

# Chapter 1.0 Introduction

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## 1.1 Purpose of the Document

The target readership of this document is primarily program managers and technical staff involved in the development and implementation of biological monitoring programs for non-wadeable streams and rivers. The document is intended to assist users in establishing or refining protocols, including the specific methods related to field sampling; laboratory sample processing; taxonomy; data entry, management, and analysis; and final assessment and reporting. It also reviews and provides information on development of monitoring designs to address certain types of environmental questions, and approaches for documenting and reporting data quality and performance characteristics for large river biological monitoring. The approaches presented are not intended to replace existing program components but may in some cases be useful for refining them. Throughout the document, “large rivers” is used as short-form for “non-wadeable streams and rivers,” which are defined as lotic systems more effectively and safely sampled with boat-based field methods than with wading techniques.

The principal purposes of this document are to:

- Serve as a framework for the development of bioassessment programs and biocriteria for large rivers, as needed by water quality management agencies for establishing Water Quality Standards (WQS), determining attainment or nonattainment of designated uses, evaluating effectiveness of mitigation or restoration activities, and to contribute to the Total Maximum Daily Load (TMDL) process;
- Provide information that can be used to enhance existing river assessment programs, including elevation of the scientific/technical foundation;
- Provide the essential technical elements for routine biological monitoring and assessment programs;
- Foster clear communication among agencies and other entities for mainstem rivers crossing jurisdictional boundaries; and
- Describe how assessment procedures and strategies can be tailored for different types of rivers.

## 1.2 Transitioning from Streams to Rivers

Streams and smaller rivers that are considered “wadeable” (Section 1.2.3) are abundant in terms of number and total length, and relatively easy to sample compared to large rivers. As a result, efforts to develop appropriate sampling protocols for the bioassessment of lotic ecosystems have been focused primarily on smaller systems (e.g., Barbour et al. 1999). As these methods become increasingly refined and accepted, a growing number of government agencies are developing sampling protocols for large rivers (Humphries et al. 1998). Realizing that this may be a relatively new area of responsibility for many, a brief overview of key ecological concepts relating to the topic is warranted.

### ***1.2.1 Key Ecological Concepts About Large Rivers***

Scientific knowledge of river ecosystems has expanded greatly over the last three decades (e.g., Johnson et al. 1995, Lorenz et al. 1997, Ward 1998, Tockner and Stanford 2002). However, there remains a need to test current assumptions with data. The following concepts of river ecosystem structures, functions, and controlling factors are generally well-accepted today by river ecologists. Future monitoring of our Nation's large rivers will probably support many of these assumptions, while some may prove incomplete. In any event, ongoing and upcoming work will provide an opportunity to develop a better understanding of this class of ecosystems.

The ecological condition of large rivers is affected by drivers (e.g., climate, geology) and stressors that exist at multiple spatial scales (Frissell et al. 1986, Lubinski 1993, Naiman 1998, Ward et al. 2001, Wiens 2002). Drivers that operate at larger spatial scales tend to exert their control over longer temporal scales and cycles (Naiman 1998, Poff and Ward 1990). Within a basin, as rivers increase in size in the downstream direction, predictable gradients occur in the forces that shape the river, control the substrate, and provide organic material (Huet 1959, Vannote et al. 1980). In response to these natural forces, rivers are ever changing as they advance downstream (Ward 1998, Fausch et al. 2002).

Rivers tend to be located at lower elevations than smaller streams within the same basin. They also often have shallower elevation gradients, trap more sediment, and have longer retention times than their upstream tributaries. These conditions, with the exception of localized areas where the channel is constricted, generally result in substrates dominated by finer particles.

