDown________ Index-Site________ StreamUp________ Other: _______, ________, _______, ________, _______, ________

Site Diagram: (sketch approximate boundaries of landuse types, fencelines, culverts, dams, pollution sources, and in-stream cover types (riffle, pool, glide or run), sample transects/points)

Stream Visual Assessment Form

Stream Reach ID:_____________

Date: _________ (e.g., 1 Jan 2009)

Time: _______ (start)

Time: _______ (end)

Element	**Score**		**Element**	**Score**
1. Channel condition			9. Pools	
2. Hydrologic alteration			10. Invertebrate habitat	
3. Riparian zone			***Score elements below only if applicable***	
4. Bank stability			11. Canopy cover	
5. Water appearance			12. Manure presence	
6. Nutrient enrichment			13. Salinity	
7. Barriers to fish movement			14. Riffle embeddedness	
8. In-stream fish cover			15. Macro-invertebrate observed	

Overall score (total/# elements scored) ____/____ = _____	Poor <6.0	Fair 6.1-7.4	Good 7.5-8.9	Excellent >9.0

Suspected causes of observed problems:

Restoration/Management Recommendations:

Stream Assessment Volunteers:

Name	Role (circle all that apply)	HLE ROLES Da	In	Eq
1	Scoring Physical Chemistry Invertebrates Forms Safety GPS			
2	Scoring Physical Chemistry Invertebrates Forms Safety GPS			
3	Scoring Physical Chemistry Invertebrates Forms Safety GPS			
4	Scoring Physical Chemistry Invertebrates Forms Safety GPS			
5	Scoring Physical Chemistry Invertebrates Forms Safety GPS			
6	Scoring Physical Chemistry Invertebrates Forms Safety GPS			
7	Scoring Physical Chemistry Invertebrates Forms Safety GPS			
8	Scoring Physical Chemistry Invertebrates Forms Safety GPS			
9	Scoring Physical Chemistry Invertebrates Forms Safety GPS			
10	Scoring Physical Chemistry Invertebrates Forms Safety GPS			

Chemical and Physical Description Form

Stream Reach ID:_____________ Date: _________ (e.g., 1 Jan 2009) Time: _______ (start) Time: _______ (end)

Water Chemistry

X-Site Point	Temp C	DO (mg/l)	pH	TDS	S (ppm)	N	P	Note
Left								
Center								
Right								
Mean								

Interval Width: ACW_______(m) / 20 = ____ . ____ (m)
(Intervals of active channel width (ACW) must be ≥10cm wide.)

Active Channel Width: __________(m)

Baseflow Width: __________(m)

X-Site Point	Dist from L Bank	Depth (cm)	Velocity (@0.6D)	Note	Substrate (circle only one)						
1$_{(IW/2)}$				Left bank	Boulder	Cobble	Gravel	Sand	Clay	Bedrock	Artificial
2$_{(pt1+IW)}$					Boulder	Cobble	Gravel	Sand	Clay	Bedrock	Artificial
3$_{(pt2+IW)}$					Boulder	Cobble	Gravel	Sand	Clay	Bedrock	Artificial
4$_{(pt3+IW)}$					Boulder	Cobble	Gravel	Sand	Clay	Bedrock	Artificial
5$_{(pt4+IW)}$					Boulder	Cobble	Gravel	Sand	Clay	Bedrock	Artificial
6$_{(pt5+IW)}$					Boulder	Cobble	Gravel	Sand	Clay	Bedrock	Artificial
7$_{(pt6+IW)}$					Boulder	Cobble	Gravel	Sand	Clay	Bedrock	Artificial
8$_{(pt7+IW)}$					Boulder	Cobble	Gravel	Sand	Clay	Bedrock	Artificial
9$_{(pt8+IW)}$					Boulder	Cobble	Gravel	Sand	Clay	Bedrock	Artificial
10$_{(pt9+IW)}$					Boulder	Cobble	Gravel	Sand	Clay	Bedrock	Artificial
11$_{(pt10+IW)}$					Boulder	Cobble	Gravel	Sand	Clay	Bedrock	Artificial
12$_{(pt11+IW)}$					Boulder	Cobble	Gravel	Sand	Clay	Bedrock	Artificial
13$_{(pt12+IW)}$					Boulder	Cobble	Gravel	Sand	Clay	Bedrock	Artificial
14$_{(pt13+IW)}$					Boulder	Cobble	Gravel	Sand	Clay	Bedrock	Artificial
15$_{(pt14+IW)}$					Boulder	Cobble	Gravel	Sand	Clay	Bedrock	Artificial
16$_{(pt15+IW)}$					Boulder	Cobble	Gravel	Sand	Clay	Bedrock	Artificial
17$_{(pt16+IW)}$					Boulder	Cobble	Gravel	Sand	Clay	Bedrock	Artificial
18$_{(pt17+IW)}$					Boulder	Cobble	Gravel	Sand	Clay	Bedrock	Artificial
19$_{(pt18+IW)}$					Boulder	Cobble	Gravel	Sand	Clay	Bedrock	Artificial
20$_{(pt19+IW)}$					Boulder	Cobble	Gravel	Sand	Clay	Bedrock	Artificial

Point 1 = interval width ÷ 2 (e.g., 1m÷2=0.5m)
Point 2 = point 1 + interval width (e.g., 0.5m + 1m =1.5m), Etc.

Boulder: >25^{cm}; Cobble: 5-25^{cm}; Gravel: 0.2-5^{cm}; Sand: <0.2^{cm} grains separate; Clay: sticky-forms ribbon between fingers

Comments:

Water and Macro-invertebrate Sampling Form

Stream Reach ID:____________	Date: _________ (e.g., 1 Jan 2009)	Time: ________ (start)	Time: ________ (end)

WATER CHEMISTRY

Sample ID	Sample Location	Comments
	Run ___ Riffle ___ Pool ___ Other ___	

REACH-WIDE MACRO-INVERTEBRATES

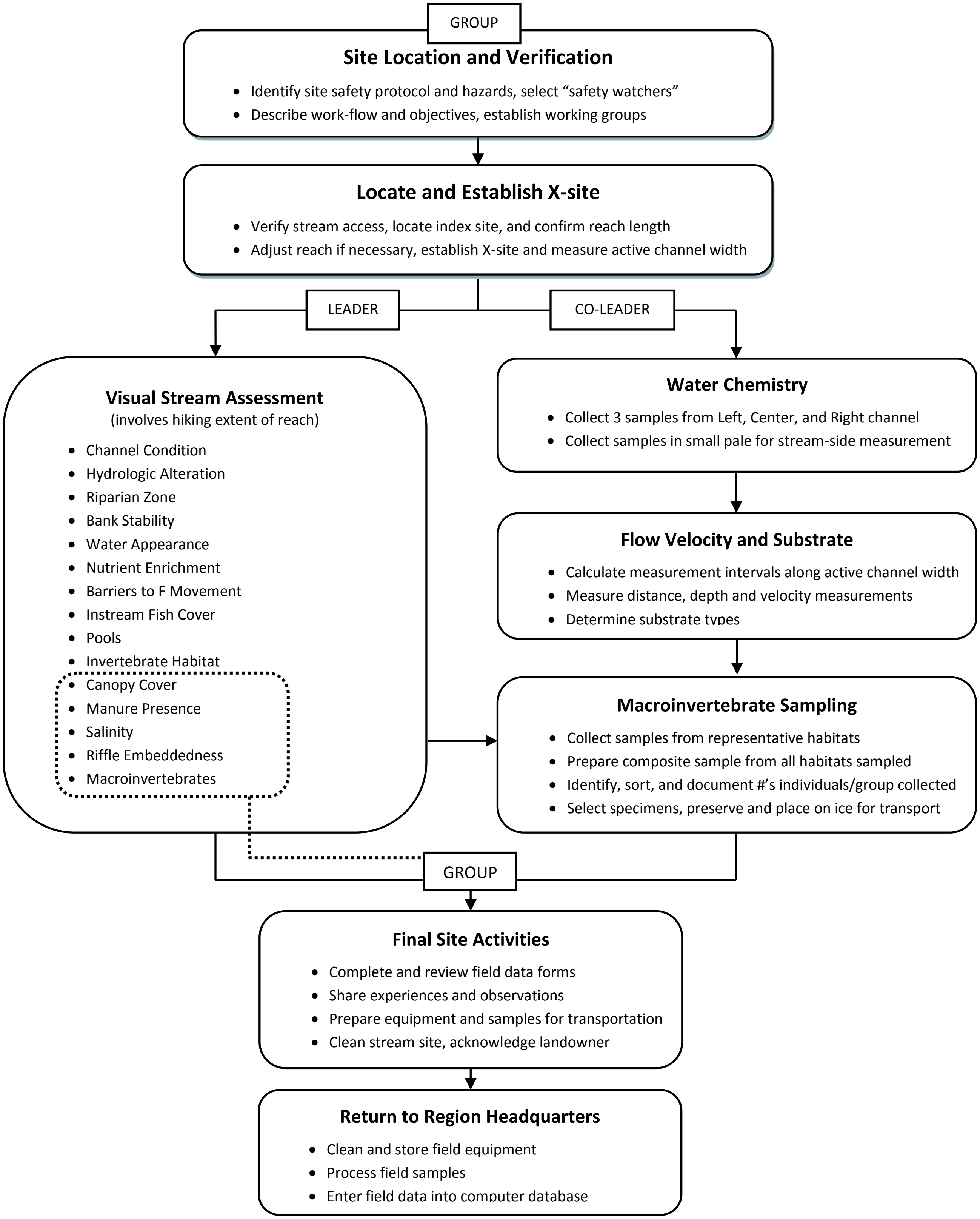
Sample ID	Sample Location In-stream Habitats Sampled (check all that apply)			
Pres. Sample _______________	woody debris ___	submerged logs ___	leaf pack ___	undercut banks ___
Live Sample _______________	boulders/cobble ___	surface water ___	Substrate ___	artificial: ___ __________

MACRO-INVERTEBRATE GROUPS OBSERVED

Group 1 Taxa (pollution sensitive)		**Group 2 Taxa** (somewhat pollution tolerant)				**Group 3 Taxa** (pollution insensitive)	
Taxa	**Tally**	**Taxa**	**Tally**	**Taxa**	**Tally**	**Taxa**	**Tally**
Caddisfly		Shrimp				Midge Fly Larva	
Riffle Beetle		Crab				Blackfly Larva	
Mayfly		Damselfly				Pouch & Pond Snails	
Gilled Snail		Crane Fly Larva				Other Snails	
		Beetle larva				Aquatic Worm	
		Dragonfly					

Comments:

FIELD ACTIVITY WORK FLOW



Site Location and Verification

- Identify site safety protocol and hazards, select “safety watchers”
- Describe work-flow and objectives, establish working groups

Locate and Establish X-site

- Verify stream access, locate index site, and confirm reach length
- Adjust reach if necessary, establish X-site and measure active channel width

Visual Stream Assessment
(involves hiking extent of reach)

- Channel Condition
- Hydrologic Alteration
- Riparian Zone
- Bank Stability
- Water Appearance
- Nutrient Enrichment
- Barriers to F Movement
- Instream Fish Cover
- Pools
- Invertebrate Habitat
- Canopy Cover
- Manure Presence
- Salinity
- Riffle Embeddedness
- Macroinvertebrates

Water Chemistry

- Collect 3 samples from Left, Center, and Right channel
- Collect samples in small pale for stream-side measurement

Flow Velocity and Substrate

- Calculate measurement intervals along active channel width
- Measure distance, depth and velocity measurements
- Determine substrate types

Macroinvertebrate Sampling

- Collect samples from representative habitats
- Prepare composite sample from all habitats sampled
- Identify, sort, and document #’s individuals/group collected
- Select specimens, preserve and place on ice for transport

Final Site Activities

- Complete and review field data forms
- Share experiences and observations
- Prepare equipment and samples for transportation
- Clean stream site, acknowledge landowner

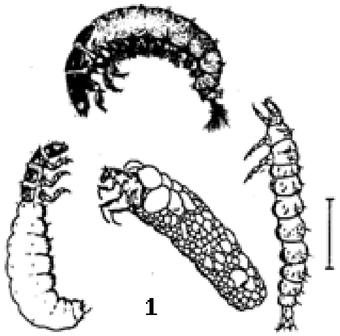
Return to Region Headquarters

- Clean and store field equipment
- Process field samples
- Enter field data into computer database

Stream Reach Description

The first page of the assessment worksheet records the identity and location of the stream reach. Most entries are self-explanatory. **Reach ID** and **Hexagon ID** should be filled out prior to the field activity. **Active channel width** can be difficult to determine. However, active channel width helps to characterize the stream. It is also an important aspect of more advanced assessment protocols; therefore, it is worth becoming familiar with the concept and field determination. For this protocol you do not need to measure active channel width accurately — an estimate to the nearest whole meter is adequate.

Active channel width is the stream width at the **bankfull discharge**. Bankfull discharge is the flow rate that forms and controls the shape and size of the **active channel**. It is approximately the flow rate at which the stream begins to move onto its **flood plain** if the stream has an active flood plain. The bankfull discharge is expected to occur every 1.5 years on average. Figure 1 illustrates the relationship between **active channel width**, **baseflow**, **bankfull flow, wetted width**, and the **flood plain**. Active channel width is best determined by locating the first flat depositional surface occurring above the bed of the stream (i.e., an active flood plain). The lowest elevation at which the bankfull surface could occur is at the top of the **point bars** or other sediment deposits in the **channel bed**. Other indicators of the bankfull surface include a break in slope on the bank, vegetation change, substrate, and debris. If you are not trained in locating the bankfull stage, ask the landowner how high the water gets every year and observe the location of permanent vegetation.



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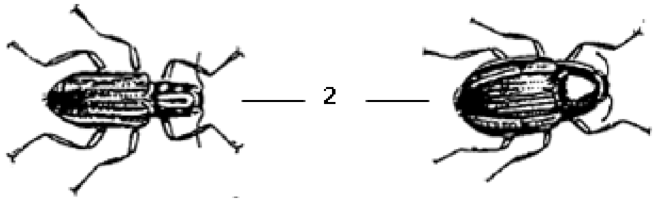

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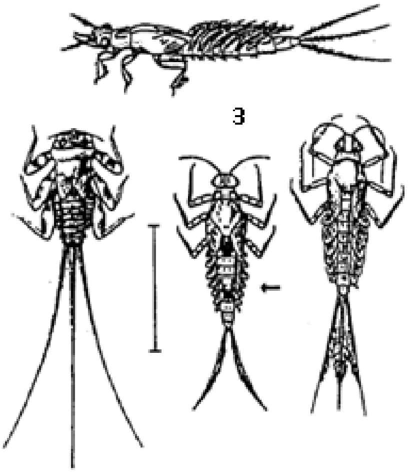

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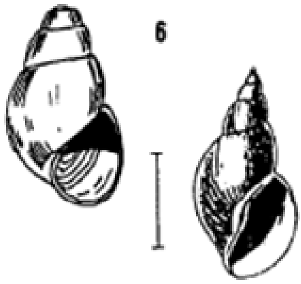

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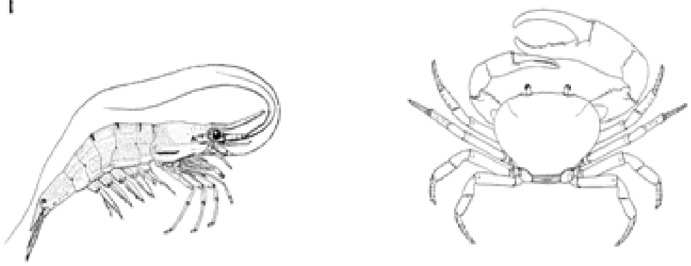


5

Stream Invertebrates

Group One Taxa

Pollution sensitive organisms found in good quality water.

1 Caddisfly: Order Trichoptera. Up to 1", 6 hooked legs on upper third of body, 2 hooks at back end. May be in a stick, rock, or leaf case with its head sticking out. May have fluffy gill tufts on underside.

2 Riffle Beetle: Order Coleoptera. 1/4", oval body covered with tiny hairs, 6 legs, antennae. Walks slowly underwater. Does not swim on surface.

3 Mayfly: Order Ephemeroptera. 1/4" to 1", brown, moving, plate-like or feathery gills on the sides of lower body (see arrow), 6 large hooked legs, antennae, 2 or 3 long hair-like tails. Tails may be webbed together.

4 Gilled Snail: Class Gastropoda. Shell opening covered by thin plate called operculum. When opening is facing you, shell usually opens on right.

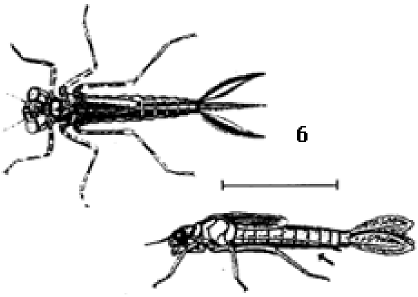
Group Two Taxa

Somewhat pollution tolerant organisms can be in good or fair quality water.

5 Shrimps and Crabs: Order Decapoda. Up to 6", 2 large claws, 8 legs.

Izaak Walton League of America, 707 Conservation Lane, Gaithersburg, MD 20878-2983. (800) BUG-IWLA

Fenner A. Chace y Horton H. Hobbs (1969). The Freshwater and terrestrial decapod crustaceans of the West Indies with special reference to Dominica. Smithsonian Biological Survey of Dominica.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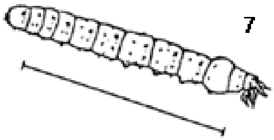
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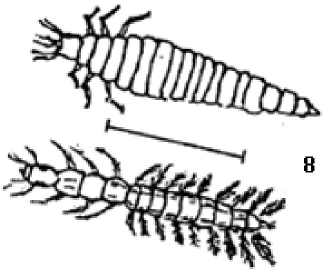
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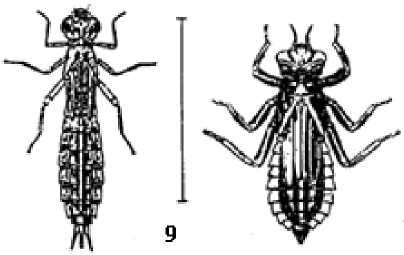
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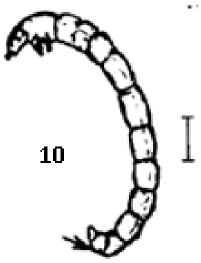
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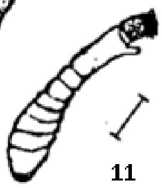
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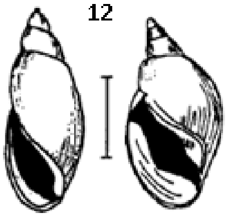
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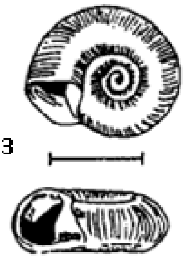
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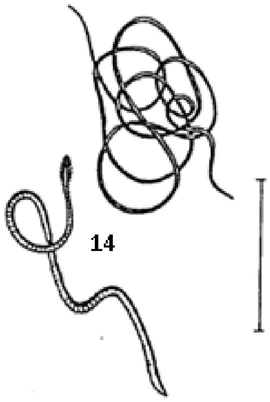
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Group Two Taxa (cont'd)

Somewhat pollution tolerant organisms can be in good or fair quality water.

6 Damselfly Larva: Suborder Zygoptera. 1/2" to 1", large eyes, 6 thin hooked legs, 3 broad oar-shaped tails, positioned like a tripod. Smooth (no gills) on sides of lower half of body. (See arrow.)

7 Crane Fly Larva: Suborder Nematocera. 1/3" to 2", milky, green, or light brown, plump caterpillar-like segmented body, 4 fingerlike lobes at back end.

8 Beetle Larva: Order Coleoptera. 1/4" to 1", light-colored, 6 legs on upper half of body, feelers, antennae.

9 Dragon Fly: Suborder Anisoptera. 1/2" to 2", large eyes, 6 hooked legs. Wide oval to round abdomen.

Group Three Taxa

Pollution tolerant organisms can be in any quality of water.

10 Midge Fly Larva: Suborder Nematocera. Up to 1/4", dark head, worm-like segmented body, 2 tiny legs on each side.

11 Blackfly Larva: Family Simulidae. Up to 1/4", one end of body wider. Black head, suction pad on other end.

12 Pouch Snail and Pond Snails: Class Gastropoda. No operculum. Breath air. When opening is facing you, shell usually open to left.

13 Other Snails: Class Gastropoda. No operculum.Breath air. Snail shell coils in one plane.

10 Aquatic Worm: Class Oligochaeta. 1/4" to 2", can be very tiny, thin wormlike body.

Appendix C: USDA Protocol

The document for Appendix C can be found at the end of this report.

Appendix D: EPA Protocol

The document for Appendix D can be found at the end of this report.

Appendix E: Water Chemistry Testing Procedures

Properly calibrate each instrument each week or if it was dropped.

Temperature

1. Rinse thermometer.
2. Place thermometer into water sample and allow reading to equilibrate.
3. Record measurement in degrees Celsius.
4. Rinse thermometer.

Dissolved Oxygen Testing Procedure

1. With an Acorn series® DO 6 meter kit, rinse probe to remove impurities.
2. Securely connect probe to meter and turn on meter.
3. Dip probe into bucket of sample water, careful to not let bubbles form at the head of the probe.
4. Hold the probe steady and allow reading to stabilize.
5. Record measurement value in mg/L.
6. Rinse probe before taking next measurement or storing it.

pH Testing Procedure

1. With an Acorn series® pH 6 meter kit, rinse pH probe and temperature probe to remove impurities.
2. Securely connect both probes to meter and turn on meter.
3. Dip probes into bucket of sample water and swirl gently.
4. Allow the reading to stabilize.
5. Record measurement value.
6. Rinse probes before taking next measurement or storing them.

Total Dissolved Solids, Salinity, and Conductivity Testing Procedure

1. If the Waterproof Multiparameter PCS Testr 35 has been stored dry, let sit in water for 30 minutes.
2. Dip probes into bucket of sample water and swirl gently.
3. Set the instrument to measure total dissolved solids.
4. Allow the reading to stabilize.
5. Record measurement value in ppm.
6. Repeat steps 3-5 for salinity (in ppm) and conductivity (in µS).
7. Rinse probes before testing next sample or storing the device.

Phosphate Testing Procedure

1. Rinse vial.
2. Use 5 mL dropper to add 10 mL of sample water to vial.
3. Add tablet of LaMotte Phosporus code 5422A-H to the vial.
4. Put cap on vial and shake until the tablet dissolves.
5. Observe the color after 5 minutes.
6. Compare the color of the solution to LaMotte's scale to determine amount of phosphate in ppm in sample.
7. Rinse vial before adding next sample or storing.

Nitrate Testing Procedure

1. Rinse vial.
2. Use 5 mL dropper to add 10 mL of sample water to vial.
3. Add tablet of LaMotte Nitrate Wide Range code 3703A-J to the vial.
4. Put cap on vial and shake until the tablet dissolves.
5. Observe the color after 5 minutes.
6. Compare the color of the solution to LaMotte's scale to determine amount of nitrate in ppm in sample.
7. Rinse vial before adding next sample or storing.

Appendix F: Stream Names and GPS Coordinates of Study Sites

Study Site Number	Stream Name	GPS Coordinates of X Site
1	Río Piedras	N 18°23.565’ W 066°03.420’
2	Río Piedras	N 18°22.884’ W 066°03.572’
3	Río Piedras	N 18°24.000’ W 066°03.693’
21	Río Canóvanas	N 18°20.559’ W 065°53.378’
27	Río Canovanillas	N 18°20.323’ W 65°54.473’
38	Río Minillas	N 18°20.772’ W 066°10.272’
44	Río Guaynabo	N 18°20.583’ W 066°06.658’
48	Río Guaynabo	N 18°22.013’ W 66°06.884’
54	Río Bayamón	N 18°19.230’ W 66°08.473’

Appendix G: Obstacle and Pollutant Pictures

WPI-RP-1 and 3: Bamboo Removal

WPI-RP-1: (top and bottom left): Bamboo blockages; (top right): Drainage pipe; (bottom right): Metal pollutants

WPI-RP-2: Fences and road blocking site entry

WPI-WP-21/27: (left to right): Horse and comparison of pools along stream

WPI-WP-38: (left to right): Dilapidated house and wooden plank

WPI-WP-44: Pollutants

WPI-WP-48: Pollutants of car parts, electronics, and bamboo

WPI-WP-54: (clockwise from top left): Rusted bus, baby diaper, car parts, algae, and dead snails

Appendix H: Pictures of Macroinvertebrates

Group 1 Taxa

Caddisfly Larva

Riffle Beetle

Mayfly Larva

Gilled Snail (Right)

Group 2 Taxa

Shrimp

Damselfly Larva

Dragonfly Larva

Water Strider

Group 3 Taxa

Midgefly Larva

Pouch Snail (Left)

Other Snail

Other Taxa

Freshwater Clam

Planorbid Snail

Whirligig Beetle

Appendix I: Total Process Timeline

Week 1 (March 15-19)
Introduction to the Trust, Learned Proper Use of Equipment In and Out of Water
Week 2 (March 22-26)
Site Selection, First Site Sampling, Visits to Fideicomiso Properties
Week 3 (March 29-April 2)
Additional Sites Selected, Sampled, and Cataloged
Week 4 (April 5-9)
Additional Sites Selected, Sampled, and Cataloged
Week 5 (April 12-16)
Additional Sites Selected, One Sampled, and Cataloged
Week 6 (April 19-23)
One Additional Site Sampled and Cataloged
Week 7 (April 26-30)
Results Analyzed, IQP Paper Assembled
Week 8 (May 3-7)
Final IQP Paper Assembled, Final Presentation

The first week at the the Trust entailed an introduction to Fideicomiso and to the equipment that would be used to perform the tests. It also included a practice field day, during which the use of all equipment was examined. The second week included visits to Fideicomiso properties to better understand its function. During this week, sites were selected for sampling and one was successfully completed. The third, fourth, fifth, and sixth weeks included the selection of additional sites, sampling at several of these sites, and the cataloging of the macroinvertebrates collected. During the final two weeks, the results were analyzed, the final IQP paper was assembled, and the final presentation was performed.

A total of nine sites on six different rivers were sampled, cataloged, and analyzed successfully. Throughout the weeks, the process at each site was reviewed, and the IQP report was assembled and revised. After all sites were sampled, suggestions for updating the Mapa de Vida program were formulated and are reported herein.

United States
Department of
Agriculture

Natural
Resources
Conservation
Service

National Water and Climate Center
Technical Note 99–1

Stream Visual Assessment Protocol

Issued December 1998

Cover photo: Stream in Clayton County, Iowa, exhibiting an impaired riparian zone.

Preface

This document presents an easy-to-use assessment protocol to evaluate the condition of aquatic ecosystems associated with streams. The protocol does not require expertise in aquatic biology or extensive training. Least-impacted reference sites are used to provide a standard of comparison. The use of reference sites is variable depending on how the state chooses to implement the protocol. The state may modify the protocol based on a system of stream classification and a series of reference sites. Instructions for modifying the protocol are provided in the technical information section. Aternatively, a user may use reference sites in a less structured manner as a point of reference when applying the protocol.

The Stream Visual Assessment Protocol is the first level in a hierarchy of ecological assessment protocols. More sophisticated assessment methods may be found in the Stream Ecological Assessment Field Handbook. The field handbook also contains background information on basic stream ecology. Information on chemical monitoring of surface water and groundwater may be found in the National Handbook of Water Quality Monitoring.

The protocol is designed to be conducted with the landowner. Educational material is incorporated into the protocol. The document is structured so that the protocol (pp. 7–20) can be duplicated to provide a copy to the landowner after completion of an assessment. The assessment is recorded on a single sheet of paper (copied front and back).

Acknowledgments

This protocol was developed by the Natural Resources Conservation Service (NRCS) Aquatic Assessment Workgroup. The principal authors were **Bruce Newton**, limnologist, National Water and Climate Center, NRCS, Portland, OR; **Dr. Catherine Pringle**, associate professor of Aquatic Ecology, University of Georgia, Athens, GA; and **Ronald Bjorkland**, University of Georgia, Athens, GA. The NRCS Aquatic Assessment Workgroup members provided substantial assistance in development, field evaluation, and critical review of the document. These members were:

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Howard Hankin, aquatic ecologist, Ecological Sciences Division, NRCS, Washington, DC
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Bianca Streif, state biologist, NRCS, Portland, OR
Billy Teels, director, Wetlands Science Institute, NRCS, Laurel, MD

Additional assistance was provided by **Janine Castro,** geomorphologist, NRCS, Portland, OR; **Mark Schuller,** fisheries biologist, NRCS, Spokane, WA; **Lyle Steffen,** geologist, NRCS, Lincoln, NE; and **Lyn Townsend,** forest ecologist, NRCS, Seattle, WA.

Contents:

Tables

Figures

Stream Visual Assessment Protocol

Introduction

This assessment protocol provides a basic level of stream health evaluation. It can be successfully applied by conservationists with little biological or hydrological training. It is intended to be conducted with the landowner and incorporates talking points for the conservationist to use during the assessment. This protocol is the first level in a four-part hierarchy of assessment protocols. Tier 2 is the NRCS Water Quality Indicators Guide, Tier 3 is the NRCS Stream Ecological Assessment Field Handbook, and Tier 4 is the intensive bioassessment protocol used by your State water quality agency.

This protocol provides an assessment based primarily on physical conditions within the assessment area. It may not detect some resource problems caused by factors located beyond the area being assessed. The use of higher tier methods is required to more fully assess the ecological condition and to detect problems originating elsewhere in the watershed. However, most landowners are mainly interested in evaluating conditions on their land, and this protocol is well suited to supporting that objective.

What makes for a healthy stream?

A stream is a complex ecosystem in which several biological, physical, and chemical processes interact. Changes in any one characteristic or process have cascading effects throughout the system and result in changes to many aspects of the system.

Some of the factors that influence and determine the integrity of streams are shown in figure 1. Often several factors can combine to cause profound changes. For example, increased nutrient loads alone might not cause a change to a forested stream. But when combined with tree removal and channel widening, the result is to shift the energy dynamics from an aquatic biological community based on leaf litter inputs to one based on algae and macrophytes. The resulting chemical changes caused by algal photosynthesis and respiration and elevated temperatures may further contribute to a completely different biological community.

Many stream processes are in a delicate balance. For example, stream power, sediment load, and channel roughness must be in balance. Hydrologic changes that increase stream power, if not balanced by greater channel complexity and roughness, result in "hungry" water that erodes banks or the stream bottom. Increases in sediment load beyond the transport capacity of the stream leads to deposition, lateral channel movement into streambanks, and channel widening.

Most systems would benefit from increased complexity and diversity in physical structure. Structural complexity is provided by trees fallen into the channel, overhanging banks, roots extending into the flow, pools and riffles, overhanging vegetation, and a variety of bottom materials. This complexity enhances habitat for organisms and also restores hydrologic properties that often have been lost.

Chemical pollution is a factor in most streams. The major categories of chemical pollutants are oxygen depleting substances, such as manure, ammonia, and organic wastes; the nutrients nitrogen and phosphorus; acids, such as from mining or industrial activities; and toxic materials, such as pesticides and salts or metals contained in some drain water. It is important to note that the effects of many chemicals depend on several factors. For example, an increase in the pH caused by excessive algal and aquatic plant growth may cause an otherwise safe concentration of ammonia to become toxic. This is because the equilibrium concentrations of nontoxic ammonium ion and toxic un-ionized ammonia are pH-dependent.

Finally, it is important to recognize that streams and flood plains need to operate as a connected system. Flooding is necessary to maintain the flood plain biological community and to relieve the erosive force of flood discharges by reducing the velocity of the water. Flooding and bankfull flows are also essential for maintaining the instream physical structure. These events scour out pools, clean coarser substrates (gravel, cobbles, and boulders) of fine sediment, and redistribute or introduce woody debris.

What's the stream type?

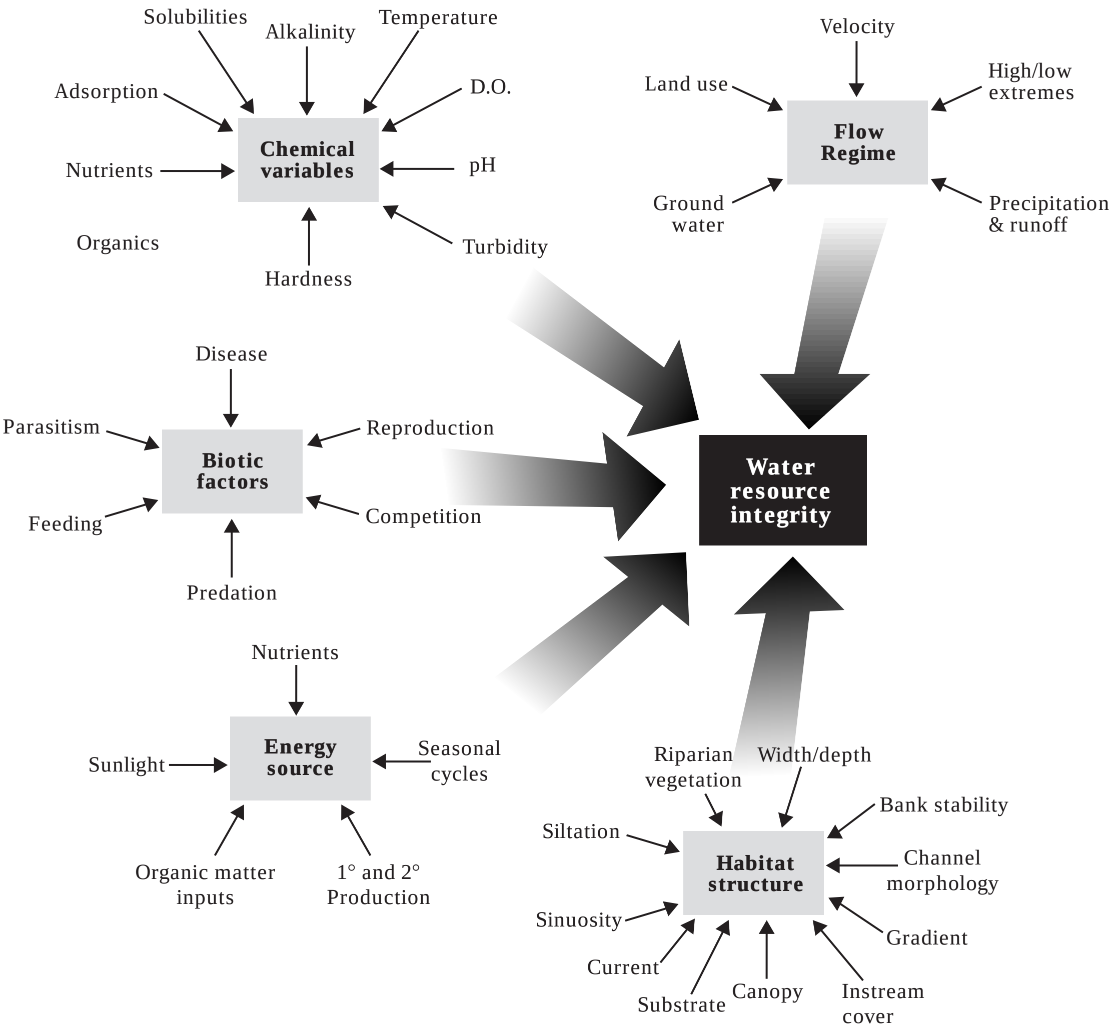
A healthy stream will look and function differently in different parts of the country and in different parts of the landscape. A mountain stream in a shale bedrock is different from a valley stream in alluvial deposits. Coastal streams are different from piedmont streams. Figuring out the different types of streams is called stream classification. Determining what types of streams are in your area is important to assessing the health of a particular stream.

There are many stream classification systems. For the purpose of a general assessment based on biology and habitat, you should think in terms of a three-level classification system based on ecoregion, drainage area, and gradient. *Ecoregions* are geographic areas in which ecosystems are expected to be similar. A national-level ecoregion map is available, and many states are working to develop maps at a higher level of resolution. *Drainage area* is the next most important factor to defining stream type. Finally, the slope or *gradient* of the reach you are assessing will help you determine the stream type. If you are familiar with another classification system, such as Rosgen or Montgomery/Buffington, you should use that system. This protocol may have been adjusted by your state office to reflect stream types common in your area.

Reference sites

One of the most difficult issues associated with stream ecosystems is the question of historic and potential conditions. To assess stream health, we need a benchmark of what the healthy condition is. We can usually assume that historic conditions were healthy. But in areas where streams have been degraded for 150 years or more, knowledge of historic conditions may have been lost. Moreover, in many areas returning to historic conditions is impossible or the historic conditions would not be stable under the current hydrology. Therefore, the question becomes what is the best we can expect for a particular stream. Scientists have grappled with this question for a long time, and the

Figure 1 Factors that influence the integrity of streams (modified from Karr 1986)



consensus that has emerged is to use reference sites within a classification system.

Reference sites represent the best conditions attainable within a particular stream class. The identification and characterization of reference sites is an ongoing effort led in most states by the water quality agency. You should determine whether your state has identified reference sites for the streams in your area. Such reference sites could be in another county or in another state. Unless your state office has provided photographs and other descriptive information, you should visit some reference sites to learn what healthy streams look like as part of your skills development. Visiting reference sites should also be part of your orientation after a move to a new field office.

Using this protocol

This protocol is intended for use in the field with the landowner. Conducting the assessment with the landowner gives you the opportunity to discuss natural resource concerns and conservation opportunities.

Before conducting the assessment, you should determine the following information in the field office:

- ecoregion (if in use in your State)
- drainage area
- stream gradients on the property
- overall position on the landscape

Your opening discussion with landowners should start by acknowledging that they own the land and that you understand that they know their operation best. Point out that streams, from small creeks to large rivers, are a resource that runs throughout the landscape—how they manage their part of the stream affects the entire system. Talk about the benefits of healthy streams and watersheds (improved baseflow, forage, fish, waterfowl, wildlife, aesthetics, reduced flooding downstream, and reduced water pollution). Talk about how restoring streams to a healthy condition is now a national priority.

Explain what will happen during the assessment and what you expect from them. An example follows:

This assessment will tell us how your stream is doing. We'll need to look at sections of the stream that are representative of different conditions. As we do the assessment we'll discuss how the functioning of different aspects of the stream work to keep the system healthy. After we're done, we can talk about the results of the assessment. I may recommend further assessment work to better understand what's going on. Once we understand what is happening, we can explore what you would like to accomplish with your stream and ideas for improving its condition, if necessary.

You need to assess one or more representative reaches. A reach is a length of stream. For this protocol, the length of the assessment reach is 12 times the active channel width. The reach should be representative of the stream through that area. If conditions change dramatically along the stream, you should identify additional assessment reaches and conduct separate assessments for each.

As you evaluate each element, try to work the talking points contained in the scoring descriptions into the conversation. If possible, involve the owner by asking him or her to help record the scores.

The assessment is recorded on a two-page worksheet. A completed worksheet is shown in figure 2. (A worksheet suitable for copying is at the end of this note.) The stream visual assessment protocol worksheet consists of two principal sections: reach identification and assessment. The identification section records basic information about the reach, such as name, location, and land uses. Space is provided for a diagram of the reach, which may be useful to locate the reach or illustrate problem areas. On this diagram draw all tributaries, drainage ditches, and irrigation ditches; note springs and ponds that drain to the stream; include road crossings and note whether they are fords, culverts, or bridges; note the direction of flow; and draw in any large woody debris, pools, and riffles.

The assessment section is used to record the scores for up to 15 assessment elements. Not all assessment elements will be applicable or useful for your site. Do not score elements that are not applicable. Score an element by comparing your observations to the descriptions provided. If you have difficulty matching descriptions, try to compare what you are observing to the conditions at reference sites for your area.

The overall assessment score is determined by adding the values for each element and dividing by the number of elements assessed. For example, if your scores add up to 76 and you used 12 assessment elements, you would have an overall assessment value of 6.3, which is classified as *fair*. This value provides a numerical assessment of the environmental condition of the stream reach. This value can be used as a general statement about the "state of the environment" of the stream or (over time) as an indicator of trends in condition.

Figure 2 Stream visual assessment protocol worksheet

USDA

Stream Visual Assessment Protocol

Owners name Elmer Smith Evaluator's name Mary Soylkahn Date 6-20-99

Stream name Camp Creek Waterbody ID number ______

Reach location About 2,000 feet upstream of equipment shed

Ecoregion ______ Drainage area 2,200 acres Gradient 1.2 % (map)

Applicable reference site Cherry Creek north of the Rt 310 bridge

Land use within drainage (%): row crop 40 hayland 30 grazing/pasture 20 forest 10 residential ______

confined animal feeding operations ______ Cons. Reserve ______ industrial ______ Other: ______

Weather conditions-today clear Past 2-5 days clear

Active channel width 15 feet Dominant substrate: boulder ______ gravel X sand X silt ______ mud ______

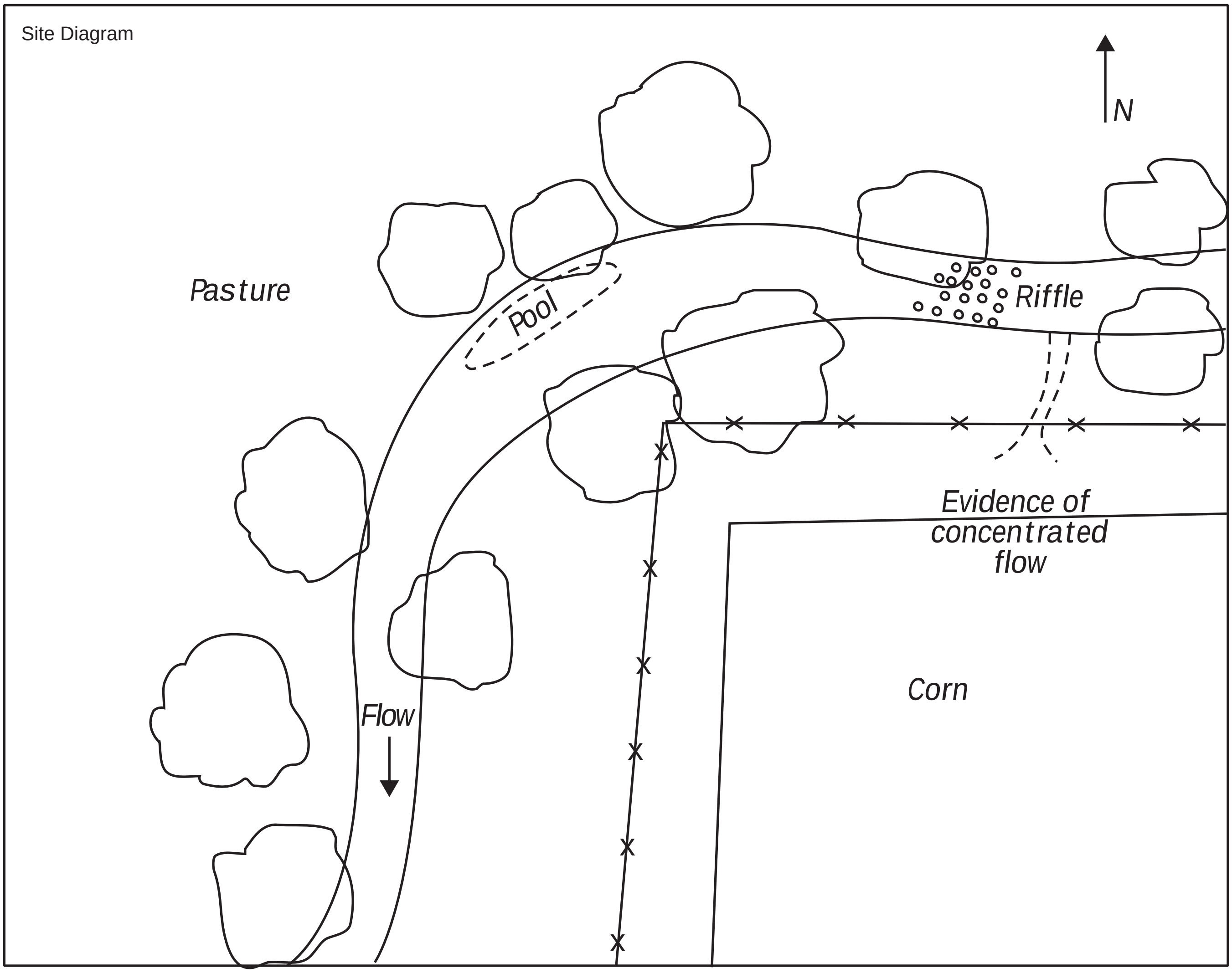


Figure 2 Stream visual assessment protocol worksheet—Continued

Assessment Scores

Channel condition	8
Hydrologic alteration	10
Riparian zone	1
Bank stability	5
Water appearance	3
Nutrient enrichment	7
Barriers to fish movement	10
Instream fish cover	3

Pools	3
Invertebrate habitat	7

Score only if applicable

Canopy cover	3
Manure presence	1
Salinity	
Riffle embeddedness	5
Marcroinvertebrates Observed (optional)	10

Overall score
(Total divided by number scored)
76/14 5.4

<6.0	[✓ **Poor**]
6.1-7.4	**Fair**
7.5-8.9	**Good**
>9.0	**Excellent**

Suspected causes of observed problems This reach is typical of the reaches on the property. Severely degraded riparian zones lack brush, small trees. Some bank problems from livestock access. Channel may be widening due to high sediment load. Does not appear to be downcutting.

Recommendations Install 391-Riparian Forest Buffer. Need to encourage livestock away from stream using water sources and shade or exclude livestock. Concentrated flows off fields need to be spread out in zone 3 of buffer. Relocate fallen trees if they deflect current into bank–use as stream barbs to deflect current to maintain channel.

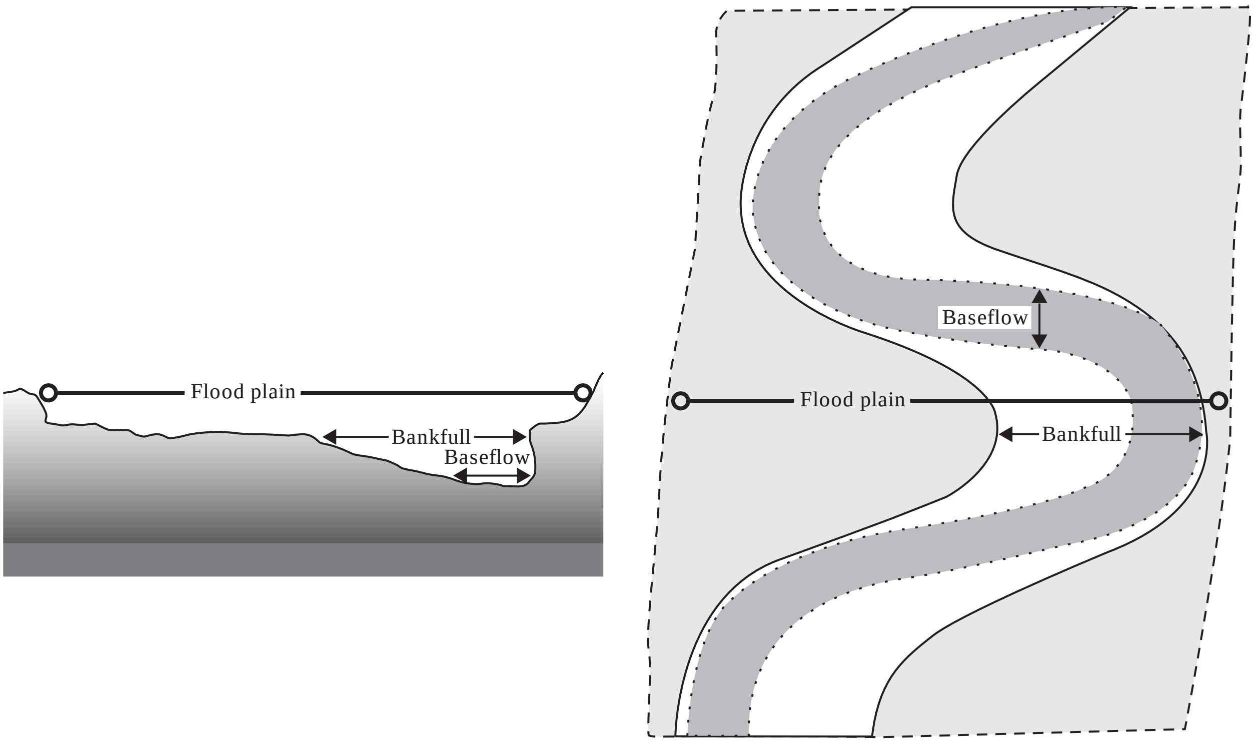
Reach description

The first page of the assessment worksheet records the identity and location of the stream reach. Most entries are self-explanatory. Waterbody ID and ecoregion should be filled out only if these identification and classification aids are used in your state.

Active channel width can be difficult to determine. However, active channel width helps to characterize the stream. It is also an important aspect of more advanced assessment protocols; therefore, it is worth becoming familiar with the concept and field determination. For this protocol you do not need to measure active channel width accurately — a visual estimate of the average width is adequate.

Active channel width is the stream width at the bankfull discharge. Bankfull discharge is the flow rate that forms and controls the shape and size of the active channel. It is approximately the flow rate at which the stream begins to move onto its flood plain if the stream has an active flood plain. The bankfull discharge is expected to occur every 1.5 years on average. Figure 3 illustrates the relationship between baseflow, bankfull flow, and the flood plain. Active channel width is best determined by locating the first flat depositional surface occurring above the bed of the stream (i.e., an active flood plain). The lowest elevation at which the bankfull surface could occur is at the top of the point bars or other sediment deposits in the channel bed. Other indicators of the bankfull surface include a break in slope on the bank, vegetation change, substrate, and debris. If you are not trained in locating the bankfull stage, ask the landowner how high the water gets every year and observe the location of permanent vegetation.

Figure 3 Baseflow, bankfull, and flood plain locations (Rosgen 1996)



Scoring descriptions

Each assessment element is rated with a value of 1 to 10. Rate only those elements appropriate to the stream. Using the Stream Visual Assessment Protocol worksheet, record the score that best fits the observations you make based on the narrative descriptions provided. Unless otherwise directed, assign the lowest score that applies. For example, if a reach has aspects of several narrative descriptions, assign a score based on the lowest scoring description that contains indicators present within the reach. You may record values intermediate to those listed. Some background information is provided for each assessment element, as well as a description of what to look for. The length of the assessment reach should be 12 times the active channel width.

Channel condition

Natural channel; no structures, dikes. No evidence of downcutting or excessive lateral cutting.	Evidence of past channel alteration, but with significant recovery of channel and banks. Any dikes or levies are set back to provide access to an adequate flood plain.	Altered channel; <50% of the reach with riprap and/ or channelization. Excess aggradation; braided channel. Dikes or levees restrict flood plain width.	Channel is actively downcutting or widening. >50% of the reach with riprap or channelization. Dikes or levees prevent access to the flood plain.
10	7	3	1

Stream meandering generally increases as the gradient of the surrounding valley decreases. Often, development in the area results in changes to this meandering pattern and the flow of a stream. These changes in turn may affect the way a stream naturally does its work, such as the transport of sediment and the development and maintenance of habitat for fish, aquatic insects, and aquatic plants. Some modifications to stream channels have more impact on stream health than others. For example, channelization and dams affect a stream more than the presence of pilings or other supports for road crossings.

Active downcutting and excessive lateral cutting are serious impairments to stream function. Both conditions are indicative of an unstable stream channel. Usually, this instability must be addressed before committing time and money toward improving other stream problems. For example, restoring the woody vegetation within the riparian zone becomes increasingly difficult when a channel is downcutting because banks continue to be undermined and the water table drops below the root zone of the plants during their growing season. In this situation or when a channel is fairly stable, but already incised from previous downcutting or mechanical dredging, it is usually necessary to plant upland species, rather than hydrophytic, or to apply irrigation for several growing seasons, or both. Extensive bank-armoring of channels to stop lateral cutting usually leads to more problems (especially downstream). Often stability can be obtained by using a series of structures (barbs, groins, jetties, deflectors, weirs, vortex weirs) that reduce water velocity, deflect currents, or act as gradient controls. These structures are used in conjunction with large woody debris and woody vegetation plantings. Hydrologic alterations are described next.

