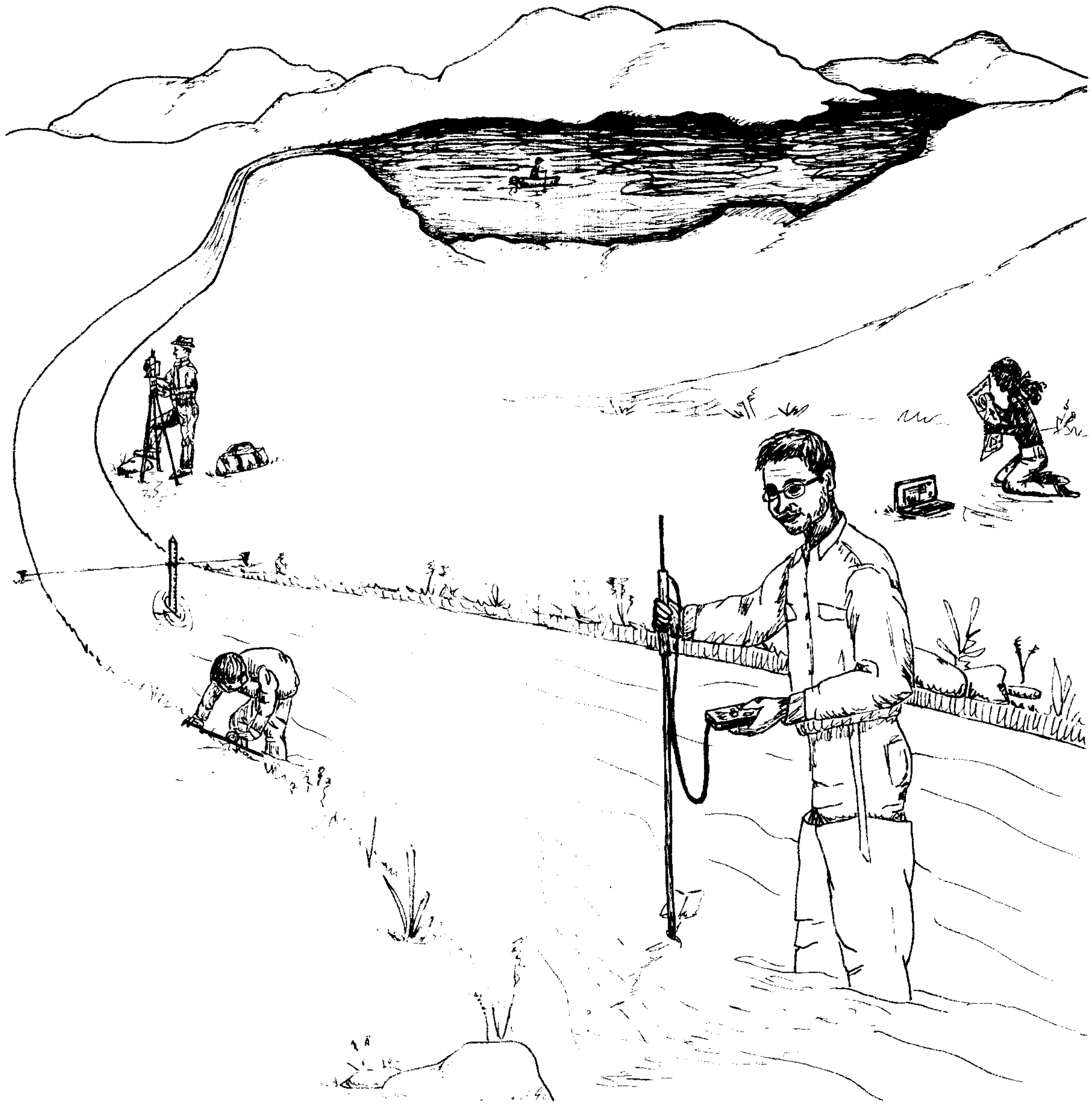
Common Methods

Aquatic Habitat Assessment



Edited by

Mark B. Bain and **Nathalie J. Stevenson**

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Symbols and Abbreviations

A	ampere
AC	alternating current
°C	degrees Celsius
cm	centimeter
Co.	Company
Corp.	Corporation
cov	covariance
DC	direct current; District of Columbia
D	dextro configuration
d	day
d	dextrorotary
df	degrees of freedom
dL	deciliter
E	east
E	expected value
e	base of natural logarithm
e.g.,	for example
eq	equivalent
et al.	(et alii) and others
etc.	et cetera
F	filial generation; Farad
°F	degrees Fahrenheit
ft	foot (30.5 cm)
g	gram
gal	gallon (3.79 L)
h	hour
ha	hectare (2.47 acres)
Hz	hertz
in	inch (2.54 cm)
Inc.	incorporated
i.e.,	that is
IU	international unit
k	kilo (10^3, as a prefix)
kg	kilogram
km	kilometer
l	levorotary
L	levo configuration
L	liter (0.264 gal, 1.06 qt)
lb	pound (0.454 kg, 454g)
log	logarithm (specify base)
M	mega (10^6, as a prefix); molar (as a suffix or by itself)
m	meter (as a suffix or by itself); milli (10^{-3}, as a prefix)
mi	mile (1.61 km)
min	minute
mol	mole
N	newton; normal; north
N	sample size
NS	not significant
n	ploidy; nanno (10^{-9}, as a prefix)
o	ortho (as a chemical prefix)
oz	ounce (28.4 g)
P	probability
p	para (as a chemical prefix)
p	pico (10^{-12}, as a prefix)
Pa	pascal
pH	negative log of hydrogen ion activity
ppm	parts per million (in the metric system, use mg/L, mg/kg, etc.)
ppt	parts per thousand
qt	quart (0.946 L)
R	multiple correlation or regression coefficient
r	simple correlation or regression coefficient
rad	radian
S	siemens (for electrical conductance); south (for geography)
s	second
SD	standard deviation
SE	standard error
sr	steradian
tris	tris(hydroxymethyl)-aminomethane (a buffer)
UK	United Kingdom
U.S.	United States (adjective)
USA	United States of America (noun)
V	volt
V, Var	variance (population)
var	variance (sample)
W	watt (for power); west (for geography)
Wb	weber
yd	yard (0.914 m, 91.4 cm)
α	probability of type I error (false rejection of null hypothesis)
β	probability of type II error (false acceptance of null hypothesis)
Ω	ohm
μ	micro (10^{-6}, as a prefix)
′	minute (angular)
″	second (angular)
°	degree (temperature as a prefix, angular as a suffix)
%	per cent (per hundred)
‰	per mille (per thousand)

Introduction 1

Mark B. Bain

1.1 Purpose of This Manual

Habitat is now the basis of most impact assessments and resource inventories, and it is the basis of many species management plans, mitigation planning, and environmental regulation. Habitats are relatively stable through time, easily defined in intuitive physical terms, and provide a tangible resource for negotiations and decision making. Numerous and varied methods of analyzing and reporting habitat conditions have been developed by federal, state, provincial, and private agencies, and habitat assessment approaches vary greatly among regions of the continent. The great variability in methods and an unusually wide range of practices have impeded the ability of agencies to share and synthesize information. A diversity of methods is desirable in the initial stages of a rapidly developing field, but enough time has passed to assess the state-of-knowledge and identify the best of the currently used methods and techniques.

This manual is intended to provide fisheries biologists with a limited set of techniques for obtaining aquatic habitat data. The manual also describes the range of information collected and used in agency habitat analyses. Agencies planning habitat programs should review the synthesis of established and documented methods being used in North America (Appendix 1) and the planning recommendations in Chapter 2. Then, the remaining chapters should be reviewed to determine what types of habitat data should be included in the agency's program.

1.2 Development of This Manual

A brief history of *Common Methods* will explain how this manual developed. In 1995, the American Fisheries Society (AFS) and the

U.S. Fish and Wildlife Service organized a joint project in response to the need for more uniform habitat assessment methods. These organizations wanted to evaluate the wide array of habitat assessment methods being used by agencies with inland fisheries management responsibilities, and to select a set of standard techniques. Enhancing the comparability among diverse agency methods was the primary goal.

The joint habitat project has produced several products culminating in this manual. In 1997, a symposium titled "Aquatic Habitat Analysis Methods: An AFS Initiative and Some Recent Advances" was organized by Steve Filipek and Mark Bain for the 127th Annual Meeting of the American Fisheries Society in Monterey, California. Some presentations from that symposium have since been published in *Fisheries*. Wayne Hubert and Eric Bergersen provided basic guidance for developing aquatic habitat assessment programs. Their recommendations were published (Hubert and Bergersen 1998) in *Fisheries* and appear in this manual as Chapter 2. Mark Bain, Tom Hughes, and Kristine Arend reported the results of a North American survey of fisheries agencies and the methods used for aquatic habitat assessment. This work was published (Bain et al. 1999) in *Fisheries* and it is included in Appendix 1 of this manual. One major product, Armantrout's (1998) *Glossary of Aquatic Habitat Inventory Terminology*, was compiled to develop consistent terminology for habitat assessment work. These preliminary products provided the foundation for a manual of common methods for inland aquatic habitat assessment.

The survey of North American fisheries agencies reported in Appendix 1 and Bain et al. (1999) was especially important. This study surveyed state, provincial, federal, and private organizations to obtain documentation of methods being used to assess aquatic habitats in the inland waters of North America. The methods documents were used to characterize the attributes of current practices. Most state, provincial, and federal agencies with fisheries management responsibility have been using some type of established (i.e., well documented and in use) method for aquatic habitat assessment. However, a substantial number (~30%) of the agencies have been relying on ad hoc procedures. The survey showed that the dominant purpose for having an established method was to standardize measurements and data collection techniques.

Most of the 52 methods reviewed by Bain et al. (1999) target habitats associated with flowing waters, but many of the methods are used exclusively with lakes and reservoirs. Methods for stream habitats included a wide array of measurements emphasizing channel structure, water movement, substrate, cover, and riparian habitat. The lentic habitat methods emphasized the littoral zone, shallow-water physical structure, and riparian areas. Many of the methods had long lists of habitat attributes that could be measured, and many measurements appeared redundant even within single assessment methods. The methods review identified 705 different habitat variables although a large portion of these were similar. Habitat attributes such as fish cover were being measured in such varied ways that any meaningful synthesis was not possible across regions, provinces, states, and even through time within single agencies.

After the methods review and synthesis was completed, the focus of the AFS project shifted to seeking a large reduction in the diverse forms of habitat data being collected by fisheries agencies and organizations. Our selection of methods and techniques provides a range of habitat assessment practices that vary in effort, precision, and detail. Nevertheless, widespread use of the techniques described in this manual will greatly reduce the variability in approaches and types of data being used in habitat assessment programs.

1.3 Selection of Methods and Techniques

This manual is organized into 16 method chapters that each contain a choice of related techniques. Methods are collections of techniques that have a common purpose. We considered an agency habitat assessment method to be all techniques described in a program manual or instruction document. For this manual, we selected techniques for a particular class of habitat data (e.g., substrate, lake morphology, water temperature) and grouped them into a method chapter covering the habitat attribute. The content of the 16 method chapters was chosen by synthesizing the list of 705 habitat data inputs that came from the comprehensive review of agency methods (Appendix 1). The list was organized by grouping the inputs into themes, and these themes became the topics of the 16 chapters. Each chapter was then planned by (1) reviewing the techniques that were documented and being used by fisheries agencies; (2) considering related techniques from any available source; and (3) selecting the fewest techniques that provide a range of choice in effort, intensity and sophistication. In addition to these considerations, selection of a technique recognized the time required to obtain measurements and data, the need for specialized equipment and training, and other factors related to the cost of the assessment and the feasibility of widespread use. Some of the techniques described here are combinations and modifications of current practices or new techniques assembled in such a way to approximate the effort, gear, and level of sophistication reflected in current methods. In general, the selection process emphasized commonly used techniques rather than the latest advancements in research literature. Hence, we titled this manual *Common Methods*.

Some may feel that recommending common methods will tend to stifle investigation, innovation, and progress. It was clear from our interactions with fisheries agencies that their habitat assessment methods are advancing at a rapid pace, and most agencies are using their first, well-developed and documented assessment method. Researchers are also producing new technologies and techniques regularly. Therefore, we recommend that AFS strive to review, improve, and update the set of methods contained in this manual, and that subsequent editions track this rapidly advancing field. New and innovative techniques should be included in *Common Methods* as they gain broad acceptance by practitioners. For now, however, we believe the methods and techniques presented here represent the good practices in current use and are generally applicable to routine agency habitat assessment needs. The use of methods that are reliable, documented, and applied in reasonably uniform ways will advance the aims of the U.S. Fish and Wildlife Service and American Fisheries Society effort to foster comparability among agency methods.