Under natural conditions, river discharge increases with downstream distance. The predictability of the flow regime of a large river is typically greater than that of its smaller, flashier tributaries (Johnson et al. 1995). Under natural conditions, the primary sources of energy in a large river (i.e., detritus, fine particulate organic material, and attached bacteria) are usually allochthonous (i.e., carried downstream by tributaries), except where water clarity allows development of substantial plant biomass. The River Continuum Concept (Vannote et al. 1980) holds that local photosynthesis in large rivers is limited by turbidity. However, the presence of dams, floodplains with large backwaters, or large amounts of woody debris in a large river reach can reset energy processes to conditions more like those that occur in moderate-sized streams (Ward and Stanford 1983, Junk et al. 1989, Thorp and DeLong 1994, Bayley 1995). Under these conditions, autochthonous (instream) energy production through photosynthesis and invertebrate production each increase.

Large rivers frequently exhibit distinctive reach or microhabitat characteristics that are attractive to individual or groups of species (Stalnaker et al. 1989, Montgomery and Buffington 1998, Ward 1998). Reach distinctions frequently are reflected in different riparian vegetative patterns, community types, and habitat (Lubinski 1993). Microhabitat associations are often observed during specific life history stages, seasons, or discharge ranges. An especially important characteristic of large rivers is that conditions in their microhabitats change widely with river discharge (Reash 1999). Population changes in response to year-to-year variations in discharge are considered to be an important contributor to riverine biodiversity (Galat et al. 1998, Knutson and Klass 1998).

The flora and fauna of large rivers are adapted to and controlled in large part by these physical, chemical, and hydrologic conditions. It is important to note, however, that large-scale distribution patterns of many species, both terrestrial and aquatic, still reflect zoogeographic patterns established by land-forming processes (e.g., glaciation) that occurred many thousands of years ago. Large rivers, in the context of either their tributary networks or even broader spatial scales, function as landscape corridors (Lubinski and Theiling 1999). The landscape corridor function of large rivers is of special value to migratory birds and fishes, especially for birds with ranges extending beyond the basin itself.

In large rivers with substantial floodplains, annual flood pulses of allochthonous material from the floodplain have been identified as perhaps the most important hydrologic feature governing year-to-year changes in ecosystem productivity, and possibly biological diversity (Junk et al. 1989, Ward 1989, Welcomme 1985). Over-bank flooding onto floodplains facilitates the lateral exchange of nutrients, organic matter, and organisms between the main channel and associated floodplains (Benke and Meyer 1988, Meyer 1990, Sparks et al. 1990). This in turn increases the biological activity of the river ecosystem (Bayley 1989, Junk et al. 1989, Meyer 1990) and expands the physical habitat available for fishes and aquatic invertebrates (Welcomme 1989). During periods of floodplain inundation, fish forage mainly on terrestrial organisms (Reimer 1991). Some organisms (e.g., burrowing crayfish, [Crustacea:Decapoda]) considered aquatic actually live in seasonally dry floodplains and actively enter the aquatic environment during flood conditions, comprising a significant portion of the diet of some riverine fish species (Flotemersch and Jackson 2003). Floodplain interactions contribute to increased food intake and growth rates in most river fishes (Lowe-McConnell 1975, Welcomme 1985), and may account for up to 75% of annual growth (Welcomme 1985).

Today, most large rivers have been altered by a variety of human activities (Welcomme 1985, Dynesius and Nilsson 1994, Galat and Frazier 1996). Humans have altered the physical templates of rivers, the hydraulic dynamics of their channels and tributary networks, and the land-use characteristics of their basins to an extent that has had a large, but complex, impact on the biota (Bayley 1995). Even so, efforts have been made to predict how riverine assemblages might respond to imposed changes (Ward and Stanford 1983, 1995). In such disturbed systems, management requires restoration of altered system features to desired levels of quality (i.e., to support designated uses) and the conservation of river features that still exhibit desirable conditions (National Research Council 1992).