What to look for: Signs of channelization or straightening of the stream may include an unnaturally straight section of the stream, high banks, dikes or berms, lack of flow diversity (e.g., few point bars and deep pools), and uniform-sized bed materials (e.g., all cobbles where there should be mixes of gravel and cobble). In newly channelized reaches, vegetation may be missing or appear very different (different species, not as well developed) from the bank vegetation of areas that were not channelized. Older channelized reaches may also have little or no vegetation or have grasses instead of woody vegetation. Drop structures (such as check dams), irrigation diversions, culverts, bridge abutments, and riprap also indicate changes to the stream channel.

Indicators of downcutting in the stream channel include nickpoints associated with headcuts in the stream bottom and exposure of cultural features, such as pipelines that were initially buried under the stream. Exposed footings in bridges and culvert outlets that are higher than the water surface during low flows are other examples. A lack of sediment depositional features, such as regularly-spaced point bars, is normally an indicator of incision. A low vertical scarp at the toe of the streambank may indicate downcutting, especially if the scarp occurs on the inside of a meander. Another visual indicator of current or past downcutting is high streambanks with woody vegetation growing well below the top of the bank (as a channel incises the bankfull flow line moves downward within the former bankfull channel). Excessive bank erosion is indicated by raw banks in areas of the stream where they are not normally found, such as straight sections between meanders or on the inside of curves.

Hydrologic alteration

Flooding every 1.5 to 2 years. No dams, no water withdrawals, no dikes or other structures limiting the stream's access to the flood plain. Channel is not incised.	Flooding occurs only once every 3 to 5 years; limited channel incision. or Withdrawals, although present, do not affect available habitat for biota.	Flooding occurs only once every 6 to 10 years; channel deeply incised. or Withdrawals significantly affect available low flow habitat for biota.	No flooding; channel deeply incised or structures prevent access to flood plain or dam operations prevent flood flows. or Withdrawals have caused severe loss of low flow habitat. or Flooding occurs on a 1-year rain event or less.
10	7	3	1

Bankfull flows, as well as flooding, are important to maintaining channel shape and function (e.g., sediment transport) and maintaining the physical habitat for animals and plants. High flows scour fine sediment to keep gravel areas clean for fish and other aquatic organisms. These flows also redistribute larger sediment, such as gravel, cobbles, and boulders, as well as large woody debris, to form pool and riffle habitat important to stream biota. The river channel and flood plain exist in dynamic equilibrium, having evolved in the present climatic regime and geomorphic setting. The relationship of water and sediment is the basis for the dynamic equilibrium that maintains the form and function of the river channel. The energy of the river (water velocity and depth) should be in balance with the bedload (volume and particle size of the sediment). Any change in the flow regime alters this balance.

If a river is not incised and has access to its flood plain, decreases in the frequency of bankfull and out-of-bank flows decrease the river's ability to transport sediment. This can result in excess sediment deposition, channel widening and shallowing, and, ultimately, in *braiding* of the channel. Rosgen (1996) defines braiding as a stream with three or more smaller channels. These smaller channels are extremely unstable, rarely have woody vegetation along their banks, and provide poor habitat for stream biota. A *split channel*, however, has two or more smaller channels (called side channels) that are usually very stable, have woody vegetation along their banks, and provide excellent habitat.

Conversely, an increase in flood flows or the confinement of the river away from its flood plain (from either incision or levees) increases the energy available to transport sediment and can result in bank and channel erosion.

The low flow or baseflow during the dry periods of summer or fall usually comes from groundwater entering the stream through the stream banks and bottom. A decrease in the low-flow rate will result in a smaller portion of the channel suitable for aquatic organisms. The withdrawal of water from streams for irrigation or industry and the placement of dams often change the normal low-flow pattern. Baseflow can also be affected by management and land use within the watershed — less infiltration of precipitation reduces baseflow and increases the frequency and severity of high flow events. For example, urbanization increases runoff and can increase the frequency of flooding to every year or more often and also reduce low flows. Overgrazing and clearcutting can have similar, although typically less severe, effects. The last description in the last box refers to the increased flood frequency that occurs with the above watershed changes.

What to look for: Ask the landowner about the frequency of flooding and about summer low-flow conditions. A flood plain should be inundated during flows that equal or exceed the 1.5- to 2.0-year flow event (2 out of 3 years or every other year). Be cautious because water in an adjacent field does not necessarily indicate natural flooding. The water may have flowed overland from a low spot in the bank outside the assessment reach.

Evidence of flooding includes high water marks (such as water lines), sediment deposits, or stream debris. Look for these on the banks, on the bankside trees or rocks, or on other structures (such as road pilings or culverts).

Excess sediment deposits and wide, shallow channels could indicate a loss of sediment transport capacity. The loss of transport capacity can result in a stream with three or more channels (braiding).

Riparian zone

Natural vegetation extends at least two active channel widths on each side.	Natural vegetation extends one active channel width on each side. or If less than one width, covers entire flood plain.	Natural vegetation extends half of the active channel width on each side.	Natural vegetation extends a third of the active channel width on each side. or Filtering function moderately compromised.	Natural vegetation less than a third of the active channel width on each side. or Lack of regeneration. or Filtering function severely compromised.
10	8	5	3	1

This element is the width of the natural vegetation zone from the edge of the active channel out onto the flood plain. For this element, the word *natural* means plant communities with (1) all appropriate structural components and (2) species native to the site or introduced species that function similar to native species at reference sites.

A healthy riparian vegetation zone is one of the most important elements for a healthy stream ecosystem. The quality of the riparian zone increases with the width and the complexity of the woody vegetation within it. This zone:

- Reduces the amount of pollutants that reach the stream in surface runoff.
- Helps control erosion.
- Provides a microclimate that is cooler during the summer providing cooler water for aquatic organisms.
- Provides large woody debris from fallen trees and limbs that form instream cover, create pools, stabilize the streambed, and provide habitat for stream biota.
- Provides fish habitat in the form of undercut banks with the "ceiling" held together by roots of woody vegetation.
- Provides organic material for stream biota that, among other functions, is the base of the food chain in lower order streams.
- Provides habitat for terrestrial insects that drop in the stream and become food for fish, and habitat and travel corridors for terrestrial animals.
- Dissipates energy during flood events.
- Often provides the only refuge areas for fish during out-of-bank flows (behind trees, stumps, and logs).

The type, timing, intensity, and extent of activity in riparian zones are critical in determining the impact on these areas. Narrow riparian zones and/or riparian zones that have roads, agricultural activities, residential or commercial structures, or significant areas of bare soils have reduced functional value for the stream. The filtering function of riparian zones can be compromised by concentrated flows. No evidence of concentrated flows through the zone should occur or, if concentrated flows are evident, they should be from land areas appropriately buffered with vegetated strips.

What to look for: Compare the width of the riparian zone to the active channel width. In steep, V-shaped valleys there may not be enough room for a flood plain riparian zone to extend as far as one or two active channel widths. In this case, observe how much of the flood plain is covered by riparian zone. The vegetation must be natural and consist of all of the structural components (aquatic plants, sedges or rushes, grasses, forbs, shrubs, understory trees, and overstory trees) appropriate for the area. A common problem is lack of shrubs and understory trees. Another common problem is lack of regeneration. The presence of only mature vegetation and few seedlings indicates lack of regeneration. Do not consider incomplete plant communities as natural. Healthy riparian zones on both sides of the stream are important for the health of the entire system. If one side is lacking the protective vegetative cover, the entire reach of the stream will be affected. In doing the assessment, examine both sides of the stream and note on the diagram which side of the stream has problems. There should be no evidence of concentrated flows through the riparian zone that are not adequately buffered before entering the riparian zone.

Bank stability

Banks are stable; banks are low (at elevation of active flood plain); 33% or more of eroding surface area of banks in outside bends is protected by roots that extend to the base-flow elevation.	Moderately stable; banks are low (at elevation of active flood plain); less than 33% of eroding surface area of banks in outside bends is protected by roots that extend to the baseflow elevation.	Moderately unstable; banks may be low, but typically are high (flooding occurs 1 year out of 5 or less frequently); outside bends are actively eroding (overhanging vegetation at top of bank, some mature trees falling into steam annually, some slope failures apparent).	Unstable; banks may be low, but typically are high; some straight reaches and inside edges of bends are actively eroding as well as outside bends (overhanging vegetation at top of bare bank, numerous mature trees falling into stream annually, numerous slope failures apparent).
10	7	3	1

This element is the existence of or the potential for detachment of soil from the upper and lower stream banks and its movement into the stream. Some bank erosion is normal in a healthy stream. Excessive bank erosion occurs where riparian zones are degraded or where the stream is unstable because of changes in hydrology, sediment load, or isolation from the flood plain. High and steep banks are more susceptible to erosion or collapse. All outside bends of streams erode, so even a stable stream may have 50 percent of its banks bare and eroding. A healthy riparian corridor with a vegetated flood plain contributes to bank stability. The roots of perennial grasses or woody vegetation typically extend to the baseflow elevation of water in streams that have bank heights of 6 feet or less. The root masses help hold the bank soils together and physically protect the bank from scour during bankfull and flooding events. Vegetation seldom becomes established below the elevation of the bankfull surface because of the frequency of inundation and the unstable bottom conditions as the stream moves its bedload.

The type of vegetation is important. For example, trees, shrubs, sedges, and rushes have the type of root masses capable of withstanding high streamflow events, while Kentucky bluegrass does not. Soil type at the surface and below the surface also influences bank stability. For example, banks with a thin soil cover over gravel or sand are more prone to collapse than are banks with a deep soil layer.

What to look for: Signs of erosion include unvegetated stretches, exposed tree roots, or scalloped edges. Evidence of construction, vehicular, or animal paths near banks or grazing areas leading directly to the water's edge suggest conditions that may lead to the collapse of banks. Estimate the size or area of the bank affected relative to the total bank area. This element may be difficult to score during high water.

Water appearance

Very clear, or clear but tea-colored; objects visible at depth 3 to 6 ft (less if slightly colored); no oil sheen on surface; no noticeable film on submerged objects or rocks.	Occasionally cloudy, especially after storm event, but clears rapidly; objects visible at depth 1.5 to 3 ft; may have slightly green color; no oil sheen on water surface.	Considerable cloudiness most of the time; objects visible to depth 0.5 to 1.5 ft; slow sections may appear pea-green; bottom rocks or submerged objects covered with heavy green or olive-green film. or Moderate odor of ammonia or rotten eggs.	Very turbid or muddy appearance most of the time; objects visible to depth < 0.5 ft; slow moving water may be bright-green; other obvious water pollutants; floating algal mats, surface scum, sheen or heavy coat of foam on surface. or Strong odor of chemicals, oil, sewage, other pollutants.
10	7	3	1

This element compares turbidity, color, and other visual characteristics with a healthy or reference stream. The depth to which an object can be clearly seen is a measure of turbidity. Turbidity is caused mostly by particles of soil and organic matter suspended in the water column. Water often shows some turbidity after a storm event because of soil and organic particles carried by runoff into the stream or suspended by turbulence. The water in some streams may be naturally tea-colored. This is particularly true in watersheds with extensive bog and wetland areas. Water that has slight nutrient enrichment may support communities of algae, which provide a greenish color to the water. Streams with heavy loads of nutrients have thick coatings of algae attached to the rocks and other submerged objects. In degraded streams, floating algal mats, surface scum, or pollutants, such as dyes and oil, may be visible.

What to look for: Clarity of the water is an obvious and easy feature to assess. The deeper an object in the water can be seen, the lower the amount of turbidity. Use the depth that objects are visible only if the stream is deep enough to evaluate turbidity using this approach. For example, if the water is clear, but only 1 foot deep, do not rate it as if an object became obscured at a depth of 1 foot. This measure should be taken after a stream has had the opportunity to "settle" following a storm event. A pea-green color indicates nutrient enrichment beyond what the stream can naturally absorb.

Nutrient enrichment

Clear water along entire reach; diverse aquatic plant community includes low quantities of many species of macrophytes; little algal growth present.	Fairly clear or slightly greenish water along entire reach; moderate algal growth on stream substrates.	Greenish water along entire reach; overabundance of lush green macrophytes; abundant algal growth, especially during warmer months.	Pea green, gray, or brown water along entire reach; dense stands of macrophytes clog stream; severe algal blooms create thick algal mats in stream.
10	7	3	1

Nutrient enrichment is often reflected by the types and amounts of aquatic vegetation in the water. High levels of nutrients (especially phosphorus and nitrogen) promote an overabundance of algae and floating and rooted macrophytes. The presence of some aquatic vegetation is normal in streams. Algae and macrophytes provide habitat and food for all stream animals. However, an excessive amount of aquatic vegetation is not beneficial to most stream life. Plant respiration and decomposition of dead vegetation consume dissolved oxygen in the water. Lack of dissolved oxygen creates stress for all aquatic organisms and can cause fish kills. A landowner may have seen fish gulping for air at the water surface during warm weather, indicating a lack of dissolved oxygen.

What to look for: Some aquatic vegetation (rooted macrophytes, floating plants, and algae attached to substrates) is normal and indicates a healthy stream. Excess nutrients cause excess growth of algae and macrophytes, which can create greenish color to the water. As nutrient loads increase the green becomes more intense and macrophytes become more lush and deep green. Intense algal blooms, thick mats of algae, or dense stands of macrophytes degrade water quality and habitat. Clear water and a diverse aquatic plant community without dense plant populations are optimal for this characteristic.

Barriers to fish movement

No barriers	Seasonal water withdrawals inhibit movement within the reach	Drop structures, culverts, dams, or diversions (< 1 foot drop) within the reach	Drop structures, culverts, dams, or diversions (> 1 foot drop) within 3 miles of the reach	Drop structures, culverts, dams, or diversions (> 1 foot drop) within the reach
10	8	5	3	1

Barriers that block the movement of fish or other aquatic organisms, such as fresh water mussels, must be considered as part of the overall stream assessment. If sufficiently high, these barriers may prevent the movement or migration of fish, deny access to important breeding and foraging habitats, and isolate populations of fish and other aquatic animals.

What to look for: Some barriers are natural, such as waterfalls and boulder dams, and some are developed by humans. Note the presence of such barriers along the reach of the stream you are assessing, their size, and whether provisions have been made for the passage of fish. Ask the landowner about any dams or other barriers that may be present 3 to 5 miles upstream or downstream. Larger dams are often noted on maps, so you may find some information even before going out into the field. Beaver dams generally do not prevent fish migration. Look for structures that may not involve a drop, but still present a hydraulic barrier. Single, large culverts with no slope and sufficient water depth usually do not constitute a barrier. Small culverts or culverts with slopes may cause high water velocities that prevent passage.

Instream fish cover

>7 cover types available	6 to 7 cover types available	4 to 5 cover types available	2 to 3 cover types available	None to 1 cover type available
10	8	5	3	1

Cover types: Logs/large woody debris, deep pools, overhanging vegetation, boulders/cobble, riffles, undercut banks, thick root mats, dense macrophyte beds, isolated/backwater pools, other: ________________________________.

This assessment element measures availability of physical habitat for fish. The potential for the maintenance of a healthy fish community and its ability to recover from disturbance is dependent on the variety and abundance of suitable habitat and cover available.

What to look for: Observe the number of different habitat and cover types *within a representative subsection of the assessment* reach that is equivalent in length to *five times* the active channel width. Each cover type must be present in appreciable amounts to score. Cover types are described below.

Logs/large woody debris—Fallen trees or parts of trees that provide structure and attachment for aquatic macroinvertebrates and hiding places for fish.

Deep pools—Areas characterized by a smooth undisturbed surface, generally slow current, and deep enough to provide protective cover for fish (75 to 100% deeper than the prevailing stream depth).

Overhanging vegetation—Trees, shrubs, vines, or perennial herbaceous vegetation that hangs immediately over the stream surface, providing shade and cover.

Boulders/cobble—Boulders are rounded stones more than 10 inches in diameter or large slabs more than 10 inches in length; cobbles are stones between 2.5 and 10 inches in diameter.

Undercut banks—Eroded areas extending horizontally beneath the surface of the bank forming underwater pockets used by fish for hiding and protection.

Thick root mats—Dense mats of roots and rootlets (generally from trees) at or beneath the water surface forming structure for invertebrate attachment and fish cover.

Dense macrophyte beds—Beds of emergent (e.g., water willow), floating leaf (e.g., water lily), or submerged (e.g., riverweed) aquatic vegetation thick enough to provide invertebrate attachment and fish cover.

Riffles—Area characterized by broken water surface, rocky or firm substrate, moderate or swift current, and relatively shallow depth (usually less than 18 inches).

Isolated/backwater pools—Areas disconnected from the main channel or connected as a "blind" side channel, characterized by a lack of flow except in periods of high water.

Pools

Deep and shallow pools abundant; greater than 30% of the pool bottom is obscure due to depth, or the pools are at least 5 feet deep.	Pools present, but not abundant; from 10 to 30% of the pool bottom is obscure due to depth, or the pools are at least 3 feet deep.	Pools present, but shallow; from 5 to 10% of the pool bottom is obscure due to depth, or the pools are less than 3 feet deep.	Pools absent, or the entire bottom is discernible.
10	7	3	1

Pools are important resting and feeding sites for fish. A healthy stream has a mix of shallow and deep pools. A *deep* pool is 1.6 to 2 times deeper than the prevailing depth, while a *shallow* pool is less than 1.5 times deeper than the prevailing depth. Pools are abundant if a deep pool is in each of the meander bends in the reach being assessed. To determine if pools are abundant, look at a longer sample length than one that is 12 active channel widths in length. Generally, only 1 or 2 pools would typically form within a reach as long as 12 active channel widths. In low order, high gradient streams, pools are abundant if there is more than one pool every 4 channel widths.

What to look for: Pool diversity and abundance are estimated based on walking the stream or probing from the streambank with a stick or length of rebar. You should find deep pools on the outside of meander bends. In shallow, clear streams a visual inspection may provide an accurate estimate. In deep streams or streams with low visibility, this assessment characteristic may be difficult to determine and should not be scored.

Insect/invertebrate habitat

At least 5 types of habitat available. Habitat is at a stage to allow full insect colonization (woody debris and logs not freshly fallen).	3 to 4 types of habitat. Some potential habitat exists, such as overhanging trees, which will provide habitat, but have not yet entered the stream.	1 to 2 types of habitat. The substrate is often disturbed, covered, or removed by high stream velocities and scour or by sediment deposition.	None to 1 type of habitat.
10	7	3	1

Cover types: Fine woody debris, submerged logs, leaf packs, undercut banks, cobble, boulders, coarse gravel, other: ____.

Stable substrate is important for insect/invertebrate colonization. *Substrate* refers to the stream bottom, woody debris, or other surfaces on which invertebrates can live. Optimal conditions include a variety of substrate types within a relatively small area of the stream (5 times the active channel width). Stream and substrate stability are also important. High stream velocities, high sediment loads, and frequent flooding may cause substrate instability even if substrate is present.

What to look for: Observe the number of different types of habitat and cover within a representative subsection of the assessment reach that is equivalent in length to five times the active channel width. Each cover type must be present in appreciable amounts to score.

Score the following assessment elements
only if applicable

Canopy cover (if applicable)

Coldwater fishery

> 75% of water surface shaded and upstream 2 to 3 miles generally well shaded.	>50% shaded in reach. or >75% in reach, but upstream 2 to 3 miles poorly shaded.	20 to 50% shaded.	< 20% of water surface in reach shaded.
10	7	3	1

Warmwater fishery

25 to 90% of water surface shaded; mixture of conditions.	> 90% shaded; full canopy; same shading condition throughout the reach.	(intentionally blank)	< 25% water surface shaded in reach.
10	7		1

Do not assess this element if active channel width is greater than 50 feet. Do not assess this element if woody vegetation is naturally absent (e.g., wet meadows).

Shading of the stream is important because it keeps water cool and limits algal growth. Cool water has a greater oxygen holding capacity than does warm water. When streamside trees are removed, the stream is exposed to the warming effects of the sun causing the water temperature to increase for longer periods during the daylight hours and for more days during the year. This shift in light intensity and temperature causes a decline in the numbers of certain species of fish, insects, and other invertebrates and some aquatic plants. They may be replaced altogether by other species that are more tolerant of increased light intensity, low dissolved oxygen, and warmer water temperature. For example, trout and salmon require cool, oxygen-rich water. Loss of streamside vegetation (and also channel widening) that cause increased water temperature and decreased oxygen levels are major contributing factors to the decrease in abundance of trout and salmon from many streams that historically supported these species. Increased light and the warmer water also promote excessive growth of submerged macrophytes and algae that compromises the biotic community of the stream. The temperature at the reach you are assessing will be affected by the amount of shading 2 to 3 miles upstream.

What to look for: Try to estimate the portion of the water surface area for the whole reach that is shaded by estimating areas with no shade, poor shade, and shade. Time of the year, time of the day, and weather can affect your observation of shading. Therefore, the relative amount of shade is estimated by assuming that the sun is directly overhead and the vegetation is in full leaf-out. First evaluate the shading conditions for the reach; then determine (by talking with the landowner) shading conditions 2 to 3 miles upstream. Alternatively, use aerial photographs taken during full leaf out. The following rough guidelines for percent shade may be used:

stream surface not visible	>90
surface slightly visible or visible only in patches	70 – 90
surface visible, but banks not visible	40 – 70
surface visible and banks visible at times	20 – 40
surface and banks visible	<20

Manure presence (if applicable)

(Intentionally blank)	Evidence of livestock access to riparian zone.	Occasional manure in stream or waste storage structure located on the flood plain.	Extensive amount of manure on banks or in stream. or Untreated human waste discharge pipes present.
	5	3	1

Do not score this element unless livestock operations or human waste discharges are present.

Manure from livestock may enter the water if livestock have access to the stream or from runoff of grazing land adjacent to the stream. In some communities untreated human waste may also empty directly into streams. Manure and human waste increase biochemical oxygen demand, increase the loading of nutrients, and alter the trophic state of the aquatic biological community. Untreated human waste is a health risk.

What to look for: Do not score this element unless livestock operations or human waste discharges are present. Look for evidence of animal droppings in or around streams, on the streambank, or in the adjacent riparian zone. Well-worn livestock paths leading to or near streams also suggest the probability of manure in the stream. Areas with stagnant or slow-moving water may have moderate to dense amounts of vegetation or algal blooms, indicating localized enrichment from manure.

Salinity (if applicable)

(Intentionally blank)	Minimal wilting, bleaching, leaf burn, or stunting of aquatic vegetation; some salt-tolerant streamside vegetation.	Aquatic vegetation may show significant wilting, bleaching, leaf burn, or stunting; dominance of salt-tolerant streamside vegetation.	Severe wilting, bleaching, leaf burn, or stunting; presence of only salt-tolerant aquatic vegetation; most streamside vegetation salt tolerant.
	5	3	1

Do not assess this element unless elevated salinity from anthropogenic sources is known to occur in the stream.

High salinity levels most often occur in arid areas and in areas that have high irrigation requirements. High salinity can also result from oil and gas well operations. Salt accumulation in soil causes a breakdown of soil structure, decreased infiltration of water, and potential toxicity. High salinity in streams affects aquatic vegetation, macroinvertebrates, and fish. Salts are a product of natural weathering processes of soil and geologic material.

What to look for: High salinity levels cause a "burning" or "bleaching" of aquatic vegetation. Wilting, loss of plant color, decreased productivity, and stunted growth are readily visible signs. Other indicators include whitish salt encrustments on the streambanks and the displacement of native vegetation by salt-tolerant aquatic plants and riparian vegetation (such as tamarix or salt cedar).

Riffle embeddedness (if applicable)

Gravel or cobble particles are < 20% embedded.	Gravel or cobble particles are 20 to 30% embedded.	Gravel or cobble particles are 30 to 40% embedded.	Gravel or cobble particles are >40% embedded.	Riffle is completely embedded.
10	8	5	3	1

Do not assess this element unless riffles are present or they are a natural feature that should be present.

Riffles are areas, often downstream of a pool, where the water is breaking over rocks or other debris causing surface agitation. In coastal areas riffles can be created by shoals and submerged objects. (This element is sensitive to regional differences and should be related to reference conditions.) Riffles are critical for maintaining high species diversity and abundance of insects for most streams and for serving as spawning and feeding grounds for some fish species. Embeddedness measures the degree to which gravel and cobble substrate are surrounded by fine sediment. It relates directly to the suitability of the stream substrate as habitat for macroinvertebrates, fish spawning, and egg incubation.

What to look for: This assessment characteristic should be used only in riffle areas and in streams where this is a natural feature. The measure is the depth to which objects are buried by sediment. This assessment is made by picking up particles of gravel or cobble with your fingertips at the fine sediment layer. Pull the particle out of the bed and estimate what percent of the particle was buried. Some streams have been so smothered by fine sediment that the original stream bottom is not visible. Test for complete burial of a streambed by probing with a length of rebar.

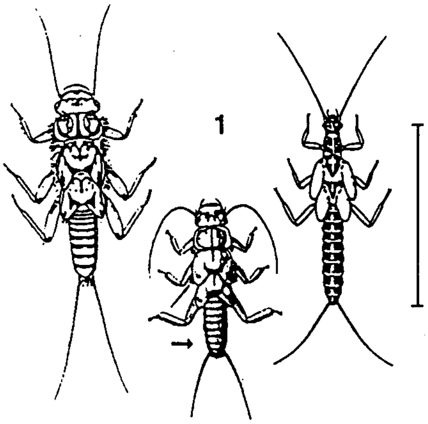
Macroinvertebrates observed

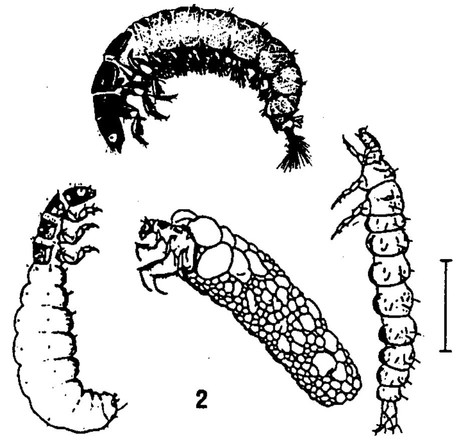
Community dominated by Group I or intolerant species with good species diversity. Examples include caddisflies, mayflies, stoneflies, hellgrammites.	Community dominated by Group II or facultative species, such as damselflies, dragonflies, aquatic sowbugs, blackflies, crayfish.	Community dominated by Group III or tolerant species, such as midges, craneflies, horseflies, leeches, aquatic earthworms, tubificid worms.	Very reduced number of species or near absence of all macroinvertebrates.
15	6	2	– 3

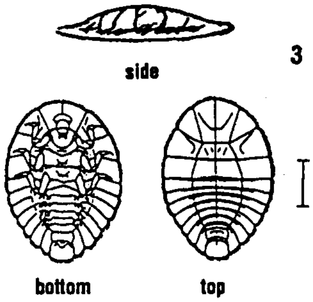
This important characteristic reflects the ability of the stream to support aquatic invertebrate animals. However, successful assessment requires knowledge of the life cycles of some aquatic insects and other macroinvertebrates and the ability to identify them. For this reason, this is an optional element. The presence of intolerant insect species (cannot survive in polluted water) indicates healthy stream conditions. Some kinds of macroinvertebrates, such as stoneflies, mayflies, and caddisflies, are sensitive to pollution and do not live in polluted water; they are considered Group I. Another group of macroinvertebrates, known as Group II or facultative macroinvertebrates, can tolerate limited pollution. This group includes damselflies, aquatic sowbugs, and crayfish. The presence of Group III macroinvertebrates, including midges, craneflies and leeches, suggests the water is significantly polluted. The presence of a single Group I species in a community does not constitute good diversity and should generally not be given a score of 15.

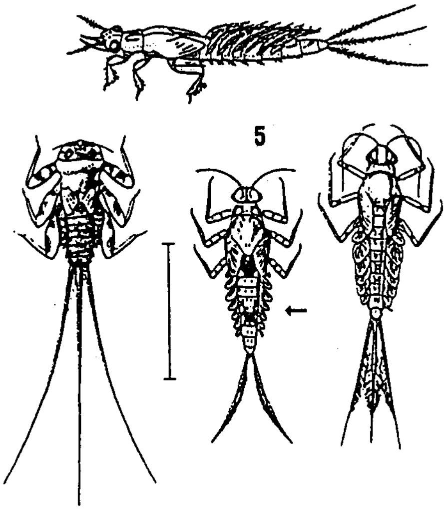
What to look for: You can collect macroinvertebrates by picking up cobbles and other submerged objects in the water. Look carefully for the insects; they are often well camouflaged and may appear as part of the stone or object. Note the kinds of insects, number of species, and relative abundance of each group of insects/macroinvertebrates. Each of the three classes of macroinvertebrates are illustrated on pages 19 and 20. ***Note that the scoring values for this element range from – 3 to 15.***

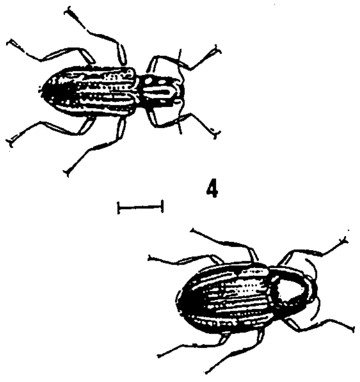
Stream Invertebrates

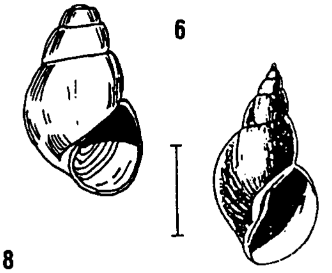


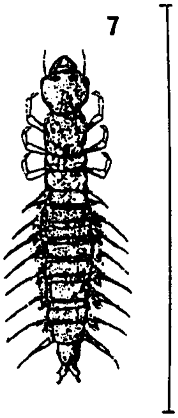


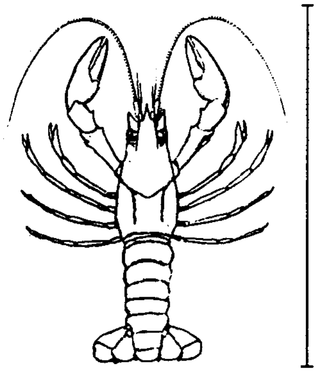


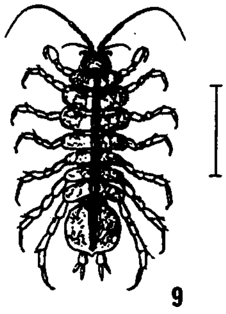












Bar line indicate relative size

Group One Taxa

Pollution sensitive organisms found in good quality water.

1 **Stonefly Order Plecoptera.** 1/2" to 1 1/2", 6 legs with hooked tips, antennae, 2 hair-line tails. Smooth (no gills) on lower half of body (see arrow).

2 **Caddisfly: Order Trichoptera.** Up to 1", 6 hooked legs on upper third of body, 2 hooks at back end. May be in a stick, rock, or leaf case with its head sticking out. May have fluffy gill tufts on underside.

3 **Water Penny: Order Coleoptera.** 1/4", flat saucer-shaped body with a raised bump on one side and 6 tiny legs and fluffy gills on the other side. Immature beetle.

4 **Riffle Beetle: Order Coleoptera.** 1/4", oval body covered with tiny hairs, 6 legs, antennae. Walks slowly underwater. Does not swim on surface.

5 **Mayfly: Order Ephemeroptera.** 1/4" to 1", brown, moving, plate-like or feathery gills on the sides of lower body (see arrow), 6 large hooked legs, antennae, 2 or 3 long hair-like tails. Tails may be webbed together.

6 **Gilled Snail: Class Gastropoda.** Shell opening covered by thin plate called operculum. When opening is facing you, shell usually opens on right.

7 **Dobsonfly (Hellgrammite): Family Corydalidae.** 3/4" to 4", dark-colored, 6 legs, large pinching jaws, eight pairs feelers on lower half of body with paired cotton-like gill tufts along underside, short antennae, 2 tails, and 2 pairs of hooks at back end.

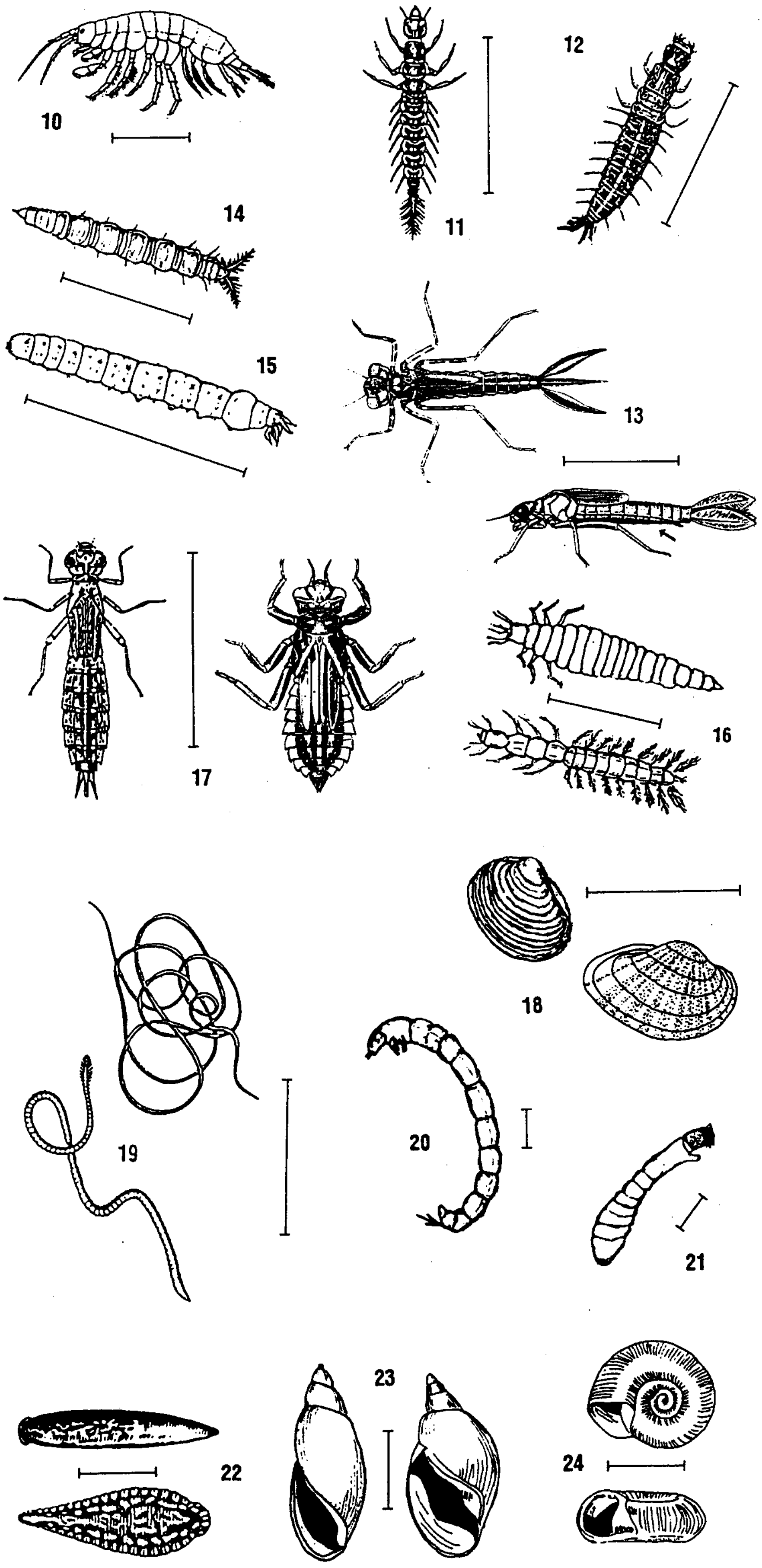
Group Two Taxa

Somewhat pollution tolerant organisms can be in good or fair quality water.

8 **Crayfish: Order Decapoda.** Up to 6", 2 large claws, 8 legs, resembles small lobster.

9 **Sowbug: Order Isopoda.** 1/4" to 3/4", gray oblong body wider than it is high, more than 6 legs, long antennae.

Source: Izaak Walton League of America, 707 Conservation Lane, Gaithersburg, MD 20878-2983. (800) BUG-IWLA



Bar line indicate relative size

Group Two Taxa

Somewhat pollution tolerant organisms can be in good or fair quality water.

10 Scud: Order Amphipoda. 1/4", white to gray, body higher than it is wide, swims sideways, more than 6 legs, resembles small shrimp.

11 Alderfly Larva: Family Sialedae. 1" long. Looks like small Hellgramite but has long, thin, branched tail at back end (no hooks). No gill tufts underneath.

12 Fishfly Larva: Family Cordalidae. Up to 1 1/2" long. Looks like small hellgramite but often a lighter reddish-tan color, or with yellowish streaks. No gill tufts underneath.

13 Damselfly: Suborder Zygoptera. 1/2" to 1", large eyes, 6 thin hooked legs, 3 broad oar-shaped tails, positioned like a tripod. Smooth (no gills) on sides of lower half of body. (See arrow.)

14 Watersnipe Fly Larva: Family Athericidae (Atherix). 1/4" to 1", pale to green, tapered body, many caterpillar-like legs, conical head, feathery "horns" at back end.

15 Crane Fly: Suborder Nematocera. 1/3" to 2", milky, green, or light brown, plump caterpillar-like segmented body, 4 finger-like lobes at back end.

16 Beetle Larva: Order Coleoptera. 1/4" to 1", light-colored, 6 legs on upper half of body, feelers, antennae.

17 Dragon Fly: Suborder Anisoptera. 1/2" to 2", large eyes, 6 hooked legs. Wide oval to round abdomen.

18 Clam: Class Bivalvia.

Group Three Taxa

Pollution tolerant organisms can be in any quality of water.

19 Aquatic Worm: Class Oligochaeta. 1/4" to 2", can be very tiny, thin worm-like body.

20 Midge Fly Larva: Suborder Nematocera. Up to 1/4", dark head, worm-like segmented body, 2 tiny legs on each side.

21 Blackfly Larva: Family Simulidae. Up to 1/4", one end of body wider. Black head, suction pad on other end.

22 Leech: Order Hirudinea. 1/4" to 2", brown, slimy body, ends with suction pads.

23 Pouch Snail and Pond Snails: Class Gastropoda. No operculum. Breath air. When opening is facing you, shell usually open to left.

24 Other Snails: Class Gastropoda. No operculum.Breath air. Snail shell coils in one plane.

Technical information to support implementation

Introduction

This section provides a guide for implementation of the Stream Visual Assessment Protocol (SVAP). The topics covered in this section include the origin of the protocol, development history, context for use in relation to other methods of stream assessment, instructions for modifying the protocol, and references.

Origin of the protocol

In 1996 the NRCS National Water and Climate Center surveyed the NRCS state biologists to determine the extent of activity in stream ecological assessment and the need for technical support. The survey indicated that less than a third of the NRCS states were active in supporting stream assessment within their state. Most respondents said they believed they should be more active and requested additional support from the National Centers and Institutes. In response to these findings, the NRCS Aquatic Assessment Workgroup was formed. In their first meeting the workgroup determined that a simple assessment protocol was needed. The Water Quality Indicators Guide (WQIG) had been available for 8 years, but was not being used extensively. The workgroup felt a simpler and more streamlined method was needed as an initial protocol for field office use.

The workgroup developed a plan for a tiered progression of methods that could be used in the field as conservationists became more skilled in stream assessment. These methods would also serve different assessment objectives. The first tier is a simple 2-page assessment — the Stream Visual Assessment Protocol (SVAP). The second tier is the existing WQIG. The third tier is a series of simple assessment methods that could be conducted by conservationists in the field. An example of a third tier method would be macroinvertibrate sampling and identification to the taxonomic level of Order. The fourth tier is fairly sophisticated methods used in special projects. Examples of fourth tier methods would be fish community sampling and quantitative sampling of macroinvertebrates with shipment of samples to a lab for identification.

The workgroup also found that introductory training and a field handbook that would serve as a comprehensive reference and guidance manual are needed. These projects are under development as of this writing.

Context for use

The Stream Visual Assessment Protocol is intended to be a simple, comprehensive assessment of stream condition that maximizes ease of use. It is suitable as a basic first approximation of stream condition. It can also be used to identify the need for more accurate assessment methods that focus on a particular aspect of the aquatic system.

The relationship of the SVAP to other assessment methods is shown in figure 4. In this figure a specific reference to a guidance document is provided for some methods. The horizontal bars indicate which aspects of stream condition (chemical, physical, or biological) are addressed by the method. The SVAP is the simplest method and covers all three aspects of stream condition. As you move upwards in figure 4 the methods provide more accuracy, but also become more focused on one or two aspects of stream condition and require more expertise or resources to conduct.

The SVAP is intended to be applicable nationwide. It has been designed to utilize factors that are least sensitive to regional differences. However, regional differences are a significant aspect of stream assessment, and the protocol can be enhanced by tailoring the assessment elements to regional conditions. The national SVAP can be viewed as a framework that can evolve over time to better reflect State or within-State regional differences. Instructions for modification are provided later in this document.

Development

The SVAP was developed by combining parts of several existing assessment procedures. Many of these sources are listed in the references section. Three drafts were developed and reviewed by the workgroup and others between the fall of 1996 and the spring of 1997. During the summer of 1997, the workgroup conducted a field trial evaluation of the third draft. Further field trials were conducted with the fourth draft in 1998. A report on the field trial results is appendix A of this document.

The field trials involved approximately 60 individuals and 182 assessment sites. The field trial consisted of a combination of replication studies (in which several individuals independently assessed the same sites) and accuracy studies (in which SVAP scores were compared to the results from other assessment methods). The average coefficient of variation in the replication studies was 10.5 percent. The accuracy results indicated that SVAP version 3 scores correlated well with other methods for moderately impacted and high quality sites, but that low quality sites were not scoring correspondingly low in the SVAP. Conservationists in the field who participated in the trial were surveyed on the usability and value of the protocol. The participants indicated that they found it easy to use and thought it would be valuable for their clients.

Revisions were made to the draft to address the deficiencies identified in the field trial, and some reassessments were made during the winter of 1998 to see how the revisions affected performance. Performance was improved. Additional revisions were made, and the fifth draft was sent to all NRCS state offices, selected Federal agencies, and other partners for review and comment during the spring of 1998.

Comments were received from eight NRCS state offices, the Bureau of Land Management, and several NRCS national specialists. Comments were uniformly supportive of the need for the guidance and for the document as drafted. Many commenters provided improved explanatory text for the supporting descriptions accompanying the assessment elements. Most of the suggested revisions were incorporated.

Implementation

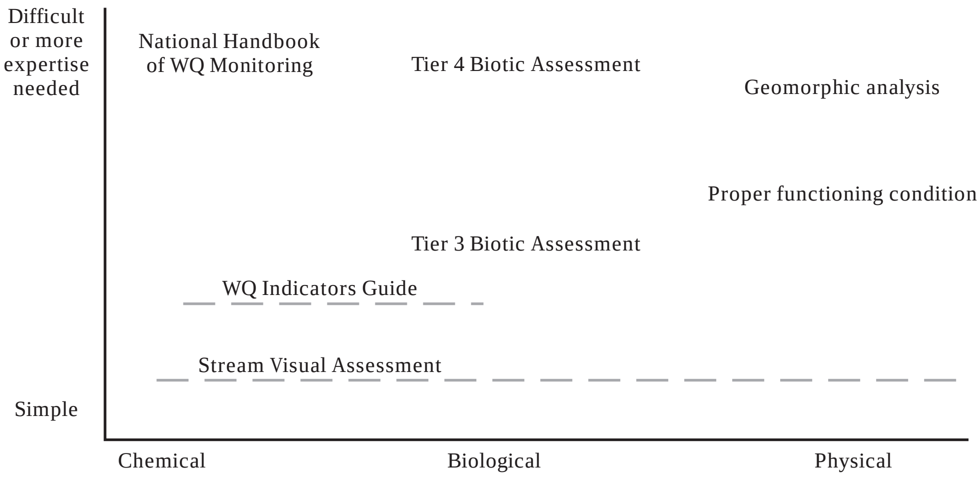
The SVAP is issued as a national product. States are encouraged to incorporate it within the Field Office Technical Guide. The document may be modified by States. The electronic file for the document may be downloaded from the National Water and Climate Center web site at http://www.wcc.nrcs.usda.gov.

A training course for conservationists in the field suitable for use at the state or area level has been developed to facilitate implementation of the SVAP. It is designed as either a 1-day or 2-day session. The first day covers basic stream ecology and use of the SVAP. The second day includes an overview of several stream assessment methods, instruction on a macroinvertebrate survey method, and field exercises to apply the SVAP and macroinvertibrate protocols. The training materials consist of an instructor's guide, slides, video, a macroinvertebrate assessment training kit, and a student workbook. Training materials have been provided to each NRCS state office.

Instructions for modification

The national version of the Stream Visual Assessment Protocol may be used without modification. It has been designed to use assessment elements that are least sensitive to regional differences. Nonetheless, it can be modified to better reflect conditions within a geographic area. Modifying the protocol would have the following benefits:
- The protocol can be made easier to use with narrative descriptions that are closer to the conditions users will encounter.
- The protocol can be made more responsive to differences in stream condition.
- Precision can be improved by modifying elements that users have trouble evaluating.
- The rating scale can be calibrated to regionally-based criteria for excellent, good, fair, and poor condition.

Figure 4 Relationship of various stream condition assessment methods in terms of complexity or expertise required and the aspects of stream condition addressed



Two parts of the SVAP may be modified—the individual elements and their narrative descriptions, and the rating scale for assigning an overall condition rating of excellent, good, fair, or poor.

The simplest approach to modifying the SVAP is based on professional experience and judgment. Under this approach an interdisciplinary team should be assembled to develop proposed revisions. Revisions should then be evaluated by conducting comparison assessments at sites representing a range of conditions and evaluating accuracy (correlation between different assessment methods), precision (reproducibility among different users), and ease of use.

A second, more scientifically rigorous method for modifying the protocol is described below. This approach is based on a classification system for stream type and the use of reference sites.

Step 1 Decide on tentative number of versions.
Do you want to develop a revised version for your state, for each ecoregion within your state, or for several stream classes within each ecoregion?

Step 2 Develop tentative stream classification.
If you are developing protocols by stream class, you need to develop a tentative classification system. (If you are interested in a statewide or ecoregion protocol, go to step 3.) You might develop a classification system based on stream order, elevation, or landscape character. Do not create too many categories. The greater the number of categories, the more assessment work will be needed to modify the protocol and the more you will be accommodating degradation within the evaluation system. As an extreme example of the latter problem, you would not want to create a stream class consisting of those streams that have bank-to-bank cropping and at least one sewage outfall.

Step 3 Assess sites.
Assess a series of sites representing a range of conditions from highly impacted sites to least impacted sites. Try to have at least 10 sites in each of your tentative classes. Those sites should include several potential “least impacted reference sites.” Try to use sites that have been assessed by other assessment methods (such as sites assessed by state agencies or universities). As part of the assessments, be sure to record information on potential classification factors and if any particular elements are difficult to score. Take notes so that future revisions of the elements can be rescored without another site visit.

Step 4 Rank the sites.
Begin your data analysis by ranking all the sites from most impacted to least impacted. Rank sites according to the independent assessment results (preferred) or by the SVAP scores. Initially, rank all of the sites in the state data set. You will test classifications in subsequent iterations.

Step 5 Display scoring data.
Prepare a chart of the data from all sites in your state. The columns are the sites arranged by the ranking. The rows are the assessment elements, the overall numerical score, and the narrative rating. If you have independent assessment data, create a second chart by plotting the overall SVAP scores against the independent scores.

Step 6 Evaluate responsiveness.
Does the SVAP score change in response to the condition gradient represented by the different sites? Are the individual element scores responding to key resource problems? Were users comfortable with all elements? If the answers are yes, do not change the elements and proceed to step 7. If the answers are no, isolate which elements are not responsive. Revise the narrative descriptions for those elements to better respond to the observable conditions. Conduct a "desktop" reassessment of the sites with the new descriptions, and return to step 4.

Step 7 Evaluate the narrative rating breakpoints.
Do the breakpoints for the narrative rating correspond to other assessment results? The excellent range should encompass only reference sites. If not, you should reset the narrative rating breakpoints. Set the excellent breakpoint based on the least impacted reference sites. You must use judgment to set the other breakpoints.

Step 8 Evaluate tentative classification system.
Go back to step 4 and display your data this time by the tentative classes (ecoregions or stream classes). In other words, analyze sites from each ecoregion or each stream class separately. Repeat steps 5 through 7. If the responsiveness is significantly different from the responsiveness of the statewide data set or the breakpoints appear to be significantly different, adopt the classification system and revise the protocol for each ecoregion or stream class. If not, a single statewide protocol is adequate.

After the initial modification of the SVAP, the state may want to set up a process to consider future revisions. Field offices should be encouraged to locate and assess least impacted reference sites to build the data base for interpretation and future revisions. Ancillary data should be collected to help evaluate whether a potential reference site should be considered a reference site.

Caution should be exercised when considering future revisions. Revisions complicate comparing SVAP scores determined before and after the implementation of conservation practices if the protocol is substantially revised in the intervening period. Developing information to support refining the SVAP can be carried out by graduate students working cooperatively with NRCS. The Aquatic Assessment Workgroup has been conducting a pilot Graduate Student Fellowship program to evaluate whether students would be willing to work cooperatively for a small stipend. Early results indicate that students can provide valuable assistance. However, student response to advertisements has varied among states. If the pilot is successful, the program will be expanded.

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Glossary

Active channel width	The width of the stream at the bankfull discharge. Permanent vegetation generally does not become established in the active channel.
Aggradation	Geologic process by which a stream bottom or flood plain is raised in elevation by the deposition of material.
Bankfull discharge	The stream discharge (flow rate, such as cubic feet per second) that forms and controls the shape and size of the active channel and creates the flood plain. This discharge generally occurs once every 1.5 years on average.
Bankfull stage	The stage at which water starts to flow over the flood plain; the elevation of the water surface at bankfull discharge.
Baseflow	The portion of streamflow that is derived from natural storage; average stream discharge during low flow conditions.
Benthos	Bottom-dwelling or substrate-oriented organisms.
Boulders	Large rocks measuring more than 10 inches across.
Channel	A natural or artificial waterway of perceptible extent that periodically or continuously contains moving water. It has a definite bed and banks that serve to confine the water.
Channel roughness	Physical elements of a stream channel upon which flow energy is expended including coarseness and texture of bed material, the curvature of the channel, and variation in the longitudinal profile.
Channelization	Straightening of a stream channel to make water move faster.
Cobbles	Medium-sized rocks which measure 2.5 to 10 inches across.
Confined channel	A channel that does not have access to a flood plain.
Degradation	Geologic process by which a stream bottom is lowered in elevation due to the net loss of substrate material. Often called downcutting.
Downcutting	See Degradation.
Ecoregion	A geographic area defined by similarity of climate, landform, soil, potential natural vegetation, hydrology, or other ecologically relevant variables.
Embeddedness	The degree to which an object is buried in steam sediment.
Emergent plants	Aquatic plants that extend out of the water.
Flood plain	The flat area of land adjacent to a stream that is formed by current flood processes.
Forb	Any broad-leaved herbaceous plant other than those in the Gramineae (Poceae), Cyperacea, and Juncaceae families (Society for Range Management, 1989).

Gabions	A wire basket filled with rocks; used to stabilize streambanks and to control erosion.
Geomorphology	The study of the evolution and configuration of landforms.
Glide	A fast water habitat type that has low to moderate velocities, no surface agitation, no defined thalweg, and a U-shaped, smooth, wide bottom.
Gradient	Slope calculated as the amount of vertical rise over horizontal run expressed as ft/ft or as percent (ft/ft * 100).
Grass	An annual to perennial herb, generally with round erect stems and swollen nodes; leaves are alternate and two-ranked; flowers are in spikelets each subtended by two bracts.
Gravel	Small rocks measuring 0.25 to 2.5 inches across.
Habitat	The area or environment in which an organism lives.
Herbaceous	Plants with nonwoody stems.
Hydrology	The study of the properties, distribution, and effects of water on the Earth's surface, soil, and atmosphere.
Incised channel	A channel with a streambed lower in elevation than its historic elevation in relation to the flood plain.
Intermittent stream	A stream in contact with the ground water table that flows only certain times of the year, such as when the ground water table is high or when it receives water from surface sources.
Macrophyte bed	A section of stream covered by a dense mat of aquatic plants.
Meander	A winding section of stream with many bends that is at least 1.2 times longer, following the channel, than its straight-line distance. A single meander generally comprises two complete opposing bends, starting from the relatively straight section of the channel just before the first bend to the relatively straight section just after the second bend.
Macroinvertebrate	A spineless animal visible to the naked eye or larger than 0.5 millimeters.
Nickpoint	The point where a stream is actively eroding (downcutting) to a new base elevation. Nickpoints migrate upstream (through a process called headcutting).
Perennial stream	A steam that flows continuously throughout the year.
Point bar	A gravel or sand deposit on the inside of a meander; an actively mobile river feature.
Pool	Deeper area of a stream with slow-moving water.
Reach	A section of stream (defined in a variety of ways, such as the section between tributaries or a section with consistent characteristics).
Riffle	A shallow section in a stream where water is breaking over rocks, wood, or other partly submerged debris and producing surface agitation.