Assessment site selection was a key issue that divided methods into distinct and contrasting groups in the survey of agency methods. We found that specific but inconsistent approaches were being used to design assessment programs. Almost all current agency methods determine assessment site location and size using one of the following approaches: principles of geomorphology (e.g., multiples of stream width), field investigator judgment (ad hoc), and past experiences (fixed site sizes). Also, assessment sites were located on the basis of representativeness, random selection, or investigator judgment. The survey found there were some efforts to expand the scope of habitat assessment by using multiple sites for watershed or for regional assessment of habitat resources. We did not attempt to address this complex issue in this manual because of the sharply contrasting approaches used among the agencies. This key aspect of habitat assessment warrants focused investigation to provide managers with guidance on tradeoffs associated with the different decisions.

Successful design of habitat assessment programs also rests on selecting methods and techniques with a full understanding of the choices available and the advantages and limitations of each. Read and understand the entire method presentation so appropriate techniques can be chosen and adapted to agency needs, region of interest, and water types. Fisheries biologists interested in selecting techniques for a specific type of habitat data should review the appropriate chapters and consider the recommended techniques. This manual does not specify what techniques should be used in aquatic habitat analyses; rather, we believe the method information, planning guidance, and technique descriptions will lead to a much more consistent set of habitat data than is now being assembled in North America. This would advance the state-of-the-art of aquatic habitat analysis, and it would promote comparability among agency programs and information.

1.4 Acknowledgments

This manual was prepared as part of an American Fisheries Society project funded by the U.S. Fish and Wildlife Service. Robert Kendall, Robert Rand, Eric Wurzbacher, and Beth Staehle of AFS assisted in many ways and improved our work throughout the effort. Beth Staehle provided final editorial expertise and Teresa Sawester did most of the graphics and illustrations. The AFS Fisheries Manage-

ment Section led the project, and members of the Section assisted in the work leading up to this manual, particularly Steve Filipek, Robert Wiley, Wayne Hubert, Eric Bergersen, and Neil Armantrout. Finally, a long list of reviewers commented on the first version of all chapters, their reviews truly exceeded normal expectations for length and value; they helped greatly in improving this manual.

Approaches to Habitat Analysis

2

Wayne A. Hubert and Eric P. Bergersen

Habitats for fishes are the places where individuals, populations, or assemblages can find the physical and chemical features needed for life. Habitat features include water quality, spawning sites, feeding areas, and migration routes. Habitat quality affects fish abundance and size as well as the species composition. Problems with inadequate, improper, or excessive fish habitat information gathered by fisheries workers are widespread and can be attributed to poorly defined goals for collecting information.

We define successful fish habitat management as a planned sequence of activities that creates or augments various habitats needed to maintain or enhance the abundance of specified species. The key word is *planned*. Planning is the selection and prearrangement of events for the attainment of an objective. In many cases, the excitement of data gathering and the sense of expedience can prompt people to get busy with something familiar and tangible but with little chance of achieving specified goals. Thus, these professionals are lured into a seductive activity trap. The success of habitat management does not start with choosing methods but with applying the fisheries management process (Krueger and Decker 1993). The process involves (1) setting goals, (2) defining objectives, (3) identifying problems, (4) implementing actions to address problems, and (5) evaluating actions to determine if objectives have been achieved. Before any habitat analysis is conducted, a clear purpose and justification for collecting data must be agreed on.

Many protocols exist for habitat analysis, which vary in purpose and types of data gathered. By deciding goals, managers can evaluate individual approaches to habitat analysis. We propose four primary goals for applying habitat analysis.

1. **Inventorying** (i.e., reconnaissance, baseline information, or documentation of resource condition). Current habitat condi-

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tions are described throughout a broad spatial scale, and the data are stored in a retrievable manner.

2. **Analyzing habitat quality.** Managers identify habitat features that impede fish abundance or production.
3. **Monitoring effects of land use.** Possible changes to and degradation of fish habitat associated with land use practices in a watershed are monitored. Changes may result from human activities such as logging or road construction.
4. **Assessing habitat improvement activities** (i.e., evaluating the success of management). When management defines specific, quantifiable objectives for a habitat improvement project or program, changes in habitat are evaluated through a systematic assessment program.

Within the defined purposes of habitat analysis, an array of sampling principles must be considered (Platts et al. 1987; Willis and Murphy 1996). Standardized sampling protocols are required to describe temporal trends (McMahon et al. 1996). Techniques must be repeatable and be sufficiently accurate and precise to detect changes. Terms and units of measure, sampling methods, criteria for evaluation, spatial and temporal scales, stratification and classification systems, and data storage and analysis should all be standardized. How ever, the specific dimensions of habitat analysis differ depending on the goal of the project.

2.1 Inventorying

One goal of habitat analysis might be describing baseline conditions. Here, the manager is concerned with broad reconnaissance and development of an information base for an extensive area. The basinwide inventory technique developed by the U.S. Forest Service is an example of a standardized inventory system developed and applied by an agency (Hankin and Reeves 1988). Interpreting data from inventories is frequently difficult because sampling techniques often are imprecise; the data give little insight into the habitat features that may affect fish; and the spatial and temporal dimensions of the data often are incongruent or not easily depicted. Vast amounts of inventory data are gathered and stored with little understanding as to how they may be used by resource managers, especially by fisheries managers. Many inventories are simply (and unfortunately) the end product of the activity trap.

2.2 Analyzing Habitat Quality

Analyzing habitat features that limit fish production is a challenge to fisheries managers. Such analyses include observation and interpretation of the habitat features that are affecting fish survival. Hunter (1991) stated that when a manager finds an attribute that does not meet a fish's minimum requirements, a limiting factor is identified. *Limiting factors* can be viewed as anything that impedes the dynamics of an organism or population. They also can be defined as the critical minimum requirements for survival. Fisheries managers want to identify limiting factors and relieve them to enhance fish production and achieve the production potential, ecological capability, or optimum productivity of a system.

However, few habitat analysis tools focus on identifying limiting factors or the relations between habitat and production potential. Such analytical approaches need to go beyond identifying the life stage or habitat feature that may limit production, and instead reveal the root cause of the problem. Sampling through the year or throughout a watershed may be necessary. As fisheries managers, we have barely begun to develop analytical tools that can identify limiting factors and specific habitat improvement needs. Much of the sampling and many of the analyses provide data that do not or cannot identify limiting factors. When this happens, the effort becomes little more than a form of occupational therapy, the activity trap.

2.3 Monitoring Effects of Land Use

Land managers also may analyze habitat to evaluate the effects of land use patterns on habitat, justify the implementation of management programs, or substantiate an organization's position in court. Platts et al. (1987) described a six-step process to identify effects of land use: (1) specify information that must be collected for use in the planning and resource management process, (2) determine a tentative approach for collecting information, (3) conduct pilot sampling to obtain preliminary data to determine the accuracy and precision of sampling, (4) collect information, (5) analyze information and interpret results, and (6) process the information for use in the management process.

Also within this process are the needs to (1) establish decision criteria at the time sampling protocols are designed, (2) identify habitat variables that respond to land use activities and provide insight into fish habitat quality, and (3) define the level of statistical confidence required of the sampling data. To conduct the analysis within reasonable costs, fisheries professionals stratify (zones, reaches, habitat types, or seasons) sampling to minimize variation and reduce measurement error. Hawkins et al. (1993) provide one example of a widely accepted stratification procedure for stream habitat. When developing a sampling protocol, managers must consider aquatic systems as continuums with interactions that occur throughout a watershed.

Monitoring programs to analyze the effects of land use on fish habitat that have defined goals and objectives, follow the general process of Platts et al. (1987), and have rigorous sampling protocols, decision criteria, and analytical protocols are rare. Unfortunately, many efforts to monitor the effects of land use on fish habitat also fall into the activity trap.

2.4 Assessing Habitat Improvement Activities

Managers assess habitat improvement activities to gain insight into the effects of management activities on fish habitat quality and fish populations. A goal is to assess whether management objectives have been met. Assessing habitat management activities involves three levels (Kershner et al. 1991).

1. Implementation: Were the prescribed improvement activities correctly implemented?
2. Effectiveness: Were the objectives achieved?
3. Validation: Were the objectives met because of the planned habitat changes?

Such an assessment requires measuring habitat features prior to any action, habitat improvement activities to determine whether they meet specification, and the same habitat features following management action for an extended time. Platts et al. (1987) proposed a process for assessing habitat management efforts that is more site-specific, focuses on improving habitat conditions to achieve management objectives, and involves prescribed activities. It also demands a more rigorous sampling design, including clearly defined hypotheses, control areas that do not receive management treatments, and efforts to control confounding factors that may harm or influence conclusions. Due to the time required to allow responses to management activities, assessing habitat improvement activities takes a long time. Consequently, management agencies must conduct long-term assessments to allow responses to occur, assure that accuracy and precision of standardized sampling techniques are maintained, and recognize the continuing obligation to monitor past management activities. Most efforts to assess habitat improvement activities lack some of the dimensions required to effectively assess long-term success of activities. Because of a focus on producing tangible habitat improvements, the assessment process is often incomplete. As a result, both the habitat improvement activities and the assessment efforts may do little more than hamper our quest to understand what is actually going on when we modify aquatic habitats—the activity trap again.

Regional Setting 3

Marcia S. Meixler

3.1 Introduction

3.1.1 Background

Broad patterns of climate and geology influence many properties of aquatic habitats such as hydrology, nutrient and temperature regimes, groundwater potential, dominant substrates, stream morphology, and the formation of various types of wetlands and lakes. Aquatic habitat is largely a product of the surrounding land and climate (Likens and Bormann 1974; Hynes 1975; Omernik and Griffith 1991); identifying the regional setting makes it easier to group similar habitats and recognize local variability (Warren 1979; Whittier et al. 1988). Resource management agencies often strive to use habitat assessments for broad, holistic, and ecosystem scale analyses (Omernik and Bailey 1997; Bailey 1998) and methods have been developed to classify habitat information in large spatial frameworks. Spatial frameworks are classification systems where a region is recognized as having a similar mosaic of aquatic habitats that contrast with those of the adjacent or different regions (Bailey et al. 1978; Hughes et al. 1986; Omernik 1987; Lyons 1989; Omernik and Bailey 1997). Several spatial frameworks are in use by fisheries management agencies for assessment and inventory of aquatic resources, and four of these are detailed below: ecoregions, watersheds, hydrologic units, and physiographic provinces.

Ecosystem or regional management must consider multiple spatial scales since aquatic systems occur in a hierarchy of varying sizes (Bailey 1998). Further, the factors that constrain or influence aquatic systems operate at different space and time scales. Some agencies have adopted hierarchical classification systems (Figure 3.1) where a series of levels are organized so that finer classified regions nest

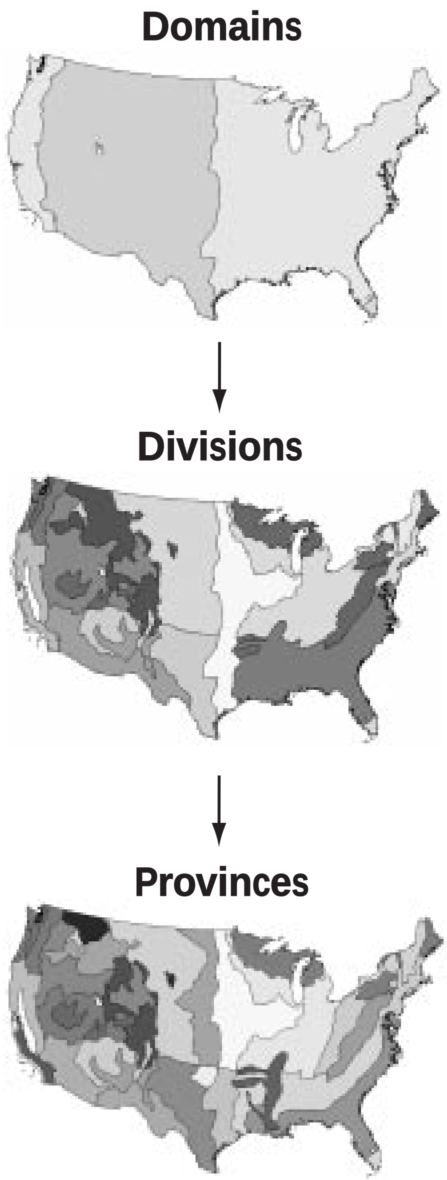


Figure 3.1 Example of a hierarchical structure in spatial frameworks (Bailey 1995).

within the next larger class, and all classes in a level are mutually exclusive of the others in that level (Bailey et al. 1978; Bailey 1995). In this way, precise, locally sensitive regions can be used while still maintaining a useful classification for larger regions (Lyons 1989). Ecosystem level stratification can increase monitoring efficiency, improve data interpretation and trend detection, and provide a framework for assessing and reporting on water quality (Omernik and Griffith 1991).