### ***1.2.2 Bioassessment and Rivers***

The aquatic life of streams and rivers (fish, insects, plants, shellfish, amphibians, etc.) integrates the cumulative effects of multiple stressors generated by both point source and non-point source (NPS) pollution. Bioassessments, consisting of surveys and other direct measures of aquatic life, are the most effective way to measure the aggregate impact of these stressors on waterbodies. Bioassessments allow evaluation of the biological integrity of a waterbody, where biological integrity is:

*The ability to support and maintain a balanced, integrated, and adaptive community with a biological diversity, composition, and functional organization*

*comparable to those of natural aquatic ecosystems in the region* (Frey 1977, Karr and Dudley 1981, Karr et al. 1986).

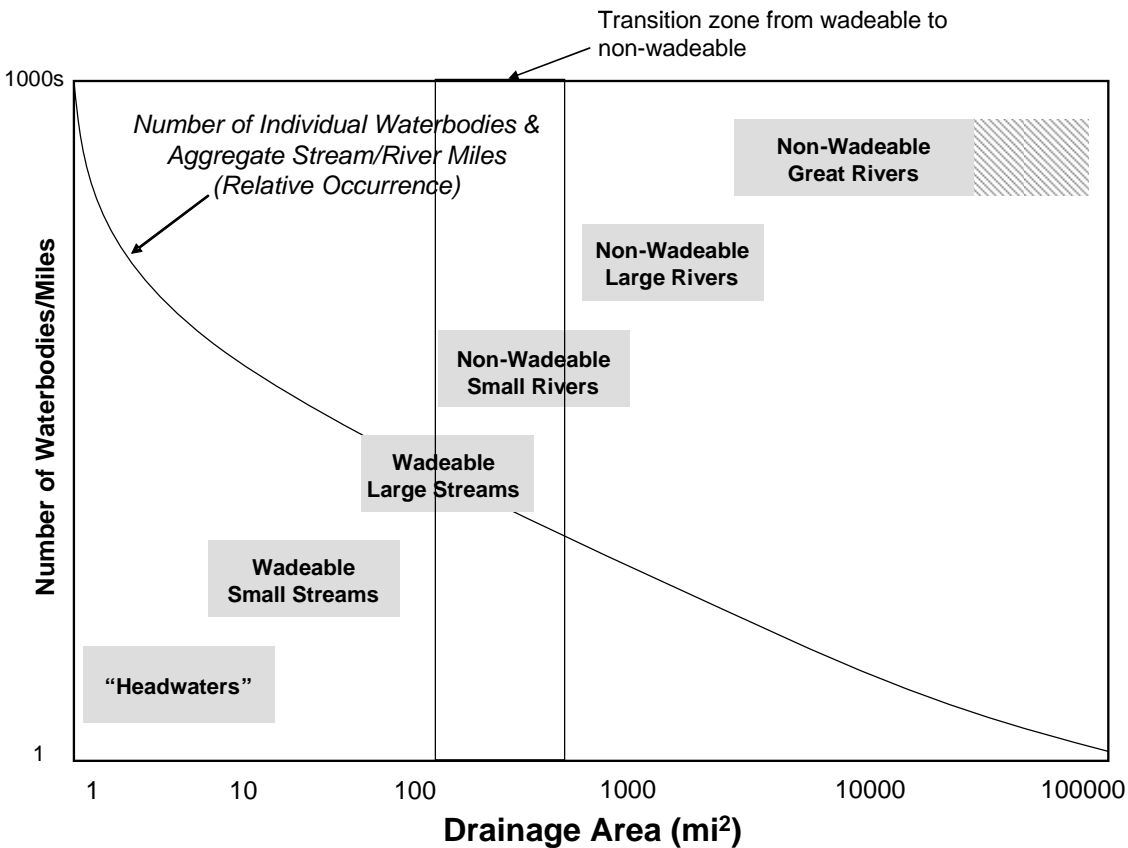
In recent years, this subject has been comprehensively addressed and interested readers should consult the large amount of existing literature (e.g., Plafkin et al. 1989, USEPA 1990, USEPA 1992, Davis and Simon 1995, Barbour et al. 1999, USEPA 2005).