Riparian	The zone adjacent to a stream or any other waterbody (from the Latin word ripa, pertaining to the bank of a river, pond, or lake).
Riprap	Rock material of varying size used to stabilize streambanks and other slopes.
Run	A fast-moving section of a stream with a defined thalweg and little surface agitation.
Scouring	The erosive removal of material from the stream bottom and banks.
Sedge	A grasslike, fibrous-rooted herb with a triangular to round stem and leaves that are mostly three-ranked and with close sheaths; flowers are in spikes or spikelets, axillary to single bracts.
Substrate	The mineral or organic material that forms the bed of the stream; the surface on which aquatic organisms live.
Surface fines	That portion of streambed surface consisting of sand/silt (less than 6 mm).
Thalweg	The line followed by the majority of the streamflow. The line connecting the lowest or deepest points along the streambed.
Turbidity	Murkiness or cloudiness of water caused by particles, such as fine sediment (silts, clays) and algae.
Watershed	A ridge of high land dividing two areas that are drained by different river systems. The land area draining to a waterbody or point in a river system; catchment area, drainage basin, drainage area.

Appendix A—1997 and 1998 Field Trial Results

Purpose and methods

The purpose of the field trials was to evaluate the accuracy, precision, and usability of the draft Steam Visual Assessment Protocol. The draft protocols evaluated were the third draft dated May 1997 and the fourth draft dated October 1997. A field trial workplan was developed with study guidelines and a survey form to solicit feedback from users. Accuracy was evaluated by comparison to other stream assessment methods. Precision was evaluated by replicate assessments conduced by different individuals at the same sites. In all studies an attempt was made to utilize sites ranging from high quality to degraded. Results consisted of the scoring data and the user feedback form for each site.

Results

Overall, 182 sites were assessed, and approximately 60 individuals participated in the field trials. The individual studies are summarized in table A–1.

Precision could be evaluated using data from the Colorado, New Jersey, Oregon, Virginia, and Georgia studies. Results are summarized in table A–2. The New Jersey sites had coefficients of variation of 9.0 (n=8), 14.4 (n=5), and 5.7 (n=4) percent. The Oregon site with three replicates was part of a course and had a coefficient of variation of 11.1 percent. One Georgia site was assessed using the fourth draft during a pilot of the training course. There were 11 replicates, and the coefficient of variation was 8.8 percent. In May 1998 the workgroup conducted replicate assessments of two sites in Virginia using the fifth draft of the protocol. Coefficients of variation were 14.7 and 3.6 percent. The average coefficient of variation of all studies in table A–2 is 10.5 percent.

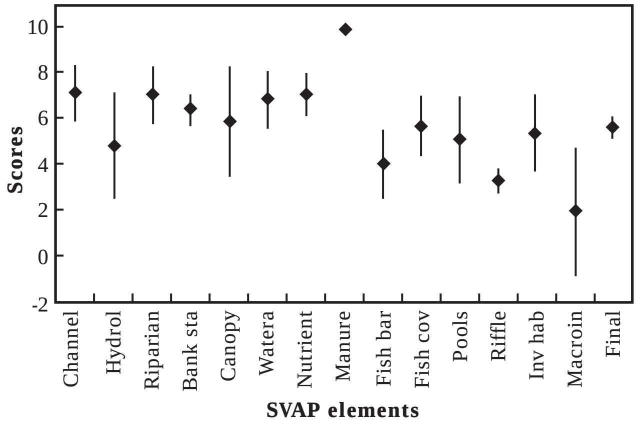
Variability within the individual elements of the SVAP was evaluated using the Georgia site with 11 replicates. The results of the individual element scores are presented in figure A–1. It should be noted that two individuals erroneously rated the "presence of manure" element.

Accuracy was evaluated by comparing the SVAP rating to other methods as noted in table A–1. Some of the comparisons involved professional judgment. In others the SVAP score could be compared with a quantitative evaluation. Figures A–2 through A–5 present data from the two studies that had larger numbers of sites. The Pearson's Correlation Coefficient is presented for these data. The results from other sites are presented in table A–3.

Table A–1 Summary of studies in the field trial

Location	Number of sites	Number of replicates	SVAP compared to	SVAP conducted by
VA	56	3, 5	IBI (fish) and Ohio QHEI	FO personnel
NC/SC	90	none	IBI, EPT	Soil scientists
MI	5	none	professional judgment	State biologist
NJ	3	4, 5, 8	NJDEP ratings	FO personnel
OR	3	none	IBI	NWCC scientist
CO	1	3	professional judgment	FO personnel
WA	3	none	professional judgment	State biologist
OR	2	3	no comparisons	FO personnel
GA	8	4-5	macroinvertebrates	FO personnel
GA	2	12, none	IBI, macroinvertebrate	FO personnel

Figure A–1 Means and standard deviations from the Parker's Mill Creek site in Americus, GA (n=11) (mean plus and minus one standard deviation is shown; SVAP version 4 used)



The SVAP version 3 scores correlated extremely well with the Ohio Qualitative Habitat Index and reasonably well with the fish community IBI in the Virginia study (fig. A–2 and A–3). However, the SVAP version 3 scores in the Carolinas study did not correlate well with either IBI or EPT Taxa (fig. A–4 and A–5). These results may reflect the fact that the SVAP primarily assesses physical habitat within the assessment reach whereas IBI and EPT Taxa are influenced by both physical habitat within the assessment reach and conditions within the watershed. Onsite physical habitat may have been a relatively more important factor at the Virginia sites than at the Carolina sites.

Overall, the field trial results for the third draft seemed to indicate that SVAP scores reflected conditions for sites in good to moderate condition. However, SVAP scores tended to be too high for poor quality sites.

Both the user questionnaires and verbal feedback indicated that users found the SVAP easy to use. Users reported that they thought it would be an effective tool to use with landowners. The majority indicated that they would recommend it to landowners.

Table A–2 Summary of replication results (version refers to the SVAP draft used; mean for overall score reported)

Site	SVAP version	No. replicates	Mean 1/	Standard deviation	Coefficient of variation
Alloway Cr. NJ	3	5	3.6 F	0.52	14.4
Manasquan R. NJ	3	4	5.1 G	0.29	5.7
S. Br. Raritan R. NJ	3	8	5.9 G	0.53	9.0
Gales Cr. OR	3	3	5.5 G	0.61	11.1
Clear Cr. CO	3	3	5.4 G	0.74	13.7
Piscola Cr. GA #1	4	5	9.2 E	0.77	8.4
Piscola Cr. GA #2	4	5	9.0 E	0.85	9.4
Piscola Cr. GA #3	4	4	4.7 F	1.10	23.4
Piscola Cr. GA #4	4	4	7.4 G	0.96	13.0
Little R. GA # 1	4	4	8.3 E	0.73	8.8
Little R. GA # 2	4	4	7.4 E	0.83	11.2
Little R. GA # 3	4	4	8.1 E	0.41	5.1
Little R. GA # 4	4	4	7.3 G	0.60	8.2
Parker's Mill Cr. GA	4	11	5.7 F	0.50	8.8
Cedar Run (up), VA	5	5	7.7 G	1.1	14.7
Cedar R. (down), VA	5	5	6.6 F	.2	3.6

1/ Includes SVAP narrative ratings (P = poor, F = fair, G = good, E = excellent)

Table A–3 Accuracy comparison data from studies with too few sites to determine a correlation coefficient

Site	SVAP version	SVAP score and rating	Comparative rating	Comparative method
Alloway Cr. NJ	3	3.6* — fair	12 — mod. impaired	NJIS (macro.)
Manasquan R. NJ	3	5.1* — good	12 — mod. impaired	NJIS (macro.)
S. Br. Raritan R. NJ	3	5.9* — good	30 — not impaired	NJIS (macro.)
Site 1 OR	3	2.7 — fair	12 — very poor	IBI (fish)
Site 2 OR	3	4.6 — good	22 — poor	IBI (fish)
Site 3 OR	3	7.0 — excellent	44 — good	IBI (fish)
Muckalee Cr. GA	4	8.6 — good	good to excellent	mussel taxa

* Mean value of replicates

Figure A–2 Correlation between SVAP and IBI values in the Virginia study (n=56)

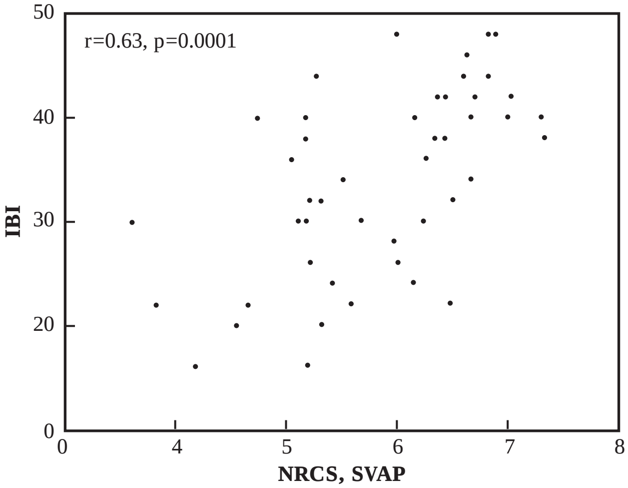


Figure A–3 Correlation between SVAP and Ohio Qualitative Habitat Evaluation Index values in the Virginia study (n=56)

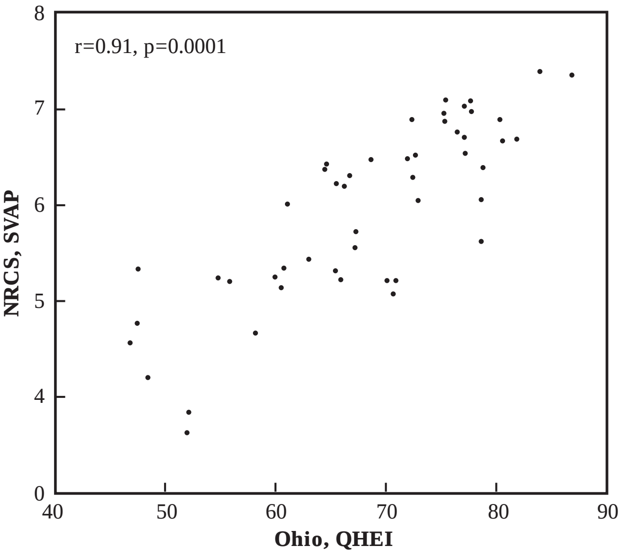


Figure A–4 Correlation between SVAP and IBI values in the Carolinas study (n=90)

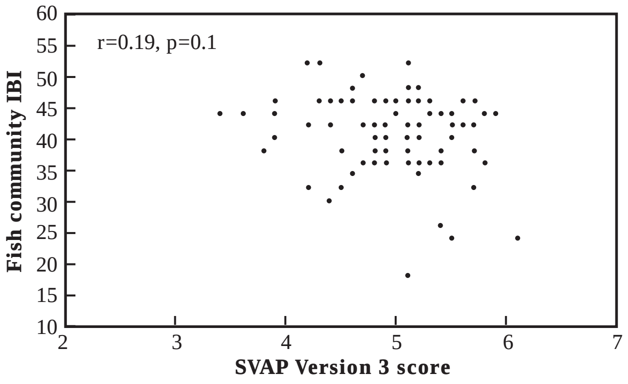
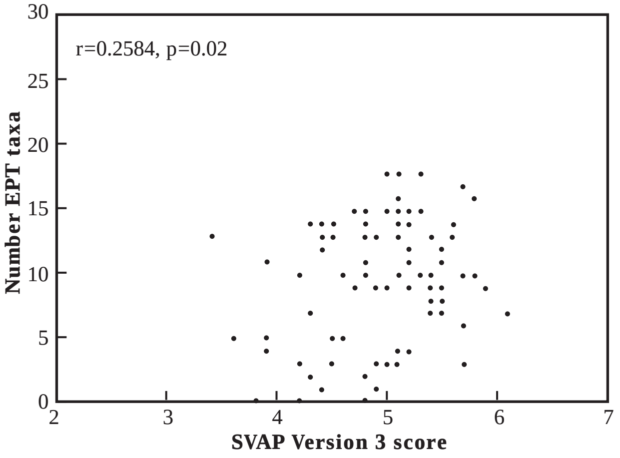


Figure A–5 Correlation between SVAP and macroinvertebrate index values in Carolinas study (n=90)



Discussion

Overall, the workgroup concluded from the first field trial that the SVAP could be used by conservationists in the field with reasonable reproducibility and a level of accuracy commensurate with its objective of providing a basic assessment of ecological condition provided the poor response to degraded streams could be corrected.

Several potential causes for the lack of accuracy with degraded sites were identified by the workgroup as follows:

- Because the overall score is an average of all assessed elements, the effect of low scoring elements can be damped out by averaging if the degradation is not picked up by many of the other assessed elements.
- Some of the elements needed to be adjusted to give lower scores for problems.
- The numerical breakpoints for the narrative ratings of poor/fair and fair/good were set too low.

To correct these problems the number of assessment elements was reduced and the instructions were modified so that certain elements are not scored if they do not apply. For example, the "presence of manure" element is not scored unless there are animal operations present. These changes reduced the potential for low scores to be damped out by the averaging process.

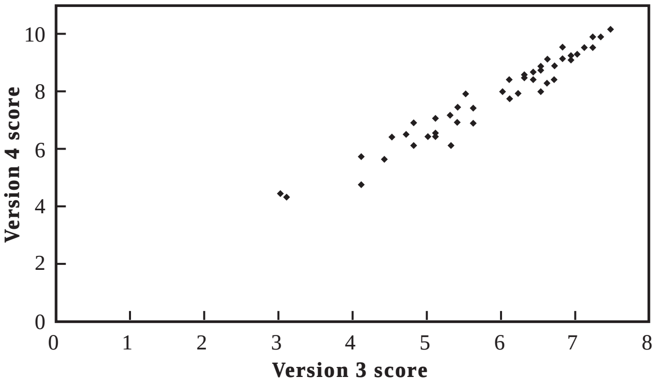
Several elements were also rewritten to reduce ambiguity at the low end of the rating scale. Additionally, several elements were rewritten to have five narrative descriptions instead of four to address a concern that users might err on the high side. The scoring scale was changed from a scale of 1 to 7 to a scale of 1 to 10 because it was felt that most people have a tendency to think in terms of a decimal scale.

The revisions were incorporated into a fourth draft and evaluated by the workgroup. Sites from the first field trial were rescored using the new draft. Response seemed to have improved as indicated by the greater separation of sites at lower scores in figure A–6.

During pilot testing of the training materials in March 1998, the fourth draft was used by 12 students independently at one site and collectively at another site. The coefficient of variation at the replication site was 8.8 percent. One of the sites had been previously assessed using other methods, and the SVAP rating corresponded well to the previous assessments.

After the evaluation of the fourth draft, minor revisions were made for the fifth draft. The breakpoints for the narrative rating of excellent, good, fair, and poor for the fifth draft were set using the Virginia data set. These breakpoints may be adjusted by the NRCS state office as explained in this document.

Figure A–6 Version 4 scores for VA plotted against version 3 scores (n=56)



Stream Visual Assessment Protocol

Owners name ___________________________________ Evaluator's name_______________________________ Date ________________

Stream name ____ Waterbody ID number ___________________________________

Reach location ____

____

Ecoregion ___________________________________ Drainage area _______________________ Gradient__________________________

Applicable reference site ____

Land use within drainage (%): row crop ______ hayland ______ grazing/pasture _______ forest ______ residential _______

confined animal feeding operations ______ Cons. Reserve ________ industrial _______ Other: _________________

Weather conditions-today ______________________________________ Past 2-5 days ____

Active channel width ______________________ Dominant substrate: boulder ______ gravel ______ sand ______ silt ______ mud ______

Site Diagram

Assessment Scores

Channel condition ☐

Hydrologic alteration ☐

Riparian zone ☐

Bank stability ☐

Water appearance ☐

Nutrient enrichment ☐

Barriers to fish movement ☐

Instream fish cover ☐

Pools ☐

Invertebrate habitat ☐

Score only if applicable

Canopy cover ☐

Manure presence ☐

Salinity ☐

Riffle embeddedness ☐

Marcroinvertebrates Observed (optional) ☐

Overall score
(Total divided by number scored) ____________

<6.0	**Poor**
6.1-7.4	**Fair**
7.5-8.9	**Good**
>9.0	**Excellent**

Suspected causes of observed problems____

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Recommendations____

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United States
Environmental
Protection Agency

Office of Research and Development
Office of Water
Washington, DC 20460

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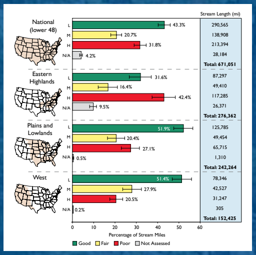
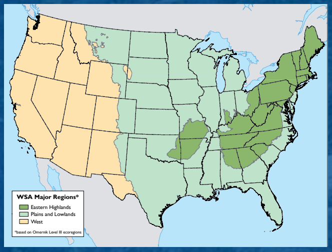
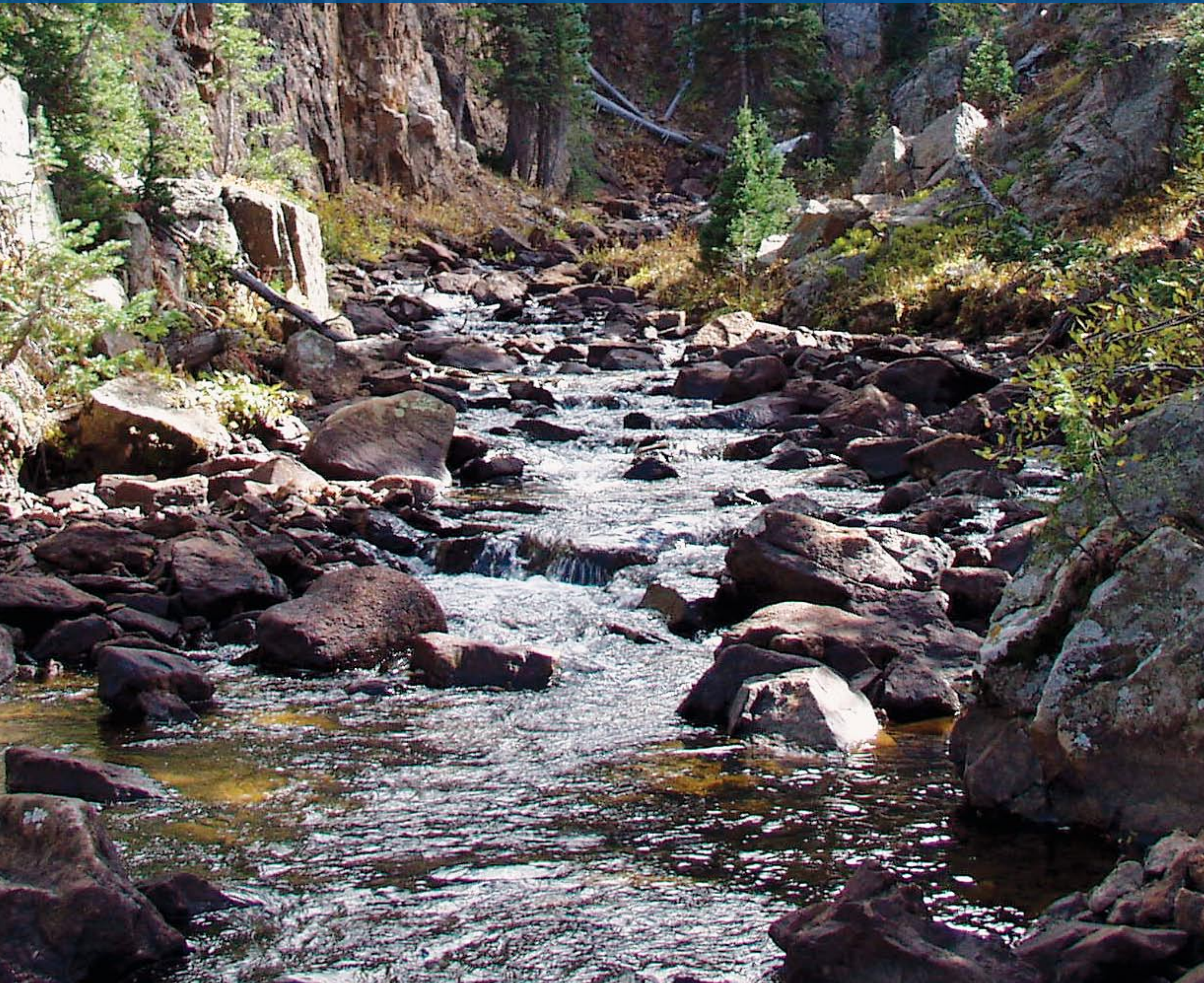
December 2006
www.epa.gov/owow/streamsurvey

Wadeable Streams Assessment

A Collaborative Survey of the Nation's Streams







Front cover photo courtesy of the Colorado Division of Wildlife

Inside cover photo courtesy of Michael L. Smith, U.S. Fish and Wildlife Service

Acknowledgments

This report resulted from a ground-breaking collaboration on stream monitoring. States came together with the U.S. Environmental Protection Agency (EPA) to demonstrate a cost-effective approach for answering one of the nation's most basic water quality questions: What is the condition of our nation's streams?

The EPA Office of Water would like to thank the many participants who contributed to this important effort and the scientists within the EPA Office of Research and Development for their research and refinement of the survey design, field protocols, and indicator development. Through the collaborative efforts of state environmental and natural resource agencies, federal agencies, universities, and other organizations, more than 150 field biologists were trained to collect environmental samples using a standardized method, and more than 25 taxonomists identified as many as 500 organisms in each sample. Each participating organization attended a national meeting to discuss and formulate the data analysis approach, as well as regional meetings to evaluate and refine the results presented in this report.

Collaborators

Alaska Department of Environmental Conservation
Arizona Game and Fish Department
Arkansas Department of Environmental Quality
California Department of Fish and Game
California State Water Resources Control Board
Colorado Department of Public Health and Environment
Colorado Division of Wildlife
Connecticut Department of Environmental Protection
Delaware Department of Natural Resources and Environmental Control
Georgia Department of Natural Resources
Idaho Department of Environmental Quality
Illinois Environmental Protection Agency
Iowa Department of Natural Resources
Kansas Department of Health and Environment
Kentucky Division of Water
Louisiana Department of Environmental Quality
Maine Department of Environmental Protection
Maryland Department of Natural Resources
Michigan Department of Environmental Quality
Minnesota Pollution Control Agency
Mississippi Department of Environmental Quality
Missouri Department of Conservation
Montana Department of Environmental Quality
Nevada Division of Environmental Protection
New Hampshire Department of Environmental Services
New Jersey Department of Environmental Protection
New Mexico Environment Department
New York State Department of Environmental Conservation
North Carolina Division of Water Quality
North Dakota Department of Health
Ohio Environmental Protection Agency
Oklahoma Conservation Commission
Oklahoma Water Resources Board
Oregon Department of Environmental Quality
Pennsylvania Department of Environmental Protection
South Carolina Department of Health and Environmental Control
South Dakota Department of Environment and Natural Resources
South Dakota Game, Fish and Parks
Tennessee Department of Environment and Conservation
Texas Commission of Environmental Quality

Utah Division of Water Quality
Vermont Department of Environmental Conservation
Virginia Department of Environmental Quality
Washington State Department of Ecology
West Virginia Department of Environmental Protection
Wisconsin Department of Natural Resources
Wyoming Department of Environmental Quality
Fort Peck Assiniboine and Sioux Tribes
Guam Environmental Protection Agency
U.S. Geological Survey
U.S. EPA, Office of Environmental Information
U.S. EPA, Office of Water
U.S. EPA, Office of Research and Development
U.S. EPA, Regions 1–10
Center for Applied Bioassessment and Biocriteria
Central Plains Center for Bioassessment
New England Interstate Water Pollution Control Commission
The Council of State Governments
Great Lakes Environmental Center
Tetra Tech, Inc.
EcoAnalysts
University of Arkansas
Mississippi State University
Oregon State University
Utah State University

The data analysis team painstakingly reviewed the data set to ensure its quality and performed the data analysis. This team included Phil Kaufmann, Phil Larsen, Tony Olsen, Steve Paulsen, Dave Peck, John Stoddard, John Van Sickle, and Lester Yuan from the EPA Office of Research and Development; Alan Herlihy from Oregon State University; Chuck Hawkins from Utah State University; Daren Carlisle from the U.S. Geological Survey; and Michael Barbour, Jeroen Gerritson, Erik Lepow, Kristen Pavlik, and Sam Stribling from Tetra Tech, Inc.

The report was written by Steve Paulsen and John Stoddard from the EPA Office of Research and Development and Susan Holdsworth, Alice Mayio, and Ellen Tarquinio from the EPA Office of Water. Major contributions to the report were made by John Van Sickle, Dave Peck, Phil Kaufmann, and Tony Olsen from the EPA Office of Research and Development and Peter Grevatt and Evan Hornig from EPA Office of Water, Alan Herlihy from Oregon State University, Chuck Hawkins from Utah State University, and Bill Arnold from the Great Lakes Environmental Center. Technical editing and document production support was provided by RTI International. This report was significantly improved by the external peer review conducted by Dr. Stanley V. Gregory, Ecologist, Oregon State University; Dr. Kenneth Reckhow, Environmental Engineer, Duke University; Dr. Kent Thornton, Principal Ecologist, FTN Associates; Dr. Scott Urquhart, Statistician, Colorado State University; and Terry M. Short of the U.S. Geological Survey. The Quality Assurance Officer for this project was Otto Gutenson from the EPA Office of Water.

Table of Contents

Figures

Acronym List

˚F	degrees Fahrenheit
ANC	acid neutralizing capacity
BMPs	best management practices
CAAA	Clean Air Act Amendments
CWA	Clean Water Act
EMAP	Environmental Monitoring and Assessment Program
EPA	U.S. Environmental Protection Agency
FWS	U.S. Fish and Wildlife Service
km	kilometers
mi^2	square miles
NAPAP	National Acid Precipitation Program
NCA	National Coastal Assessment
NCCR	National Coastal Condition Report
NCCR II	National Coastal Condition Report II
NEP	National Estuary Program
NEP CCR	National Estuary Program Coastal Condition Report
NHD	National Hydrography Dataset
NLCD	National Land Cover Dataset
NOAA	National Atmospheric and Oceanic Administration
O/E	observed/expected
PCBs	polychlorinated biphenyls
RBS	relative bed stability
TDS	total dissolved solids
μeq/L	microequivalents per liter
USGS	U.S. Geological Survey
VOCs	volatile organic compounds
WSA	Wadeable Streams Assessment

Executive Summary

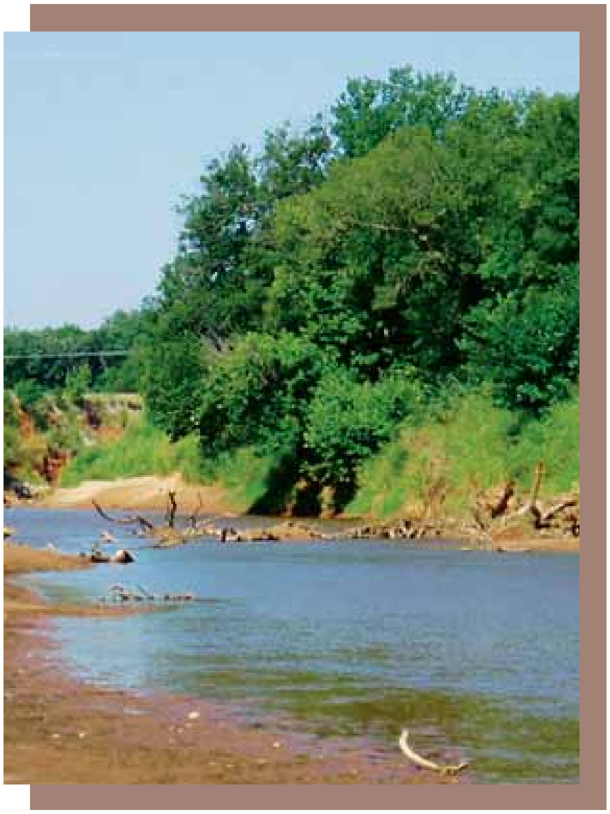
Photo courtesy of Monty Porter

Executive Summary

"I started out thinking of America as highways and state lines. As I got to know it better, I began to think of it as rivers. America is a great story, and there is a river on every page of it."

This quote by well-known journalist Charles Kuralt reflects on the central role that rivers and streams have played in shaping the history and character of our nation. Because the health and survival of U.S. families and communities are dependent on these waterbodies, their condition, as well as how they are protected, reflects our values and choices as a society.

The Wadeable Streams Assessment (WSA) provides the first statistically defensible summary of the condition of the nation's streams and small rivers. In the 35 years since the passage of the Clean Water Act (CWA), the U.S. Congress, American public, and other interested parties have asked the U.S. Environmental Protection Agency (EPA) to describe the water quality condition of U.S. waterbodies. These requests have included seemingly simple questions: Is there a water quality problem? How extensive is the problem? Does the problem occur in "hotspots" or is it widespread? Which environmental stressors affect the quality of the nation's streams and rivers, and which are most likely to be detrimental? This WSA report presents the initial results of what will be a long-term partnership between EPA, other federal agencies, states, and tribes to answer these questions.



Little Washita River, OK, in the Southern Plains ecoregion (Photo courtesy of Monty Porter).

The WSA encompasses the wadeable streams and rivers that account for a vast majority of the length of flowing waters in the United States. To perform the assessment, EPA, states, and tribes collected chemical, physical, and biological data at 1,392 wadeable, perennial stream locations to determine the biological condition of these waters and the primary stressors affecting their quality. Research teams collected samples at sites chosen using a statistical design to ensure representative results. The results of this analysis provide a clear assessment of the biological quality of wadeable, perennial streams and rivers across the country, as well as within each of three major climatic and landform regions and nine ecological regions, or ecoregions.

The information provided in this report fills an important gap in meeting the requirements of the CWA. The purpose of the WSA is four-fold:

- Report on the ecological (biological, chemical, and physical) condition of all wadeable, perennial streams and rivers within the conterminous United States. (Pilot assessment projects are also underway in Alaska and Hawaii.)
- Describe the biological condition of these systems using direct measures of aquatic life. Assessments of stream quality have historically relied primarily on chemical analyses of water, or sometimes, on the status of game fish.
- Identify and rank the relative importance of chemical and physical stressors (disturbances) affecting stream and river condition.
- Enhance the capacity of states and tribes to include these design and measurement tools in their water quality monitoring programs so that assessments will be ecologically and statistically comparable, both regionally and nationally.

The results of the WSA show that 42% of the nation's stream length is in poor biological condition compared to least-disturbed reference sites in the nine ecoregions, 25% is in fair biological condition, and 28% is in good biological condition (Figure ES-1). Five percent of the nation's stream length was not assessed for biological condition during the WSA.

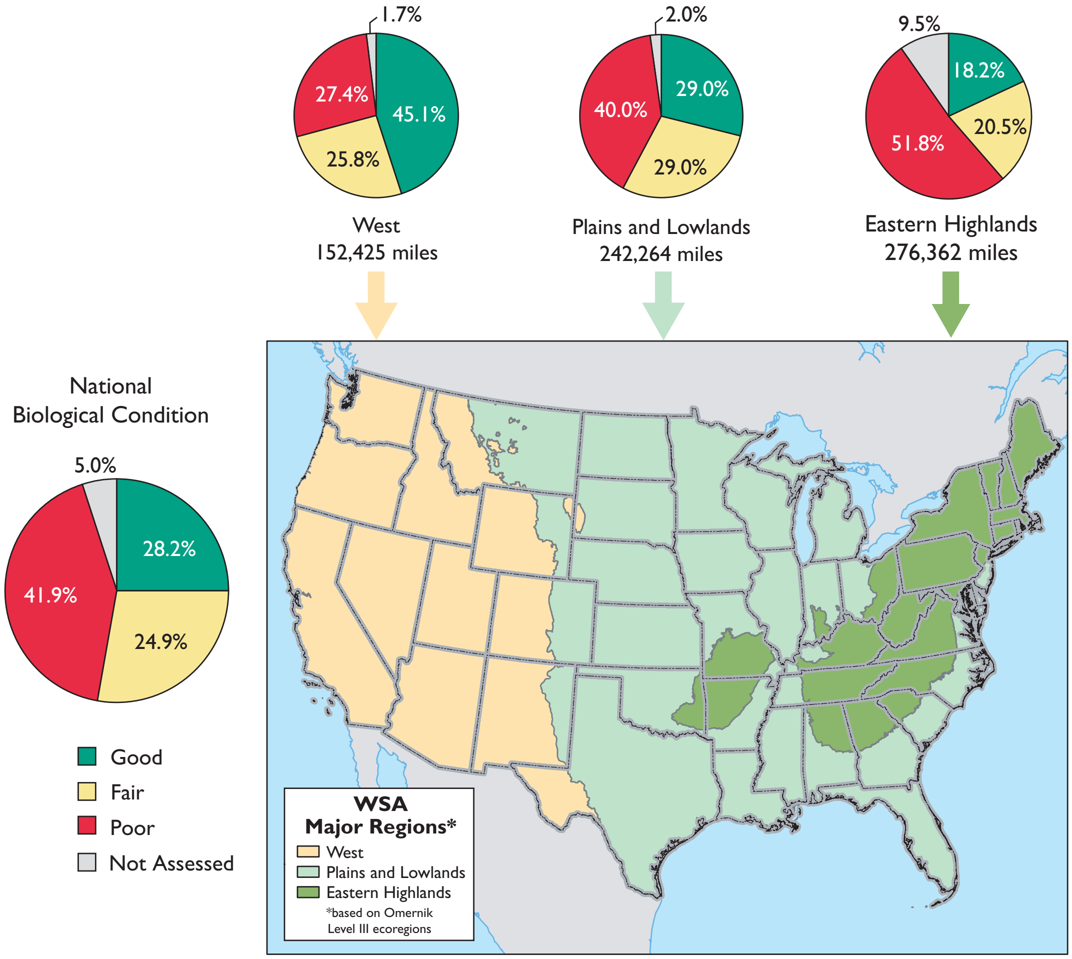


Figure ES-1. Biological condition of wadeable streams (U.S. EPA/WSA).

Of the three major regions discussed in this report, the West is in the best biological condition, with 45% of stream length in good biological condition. The Plains and Lowlands region has almost 30% of stream length in good biological condition and 40% in poor biological condition. The Eastern Highlands region presents the most concerns, with only 18% of stream length in good biological condition and 52% in poor biological condition.

The WSA also examines the key factors most likely responsible for diminishing biological quality in flowing waters, as determined by aquatic macroinvertebrate communities. The most widespread stressors observed across the country and in each of the three major regions are nitrogen, phosphorus, riparian disturbance, and streambed sediments. Increases in nutrients (e.g., nitrogen and phosphorus) and streambed sediments have the highest impact on biological condition; the risk of having poor biological condition was two times greater for streams scoring poor for nutrients or streambed sediments than for streams that scored in the good range for the same stressors (Figure ES-2).

Understanding the current condition of the nation's wadeable streams and rivers is critical to supporting the development of water quality management plans and priorities that help maintain and restore the ecological condition of these resources. This report provides a primary-baseline assessment to track water quality status and trends. The results of the WSA and similar assessments in the future will inform the public, water quality managers, and elected officials of the effectiveness of efforts to protect and restore water quality, as well as the potential need to refocus these efforts.

Readers who wish to learn more about the technical background of the WSA are directed to literature cited in the References section at the end of this report and to material posted on the EPA Web site at http://www.epa.gov/owow/streamsurvey.

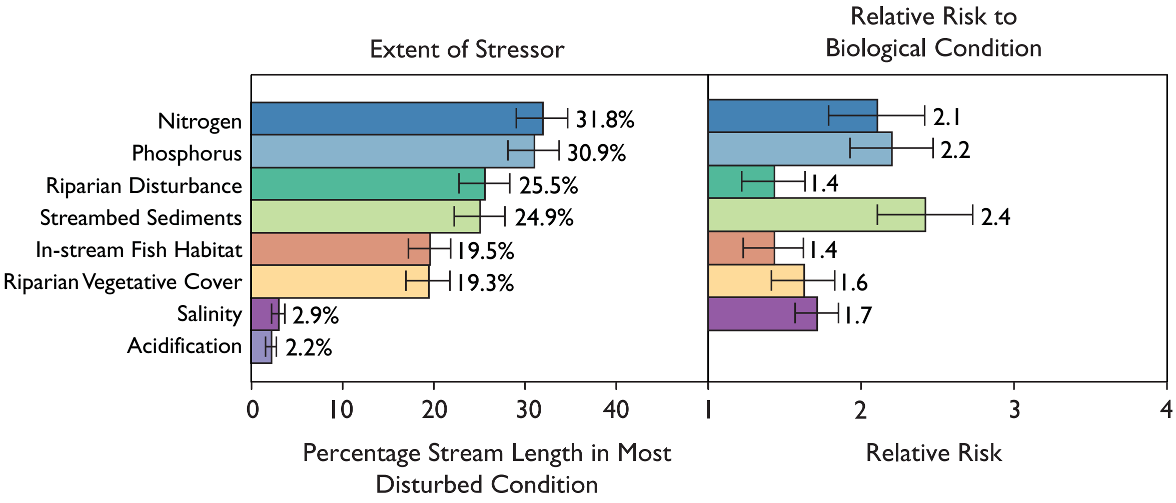


Figure ES-2. Extent of stressors and their relative risk to the biological condition of the nation's streams (U.S. EPA/WSA).

Introduction

Photo courtesy of the Georgia Department of Natural Resources

Introduction

In 1972, the U.S. Congress enacted the landmark Clean Water Act (CWA) to protect the nation's vital water resources. A critical section of the CWA calls for periodic accounting to Congress and the American public on the success or failure of efforts to protect and restore the nation's waterbodies. In recent years, a number of groups reviewed the available data and concluded that the U.S. Environmental Protection Agency (EPA) and state environmental agencies have been unable to provide Congress and the public with adequate information regarding the condition of the nation's waterbodies.

In 2000, the General Accounting Office issued a report noting that EPA and the states could not make statistically valid inferences about water quality and lacked data to support management decisions. A National Research Council report in 2001 found that a uniform, consistent approach to ambient monitoring and data collection was necessary to support core water programs. In 2002, the National Academy of Public Administration and the H. John Heinz III Center for Science, Economics, and the Environment issued similar conclusions.

Following the 2002 release of the Heinz Center's report *The State of the Nation's Ecosystems*, the national newspaper USA Today published an editorial discussing the lack of environmental information available to the public. This editorial emphasized the failure of state and federal agencies to fund the collection of necessary environmental data despite very effective collection of comparable information on the U.S. economy, population, energy usage, human health issues, and crime rate. The editorial concluded that "without such information, the public doesn't know when to celebrate environmental successes, tackle new threats, or end efforts that throw money down a drain" (USA Today, September 21, 2002).

Little Washita River, OK, in the Southern Plains ecoregion (Photo courtesy of Monty Porter).

To bridge this information gap, EPA, other federal agencies, states, and tribes, are collaborating to provide the public with improved environmental information. This collaboration includes a new monitoring effort to assess the quality of the nation's waterbodies, an effort that has produced reports on three national water quality assessments during the past five years for coastal and estuarine waters (see *Highlight: National Report on Coastal Waters*). Similar efforts are planned for other water resource assessments in the future. The Wadeable Streams Assessment (WSA)—the first nationally consistent, statistically valid study of the nation's wadeable streams—marks the continuation of a commitment to produce statistically valid scientific assessments of the nation's fresh waters.

State water quality agencies, tribes, and other partners, with support from EPA, conducted the work for the WSA using standardized methods at all sites to ensure the comparability of results across the country. Beyond yielding scientifically credible information on the condition and health of the nation's wadeable streams, the WSA was designed to provide states with funding and expertise that enhances their ability to monitor and assess the quality of their waters.

EPA and its collaborating partners plan to conduct similar assessments of other types of waterbodies (e.g., lakes, rivers, and wetlands) in the future, with the goal of producing updated assessments for each type of waterbody every five years. These repeated studies will ensure that the public remains informed as to whether the collective efforts to protect and restore the nation's waters are meeting with success.

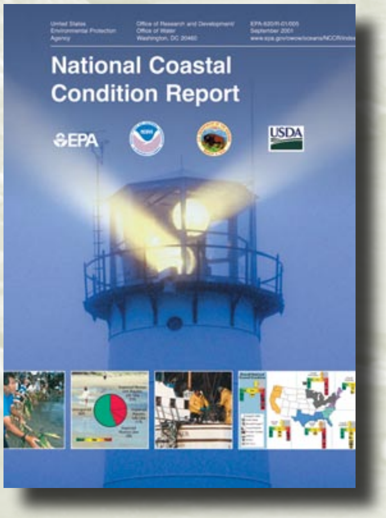
Photo courtesy of Gary Kramer, U.S. Department of Agriculture Natural Resources Conservation Service.

Highlight

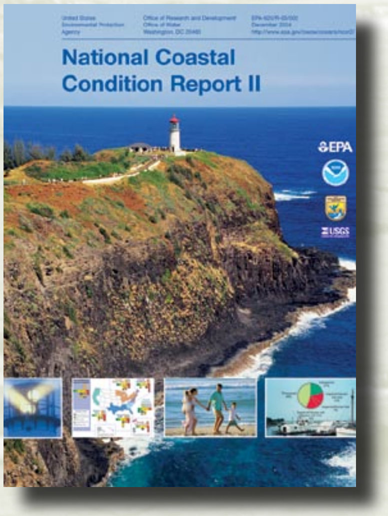
National Reports on Coastal Waters

The National Coastal Assessment (NCA) surveys the condition of the nation's coastal resources, as well as state efforts to protect, manage, and restore coastal ecosystems. The results of these surveys are compiled periodically into the *National Coastal Condition Report* (NCCR) series. The states, EPA, and partner agencies, including the National Oceanic and Atmospheric Administration (NOAA), U.S. Geological Survey (USGS), and U.S. Fish and Wildlife Service (FWS), issued the *National Coastal Condition Report II* (NCCR II) in January 2005 as the second in this series of reports on environmental surveys of U.S. coastal waters. The NCCR II includes evaluations of 100% of the nation's estuaries in the conterminous 48 states and Puerto Rico. Federal, state, and local agencies collected more than 50,000 samples between 1997 and 2000 for the NCCR II, using nationally consistent methods and a probability-based design to assess five key indices of coastal water health: water quality, coastal habitat loss, sediment quality, benthic community condition, and fish tissue contaminants levels.

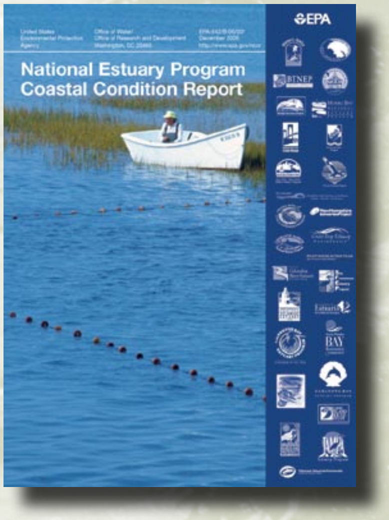
The *National Estuary Program Coastal Condition Report* (NEP CCR) focuses specifically on the condition of the 28 estuaries in the National Estuary Program (NEP) using data collected from 1997 through 2003 for EPA's NCA. The NEP CCR also presents monitoring data collected and analyzed by each individual NEP and its partners for a variety of estuarine quality indicators. The 28 NEPs are using these data to develop and implement sets of program-specific indicators of estuarine condition.



National Coastal Condition Report



National Coastal Condition Report II



National Estuary Program Coastal Condition Report

Chapter 1

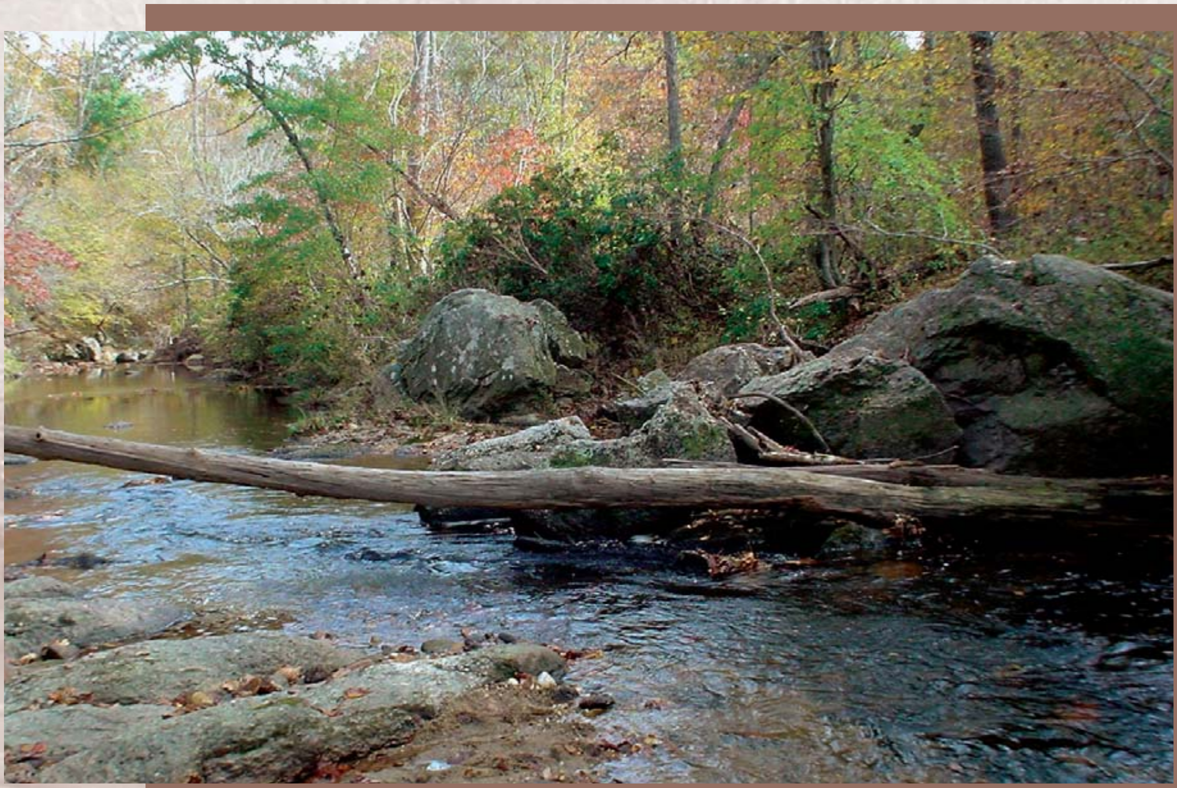


Photo courtesy of the Georgia Department of Natural Resources

Design of the Wadeable Streams Assessment

Design of the Wadeable Streams Assessment

Why Focus on Wadeable Streams?

Like the network of blood vessels that supply life-giving oxygen and nutrients to all parts of the human body, streams and rivers form a network that carries essential water to all parts of the nation. The human body has far more small capillaries than large, major arteries and veins; similarly, only a few U.S. rivers span large portions of the country (e.g., the Mississippi, Missouri, or Columbia rivers). Most of the nation's waterways are much smaller stream and river systems that form an intimate linkage between land and water.

The WSA addresses these smaller systems, which ecologists often refer to as "wadeable" because they are small and shallow enough to adequately sample without a boat. Almost every state, university, federal agency, and volunteer group involved in water quality monitoring has experience sampling these smaller flowing waters; therefore, a wide range of expertise was available for the WSA's nationwide monitoring effort.

About 90% of perennial stream and river miles in the United States are small, wadeable streams. Stream and river ecologists commonly use the term Strahler stream order to refer to stream size, and wadeable streams generally fall into the 1st- through 5th-order range (Figure 1). First-order streams are the headwaters of a river, where the life of a river begins; as streams join one another, their stream order increases. It is important to note that many 1st-order streams, particularly those located in the western United States, do not flow continuously. These intermittent or ephemeral streams were not included in the WSA because well-developed indicators to assess these waterbodies do not yet exist. At the other end of the range are larger-order rivers and streams that

Sawmill Creek, MA, in the Northern Appalachians ecoregion
(Photo courtesy of Colin Hill, Tetra Tech, Inc.).

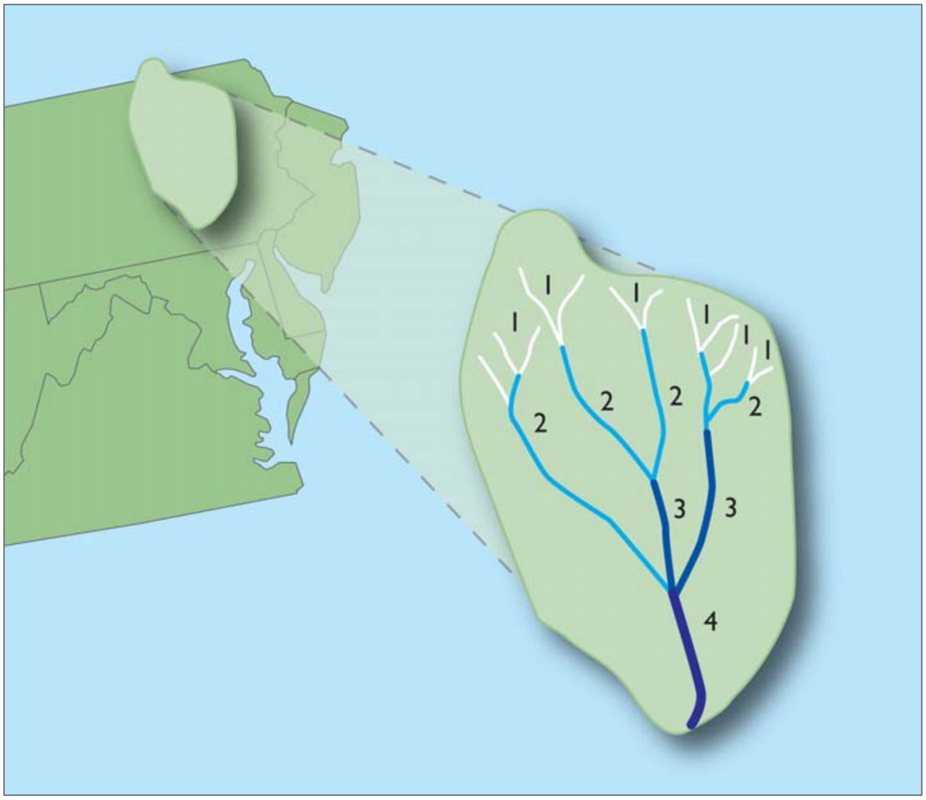


Figure 1. Strahler stream order diagram (U.S. EPA/WSA). Stream size is categorized by Strahler stream order, demonstrated here for a watershed. The confluence (joining) of two 1st-order streams forms a 2nd-order stream; the confluence of two 2nd-order streams forms a 3rd-order stream.

are too deep for wadeable sampling methods. These deeper waterbodies will be included in a future survey of non-wadeable rivers.

Stream order (stream size) affects a stream's natural characteristics, including the biological communities that live in the stream, such as fish and invertebrates. Very small 1st-order and 2nd-order streams are often quite clear and narrow and are frequently shaded by grasses, shrubs, and trees that grow along the stream bank (Figure 2). The food base of these streams is found along the stream bank and tends to consist of leaves and terrestrial insects, which dominate the streams' ecology, along with algae that attach to rocks and wood, aquatic insects adapted to shredding leaves and scraping algae, and small fish that feed on these organisms. In contrast, larger 6th- and 7th-order rivers typically appear muddy because their flow carries accumulated sediments downstream. These rivers are wide enough that the canopy cover along their banks shades only a narrow margin of water along the river's edge. The food base for these waterbodies shifts towards in-stream sources, such as algae; downstream drift of small organisms; and deposition of fine detritus. Although the aquatic communities of larger rivers include the algae and terrestrial insects found in streams, these rivers are dominated by insects adapted to filtering and gathering fine organic particles, and larger fish that are omnivorous (feeding on plants and animals) and/or piscivorous (feeding on smaller fish).