Ecoregions, the first of four spatial frameworks presented, were developed as broad, hierarchical, landscape classifications. Ecoregion classifications provide an overview of the spatial patterns and the most influential environmental variables for aquatic habitats. Ecoregion classifications are based on a few easily measured or well-known characteristics (e.g., climate, geology, landform) which shape the contained aquatic habitats and could account for much of the variation in the distribution of biotic communities (Bailey 1983; Bailey and Hogg 1986; Omernik 1987). Ecoregions provide managers, planners, and scientists with a common base for communicating a habitat's regional setting. Habitat issues addressed in the context of ecoregions are typically ranges in chemical quality, biotic assemblages, lake trophic state, and management of lands. Finally, ecoregions can be used in selecting reference or monitoring sites, and extrapolating habitat assessment results regionally (Bailey 1983; Rohm et al. 1987).

Watersheds, the second type of spatial framework, are defined as topographic areas within which apparent runoff drains to a specific point on a stream or to a water body such as a lake (Omernik and Bailey 1997). The term basin is often used to describe large watersheds such as those for major rivers. Watersheds are the most common spatial units used by fisheries management agencies in habitat assessment activities and in framing guidelines for controls and remediation (Omernik and Griffith 1991). Watersheds accumulate the surface and subsurface flow of water up gradient from a habitat assessment site. Consequently it is possible to document factors that could influence habitat quality, such as upstream pollution sources and nonpoint source runoff (Omernik and Bailey 1997).

A third spatial framework is the U.S. Geological Survey's (Seaber et al. 1994) hydrologic units that are composed of watersheds, segments of watersheds, and sometimes adjacent areas in between watersheds (Omernik and Griffith 1991). Hydrologic unit maps and codes provide a standardized base for locating, coding, retrieving, indexing, and inventorying hydrologic data and are useful in many water resource management activities (Omernik and Griffith 1991).

The fourth and final spatial framework is physiographic provinces or broad regional units with similar landform characteristics. These provinces are defined primarily from topography in combination with tectonics, geologic structure, lithology, and erosion and sedimentation processes (Hanson 1998). Physiographic provinces and drainage basins have often been used for many years to explain fish distributions (Miller 1958; Pflieger 1971; Trautman 1981; Hughes et al. 1987; Whittier et al. 1988).

3.1.2 Selection of Techniques

The four classification techniques were selected to provide choices in usage, applicability, and practicality. All could be used collectively to obtain a full description of the regional setting for habitat assessments. Table 3.1 compares and contrasts the key characteristics of the four classification systems.

Ecoregion classification synthesizes information on terrestrial variables, which can lead to insight into the broad habitat characteristics of water bodies. Neither watersheds nor physiographic provinces provide similar information (Hughes et al. 1987). This holistic approach to regional classification reveals relationships better than single-factor classifications (Bailey et al. 1978). However, ecoregion classification is not effective with limited geographic areas and individual waters (Lyons 1989).

Watershed frameworks are appropriate for fisheries management agencies to use when assessing the relative contribution of human activities to habitat quality by stream or water body. How-

Table 3.1 Comparison of the ecoregion, watershed, hydrologic unit, and physiographic province spatial frameworks.

Spatial framework	Attributes	Delineation	Primary uses	Geographical coverage
Ecoregions	Multifactor Geographical Regional Hierarchical	Climate, soils, geology, hydrology, landform, elevation	Studies of the health, integrity, and quality of environmental resources over large areas	Global, continental, national, regional, and state
Watersheds	Single factor Geographical Regional Hierarchical	Topographic divides	Studies of the effects of natural and anthropogenic phenomena on water quality and quantity; used mostly at the local level	National, regional, state, and local
Hydrologic units	Single factor Geographical Regional Hierarchical	Surface topography; not true watersheds	Geographical cataloging; coordination, storage, and retrieval of survey information; manipulation, organization, and dissemination of data on a geographic, political, and hydrologic basis	National and state
Physiographic provinces	Single factor Geographical Regional Hierarchical	Topography, structure, and, to a lesser extent, climate	Identification of fish distributions	Global, continental, national, regional, state, and local

ever, the larger river basin scale does not account for changes in local habitat characteristics due to surrounding land uses (Whittier et al. 1988). Another drawback of watershed classification is that information in a watershed cannot be extrapolated. Geoclimatic and biological characteristics as well as anthropogenic disturbances in larger regions seldom correspond to watersheds or basins (Omernik and Bailey 1997).

Hydrologic units are defined by single-factor delineation of boundaries much like watersheds, but most hydrologic units are not true topographic watersheds (Omernik and Bailey 1997). The units are useful for capturing and managing hydrologic data and are used in water resource management (Omernik and Griffith 1991). The drainage divides used to delineate hydrologic units help to explain spatial differences in fish assemblages and abundance (Omernik and Bailey 1997). However, hydrologic units do not correspond to patterns in vegetation, soils, land forms, land use, and other characteristics that control or reflect spatial variations in surface waters. The true spatial variations in quality are masked (Omernik and Griffith 1991) when hydrologic units are used as a primary framework to aggregate data, illustrate patterns, and suggest management options.

Physiographic provinces are hierarchical and based on a single-factor for delineation of boundaries. Physiographic provinces are traditionally used by ichthyologists to describe fish distributions in aquatic systems (Pflieger 1971; Trautman 1981); however, Hughes et al. (1987) found that physiographic provinces and river basins were less useful than Omernik's ecoregions for explaining historical fish distribution patterns in Oregon. Although physiographic provinces can account for many of the attributes that shape aquatic systems, they do not necessarily correspond with soil, climate, land use, and other attributes (Omernik 1987). Despite this, physiographic provinces are considered more accurate classifications than traditional river basins for defining regional settings (Omernik and Bailey 1997), and they have a long history of use for resource assessment (e.g., Powell 1896).

3.2 Ecoregion Identification

3.2.1 Rationale

Ecoregions are relatively uniform areas defined by generally coinciding boundaries of several key geographic variables. Delineation of regions is accomplished by examining patterns in the homogeneity of several terrestrial variables expected to have major influences on aquatic ecosystems (Hughes et al. 1986). Ecoregions have been defined holistically using a set of physical and biotic factors (e.g., geology, landform, soil, vegetation, climate, wildlife, water, and human factors) rather than a single factor (Commission for Environmental Cooperation 1997). This delineation lends itself to a hierarchical scale, from very site-specific aquatic conditions to large broad scale ecosystems, where finer classified regions nest within the next larger classification category.

The first national scale ecoregions emerged in the mid-1980s with Wiken's (1986) classification for Canada and Omernik's (1987) for the United States. The Commission for Environmental Cooperation (1997) organized ecoregional classifications of Canada, the United States, and Mexico to provide a common framework for the ecoregional classification of North America, and recently several classification systems have emerged on a global scale (Busch and Sly 1992; Angermeier and Schlosser 1995; Bailey 1995; Jensen et al., in press). Ecoregions are used to

1. compare the regional similarities and differences in hydrology, temperature and nutrient regimes;
2. identify the natural characteristics and potential of aquatic systems;
3. determine precise regional criteria to measure and evaluate aquatic ecosystem integrity;
4. establish water quality standards which reflect regional patterns of tolerance, resilience to and recovery from human impacts;
5. set management goals for nonpoint source pollution;
6. locate monitoring, demonstration, or reference sites;
7. extrapolate regional information from existing site-specific studies (Rohm et al. 1987);
8. predict the effects of changes in land use and pollution controls (Omernik 1987);
9. estimate ecosystem productivity and likely responses to management action (Hughes et al. 1986);
10. evaluate temporal and spatial changes in ecological integrity (Bailey 1983); and
11. plan at the national and international levels (Bailey 1978).

Two of the most commonly used ecoregional systems, Bailey's and Omernik's, are described for use in this section. Bailey's objective in creating an ecoregion map was to provide a broad synthesis of our current knowledge about the ecosystem geography of the United States and a useful reference for persons who desire a comparative overview (Bailey 1978). Macroclimate, the climate that lies just beyond the local modifying irregularities of landform and vegetation, is interpreted as having an overriding effect on the composition and productivity of ecosystems from region to region (Bailey 1998). Information on macroclimate and prevailing plant formations was used to classify the continent into three levels of detail. Bailey's coarsest hierarchical classifications include 4 (for the United States) domains, 15 divisions, 53 provinces, and 194 sections. These regional classes are based largely on broad ecological climate zones (identified by Koppen [1931] and modified by Trewartha [1968]) and thermal and moisture limits for plant growth (Bailey 1995, 1998). Domains are groups of related climates, and divisions are types of climate based on seasonality of precipitation or degree of dryness or cold. Divisions are further subdivided into provinces based on macrofeatures of the vegetation. Provinces are distinct enough to describe the zonation in altitude of mountains and the climatic regime of the adjacent lowlands. Provinces include characterizations of land-surface form, climate, vegetation, soils, and fauna (Bailey 1995). The subdivision of provinces into sections is based on physiography (i.e., landform and geology) which exerts control over habitats within climatic–vegetation zones (Bailey et al. 1994). Sections include characterizations of geomorphology, stratigraphy and lithology, soil taxa (temperature, moisture regimes), potential natural vegetation, elevation, precipitation, temperature, growing season, surface water characteristics, and disturbance (Bailey et al. 1994). Some areas of the country are mapped further to subsections with detailed subsection descriptions. Information from domains, divisions, and provinces is used for modeling, sampling, strategic planning, and assessment. Information from sections and subsections is used for strategic, multi-forest, statewide, and multi-agency analysis and assessment. Information from smaller regions, called landscapes, is used for forest planning; watershed analysis and even smaller land unit classifications are intended for planning and analysis of projects and management areas.

Omernik's ecoregion system was formed in response to a need for an alternative classification for regionalizing water resource management (Omernik 1987) and to distinguish regional patterns of water quality in ecosystems as a result of land use. Omernik's system is suited for classifying aquatic ecoregions and monitoring water quality because of the ecological way it was developed; its level of resolution; its use of physical, chemical, and biological mapped information; and a lack of necessary data collection (Hughes et al. 1986). Omernik's system has been extensively tested and found to correspond well to spatial patterns of water chemistry and fish distribution (Whittier et al. 1988). Much like Bailey's system, Omernik's system is hierarchical, dividing an area into finer regions in a series of levels. There are 9 level I ecoregions in North America, 32 level II classes, and 78 level III classes (September 1996 version; U.S. Environmental Protection Agency 1996). The description of level III ecoregions includes characterizations of land surface form, potential natural vegetation, land use, and soils. Portions of the United States have been further subdivided into level IV ecoregions.

Omernik delineated regional boundaries by analyzing the most important component maps and sketching out regions that appeared to be homogeneous in their land use, land surface form, soils, and potential natural vegetation (Omernik 1987). Some regions could be easily delineated by the distinctiveness of all four characteristics. Less distinct regions were identified by broader groupings of some of the characteristics or by using fewer characteristics. The boundaries were then ascertained from the initial sketches and with characteristic tables which typified each component region. Overlay combinations were examined and final delineations shaped for each ecoregion (U.S. Geological Survey 1997). Once completed, the map of the United States was divided into ecoregions, and an attribute was added to indicate if the polygons were either most typical or generally typical of a particular region. Consequently, two map versions are available: one version of the map represents the ecoregions, and the other version of the map delineates the most typical portions of each ecoregion. The most typical portions are defined as areas sharing all of the characteristics of the ecoregion, whereas the generally typical portions of each ecoregion share most, but not all, of the same characteristics.

3.2.2 Preparation

- Develop familiarity with web browsing if using the Internet to locate site. Develop competence with ARC/INFO geographic information systems if downloading the digital map version. Assemble map or description of sites to locate, and acquire necessary maps and ecoregion descriptions as described below.

- Bailey's ecoregion map and descriptions can be obtained from one of the sources below.
  - Paper maps and accompanying literature (1995 version): available from U.S. Forest Service, Fort Collins, Colorado, 303-498-1768; fine-scale maps can be obtained from the U.S. Forest Service Regional Office in each state.
  - CD-ROM: contact the Southern Geometronics Service Center for information on a CD-ROM for some western U.S. regions.
  - ARC/INFO geographic information systems files: free digital compressed ARC/INFO ecoregion maps are available at http://www.epa.gov/docs/grd/bailey/
  - Digital versions in ARC/INFO format can also be obtained from the U.S. Forest Service, Ecosystem Management Analysis Center, on a cost-of-production basis.
  - Ecoregion descriptions are available for domains, divisions and provinces at http://www.fs.fed.us/land/ecosysmgmt/ecoreg1_home.html and for sections at http://www.fs.fed.us/land/pubs/ecoregions/toc.html

- Omernik's ecoregion map and descriptions can be obtained from one of the sources below.
  - Paper version: Omernik, J. M. 1987. Ecoregions of the conterminous United States. *Annals of the Association of American Geographers* 77:118–125. Level I–III ecoregion maps and some finer scale level IV maps with detailed ecoregion descriptions can be ordered from the U.S. Environmental Protection Agency Environmental Research Laboratory, Corvallis, Oregon, 541-754-4450.
  - ARC/INFO geographic information systems files: Omernik's level III ecoregions (1987 version) in digital version are available as one of the datasets on the CD-ROM, Conterminous U.S. AVHRR Companion Disc from Customer Services, U.S. Geological Survey, EROS Data Center, Sioux Falls, South Dakota 57198, 605-594-6151 (fax: 605-594-6589; email: custserv@edcserver1.cr.usgs.gov).