All streams and rivers are susceptible to cumulative impacts from all upstream anthropogenic disturbances including chemical and organic pollution, dams, channelization, overharvest, invasive species, and land use. The greater the distance between a reach and its headwaters, the more these disturbances accumulate, so that large rivers are often the most ubiquitously disturbed type of lotic system. As a result, determining undisturbed conditions for large rivers is difficult. The fact that the natural structure and function of larger order streams are fundamentally different from those of smaller, wadeable systems (Vannote et al. 1980, Minshall et al. 1983, Junk et al. 1989, Sedell et al. 1989) highlights the need for bioassessment methods tailored to the special circumstances that large rivers present. For example, there are physical habitat conditions that are unique or of increased significance to large rivers, such as backwater habitat (Sheaffer and Nickum 1986, Scott and Nielsen 1989), islands (Thorp 1992), woody snags (Lehtinen et al. 1997), and floodplains (Petts 1996, Benke 2001). Because these areas serve as additional physical habitat in large rivers, they influence the dynamics of the biological community. However, although science recognizes the importance of these unique habitats to the overall condition of a river system, relatively few attempts have been made to incorporate habitat condition into an overall assessment of river condition (Poulton et al. 2003, Gutreuter et al. 1995).

The size of large rivers makes expense, logistics, and safety important issues that need to be incorporated into ecologically-sound sampling methods. For an adequate assessment of large rivers, the length of channel that must be sampled to capture the diversity of organisms and habitats is greater than that for smaller, wadeable streams. Many wadeable stream techniques are also not feasible or relevant to large river systems. These complications have led many river assessment programs to: 1) omit biological assessment of large rivers, 2) simply apply wadeable methods to wadeable areas of larger rivers, or 3) drop certain assessment parameters that are more difficult to measure in large rivers, such as benthic macroinvertebrates, and base assessments only on fish sampling and visual habitat assessments. None of these solutions allow for a comprehensive, and scientifically defensible evaluation of the condition of our Nation's large river systems, and therefore, will not provide the information needed to determine appropriate Aquatic Life Uses (ALUs) for the Clean Water Act (CWA).

### ***1.2.3 Resource Typology***

No consensus has been reached on what criteria should be used to differentiate between wadeable and non-wadeable (i.e., large river) systems. There is no clear geographic point along rivers that consistently discriminates when they become non-wadeable. Rather, there is a zone of gradual transition between wadeable and non-wadeable conditions before a river becomes predominately non-wadeable (Figure 1-1). As a result, criteria for defining large rivers will likely vary across the country.



**Figure 1-1. The delineation between wadeable and non-wadeable streams is not discrete, but rather a gradual transition (after C. Yoder, personal communication).**

Some of the more common designations in use include a priori stream designations such as stream order (e.g., >4<sup>th</sup> order) (Strahler 1957) and drainage area (e.g., >5000 km<sup>2</sup>). Using Strahler order, Leopold et al. (1964) estimated that there are approximately 5000 rivers of 5<sup>th</sup> through 7<sup>th</sup> order, and 50 of 8<sup>th</sup> through 10<sup>th</sup> order in North America. However, use of Strahler order alone has not proven to be a reliable stand-alone predictor of whether a river is wadeable or non-wadeable and, hence, whether a wadeable or non-wadeable sampling approach will be required for collection of a representative sample. In a recent paper by Wilhelm et al. (2005), the problem of defining the resource is discussed and quoted herein:

A non-wadeable or large river can be defined as a reach where the investigator cannot wade along its length (Meador et al. 1993) or from bank to bank (Edsall et al. 1997). However, the progression from small to large river is continuous, and even the demarcation between wadeable and non-wadeable is an indistinct boundary, because the status of a single location can change between wet and dry months or years. It is desirable to establish guidelines that can be applied prior to visiting a site and used to define the sampling universe of large rivers for a region. Large rivers have been defined as those that exceed a drainage area of 1600 km<sup>2</sup> (Ohio EPA 1989); an average depth of

1 m (Stalnaker et al. 1989); a width of 50 m (Simonson et al. 1994); or a river order of six or greater (Vannote et al. 1980, Sheehan and Rasmussen 1999). In contrast, Reash (1999) set a much higher threshold by defining a large river as one with a drainage area greater than 20,000 km<sup>2</sup>.