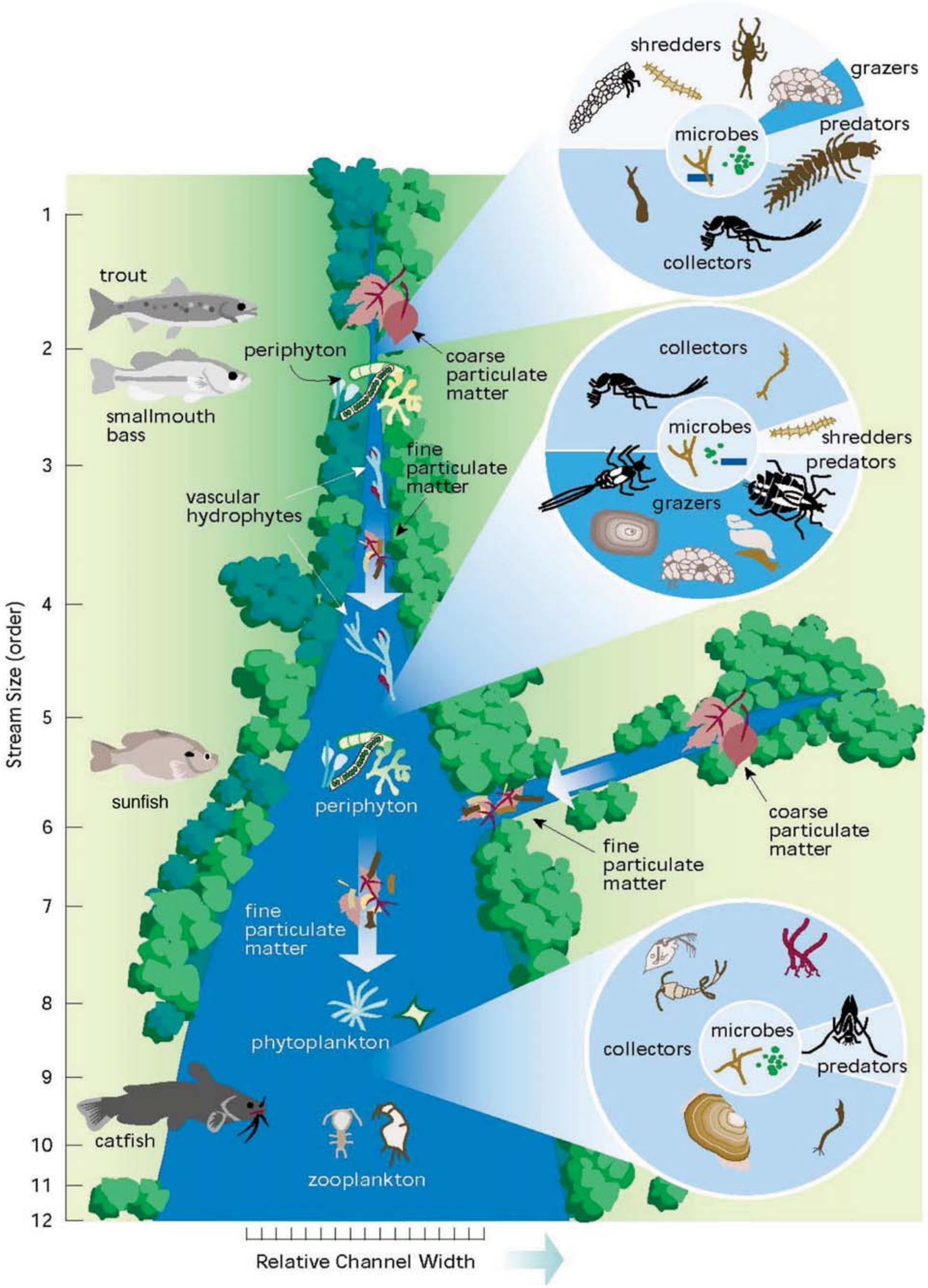


Figure 2. Stream characteristics change as the stream's size or stream order increases (Vannote et al., 1980).

What Area Does the WSA Cover?

This WSA encompasses the wadeable streams of the conterminous United States, or lower 48 states (Figure 3). This land area covers 3,007,436 square miles (mi^2) and includes private, state, tribal, and federal land. Although not included in this report, initial stream-sampling projects outside the conterminous United States have begun and will be included in future assessments. For example, scientists in Alaska sampled streams in the Tanana River Basin (a subbasin to the Yukon River) during 2004 and 2005, and they expect to report their results in 2007; Guam has begun implementation of a stream survey; and Puerto Rico is developing indicators for assessing the condition of its tropical streams. In addition, the State of Hawaii began stream sampling using WSA techniques on the island of Oahu in 2006.

State boundaries offer few insights into the true nature of features that mold our streams and rivers. The most fundamental trait that defines U.S. waters is annual precipitation (Figure 4). A sharp change occurs on either side of the

Figure 3. Major rivers and streams of the conterminous United States (NationalAtlas.gov, 2006). Major rivers comprise only 10% of the length of U.S. flowing waters, whereas the nation's wadeable streams and rivers comprise 90% of the length of U.S. flowing waters.

100th longitude that runs from west Texas through North Dakota, with precipitation falling plentifully to the east, but sparsely to the west. (The high mountains of the western United States and the Pacific coast are exceptions to the general scarcity of water in the West.) The east-west divide in moisture has not only shaped the character of the nation's waters, but also how they are used, valued, and the even the legal systems with which they are managed. A second divide that defines the nature of U.S. rivers and streams is the north-south gradient in temperature.

Young Womans Creek, PA, in the Southern Appalachians ecoregion (Photo courtesy of the Great Lakes Environmental Center).

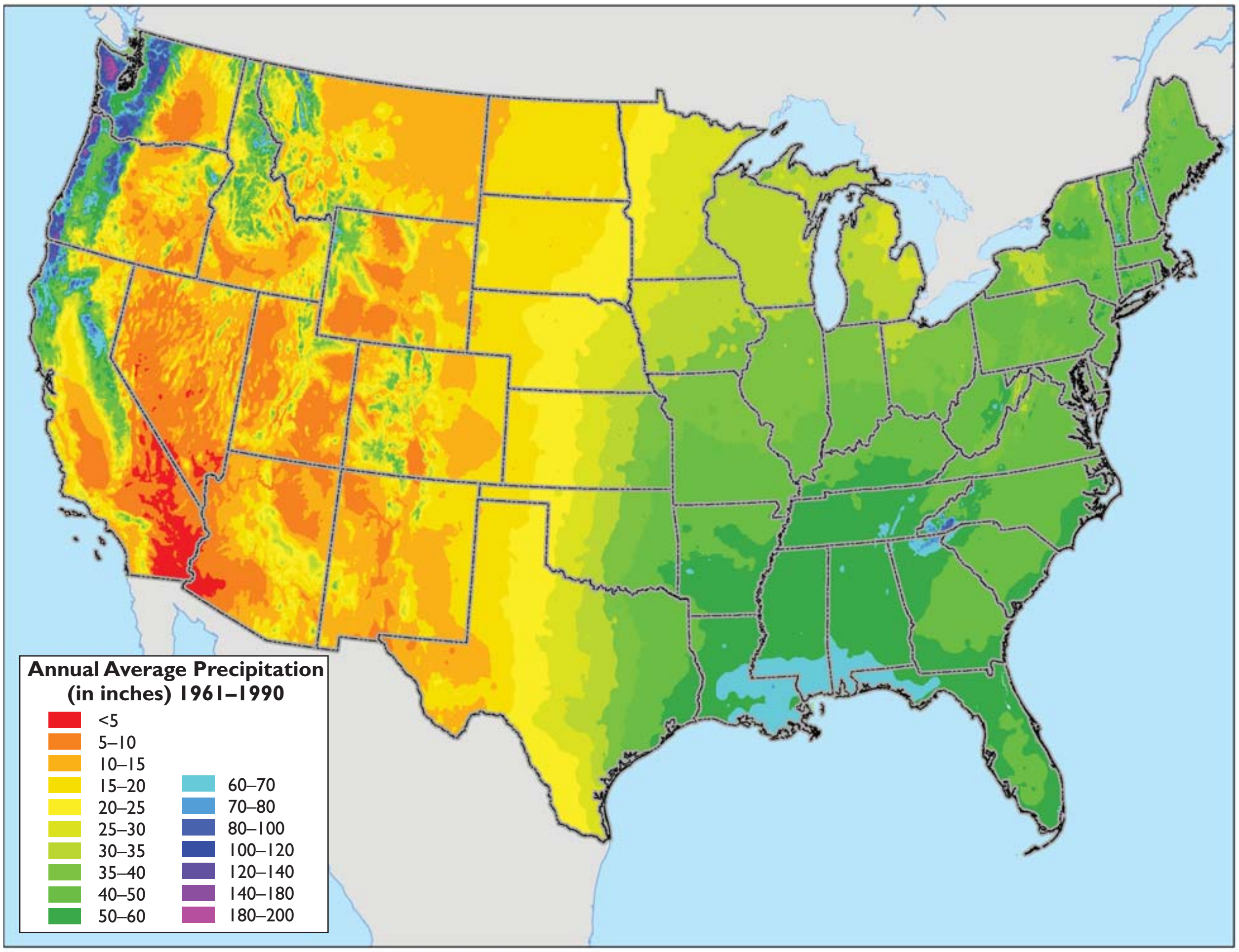


Figure 4. Average annual precipitation of the United States, 1961–1990 (NOAA, National Climatic Data Center). The 100th longitude meridian runs from Texas north through North Dakota and reveals a major gradient of precipitation that defines differences in western and eastern streams.

The nation includes a wide diversity of landscapes, from the varied forests of the East, to the immense agricultural plains and grasslands of the Midwest, to the deserts and shrublands of the Southwest, to the giant mountain ranges of the West (Figure 5). In the eastern part of the country, the Appalachian mountains run from Maine to Alabama, crossing climatic boundaries and separating the waters flowing to the Atlantic Ocean from those flowing to the Gulf of Mexico. The larger mountain ranges in the West link their landscapes together: the Rockies through the heart of the West; the Cascades, which crown the Northwest in snow; the Sierra Nevada in California; and the Coastal Range, which plummets to the Pacific Ocean, with a fault-block shoreline that stretches from the Santa Monica mountains to Kodiak Island. The Coastal Plains of the East and Southeast and the Great Plains of the interior provide other major landform features that mark the country.

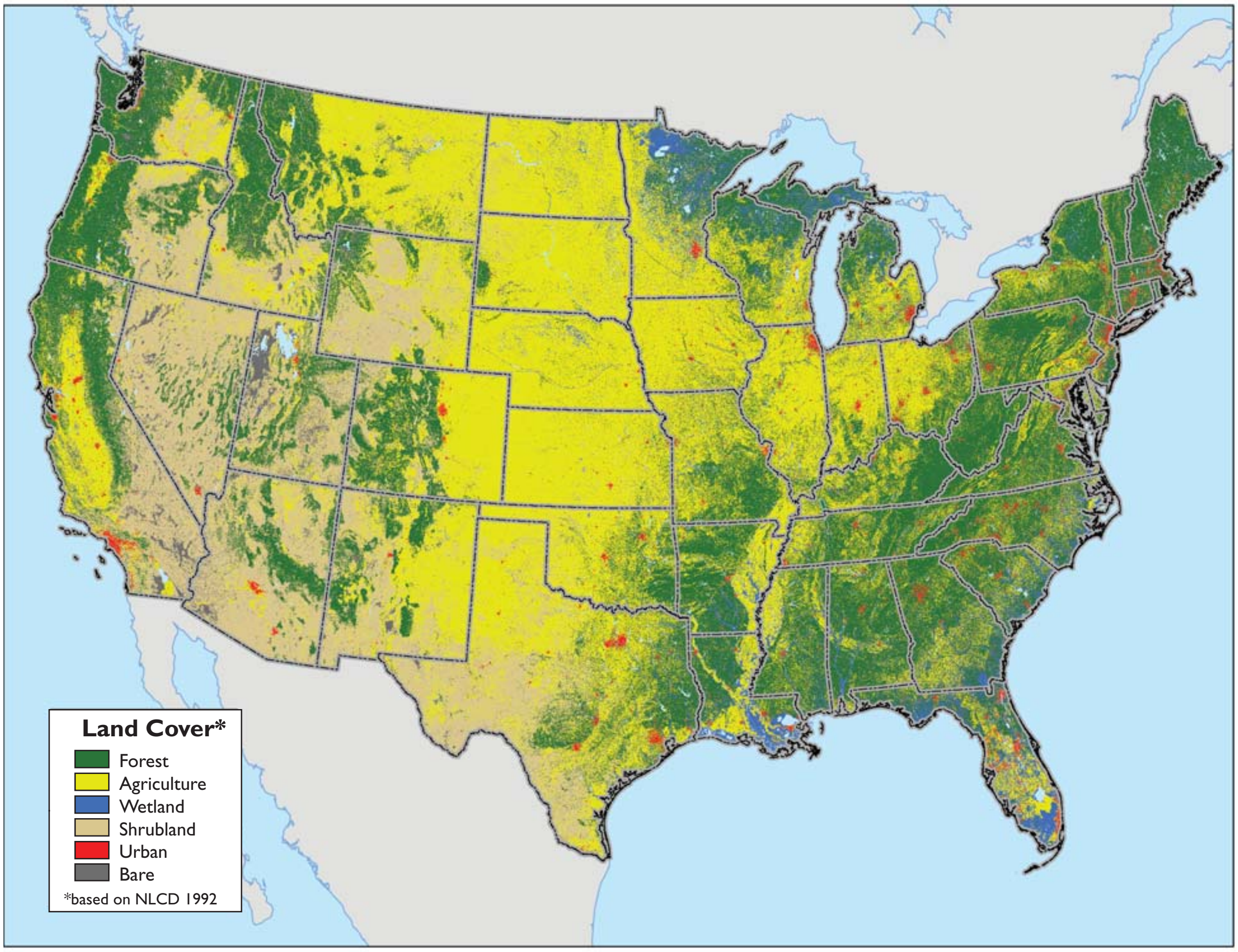


Figure 5. Major land cover patterns of the conterminous United States (USGS, 2000).

The establishment and spread of European colonies and the Industrial Revolution intensified the transformation of the nation's natural landscape, as greater numbers of people arrived and modified many of the features of the land and waters. As the nation's population grew and cities and towns were established, tens of thousands of dams were constructed to alter the flow of virtually every major river in the United States.

Historically, people have tended to live where water is more abundant. Current population patterns based on 2000 U.S. Census Bureau data reflect the historical abundance of waters in the East and forecast the growing challenges facing the water-scarce regions in the West, where population has grown in recent years (Figure 6). The current and future condition of the nation's waters will continue to be influenced by population patterns, as well as how the components of a watershed, including surface water, groundwater, and the land itself, are used.

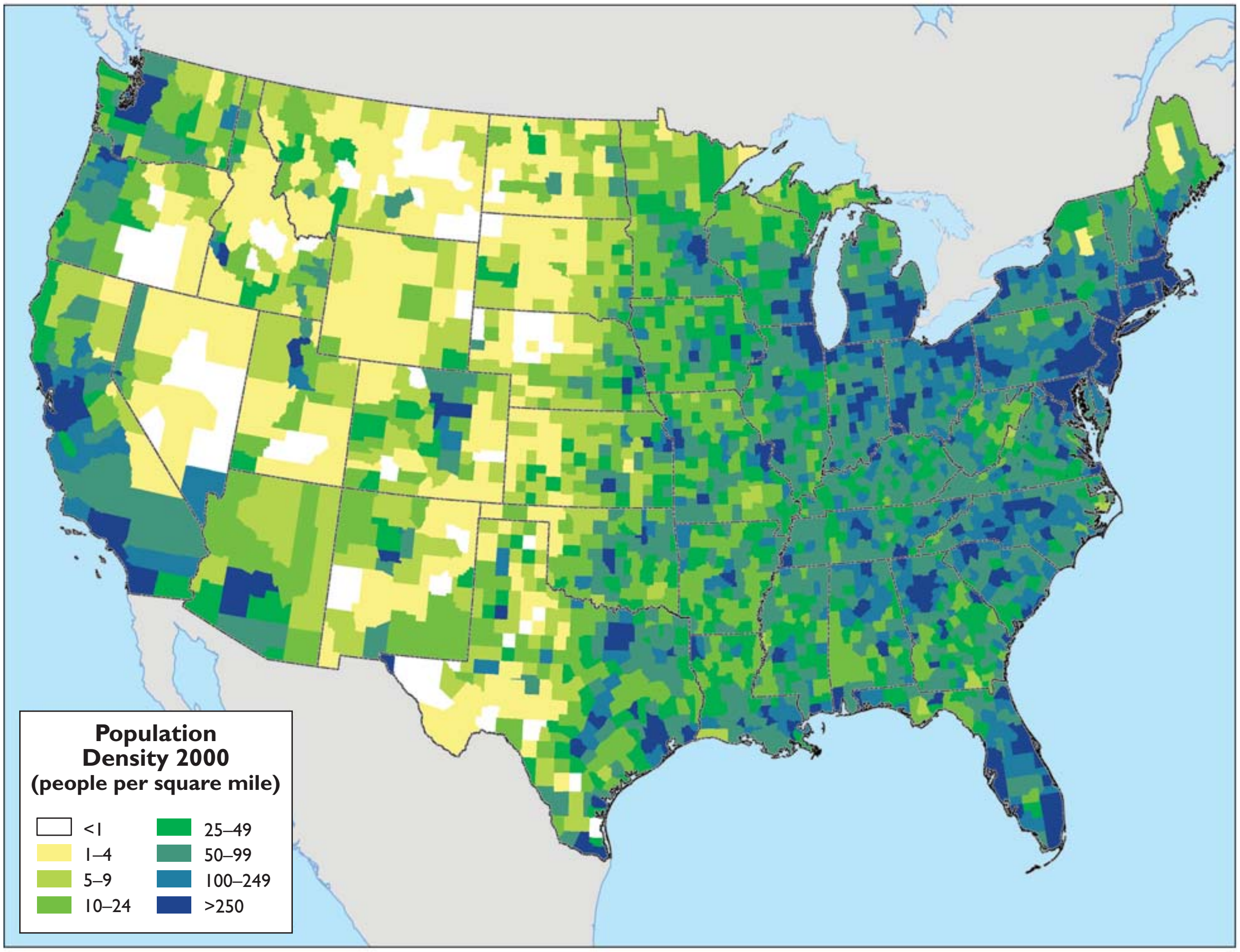


Figure 6. Human population density (people per square mile) based on 2000 U.S. Census Bureau data (ESRI, 2005).

What Areas Are Used to Report WSA Results?

The conterminous United States is the broadest-scale unit for which WSA results are reported. For this report, this area has been split into three major regions—the Eastern Highlands, the Plains and Lowlands, and the West. These three regions correspond to major climate and landform patterns across the United States (Figure 7).

The Eastern Highlands region is composed of the mountainous areas east of the Mississippi River and includes the piedmont to the east of the Appalachians and the interior plateau to their west. The Plains and Lowlands region encompasses the Atlantic and Gulf of Mexico coastal plains and the lowlands of the Mississippi Delta, as well as the portions of the Midwest from the Dakotas down through most of Texas. The West region includes the western portion of the country, from the desert southwestern United States and the Rocky Mountains to the Pacific Ocean. Chapter 2 of this report describes the WSA results for these three major regions.

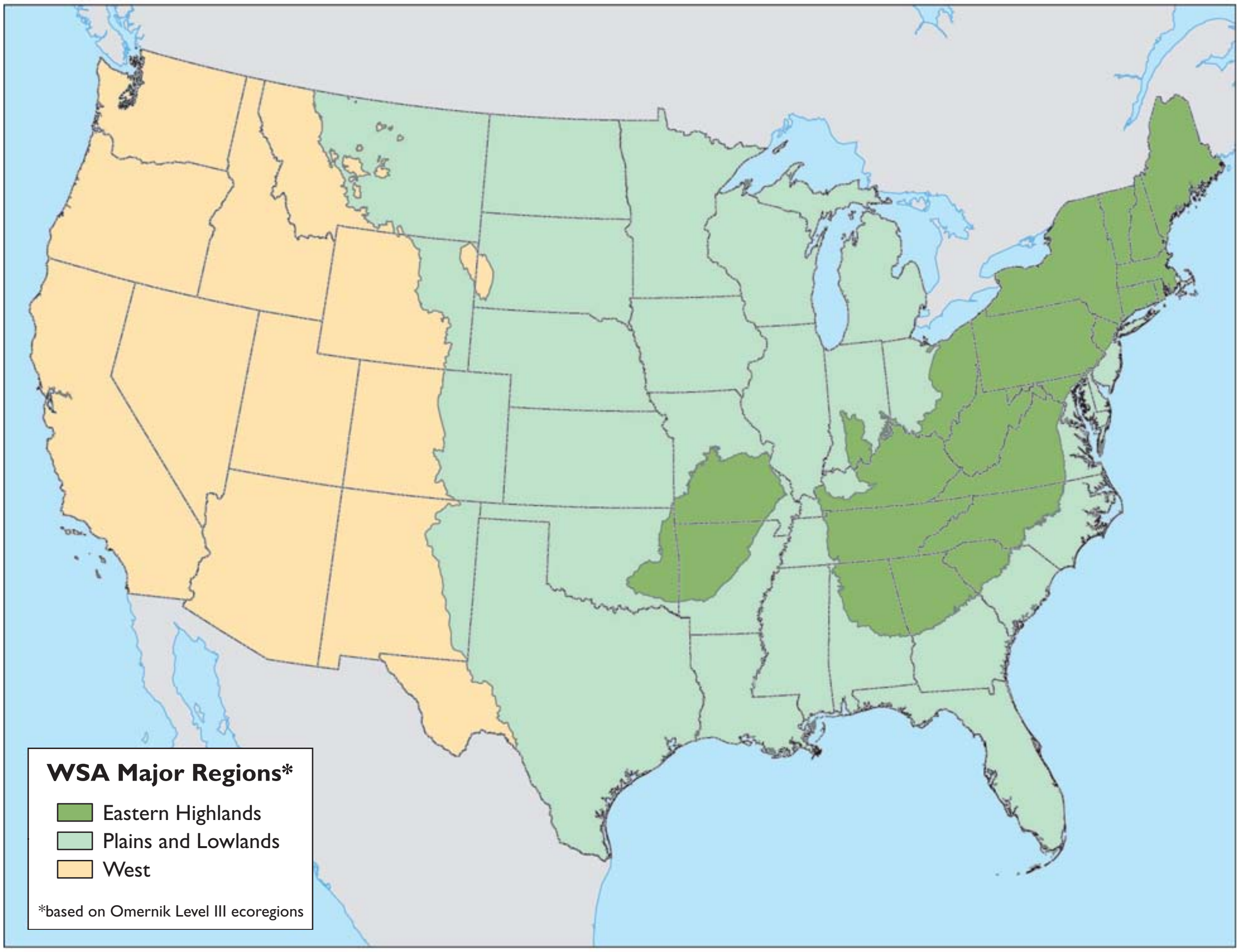


Figure 7. Three major regions were surveyed for the WSA (U.S. EPA/WSA).

A finer-scale reporting unit included in the WSA consists of nine ecological regions (ecoregions) (Figure 8) that further divide the three major regions. The three major regions and the nine ecoregions outlined in this report are aggregations of smaller ecoregions defined by EPA. Areas are included in an ecoregion based on similar landform and climate characteristics. For example, water resources within a particular ecoregion have similar natural characteristics and respond similarly to natural and anthropogenic stressors. Typically, management practices aimed at preventing degradation or restoring water quality apply to many flowing waters with similar problems throughout an ecoregion. This report presents results by ecoregions because the patterns of response to stress, and the stressors themselves, are often best understood in a regional context. The results for the nine ecoregions are reviewed in Chapter 3 of this report.

The Eastern Highlands region is divided into two ecoregions: the Northern Appalachians ecoregion, which encompasses New England, New York, and northern Pennsylvania, and the Southern Appalachians ecoregion, which extends from Pennsylvania into Alabama, through the eastern portion of the Ohio Valley, and includes the Ozark Mountains of Missouri, Arkansas, and Oklahoma.

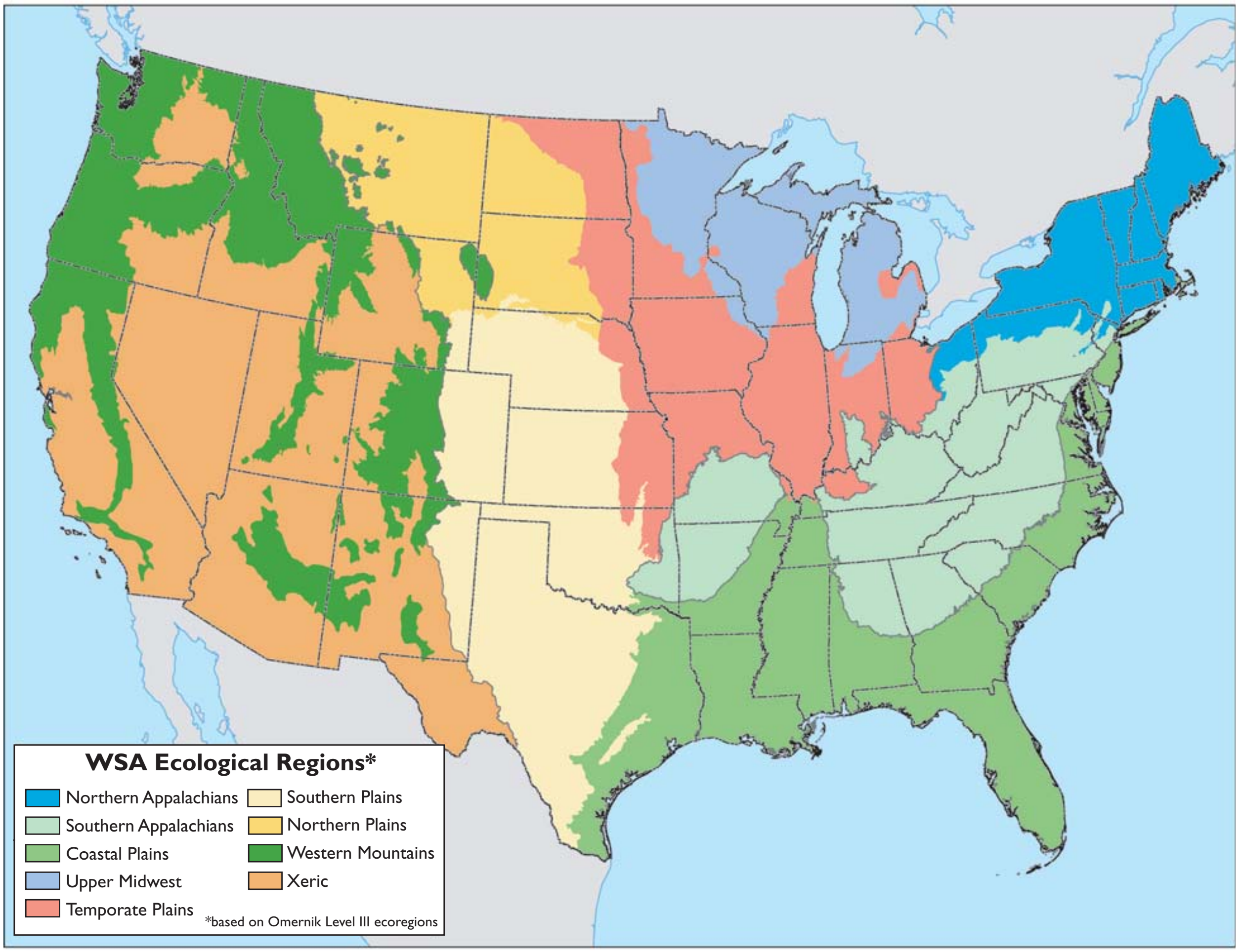


Figure 8. Nine ecoregions were surveyed for the WSA (U.S. EPA/WSA).

The Plains and Lowlands region includes five WSA ecoregions: the Coastal Plains, the Upper Midwest, the Temperate Plains, the Northern Plains, and the Southern Plains. The Coastal Plains ecoregion covers the low-elevation areas of the East and Southeast, including the Atlantic and Gulf of Mexico coastal plains and the lowlands of the Mississippi Delta, which extend from the Gulf of Mexico northward through Memphis, TN. The Upper Midwest ecoregion is dominated by lakes and has little elevation gradient. The Temperate Plains ecoregion in the midwestern United States is probably most well-known as the Cornbelt. The Northern Plains and Southern Plains ecoregions are better known as the Great Prairies, with the Northern Plains ecoregion encompassing North Dakota, South Dakota, Montana, and northeast Wyoming, and the Southern Plains ecoregion encompassing parts of Nebraska, Kansas, Colorado, New Mexico, Oklahoma, and Texas.

The West region includes two WSA ecoregions: the Western Mountains ecoregion and the arid or Xeric ecoregion. The Western Mountains ecoregion includes the Cascade, Sierra Nevada, and Pacific Coast mountain ranges in the coastal states; the Gila Mountains in the southwestern states; and the Bitteroot and Rocky Mountains in the northern and central mountain states. The Xeric ecoregion includes both the true deserts and the arid lands of the Great Basin.

Some states participating in the WSA assessed an even finer state-scale resolution than the ecoregion scale by sampling additional random sites within their state borders. Although these data are included in the analysis described in this report, state-scale results are not presented for each state. These states are preparing similar analyses that reflect their respective water quality standards and regulations.

How Were Sampling Sites Chosen?

The WSA sampling locations were selected using modern survey design approaches. Sample surveys have been used in a variety of fields (e.g., election polls, monthly labor estimates, forest inventory analyses, National Wetlands Inventory) to determine the status of populations or resources of interest using a representative sample of a relatively few members or sites. This approach is especially cost effective if the population is so large that all components cannot be sampled or if obtaining a complete census of the resource is unnecessary to reach the desired level of precision for describing conditions.

Survey data are frequently reported in the news. For example, the percentage of children 1–5 years old living in the United States who have high lead levels in their blood is 2.2% +/- 1.2%, an estimate based on a random sample of children in the United States. The WSA results have similar rigor in their ability to estimate the percentage of stream miles, within a range of certainty, that are in good condition.

To pick a random sample, the location of members of the population of interest must be known. The target population for the WSA was the wadeable, perennial streams in the conterminous United States. The WSA design team used the National Hydrography Dataset (NHD)—a comprehensive set of digital spatial data on surface waters—to identify the location of wadeable, perennial streams. They also obtained information about stream order from the River Reach File, a related series of hydrographic databases that provide additional attributes about stream reaches. Using these resources, researchers determined the length of wadeable streams for each of the nine ecoregions (Figure 9).

For this WSA report, the wadeable stream miles assessed for the nation, regions, and ecoregions are referred to as the stream length. The total stream length represented in the WSA for the nation is 671,051 miles. For the Eastern Highlands, Plains and Lowlands, and West regions, the total stream length assessed for the WSA is 276,362 miles, 242,264 miles, and 152,425 miles, respectively.

The 1,392 sites sampled for the WSA were identified using a particular type of random sampling technique called a probability-based sample design, in which every element in the population has a known probability of being selected for sampling. This important feature ensures that the results of the WSA reflect the full range in character and variation among wadeable streams across the United States. Rules for site selection included weighting to provide balance in the number of stream sites from each of the 1st- through 5th-order size classes and controlled spatial distribution to ensure that sample sites were distributed across the United States (Figure 10).

The WSA sites were allocated by EPA Region and WSA ecoregion based on the distribution of 1st- through 5th-order streams within those regions. Within each EPA Region, random sites are more densely distributed where the perennial 1st- through 5th-order streams are more densely located and more sparsely distributed where streams are sparse. For example, EPA Region 4 in the southeastern United States includes large portions of the Southern Appalachian and Coastal Plains ecoregions. The survey design in EPA Region 4 identified more sites in the Southern Appalachians ecoregion, where the stream length is 178,449 miles, than in the Coastal Plains ecoregion, where the stream length is 72,130 miles (see Figure 9).

The basic sampling design drew 50 sampling sites randomly distributed in each of the EPA Regions and WSA ecoregions. Some of the unusually dense site patterns visible on Figure 10 occur because some states opted to increase the intensity of random sampling throughout

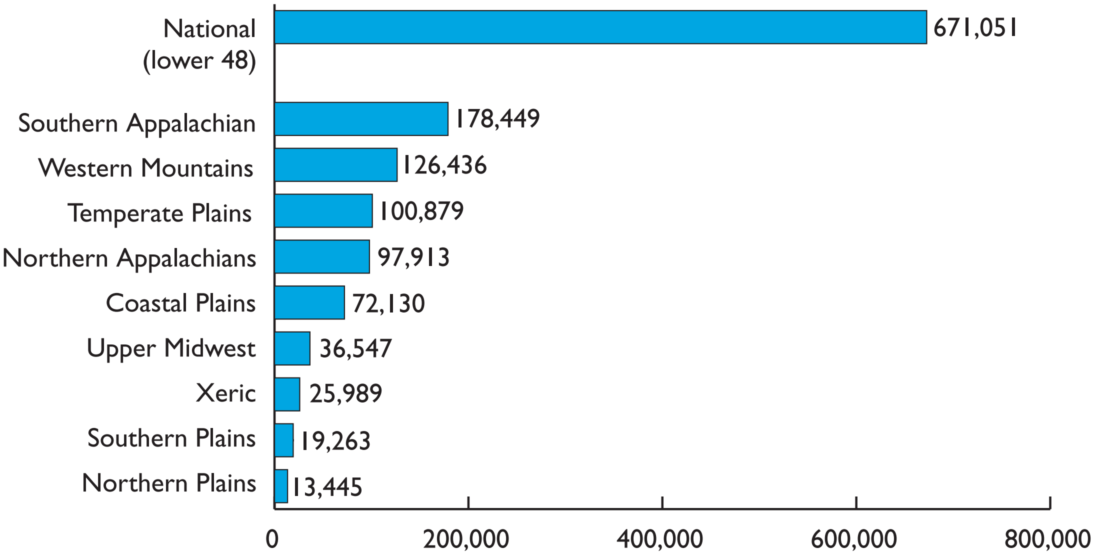


Figure 9. Length of wadeable, perennial streams in each WSA ecoregion (U.S. EPA/WSA).

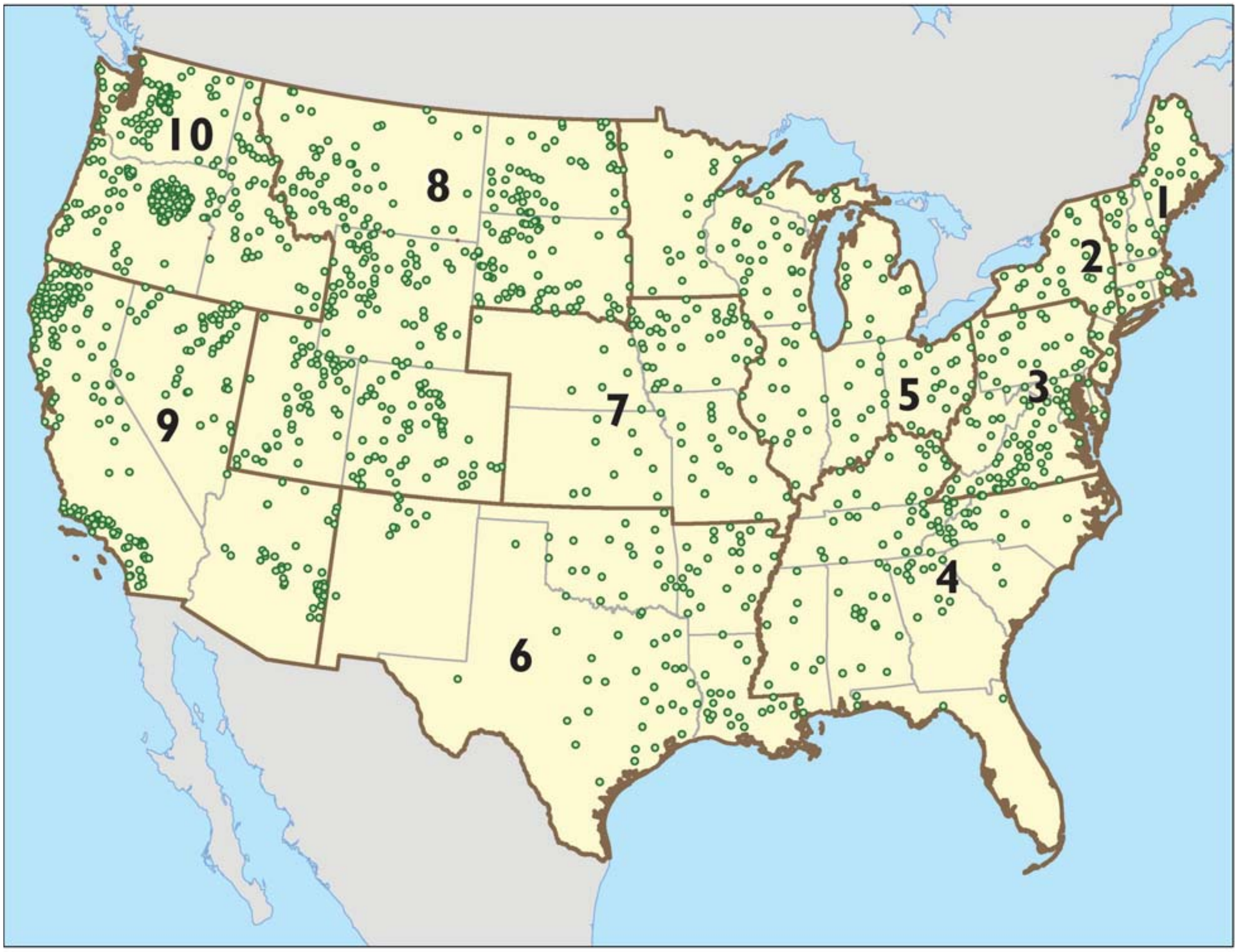


Figure 10. Sites sampled for the WSA by EPA Region (U.S. EPA/WSA).

their state to characterize statewide conditions. Fifteen states, including all states in EPA Regions 8, 9, and 10, increased the number of random sites to 50 sites throughout each state to support state-scale characterizations of stream condition. States also added clusters of random sites to characterize areas of special interest in Washington, Oregon, and California. When sites from an area of intensification were used in the ecoregion assessments, the weights associated with those sites were adjusted so that the additional sites did not dominate the results. The unbiased site selection of the survey design ensures that assessment results represent the condition of the streams throughout the nation.

An additional 150 reserve replacement sites were generated for each of the 10 EPA Regions. These replacement sites were used when site reconnaissance activities documented that one of the original stream sites could not be sampled. For example, sites were replaced when a waterbody did not meet the definition of a wadeable stream (e.g., no flowing water over 50% of the reach) or was unsafe for sampling, or when access to the stream was denied by the landowner.

Highlight

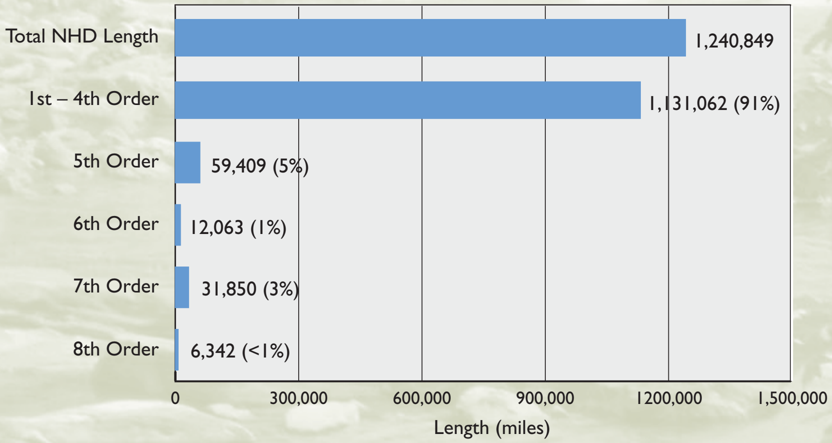
WSA Sampling Frame

The basis of the WSA target population is 1st- through 5th-order perennial streams, which are the streams most likely to be wadeable. The sampling frame used to represent the target population and to select the sites for the WSA is based on the perennial stream network contained in the USGS-EPA NHD. The NHD is a digitized version of 1:100K USGS topographic maps and shows both perennial and non-perennial (e.g., intermittent and ephemeral) streams.

The total stream length in the NHD stream and river network labeled perennial in the conterminous United States is 1,204,859 miles. Of this amount, 1,131,062 miles are 1st- through 4th-order streams, which make up 91% of the total stream length of the nation's flowing waters (see figure below).

Of the more than 1 million miles of stream length labeled as perennial, almost 34% (400,000 miles) were found to be non-perennial or non-target waterbodies (e.g., wetlands, reservoirs, irrigation canals). The remaining target stream length represents the portion of the NHD that meets criteria for inclusion in the WSA (e.g., perennial, wadeable streams). A portion of that target stream length was not sampled for various reasons, including denial of access by a landowner or inaccessibility.

In addition to generating results on the condition of perennial streams, the WSA provides data on the total length of perennial stream miles in the United States. These results will be loaded into the NHD so that the database is updated on the status of perennial/non-perennial stream information.



Estimate of perennial length of streams and rivers from the NHD (U.S. EPA/WSA). The 1st- through 4th-order streams comprise 91% of total estimated stream length in the NHD. The 1st- through 5th-order streams form the basis for the sampling design frame for the WSA.

How Were Waters Assessed?

Each WSA site was sampled by a two- to four-person field crew between 2000 and 2004 during a summer index period. More than 40 trained crews, comprised primarily of state environmental staff, sampled 1,392 stream sites using standardized field protocols. The field protocols were designed to consistently collect data relevant to the biological condition of stream resources and the resources' key stressors.

During each site visit, crews laid out the sample reach and the numerous transects to guide data collection (Figure 11). Field crews sent water samples to a laboratory for basic chemical analysis, whereas biological samples collected from 11 transects along each stream reach were sent to taxonomists for identification of macroinvertebrates. Crews also completed roughly 35 pages of field forms, recording data and information about the physical characteristics

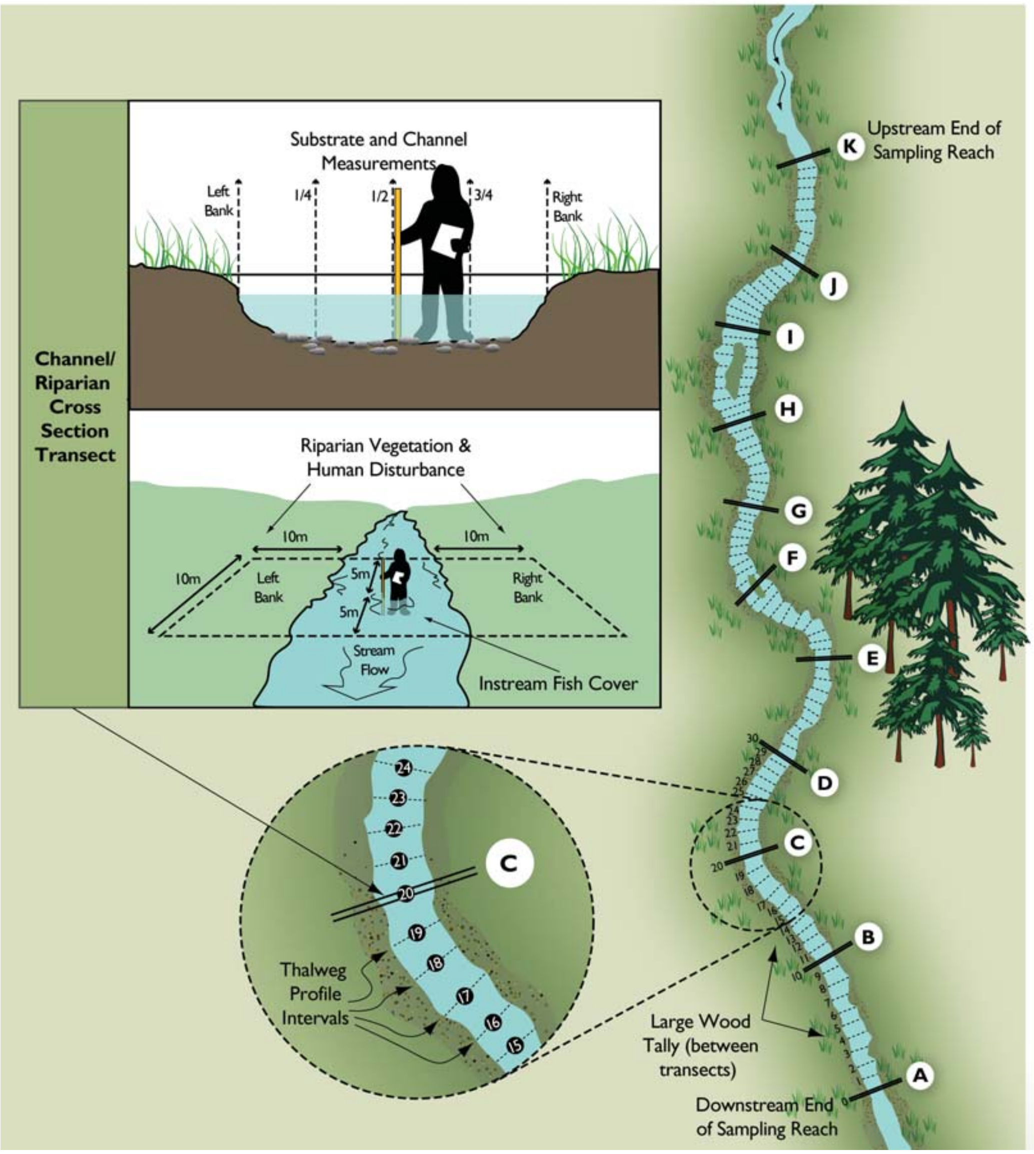


Figure 11. Reach layout for sampling (U.S. EPA/WSA).

of each stream and the riparian area adjacent to its banks. Each crew was audited, and 10% of the sites were revisited as part of the quality assurance plan for the survey.

The use of standardized field and laboratory protocols for sampling is a key feature of the WSA. Because ecologists use a range of methods to sample streams, it is often difficult to compare data collected by different states, regions, or agencies on a regional or national level. Standardization allows the data to be combined to produce a nationally consistent assessment. In addition to collecting a national set of consistent data, this nationwide sampling effort provided an opportunity to examine the comparability of different sample protocols by applying both the WSA method and various state or USGS methods to a subset of the sites. A separate analysis is underway to examine the comparability of these methods and explore options for how the resulting data may be used together.

The WSA uses benthic macroinvertebrates (e.g., aquatic larval stages of insects, crustaceans, worms, mollusks) as the biological indicator of a stream's ecological condition. Benthic macroinvertebrates live throughout the stream bed, attaching to rocks and woody debris and burrowing in sandy stream bottoms and among the debris, roots, and grasses that collect and grow along the water's edge (Figure 12). The

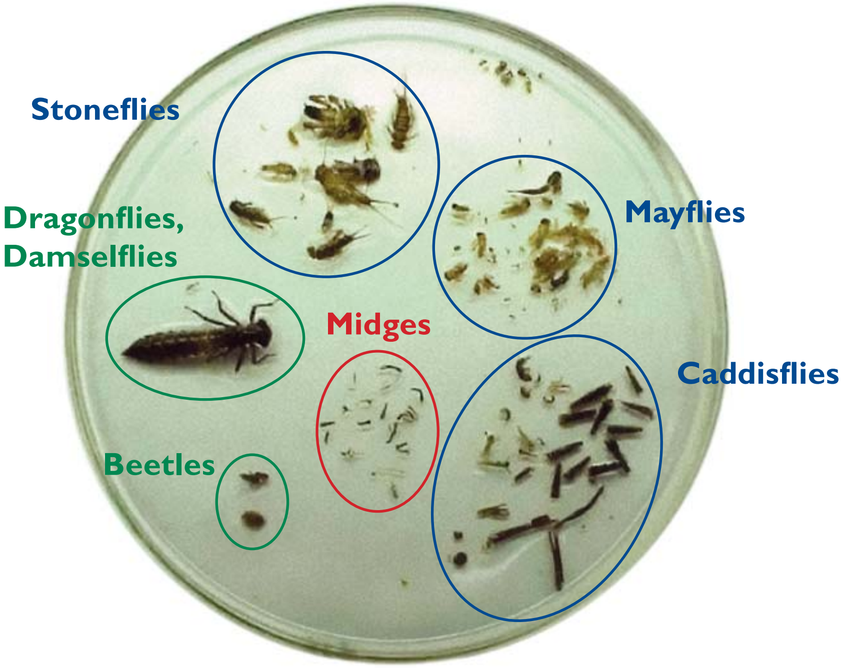


Figure 12. Stream macroinvertebrates (Photo courtesy of Maine Department of Environmental Protection). Macroinvertebrates in streams serve as the basis for the indicators of biological condition for the WSA.

WSA focuses on these macroinvertebrates because of their inherent capacity to integrate the effects of the stressors to which they are exposed, in combination and over time. Stream macroinvertebrates generally cannot move very quickly or very far; therefore, they are affected by, and may recover from, a number of changes in physical conditions (e.g., habitat loss), chemical conditions (e.g., excess nutrients), and biological conditions (e.g., the presence of invasive or non-native species). Some types of macroinvertebrates are affected by these conditions more than others.

Macroinvertebrates provide a measurement of biological condition or health relative to the biological integrity of a stream. Biological integrity represents the capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitat of the region. Macroinvertebrates are researched by almost every state and federal program that monitors streams and are also increasingly evaluated by volunteer organizations that monitor water quality. In addition, water quality monitoring and management programs are enhancing the understanding of the biological condition of streams by adding other biological assemblages, including fish and algae.

The WSA supplements information on the biological condition of streams with measurements of key stressors that might negatively influence or affect stream condition. Stressors are the chemical, physical, and biological components of the ecosystem that have the potential to degrade stream biology. Some stressors are naturally occurring, whereas others result only from human activities, although most come from both sources.

Most physical stressors are created when we modify the physical habitat of a stream or its watershed, such as through extensive urban or agricultural development, excessive upland or bank erosion, or loss of streamside trees and vegetation. Examples of chemical stressors include toxic compounds (e.g., heavy metals, pesticides), excess nutrients (e.g., nitrogen and phosphorus), or acidity from acidic deposition or mine drainage. Biological stressors are characteristics of the biota that can influence biological integrity, such as the proliferation of non-native or invasive species (either in the streams and rivers, or in the riparian areas adjacent to these waterbodies).

The WSA water chemistry data allow an evaluation of the distribution of nutrients, salinity, and acidification in U.S. streams. The physical habitat data provide information on the prevalence of excess sediments, the quality of in-stream fish habitat, and the quality of riparian habitat alongside streams. Although these are among the key stressors identified by states as affecting water quality, they do not reflect the full range of potential stressors that can impact water quality. Future water quality surveys will include an assessment of additional stressors.

One of the key components of an ecological assessment is a measure of how important (e.g., how common) each stressor is within a region and how severely it affects biological condition. In addition to looking at the extent of streams affected by key stressors, the WSA evaluated the relative risk posed by key stressors to biological condition.

Highlight

Understanding Biological Condition

The main goal of the WSA is to develop a baseline understanding of the biological condition of our nation's streams. Why is this important?

One of the most meaningful ways to answer basic questions about water quality is to directly observe the communities of plants and animals that live in waterbodies. Aquatic plants and animals—especially the small creatures that are the focus of this study—are constantly exposed to the effects of various stressors; therefore, they reflect not only current conditions, but also the cumulative impacts of stresses and changes in conditions over time.

Benthic macroinvertebrates are widely used to determine biological condition. These organisms can be found in all streams, even in the smallest streams that cannot support fish. Because they are relatively stationary and cannot escape pollution, macroinvertebrate communities integrate the effects of stressors over time (i.e., pollution-tolerant species will survive in degraded conditions, and pollution-intolerant species will die). These communities are also critically important to fish because most game and non-game species require a good supply of benthic macroinvertebrates as food. Biologists have been studying the health and composition of benthic macroinvertebrate communities in streams for decades.

Biological condition is the most comprehensive indicator of waterbody health; when the biology of a stream is healthy, the chemical and physical components of the stream are also typically in good condition. In fact, several states have found that biological data frequently detect stream impairment where chemistry data do not.