- ARC/INFO Internet files: a digital version of level III ecoregions of the conterminous United States (1996 version) is available at ftp.epa.gov/pub/spdata/ecoreg.e00.gz with documentation at http://www.epa.gov/envirofw/html/nsdi/nsditxt/useco.txt

3.2.3 Procedure

- **Identify ecoregion.** Determine the location of the study site on the ecoregion map and note Bailey's hierarchical classifications: domains, divisions, provinces, and if possible the sections and subsections. Also note Omernik's level I, level II, level III, and if possible, the level IV ecoregions. One or both ecoregion systems could be used. County, state, or U.S. maps may be helpful.

- **Describe ecoregion.** Use the ecoregion descriptions (either or both systems) to characterize the regional setting of the assessment site (example in Box 3.1 with Bailey's ecoregion description, and Box 3.2 with Omernik's ecoregion description). If the study site appears to be on an ecoregion line, use the descriptions of the ecoregions on either side of the line and determine which best fits the study site area. Often a stream or river assessment site is influenced more by the upstream ecoregion which produces most of the water, wood, and sediments than by the ecoregion in which the site is located. Note the provinces or sections drained by the watershed of the site if interested in longitudinal stream effects.

3.2.4 Notes

Omernik's classification system has been extensively tested and is widely used by state water quality agencies, many of whom are collaborating with Omernik to produce level IV ecoregions. Due to the extensive testing proving the utility and accuracy of Omernik's classification system, Whittier et al. (1988) concluded that Omernik's ecoregions represented the most appropriate framework for classification of lotic systems.

3.3 Watershed Identification

3.3.1 Rationale

Watersheds are delineated along the topographic divide (see Chapter 4, Drainage Basins) or more simply by noting which streams belong to the same drainage network. Watershed identity is used primarily at the local level to classify effects of natural and anthropogenic phenomena on water quality and quantity. Watersheds are also the appropriate units for explaining fish distribution (Miller 1958) due to the interconnectedness of river basins (Whittier et al. 1988).

Box 3.1 Example of regional setting form with Bailey's ecoregion system.

Investigator: Jane Howard

Date: 01 August 1998

Study site name: Allegheny River

Code #: USEPA Reach 05010001 15 6.30

Watershed name: Allegheny River watershed

Reference: Smith, C. L. 1985. The inland fishes of New York state. The NYS Department of Environmental Conservation, Albany, NY

Hydrologic unit name and code: Upper Allegheny 50010001

Reference: USEPA Surf Your Watershed http://www.epa.gov/surf2/hucs/05010001/

Physiographic province: Appalachian plateau

Reference: Hanson, L. Physiographic provinces of the United States. http://www.salem.mass.edu/~lhanson/gls210/phpr_index.htm

Ecoregion name and number: Laurentian mixed forest — Province 212

Reference: Bailey, R.G. 1995. Description of the ecoregions of the United States. 2nd ed. Pub. No. 1391 Washington, D.C.

Site description:

About the ecoregion

Land-surface form: Most of this province has low relief, but rolling hills occur in many places. Lakes, poorly drained depressions, morainic hills, drumlins, eskers, outwash plains, and other glacial features are typical of the area, which was entirely covered by glaciers during parts of the Pleistocene. Elevations range from sea level to 2,400 ft (730 m).

Climate: Winters are moderately long and somewhat severe, but more than 120 days have temperatures above 50°F (10°C). Average annual temperatures range 35–50°F (2–10°C). A short growing season imposes severe restrictions on agriculture; the frost-free season lasts 100–140 days. Snow usually stays on the ground all winter. During winter, the province lies north of the main cyclonic belt; but during summer it lies within this belt, and the weather is changeable. Average annual precipitation is moderate, 24–45 in (610–1,150 mm); maximum precipitation comes in summer.

Vegetation: This province lies between the boreal forest and the broadleaf deciduous forest zones and is therefore transitional. Part of it consists of mixed stands of a few coniferous species (mainly pine) and a few deciduous species (mainly yellow birch, sugar maple, and American beech); the rest is a macromosaic of pure deciduous forest in favorable habitats with good soils and pure coniferous forest in less favorable habitats with poor soils. Mixed stands have several species of conifer, mainly northern white pine in the Great Lakes region, with a mixture of eastern hemlock. Eastern red cedar is found in the southeast. Pine trees are often the pioneer woody species that flourish in burned-over areas or on abandoned arable land. Because they grow more rapidly than deciduous species where soils are poor, they quickly form a forest canopy; but where deciduous undergrowth is dense, they have trouble regenerating and remain successful only where fire recurs. Fires started by lightning are common in this province, particularly where soils are sandy and there is a layer of dry litter in summer.

Soils: The greatly varying soils include peat, muck, marl, clay, sand, gravel, and boulders, in various combinations. Spodosols are dominant in New England and along the Great Lakes coast; Inceptisols are dominant farther inland. The Alfisols are medium to high in bases and have gray to brown surface horizons and subsurface horizons of clay accumulation.

Fauna: In winter, the shorttail weasel (ermine) and snowshoe hare turn white, as they do in polar provinces. The black bear, striped skunk, marmot, chipmunk, and two genera of jumping mice all pass the winter in hibernation. So do badger and the striped ground squirrel that live in the western parts of the province. Beaver and muskrat remain active all winter, working beneath the ice that covers the lakes and streams. Ptarmigan also turn white in winter. Many other birds, especially insectivorous species, migrate south. Common summer resident birds include the white-throated sparrow, northern junco, and the yellow-bellied sapsucker.

Comments: Bailey's province 212 is within division 210 and domain 200

Box 3.2 Example of regional setting form with Omernik's ecoregion system.

Investigator: Jane Howard

Date: 01 August 1998

Study site name: Allegheny River

Code #: USEPA Reach 05010001 15 6.30

Watershed name: Allegheny River watershed

Reference: Smith, C. L. 1985. The inland fishes of New York state. The NYS Department of Environmental Conservation, Albany, NY

Hydrologic unit name and code: Upper Allegheny 50010001

Reference: USEPA Surf Your Watershed http://www.epa.gov/surf2/hucs/05010001/

Physiographic province: Appalachian plateau

Reference: Hanson, L. Physiographic provinces of the United States. http://www.salem.mass.edu/~lhanson/gls210/phpr_index.htm

Ecoregion name and number: Northern Appalachian Plateau and Uplands — 60

Reference: Omernik, J.M. 1987. Aquatic ecoregions of the conterminous United States. Annals of the Association of American Geographers 77(1):118-125

Site description:

About the ecoregion

Land-surface form: open high hills, tablelands with moderate to considerable relief

Potential natural vegetation: northern hardwoods (maple, birch, beech, hemlock)

Land use: mosaic of cropland, pasture, woodland, and forest

Soils: inceptisols

About the physiographic province

Geomorphology: Moderately to heavily dissected plateau with surface elevations ranging from 1,000 to 4,500 feet (305 to 1372 m). The plateau surface is tilted to the east and is separated from the Valley and Ridge province by a prominent escarpment formed by parallel retreat. Sandstones (e.g., Pocono ss.) create a resistant cap rock.

Geology: Composed of gently dipping sedimentary rocks ranging in age from Devonian through Permian. Foreland basin deposits shed eastward from the rising orogenic belts. The Catskill Mountains are comprised of the Acadian clastic wedge. Deposition of the Ordovician Queenston clastic wedge followed the Taconic orogeny. Portions of the plateaus region that is heavily dissected are referred to as "mountains," less dissected areas are "plateaus." The mountains are residual hills formed by extensive dissection of the plateau. The Plateau in New York, and parts of Pennsylvania and Ohio were glaciated.

Resources: Coal (bituminous), oil and gas, limestone, salt

Comments:

Watersheds have been widely used by resource management agencies to organize reports on the status of water quality in individual states, evaluate the effectiveness of stream buffer strips, clarify nonpoint source–stream nutrient level relationships, and map sensitivity of surface waters to acidification. Omernik and Bailey (1997) compared ecoregion and watershed frameworks and concluded that basins and watersheds are appropriate units for resource management agencies to assess the relative contribution of human activities to the quality and quantity of water at specific points.

3.3.2 Preparation

- Assemble description of sites to locate, necessary maps, watershed identities commonly used in regional or local management, and descriptive information of regional watersheds. Local, provincial, or state maps may be useful for locating study sites near cultural landmarks (e.g., roads, towns).

3.3.3 Procedures

- **Identify watershed.** Select the watershed and optionally the larger river basin from maps showing streams and rivers that include the sites of habitat analysis. Notes can be entered on a regional setting form like the example in Box 3.1 and Box 3.2.

3.3.4 Notes

The U.S. Environmental Protection Agency Surf Your Watershed web site (http://www.epa.gov/surf2/locate/map2.html) could be used to determine the scale of watershed and river basin identities. The web site provides information by watershed so it serves as an example of management scale designations in many parts of the United States.

3.4 Hydrologic Units

3.4.1 Rationale

Hydrologic unit maps, created by the U.S. Geological Survey, provide information on the drainage, hydrography, culture, political, and hydrologic boundaries of the river basins of the United States including Alaska, Hawaii, Puerto Rico, and the Caribbean. These maps depict basic hydrological and political areal planning units, and provide a standard geographical framework for water resource and related land resource planning (Seaber et al. 1994). A hierarchical system was used by designating unique names and codes for 21 major geographic regions (based on surface topography), then subdividing these into 222 subregions designated by the U.S. Water Resources Council, then into 352 accounting units of the U.S. Geological Survey's National Water Data Network, and finally into 2,149 cataloging units of the U.S. Geological Survey's Catalog of Information on Water Data (Seaber et al. 1994).

The 21 major geographic regions are composed of the drainage area of a major river or combined drainage areas of a series of rivers. The second level of classification, the 222 subregions, include the area drained into a river system, a reach of a river and its tributaries in that reach, a closed basin, or a group of streams forming a coastal drainage area (Seaber et al. 1994). The third level of classification includes subdivisions of subregions. Cataloging units, the finest level of classification, are geographic areas representing part or all of a surface drainage basin, a combination of drainage basins, or a distinct hydrologic feature. The cataloging units are generally greater than 700 square miles in area (1,813 km^2).

These four levels of subdivisions are collectively referred to as hydrologic units. The boundaries of these hydrologic units were adapted from several publications: Federal Interagency Committee on Water Resources (1961); U.S. Department of Agriculture (1963, 1970); U.S. Water Resources Council (1970); U.S. Geological Survey (1973); and state planning maps. Political subdivisions are also encoded in the map using the Federal Information Processing Standards codes issued by the U.S. National Bureau of Standards (U.S. National Bureau of Standards 1983). Two basic criteria were followed in delineating boundaries: (1) all boundaries were hydrologic within the United States, though regions and subregions end at international boundaries, and (2) all smaller units nest within the next larger unit.

Hydrologic unit maps are used by water resource organizations for geographical cataloging, coordination, storage and retrieval of survey information and manipulation, organization, and dissemination of data on a geographic, political, and hydrologic basis. The units are widely accepted for use in planning and describing water use and land use activities (Seaber et al. 1994). Agencies are using hydrologic units for managing natural resource data (water rights, water resources, field inventories and surveys, electric generating plants), presenting stream survey and monitoring results, storing and retrieving water quality data, and mapping land cover. The mapping of hydrologic units by the U.S. Geological Survey began in 1972 to provide a standardized nationwide hydrologic reference system for use by a broad range of natural resource agencies.

3.4.2 Preparation

- Acquire hydrologic unit maps for the region of interest (see http://www-atlas.usgs.gov/atlasmap.html or contact the state office of the U.S. Geological Survey Water Resources Division) and habitat analysis site maps or descriptions. Detailed information on cataloging units can be found at the U.S. Environmental Protection Agency Surf Your Watershed web site (http://www.epa.gov/surf2/locate/map2.html).

3.4.3 Procedure

- **Identify hydrologic unit.** Determine the location of the habitat analysis sites on the hydrologic unit map, and note the names of the major geographic region, subregion, accounting unit, and cataloging unit. Record hydrologic unit information and any notes as shown on the regional setting form (see example in Boxes 3.1 and 3.2).

3.4.4 Notes

Hydrologic units are not true topographic watersheds and they lack direct correspondence to waters with similar quality and quantity characteristics (Omernik and Bailey 1997).