An alternative to strict, a priori order or area designations is for field crews to make the designation after arriving on site. Others have adopted a multi-criteria approach. For example, Wilhelm et al. (2005) defined non-wadeable rivers of Michigan as those that equaled or exceeded a river order of five, drainage area of 1600 km<sup>2</sup>, mainstem length of 100 km, and mean annual discharge of 15 m<sup>3</sup>/s. Another example is provided by the Idaho Department of Environmental Quality (Grafe 2002) where several criteria are used for designating a system as wadeable or non-wadeable. Criteria considered include average width at baseflow, average depth at baseflow, average greatest depth, site discharge, mean annual site discharge, and site drainage area. After a review of the strengths and weaknesses of each parameter, three were selected, each of which is scored and then averaged. They are: 1) stream order on a 1:100,000-scale map, equal to or greater than 5 = 1 point, 2) average wetted width at base flow greater than or equal to 15 meters = 1 point, and 3) average depth at base flow greater than or equal to 0.4 meters = 1 point. If the average of the scores in the three categories is greater than or equal to 1.7, it is classified as non-wadeable. If the average is less than 1.7, it is considered a wadeable stream. Additional criteria are used to delineate between medium and large rivers. However, the same protocol is used in each.

Two other characteristics that can be used to classify sites as non-wadeable are whether they are boatable or raftable and whether riverine species predominate. This would include sites that have lowhead dams, small hydroelectric facilities, or navigational dams, yet retain the generalized form and function of a flowing river ecosystem. It would exclude sites that function as reservoirs (e.g., publicly owned reservoirs, reservoirs managed for flood control or water supply), which are better assessed with protocols designed specifically for lentic systems (e.g., USEPA 1998). An example of an application following the non-wadeable logic is Lyons et al. (2001) which defined rivers in Wisconsin as lotic systems having at least 3 km of contiguous river channel too deep to be sampled using wadeable techniques.

As an alternative, a conceptual classification that combines features of the above approaches with physical and biological attributes of the system can be used. As summarized by the River Continuum Concept (RCC) (Vannote et al. 1980), lotic systems present a longitudinal gradient of physical conditions including width, depth, velocity, flow volume, and temperature. For example, proceeding downstream, river systems become broader, canopy cover decreases, and water temperatures increase. In response to these changes, stream segments are progressively influenced less by adjacent and more by upstream contributions of materials. This conceptualization, however, must be tempered with the realization that many rivers receive significant inputs from the seasonal coupling with their adjacent floodplains as well as connections with adjoining off-channel waterbodies (e.g., wetlands, oxbows) (Junk et al. 1989, Meyer 1990). This gradient of conditions is likewise reflected in the aquatic communities (e.g., algae, benthic macroinvertebrates, and fish) that have adapted to the physical conditions of a given reach along the system (Flotemersch and Jackson 2003, 2005).

In response to this gradient of changes, the methods used to sample the biotic communities must likewise change. For fish sampling, this means a progression in gear from backpack electrofishers in fully wadeable stream reaches, to the use of tote barges in deeper wadeable waters, to boat- or raft-based electrofishers. For macroinvertebrate sampling, the downstream progression from wadeable to non-wadeable reaches generally entails a shift from sampling the available habitat of the full channel to sampling in shoreline areas with dip-nets or artificial substrates. For sampling of algae, there may be a need to switch from an assessment based completely on periphytic diatoms to one including phytoplankton and soft algae. It should be noted that at some sites, transitional zones may be encountered that are composed of both wadeable and non-wadeable sections, and thus may require a hybrid approach to meet specific study objectives.