Data on biological condition are invaluable for managing the nation's aquatic resources and ecosystems. Water quality managers can use these data to set protection and restoration goals, decide which indicators to monitor and how to interpret monitoring results, identify stresses to the waterbody and decide how they should be controlled, and assess and report on the effectiveness of management actions. In fact, many specific state responsibilities under the CWA—such as determining the extent to which waters support aquatic life uses, evaluating cumulative impacts from polluted runoff, and determining the effectiveness of discharger permit controls—are tied directly to an understanding of biological condition.

Setting Expectations

To interpret the data collected and assess current ecological condition, chemical, physical, and biological measurements must be compared to a benchmark or estimate of what one would expect to find in a natural condition. Setting reasonable expectations for an indicator is one of the greatest challenges to making an assessment of ecological condition. Should we take an historical perspective and try to compare current conditions to an estimate of pre-colonial conditions, pre-industrial conditions, or conditions at some other point in history, or should we accept that some level of anthropogenic disturbance is expected and simply use the best of today's conditions as the benchmark against which everything else is compared?

These questions, and their answers, all relate to the concept of reference condition. What do we use as a reference condition to set the benchmark for assessing the current status of these waterbodies? Because of the difficulty of estimating historical conditions for many of the WSA indicators, the assessment used the conditions at a collection of "least-disturbed" sites as the reference condition. This means that the condition at these sites represents the best available chemical, physical, and biological habitat conditions given the current state of the landscape. Least-disturbed sites were identified by evaluating data collected at sites according to a set of explicit screening levels that define what is least disturbed by human activities. To reflect the natural variability across the American landscape, these levels varied among the nine ecoregions. The WSA compared physical and chemical data collected at each site (e.g., nutrients, riparian condition, chloride, turbidity, fine sediments) to the screening levels to determine whether any given site was in least-disturbed condition for its ecoregion.

A researcher collects macroinvertebrate samples from a small stream in the Northern Appalachians ecoregion (Photo courtesy of the Vermont Department of Environmental Conservation).

Data on land use in the watersheds were not used to screen-out sites. For example, sites in agricultural areas with effective best management practices (BMPs) may have been considered least disturbed, provided they exhibited chemical and physical conditions that were among the best for their region. The WSA also did not use data on biological assemblages as a screening factor to select reference sites because that would have pre-judged expectations for biological condition. Similarly, when selecting least-disturbed reference sites for each stressor, the WSA excluded the specific stressors themselves from the screening process.

The WSA screening process resulted in the identification of a set of least-disturbed reference sites for each WSA ecoregion. These sites were distributed throughout the ecoregions and covered the range of natural variability across each area. Some of these sites included a degree of human-caused variability.

The results from samples collected at the reference sites for the various indicators (e.g., biological condition, nutrients) represent the range of expected values for least-disturbed reference condition. The WSA used this reference distribution as a benchmark for setting thresholds between good, fair, and poor condition. These thresholds were then applied to the random sites to generate the percentage of stream length in each condition class.

The WSA's approach examined the range of values for indicators in all of the reference sites in a region and used the 5th percentile of the reference distribution for that indicator to separate the poor sites from fair sites. Using the 5th percentile means that stream sites and associated stream length in poor condition were worse than 95% of the sites used to define least-disturbed reference condition. Similarly, the 25th percentile of the reference distribution was used to distinguish between sites in fair and good condition. This means that stream length reported as being in good condition was as good as or better than 75% of the sites used to define least-disturbed reference condition.

Within the reference site population, there exist two sources of variability: natural variability and variability due to human activities. Natural variability—the wide range of habitat types naturally found within each ecoregion—creates a spread of reference sites representing these differing habitats. Capturing natural variability in reference sites helps establish reference conditions that represent the range of environments in the ecoregions.

The second source of variation within the reference population is change resulting from human activities. Many areas in the United States have been altered, with natural landscapes transformed by cities, suburban sprawl, agricultural development, and resource extraction. The extent of those disturbances varies across regions. Some of the regions of the country have reference sites in watersheds with little to no evidence of human impact, such as mountain streams or streams in areas with very low population densities. Other regions of the country have few sites that have not been influenced by human activities. The least-disturbed reference sites in these widely influenced watersheds display more variability in quality than those in watersheds with little human disturbance.

Variation within the reference distribution due to disturbance was addressed before benchmarks were set for the condition classes of good, fair, and poor. For regions where the reference sites exhibited a disturbance signal, the data analysis team accounted for this disturbance by shifting the mean of the distribution toward the less-disturbed reference sites.

At a national meeting to discuss data analysis options, WSA collaborators supported this reference condition-based approach, which is consistent with EPA guidance and state practice on the development of biological and nutrient criteria. Additional details on how the least-disturbed condition and benchmarks for the condition categories were established for the WSA can be found in the data analysis method available on the EPA Web site at http://www.epa.gov/owow/streamsurvey.

Chapter 2

Photo courtesy of the Georgia Department of Natural Resources

Condition of the Nation's Streams

Condition of the Nation's Streams

Background

The CWA explicitly aims "to restore and maintain the chemical, physical, and biological integrity of the nation's waters." The WSA examines these three aspects of water quality through a small set of commonly used and widely accepted indicators. Although this WSA report does not include all aspects of biological integrity or review all possible chemical, physical, or biological stressors known to affect water quality, it does present the results of important indicators for an entire class of water resources—wadeable, perennial streams.

This chapter describes the results of the WSA and is organized as follows:

- **Indicators of Biological Condition** – Provides a description of the indicators or attributes of biological condition that were measured by the WSA survey and the results of the data analysis.
- **Aquatic Indicators of Stress** – Presents findings on the stressors evaluated for the study.
- **Ranking of Stressors** – Presents an analysis of the relative importance of the stressors in affecting biological condition.

Results for each indicator are shown for the nation's streams and for the three major regions (Eastern Highlands, Plains and Lowlands, and West). Chapter 3 of this report presents indicator results for each of the nine WSA ecoregions.

Indicators of Biological Condition

Ecologists evaluate the biological condition of water resources, including wadeable streams, by analyzing key characteristics of the communities of organisms that live in these waterbodies. These characteristics include the composition and relative abundance of key groups of animals (e.g., fish and invertebrates) and plants (e.g., periphyton, or algae that attach themselves to stream bottoms, rocks, and woody debris)

Jellison Meadow Brook, ME, in the Eastern Highlands region
(Photo courtesy of Colin Hill, Tetra Tech, Inc.).

found in streams. The WSA focused on just one assemblage, benthic macroinvertebrates (e.g., aquatic insects, crustaceans, worms and mollusks); however, some WSA participants also researched other assemblages.

Why focus on macroinvertebrates? Macroinvertebrates are key organisms that reflect the quality of their environment and respond to human disturbance in fairly predictable ways. As all fly-fishermen know, the insects emerging from streams and rivers are good indicators of the water quality and serve as an important food source for both game and non-game fish. Given the wide geographic distribution of macroinvertebrates, as well as their abundance and link to fish and other aquatic vertebrates, these organisms serve as excellent indicators of the quality of flowing waters and the human stressors that affect these systems.

WSA researchers collected samples of these organisms and sent them to laboratories for analysis, yielding a data set that provided the types and number of taxa (i.e., classifications or groupings of organisms) found at each site. To interpret this data set, the WSA used two indicators of biological condition: the Macroinvertebrate Index of Biotic Condition and the Observed/Expected (O/E) Ratio of Taxa Loss.

Macroinvertebrate Index of Biotic Condition

The Macroinvertebrate Index of Biotic Condition (henceforth referred to as the Macroinvertebrate Index) is similar in concept to the economic Consumer Confidence Index (or the Leading Index of Economic Indicators) in that the total index score is the sum of scores for a variety of individual measures, also called indicators or metrics. To determine the Leading Index, economists look at a number of metrics, including manufacturers' new orders for consumer goods, building permits, money supply, and other aspects of the economy that reflect economic growth. To determine the Macroinvertebrate Index, ecologists look at such metrics as taxonomic richness, habit and trophic composition, sensitivity to human disturbance, and other biotic aspects that reflect "naturalness." Originally developed as an Index of Biotic Integrity for fish in Midwestern streams, the Macroinvertebrate Index has been modified and applied to other regions, taxonomic groups, and ecosystems.

What are Taxa?

Taxa (plural of taxon) are groupings of living organisms, such as phylum, class, order, family, genus, or species. Biologists scientifically describe and organize organisms into taxa in order to better identify and understand them.

The metrics used to develop the Macroinvertebrate Index for the WSA covered six different characteristics of macroinvertebrate assemblages that are commonly used to evaluate biological condition:

- **Taxonomic richness** – This characteristic represents the number of distinct taxa, or groups of organisms, identified within a sample. Many different kinds of distinct taxa, particularly those that belong to pollution-sensitive insect groups, indicate a variety of physical habitats and food sources and an environment exposed to generally lower levels of stress.

Highlight

Using Multiple Biological Assemblages to Determine Biological Condition

EPA's guidance on developing biological assessment and criteria programs recommends the use of multiple biological assemblages to determine biological condition. The term "multiple biological assemblages" simply refers to the three main categories of life found in a waterbody: plants (e.g., algae), macroinvertebrates, and vertebrates (e.g., fish). The purpose of examining multiple biological assemblages is to generate a broader perspective of the condition of the aquatic resource of interest.

Each assemblage plays a different role in the way that rivers and streams function. Algae and macroinvertebrates occur throughout all types and sizes of streams, whereas very small streams may be naturally devoid of fish. Algae are the base of the food chain and capture light and nutrients to generate energy. They are sensitive to changes in shading, turbidity, and increases or decreases in nutrient levels. Macroinvertebrates feed on algae and other organic material that enters the aquatic system from the surrounding watershed. Macroinvertebrates also form the base of the food chain for many aquatic vertebrates. Fish are an example of these aquatic vertebrates and also serve as an important food source for people and wildlife. Each of these groups of aquatic organisms is sensitive in its own way to different human-induced disturbances.

The WSA collaboration began as a partnership among 12 western states; EPA Regions 8, 9, and 10; and EPA's Western Ecology Division (Environmental Monitoring and Assessment Program [EMAP] West) before it was expanded to include the entire United States. The original EMAP West program addressed fish, macroinvertebrates, and algae; future WSA reports will also address multiple assemblages.

To learn more about EMAP West and its use of multiple biological assemblages, visit www.epa.gov/emap/west/index.html.

- **Taxonomic composition** – Ecologists calculate composition metrics by identifying the different taxa groups, determining which taxa in the sample are ecologically important, and comparing the relative abundance of organisms in those taxa to the whole sample. Healthy stream systems have organisms from across many different taxa groups, whereas unhealthy stream systems are often dominated by a high abundance of organisms in a small number of taxa that are tolerant of pollution.
- **Taxonomic diversity** – Diversity metrics look at all the taxa groups and the distribution of organisms among those groups. Healthy streams should have a high level of diversity throughout the assemblage.
- **Feeding groups** – Many macroinvertebrates have specialized strategies to capture and process food from their aquatic environment. As a stream degrades from its natural condition, the distribution of animals among the different feeding groups will change. For example, as a stream loses its canopy (a source of leaves and shading), the aquatic community will shift from a more diverse food chain to one of predominantly algal-feeding animals that are tolerant of warm water.
- **Habits** – Just like other organisms, benthic macroinvertebrates are characterized by certain habits, including how they move and where they live. These habits are captured in the habit metrics. For example, some taxa burrow under the streambed sediment, whereas others cling to rocks and debris within the stream channel. A stream that naturally includes a diversity of habitat types will support animals with diverse habits; however, if a stream becomes laden with silt, the macroinvertebrates that cling, crawl, and swim will be replaced by those that burrow.
- **Pollution tolerance** – Each macroinvertebrate taxa can tolerate a specific range of stream contamination, which is referred to as their pollution tolerance. Once this level is exceeded, the taxa are no longer present in that area of the stream. Highly sensitive taxa, or those with a low pollution tolerance, are found only in streams with good water quality.

The specific metrics chosen for each of these categories varied among the nine ecoregions used in the analysis. Each metric was scored and then combined to create an overall Macroinvertebrate Index for each region, with values ranging from 0 to 100. For the WSA, analysts calculated a Macroinvertebrate Index score for each site, factored in the stream length represented by the site, and then generated an estimate of the stream length in a region, and nationally, with a given Macroinvertebrate Index score.

Six different characteristics of macroinvertebrate assemblages are commonly used to evaluate biological condition in wadeable streams (Photo courtesy of Lauren Holbrook, IAN Image Library).

Findings for the Macroinvertebrate Index of Biotic Condition

As illustrated in Figure 13, the Macroinvertebrate Index indicator results show that 42% of the nation's stream length (281,170 miles) is in poor condition, 25% (167,092 miles) is in fair condition, and 28% (189,236 miles) is in good condition compared to the least-disturbed reference condition in each of the nine WSA ecoregions. The 28% of stream length in good condition has conditions most similar to the reference distribution derived from the best-available (least-disturbed) sites in each ecoregion. The 5% (33,553 miles) of unassessed stream length results from the fact that 1st-order streams in New England were not sampled for the WSA.

Macroinvertebrate Index results show that the Eastern Highlands region has the highest proportion of stream length (52%, or 143,170 miles) in poor condition, followed by the Plains and Lowlands (40%, or 96,905 miles) and the West (27%, or 41,754 miles).

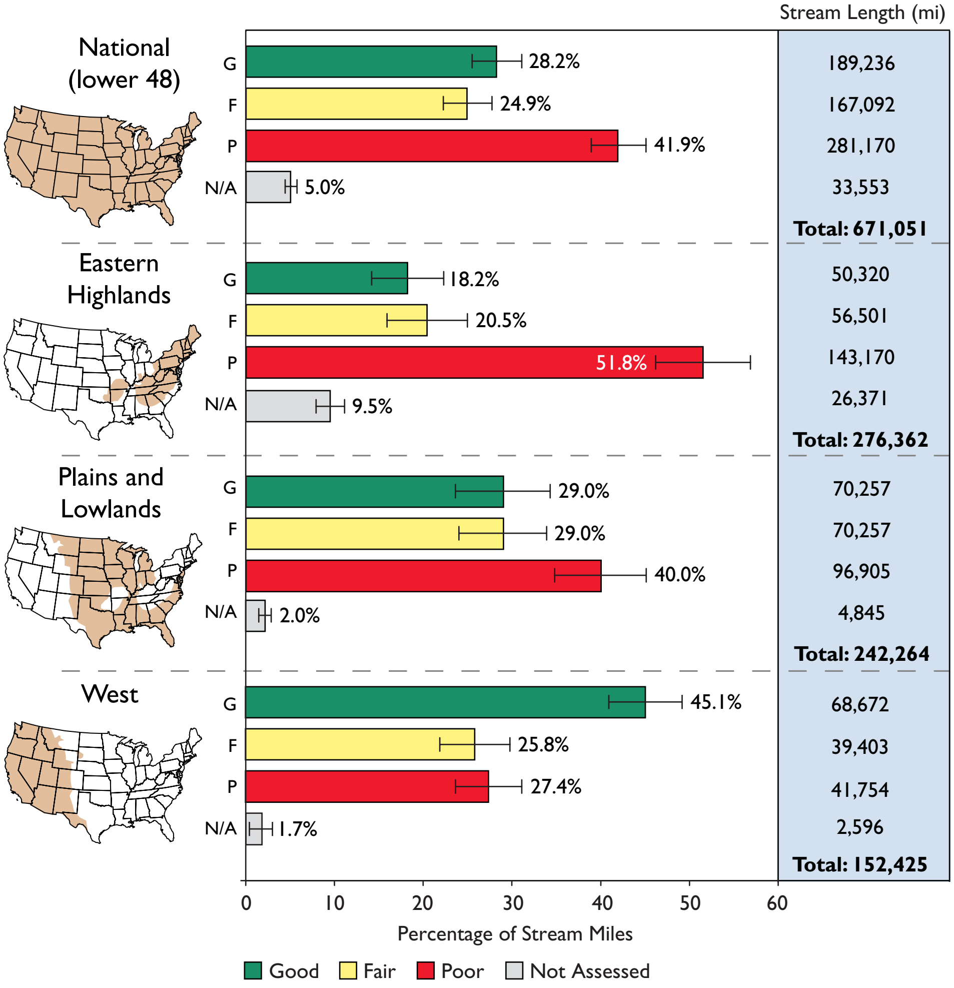


Figure 13. Biological condition of streams based on Macroinvertebrate Index of Biotic Condition (U.S. EPA/WSA). The Macroinvertebrate Index combines metrics of benthic community structure and function into a single index for each region. The thresholds for defining good, fair, and poor condition were developed for each of the nine WSA ecoregions based on condition at the least-disturbed reference sites. Stream length in good condition is most similar to least-disturbed reference condition; in fair condition has Macroinvertebrate Index scores worse than 75% of reference condition; and in poor condition has Macroinvertebrate Index scores worse than 95% of reference condition.

What are Confidence Intervals?

Confidence intervals (i.e., the small lines at the end of the bars in this report's charts) are provided to convey the level of certainty or confidence that can be placed in the information presented in this report. For example, for the national Macroinvertebrate Index, the WSA finds that 28.2% of the nation's stream length is in good condition, and the confidence is +/- 2.8%, which means that there is a 95% certainty that the real value is between 25.4% and 31%. The confidence interval depends primarily on the number of sites sampled; as more streams are sampled, the confidence interval becomes narrower, meaning there is more confidence in the findings. When fewer streams are sampled, the confidence interval become broader, meaning there is less certainty in the findings. Figure 13 shows an example of this pattern, in which the confidence interval for the national results (the largest sample size) is narrowest, whereas the confidence intervals for the major regions, where a smaller number of streams were sampled, are generally broader. Ultimately the breadth of the confidence interval is a tradeoff between the need for increased certainty to support decisions and the money and resources dedicated to monitoring.

Macroinvertebrate Observed/Expected (O/E) Ratio of Taxa Loss

The Macroinvertebrate O/E Ratio of Taxa Loss (henceforth referred to as O/E Taxa Loss) measures a specific aspect of biological health: taxa that have been lost at a site. The taxa expected (E) at individual sites are predicted from a model developed from data collected at least-disturbed reference sites; thus, the model allows a precise matching of sampled taxa with those that should occur under specific, natural environmental conditions. By comparing the list of taxa observed (O) at a site with those expected to occur, the proportion of expected taxa that have been lost can be quantified as the ratio of O/E. Originally developed for streams in the United Kingdom, O/E Taxa Loss models are modified for the specific natural conditions in each area for which they are used. The O/E Taxa Loss indicator is currently used by several countries and numerous states in the United States.

O/E Taxa Loss values range from 0 (none of the expected taxa are present) to slightly greater than 1 (more taxa are present than expected). These values are interpreted as the percentage of the expected taxa present. Each tenth of a point less than 1 represents a 10% loss of taxa at a site; thus, an O/E Taxa Loss score of 0.9 indicates that 90% of the expected taxa are present and 10% are missing. O/E Taxa Loss values must be interpreted in the context of the quality of reference sites used to build the predictive models, because the quality of reference sites available in a region sets the bar for what is expected (i.e., regions with lower-quality reference sites will have a lower bar). Although an O/E Taxa Loss value of 0.8 means the same thing regardless of a region (i.e., 20% of taxa have been lost relative to reference conditions in each region), the true amount of taxa loss will be underestimated if reference sites are of low quality.

The WSA developed three O/E Taxa Loss models to predict the extent of taxa loss across streams of the United States, one model for each of the three major regions outlined in this report (Eastern Highlands, Plains and Lowlands, West). Analysts used the O/E Taxa Loss scores observed at each site to generate estimates of the nation's stream length estimated to fall into four categories of taxa loss.

Although in many cases the results of O/E Taxa Loss analysis are similar to the results of the Macroinvertebrate Index, such agreement will not always occur. The O/E Taxa Loss indicator examines a specific aspect of biological condition (biodiversity loss), whereas the Macroinvertebrate Index combines multiple characteristics. For the WSA, the two indicators provided similar results in those WSA ecoregions that had a lower disturbance signal among their reference sites.

Findings for O/E Taxa Loss

Figure 14 displays the national and regional O/E Taxa Loss summary. These data are presented in four categories: (1) less than 10% taxa loss, (2) 10–20% taxa loss, (3) 20–50% taxa loss, and (4) more than 50% taxa loss. Forty-two percent of the nation's stream length retained more than 90% of expected taxa; 13% lost 10–20% of taxa; 26% lost 20–50% of taxa; and 13% lost more than 50% of taxa.

Within the three regions, stream length in the Eastern Highlands experienced the greatest loss of expected taxa, with 17% experiencing a loss of 50% or more. An additional 29% of stream length in this region lost 20–50% of taxa; 13% lost 10–20% of taxa; and only 28% of stream length lost fewer than 10% of taxa. Eleven percent of stream length in the Plains and Lowlands region experienced a taxa loss of 50% or more, 25% of stream length lost 20–50% of

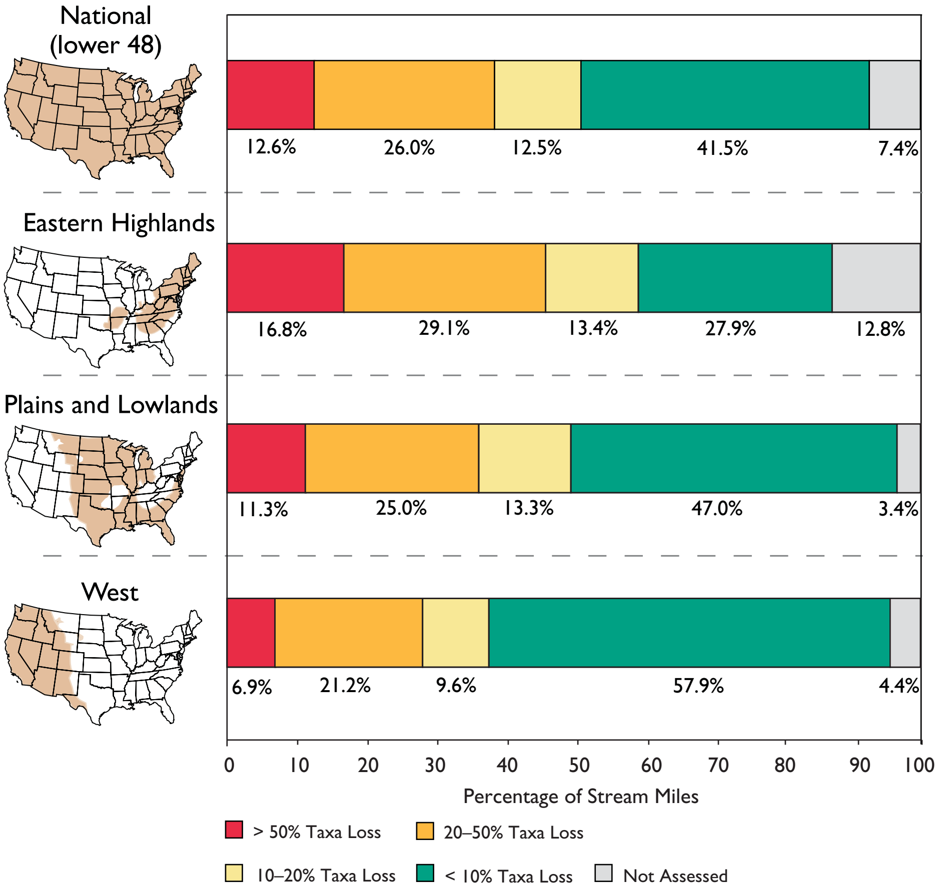


Figure 14. Macroinvertebrate taxa loss as measured by the O/E Ratio of Taxa Loss (U.S. EPA/WSA). The O/E Taxa Loss indicator displays the loss of taxa from a site compared to reference for that region. Scores 0.1 lower than reference represent a 10% loss in taxa.

taxa; 13% lost 10–20% of taxa; and 47% lost fewer than 10% of taxa. In the West, 7% of stream length experienced a taxa loss of 50% or more, 21% of stream length lost 20–50% of taxa; 10% lost 10–20% of taxa; and 58% of stream length lost less than 10% of taxa.

Aquatic Indicators of Stress

As people use the landscape, their actions can produce effects that are stressful to aquatic ecosystems. These aquatic stresses can be chemical, physical, or in some cases, biological. The WSA has selected a short list of stressors from each of these categories as indicators for assessment. This list is not intended to be all-inclusive, and in fact, some important stressors are not included because there is currently no way to assess them at the site scale (e.g., water withdrawals for irrigation). Future assessments of U.S. stream and river condition will include a more comprehensive list of stressors from each of these categories.

WSA indicators are based on direct measures of stress in the stream or adjacent riparian areas, not on land use or land cover alterations, such as row crops, mining, or grazing. Many human activities and land uses can be sources of one or more stressors to streams; however, the WSA only assesses stressors to determine the general condition of the resource and which stressors are most significant and does not track the source of these stressors. Source tracking, an expensive and time-consuming process, is a logical future step for the WSA and similar national assessments.

A summary of the national and regional results for indicators of chemical and physical habitat are shown in Figures 15 through 22. WSA results for these indicators for each of the nine WSA ecoregions are presented in Chapter 3 of this report.

Chemical Stressors

Four chemical stressors were assessed as indicators in the WSA: total phosphorus, total nitrogen, salinity, and acidification. These stressors were selected because of national or regional concerns about the extent to which each might be impacting the quality of stream biota. The thresholds for interpreting data were developed from a set of least-disturbed reference sites for each of the nine WSA ecoregions, as described in Chapter 1, *Setting Expectations*. The results for each ecoregion were tallied to report on conditions for the three major regions and the entire nation.

Total Phosphorus Concentrations

Phosphorus is usually considered the most likely nutrient limiting algal growth in U.S. freshwater waterbodies. Because of the naturally low concentrations of phosphorus in stream systems, even small increases in phosphorus concentrations can impact a stream's water quality. Some waters—such as streams originating from groundwater in volcanic areas of eastern Oregon and Idaho—have naturally higher concentrations of phosphorus. This natural variability is reflected in the regional thresholds for high, medium, and low, which are based on the least-disturbed reference sites for each of the nine WSA ecoregions.

Highlight

Nutrients and Eutrophication in Streams

Eutrophication is a condition characterized by excessive plant growth that results from high levels of nutrients in a waterbody. Although eutrophication is a natural process, human activities can accelerate this condition by increasing the rate at which nutrients and organic substances enter waters from their surrounding watersheds. Agricultural runoff, urban runoff, leaking septic systems, sewage discharges, eroded streambanks, and similar sources can increase the flow of nutrients and organic substances into streams, and subsequently, into downstream lakes and estuaries. These substances can overstimulate the growth of algae and aquatic plants, creating eutrophic conditions that interfere with recreation and the health and diversity of insects, fish, and other aquatic organisms.

Nutrient enrichment due to human activities has long been recognized as one of the leading problems facing our nation's lakes, reservoirs, and estuaries. It has also been more recently recognized as a contributing factor to stream degradation. In broadest terms, nutrient over-enrichment of streams is a problem because of the negative impacts on aquatic life (the focus of the WSA); adverse health effects on humans and domestic animals; aesthetic and recreational use impairment; and excessive nutrient input into downstream waterbodies, such as lakes.

Excess nutrients in streams can lead to excessive growth of phytoplankton (free-floating algae) in slow-moving rivers, periphyton (algae attached to the substrate) in shallow streams, and macrophytes (aquatic plants large enough to be visible to the naked eye) in all waters. Unsightly filamentous algae can impair the aesthetic enjoyment of streams. In more extreme situations, excessive growth of aquatic plants can slow water flow in flat streams and canals, interfere with swimming, snag fishing lures, and clog the screens on water intakes of water treatment plants and industries.

Nutrient enrichment in streams has also been demonstrated to affect animal communities in these waterbodies (see the References section at the end of this report for examples of published studies). For example, declines in invertebrate community structure have been correlated directly with increases in phosphorus concentration. High concentrations of nitrogen in the form of ammonia (NH_3) are known to be toxic to aquatic animals. Excessive levels of algae have also been shown to be damaging to invertebrates. Finally, fish and invertebrates will experience growth problems and can even die if either oxygen is depleted or pH increases are severe; both of these conditions are symptomatic of eutrophication.

As a system becomes more enriched by nutrients, different species of algae may spread and species composition can shift; however, unless such species shifts cause clearly demonstrable symptoms of poor water-quality—such as fish kills, toxic algae, or very long streamers of filamentous algae—the general public is unlikely to be aware of a potential ecological concern.

Phosphorus influx leads to increased algal growth, which reduces dissolved oxygen levels and water clarity within the stream. (See *Highlight: Nutrients and Eutrophication in Streams* for more information about the impacts of excess phosphorus and nitrogen.) Phosphorus is a common component of fertilizers, and high phosphorus concentrations in streams may be associated with poor agricultural practices, urban runoff, or point-source discharges (e.g., effluents from sewage treatment plants).

Findings for Total Phosphorus

Approximately 31% of the nation's stream length (207,355 miles) has high concentrations of phosphorus, 16% (108,039 miles) has medium concentrations, and 49% (327,473 miles) has low concentrations (Figure 15). Of the three major regions, the Eastern Highlands has the greatest proportion of stream length with high concentrations of phosphorus (43%, or 117,730 miles), followed by the Plains and Lowlands (25%, or 60,324 miles) and the West (19%, or 28,174 miles) regions.

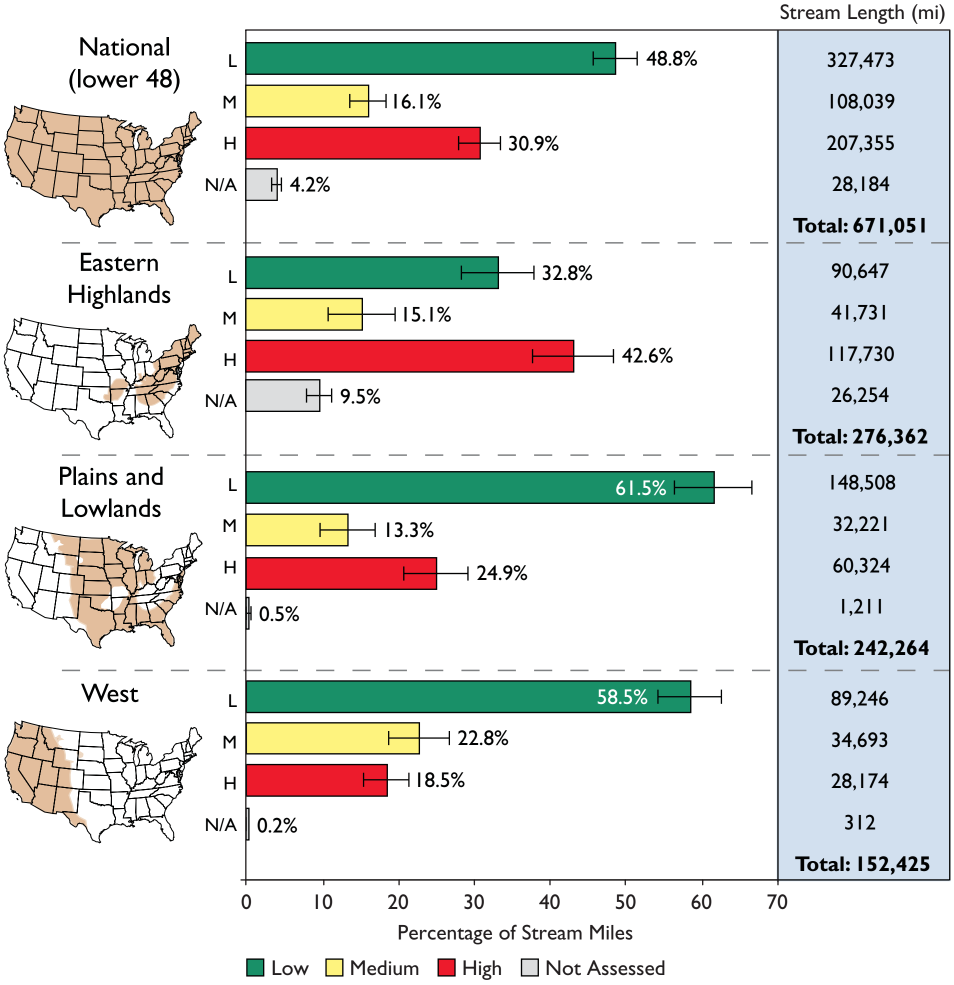


Figure 15. Total phosphorus concentrations in U.S. streams (U.S. EPA/WSA). Percent of stream length with low, medium, and high concentrations of phosphorus based on regionally relevant thresholds derived from the least-disturbed regional reference sites. Low concentrations are most similar to reference condition; medium concentrations are greater than the 75th percentile of reference condition; and high concentrations are greater than the 95th percentile of reference condition.

Total Nitrogen Concentrations

Nitrogen, another nutrient, is particularly important as a contributor to coastal and estuarine algal blooms. Nitrogen is the primary nutrient limiting algal growth in some regions of the United States, particularly in granitic or basaltic geology found in parts of the Northeast and the Pacific Northwest. Increased nitrogen inputs to a stream can stimulate growth of excess algae, such as periphyton, which results in low dissolved oxygen levels, a depletion of sunlight available to the streambed, and degraded habitat conditions for benthic macroinvertebrates and other aquatic life (see *Highlight: Nutrients and Eutrophication in Streams*). Common sources of excess nitrogen include fertilizers, wastewater, animal wastes, and atmospheric deposition.

Findings for Total Nitrogen

A significant portion of the nation's stream length (32%, or 213,394 miles) has high concentrations of nitrogen compared to least-disturbed reference conditions, 21% (138,908 miles) has medium concentrations, and 43% (290,565 miles) has relatively low concentrations (Figure 16). As with phosphorus, the Eastern

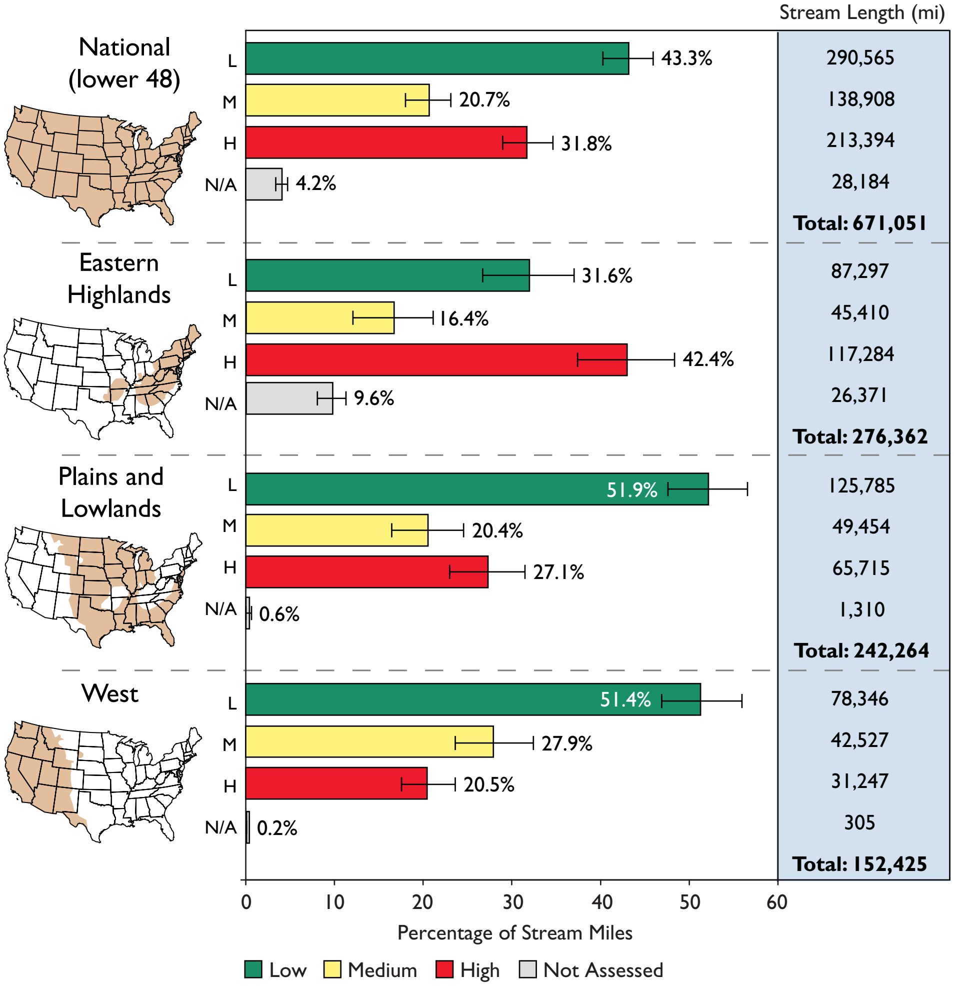


Figure 16. Total nitrogen concentrations in U.S. streams (U.S. EPA/WSA). Percent of stream length with low, medium, and high concentrations of nitrogen based on regionally relevant thresholds derived from the least-disturbed regional reference sites. Low concentrations are most similar to reference condition; medium concentrations are greater than the 75th percentile of reference condition; and high concentrations are greater than the 95th percentile of reference condition.

Highlands region has the greatest proportion of stream length with high concentrations of nitrogen (42%, or 117,284 miles), followed by the Plains and Lowlands (27%, or 65,715 miles) and the West (21%, or 31,247 miles).

Salinity

Excessive salinity occurs in areas with high evaporative losses of water and can be exacerbated by repeated use of water for irrigation or by water withdrawals. Both electrical conductivity and total dissolved solids (TDS) can be used as measures of salinity; however, conductivity was used for the WSA.

Findings for Salinity

Roughly 3% of the nation's stream length (19,889 miles) has high levels of salinity, 10% (69,585 miles) has medium levels, and 83% (553,530 miles) has low levels compared to levels found in least-disturbed reference sites for the nine WSA ecoregions (Figure 17). The Plains and Lowlands region has the greatest proportion of stream length with high levels of salinity (5%, or 12,113 miles), followed by the West (3%, or 4,009 miles) and Eastern Highlands (1%, or 3,593 miles).

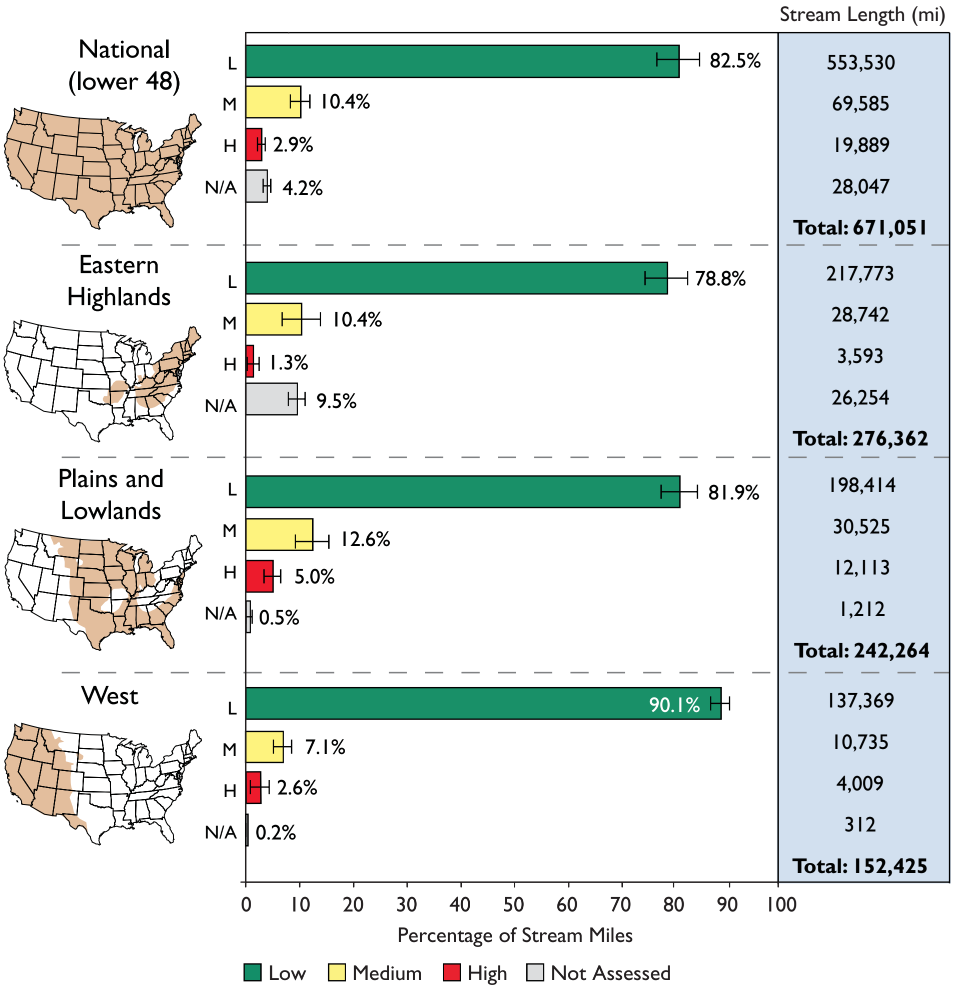


Figure 17. Salinity conditions in U.S. streams (U.S. EPA/WSA). This indicator is based on electrical conductivity measured in water samples. Thresholds are based on conditions at least-disturbed regional reference sites.

Acidification

Streams and rivers can become acidic through the effects of acid deposition (e.g., acid rain) or acid mine drainage, particularly from coal mining. Previous studies have shown that these issues, while of concern, tend to be focused in a few geographic regions of the country. Streams and rivers can also be acidic because of natural sources, such as high levels of dissolved organic compounds. The WSA identifies the extent of systems that are not acidic, naturally acidic (i.e., similar to reference), and acidic because of anthropogenic disturbance. This last category includes streams that are acidic because of deposition (either chronic or episodic) or because of mine drainage.

Acid rain forms when smokestack and automobile emissions (particularly sulfur dioxide and nitrogen oxides) combine with moisture in the air to form dilute solutions of sulfuric and nitric acid. Acid deposition can also occur in dry form, such as the particles that make up soot. When wet and dry deposition fall on sensitive watersheds, they can have deleterious effects on soils, vegetation, and streams and rivers.

In assessing acid rain's effects on flowing waters, the WSA relied on a measure of the water's ability to buffer inputs of acids, called acid-neutralizing capacity (ANC). When ANC values fall below zero, the water is considered acidic and can be either directly or indirectly toxic to biota (i.e., by mobilizing toxic metals, such as aluminum). When ANC is between 0 and 25 milliequilivents, the water is considered sensitive to episodic acidification during rainfall events. These threshold values were determined based on values derived from the National Acid Precipitation Assessment Program (NAPAP).

Acid mine drainage forms when water moves through mines and mine tailings, combining with sulfur released from certain minerals to form strong solutions of sulfuric acid and mobilize many toxic metals. As in the case of acid rain, the acidity of waters in mining areas can be assessed by using ANC values. Mine drainage also produces extremely high concentrations of sulfate—much higher than those found in acid rain. Although sulfate is not directly toxic to biota, it serves as an indicator of mining's influence on streams and rivers. When ANC values and sulfate concentrations are low, acidity can be attributed to acid rain. When ANC values are low and sulfate concentrations are high, acidity can be attributed to acid mine drainage. Mine drainage itself, even if not acidic, can harm aquatic life; however, the WSA does not include an assessment of the extent of mine drainage that is not acidic.

Acidic mine drainage forms when water moves through mines and mine tailings (Photo courtesy of Ben Fertig, IAN Image Library).

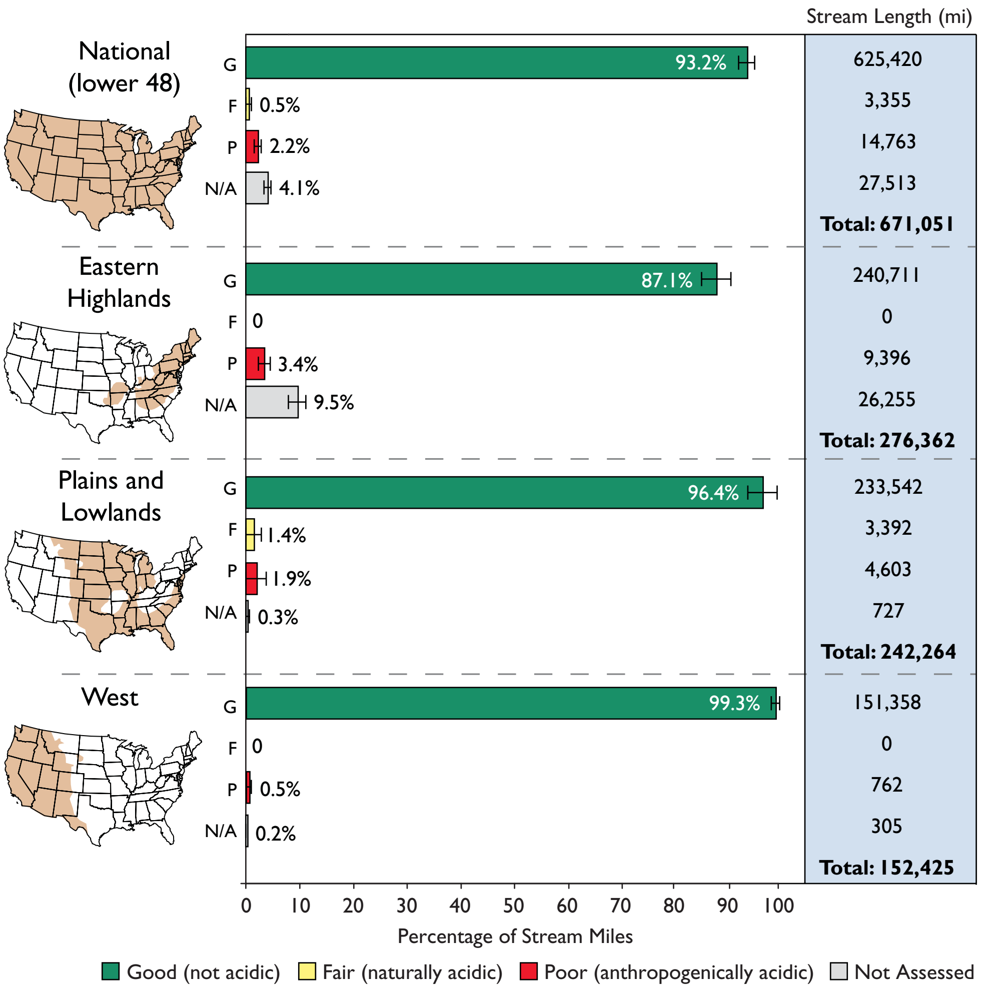


Figure 18. Acidification in U.S. streams (U.S. EPA/WSA). Streams are considered acidic when ANC values fall below zero. Streams are considered sensitive to acidification during rainfall events when ANC values are between 0 and 25 milliequilivents. Both ranges were scored as anthropogenically acidic in poor condition. Acidic streams with high concentrations of sulfate are associated with acid mine drainage, whereas low concentrations of sulfate indicate acidification due to acid rain.

Findings for Acidification

Figure 18 shows that about 2% of the nation's stream length (14,763 miles) is impacted by acidification from anthropogenic sources. These sources include acid deposition (0.7%), acid mine drainage (0.4%), and episodic acidicity due to high-runoff events (1%). Although these percentages appear relatively small, they reflect a significant impact in certain parts of the United States, particularly in the Eastern Highlands region, where 3% of the stream length (9,396 miles) is impacted by acidification.

Physical Habitat Stressors

A number of human activities can potentially impact the physical habitat of streams upon which the biota rely. Soil erosion from road construction, poor agricultural practices, and other disturbances can result in increases in the amount of fine sediment on the stream bottom; these sediments can negatively impact macroinvertebrates and fish. Physical alterations to vegetation along stream banks, alterations to the physical characteristics within the stream itself, and changes in the flow of water all have the potential to impact stream biota.

Although many aspects of stream and river habitats can become stressful to aquatic organisms when these aspects are modified, the WSA focuses on four specific stressors as habitat indicators: streambed sediments, in-stream fish habitat, riparian vegetation, and riparian disturbance.

Streambed Sediments

The supply of water and sediments from drainage areas affects the shape of river channels and the size of streambed particles in streams and rivers. One measure of the interplay between sediment supply and transport is relative bed stability (RBS). The measure of RBS used in the WSA is a ratio that compares measures of particle size of observed sediments to the size of sediments that each stream can move or scour during its flood stage (based on measures of the size, slope, and other physical characteristics of the stream channel). The expected RBS ratio differs naturally among regions, depending upon landscape characteristics, such as geology, topography, hydrology, natural vegetation, and natural disturbance history.

Values of the RBS ratio can be either substantially lower (e.g., finer, more unstable streambeds) or higher (e.g., coarser, more stable streambeds) than those expected, based on the range found at least-disturbed reference sites. Both high and low values are considered to be indicators of ecological stress. Excess fine sediments in a stream bed can destabilize streams when the supply of sediments from the landscape exceeds the ability of the stream to move them downstream. This imbalance results from a number of human uses of the landscape, including agriculture, road building, construction, and grazing. Streams with significantly more stable streambeds than reference condition (e.g., evidence of hardening and scouring, streams that have been lined with concrete) were not included in the assessment of this indicator. These stream conditions occurred so rarely in the survey that it was not necessary to separate them from the overall population. The WSA focuses on increases in streambed sediment levels, represented by lower-than-expected streambed stability as the indicator of concern.

Lower-than-expected streambed stability may result either from high inputs of fine sediments (e.g., erosion) or increases in flood magnitude or frequency (e.g., hydrologic alteration). When low RBS results from inputs of fine sediment, the sediment can fill in the habitat spaces between stream cobbles and boulders. The instability (low RBS) resulting from hydrologic alteration can be a precursor to channel incision and gully formation.

WSA researchers collected data on indicators of biological condition and aquatic indicators of stress at 1,392 wadeable stream locations in the conterminous United States (Photo courtesy of Tetra Tech, Inc.).

Findings for Streambed Sediments

Approximately 25% of the nation's stream length (167,092 miles) has streambed sediment characteristics in poor condition compared to regional reference condition (Figure 19). Streambed sediment characteristics are rated fair in 20% of the nation's stream length (132,197 miles) and good in 50% of stream length (336,196 miles) compared to reference condition. The two regions with the greatest percentage of stream length in poor condition for streambed sediment characteristics are the Eastern Highlands (28%, or 77,381 miles) and the Plains and Lowlands (26%, or 63,958 miles), whereas the West has the lowest percentage of stream length (17%, or 26,522 miles) in poor condition for this indicator.

In-stream Fish Habitat

The most diverse fish and macroinvertebrate assemblages are found in streams and rivers that have complex forms of habitat, such as boulders, undercut banks, tree roots, and large wood within the stream banks. Human use of streams and riparian areas often results in the simplification of this habitat, with potential effects on biological

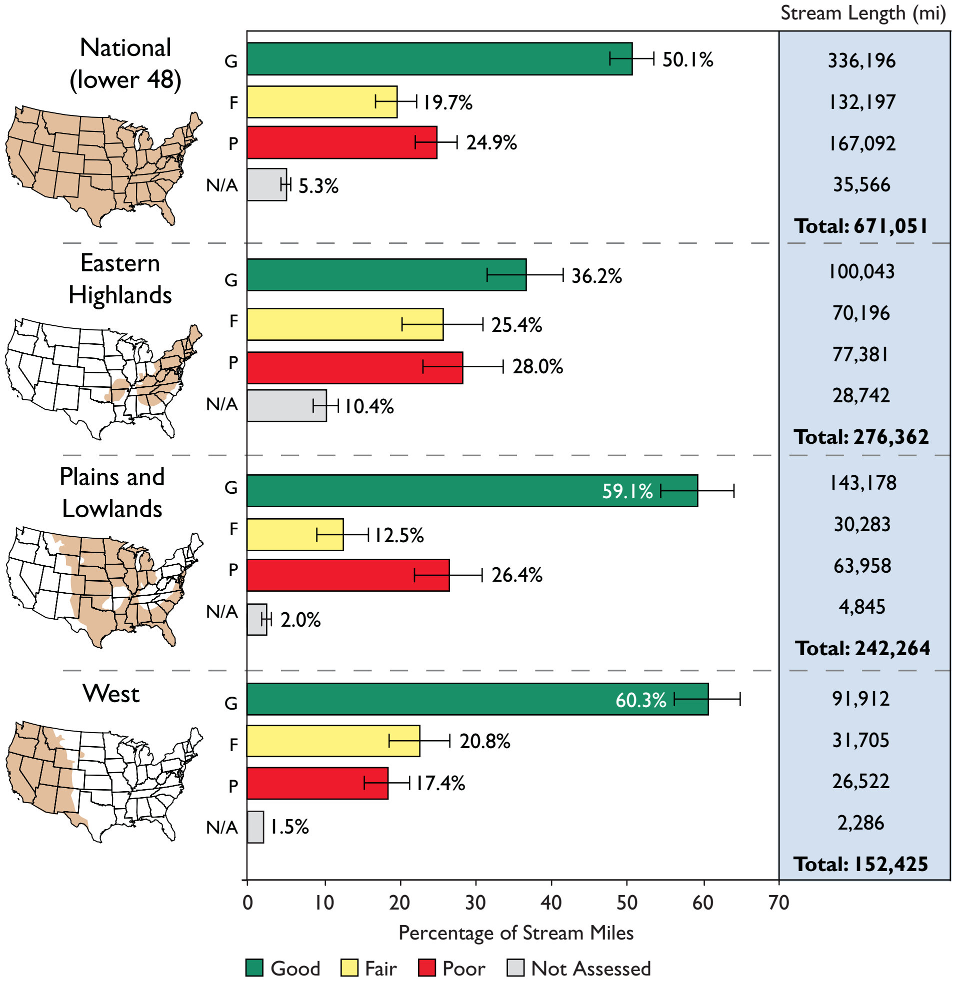


Figure 19. Streambed sediments in U.S. streams (U.S. EPA/WSA). This indicator measures the percentage of streambeds impacted by increased sedimentation, which indicates alteration from reference condition as defined by least-disturbed reference sites in each of the nine WSA ecoregions.

integrity. The WSA used a habitat complexity measure that sums the amount of in-stream fish concealment features and habitat consisting of undercut banks, boulders, large pieces of wood, brush, and cover from overhanging vegetation within a stream and its banks.