3.5 Physiographic Provinces

3.5.1 Rationale

Physiographic provinces are the simplest subdivisions of a land area into hierarchical natural regions. Delineation of physiographic provinces is based on topography (mountains, plains, plateaus, and uplands; Atwood 1940) and, to a lesser extent, climate which governs the processes that shape the landscape (weathering, erosion, and sedimentation; Hunt 1967). The major physiographic provinces of the United States were described by Powell (1896), adopted by geographers, and later refined (Fenneman 1931, 1938). Since the 1930s, several versions of physiographic provinces have been published at the state and national levels with maps and descriptions of characteristics.

Recent delineations of the United States have created 11 major divisions (the broadest hierarchical level) and 34 natural regions (subdivisions of major divisions) called physiographic provinces which include descriptions of climate, vegetation, surficial deposits and soils, water supply or resources, mineral resources, and additional information on features particular to a province where applicable (Hunt 1967). For the most part, the boundaries between provinces are sharp, consisting of a distinct change in structure or topography. However, several provinces grade into one another and boundary lines are necessarily arbitrary (Hunt 1967). Physiographic provinces (Pflieger 1971; Trautman 1981) and drainage basins (Miller 1958) have traditionally been used in aquatic research to identify fish distributions (Hughes et al. 1987; Whittier et al. 1988).

3.5.2 Preparation

- Assemble descriptions and maps of habitat analysis sites, physiographic province maps, and descriptions of province characteristics. Physiographic maps and province descriptions can be obtained in different forms (maps, reference books, and Internet) and spatial coverages: earth (e.g., Chesser 1975), North America (e.g., Atwood 1940; Lobeck 1948), United States (e.g., Hanson 1998), regional (e.g., Miller 1990; Olcott 1995; U.S. Geological Survey 1999b), and states (e.g., Texas Bureau of Economic Geology 1998; U.S. Geological Survey 1998; Maryland State Archives 1999). Some state ichthyological references, such as Pflieger (1975), carry an introduction to physiographic provinces with maps and province characteristics. Detailed information about physiographic provinces of the United States can be found at http://www.salem.mass.edu/~lhanson/gls210/phpr_index.htm. Local, provincial, or state maps may be useful for locating study sites near roads and towns.

3.5.3 Procedure

- **Identify physiographic provinces.** Determine the location of the study site on the map of physiographic provinces and note the description of characteristics. If the study site appears to be on the border line between physiographic provinces, read the descriptions of the provinces on either side of the line and determine which best fits the study site area. A suggested format for data recording is displayed in Boxes 3.1 and 3.2.

3.5.4 Notes

Often a reach is influenced more by the upstream physiographic province which produces most of the water, wood, and sediments than by the province in which the reach is located.

4 Drainage Basins

Anne S. Gallagher

4.1 Introduction

4.1.1 Background

A drainage basin is an area of the earth's surface occupied by a surface stream or lentic water body together with all of the tributary streams, surface, and subsurface water flows. Drainage basins are important to understanding the characteristics of stream habitats (Frissell et al. 1986). The boundaries of a drainage basin are used to explain biogeographic distributions of fish species. Basin features are a factor in predicting flood patterns, estimating sediment yield, and predicting water availability and quality. The downstream transfer of water, sediment, nutrients, and organic material all influence the characteristics of stream habitats. It is therefore important to understand the geologic, hydrologic, morphologic, and vegetational setting of a stream in its basin.

Large-scale features of a drainage basin include the size, shape, and relief of the basin. Small-scale features include measurements of channel length and slope, storage capacity, and drainage density of the stream network within the basin. Each of these geomorphic properties can be used to compare basins. Finally, understanding drainage basin attributes aids habitat investigators when interpreting field data. This chapter has no field component because basin-scale attributes are regularly estimated from maps and digital terrain and land cover data. The information discussed here should be used to complement the biotic and abiotic data acquired through fieldwork.

4.1.2 Selection of Techniques

Three techniques are reviewed below for characterizing different aspects of a drainage basin. The first technique involves quantifying geomorphic properties of a river basin. These properties include a variety of measurements that are best used to compare the environmental settings of different habitat assessment sites in the same region. Quantifying geomorphic properties requires detailed work with topographic maps or geographic information systems (GIS) data. The second technique, stream ordering, provides an easy method for classifying streams in a drainage network based on their size and type of tributary junctions. Stream order is probably the single most common descriptor of fish sampling sites reported by fisheries biologists, and stream order is routinely reported in fisheries field studies. The third technique is used to classify the land use and land cover of the basin. Land cover and use information is increasingly being made available in digital form.

4.2 Geomorphic Properties

4.2.1 Rationale

The most useful basin attributes for characterizing the setting of a stream and drainage basin are described here. The properties can be measured and estimated by one of two basic approaches. Basic area and length measurements can be done by hand on topographic maps. Alternatively, a computer program of the U.S. Geological Survey (Basinsoft; Harvey and Eash 1996) can be used with GIS data to compute the geomorphic properties.

4.2.2 Preparation

- Acquire U.S. Geological Survey (USGS) topographic maps at 1:24,000 scale (preferred, or use 100,000 scale) that cover the entire drainage network of streams and adjacent drainage basin streams.

- Gain access to a GIS unit with a digitizer, software, and a trained technician. Alternatively, obtain a polar planimeter or a 100 dot-per-square-inch transparent overlay with a map measurer (see Figure 16.1) and ruler.

4.2.3 Procedures

- Delineate the drainage basin on a topographic map. The drainage basin divide (border) should approximate all locations at which surface run-off splits flow into and away from the basin. For all of the land enclosed in the drainage divide, precipitation drains by gravity into the stream or water body within the basin. Review the topographic map features outlined in Box 4.1 to properly interpret map notations. Draw the drainage divide according to the following steps and refer to Figure 4.1 for an example. The drainage divide should begin and end at the mouth of the stream or river being studied and should enclose only its tributaries. Draw the drainage divide perpendicular to each of the contour lines it crosses. On flat areas, such as along contour lines, divide in half the areas between streams of different basins. This division should approximate the location at which surface waters split flow and fall naturally by gravity into their respective basins. If only a portion of a drainage basin is being considered (e.g., the drainage area of a study site along a stream segment), the drainage divide line may turn abruptly and proceed straight down to the channel at the study site.

Estimate the total drainage area by measuring the map area enclosed by the drainage divide in one of three ways.

1. Digitize the drainage basin into a GIS file and obtain the drainage area using the computer software. Note that some drainage basins may already be digitized by state or federal agencies and this information may be accessible to the public.

2. Outline the drainage basin with a polar planimeter (a device that calculates the area of any plane) by moving the tracer point along the drainage divide and recording the enclosed area in vernier units. Convert the vernier units to a conve-

Box 4.1 Topographic map features for determining a drainage divide.

- Streams on a topographic map are represented by blue lines. Solid blue lines represent perennial streams. Dashed blue lines represent intermittent streams.
- Water bodies are blue.
- Brown lines are contour lines, which mark areas of equal elevation. Closely spaced contour lines mark areas of steep gradient, while distant contour lines indicate a more gradual slope.
- Contour lines tend to form “V”s where they intersect streams and “M”s above stream junctions. These “V”s and “M”s point upstream. Use this to help locate all upstream contributing stream segments.
- Note the location of the headwater streams (i.e., streams with no tributaries). They should be enclosed in the drainage divide separated from the headwater streams supplying different drainage basins. Only streams that flow into the study site should be included in the drainage divide.

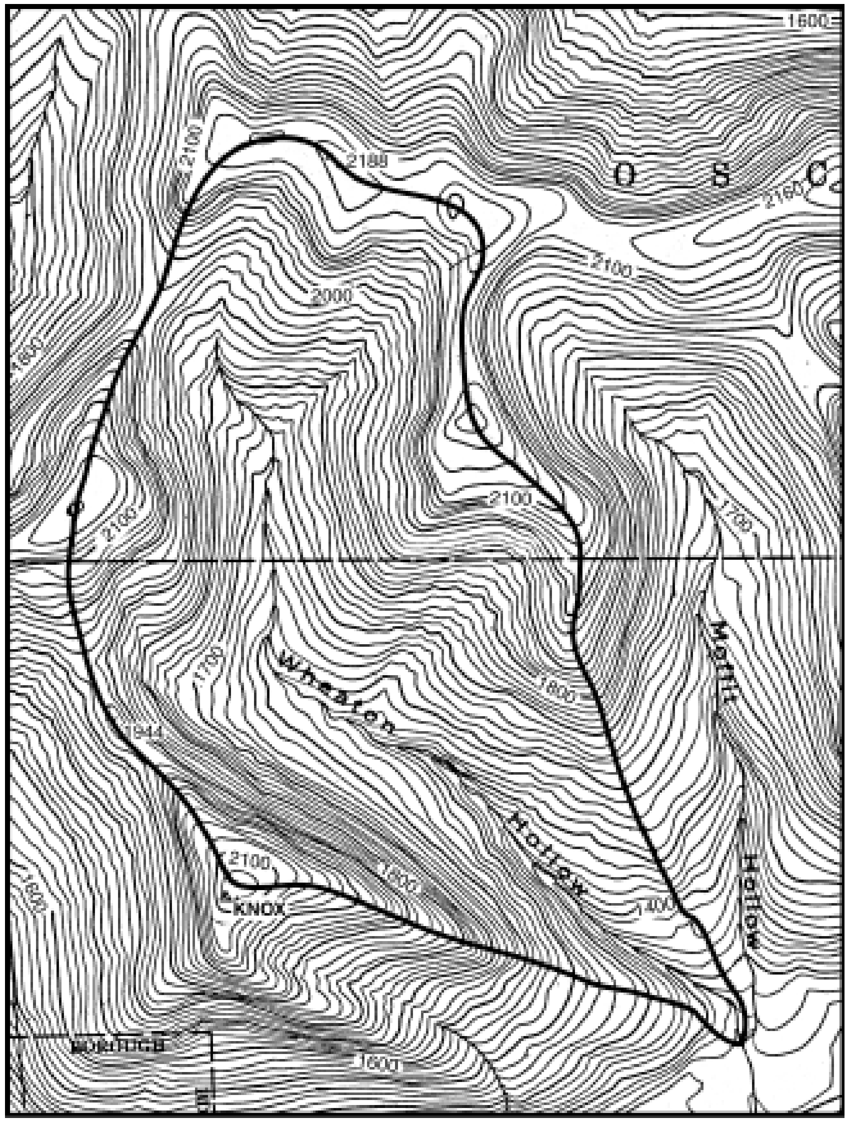


Figure 4.1 Example drainage divide on a topographic map.

nient area measurement (e.g., square kilometers) based on the scale of the map and the conversions provided with the planimeter.

3. Use a 100 dot-per-square-inch transparent overlay placed over the drainage basin. Count the total number of dots falling within the basin divide and one-half of the number of dots falling on the divide line. If the basin is larger than the overlay, divide the basin into smaller sections and measure each smaller area. Check Table 16.1 for the correct conversion factor (note map scale) and multiply the total number of dots counted by this conversion factor to obtain the area of the basin in square kilometers. Note that the precision of this

measurement can be improved by increasing grid density on the overlay.

Once the drainage divide is drawn on a map and the area has been estimated, the geomorphic properties can be estimated, measured, or computed. Each of the geomorphic properties listed below includes a definition and explanation of its importance to basin characterization.

Basin length. Basin length is estimated as the straight-line distance between the mouth of the basin and the drainage divide nearest to the source of the main stream. Use a map measurer or a ruler to measure a line drawn on the map. Basin length is used to calculate drainage shape.

Basin relief. Basin relief is the difference in elevation between the highest and lowest points in the basin. It controls the stream gradient and therefore influences flood patterns and the amount of sediment that can be transported. Hadley and Schumm (1961) showed that sediment load increases exponentially with basin relief.

Basin relief ratio. The basin relief ratio index is the basin relief divided by the basin length. It is useful when comparing basins of different sizes because it standardizes the change in elevation over distance.

Basin surface storage. The percentage of the basin covered in lentic and impounded water bodies, including wetlands (optional), reflects the surface storage capacity of the basin. Determine the basin surface storage by measuring the area of each lake or impounded water body. Wetland areas will have to be estimated because the borders are not delineated on topographic maps. Follow the instructions for measuring area given above. Add all water body and wetland areas and divide this sum by the drainage area.

Drainage density. An index of the length of stream per unit area of basin is calculated by dividing the drainage area by the total stream length. This ratio represents the amount of stream necessary to drain the basin. High drainage density may indicate high water yield and sediment transport, high flood peaks, steep hills, low suitability for agriculture, and high difficulty of access.

Drainage shape. An index of drainage shape is computed as a unitless dimension of drainage area divided by the square of basin length (Horton 1932). It describes the elongation of the basin and is useful for comparing basins. If two basins have the same area, the more elongated one will tend to have smaller flood peaks but longer lasting flood flows (Gregory and Walling 1973).