Integrating these additional attributes of systems, a conceptual classification can be constructed to serve as a guide for site classification and assessment approaches. Descriptive characteristics could include drainage area, Strahler order, functional features, narrative definitions (i.e., ability to sample), or other discriminatory characteristics useful for a particular region. An advantage of this approach is that by paralleling the conceptual framework of the RCC, conceptual classification can be used to place a site or reach in context within a larger watershed or landscape and thus help define and focus bioassessment and monitoring activities and restoration goals. One drawback of this approach is that a categorical framework is being applied to a system that exists along a continuum. Consequently, some sites may not fit neatly into a single category. In such cases, additional information may be required or a weight-of-evidence approach employed.

Here we present a prototype classification that includes classes for large and great rivers using some of these characteristics (Table 1-1). Because of geographic differences that exist among river systems, modifications to the table will certainly be required to ensure broad applicability. As is evident in the provided example, the chart may be very general, exhibit much overlap, and vary greatly by region. The “Functional features” presented assume the systems being discussed are in undisturbed condition.

### **1.3 Overview of the Large River Bioassessment Protocols**

As stated in the Preface, the impetus for the development of the Large River Bioassessment Protocols (LR-BP) was a need expressed by Regional scientists of the USEPA to develop standardized protocols specifically designed for the bioassessment of large rivers by States and Tribes. Criteria established for the final protocols were that they:

- permit the sampling of one or more sites per day;
- be scientifically defensible and statistically robust;
- be suitable for incorporation into routine monitoring programs;
- have the capacity of addressing often multiple and simultaneous objectives of agencies; and
- produce assessments acceptable to State, Tribal, and National programs with a reasonable level of effort.

**TABLE 1-1. Prototype site classification approach for streams and rivers.**

Bioassessment protocol class	Drainage area (range, km <sup>2</sup> ) <sup>a</sup>	Strahler order	Functional features (ecological)	Narrative definition (sampleability)
A. Headwater streams (Intermittent, Ephemeral)	< 3 km	0 – 3 <sup>rd</sup>	<p><b>Habitat:</b> Riparian shading/canopy is heavy in forested streams but may be light along those draining desert, grassland, and agricultural fields. Debris dams common in forested headwater streams. Substrate type will vary depending upon geology and gradient. Bed material of high gradient streams will be dominated by cobble, boulder and bedrock, whereas finer substrates commonly dominate low gradient channels. The length of habitat units tend to be small relative to channel width; therefore, the distances between alternating units is short, particularly for high-gradient (&gt;20%) channels that have step-pool formations. Headwater channels also have high length:width and width:depth ratios, such that a high proportion of water flowing through these streams is in direct contact with the stream bed and banks.<sup>b</sup></p> <p><b>Typical biotic assemblages:</b></p> <p><i>Algae:</i> Primarily benthic diatoms; some blue-green and green algae; mosses and liverworts common.</p> <p><i>Benthic macroinvertebrates:</i> Shredders and predators (forested), collectors, scrapers, and predators (grassland and desert), endemic species commonly associated with spring-fed streams.</p> <p><i>Fish:</i> Few (e.g., <i>Semotilus atromaculatus</i>, <i>Salvelinus fontinalis</i>) to none.</p> <p><i>Amphibians:</i> Salamanders (e.g., Plethodontidae) and frogs (e.g., <i>Ascaphus</i> spp., <i>Rana clamitans</i>); salamanders are frequently the top stream predators.</p>	<p>All habitats are accessible for sampling; however modified methods may be required for the shallow and low-flow conditions. Summer sampling may be limited due to naturally intermittent streams, where channels may be completely dry or surface water is limited to isolated pools.</p>

<sup>a</sup> There is overlap between estimated ranges of drainage areas.

<sup>b</sup> This generalized description pertains to systems with relatively undisturbed riparian vegetation. Disturbed reaches may have characteristics more typical of larger systems.