Findings for In-stream Fish Habitat

Twenty percent of the nation's stream length (130,928 miles) is in poor condition for in-stream fish habitat, 25% (166,851 miles) is in fair condition, and 52% (345,766 miles) is in good condition compared to least-disturbed reference condition (Figure 20). In the three major regions, the highest proportion of stream length in poor condition for in-stream habitat is in the Plains and Lowlands (37%, or 89,638 miles), whereas only 12% of stream length (18,748 miles) in the West and 8% of stream length (22,797 miles) in the Eastern Highlands region is rated poor for this indicator.

Riparian Vegetative Cover

The presence of complex, multi-layered vegetative cover in the corridor along a stream or river is a measure of how well the stream network is buffered against sources of stress in the

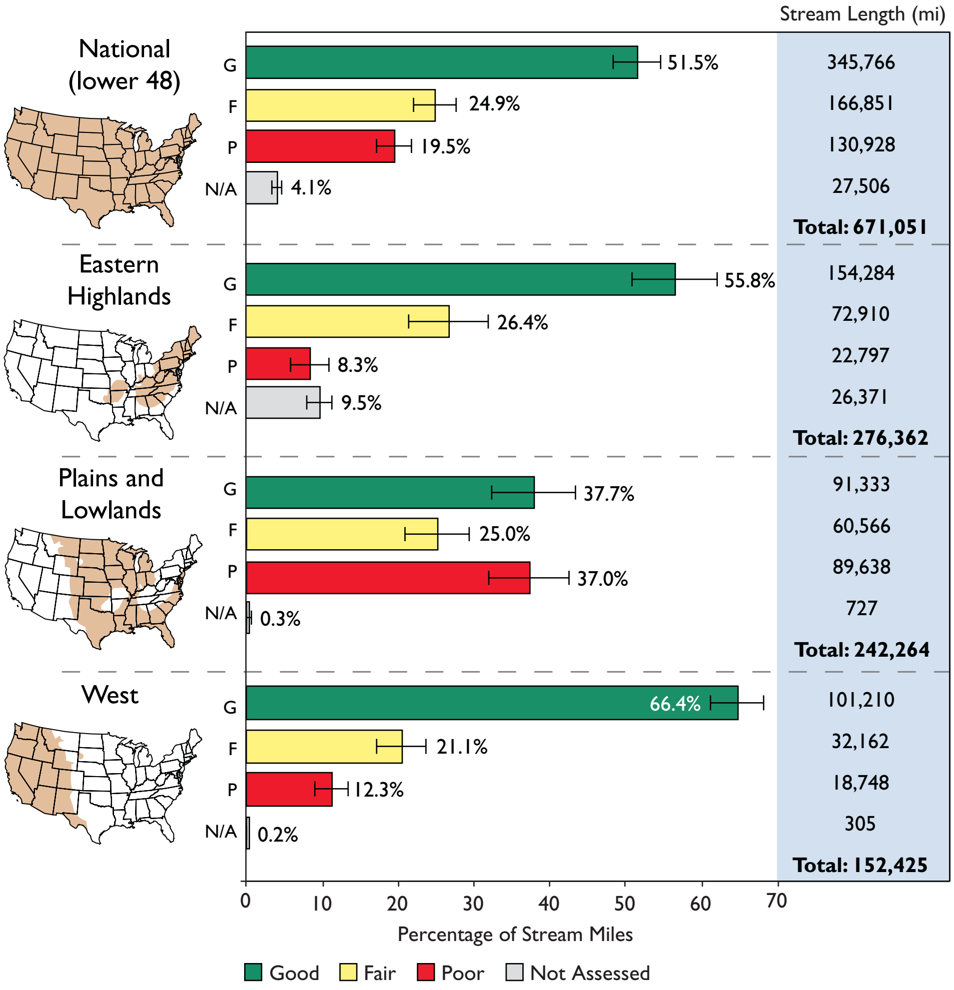


Figure 20. In-stream fish habitat in U.S. streams (U.S. EPA/WSA). This indicator sums the amount of in-stream habitat that field crews found in streams. Habitat consisted of undercut banks, boulders, large pieces of wood, and brush. Thresholds are based on conditions at regional reference sites.

watershed. Intact riparian areas can help reduce nutrient and sediment runoff from the surrounding landscape, prevent streambank erosion, provide shade to reduce water temperature, and provide leaf litter and large wood to serve as food and habitat for stream organisms. The presence of large, mature canopy trees in the riparian corridor indicates riparian longevity; the presence of smaller woody vegetation typically indicates that riparian vegetation is reproducing and suggests the potential for future sustainability of the riparian corridor. The WSA uses a measure of riparian vegetative cover that sums the amount of woody cover provided by three layers of riparian vegetation: the ground layer, woody shrubs, and canopy trees.

Findings for Riparian Vegetative Cover

Nineteen percent of the nation's stream length (129,748 miles) is in poor condition due to severely simplified riparian vegetation, 28% of stream length (190,034 miles) is in fair condition, and almost 48% (319,548 miles) is in good condition relative to least-disturbed reference condition in each of the nine WSA ecoregions (Figure 21). The West (12%, or 18,596 miles) and Eastern Highlands (18%, or 48,640 miles)

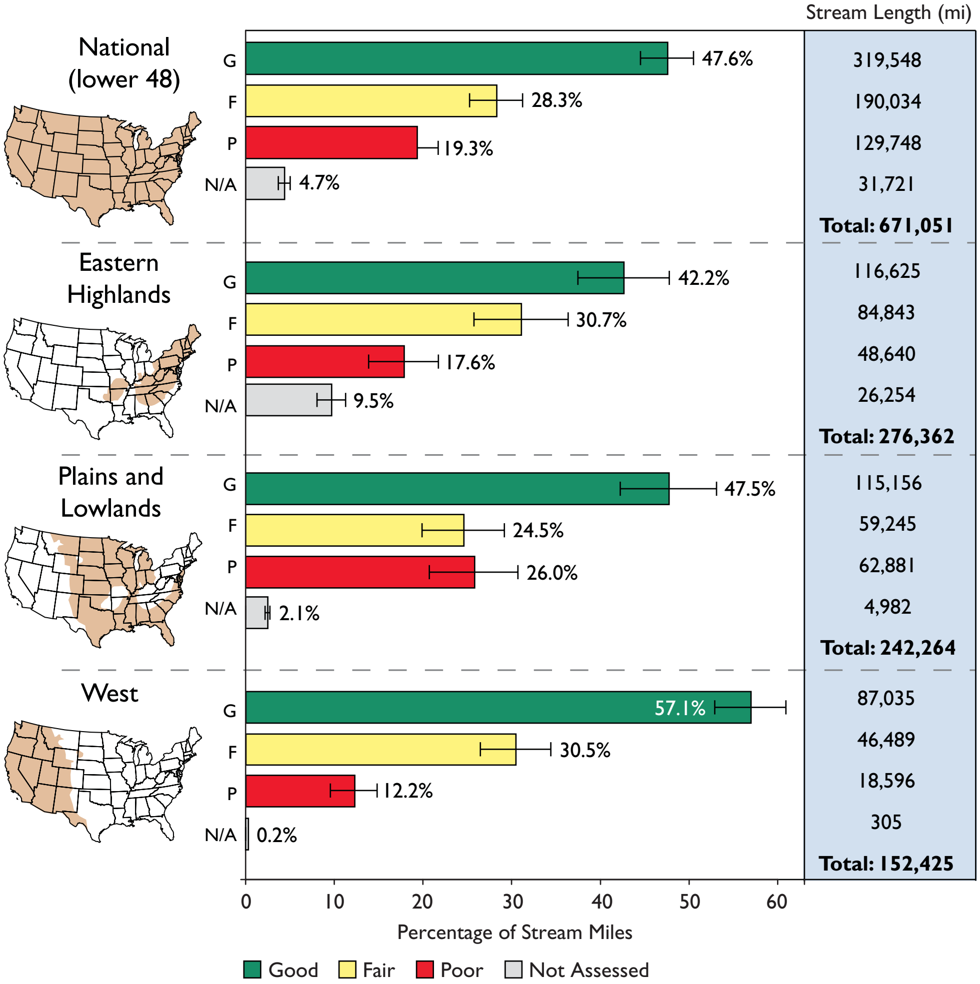
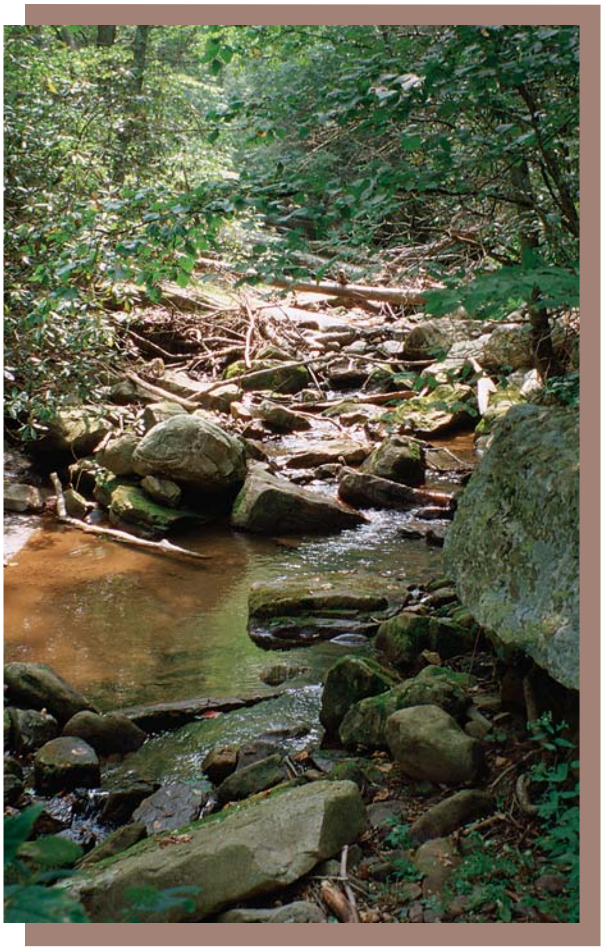


Figure 21. Riparian vegetative cover in U.S. streams (U.S. EPA/WSA). This indicator sums the amount of woody cover provided by three layers of riparian vegetation: the ground layer, woody shrubs, and canopy trees. Thresholds are based on conditions at regional reference sites.

regions have similar proportions of stream length with riparian vegetation in poor condition, though this equates to a greater number of stream miles in the Eastern Highlands region, where water is more abundant. In the Plains and Lowlands region, a larger proportion of stream length (26%, or 62,881 miles) has riparian vegetation in poor condition.



The most diverse fish and macroinvertebrate assemblages are found in streams and rivers that have complex forms of habitat, such as boulders, undercut banks, tree roots, and large wood within the stream banks (Photo courtesy of Michael L. Smith, FWS).

Riparian Disturbance

The vulnerability of the stream network to potentially harmful human activities increases with the proximity of those activities to the streams. The WSA uses a direct measure of riparian human disturbance that tallies 11 specific forms of human activities and disturbances along the stream reach and their proximity to a stream in 22 riparian plots along the stream. For example, streams scored medium if one type of human influence was noted in at least one-third of the plots, and streams scored high if one or more types of disturbance were observed in the stream or on its banks at all of the plots.

Findings for Riparian Disturbance

Twenty-six percent of the nation's stream length (171,118 miles) has high levels of human influence along the riparian zone that fringes stream banks, and 24% of stream length (158,368 miles) has relatively low levels of disturbance (Figure 22). The Eastern Highlands region has the greatest proportion of stream length with high riparian disturbance (29%, or 79,591 miles), followed by the Plains and Lowlands (26%, or 62,504 miles) and the West (19%, or 29,570 miles). One of the striking findings of the WSA is the widespread distribution of intermediate levels of riparian disturbance; 47% of the nation's stream length (314,052 miles) has intermediate levels of riparian disturbance when compared to reference condition, and similar percentages are found in each of the three major regions.

It is worth noting that for the nation and the three regions, the amount of stream length with good riparian vegetative cover was significantly greater than the amount of stream length with low levels of human disturbance in the riparian zone. This finding warrants

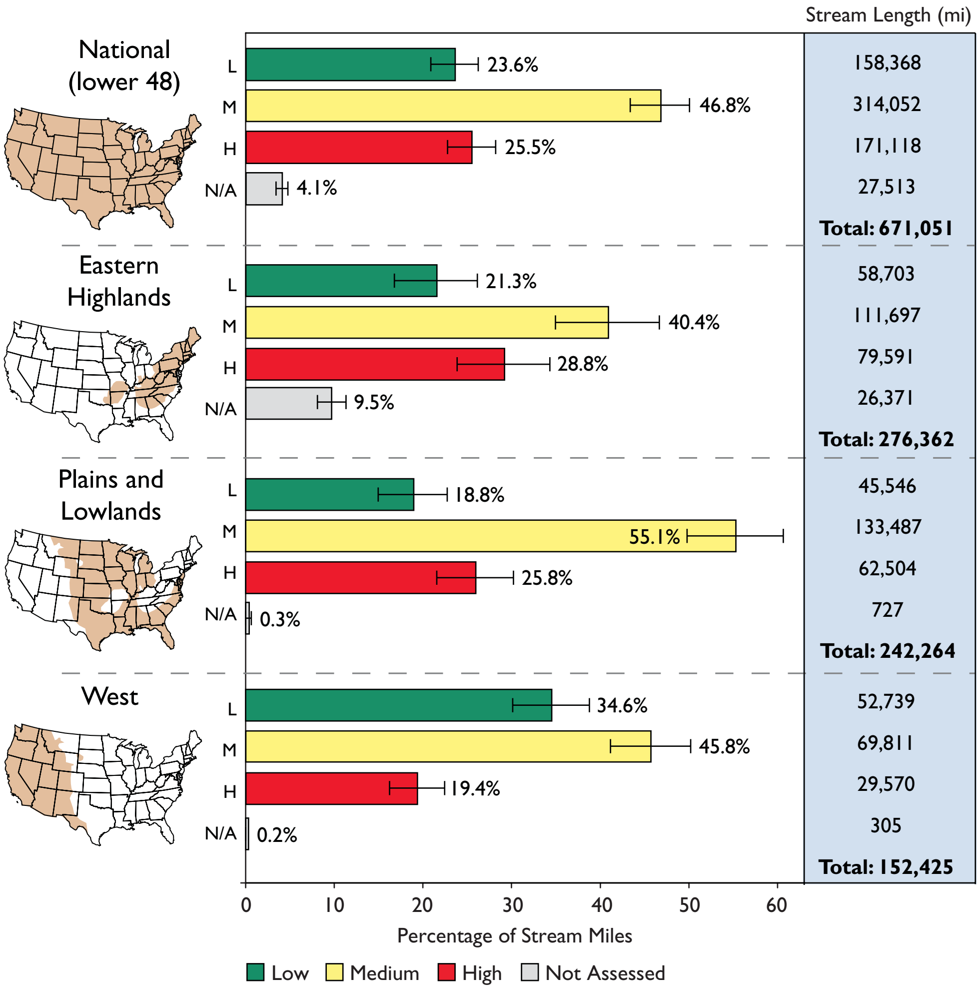


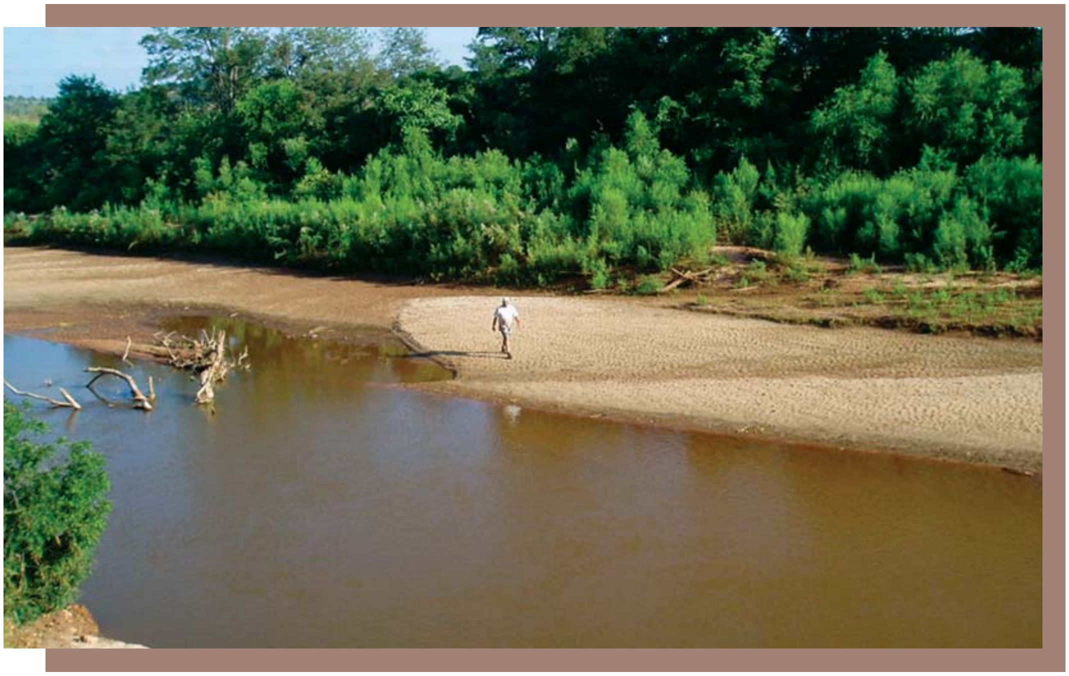
Figure 22. Riparian disturbance in U.S. streams (U.S. EPA/WSA). This indicator is based on field observations of 11 different types of human influence (e.g., dams, pavement, pasture) and their proximity to a stream in 22 riparian plots along the stream.

additional investigation, but suggests that land managers and property owners are protecting and maintaining healthy riparian vegetation buffers, even along streams where disturbance from roads, agriculture, and grazing is widespread.

Biological Stressors

Although most of the factors identified as stressors to streams and rivers are either chemical or physical, there are biological factors that also create stress in wadeable streams. Biological assemblages can be stressed by the presence of non-native species that can either prey on, or compete with, native species. In many cases, non-native species have been intentionally introduced to a waterbody; for example, brown trout and brook trout are common inhabitants of streams in the higher elevation areas of the West, where they have been stocked as game fish.

When non-native species become established in either vertebrate or invertebrate assemblages, their presence conflicts with the definition of biological



Little Washita River, OK, in the Plains and Lowlands region (Photo courtesy of Monty Porter).

integrity that the CWA is designed to protect (i.e., "having a species composition, diversity, and functional organization comparable to that of the natural habitat of the region"). Therefore, to the extent that non-native species compete with and potentially exclude native species, they might be considered a threat to biological integrity. These indicators were not included in the WSA, but may be included in future assessments.

Ranking of Stressors

A prerequisite to making policy and management decisions is to understand the relative magnitude or importance of potential stressors. It is important to consider both the prevalence of each stressor (i.e., what is its extent, in miles of stream, and how does it compare to other stressors) and the severity of each stressor (i.e., how much influence does it have on biological condition, and is its influence greater or smaller than the influence of other stressors). The WSA presents separate rankings of the extent and the relative severity of stressors to the nation's flowing waters. Ideally, both of these factors (extent and effect) should be combined into a single measure of relative importance. EPA is pursuing methodologies for combining the two rankings and will present them in future assessments.

Extent of Stressors

Figure 23 shows the WSA stressors ranked according to the proportion of stream length that is in poor condition. Results are presented for the nation (top panel) and for each major region, with the stressors ordered (in all panels) according to their relative extent nationwide.

Figure 23 reveals that excess total nitrogen is the most pervasive stressor for the nation, although it is not the most pervasive in each region. Approximately 32% of the nation's stream length (213,394 miles) shows high concentrations of nitrogen compared to reference conditions. In the Plains and Lowlands region, nitrogen is at high concentrations in 27% of stream length (65,715 miles), whereas this proportion climbs to 42% (117,285 miles) in the Eastern Highlands region. Even in the West, where levels of disturbance are generally lower than the other major regions, excess total nitrogen is found in 21% of the stream length (31,247 miles). Phosphorus exhibits comparable patterns to nitrogen and is the second most-pervasive stressor for the nation's stream length.

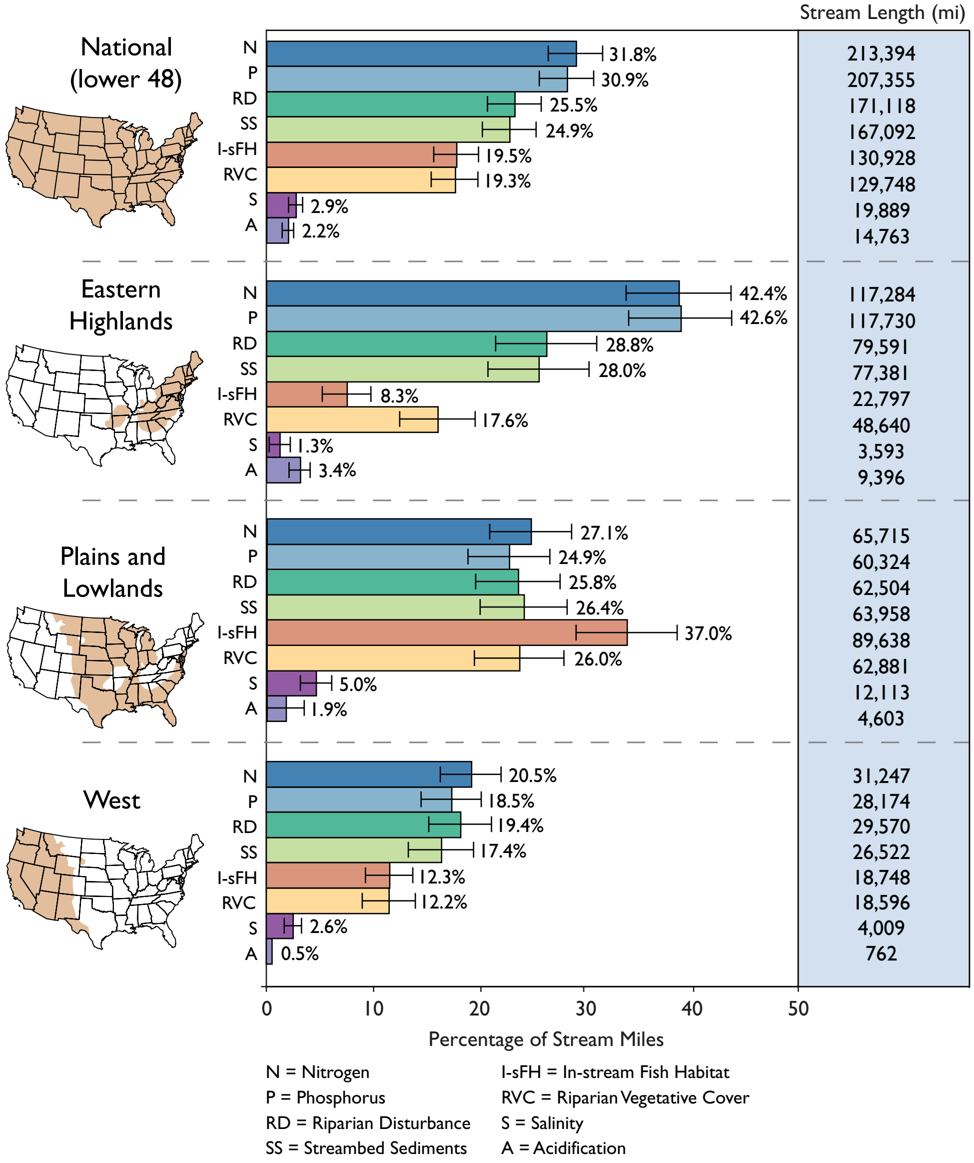


Figure 23. Extent of stressors (i.e., proportion of stream length ranked in poorest category for each stressor) (U.S. EPA/WSA).

The least-common stressors for the nation's stream length are salinity and acidification. Only 3% (19,889 miles) and 2% (14,763 miles), respectively, of the nation's stream length is in poor condition for salinity and acidification levels. Although these stressors are not present in large portions of the nation's streams, they can have a significant impact where they do occur.

The extent of stressors measured in the WSA varies across the three major regions. In the Plains and Lowlands region, the stressor rated poor for the greatest proportion of stream length (37%, or 89,638 miles) is loss of in-stream fish habitat. In the Eastern Highlands region, high total nitrogen and total phosphorus concentrations were found in more than 42% of the stream length (117,285 and 117,730 miles, respectively). In the West, no stressor is found to affect more than 21% of stream length (31,247 miles), although nitrogen, phosphorus, and riparian disturbance are the most widespread stressors in this region as well.

Relative Risk of Stressors to Biological Condition

This report borrows the concept of relative risk from the medical field to address the question of severity of stressor effects. We have all heard that we run a greater risk of developing heart disease if we have high cholesterol levels. Often such results are presented in terms of a relative-risk ratio (e.g., the risk of developing heart disease is 4 times higher for a person with a total cholesterol level greater than 300 mg than for a person with a total cholesterol level of less than 150 mg).

The relative-risk values for aquatic stressors can be interpreted in the same way as the cholesterol example. For each of the key stressors, Figure 24 depicts how much more likely a stream is to have poor biological condition if stream length is in poor condition for a stressor or if high concentrations of a stressor are present than if the stream length is in good condition for a stressor or a stressor is found at low concentrations. Because different aspects of the macroinvertebrate assemblage (i.e., biological condition vs. taxa loss) are expected to be affected by different stressors, the WSA calculates relative risk separately for each of the two biological condition indicators (Macroinvertebrate Index and O/E Taxa Loss).

A relative-risk value of 1 indicates that there is no association between the stressor and the biological indicator, whereas values greater than 1 suggest that the stressor poses a greater relative risk to biological condition. The WSA also calculates confidence intervals (Figure 24) for each relative risk ratio. When the confidence interval extending above and below the ratio does not overlap the value of 1, the relative risk estimate is statistically significant.

The relative risks shown in Figure 24 provide an estimate of the severity of each stressor's effect on the macroinvertebrate community in streams. Almost all of the stressors evaluated for the WSA were associated with increased risk for macroinvertebrates. Evaluating relative risk provides insight on which stressors might be addressed to improve biological condition. Excess nitrogen, phosphorus, and streambed sediments stand out as having the most significant impacts on biological condition based on both the Macroinvertebrate Index and O/E Taxa Loss indicators. Findings show that streams with relatively high concentrations of nutrients or excess streambed sediments are two to four times more likely to have poor macroinvertebrate condition.

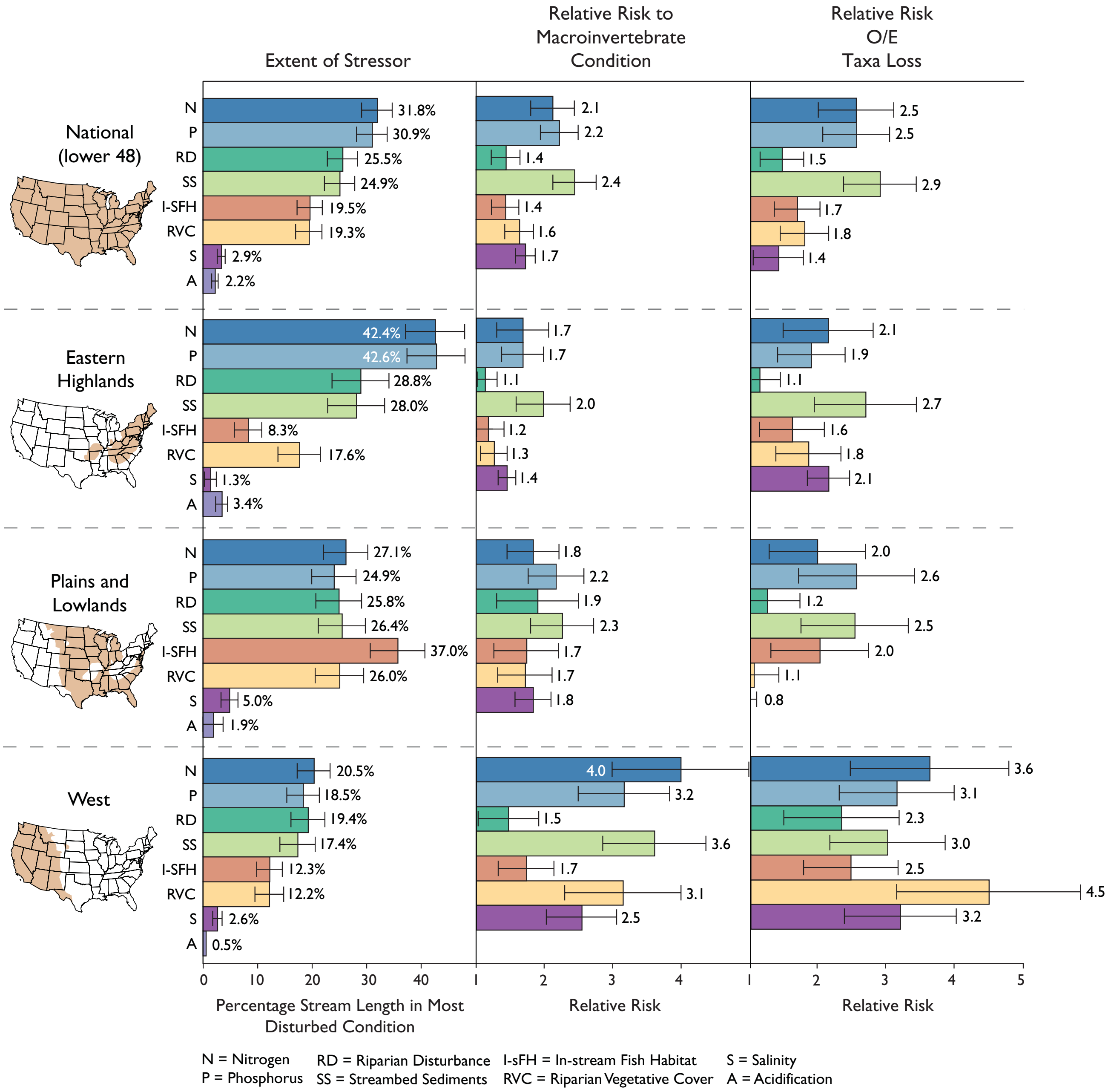


Figure 24. Extent of stressors and their relative risk to Macroinvertebrate Condition and O/E Taxa Loss (U.S. EPA/WSA). This figure shows the association between a stressor and biological condition and answers the question, "What is the increased likelihood of poor biological condition when stressor X is rated in poor condition?" It is important to note that this figure treats each stressor independently and does not account for the effects of combinations of stressors.

There are differences in relative risk from a geographic perspective. In general, the West exhibits a higher relative risk for the majority of stressors than the Eastern Highlands and the Plains and Lowlands regions. There are also differences associated with the different indicators of biological condition. The O/E Taxa Loss indicator has somewhat higher relative risk ratios for most of the stressors than the Macroinvertebrate Index. Additional analysis is needed to further explore these differences.

In this assessment of relative risk, it is impossible to separate completely the effects of the individual stressors that often occur together. For example, streams with high nitrogen concentrations often exhibit high phosphorus concentrations, and streams with high riparian disturbance often have sediments far in excess of expectations; however, the analysis presented in Figure 24 treats the stressors as if they operate independently.

Combining Extent and Relative Risk

The most comprehensive assessment of the ranking of stressors comes from evaluating both the extent (Figure 23) and relative risk (Figure 24) results. Stressors that pose the greatest overall risk to biological integrity will be those that are both widespread (i.e., rank high in terms of the extent of stream length in poor condition for a stressor in Figure 23) and whose effects are potentially severe (i.e., exhibit high relative risk ratios in Figure 24). The WSA facilitates this combined evaluation of stressor importance by including side-by-side comparisons of the extent of stressors and relative risk to macroinvertebrate condition in Figure 24.

An examination of nationwide results suggests some common patterns for key stressors and the two indicators of biological condition. Total nitrogen, total phosphorus, and excess streambed sediments are stressors posing the greatest relative risk nationally (relative risk greater than 2), and they also occur in 25–32% of the nation's stream length. This suggests that management decisions aimed at reducing excess sediment, nitrogen, and phosphorus loadings to streams could have a positive impact on macroinvertebrate biological integrity and prevent further taxa loss across the country.

High salinity in the West is strongly associated with a poor Macroinvertebrate Index score (relative risk = 2.5) and O/E Taxa Loss score (relative risk > 3.1 or = 3.2); however, the rarity of this occurrence (salinity affects only 3% of stream length in the West region) suggests that excess salinity is a local issue requiring a locally targeted management approach rather than a national or regional effort.

Relative risks for all stressors in the West region are consistently larger than for the nation overall or for the other two regions, yet the extent of streams in poor condition for these stressors is consistently lower in the West. This suggests that although the stressors are not widespread in the West, the region's streams are particularly sensitive to a variety of disturbances.

Chapter 3

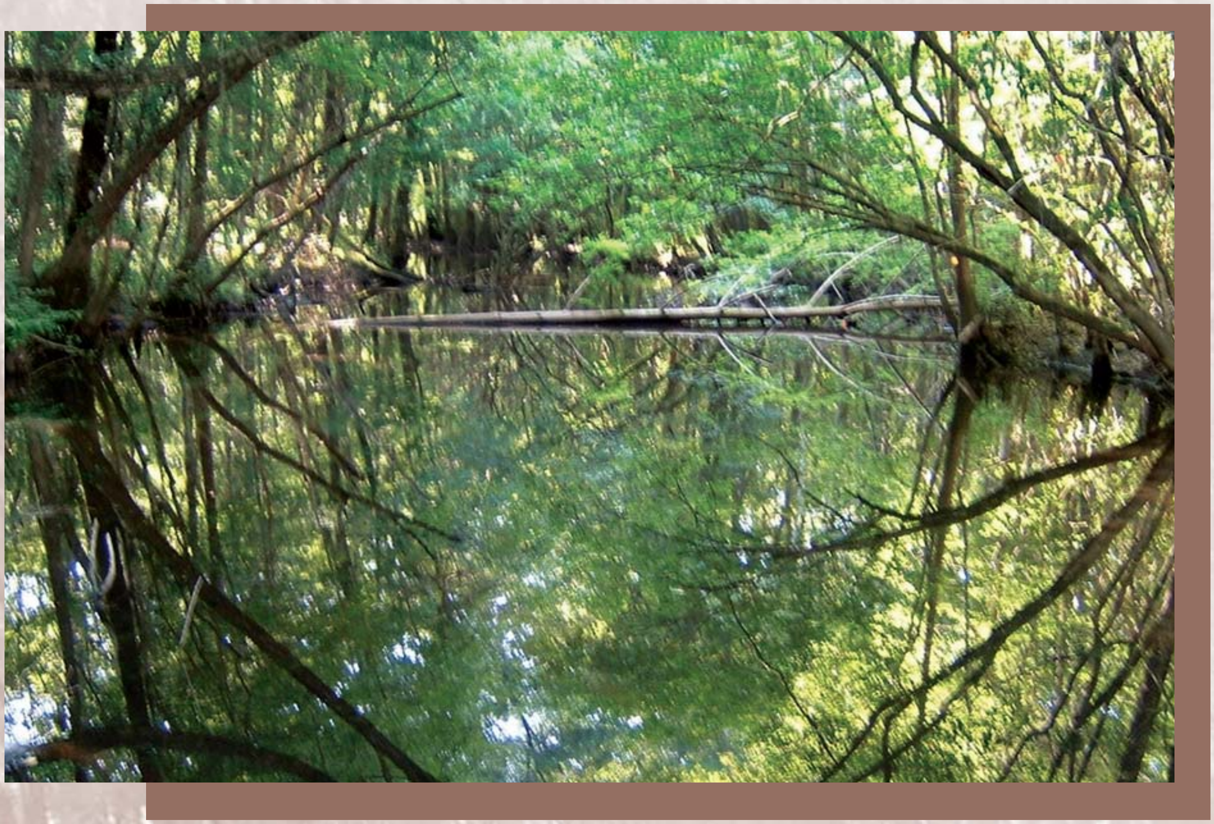


Photo courtesy of the Georgia Department of Natural Resources

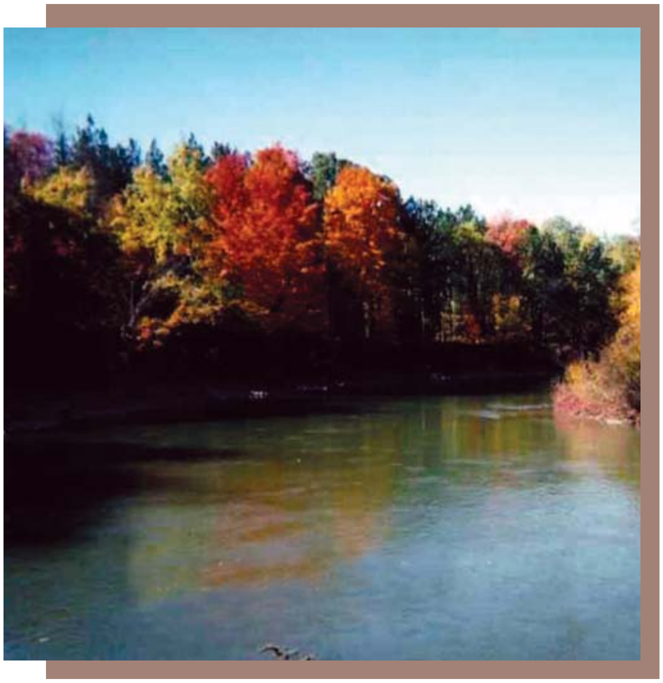
Wadeable Streams Assessment Ecoregion Results

Wadeable Streams Assessment Ecoregion Results

The WSA is designed to report on three geographic scales: national, regional, and ecoregional. Chapter 2 presented the national- and regional-scale results, and this chapter will focus on the results for the nine WSA ecoregions.

Ecoregions are areas that contain similar environmental characteristics, such as climate, vegetation, soil type, and geology. EPA has defined ecoregions at various scales, ranging from coarse (Level I) ecoregions at the continental scale to fine (Levels III and IV) ecoregions that divide states into smaller ecosystem units. Ecoregions are designed to be used in environmental assessments, for setting water quality and biological criteria, and to set management goals for non-point source pollution.

The nine WSA ecoregions are aggregations of the Level III ecoregions delineated by EPA for the conterminous United States. This chapter provides background information on physical setting, biological setting, and human influence for each of the WSA ecoregions and describes WSA results for the wadeable stream length throughout each ecoregion. The WSA results may not be extrapolated to an individual state or stream within the ecoregion because the study design was not intended to characterize stream conditions at these finer scales. Note that a number of states implement randomized designs at the state scale to characterize water quality throughout their state, but these characterizations are not described in this WSA report.



Manistee River, MI, in the Upper Midwest ecoregion (Photo courtesy of the Great Lakes Environmental Center).

The nine ecoregions encompass a variety of habitats and land uses, and the least-disturbed reference sites used to set benchmarks for good, fair, and poor condition reflect that variability. For some ecoregions, the variability among reference sites is very small, while it is larger in others. During a series of WSA workshops held around the country, professional biologists examined the variability of reference sites and implications to the benchmarks used to characterize an ecoregion and to compare stream condition across ecoregions. These benchmarks or thresholds were adjusted for those ecoregions where there was a disturbance signal associated with the variability among reference sites. Additional details on the development of benchmarks or thresholds for each of the indicators can be found in the data analysis method available in Chapter 1 and on the EPA Web site at http://www.epa.gov/owow/streamsurvey.

This report includes brief descriptions of the WSA ecoregions. It should be noted that there are many specific and unique features within each ecoregion that are not fully captured in these brief descriptions (see the References section at the end of this report for more information). The nine ecoregions displayed in Figure 25 and defined in this text are the following:

- Northern Appalachians
- Southern Appalachians
- Coastal Plains
- Upper Midwest
- Temperate Plains
- Southern Plains
- Northern Plains
- Western Mountains
- Xeric.

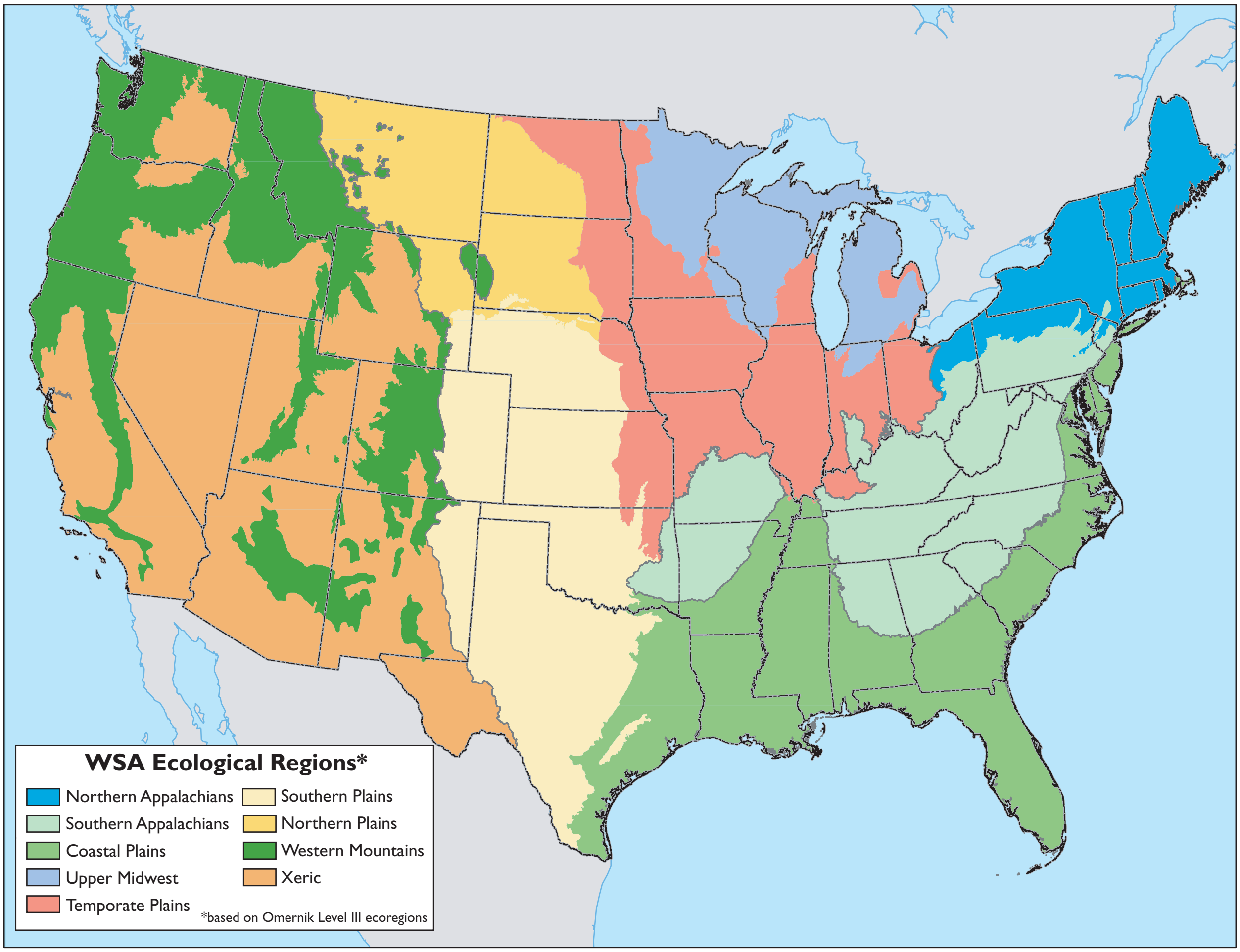


Figure 25. Ecoregions surveyed for the WSA (U.S. EPA/WSA).

Northern Appalachians Ecoregion

Physical Setting

The Northern Appalachians ecoregion covers all of the New England states, most of New York, the northern half of Pennsylvania, and northeastern Ohio. This ecoregion encompasses New York's Adirondack and Catskill mountains and Pennsylvania's mid-northern tier, including the Allegheny National Forest. Major river systems for the Northern Appalachians ecoregion are the St. Lawrence, Allegheny, Penobscot, Connecticut, and Hudson rivers, and major waterbodies include Lake Ontario, Lake Erie, New York's Finger Lakes, and Lake Champlain. The total stream length represented in the WSA for the Northern Appalachians ecoregion is 97,913 wadeable stream miles.

The topography of this ecoregion is generally hilly, with some intermixed plains and old mountain ranges. River channels in the glaciated uplands of the northern parts of this ecoregion have steep profiles and rocky beds, and flow over glacial sediments. The climate is cold to temperate, with mean annual temperatures ranging from 39 to 48 °F. Annual precipitation totals range from 35 to 60 inches. The land area of Northern Appalachians ecoregion comprises some 139,424 mi^2 (4.6% of the United States), with about 4,722 mi^2 (3.4%) of land under federal ownership. Based on satellite images from the 1992 National Land Cover Dataset (NLCD), the distribution of land cover in this ecoregion is 69% forested and 17% planted/cultivated, with the remaining 14% of the ecoregion comprised of other types of land cover.

Cedar Stream, NH, in the Northern Appalachians ecoregion (Photo courtesy of Colin Hill, Tetra Tech, Inc.).

Biological Setting

Contemporary fish stocks are lower than at the time of European contact, but the coastal rivers of the Northern Appalachians ecoregion still have a wide variety of anadromous fish, including shad, alewife, salmon, and sturgeon.

Human Influence

Early European settlers in 17th-century New England removed beaver dams, allowing floods to pass more quickly, thereby flushing sediment and decreasing the diversity and availability of riparian habitat. Forests were cleared to introduce crops and pasture for grazing animals, and these efforts caused the erosion of sediments, increased nutrients, and reduced riparian habitat. Roughly 96% of the original virgin forests of the eastern and central states were gone by the 1920s.

Smaller tributaries in this ecoregion were often disrupted through splash damming — a 19th century practice of creating dam ponds for collecting timber and then exploding the dams to move timber downstream with the resulting torrent of flood waters. These waters carried flushed sediment and wood downstream, and these materials scoured many channels to bedrock. Streams that were not splash dammed currently have tens to hundreds of times more naturally occurring woody debris and deeper pools. During the 18th and early 19th centuries, streams with once-abundant runs of anadromous fish declined due to stream sedimentation, clogging from sawmill discharges, and the effects of dams. Increased human and animal waste from agricultural communities changed stream nutrient chemistry. When agriculture moved west and much of the ecoregion's eastern farmland converted back into woodlands, sediment yields declined in some areas.

Today, major manufacturing, chemical, steel, and power production (e.g., coal, nuclear, oil) occur in the large metropolitan areas found around New York City and the states of Connecticut and Massachusetts. Many toxic substances, including petroleum products, organochlorines, polychlorinated biphenyls (PCBs), and heavy metals, along with increased nutrients such as nitrates and phosphates, are the legacy of industrial development. There are currently 215 active, 6 proposed, and 45 former EPA Superfund National Priority List sites in the Northern Appalachian ecoregion.

It is also common for treated wastewater effluent to account for much of the stream flow downstream from major urban areas in this ecoregion. Treated wastewater can be a major source of nitrate, ammonia, phosphorus, heavy metals, volatile organic chemicals (VOCs), PCBs, and other toxic compounds.

This ecoregion supports forestry; mining; fishing; wood processing of pulp, paper, and board; tourism; and agricultural activities, such as dairy cattle farming, potato production, poultry farming, and timber harvesting.

The approximate population within the Northern Appalachians ecoregion is 40,550,000, representing approximately 14% of the total population of the United States.

Summary of WSA Findings

A total of 85 WSA sites were sampled during the summer of 2004 to characterize the condition of wadeable streams in the Northern Appalachians ecoregion. An overview of the WSA survey results for this ecoregion is shown in Figure 26. These results may not be extrapolated to accurately assess the ecological condition of an individual state or stream within the ecoregion because the study design was not intended to characterize stream conditions at these finer scales.

It should be noted that about 27% of wadeable stream length in the Northern Appalachians ecoregion was not assessed because small, 1st-order streams in New England were not included in the sample frame. These streams were excluded from the WSA due to a decision to match an earlier New England random design. The numbers cited below apply to the 73% of wadeable stream length that was assessed in the Northern Appalachians ecoregion.

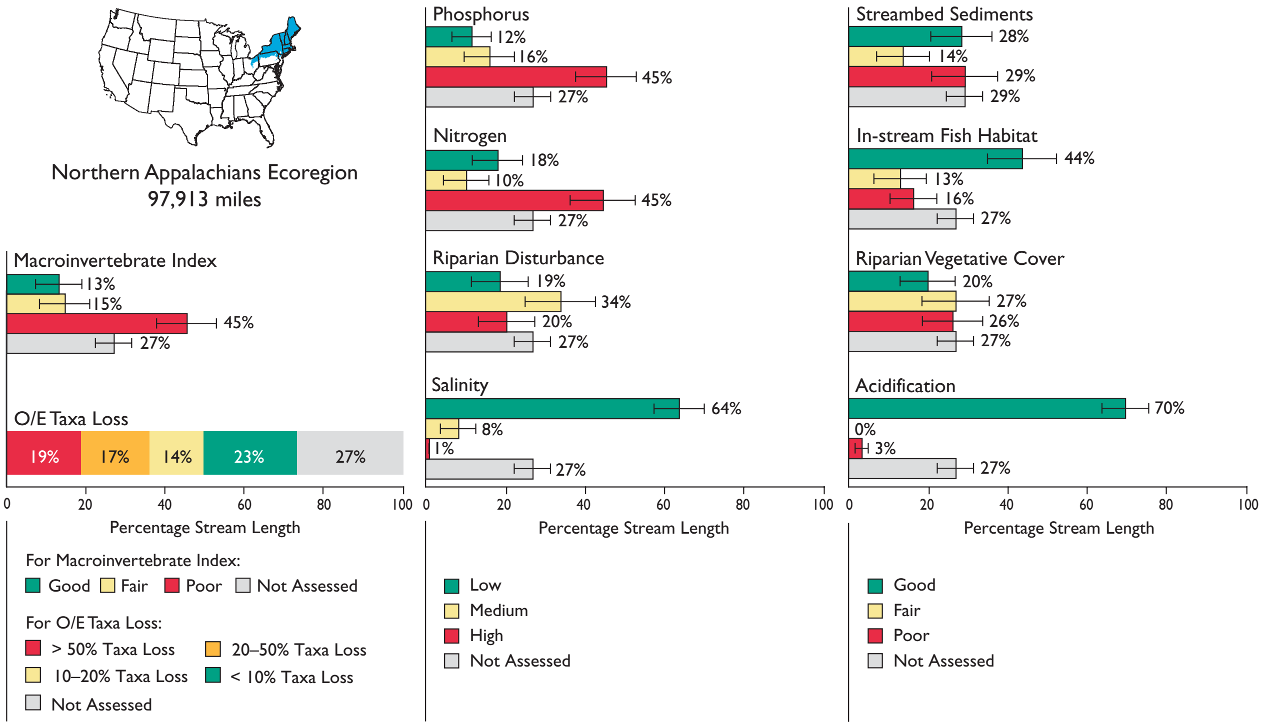


Figure 26. WSA survey results for the Northern Appalachians ecoregion (U.S. EPA/WSA). Bars show the percentage of stream length within a condition class for a given indicator. Lines with brackets represent the width of the 95% confidence interval around the percent of stream length. Percents may not add up to 100 because of rounding.