Main channel slope. Main channel slope is an estimate of the typical rate of elevation change along the main channel that drains the basin. This measurement is often related to peak flow magnitude and flood volume. Estimate the main channel slope by measuring the length of the main channel from the mouth of the stream or the study site to the mapped source of the main stream. At each stream channel bifurcation, follow the fork with either the higher stream order number (explained below) or the longer pathway to a stream source. Mark off 10% and 85% of the main channel length on the map. Estimate the elevation in meters at the 10% and 85% distance points, using the contour lines on the topographic map. Compute the main channel slope as follows:

Slope = (elevation at 85% length – elevation at 10% length) / 0.75 (main channel length).

Total stream length. Total stream length is the sum of the lengths of all perennial streams within a basin as shown on a topographic map. Determine the total stream length by measuring the length of each perennial stream section with a map measurer. Sum these individual stream lengths. The summed stream lengths determine the total amount of stream habitat in a basin and the availability of sediment for transport (Meador 1998).

The Basinsoft computer program of the U.S. Geological Survey produces estimates for all of the above geomorphic properties and several more. The program requires four digital map layers: drainage basin boundary, hydrography, hypsography, and a lattice elevation model. Habitat investigators with access to GIS usually find that the computer program is the most efficient method for basin geomorphic assessment. The software is described by Harvey and Eash (1996), and the U.S. Geological Survey is continuing development of this software. For the most recent information, contact: Craig Harvey, U.S. Geological Survey, Water Resources Division, 308 South Airport Road, Pearl, Mississippi 39208-6649, 601-933-2983 (email: caharvey@usgs.gov).

4.3 Stream Order

4.3.1 Rationale

Stream order, or classifying streams based on the number and type of tributary junctions, is an easily obtained, useful, but general indicator of stream size, discharge, and drainage area. There are several techniques for determining stream order. Horton (1945) developed a system for ordering streams that Strahler (1964) later refined. In this system, the headwaters of a stream are designated first order, and the confluence of two streams of order n forms a stream of order $n + 1$. For example, the confluence of two second-order streams forms a third-order stream, but the confluence of a second- and third-order stream yields a third-order stream. Given this system, relationships can be developed between stream order and the number of stream segments within the drainage network, and between stream order and stream length. The higher the stream order, the fewer the number of streams at that order and the longer the stream length. In addition, the amount of water drained by a stream increases with stream order. As stream order increases from order n to order $n + 1$, there are usually three to four times fewer streams, each of which is generally twice as long and drains four to five times as much area (Allan 1995).

Shreve (1967) developed the link system of ordering streams in which the orders of upstream tributaries are summed. For example, the confluence of a second-order and a third-order stream forms a fifth-order stream. This system relates a given stream segment to upstream and downstream influences within its basin. This information may be useful when analyzing fisheries data. For example, a small tributary stream that feeds a large river might have a large link number, which would indicate that although the stream is small, it may have large river species (Meador 1998).

Both of the techniques are outlined below. Choosing which technique to use for ordering streams should depend on how the information will be used. The Strahler system of stream ordering is used most frequently, and unless otherwise noted, it is assumed that this is the technique used.

4.3.2 Preparation

- Acquire USGS topographic maps at 1:24,000 scale that cover the entire drainage network of streams. All stream ordering methods depend on the source and scale of maps used to count tributaries. By common practice, it is assumed that stream ordering is done at the 1:24,000 scale. Other scales may be used, but always use the same source and scale of map when ordering streams and making comparisons among basins. Be sure to report the scale when a scale other than 1:24,000 is used.

4.3.3 Procedures

- For both the Strahler and the link systems, a first-order stream is the furthest upstream section of a stream (headwater stream), and a stream section is a length of stream between any two intersections (sources, mouths, or tributary mouths). Leopold et al. (1964) recommended counting both perennial and intermittent streams when using a 7.5-min USGS topographic map. Others count only perennial streams. Either approach may be used if it is used consistently.

- For the Strahler system, order streams as follows. Two first-order streams meet to form a second-order stream. Two second-order streams meet to form a third-order stream. This pattern continues such that when two streams of order n meet, they form a stream of order $n + 1$. When one stream is met by another stream of a lesser order, its order does not change. Both streams must be of the same order when they flow together to create a stream of the next higher order. See Figure 4.2A for an example.

- For the link system, order streams as follows. Add the stream order numbers of the upstream tributaries to get the order of the resulting stream. Two first-order streams meet to form a second-order stream, and two second-order streams meet to form a fourth-order stream. See Figure 4.2B for an example.

4.4 Basin Land Cover

4.4.1 Rationale

Land cover comprises the geology, soils, vegetation, and land use of an area. Geology influences the shape of drainage basin patterns, streambed material, water chemistry, and base streamflow. Soils influence infiltration rates and vegetation types, and vegetation has a large role in determining channel bank stability, surface runoff, and water loss through evapotranspiration (Dunne and Leopold 1978). Land use can effect soil permeability, vegetation, and most parts of the hydrologic cycle. Characterizing these interrelated components of a drainage basin provides important information for interpreting field and biological data.

4.4.2 Preparation

▶ Obtain printed or digital maps of land cover for the drainage basin being studied. Thematic digital maps of land use, geology, soils, and vegetation are available from the USGS EROS Data Center (http://edcwww.cr.usgs.gov) and the USGS Global Land Information System (http://edcwww.cr.usgs.gov/webglis/glisbin/glismain.pl). Local or regional maps and aerial photographs may provide better resolution and more recent data than national maps.

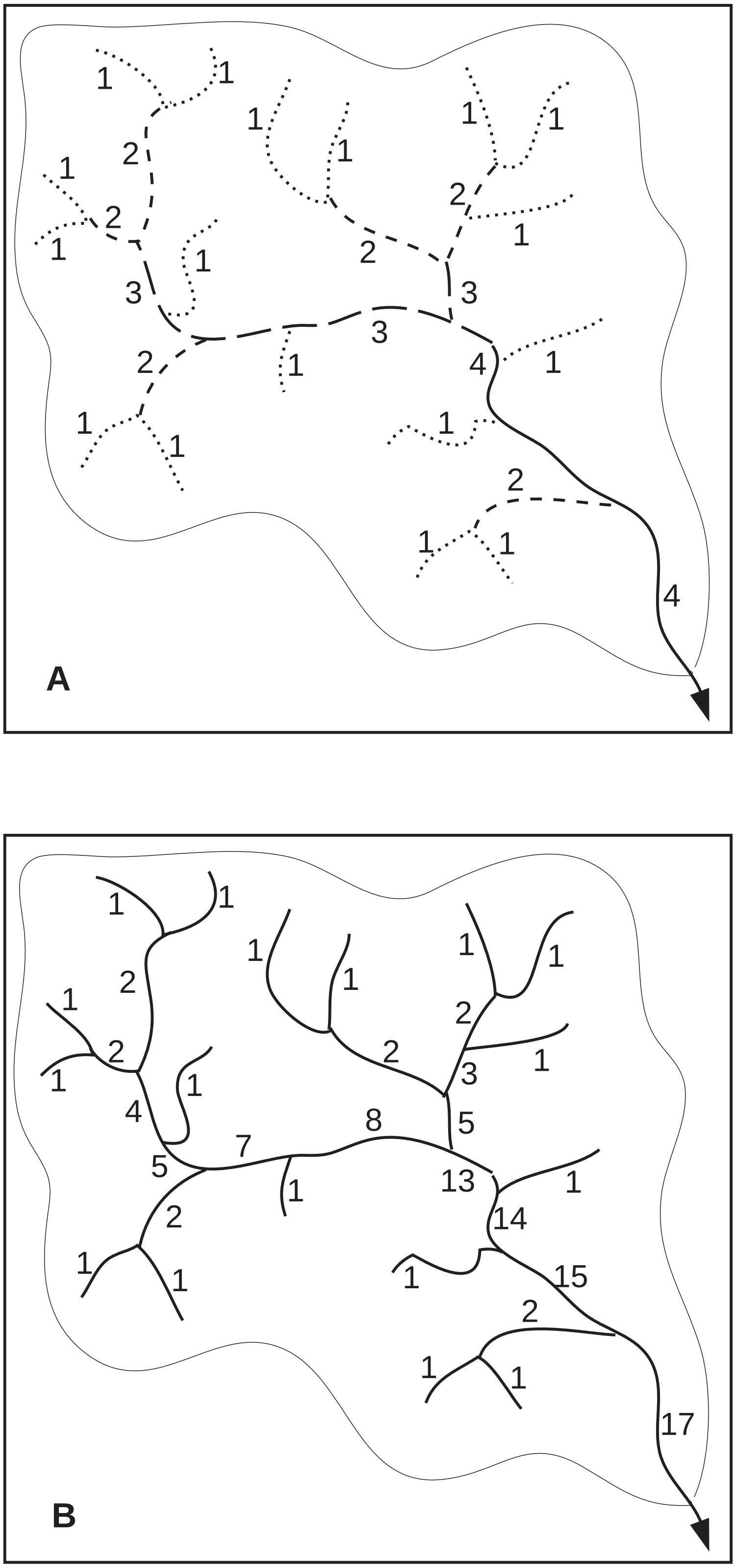


Figure 4.2 Numbering stream orders using the Strahler system (A) and the link system (B).

4.4.3 Procedures

- Geographic information systems with thematic maps and the drainage area divide can be used to break down land cover features in area measures (km^2) or percentages. The same values can be obtained by manually working (area estimates described above) with map overlays produced from the thematic maps or similar information.

Water Body Identification 5

Marcia S. Meixler

5.1 Introduction

5.1.1 Background

The term water body refers to any source of water or hydrologic feature such as a stream, river, lake, pond, canal, wetland, reservoir, or spring (see definitions in Table 5.1). Thorough and detailed identification of water bodies for sampled sites is important for organization in databases, identification by other data users, and relocation on maps or in the field. In addition, carefully documented databases with precise location identifiers can be used to create spatial hydrological representations using geographic information systems (GIS). Once in GIS, current data can easily be related to previously collected data and examined for changes over time or used in land and resource management planning over large geographical areas.

Three distinct forms of documentation are described in this chapter: position identification, location coding, and descriptive attributes. Each form of documentation is important on its own merit for particular data uses; however, when all used together, a water body is thoroughly identified and documented. Position identifiers such as latitude, longitude, elevation, and universal transverse mercator (UTM) coordinates are helpful in locating the water body on topographic maps. Location coding assigns a unique number to each water body. This is the primary requirement for relational data, because it links field data to point, line, and polygon entities which represent water bodies in GIS. Descriptive attributes such as water body name and type, land ownership, accessibility, and general comments are important field identifiers for the site.

Table 5.1 Water body types and definitions from Armantrout (1996) with designation codes for use on field forms and in databases.

Type	Code	Description
Catchment, pit	C	Basin for catching water from surface runoff or seepage. Pond formed by accumulation of water in an area excavated to catch and store water.
Bog, marsh, wetland	B	Lands where saturation with water is the dominant factor determining the nature of soil development and the types of plant and animal communities living in the soil and on its surface. Soils or substrates that are at least periodically saturated with or covered by water, and differ from adjoining non-inundated areas.
Spring, seep	S	An issue of water from the earth taking the form, on the surface, of a stream or body of water. A small spring, pool, or other place where a minor amount of groundwater has emerged to the land surface or into a stream. A seep describes an amount of water coming to the surface which is too small to be considered a spring.
Well	W	A hole dug or drilled into the earth, or a natural spring source of water.
Guzzler	G	Water entrapment and containment structure used primarily to provide water for wildlife and livestock in arid regions.
Pond	P	Body of standing water smaller than a lake.
Gully, wash	Y	A depression or channel with water seasonally or periodically and formed by water such as the dry bed of an ephemeral stream.
River	R	Natural stream flowing in a definite course or channel, or a series of diverging and converging channels. Includes streams, creeks, brooks, runs.
	R1	Any river or stream not specified by other codes below.
	R2	Falls: a reach that is either a waterfall, drop spillway, or a reach of rapids.
	R3	Headwater: a headwater reach that has no reaches above it but one or several reaches on its downstream end.
	R4	Terminal: a reach downstream from which there is no other reach (e.g., a reach that terminates into an ocean or the ground).
Lake	L	Body of fresh or saline water of considerable size completely surrounded by land.
	L1	Any lake not specified by other codes below.
	L2	Reservoirs: a body of impounded water stored for the purpose of altering the timing of flow for future use such as irrigation, flow augmentation, treatment, and power generation.
	L3	Cirque lake: a small body of water occupying a cirque (a deep, steep-walled recess in a mountain caused by glacial erosion) depression dammed by a rock lip, small moraine, or both.

Table 5.1 Continued.