**TABLE 1-1. Continued.**

<b>Bioassessment protocol class</b>	<b>Drainage area (range, km<sup>2</sup>)<sup>a</sup></b>	<b>Strahler order</b>	<b>Functional features (Ecological)</b>	<b>Narrative definition (Sampleability)</b>
B. Wadeable streams and rivers	<1 – 700	1 <sup>st</sup> – 3 <sup>rd</sup> , or 4 <sup>th</sup>	<p><b>Habitat:</b> Riparian shading/canopy cover may be heavy in forested streams. Channel dominated by stable substrates. Energy sources mainly from outside of stream (allochthonous); thus coarse particulate organic material (CPOM) contributions are significant. For desert streams, perennial water will persist in most seasons, but the water may disappear underground into the porous, sandy stream bottom. Pools may persist. The stream is open to direct sunlight.</p> <p><b>Typical biotic assemblages:</b>  <i>Algae:</i> Periphyton in desert streams: filamentous green algae.  <i>Benthic macroinvertebrates:</i> Shredders/collectors, in desert stream mainly fine particulate organic material (FPOM) - feeding gathering-collectors.  <i>Fish:</i> Surface and water column feeders, generalized invertebrate feeders, and benthic invertebrate feeders.</p>	River reaches where sampling of multiple habitats can be accomplished using simple wadeable techniques.
C. Transitional streams and rivers	500 – 1000	3 <sup>rd</sup> – 5 <sup>th</sup>	<p><b>Habitat:</b> Riparian shading significant in forested streams, but openings in canopy cover increasing. Channel dominated by stable substrates with increasing occurrence of unstable substrates. Unique habitats exist that host fauna from adjoining upstream and downstream segments. Transition in importance of energy sources from CPOM to FPOM.</p> <p><b>Typical biotic assemblages:</b>  <i>Algae:</i> Periphyton.  <i>Benthic macroinvertebrates:</i> Collectors/grazers.  <i>Fish:</i> Benthic invertebrate and generalized invertebrate feeders common.</p>	Contains both wadeable and non-wadeable segments with a mosaic of habitat types that shift in quantity and quality in response to prevailing flow conditions. Sampling often requires a combination of methods developed for wadeable streams and large rivers.

<sup>a</sup> There is overlap between estimated ranges of drainage areas as well as among orders.

**TABLE 1-1. Continued.**

<b>Bioassessment protocol class</b>	<b>Drainage area (range, km<sup>2</sup>)<sup>a</sup></b>	<b>Strahler order</b>	<b>Functional features (Ecological)</b>	<b>Narrative definition (Sampleability)</b>
D. Non-wadeable streams and rivers	800 – 40,000	4 <sup>th</sup> – 8 <sup>th</sup>	<p><b>Habitat:</b> Importance of riparian shading is minimal, even in forested streams, and stream surface area mostly unshaded. Left and right banks increasingly divergent in character but not functionally independent. Influences on stream reaches affect both banks but maybe to differing degrees. Occurrence of unstable substrates artificially high in impounded reaches. Importance of FPOM &gt; CPOM. Most desert streams are heavily diverted in lower reaches and therefore may only have intermittent flow and no non-wadeable reaches, or are only non-wadeable during certain times of the year.</p> <p><b>Typical biotic assemblages:</b></p> <p><i>Algae:</i> Periphyton more prevalent in free-flowing reaches. Increasing importance of phytoplankton where water retention time is sufficient for development. Especially true immediately upstream of dams and other heavily impounded sections. Macrophytes infrequent but increasing in incidence.</p> <p><i>Benthic macroinvertebrates:</i> Collectors with appearance of great river species, more so with increasing impoundment levels. Mussels infrequent to frequent.</p> <p><i>Fish:</i> Herbivore-detritivores increasingly dominant. Occurrence of great river species common in impounded reaches.</p>	River reaches where boats are always necessary to access sample points; occasionally necessary to pull boats through shallow areas.

<sup>a</sup> There is overlap between estimated ranges of drainage areas.

TABLE 1-1. Continued.