During a series of WSA workshops conducted to evaluate assessment results, professional biologists working in the Northern Appalachians ecoregion said that many least-disturbed reference sites in this ecoregion are nearly undisturbed streams, with sparse human population in the immediate watershed; therefore, the reference condition for the ecoregion is of very high quality.

Biological Condition

- The findings of the Macroinvertebrate Index show that 45% of stream length in the Northern Appalachians ecoregion is in poor condition, 15% is in intermediate or fair condition, and 13% is in good condition when compared to least-disturbed reference condition. As noted above, 1st-order streams, which are generally considered to be of high quality in this ecoregion, were not included in the WSA.
- The O/E Taxa Loss results show that 50% of stream length in the Northern Appalachians ecoregion has lost 10% or more of the macroinvertebrate taxa expected to occur, and 19% has lost more than 50% of taxa. These results indicate that 23% of stream length has retained 90% of the groups or classes of organisms expected to occur based on least-disturbed reference condition.

Indicators of Stress

Leading indicators of stress in the Northern Appalachians ecoregion include total phosphorus, total nitrogen, streambed sediments, and riparian vegetative cover.

- Approximately 45% of stream length in the Northern Appalachians ecoregion has high phosphorus concentrations, 16% has medium phosphorus concentrations, and 12% has low phosphorus concentrations based on least-disturbed reference condition.
- Similarly, approximately 45% of the ecoregion's stream length has high nitrogen concentrations, 10% has medium nitrogen concentrations, and 18% has low nitrogen concentrations based on least-disturbed reference condition.
- Riparian disturbance, or evidence of human influence in the riparian zone, is at high levels in 20% of stream length, at medium levels in 34% of stream length, and at low levels in 19% of stream length.
- Salinity is found at high levels in 1% of stream length, at medium levels in 8% of stream length, and at low levels in 64% of stream length.
- Streambed sediments are rated poor in 29% of stream length in the Northern Appalachians ecoregion, fair in 14%, and good in 28%.
- In-stream fish habitat is in poor condition in 16% of stream length, fair in 13% of stream length, and good in 44%.
- Vegetative cover in the riparian zone along stream banks is in poor condition for 26% of stream length, fair condition for 27% of stream length, and good condition for 20% of stream length.
- Acidification, which is primarily associated with acid rain in this ecoregion, is rated poor in 3% of stream length.

Stream channels in the glaciated uplands of the Northern Appalachians are characterized by steep profiles and rocky beds (Photo courtesy of Lauren Holbrook, IAN Image Library).

Southern Appalachians Ecoregion

Physical Setting

The Southern Appalachians ecoregion stretches over 10 states, from northeastern Alabama to central Pennsylvania, and includes the interior highlands of the Ozark Plateau and the Ouachita Mountains in Arkansas, Missouri, and Oklahoma.

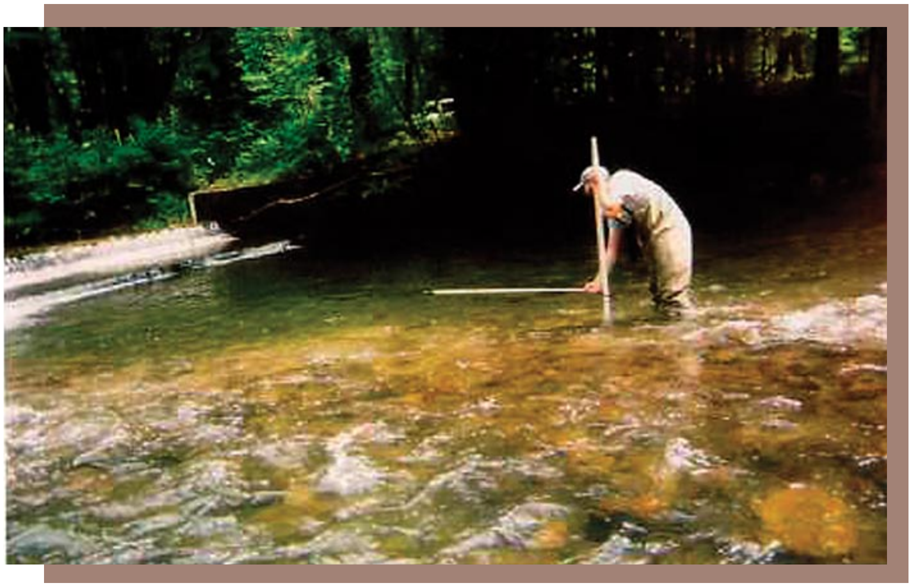
The land area of the Southern Appalachians ecoregion covers about 321,900 mi^2 (10.7% of the United States), with about 42,210 mi^2 (13.1%) of land under federal ownership. Many significant public lands, such as the Great Smoky Mountains National Park, the George Washington and Monongahela national forests, and the Shenandoah National Park, reside within this ecoregion. The topography is mostly hills and low mountains, with some wide valleys and irregular plains. Piedmont areas are included within the Southern Appalachians ecoregion.

Rivers in this ecoregion flow mostly over bedrock and other resistant rock types, with steep channels and short meander lengths. Major rivers such as the Susquehanna, James, and Potomac, along with feeders into the Ohio and Mississippi river systems, such as the Greenbrier River in West Virginia, originate in this ecoregion. The total stream length represented in the WSA for the Southern Appalachians ecoregion is 178,449 wadeable stream miles.

This ecoregion's climate is considered temperate wet, and annual precipitation totals average 40 to 80 inches. Mean annual temperature ranges from 55 to 65 °F. Based on satellite images in the 1992 NLCD, the distribution of land cover in this ecoregion is 68% forested and 25% planted/cultivated, with the remaining 7% in other types of land cover.

Biological Setting

The Southern Appalachians ecoregion has some of the greatest aquatic animal diversity of any area in North America, especially for species



Young Womans Creek, PA, in the Southern Appalachians ecoregion (Photo courtesy of the Great Lakes Environmental Center).

of amphibians, fishes, mollusks, aquatic insects, and crayfishes. Salamanders, plants, and fungi reach their highest North American diversity in the Southern Appalachians ecoregion; however, some 18% of animal and plant species in the ecoregion are threatened or endangered.

Some areas in the Southern Appalachians ecoregion are among the least-impacted pre-settlement vegetative cover in the United States, such as the spruce-fir forests in the southern part of the ecoregion. The Great Smoky Mountains National Park and other national forests continue to protect exceptional stands of old-growth forest riparian ecosystems.

Human Influence

The effects of habitat fragmentation, urbanization, agriculture, channelization, diversion, and impoundments on river systems have altered a large amount of stream length in the Southern Appalachians ecoregion. Placer mining, which disrupts streambeds and increases a stream's ability to transport fine sediments that influence habitat and water quality downstream, began in the Appalachians in the 1820s. In addition, some 800 mi^2 were surface mined in the Appalachian Highlands between 1930 and 1971, leading to the acidification of streams and reduction of aquatic diversity. Placer mining and surface mining operations have introduced many toxic contaminants to river systems in the Southern Appalachians ecoregion, including arsenic, antimony, copper, chromium, cadmium, nickel, lead, selenium, silver, and zinc. There are 224 active, 5 proposed, and 46 deleted EPA Superfund National Priority List sites in this ecoregion.

Economic activities in the Southern Appalachians ecoregion include forestry, coal mining, and some local agriculture and tourism industries. Petroleum and natural gas extraction are prevalent along the coal belt, and the ecoregion supports coal, bauxite, zinc, copper, and chromium mining activities. Utility industries include hydro-power in the Tennessee Valley and numerous coal-fired plants throughout the ecoregion. Significant agricultural activities are alfalfa production in Pennsylvania, with apple and cattle production occurring throughout the ecoregion. Wood processing and pulp, paper, and board production are also prevalent.

Approximately 50,208,000 people live in the Southern Appalachians ecoregion, representing approximately 17% of the total population of the United States.

Summary of WSA Findings

A total of 184 random sites were sampled during the summer of 2004 to characterize the condition of wadeable streams in the Southern Appalachians ecoregion. An overview of the WSA survey results for the ecoregion is shown in Figure 27. These results may not be extrapolated to an individual state or stream within the ecoregion because the study design was not intended to characterize stream conditions at these finer scales.

During a series of WSA workshops conducted to evaluate assessment results, professional biologists working in the Southern Appalachians ecoregion said that the least-disturbed reference streams in the ecoregion represent varying degrees of human influence. Although some reference streams are in remote areas, others are intricately linked with road systems in narrow floodplains.

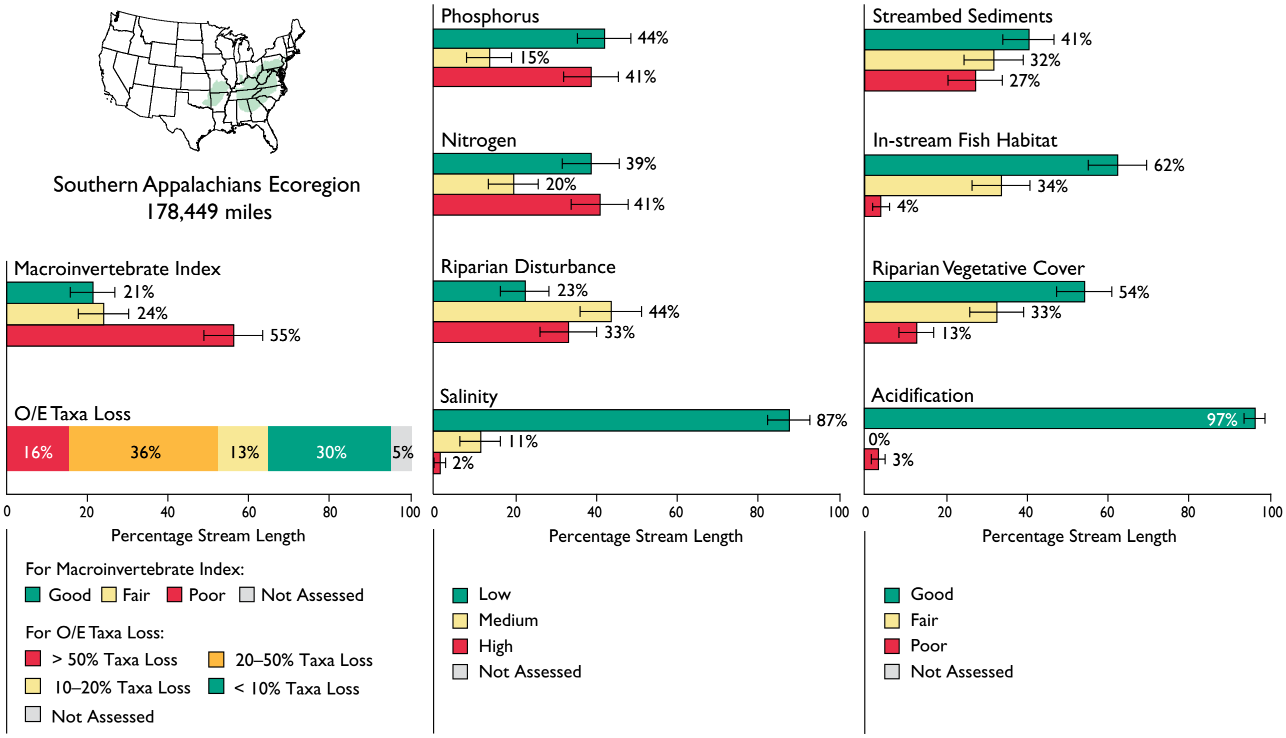


Figure 27. WSA survey results for the Southern Appalachians ecoregion (U.S. EPA/WSA). Bars show the percentage of stream length within a condition class for a given indicator. Lines with brackets represent the width of the 95% confidence interval around the percent of stream length. Percents may not add up to 100 because of rounding.

Biological Condition

- The Macroinvertebrate Index shows that 55% of stream length in the Southern Appalachians ecoregion is in poor condition, 24% is in fair or intermediate condition, and 21% is in good condition compared to least-disturbed reference condition.
- The O/E Taxa Loss results show that 65% of stream length in the Southern Appalachians ecoregion has lost 10% or more of the macroinvertebrate taxa that are expected to occur, and 16% has lost more than 50% of taxa. These results also indicate that 30% of stream length has retained 90% of the groups or classes of organisms expected to occur based on least-disturbed reference condition.

Indicators of Stress

Leading indicators of stress in the Southern Appalachians ecoregion include total nitrogen, total phosphorus, riparian disturbance, and streambed sediments.

- Forty-one percent of stream length in the Southern Appalachians ecoregion has high phosphorus concentrations, 15% has medium phosphorus concentrations, and 44% has low phosphorus concentrations based on least-disturbed reference condition.
- Nitrogen concentrations in the ecoregion are high in 41% of stream length, medium in 20% of stream length, and low in 39% of stream length based on least-disturbed reference condition.

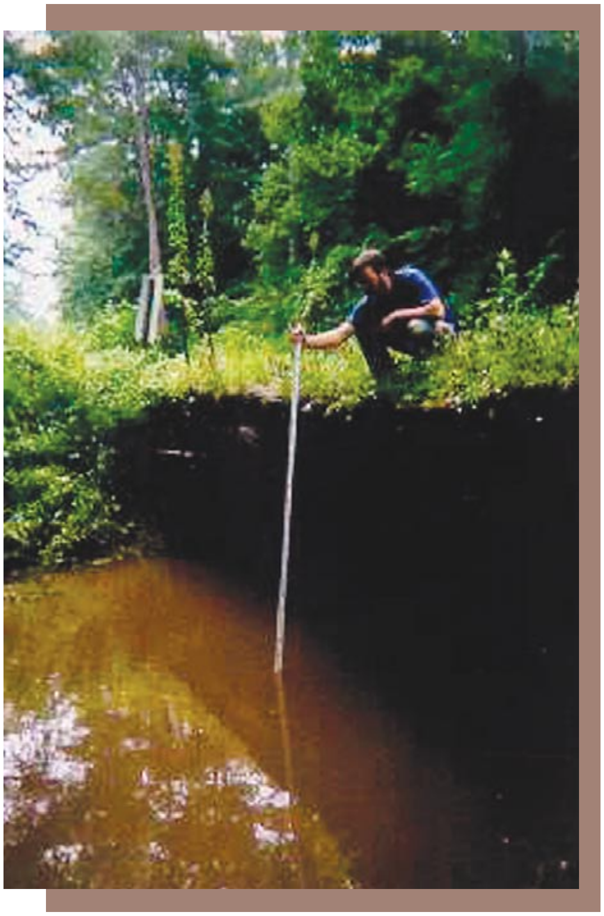
- Riparian disturbance, or evidence of human influence in the riparian zone, is at high levels in 33% of stream length, at medium levels in 44% of stream length, and at low levels in 23% of stream length.
- Salinity is found at high levels in only 2% of stream length, at medium levels in 11% of stream length, and at low levels in 87% of stream length.
- Streambed sediments are rated poor in 27% of stream length in the Southern Appalachians ecoregion, fair in 32%, and good in 41%.
- In-stream fish habitat is in poor condition in 4% of stream length, fair in 34% of stream length, and good in 62%.
- Vegetative cover in the riparian zone along Southern Appalachian stream banks is in poor condition in 13% of stream length, fair in 33% of stream length, and good in 54% of stream length.
- Acidification, which is primarily associated with acidic deposition and acid mine drainage in this ecoregion, is rated poor in 3% of stream length.

Coastal Plains Ecoregion

Physical Setting

The Coastal Plains ecoregion covers the Mississippi Delta and Gulf Coast, north along the Mississippi River to the Ohio River, all of Florida and eastern Texas, and the Atlantic seaboard from Florida to New Jersey. The total land area of this ecoregion is about 395,000 mi^2 (13.2% of the United States), with 25,890 mi^2 (6.6%) of land under federal ownership. River systems lying within or intersecting the Coastal Plains ecoregion are the Mississippi, Suwannee, Savannah, Roanoke, Potomac, Delaware, Susquehanna, James, Sabine, Brazos, and Guadalupe rivers.

Rivers in the Coastal Plains meander broadly across flat plains created by thousands of years of river deposition and form complex wetland topographies with levees, backswamps, and oxbow lakes. Rivers typically drain densely vegetated catchment areas, while well-developed soils and less intensive rains and subsurface flows keep suspended sediment levels in the rivers relatively low. The Mississippi River carries large loads of sediments from dry lands in the central and western portion of the drainage. The total stream length represented in the WSA for the Coastal Plains ecoregion is 72,130 wadeable stream miles.



Sandy Creek, LA, in the Coastal Plains ecoregion (Photo courtesy of the Great Lakes Environmental Center).

The Coastal Plains ecoregion contains about one-third of all remaining U.S. wetlands, more than half of U.S. forested wetlands, and the largest aggregate area of U.S. riparian habitat. The topography of the area is mostly flat plains, barrier islands, numerous wetlands, and about 50 important estuarine systems that lie along the coastal margins. The climate of this ecoregion is considered temperate wet to subtropical in the south, with average annual temperatures ranging from 50 to 80 °F and annual precipitation ranging from 30 to 79 inches. Based on satellite images in the 1992 NLCD, the distribution of land cover in this ecoregion is 39% forested, 30% planted/cultivated, and 16% wetlands, with the remaining 15% of the ecoregion comprised of other types of land cover.

Biological Setting

River habitats in the Coastal Plains ecoregion have tremendous species richness and the highest number of endemic species of aquatic organisms in North America. Abundant fish, crayfish, mollusk, aquatic insect, and other species include such unique species as paddlefish, catostomid suckers, American alligator, and giant aquatic salamanders; however, it is estimated that some 18% of the aquatic species in this ecoregion are threatened or endangered. The Coastal Plains ecoregion includes the Florida Everglades, which contains temperate and tropical plant communities and a rich variety of bird and wildlife species; however, because it is a unique aquatic ecosystem, the Everglades is not represented in the WSA.

Human Influence

Historically, the Coastal Plains ecoregion had extensive bottomlands that flooded for several months; these areas are now widely channelized and confined by levees. Damming, impounding, and channelization in almost all major rivers have altered the rate and timing of water flow, as well as the productivity of riparian habitats. Pollution from acid mine drainage, urban runoff, air pollution, sedimentation, and recreation, as well as the introduction of non-indigenous fishes and aquatic plants, have also affected riparian habitats and native aquatic fauna. There are currently 275 active, 13 proposed, and 77 deleted EPA Superfund National Priority List sites in the Coastal Plains ecoregion.

The ecoregion's economy is varied and includes many activities. Agriculture in this ecoregion includes citrus, peanut, sugar cane, tobacco, cattle, poultry, cotton, corn, rice, vegetable, and stone fruit production. Industries include pulp, paper, board, and board wood processing; aluminum production; salt, sulfur, bauxite, and phosphate mining; and chemical and plastics production. The Coastal Plains contain approximately 40% of U.S. petrochemical refinery capacity, much of which is located offshore in the Gulf of Mexico.

This ecoregion also includes many large coastal cities, which contribute to a population of approximately 56,168,000, the largest population of all the WSA ecoregions, representing approximately 19% of the population of the United States.

Summary of WSA Findings

A total of 83 random sites were sampled during the summer of 2004 to characterize the condition of wadeable streams in the Coastal Plains ecoregion. An overview of the WSA survey results for this ecoregion is shown in Figure 28. These results may not be extrapolated to an individual state or stream within the ecoregion because the study design was not intended to characterize stream conditions at these finer scales.

During a series of WSA workshops conducted to evaluate assessment results, professional biologists working in the Coastal Plains ecoregion said that the high prevalence of human population centers, agriculture, and industry makes it difficult to find truly undisturbed streams in this ecoregion; therefore, the ecoregion's least-disturbed reference sites are influenced to some degree by human activities.

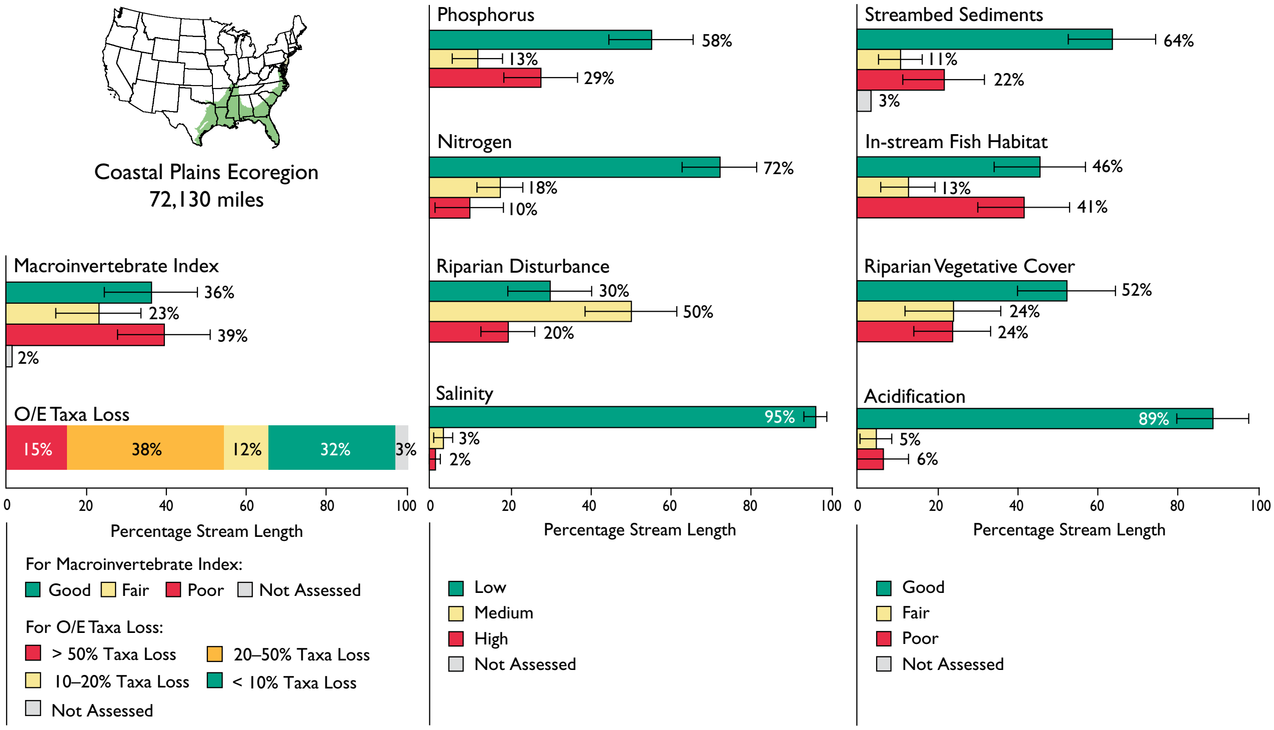


Figure 28. WSA survey results for the Coastal Plains ecoregion (U.S. EPA/WSA). Bars show the percentage of stream length within a condition class for a given indicator. Lines with brackets represent the width of the 95% confidence interval around the percent of stream length. Percents may not add up to 100 because of rounding.

Biological Condition

- The Macroinvertebrate Index reveals that 39% of stream length in the Coastal Plains ecoregion is in poor condition, 23% is in fair or intermediate condition, and 36% is in good condition compared to least-disturbed reference condition. No data were available to evaluate 2% of the ecoregion's stream length.
- The O/E Taxa Loss results show that 65% of stream length in the Coastal Plains ecoregion has lost 10% or more of the macroinvertebrate taxa that are expected to occur, and 15% has lost more than 50% of taxa. These results also indicate that 32% of stream length has retained 90% of the groups or classes of organisms expected to occur based on least-disturbed reference condition.

Indicators of Stress

Leading indicators of stress in the Coastal Plains ecoregion include total phosphorus, in-stream fish habitat, riparian vegetative cover, and streambed sediments.

- Twenty-nine percent of stream length in the Coastal Plains ecoregion has high phosphorus concentrations, 13% has medium phosphorus concentrations, and 58% has low phosphorus concentrations based on least-disturbed reference condition.
- Ten percent of the ecoregion's stream length has high nitrogen concentrations, 18% has medium nitrogen concentrations, and 72% has low nitrogen concentrations based on least-disturbed reference condition.
- Riparian disturbance, or evidence of human influence in the riparian zone, is at high levels in 20% of stream length, at medium levels in 50% of stream length, and at low levels in 30% of stream length.
- Salinity is found at high or medium levels in 5% of stream length, with the remaining 95% of stream length showing low levels for this indicator.
- Streambed sediments are rated poor in 22% of stream length in the Coastal Plains ecoregion, fair in 11% of stream length, and good in 64% of stream length based on least-disturbed reference condition; no data were available to assess the remaining 3% of stream length.
- In-stream fish habitat is in poor condition in 41% of stream length, fair in 13% of stream length, and good in 46% of stream length, based on least-disturbed reference condition.
- Vegetative cover in the riparian zone along stream banks is in poor condition for 24% of stream length, fair condition for 24% of stream length, and good condition in the remaining 52% of stream length based on least-disturbed reference condition.
- In this ecoregion, the ANC is low enough to result in episodic acidification during rainfall in 6% of stream length. Another 5% of stream length has naturally lower pH.

Upper Midwest Ecoregion

Physical Setting

The Upper Midwest ecoregion covers most of the northern half and southeastern part of Minnesota, two-thirds of Wisconsin, and almost all of Michigan. The land area of the Upper Midwest ecoregion comprises some 160,374 mi^2 (5.3% of the United States). The river systems in this ecoregion empty into portions of the Great Lakes regional watershed and the upper Mississippi River watershed. Major river systems include the upper Mississippi River in Minnesota and Wisconsin; the Wisconsin, Chippewa, and St. Croix rivers in Wisconsin; and the Menominee and Escanaba rivers in Michigan. Streams in the Upper Midwest ecoregion typically drain relatively small catchments and empty directly into the Great Lakes or upper Mississippi River. These streams generally have steep gradients, but their topography and soils tend to slow runoff and sustain flow throughout the year.

The total stream length represented in the WSA for the Upper Midwest ecoregion is 36,547 wadeable stream miles. Sandy soils dominate these waterbodies, with relatively high water quality in streams supporting cold-water fish communities. Important waterbodies in this ecoregion include the Upper Mississippi River system and Lakes Superior, Michigan, Huron, and Erie.

The glaciated terrain of this ecoregion typically consists of plains with some hill formations. Numerous lakes, rivers, and wetlands predominate in most areas. The climate is characterized by cold winters and relatively short, warm summers, with mean annual temperatures ranging from 34 to 54 °F and annual precipitation in the 20- to 47-inch range. Much of the land in this ecoregion is covered by national and state forests, and federal lands account for 15.5% of the area (roughly 25,000 mi^2). Based on satellite images in the 1992 NLCD, the distribution of land cover in this ecoregion is 40% forested, 34% planted/cultivated, and 17% wetlands, with the remaining 9% of the ecoregion comprised of other types of land cover.

Raisin River, MI, in the Upper Midwest ecoregion (Photo courtesy of the Great Lakes Environmental Center).

Biological Setting

Vegetative cover for the Upper Midwest ecoregion is mixed boreal woodland, mixed oak-hickory associations, and conifers, as well as bog and moss barrens. The Great Lakes aquatic ecosystems are subject to increasing intrusion by invasive animal and plant species introduced by ocean shipping. These species include the zebra mussel, the round goby, the river ruffe, the spiny water flea, and Eurasian watermilfoil.

Human Influence

The Upper Great Lakes portion of the Upper Midwest ecoregion was entirely forested in pre-colonial times. Virtually all of the virgin forest was cleared in the 19th and early 20th centuries, and streams and rivers were greatly affected by the logging industry. The upper Mississippi River portion of the Upper Midwest ecoregion was also heavily influenced by logging and agriculture.

Major manufacturing, chemical, steel, and power production (e.g., coal, nuclear, oil) occur in the large metropolitan areas found in the Upper Midwest ecoregion. Other key economic activities are forestry, mining, and tourism. Agriculture includes dairy production, grain crops in the western areas, fruit production around the Great Lakes, and hay and cattle farming throughout the ecoregion. Pulp, paper, and board wood processing are prevalent throughout the northern parts of the ecoregion. The area includes the shipping ports at Duluth, MN, and Superior, WI, as well as cities like Marquette, MI, and Hibbing, MN, which were built up along with the mining industry. The Upper Peninsula of Michigan lies entirely within the Upper Midwest ecoregion, as does Minnesota's Mesabi Range, the largest U.S. iron ore deposit. This area is subject to the environmental effects of mining operations. There are currently 112 active, 1 proposed, and 12 deleted EPA Superfund National Priority List sites in this ecoregion.

The approximate population of this area is 15,854,000, representing approximately 5% of the population of the United States.

Summary of WSA Findings

A total of 56 random sites were sampled in the Upper Midwest ecoregion during the summer of 2004 to characterize the condition of its wadeable streams. An overview of the WSA survey results for the Upper Midwest ecoregion is shown in Figure 29. These results may not be extrapolated to an individual state or stream within the ecoregion because the study design was not intended to characterize stream conditions at these finer scales.

During a series of WSA workshops conducted to evaluate assessment results, professional biologists working in the Upper Midwest ecoregion said that some of the ecoregion's least-disturbed streams that serve as a benchmark for reference condition are influenced by some form of human activity or land use; however, most of the least-disturbed reference sites are streams in relatively undisturbed areas in the northern portion of the ecoregion.

Biological Condition

- The Macroinvertebrate Index reveals that 39% of stream length in the Upper Midwest ecoregion is in poor condition, 31% is in fair condition, and 28% is in good condition based on least-disturbed reference condition.
- The O/E Taxa Loss results show that 54% of stream length in the Upper Midwest ecoregion has lost 10% or more of the macroinvertebrate taxa that are expected to occur, and 5% has lost more than 50% of taxa. These results also indicate that 45% of stream length has retained at least 90% of the groups or classes of organisms expected to occur based on least-disturbed reference condition.

Indicators of Stress

Leading indicators of stress in the Upper Midwest ecoregion include total phosphorus, total nitrogen, streambed sediments, and in-stream fish habitat.

- Thirty-eight percent of stream length in the Upper Midwest ecoregion has high phosphorus concentrations, 18% has medium

Figure 29. WSA survey results for the Upper Midwest ecoregion (U.S. EPA/WSA). Bars show the percentage of stream length within a condition class for a given indicator. Lines with brackets represent the width of the 95% confidence interval around the percent of stream length. Percents may not add up to 100 because of rounding.

phosphorus concentrations, and 42% has low phosphorus concentrations based on least-disturbed reference condition.

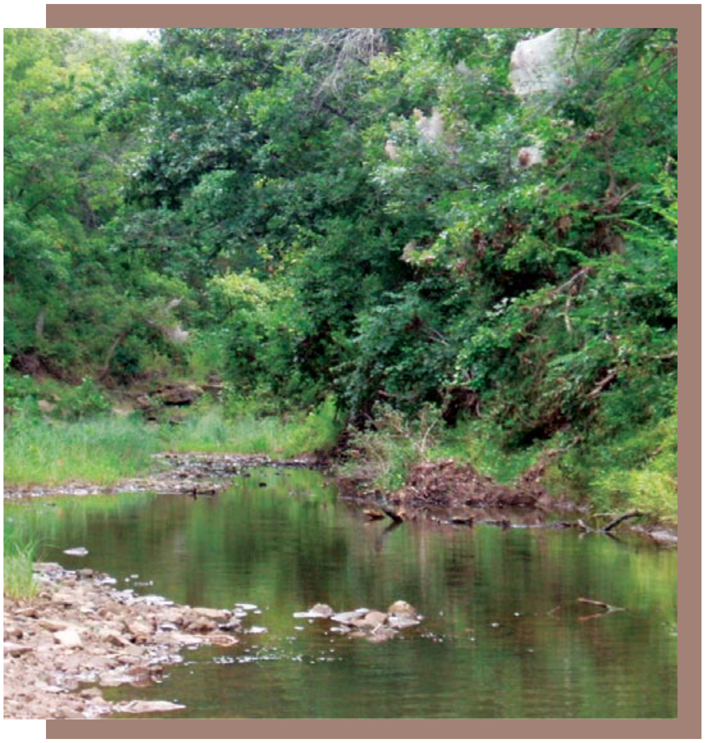
- Twenty-one percent of the ecoregion's stream length has high nitrogen concentrations, 30% of stream length has medium nitrogen concentrations, and 48% of stream length has low nitrogen concentrations based on least-disturbed reference condition.
- Riparian disturbance, or evidence of human influence in the riparian zone, is at high levels in 6% of stream length, at medium levels in 45% of stream length, and at low levels in 49% of stream length.
- Salinity is found at medium levels in 22% of stream length and at low levels in 77% of stream length. None of the steam length of the Upper Midwest ecoregion showed high levels for this indicator.
- Streambed sediments are rated poor in 50% of stream length, fair in 11%, and good in 37%; data for this indicator were not available for 2% of stream length.
- In-stream fish habitat is in poor condition in 17% of stream length, fair in 69% of stream length, and good in 14% of stream length based on least-disturbed reference condition.
- Vegetative cover in the riparian zone along stream banks is in poor condition in 13% of stream length, fair condition in 38% of stream length, and in good condition in 44% of stream length.
- The effects of acidification are not noted for the Upper Midwest ecoregion.

Temperate Plains Ecoregion

Physical Setting

The Temperate Plains ecoregion includes the open farmlands of Iowa; the eastern Dakotas; western Minnesota; portions of Missouri, Kansas, and Nebraska; and the flat farmlands of western Ohio, central Indiana, Illinois, and southeastern Wisconsin. The area of this ecoregion covers some 342,200 mi^2 (11.4% of the United States), with approximately 7,900 mi^2 (2.3%) of land under federal ownership. The ecoregion's terrain consists of smooth plains and numerous small lakes and wetlands. The climate is temperate, with fairly cold winters; hot, humid summers; and mean temperatures ranging from 36 to 55 °F. Annual precipitation in the Temperate Plains ecoregion ranges from 16 to 43 inches.

Many of the rivers in this ecoregion drain into the Upper Mississippi and Ohio regional watersheds, and a few systems empty into the Great Lakes watershed near Toledo, OH; Saginaw, MI; Detroit, MI; and southeastern Wisconsin. Rivers are either supplied by snowmelt or groundwater. Rivers in the tall grass prairie start from prairie potholes and springs and are likely to be ephemeral (flowing for a short time after snowmelt or rainfall). The prairie rivers carry large volumes of fine sediments and tend to be turbid, wide, and shallow. The total stream length represented in the WSA for the Temperate Plains ecoregion is 100,879 wadeable stream miles. Based on satellite images in the 1992 NLCD, the distribution of land cover in this ecoregion is 9% forested and 76% planted/cultivated, with the remaining 15% of the ecoregion comprised of other types of land cover.



Grey Horse Creek, OK, in the Temperate Plains ecoregion (Photo courtesy of Monty Porter).

Biological Setting

Vegetation for the Temperate Plains ecoregion consists primarily of oak, hickory, elm, ash, beech, and maple, with increasing amounts of prairie grasses to the west. Rivers have rich fish fauna with many species, including minnows, darters, killifishes, catfishes, suckers, sunfishes, and black bass. Few species are endemic to the ecoregion.

Human Influence

Pre-settlement vegetation of the area was prairie grass and aspen parkland, but is now comprised of about 75% arable cultivated lands. This ecoregion is rich in agricultural production, including field crops such as corn, wheat, alfalfa, soybeans, flaxseed, and rye, along with vegetable crops such as peanuts and tomatoes. Hog and cattle production and processing are also prevalent. Crops and grazing have reduced natural riparian vegetation cover, increased sediment yield, and introduced pesticides and herbicides into the watershed. Conservation tillage — a reduced-cultivation method — has been implemented in about 50% of crop fields in the Maumee River Basin and in northwestern Ohio tributaries draining to Lake Erie. USGS findings from 1993–1998 in these rivers showed significant decreases in the amounts of suspended sediment. Rivers in the Temperate Plains ecoregion also tend to have high nitrogen concentrations due to nutrients from agriculture and from fertilizer applied to lawns and golf courses in urban areas. In Illinois, where land is intensively developed through urbanization and agriculture, more than 25% of all sizable streams have been channelized, and almost every stream in the state has at least one dam.

Coal mining, petroleum and natural gas production, and zinc and lead mining occur across the Temperate Plains ecoregion. There are very active areas of manufacturing, steel production, and chemical production in the ecoregion's urban centers, with especially high concentrations near Detroit, MI, and the industrial belt from Gary, IN, to Chicago, IL, and Milwaukee, WI. Industrial activities in these large urban centers have contributed sewage, toxic compounds, and silt to river systems. Heavy metals, organochlorines, and PCBs are especially prevalent and persistent river contaminants found in industrial areas; however, many rivers have improved from their worst state in the 1960s. There are currently 133 active, 17 proposed, and 44 deleted EPA Superfund National Priority List sites in the Temperate Plains ecoregion.

The approximate population of this ecoregion is 38,399,000, representing approximately 13% of the U.S. population.

Summary of WSA Findings

A total of 132 random sites were sampled during the summer of 2004 to characterize the condition of wadeable streams throughout the Temperate Plains ecoregion. An overview of the WSA survey results for the Temperate Plains ecoregion is shown in Figure 30. These results may not be extrapolated to an individual state or stream within the ecoregion because the study design was not intended to characterize stream conditions at these finer scales.

During a series of WSA workshops conducted to evaluate assessment results, professional biologists working in the Temperate Plains ecoregion said that it is hard to find high-quality reference sites in the ecoregion because even the least-disturbed streams are influenced by a long history of land use. Extensive agriculture and development have influenced virtually all waterbodies in this ecoregion.

Biological Condition

- The Macroinvertebrate Index reveals that 37% of stream length in the Temperate Plains ecoregion is in poor condition, 36% is in fair condition, and 26% is in good condition compared to least-disturbed reference condition.
- The O/E Taxa Loss results show that 39% of stream length in the Temperate Plains ecoregion has lost 10% or more of the macroinvertebrate taxa that are expected to occur, and 10% has lost more than 50% of taxa. These results also indicate that 58% of stream length has retained 90% of the groups or classes of organisms expected to occur based on least-disturbed reference condition.

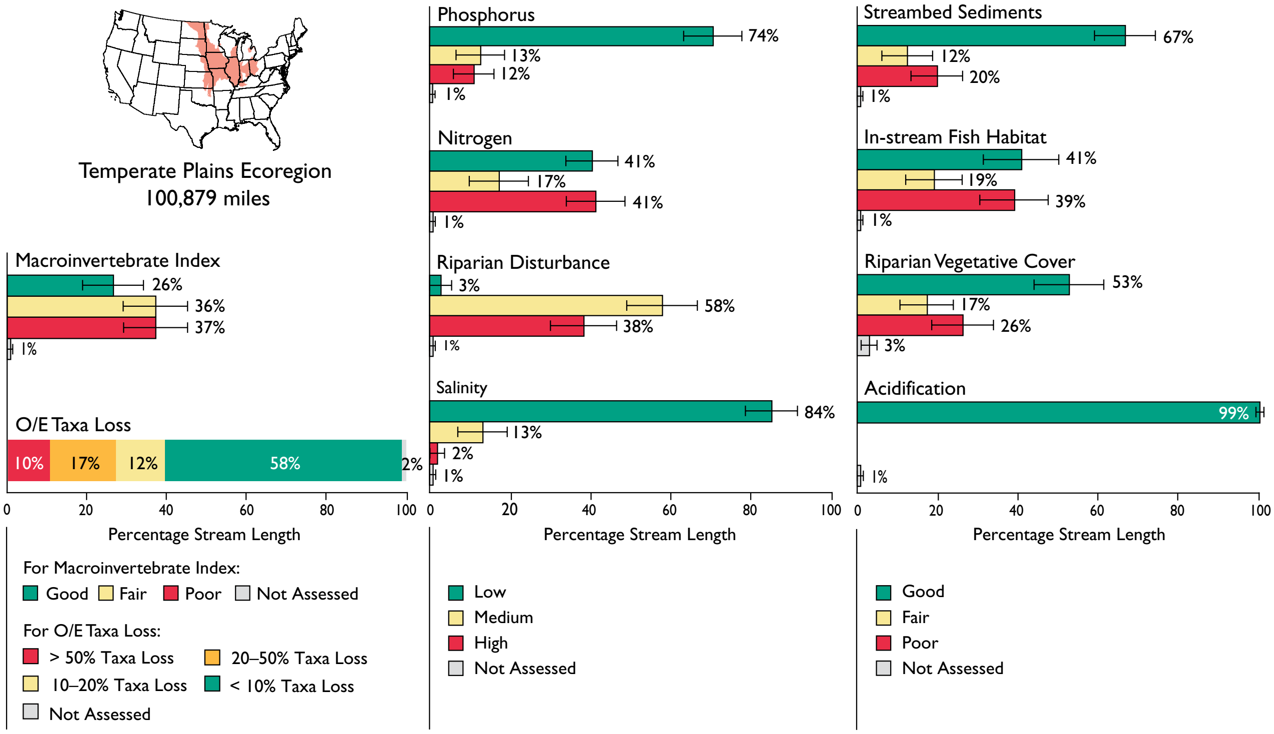


Figure 30. WSA survey results for the Temperate Plains ecoregion (U.S. EPA/WSA). Bars show the percentage of stream length within a condition class for a given indicator. Lines with brackets represent the width of the 95% confidence interval around the percent of stream length. Percents may not add up to 100 because of rounding.

Indicators of Stress

Leading indicators of stress in the Temperate Plains ecoregion include total nitrogen, riparian disturbance, in-stream fish habitat, and riparian vegetative cover.

- Approximately 12% of stream length in the Temperate Plains ecoregion has high phosphorus concentrations, 13% has medium phosphorus concentrations, and 74% has low phosphorus concentrations based on least-disturbed reference condition.
- Approximately 41% of the ecoregion's stream length has high nitrogen concentrations, 17% has medium nitrogen concentrations, and 41% has low nitrogen concentrations based on least-disturbed reference condition.
- Riparian disturbance for this ecoregion is at high levels in approximately 38% of stream length, at medium levels in 58% of stream length, and at low levels in 3% of stream length.
- Salinity is found at high levels in 2% of stream length, at medium levels in 13% of stream length, and at low levels in 84% of stream length.
- Excess streambed sediments affect streams in the Temperate Plains ecoregion to a lesser extent than other physical stressors. Streambed sediments are rated poor in 20% of stream length in this ecoregion, fair in 12%, and good in 67% based on least-disturbed reference condition.

- In-stream fish habitat is in poor condition in 39% of stream length, fair in 19% of stream length, and good in 41% of stream length based on least-disturbed reference condition.
- Vegetative cover in the riparian zone along stream banks is in poor condition for 26% of stream length, fair condition for 17% of stream length, and good condition for 53% of stream length.
- The effects of acidification are not noted for the Temperate Plains ecoregion.

Southern Plains Ecoregion

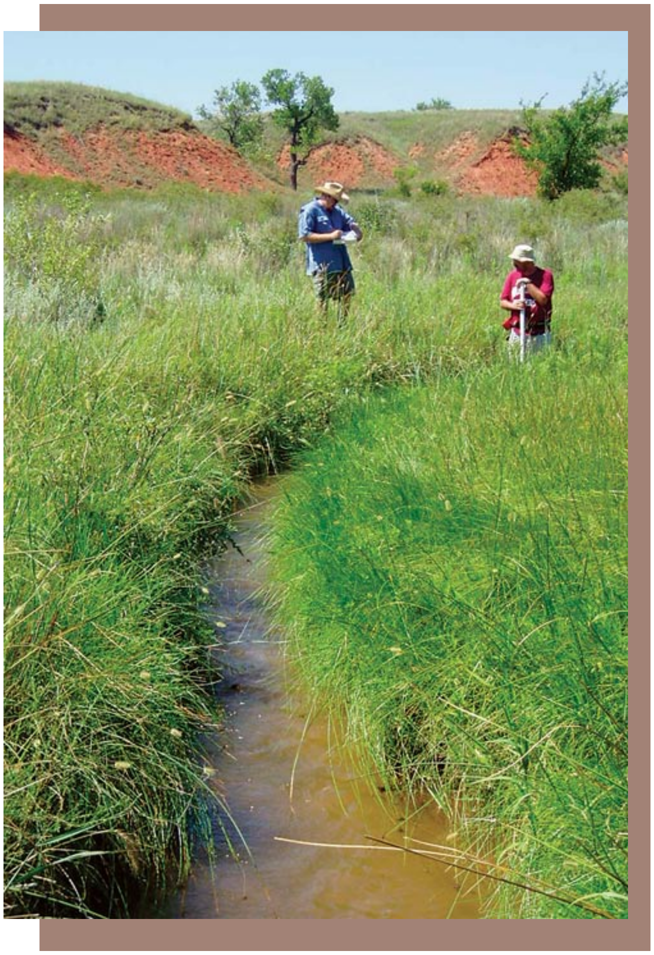
Physical Setting

The Southern Plains ecoregion covers approximately 405,000 mi^2 (13.5% of the United States) and includes central and northern Texas; most of western Kansas and Oklahoma; and portions of Nebraska, Colorado, and New Mexico. The terrain is a mix of smooth and irregular plains interspersed with tablelands and low hills. The Arkansas, Platte, White, Red, and Rio Grande rivers flow through this ecoregion, and most of the great Ogallala aquifer lies underneath this ecoregion. The total stream length represented in the WSA for the Southern Plains ecoregion is 19,263 wadeable stream miles.

Most of the land use is arable and arable with grazing, with desert or semi-arid grazing land in the south. Based on satellite images in the 1992 NLCD, the distribution of land cover in this ecoregion is 45% grassland, 32% planted/cultivated, and 14% shrubland, with the remaining 9% of the ecoregion comprised of other types of land cover. Federal land ownership in this ecoregion totals about 11,980 mi^2 or approximately 3% of the total, the lowest share of all WSA aggregate ecoregions. The climate is dry temperate, with the mean annual temperature ranging from 45 to 79 °F. Annual precipitation for the ecoregion is between 10 and 30 inches.

Biological Setting

Vegetative cover in the northern portion of this ecoregion is mainly short prairie grasses such as buffalo grass, while in the southern portion, grasslands with mesquite, juniper, and oak woody vegetation are common. Coastal vegetation in the southern Plains ecoregion is typically more salt-tolerant in nature.



Commission Creek, OK, in the Southern Plains ecoregion (Photo courtesy of Monty Porter).

Human Influence

The Great Prairie grasslands, which once covered much of the Southern Plains ecoregion, are the most altered and endangered large ecosystem in the United States. About 90% of the original tall grass prairie was replaced by other vegetation or land uses. Agriculture is an important economic activity in this ecoregion and includes sorghum, wheat, corn, sunflower, bean, and cotton production. Livestock production and processing is prevalent, especially goats, sheep, and cattle. The ecoregion contains a sizable portion of U.S. petroleum and natural gas production in Oklahoma, Kansas, and Texas. Electricity in this ecoregion is generated almost exclusively with gas-fired power plants. Some uranium and zinc mining is found in Oklahoma and the Texas panhandle. There are currently 39 active, 5 proposed, and 14 deleted EPA Superfund National Priority List sites in this ecoregion.

The approximate population in this ecoregion is 18,222,000, representing roughly 6% of the population of the United States.

Summary of WSA Findings

A total of 49 random sites were sampled during the summer of 2004 to characterize the condition of wadeable streams throughout the Southern Plains ecoregion. An overview of the WSA survey results for the ecoregion is shown in Figure 31. These results may not be extrapolated to an individual state or stream within the ecoregion because the study design was not intended to characterize stream conditions at these finer scales.

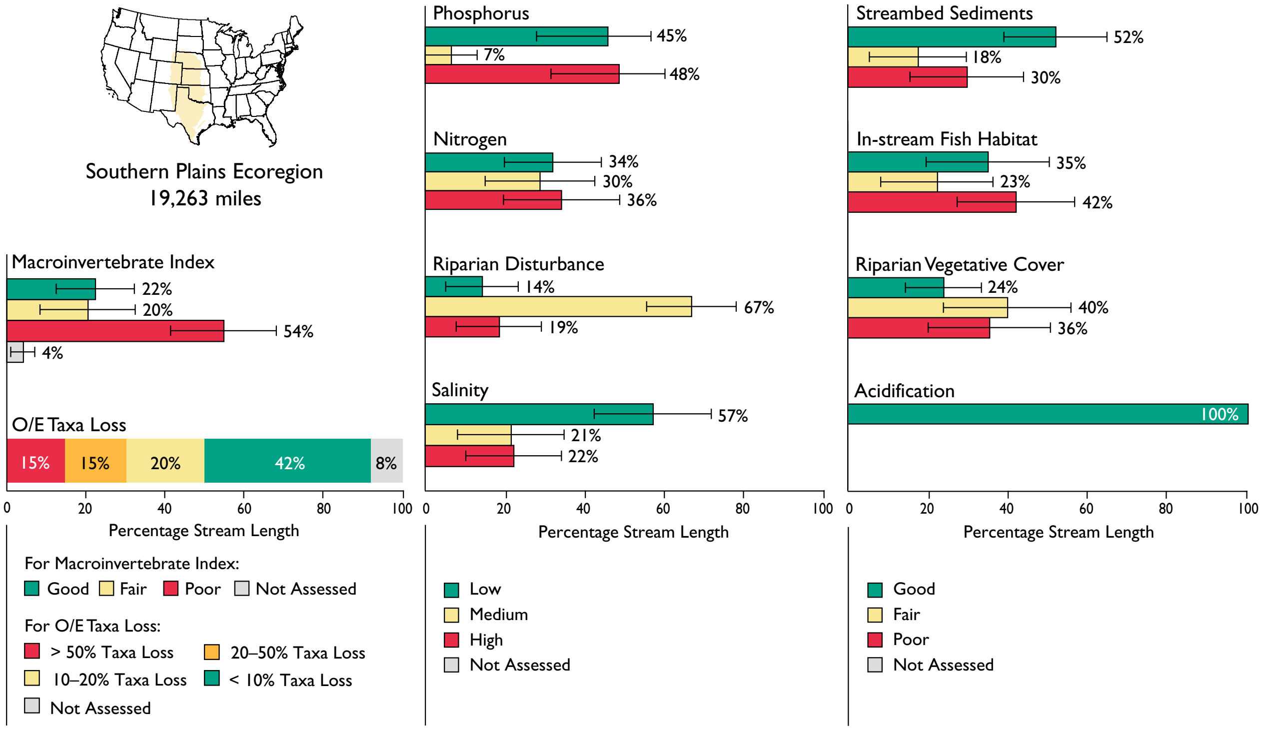


Figure 31. WSA survey results for the Southern Plains ecoregion (U.S. EPA/WSA). Bars show the percentage of stream length within a condition class for a given indicator. Lines with brackets represent the width of the 95% confidence interval around the percent of stream length. Percents may not add up to 100 because of rounding.

During a series of WSA workshops conducted to evaluate assessment results, professional biologists working in the Southern Plains ecoregion said that no undisturbed streams remain in the ecoregion. The least-disturbed streams are those that retain natural configuration and have riparian buffer zones.

Biological Condition

- The Macroinvertebrate Index reveals that 54% of stream length in the Southern Plains ecoregion is in poor condition, 20% is in fair condition, and 22% is in good condition compared to least-disturbed reference condition. There are no data for the remaining 4% of stream length.
- The O/E Taxa Loss results show that 50% of stream length in the Southern Plains ecoregion has lost 10% or more of the macroinvertebrate taxa expected to occur, and 15% has lost more than 50% of taxa. These results also indicate that 42% of the ecoregion's stream length has retained 90% of the groups or classes of organisms expected to occur based on least-disturbed reference condition.

Indicators of Stress

The most widespread indicators of stress in the Southern Plains ecoregion include total phosphorus, total nitrogen, in-stream fish habitat, and riparian vegetative cover.