Type	Code	Description
	L4	Moraine lake: a lake formed by glacial drift blocking a valley or drainage courses.
	L5	Potholes, kettles: a lake in a drift depression made by the wasting away of a detached mass of glacier ice that had been either wholly or partly buried in the drift.
	L6	Oxbow lake: a lake formed in an abandoned riverbed which has become separated from the main stream by a change in the course of the river.
	L7	Pasternoster lake: a chain of smaller lakes in a glaciated valley formed by the corrosive action of ice.
	L8	Thaw lake: a lake or pond basin in permafrost areas that are formed by the thawing of ground ice. A pool of water on the surface of sea ice or formed by accumulation of melt water on large glaciers.
	L9	Beaver pond: impoundment made by beavers.
	L10	Playa: broad, shallow sheets of water that quickly gather and almost as quickly evaporate, leaving mud flats to mark their sites.
	L11	Alkali: a lake formed in low depressions. Water evaporation deposits fine sediments and dissolved minerals which form a hard surface if mechanical sediments prevail or a crumbly powdered surface if efflorescent salts are abundant.
	L12	Coastal: a lake on any plain that has its margin on the shore of a large body of water, particularly the sea, and generally represents a strip of recently emerged sea bottom.
	L13	Gravel pit: lake formed in excavations resulting from the removal of sand and gravel.
	L14	Rift: a lake formed in depressions resulting from the intersection of a fault plane with the land surface.
	L15	Sink: a lake formed in a depression or poorly drained area formed where the underlying rock dissolves and water collects.

5.1.2 Selection of Techniques

Water body identification techniques can either work together to achieve detailed site documentation or each can be used independently to record select information for future reference. Location information is easy to obtain in the office or at the study site and is useful for identifying the position of the site on topographic maps or in GIS. Most global positioning system units used in the field give fairly accurate latitude, longitude, elevation, and UTM data, reducing the need to obtain this information from topographic maps.

An assessment site or water body identifying code should be made up entirely of numbers, unique for every water body, objectively determined (e.g., each user would determine the same code independently), available at a fine scale, and used nationally. The closest system for this is the nationally used U.S. Environmental Protection Agency (USEPA) reach coding system, which assigns a unique 17-digit number for each water body (U.S. Environmental Protection Agency 1994). This coding system is oriented toward relating database information on streams to spatial hydrology in GIS and, therefore, the coding information is provided to the public in digital format compatible with GIS. Individuals without access to GIS may have difficulty obtaining paper maps that show the USEPA reach code numbers. Another drawback of this system is the scale. Only water bodies visible at the 1:100,000 scale will be represented in the USEPA reach system. There is currently no national coding system for water bodies at a scale finer than 1:100,000. General coding information, the U.S. Geological Survey (USGS) hydrologic accounting unit and catalog unit codes, can be used to give an approximate location of the water body. These codes are easily identifiable, made up entirely of numbers, unique, objective, and used nationally.

Finally, descriptive attributes (water body name and type, land ownership, and accessibility) are easy to determine and useful in finding field sites on future visits. Descriptive attributes take time to complete, but there are no other disadvantages to using this technique.

5.2 Position Identification

5.2.1 Rationale

Often data are shared by many biologists or agencies to enhance databases or create applications in GIS. Consequently, it is important for data users to be able to easily locate sampled water bodies on topographic maps. Latitude, longitude, elevation, and UTM coordinates can be quickly and easily obtained from USGS topographic maps in the office or the field.

Latitude, longitude, and UTM coordinates define the location of a point on earth in two-dimensional space. The addition of elevation to latitude and longitude coordinates enables the description of a point in three-dimensional space. The combination of latitude, longitude, and elevation is the most common coordinate system in use today. Locations in GIS applications are often defined by UTM coordinates and are as easy to read as latitude, longitude, and elevation values. Dana (1998) provides a thorough review of these coordinate systems.

Lines of longitude run north and south and lines of latitude run east and west. The longitudinal line at zero degrees is called the prime meridian and the latitudinal line at zero degrees is the equator. Values for longitude and latitude are given in degrees, minutes, and seconds with an indication of position north (N) or south (S) of the equator for lines of latitude and east (E) or west (W) of the prime meridian for lines of longitude. When defining a point, use both latitude and longitude values and note whether the value is north, south, east, or west. Elevations are defined in feet or meters of altitude above sea level. A typical format for defining position using longitude, latitude, and elevation is shown on the water body identification form in Box 5.1.

The universal transverse mercator projection was designed by the U.S. military and uses a system of rectangular zones defining an area in 6º longitudinal strips extending from 80º south latitude to 84º north latitude. Each zone has a central meridian situated 3º in longitude from each border; therefore, in zone 17, the central meridian is at 81º west longitude since the zone extends from 78 to 84º west longitude (see Dana 1998 for a graphical depiction). North and south coordinates called northings, east and west coordinates called eastings, and a zone number are used to describe geographic location using UTM coordinates. Eastings are measured as distance in meters from the central meridian and northings are measured as distance in meters from the equator. An additional 500 km are added to the easting coordinate value to ensure positive coordinates (called a false easting) and 10,000 km are added to values for positions south of the equator (called a false northing). Box 5.1 shows the typical format for defining position using UTM coordinates.

5.2.2 Preparation

- Acquire USGS topographic maps at 1:24,000 scale (or use 100,000 scale) from 1-800-USA-MAPS (1-800-872-6277), or 1-800-HELP-MAP (1-800-435-7627), or from a local store. If unsure which maps you will need, see the U.S. Geological Survey (1999a) Geographic Names Information System at http://mapping.usgs.gov/www/gnis/gnisform.html

- Prepare data recording sheets.

5.2.3 Procedures

- **Record basic information.** Locate the water body on the appropriate map and record basic topographic information on a data sheet for each water body or habitat. Note the USGS topographic map name provided on the map in the bottom right corner. Also record the county, state, date of map, and scale (bottom, center of map).

- **Identify latitude and longitude coordinates.** Determine and record the latitude and longitude of the water body from the topographic map; include degrees, minutes, seconds, then direction (N or S for latitude, E or W for longitude). To determine the latitude for water bodies that do not fall directly on latitude and longitude lines, (1) align a straightedge horizontally from the water body to the point of intersection with the edge of the map, Box 5.1 Example of water body identification form use.

Observer(s): Jane Howard Date: 01 August 1998

Position identification

USGS topographic map name Knapp Creek Scale 1:24,000

County Cattaraugus State New York Date of map 1979

Latitude 42'05"24°N N or S Longitude 78'30"6.6°W E or W

Elevation 1410 Feet Feet or meters

UTM 4662572mN 706928.6mE Zone 17

Water body coding

General coding:

USGS hydrologic accounting unit: name Ohio Region, Allegheny River Basin code# 050100

USGS catalog unit: name Upper Allegheny code# 05010001

USEPA reach code 05010001 15 6.30

State or other codes: code name: WIN code#: PA-53

State or other codes: code name: NY state code code#: 21NYDECA

Descriptive attributes

Water body name Allegheny River

Water body type R1 Land ownership Private 4

Accessibility and location Site along right side of Rt. 60 heading west after bridge leaving the town of Allegany; mostly chest deep water, but canoe helpful in places

Photographs: Roll 2 Frames 5,6,7

Comments: Frame explanation: 5 (upstream) , 6 (downstream), 7 (bank erosion); Mucky bottom

(2) find the tick marks for the nearest coordinates and determine their distance from the straightedge using a ruler or instrument with tick marks, and (3) add to or subtract from the nearest coordinate value as necessary to determine the latitude of the water body. For example, on a 1:24,000 scale topographic quadrangle, longitudinal and latitudinal tick marks are 2 min and 30 s apart. If a straightedge intersects the edge of the map four-fifths of the distance above the nearest lower (southern) coordinate value, 30 s should be subtracted from the value above (northern) to determine the latitude of the water body. The process should be repeated using the straightedge in the vertical direction to calculate the longitude of the water body.

- **Estimate elevation.** Determine the elevation of the water body from the contour lines on the topographic map. Make sure to note if the value is in feet or meters. The topographic map will have information on the contour interval and units in the bottom, center of the map. Record the elevation interval for the location or use interpolation to obtain a more precise elevation value.

- **Identify UTM coordinates.** Determine the UTM coordinates and zone of the water body from the topographic map. Alternatively, to convert latitude and longitude coordinates to UTM coordinates, look on the Internet: http://www.geod.nrcan.gc.ca/products/html-public/GSDapps/English/online_applications.html (Natural Resources Canada 1999).

5.2.4 Notes

A suggested format for data recording is given in Box 5.1, and a blank data sheet is in Box 5.2.

Latitude, longitude, elevation, and UTM coordinates can also be determined from a precision instrument called a global positioning system (GPS). Specially coded signals from four satellites are processed in a GPS receiver, which then computes position, velocity, and time. Latitude and longitude are usually provided in the geodetic datum on which GPS is based (WGS-84), however, receivers can often be set to convert to other user-required datums (such as UTM, Dana 1998). Global positioning systems are available in many sizes and with varying degrees of sophistication. Several have the ability to store information which can be downloaded directly to a computer. Accuracy of the data from GPS receivers depends on level of noise, bias such as Selective Availability (SA) interference by the U.S. government to maintain optimum effectiveness of the military system, and user error. The noise and bias errors combine to cause typical ranging errors of around 15 m for each satellite signal used by the GPS unit to compute a position (minimum of four satellites). User errors alone (e.g., incorrect GPS unit configuration), can result in errors of hundreds of meters (Dana 1998).

Box 5.2 Water body identification form.

Observer(s): ______________________ Date: ______________________

Position identification

USGS topographic map name ______________________ Scale ____________

County ____________ State ____________ Date of map ____________

Latitude ____________ N or S Longitude ____________ E or W

Elevation ____________ Feet or meters

UTM ____________ ____________ Zone ____________

Water body coding

General coding:

USGS hydrologic accounting unit: name ____________ code# ________

USGS catalog unit: name ____________ code# ________

USEPA reach code ______________________

State or other codes: code name: ____________ code#: ________

State or other codes: code name: ____________ code#: ________

Descriptive attributes

Water body name ______________________

Water body type ____________ Land ownership ____________

Accessibility and location ______________________

____

Photographs: Roll ____________ Frames ____________

Comments: ______________________

____

____

____

____

____

5.3 Water Body Coding

5.3.1 Rationale

Water body codes are unique, identifying numbers for each stream and lake in the United States. Coded survey data are stored in relational databases for later evaluation, manipulation, and location identification. At present there is no nationwide coding system at a scale finer than 1:100,000. The coding systems presented here include coarse-scale watershed codes and the USEPA reach codes. The coarse-scale codes are from the USGS hydrologic accounting units (sample, Figure 5.1). This information can be used to give a researcher the approximate location of the water body. Finer-scale codes are from the USEPA reach file version 3 (U.S. Environmental Protection Agency 1994). Code numbers are obtained from digital GIS files (example in Figure 5.2) given to the public by the USEPA. The USEPA reach file is only applicable for water bodies that appear on maps at the 1:100,000 scale, but the file has unique 17-digit numbers for each water body segment. The USEPA reach codes are available on a national scale and they are easy to determine. However, this system may be difficult to use if habitats and water bodies appear only on fine-scale maps, and when access to GIS is not readily available. Many states have developed coding systems for water bodies at a fine scale, and these should be used when possible.

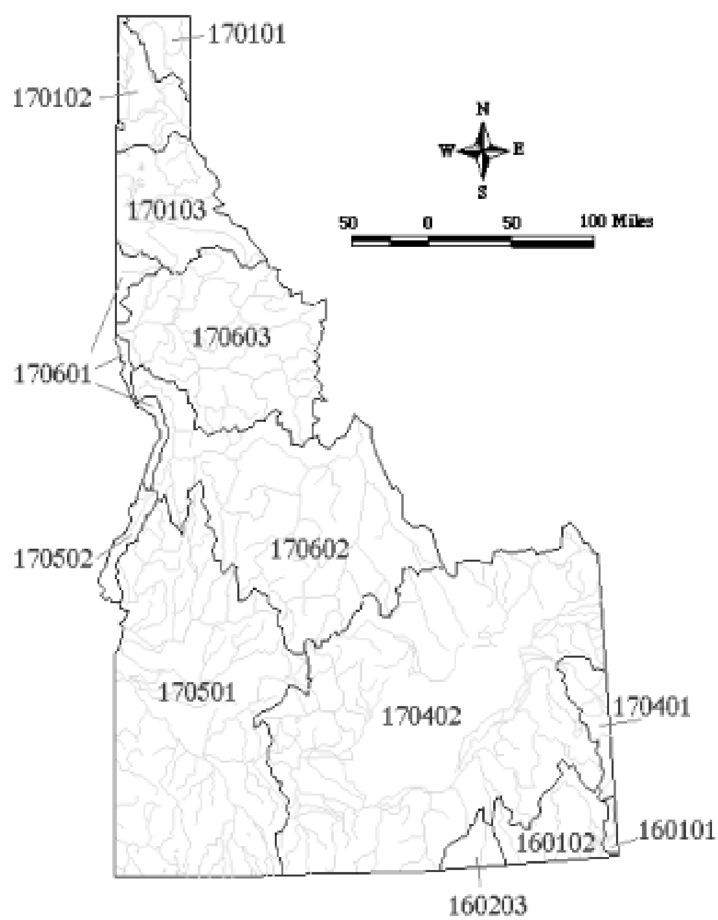


Figure 5.1 U.S. Geological Survey hydrologic units for the state of Idaho. Source: University of Montana(1999).