Bioassessment protocol class	Drainage area (range, km <sup>2</sup> ) <sup>a</sup>	Strahler order	Functional features (Ecological)	Narrative definition (Sampleability)
E. Great rivers	>25,000	> 8 <sup>th</sup>	<p><b>Habitat:</b> Canopy opening extensive, even in forested streams, with stream surface largely unshaded. Channel dominated by unstable substrates. Left and right banks often independently affected by physical, hydrologic, and stressor conditions as a result of laminar flow along banks. A single habitat type may prevail for kilometers along a bank. Reaches frequently defined by large dams, which can limit the habitat heterogeneity and biotic diversity of a reach, especially true upstream of dams. System largely defined by FPOM. Allochthonous inputs of organic matter from upstream and lateral inputs are significant. Only autochthonous production is by phytoplankton.</p> <p><b>Typical biotic assemblages:</b></p> <p><i>Algae:</i> Phytoplankton. Water retention time sufficient for assemblages to establish. Main channel unsuitable for macrophytes or periphyton due to turbidity, swiftness of current, and scarcity of stable substrates. Macrophytes potentially abundant particularly on river margins and in backwaters.</p> <p><i>Benthic macroinvertebrates:</i> Dominated by collectors. Mussels potentially locally abundant but not ubiquitous.</p> <p><i>Fish:</i> Regular occurrence of great river species. Planktivores, herbivore-detritivores common.</p>	<p>River reaches where boats are always necessary to access sample points. Habitat types are frequently large and thus may require the development of habitat-specific expectations for biotic assemblages. Consequently, complete assessment may require sampling and assessment of different habitats.</p>

<sup>a</sup> There is overlap between estimated ranges of drainage areas.

Among the protocols discussed in this document, several were reviewed in detail before, during, and after the LR-BP research, and thus contributed directly to the development of the LR-BP (i.e., Ohio Environmental Protection Agency [Ohio EPA], US Geological Survey-National Water Quality Assessment [USGS-NAWQA] and the USEPA-Environmental Monitoring and Assessment Program [USEPA-EMAP]). Other programs and protocols discussed represent current research USEPA is conducting (i.e., USEPA-EMAP-Great Rivers Ecosystems [GRE]), and programs USEPA is currently collaborating with (Ohio River Valley Water Sanitation Commission [ORSANCO]).

The LR-BP represents an integrated approach to sampling in that the protocols for algae, benthic macroinvertebrates, and fish can be applied using the same sampling design. They are designed for rivers and, depending on the scale and scope of programmatic data needs, can be used for regional and site-specific studies. Also, while the protocols are not intended for application to great rivers (Table 1-1), adjustment of one or more components of the protocols will make them better suited for those kinds of systems. The LR-BP for physical habitat is not presented herein because refinements to the protocol are being field tested.

Much like the USEPA-EMAP and USGS-NAWQA protocols, the LR-BP for algae, benthic macroinvertebrates, and physical habitat are transect-based. This design has many desirable features for field studies; and as long as the first point is selected at random, remaining points based on that point can be considered random as well (Cochran 1977). The simplicity of this type of design makes it easy to execute without mistakes and results in significant time saving in the field. It also results in the drawn sample being spread more evenly over the population (Cochran 1977, Manly 2001). A common concern expressed about the transect approach to sampling is that the most productive habitat of a study reach may fall between transects and thus go unsampled. This will occur, but sampling what is perceived to be the most productive habitat is equivalent to selectively visiting the nicest house in a neighborhood and using it as a measure of the mean living conditions in that community. Another concern expressed is that at some sites, a standardized protocol may sample greater distances than required to achieve the data quality requirements (e.g., % of total species) set by the study. This is in all probability true, but if a standardized protocol is to be applied at all sites, it must adequately sample all, or a predetermined percentage, of the sites.

The combination of field-based comparative studies and collaborative field tests involving State agency biologists, Tribal members, and academic researchers was critical in ensuring the resulting protocols were consistent with the criteria established for the products. Findings from these studies, justification for follow-up research, and the performance of developed methods are discussed in this document where applicable.