- Forty-eight percent of stream length in the Southern Plains ecoregion has high phosphorus concentrations, 7% has medium phosphorus concentrations, and 45% has low phosphorus concentrations based on least-disturbed reference condition.
- Approximately 36% of the ecoregion's stream length has high nitrogen concentrations, 30% has medium nitrogen concentrations, and 34% has low nitrogen concentrations based on least-disturbed reference condition.
- Riparian disturbance in this ecoregion is at high levels in 19% of stream length. The majority of stream length (67%) has medium levels of riparian disturbance, and only 14% has low levels for this indicator.
- Salinity is found at high levels in 22% of stream length, at medium levels in 21% of stream length, and at low levels in 57% of stream length.
- Streambed sediments are rated poor in 30% of stream length, fair in 18%, and good in 52% based on least-disturbed reference condition.
- In-stream fish habitat is in poor condition in 42% of stream length, fair in 23% of stream length, and good in 35% of stream length based on least-disturbed reference condition.
- Vegetative cover in the riparian zone along stream banks is in poor condition for 36% of stream length, in fair condition for 40% of stream length, and good condition for 24% of stream length.
- The effects of acidification are not noted for the Southern Plains ecoregion.

Northern Plains Ecoregion

Physical Setting

The Northern Plains ecoregion covers approximately 205,084 mi^2 (6.8% of the United States), including the western Dakotas, Montana east of the Rocky Mountains, northeast Wyoming, and a small section of northern Nebraska. Federal lands account for 52,660 mi^2 or a relatively large (25.7%) share of the total area. The Great Prairie grasslands were also an important feature of this ecoregion, but about 90% of these grasslands have been replaced by other vegetation or land use. The ecoregion's terrain is irregular plains interspersed with tablelands and low hills. This ecoregion is the heart of the Missouri River system and is almost exclusively within the Missouri River's regional watershed. The total stream length represented in the WSA for the Northern Plains ecoregion is 13,445 wadeable stream miles.

Land use is arable with grazing or semi-arid grazing. Based on satellite images in the 1992 NLCD, the distribution of land cover in this ecoregion is 56% grassland and 30% planted/cultivated, with the remaining 14% of the ecoregion comprised of other types of land cover. Significant wetlands are also found in the Nebraska Sandhills area. The climate is dry and continental, characterized by short, hot summers and long, cold winters. Temperatures average 36 to 46 °F, and annual precipitation totals range from 10 to 25 inches. High winds are an important climatic factor in this ecoregion. It is also subject to periodic, intense droughts and frosts.

Biological Setting

The predominant vegetative cover for the Northern Plains ecoregion was formerly native short prairie grasses, such as wheat grass and porcupine grass, but now cropland is much more prevalent.

Wolf Creek, McCook County, SD, in the Northern Plains ecoregion (Photo courtesy of Dynamac Corp).

Human Influence

Human economic activity is primarily agriculture, including cattle and sheep grazing, as well as the growing of wheat, barley, and sugar beets. Coal mining occurs in the North Dakota, Montana, and Wyoming portions of the ecoregion. Petroleum and gas production has grown considerably in the Cut Bank region in north-central Montana. There are several large Indian reservations in this ecoregion, including the Pine Ridge, Standing Rock, and Cheyenne reservations in South Dakota and the Blackfeet, Crow, and Fort Peck reservations in Montana. There are currently four active and one proposed EPA Superfund National Priority List sites in this ecoregion.

The approximate population of this ecoregion is relatively small at 1,066,000, or 0.4% of the population of the United States.

Summary of WSA Findings

A total of 98 random sites were sampled during the summers of 2000–2004 to characterize the condition of wadeable streams throughout the Northern Plains ecoregion. An overview of the WSA survey results for the ecoregion is shown in Figure 32. These results may not be extrapolated to an individual state or stream within the ecoregion because the study design was not intended to characterize stream conditions at these finer scales.

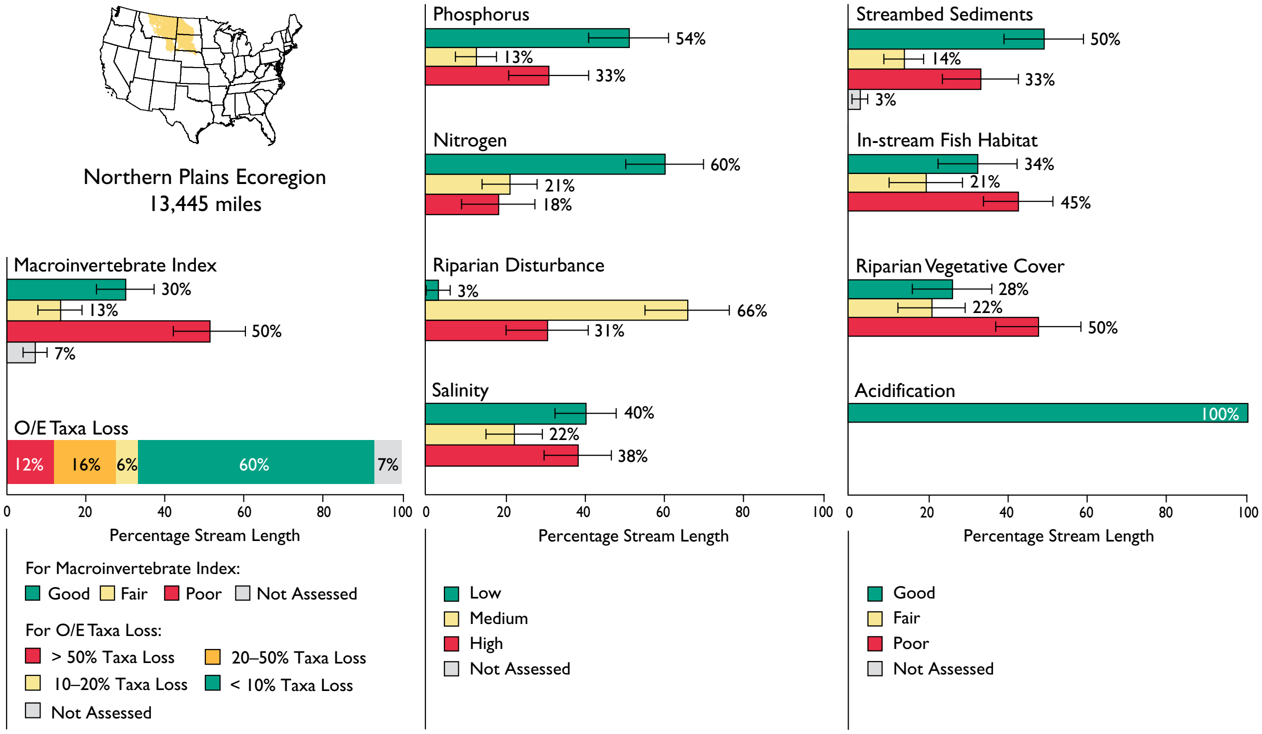


Figure 32. WSA survey results for the Northern Plains ecoregion (U.S. EPA/WSA). Bars show the percentage of stream length within a condition class for a given indicator. Lines with brackets represent the width of the 95% confidence interval around the percent of stream length. Percents may not add up to 100 because of rounding.

During a series of WSA workshops conducted to evaluate assessment results, professional biologists working in the Northern Plains ecoregion said that although the ecoregion has relatively few undisturbed streams, the majority are in areas of low-level agriculture and pastureland.

Biological Condition

- The Macroinvertebrate Index reveals that 50% of stream length in the Northern Plains ecoregion is in poor condition, 13% is in fair condition, and 30% is in good condition compared to least-disturbed reference condition. There are no data for the remaining 7% of stream length.
- The O/E Taxa Loss results show that 34% of stream length has lost 10% or more of the macroinvertebrate taxa expected to occur, and 12% has lost more than 50% of taxa. These results also indicate that 60% of the ecoregion's stream length has retained 90% of the groups or classes of organisms expected to occur based on least-disturbed reference condition.

Indicators of Stress

The most widespread indicators of stress in the Northern Plains ecoregion include riparian vegetative cover, in-stream fish habitat, riparian disturbance, and salinity.

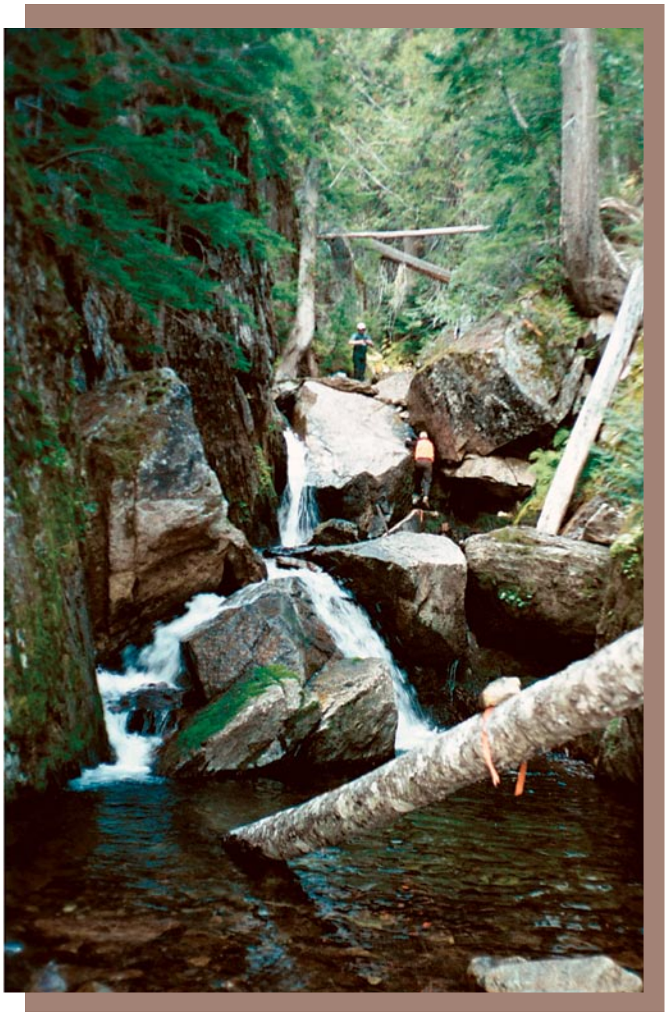
- Thirty-three percent of stream length in the Northern Plains ecoregion has high phosphorus concentrations, 13% has medium phosphorus concentrations, and 54% has low phosphorus concentrations based on least-disturbed reference condition.
- Eighteen percent of the ecoregion's stream length has high nitrogen concentrations, 21% has medium nitrogen concentrations, and 60% has low nitrogen concentrations based on least-disturbed reference condition.
- Riparian disturbance in the Northern Plains ecoregion is at high levels in 31% of stream length, at medium levels in 66% of stream length, and at low levels in 3% of stream length.
- Salinity is a significant stressor in the Northern Plains. Salinity is high in 38% of stream length, medium in 22% of stream length, and low in 40% of stream length.
- Streambed sediments are rated poor in 33% of stream length in the Northern Plains ecoregion, fair in 14%, and good in 50% based on least-disturbed reference condition; data for this indicator were unavailable for 3% of stream length.
- In-stream fish habitat is in poor condition in 45% of stream length, fair in 21% of stream length, and good in 34% of stream length based on least-disturbed reference condition.
- Vegetative cover in the riparian zone along stream banks is in poor condition for 50% of stream length, in fair condition for 22% of stream length, and in good condition for 28% of stream length.
- The effects of acidification are not noted for the Northern Plains ecoregion.

Western Mountains Ecoregion

Physical Setting

The Western Mountains ecoregion includes the Cascade, Sierra Nevada, and Pacific Coast ranges in the coastal states; the Gila Mountains in the southwestern states; and the Bitteroot and Rocky mountains in the northern and central mountain states. This ecoregion covers approximately 397,832 mi^2, with about 297,900 mi^2 or 74.8% classified as federal land — the highest proportion of federal property among all the 9 aggregate ecoregions. The terrain of this area is characterized by extensive mountains and plateaus separated by wide valleys and lowlands. Coastal mountains are transected by numerous fjords and glacial valleys, are bordered by coastal plains, and include important estuaries along the ocean margin. Soils are mainly nutrient-poor forest soils. Based on satellite images in the 1992 NLCD, the distribution of land cover in this ecoregion is 59% forested, 19% shrubland, and 13% grassland, with the remaining 9% of the ecoregion comprised of other types of land cover.

The headwaters and upper reaches of the Columbia, Sacramento, Missouri, and Colorado river systems all occur in this ecoregion. Smaller rivers share many characteristics, starting as steep mountain streams with staircase-like channels and steps and plunge pools, with riffles and pools appearing as slope decreases. Upper river reaches experience debris flows and landslides when shallow soils become saturated by rainfall or snowmelt. The total stream length represented in the WSA for the Western Mountains ecoregion is 126,436 wadeable stream miles.



Unnamed tributary to Lake Creek, Chelan County, WA, in the Western Mountains ecoregion (Photo courtesy of the Washington Department of Ecology).

The climate is sub-arid to arid and mild in southern lower valleys, and humid and cold at higher elevations. The wettest climates of North America occur in the marine coastal rain forests of this ecoregion. Mean annual temperatures range from 32 to 55 °F, and annual precipitation ranges from 16 to 240 inches.

Biological Setting

Rivers in this ecoregion drain dense forested catchments and contain large amounts of woody debris that provide habitat diversity and stability. Rivers reaching the Pacific Ocean historically had large runs of salmon and trout, including pink, chum, sockeye, coho, and chinook salmon, as well as cutthroat and steelhead trout. Many of these anadromous fish populations have been reduced since the time of European settlement due to the effects of overfishing, introduced species, flow regulations, and dams. Spawning habitats in stream pools have been drastically reduced due to increased sediments from logging, mining, and other land use changes.

Human Influence

Deforestation and urbanization continue to alter stream habitats in the mountainous west. The Western Mountains riparian ecosystems first encountered pressure from grazing and mining from the mid-1800s to about 1910 and then from the logging roads and fire management practices that occur to the present day.

Placer mining, which disrupts stream sediment habitats, was once widespread in the Western Mountains ecoregion. Particularly damaging in mountainous areas was the introduction of mercury, which was used extensively in placer mining for gold. Toxic contaminants from mining also include arsenic, antimony, copper, chromium, cadmium, nickel, lead, selenium, silver, and zinc. In addition to mining, other activities such as logging, grazing, channelization, dams, and diversions in the Sierra Nevada area also significantly impacted rivers and streams. Introduced fish provided further stress, with several native fish species threatened or endangered.

The principal economic activities in this ecoregion are high-tech manufacturing, wood processing, international shipping, U.S. naval operations, commercial fishing, tourism, grazing, and timber harvesting. Hydroelectric power generation is prevalent in the Pacific Northwest area and California. Bauxite mining also occurs in the Pacific Northwest portions of the ecoregion. There are currently 74 active, 7 proposed, and 22 deleted EPA Superfund National Priority List sites in the Western Mountains ecoregion.

The approximate population in the Western Mountains ecoregion is 9,742,192, representing approximately 3% of the population of the United States.

Summary of WSA Findings

A total of 529 random sites were sampled during the summers of 2000–2004 to characterize the condition of wadeable streams throughout the Western Mountains ecoregion. This ecoregion had the greatest number of sample sites because all the western states enhanced the scale of the national survey by including additional random sites. Although there are enough sites to develop state-scale estimates of condition, this report did not produce those estimates. The individual states are analyzing the survey results in the context of their own water quality standards and assessment methodologies. An overview of the WSA survey results for the Western Mountains ecoregion is shown in Figure 33. These results may not be extrapolated to an individual state or stream within the ecoregion.

During a series of WSA workshops conducted to evaluate assessment results, professional biologists working in the Western Mountains ecoregion said that many least-disturbed streams in the ecoregion are of relatively high quality; however, some of these streams have mining and logging impacts, leading to reference conditions of varying degrees of quality.

Biological Condition

- The Macroinvertebrate Index reveals that 25% of stream length in the Western Mountains ecoregion is in poor condition, 28% is in fair condition, and 46% is in good condition compared to least-disturbed reference condition. There are no data for about 1% of stream length.
- The O/E Taxa Loss results show that 33% of stream length has lost 10% or more of the macroinvertebrate taxa expected to occur, and 5% has lost more than 50% of taxa. These results indicate that 63% of stream length has retained 90% of the groups or classes of organisms expected to occur based on least-disturbed reference condition.

Indicators of Stress

The most widespread indicators of stress in the Western Mountains ecoregion include total nitrogen, total phosphorus, riparian disturbance, and streambed sediments.

- Sixteen percent of stream length in the Western Mountains ecoregion has high phosphorus concentrations, 25% has medium phosphorus concentrations, and 59% has low phosphorus concentrations based on least-disturbed reference condition.

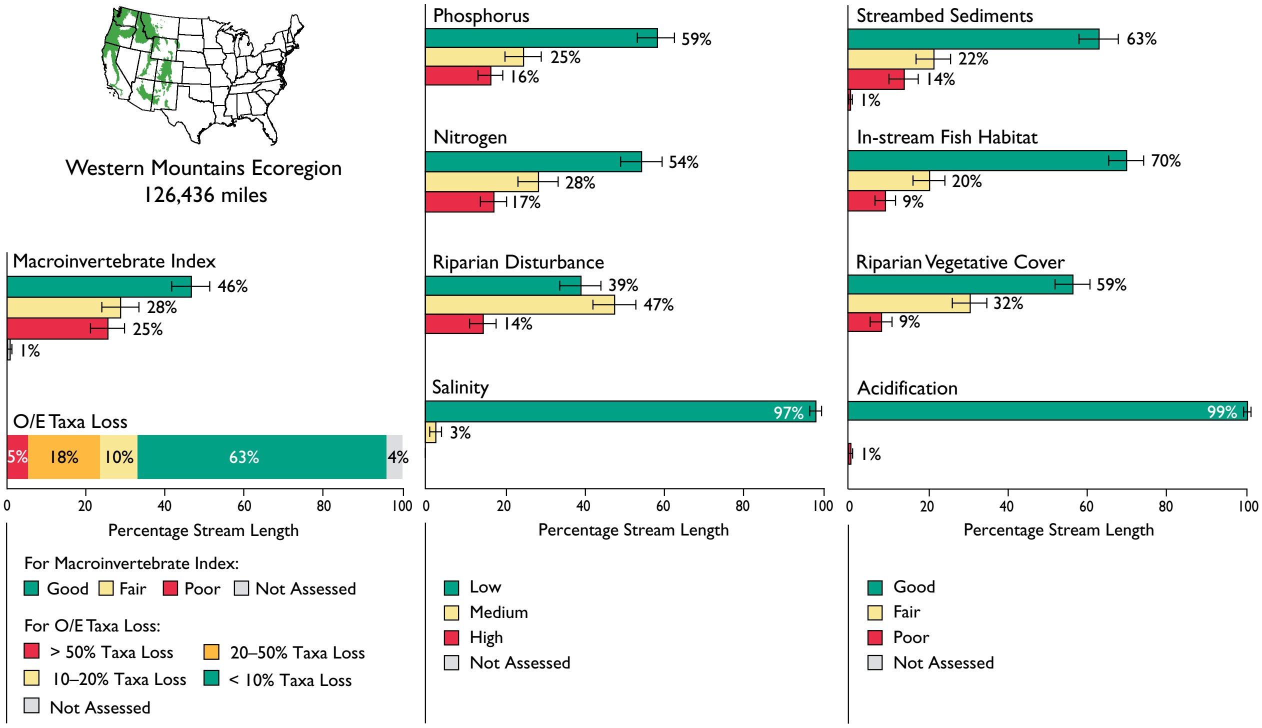
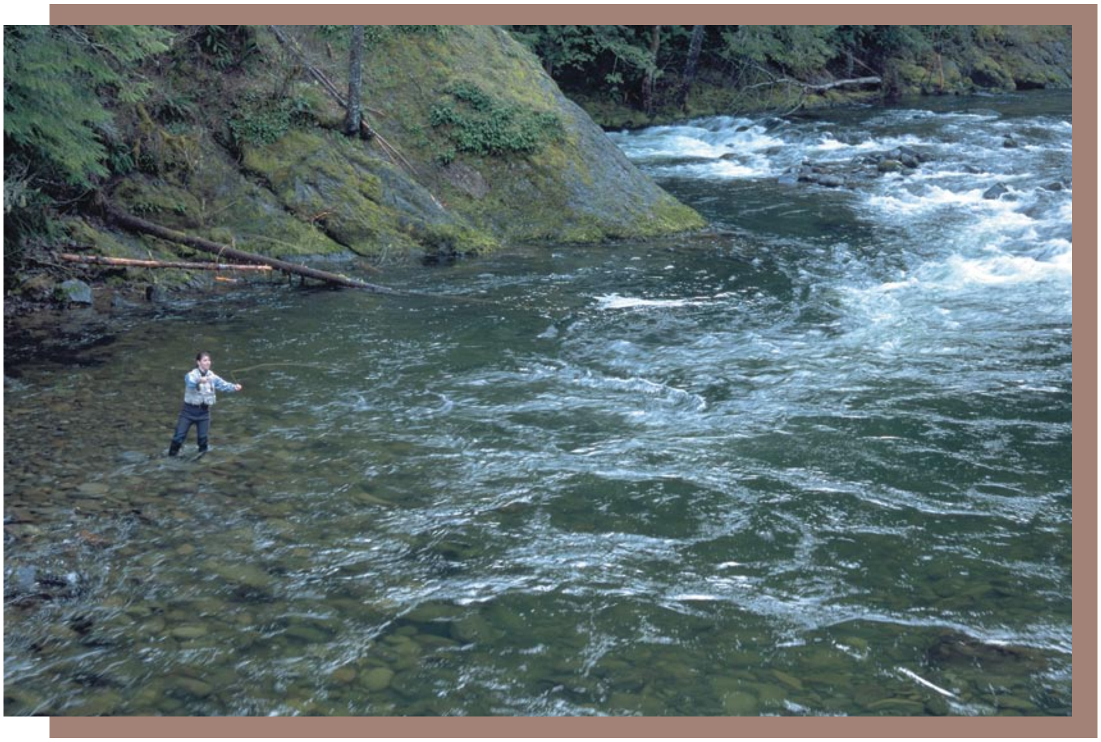


Figure 33. WSA survey results for the Western Mountains ecoregion (U.S. EPA/WSA). Bars show the percentage of stream length within a condition class for a given indicator. Lines with brackets represent the width of the 95% confidence interval around the percent of stream length. Percents may not add up to 100 because of rounding.

- Seventeen percent of the ecoregion's stream length has high nitrogen concentrations, 28% has medium nitrogen concentrations, and 54% has low nitrogen concentrations based on least-disturbed reference condition.
- Riparian disturbance, or evidence of human influence in the riparian zone, is at high levels in 14% of stream length, at medium levels in 47% of stream length, and at low levels in 39% of stream length.
- Levels of salinity are medium in 3% of stream length and low in 97% of stream length. None of the stream length for the Western Mountains ecoregion had high levels of salinity.
- Streambed sediments are rated poor in 14% of stream length in this ecoregion, fair in 22%, and good in the remaining 63%.
- In-stream fish habitat is in poor condition in 9% of stream length, fair in 20% of stream length, and good in 70% of stream length.
- Vegetative cover in the riparian zone along stream banks is in poor condition for 9% of stream length, in fair condition for 32% of stream length, and in good condition for 59% of steam length.
- Acidification is rated poor in nearly 1% of stream length and good in 99% of stream length.



Fishing and tourism are important economic activities in the Western Mountains ecoregion (Photo courtesy of Ron Nichols, U.S. Department of Agriculture National Resources Conservation Service).

Xeric Ecoregion

Physical Setting

The Xeric ecoregion covers the largest area of all WSA aggregate ecoregions and includes the most total land under federal ownership. This ecoregion covers portions of eleven western states and all of Nevada for a total of about 636,583 mi^2 (21.2% of the United States). Some 453,000 mi^2 or 71.2% of the land is classified as federal lands, including large tracts of public land, such as the Grand Canyon National Park, Big Bend National Park, and the Hanford Nuclear Reservation. Tribal lands include the Navajo, Hopi, and Yakima reservations. Based on satellite images in the 1992 NLCD, the distribution of land cover in this ecoregion is 61% shrubland and 15% grassland, with the remaining 24% of the ecoregion comprised of other types of land cover.

The Xeric ecoregion is comprised of a mix of physiographic features, including plains with hills and low mountains, high-relief tablelands, piedmont, high mountains, and intermountain basins and valleys. The ecoregion includes the flat to rolling topography of the Columbia/Snake River Plateau; the Great Basin; Death Valley; and the canyons, cliffs, buttes, and mesas of the Colorado Plateau. All of the non-mountainous area of California falls in the Xeric ecoregion and is distinguished by a mild Mediterranean climate, agriculturally productive valleys, and large metropolitan areas.

This ecoregion's relatively limited surface water supply contributes to the Upper and Lower Colorado, Great Basin, California, Rio Grande, and Pacific Northwest regional watersheds. Large rivers flow all year, are supplied by snowmelt,

West Clear Creek, Yavapai County, AZ, in the Xeric ecoregion
(Photo courtesy of the Arizona Game and Fish Department/USGS).

and peak in early summer. Small rivers in this ecoregion are mostly ephemeral. Most rivers are turbid because they drain erodable sedimentary rock in a dry climate, where sudden rains flush sediments down small rivers. Rivers are often subject to rapid change due to flash floods and debris flows. In southern areas, dry conditions and water withdrawals produce internal drainages that end in saline lakes or desert basins without reaching the ocean (e.g., Utah's Great Salt Lake). The total stream length represented in the WSA for the Xeric ecoregion is 25,989 wadeable stream miles.

The Xeric ecoregion's climate varies widely from warm and dry to temperate, with mean annual temperatures ranging from 32 to 75 °F and annual precipitation in the 2- to 40-inch range. The dry weather in the Sonoran, Mojave, and Chihuahuan deserts is created by the rain shadows cast by the mountains to the west and is punctuated by heavy, isolated episodic rainfalls.

Biological Setting

Rivers create a riparian habitat oasis for plants and animals in the dry Xeric ecoregion areas. Many fish are endemic, are restricted to the Colorado River basin, and have evolved to cope with warm, turbid waters. Examples include the humpback chub, bonytail chub, Colorado pikeminnow, roundtail chub, razorback sucker, Colorado squawfish, Pyramid Lake cui-ui, and Lahontan cutthroat trout. Most of these fish are threatened or endangered as a result of flow regulations from dams, water withdrawals, and introduced non-native species. Threatened species of fish in desert areas include the Sonora chub and beautiful shiner.

Human Influence

Impacts to the Xeric ecoregion riparian habitats have been heavy in the past 250 years because of water impoundment and diversion; groundwater and surface water extraction; grazing and agriculture; and mining, road development, and heavy recreational demand. Both the least-altered and most-altered pre-settlement natural vegetation types are found in this ecoregion. Riparian habitats in this ecoregion have also been widely impacted by invasive species and contamination from agriculture and urban runoff. Big rivers in the southwestern canyon regions were altered due to large dam construction and large-scale water-removal projects for cities and agriculture, with attendant small streams that experience cycles of draining and filling in response to grazing, groundwater withdrawal, and urbanization. In many desert areas, dissolved solids such as boron, molybdenum, and organophosphates leach from desert soils into irrigation waters. Almost every tributary in California's Central Valley has been altered by canals, drains, and other waterways.

Principal economic activities include recreation and tourism; mining; agriculture; grazing; manufacturing and service industries; agriculture and food processing; aerospace and defense industries; and automotive-related industries. Petroleum production is prevalent in California. Agriculture includes production of a wide range of crops, from wheat, dry peas, lentils, and potatoes to grapes and cotton. Large agricultural irrigation projects include the Salt and Gila valleys and the Imperial and Central valleys in California. There are currently 139 active, 6 proposed, and 24 deleted EPA Superfund National Priority List sites in this ecoregion.

The total population in the Xeric ecoregion is the third largest of all WSA ecoregions at approximately 46,800,000 people, or 16% of the population of the United States.

Summary of WSA Findings

A total of 176 random sites were sampled during the summers of 2000–2004 to characterize the condition of wadeable streams throughout the Xeric ecoregion. An overview of the WSA survey results for the Xeric ecoregion is shown in Figure 34. These results may not be extrapolated to an individual state or stream within the ecoregion.

During a series of WSA workshops conducted to evaluate assessment results, professional biologists working in the Xeric ecoregion said that many of the perennial, least-disturbed streams in this ecoregion have been influenced by past and current human activities.

Biological Condition

- The Macroinvertebrate Index reveals that 39% of stream length in the Xeric ecoregion is in poor condition compared to least-disturbed reference condition, 15% is in fair condition, and 42% is in good condition. There are no data for about 4% of stream length.
- The O/E Taxa Loss results show that 60% of stream length in the Xeric ecoregion has lost 10% or more of the macroinvertebrate taxa expected to occur and 15% has lost more than 50% of taxa. These results also indicate that 34% of stream length has retained 90% of the groups or classes of organisms expected to occur based on least-disturbed reference condition.

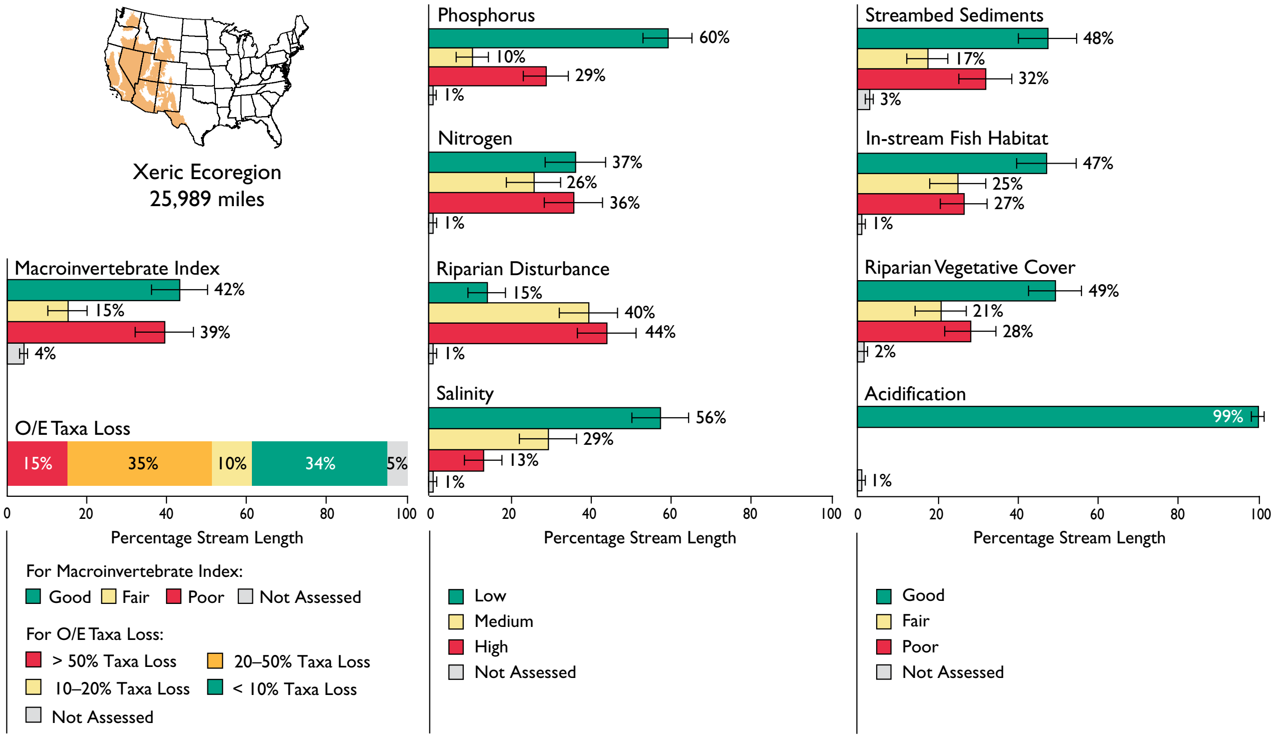


Figure 34. WSA survey results for the Xeric ecoregion (U.S. EPA/WSA). Bars show the percentage of stream length within a condition class for a given indicator. Lines with brackets represent the width of the 95% confidence interval around the percent of stream length. Percents may not add up to 100 because of rounding.

Indicators of Stress

The leading indicators of stress in the Xeric ecoregion include riparian disturbance, total nitrogen, streambed sediments, and in-stream fish habitat.

- Twenty-nine percent of stream length in the Xeric ecoregion has high phosphorus concentrations, 10% has medium phosphorus concentrations, and 60% has low phosphorus concentrations based on least-disturbed reference condition.
- Nitrogen is the leading chemical stressor in the Xeric region. Approximately 36% of stream length has high nitrogen concentrations, 26% has medium nitrogen concentrations, and 37% has low nitrogen concentrations based on least-disturbed reference condition.
- Riparian disturbance, or evidence of human influence in the riparian zone, is the leading physical stressor for the Xeric ecoregion. Riparian disturbance in this ecoregion is at high levels in 44% of stream length, at medium levels in 40% of stream length, and at low levels in 15% of stream length.
- Salinity is rated high in 13% of stream length and medium in 29%, with 56% of stream length showing low levels of this indicator. Data for this indicator were unavailable for approximately 1% of stream length.
- Streambed sediments are rated poor in 32% of stream length in the Xeric ecoregion, fair in 17%, and good in 48%; data on this indicator were unavailable for 3% of stream length.
- In-stream habitat is in poor condition in 27% of stream length, fair in 25%, and good in 47% based on least-disturbed reference condition; data were unavailable for 1% of stream length.
- Vegetative cover in the riparian zone along stream banks is in poor condition in 28% of stream length, in fair condition in 21% of stream length, and in good condition in 49% of stream length.
- The effects of acidification are not noted for the Xeric ecoregion.

The Xeric ecoregion is comprised of a mix of physiographic features, including plains with hills and low mountains, high-relief tablelands, piedmont, high mountains, and intermountain basins and valleys (Photo courtesy of Tim McCabe, U.S. Department of Agricultural Natural Resources Conservation Service).

Chapter 4

Photo courtesy of Jeffrey Cole

Summary and Next Steps

Summary and Next Steps

Summary

The United States covers an enormous and diverse landscape, and not surprisingly, the biological condition of the nation's streams varies widely geographically. Overall, 42% percent of the nation's stream length is in poor biological condition compared to least-disturbed reference condition in each of the WSA ecoregions. The Eastern Highlands region has the largest proportion of streams in poor biological condition (52%), whereas the West has the lowest proportion (27%). In the Plains and Lowlands region, 40% of stream length is in poor biological condition.

Stream miles, represented as stream length, are not evenly distributed across the country. The densest coverage of perennial streams in the lower 48 states is in the Eastern Highlands region, which has approximately 276,362 miles of perennial streams and the smallest land area of the three major regions. The Plains and Lowlands region, which covers the largest portion of the United States, has 242,264 miles of perennial streams. The West has 152,425 miles of streams. It is important to evaluate the survey results in terms of both stream length percentages and absolute stream miles in each condition class. For example, the percentage of stream length in good condition varies dramatically between the West (45%) and Plains and Lowlands regions (29%); however, if these percentages are converted to stream miles, the West has 68,672 miles in good condition, whereas the Plains and Lowlands region has 70,257 miles in good condition.

The WSA finds that the most widespread or common stressors are elevated levels of the nutrients nitrogen and phosphorus, riparian disturbance, and excess streambed sediments. Nationally, 32% of stream length (213,394 miles) has high concentrations of nitrogen compared to least-disturbed reference conditions, and 31% (207,355 miles) has high concentrations of phosphorus. Twenty-six percent of the nation's stream length (171,118 miles) has high levels of riparian disturbance (e.g., human influence along the riparian zone), and 25% (167,092 miles) has streambed sediment characteristics in poor condition. Analysis of the association between stressors and biological condition finds that high levels of nutrients and excess streambed sedimentation more than double the risk of poor biological condition.

The WSA provides the first nationally consistent baseline of the condition of the nation's streams. This baseline will be used in future assessments to evaluate changes in conditions and to provide insights as to the effectiveness of water resource management actions. *Highlight: Acidification Trends and the Clean Air Act* illustrates how this type of survey can be used to evaluate the effectiveness of management actions on improving water quality. States, EPA, and other partners plan to use this approach to implement large-scale assessments of lakes in 2007 and similar assessments of rivers, wetlands, and coastal waters in future years.

Highlight

Acidification Trends and the Clean Air Act

Although this WSA provides a snapshot of the current conditions in the nation's streams, future surveys will allow us to detect trends in stream conditions and in the stressors that affect them. One example in which probability-based survey designs were implemented repeatedly over the course of 10 years has been the evaluation of the responsiveness of acid-sensitive lakes and streams to changes in policy and management actions. Title IV of the 1990 Clean Air Act Amendments (CAAA) set target reductions for sulfur and nitrogen emissions from industrial sources as a means of reducing the acidity in deposition. One of the intended effects of the reductions was to decrease the acidity of low-alkalinity waters. A 2003 EPA report by Stoddard et al., assessed recent changes in surface water chemistry in the northern and eastern United States to evaluate the effectiveness of the CAAA. At the core of the monitoring, known as the Temporally Integrated Monitoring of Ecosystems (TIME) project, was the concept of a probability survey, where a set of sampling sites was chosen to be statistically representative of a target population. In the Northeast (New England and Adirondacks), this target population consists of lakes likely to be responsive to changes in rates of acidic deposition. In the Mid-Atlantic, the target population is upland streams with a high probability of responding to changes in acidic deposition. Repeated surveys of this population allowed an assessment of trends and changes in the number of acidic systems during the past decade. The trends reported in the following table are for recovery from chronic acidification. The analysis found that during the 1990s, the amount of acidic waters in the target population declined. The number of acidic lakes in the Adirondacks dropped by 38%, and the number of acidic lakes in New England dropped by 2%. The length of acidic streams declined by 28% in the Mid-Atlantic area.

Estimates of change in number and proportion of acidic surface waters in acid-sensitive regions of the northern and eastern United States. Estimates are based on applying current rates of change in Gran ANC[a] to past estimates of population characteristics from probability surveys.

Region	Number of Lakes	Number Acidic[b]	% Acidic[c]	Time Period of Estimate	Current Rate of ANC Change[d]	Estimated Number Currently Acidic[e]	Current % Acidic	% Change in Number of Acidic Systems
New England	6,834 lakes	386 lakes	5.6%	1991–1994	+0.3	374 lakes	5.5%	-2%
Adirondacks	1,830 lakes	238 lakes	13.0%	1991–1994	+0.8	149 lakes	8.1%	-38%
Mid-Atlantic	42,426 km	5,014 km	11.8%	1993–1994	+0.7	3,600 km	8.5%	-28%

[a] For both Northeast lakes and Mid-Atlantic streams, waterbodies with ANC (using the analytical technique of Gran titration, with the result known as "Gran ANC") of < 100 µeq/L are particularly vulnerable.
[b] Number of lakes/streams with Gran ANC < 0 in past probability survey (data collected at "Time Period of Estimate" in column 5).
[c] Percent of population (from Column 2) with Gran ANC < 0 in past probability survey (data collected at "Time Period of Estimate" in column 5).
[d] Based on regional trends in µeq/L/year.
[e] Based on trends from repeated surveys through 2001.

Next Steps

In addition to characterizing the biological condition of the nation's stream resources, the WSA provides a rich data set that has sparked interest in many additional areas of investigation. These include the following:

- **Support Protection and Restoration Actions** – The WSA finds that between 25 and 32% of stream length is rated poor due to high levels of nutrients or excess streambed sedimentation. These streams are two times more likely to score poor for biological condition than streams with low levels of these parameters. This national-scale finding reinforces reports from states and the USGS on specific watersheds and stream segments that identify nutrients and streambed sedimentation as leading water quality stressors. EPA is pursuing opportunities to use the WSA data in combination with other data to inform decision-makers responsible for water resource protection and restoration actions. Specific actions in the short term include analyzing the WSA dataset to determine associations between watershed characteristics (e.g., size, slope, and soil type) to help target where improvements are needed; using these characteristics in conjunction with information on the effectiveness of best management practices (BMPs) to help identify successful non-point source pollution controls; and supporting states' development of water quality standards for nutrients and sediments.
- **Future Designs** – It is clear that future surveys will continue to be based on sample survey designs and that the detection of changes and trends will be of greater interest; therefore, future survey designs will include provision for estimating both current status and future trends. This will require a determination of the number of sites that are revisited versus new sites. Current analyses of variance components suggest that in future surveys, a substantial percentage of the sites (possibly 20–50%) should be replaced with new sites and that this replacement should continue with each new survey. This replacement will help detect change; incorporating new sites will improve future status assessments and reduce the likelihood that bias will be introduced by repeated sampling of the same locations. As individual states and tribes begin adopting sample survey designs into their programs, the results from their efforts can be incorporated into the national assessments.
- **Indicators** – This initial assessment was unable to incorporate a large set of biological and stressor indicators because of a short planning timeline. In future national stream surveys, the WSA will consider including fish assemblages, algal assemblages (e.g., periphyton in streams), fish tissue contamination by metals and organics, and/or sediment contamination assessed through either sediment metal and organic chemistry or sediment toxicity tests. It will also be possible to add emerging stressor indicators of concern. This will allow for a more comprehensive assessment of both the conditions in wadeable streams and the stressors potentially affecting them.
- **Field Protocols** – The field protocols used for the WSA are widely used and were well tested across the country. These protocols have demonstrated a strong ability to detect environmental signals against the background

of natural variability. For this initial assessment of wadeable streams, using the same protocols across the country reduced the complexity of interpreting the results; however, for future national stream surveys, the use of different yet comparable methods will be evaluated for different types of streams (e.g., low gradient vs. high gradient). EPA and the states will also explore integrating and sharing data from multiple sources, as well as options to improve sample collection methods.

- **Reference Conditions** – Stream ecologists and state and federal managers agree that they should be able to describe least-disturbed reference condition at a more refined spatial scale than that of the nine regions presented in the WSA. To do so will require substantial coordinated efforts among state, tribal, and federal partners. There are also likely to be some regions of the country in which land-use changes have been so dramatic that even the "best" streams may have experienced substantial chemical, physical, and biological degradation. Additional research will be required to provide a better solution to setting expected conditions for those regions of the country.
- **Stressor Ranking** – The presentation on stressors in the WSA showed both their extent (i.e., the percent of stream length with excessive levels of the stressors) and relative risk (i.e., the increased chance of finding poor biological condition). To make the best use of this information, the WSA must look for stressors that have both high relative risk and large extent. The human health assessment community combines these two sets of information into a single number called the "population attributable relative risk." If, during investigation, this summary number proves reliable for ecological studies, it will simplify the ranking of stressors in future assessments. However, use of more than one biological assemblage in future assessments will result in multiple relative risk values, one for each biological indicator. It would

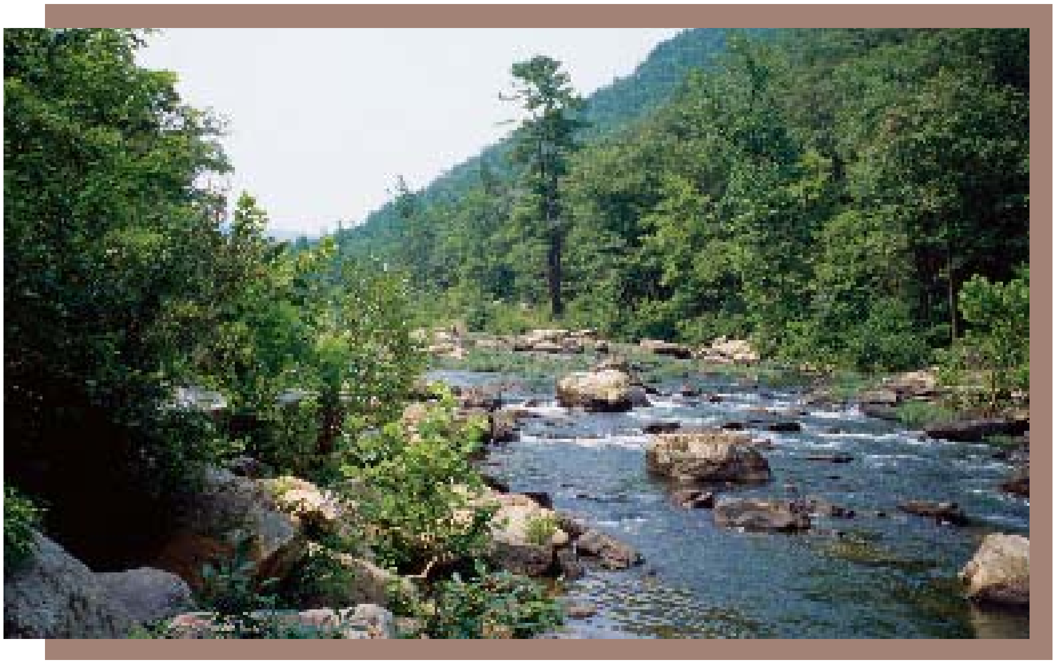


Photo courtesy of Michael L. Smith, FWS

not be surprising if EPA and its partners find that the relative risk posed by each stressor depends on the biological community being evaluated. Although these added numbers may complicate the ranking of stressors, they will also aid in understanding which component of the stream biota is sensitive to each stressor and will provide additional options for management.

- **Future National Assessments** – EPA and its state, tribal, and federal partners will produce national assessments of waterbody types on a yearly cycle. For lakes and reservoirs, a field survey will occur in 2007 with a national assessment report of the results in 2009. Rivers will be surveyed in 2008, and a national assessment report will follow in 2010. Wadeable streams will be surveyed again in 2009, and the assessment report that follows in 2011 will include all flowing waters – both rivers and streams. That report will also evaluate any changes in biological condition that occurred in streams. An NCCR assessment will be repeated in 2012, with the results of the field survey from 2010. Wetlands will be surveyed during the 2011 sampling season, followed by a national assessment report in 2013. From that point on, the surveys and national assessment reports will be repeated in sequence, with changes and trends becoming a greater focus for each resource survey.

The continued utility of these national surveys and their assessment reports requires continued consistency in design, as well as in field, lab, and assessment methods from assessment to assessment; however, the surveys must also provide flexibility that allows the science of monitoring to improve over time. Maintaining consistency while allowing flexibility and growth will be one of the many challenges facing the national assessment program in coming years.

This national survey would not have been possible without the involvement of hundreds of dedicated scientists working for state, tribal, and federal agencies and universities across the United States. Future surveys will rely on this continued close collaboration, a free exchange of knowledge, and a deep well of energy and enthusiasm. It is EPA's goal that participants translate the expertise they gained through these national surveys to studies of their own waters and use this substantial and growing baseline of information to evaluate the success of efforts to protect and restore the quality of the nation's waters.

Photo courtesy of National Park Service

Glossary of Terms

Benthic macroinvertebrates: Aquatic larval stages of insects such as dragonflies; aquatic insects such as aquatic beetles; crustaceans such as crayfish; worms; and mollusks. These small creatures live throughout the stream bed attached to rocks, vegetation, and logs and sticks or burrowed into stream bottoms.

Biological assemblages: Key groups of animals and plants—such as benthic macroinvertebrates, fish, or algae—that are studied to learn more about the condition of water resources.

Biological integrity: State of being capable of supporting and maintaining a balanced community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitat of the region.

Ecoregions: Ecological regions that are similar in climate, vegetation, soil type, and geology; water resources within a particular ecoregion have similar natural characteristics and similar responses to stressors.

In-stream fish habitat: Areas fish need for concealment and feeding. These areas include large wood within the stream banks, boulders, undercut banks, and tree roots.

Intermittent (ephemeral) streams: Streams that flow only during part of the year, such as in the spring and early summer after snowmelt.

Macroinvertebrate Index of Biotic Condition: The sum of a number of individual measures of biological condition, such as the number of taxa in a sample, the number of taxa with different habits and feeding strategies, etc.

National Hydrography Dataset: Comprehensive set of digital spatial data—based on U.S. Geological Survey 1:100,000 scale topographic maps—that contains information on surface water features such as streams, rivers, lakes, and ponds.

Nutrients: Substances such as nitrogen and phosphorus that are essential to life but can overstimulate the growth of algae and other plants in water. Excess nutrients in streams and lakes can come from agricultural and urban runoff, leaking septic systems, sewage discharges, and similar sources.

O/E (Observed/Expected) Ratio of Taxa Loss: A ratio comparing the number of taxa expected (E) to exist at a site to the number that are actually observed (O). The taxa expected at individual sites are based on models developed from data collected at reference sites.

Perennial streams: Streams that flow continuously throughout the year.

Physical habitat: For streams and rivers, the area in and around the stream or river, including its bed, banks, in-stream and overhanging vegetation, and riparian zone.

Probability-based design: A type of random sampling technique in which every element of the population has a known probability of being selected for sampling.

Reach: A discrete segment of a stream.

Reference condition: The least-disturbed condition available in an ecological region; determined based on specific criteria and used as a benchmark for comparison with other sample sites in the region.

Riparian: Pertaining to a stream or river and its adjacent area.

Riparian disturbance: A measure of the evidence of human activities in and alongside streams, such as dams, roadways, pastureland, and trash.

Riparian vegetative cover: Vegetation corridor alongside streams and rivers. Intact riparian vegetative cover reduces pollution runoff, prevents streambank erosion, and provides shade, lower temperatures, food, and habitat for fish and other aquatic organisms.

Stream order: Stream size, based on the confluence of one stream with another. First-order streams are the origin or headwaters. The confluence or joining of two 1st-order streams forms a 2nd-order stream, the confluence of two 2nd-order streams forms a 3rd-order stream, and so on.

Streambed sediments: Fine sediments and silt on the streambed. In excess quantities, they can fill in the habitat spaces between stream pebbles, cobbles, and boulders and suffocate macroinvertebrates and fish eggs.

Stressors: Factors that adversely effect—and therefore degrade—aquatic ecosystems. Stressors may be chemical (e.g., excess nutrients), physical (e.g., excess sediments on the streambed), or biological (e.g., competing invasive species).

Taxa: Plural of taxon; groupings of living organisms, such as phylum, class, order, family, genus, or species. Scientists organize organisms into taxa in order to better identify and understand them.

Transect: A path or line along which one counts and studies various aspects of a stream, river, or other study area.

Wadeable streams: Streams that are small and shallow enough to adequately sample by wading, without a boat.

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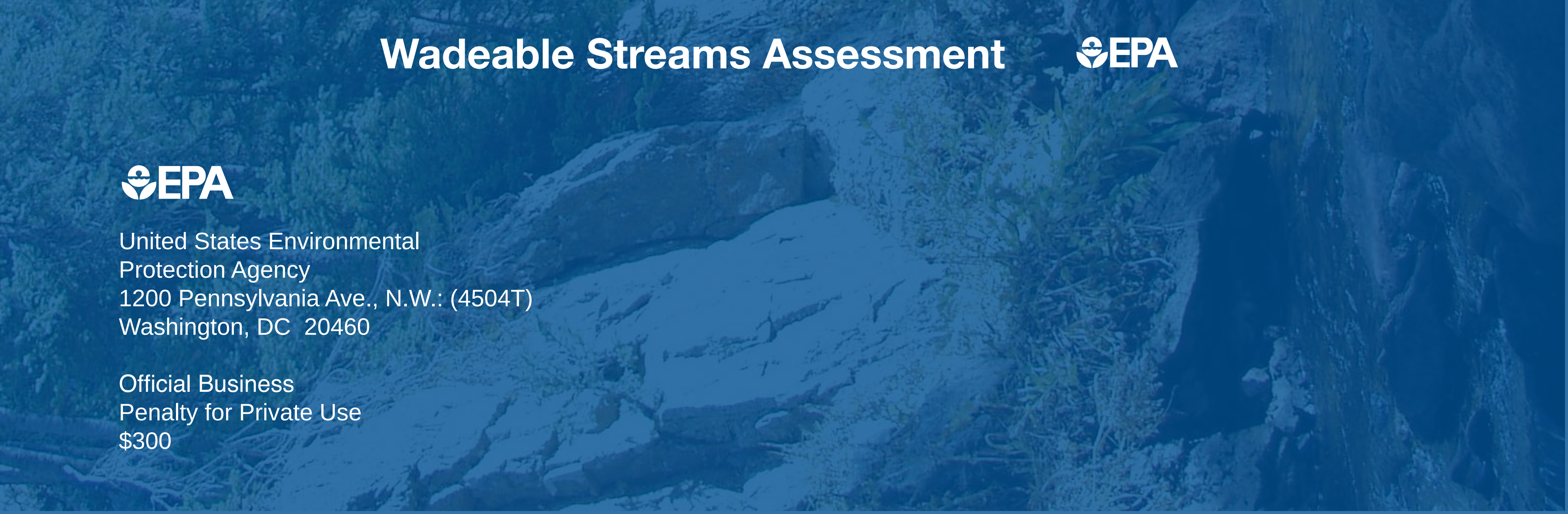

Wadeable Streams Assessment

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