5.3.2 Preparation

- Acquire USGS topographic maps at 1:24,000 scale (see section 5.2.2), locate water body, and prepare data sheets.

- Access hydrologic unit codes from the USGS internet site (http://water.usgs.gov/Public/GIS/huc.html), USEPA's Surf Your Watershed site (http://ww.epa.gov.surf2), or obtain a listing of hydrologic accounting units and catalog unit names from USGS Water Supply Paper 2294 (Seaber et al. 1987), available from the U.S. Geological Survey Information Services, Den-

Figure 5.2 Sample stream network map from the U.S. Environmental Protection Agency reach file showing codes for all stream segments.

ver Federal Center, Box 25286, Denver, Colorado 80225, 1-800-435-7627.

- Obtain the necessary USEPA digital maps from 1-800-424-9067; you must know the hydrologic accounting unit and catalog unit codes when calling (see section 5.3.3). Print a copy of the USEPA reach file (version 3) map with associated reach codes if coding in the field.

5.3.3 Procedures

- **Coarse-scale codes.** Determine the USGS hydrologic accounting and catalog unit names and codes for the water body from the Internet or the USGS Water Supply Paper 2294.

- **Fine-scale codes.** Use a topographic map to locate the water body on the digital or paper version of the USEPA reach map (produced by GIS). Determine the reach code (called an “Rf3rchid” code in the USEPA reach program).

5.3.4 Notes

A suggested format for data recording is displayed in Box 5.1, and a blank data sheet is in Box 5.2.

Many states have developed their own systems for identifying water bodies. It maybe useful to locate a paper or digital explanation of the coding system used by your state.

A coordinated effort was underway to combine the features of the USEPA river reach files (RF3) with the USGS digital line graph (DLG-3) hydrography files to create a National Hydrography Dataset (NHD). The goal is a comprehensive digital nationwide 1:24,000-scale dataset, available on the Internet. Each water body at the 1:24,000 scale will be assigned a unique 14-digit code number.

The final datasets will be made publicly available. You can track progress of this effort at http://www.usgs.gov or http://www.epa.gov or by searching for "national hydrography dataset" on USGS and EPA web sites.

5.4 Descriptive Attributes

5.4.1 Rationale

Describing surveyed water bodies and habitats is a valuable part of the site identification process. Water body name and type, land ownership, accessibility, and general notes are recorded while at habitat assessment sites. Markings on topographic maps and pictures are helpful if the site has not been previously documented. A water body name can reflect local terminology, and the water body type designation facilitates comparisons among comparable waters (Armantrout 1996). Land ownership identifies the property rights associated with the land surrounding the water body. Accessibility is a short, written description of how to reach the water body. General comments account for anything not covered above.

5.4.2 Preparation

- Assemble topographic maps, camera, and data sheet.
- Obtain permission to survey on private land, if necessary
- Become familiar with the water body if notes are to be completed independently of the habitat assessment.

5.4.3 Procedure

- Determine the water body name from the topographic map or local knowledge of the area. Using water body type definitions in Table 5.1, determine the type and enter the code on the data sheet. Note any new management actions and the responsible agency. Note site ownership and characterize accessibility as: (1) entry prohibited, (2) access through public property, (3) access not available at all times to all people, (4) public is permitted. Accessibility descriptions should be written descriptively, noting landmarks and road names if applicable. Take photographs of the site and record the roll and frame numbers. Mark the location of the habitats and water body on a topographic map. Additional description of the water body can be included in the comments section of the sample data sheet (Box 5.2).

Stream Reach Surveys and Measurements

6

Kristin K. Arend and Mark B. Bain

6.1 Introduction

6.1.1 Background

Channel dimensions are closely related to the hydrology, local geology, climate, and condition of the watershed. An assessment of channel dimensions provides the finest level of resolution at which a stream reach can be related to the whole stream as well as the entire watershed. Data from channel assessments are typically compiled to develop a detailed description of habitat unit (e.g., pool, riffle, etc.) dimensions, channel form and pattern, discharge, substrate, bank condition, and riparian vegetation. Also, when values are known for certain dimensions, estimates and values of other stream reach characteristics can be calculated. For example, water velocity is directly related to stream width, depth, slope, and channel roughness, and from these values the discharge of a stream can be calculated. Finally, measurements of channel dimensions are frequently used to map assessment sites and scale maps provide accurate descriptions of habitat units.

Cross-sectional and longitudinal (upstream–downstream) profile surveys are conducted along a series of transects spaced throughout a stream reach to create a geomorphic depiction of the assessment site. At each transect, surveyors take measurements and collect data necessary to accurately record the dimensions of a stream site and to precisely quantify the position of stream features. Cross-sectional and longitudinal profile surveys are often conducted along permanent transects so they can be reevaluated over time and during different seasons. Changes in stream hydrology and morphology can then be monitored and related to management or restoration efforts, anthropogenic activities, or natural events.

The objective of a stream reach survey is to deduce a representation of the stream as accurately as possible, without actually sampling it in entirety. Therefore, select survey sites (i.e., stream reaches) that are representative of a stream. Field sketches and dimensional data are used to produce an accurate, representative picture of the stream and to locate the reach for subsequent surveys. General surveys can be conducted throughout the year and under various flow conditions; however, many of the techniques used in reach surveys (e.g., water surface elevation measurements) can only be conducted in wadeable streams during periods of low flow because of equipment limitations and safety concerns. Reach surveys should be conducted at typical low flow conditions when habitat features are most evident.

6.1.2 Selection of Techniques

This chapter presents techniques for conducting two-dimensional map and one-dimensional cross-sectional and longitudinal profile surveys and for measuring channel and habitat dimensions. Many other stream assessment techniques can be incorporated into the reach survey (e.g., reach type classification, channel geomorphic unit identification, riparian vegetation characterization, and fish cover). The following techniques are commonly used, time efficient, and reasonably accurate. They focus on establishing an assessment site, conducting cross-section measurements, developing a scale map, and producing a longitudinal profile. Select specific techniques according to study objectives and equipment and time restrictions. Instructions for using surveying equipment are not provided, but can be found in many survey manuals including some that focus on stream habitats (Gordon et al. 1992; Harrelson et al. 1994).

6.2 Preparation

- Field staff should be experienced in the use of surveying equipment and terminology. Practice and the study of survey technique manuals (e.g., Harrelson et al. 1994) are the best ways to gain experience.

- Acquire measuring tapes, stakes and flagging, a survey level, a telescoping surveyor's rod, a folding tripod, chest and hip waders, a compass, and material for making field sketches. Two-way radios equipped with headsets are optional but very helpful for communication between surveyors in high gradient streams with rapids.

6.3 Procedures

- **Select site and transect arrangement.** Choose a section of a stream where channel form and characteristics are representative of the larger stream being assessed. This stream section will be the assessment site. The recommended length of a stream site varies among specialists from lengths equal to 5 to 7 times the average stream width (from channel sequence interval described in Leopold et al. 1964), to as much as 40 times the average stream width (Simonson et al. 1994; Kaufmann and Robison 1995). The time and effort to complete reach measurements increases with site length, so use program objectives and constraints to identify an appropriate stream length. When the site length is determined, locate an assessment site that has common channel features; encompasses one or more riffle and pool sequences; is accessible to field staff; where the upstream and downstream ends line up with habitat breaks (e.g., the head of a riffle or pool); that avoids tributary junctions; and where altered sections are not included unless modified channels are typical for the section or the features of interest. After the site is located, mark the location of transects (cross sections that include the banks up onto the floodplain) with stakes on each bank and flagging. Again, recommendations vary regarding the number of transects to include for a site. Also, uniform channels can be represented with fewer transects than more physically complex channels. As an approximate number, transects can be established every one-tenth of the site length and at the ends (11 total).

- **Collect transect measurements.** Establish a permanent (for repeated site surveys) or temporary benchmark (see Notes below for benchmarks) near one end of each transect. Use wooden stakes or trees to hold a metal measuring tape or beaded steel wire tag line tight on the transect. Use a level to check that the tape or line is not slanted. Referring to Figure 6.1 (letters in text below correspond to letters in figure), make a series of measurements—in any order—and record them on a sketch of the cross-section, always recording the transect distance. Record (A) the vertical distance between the benchmark and the transect line or tape to establish the actual elevation of all other measurements. Make two measurements that correspond with the thalweg (transect location with the greatest water depth, B): the distance from the tape or line to the stream bottom, and the distance to the water surface. Subtract these measurements to get the maximum water depth. Record the distances from the transect to the stream edges (C). Identify the bankfull water edge (D, see Notes below) on each bank, and record the vertical distance from the transect line to the ground (average the two values if different) and the transect distances. These measurements provide the bankfull width (difference of transect distances) and the bankfull depth (total vertical distance at B minus values at D points).

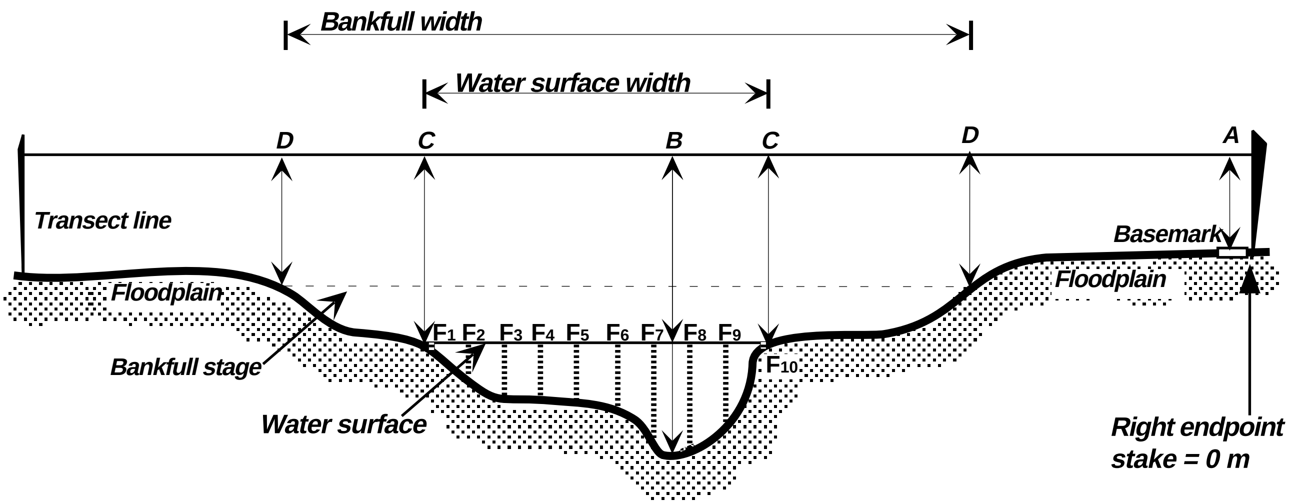


Figure 6.1 Diagram of transect measurements of a stream cross section. Letters are explained in the text.

Record 10 evenly spaced water depths (F_1, F_2, . . . F_{10}) and the corresponding transect line distances. Measure water depth with a level rod, ruled rod, or tape measure. Read the depth on the downstream side of the measuring tool to avoid inaccuracies created by the wave formed by an object in moving water. The depth values can be averaged to get the mean water depth for the cross section. Finally, lay a chain from water edge to water edge (C points) allowing it to follow the bottom contours. Mark the water edge endpoints on the chain and measure the straight distance to get the wetted perimeter to the cross section (subtract islands).

- **Map the site.** In the field, obtain information for a scale map of an assessment site using a survey level and rod, compass, and tape measures. The basic approach is to survey distances and angles off north from a survey level position to at least one transect endpoint for a set of site transects. Then, the angle off north and distances along the transect can be used to position the transect, water edges, and thalweg in space. Accuracy is much better if both transect endpoints are surveyed. A site sketch is done and measurements are recorded on the sketch with some basic habitat information added as in Figure 6.2. Accuracy will vary depending on the precise combination of tools, steps, and measurements but with care and some survey experience, a reasonably accurate scale map can be assembled within a few hours. Figure 6.2 shows one choice of measurements for a site with five transects. In this example, a survey level is located so both endpoints of each of five transects can be seen. The angles off north and distances (in feet for example) from the survey level to each transect endpoint are recorded and entered on a

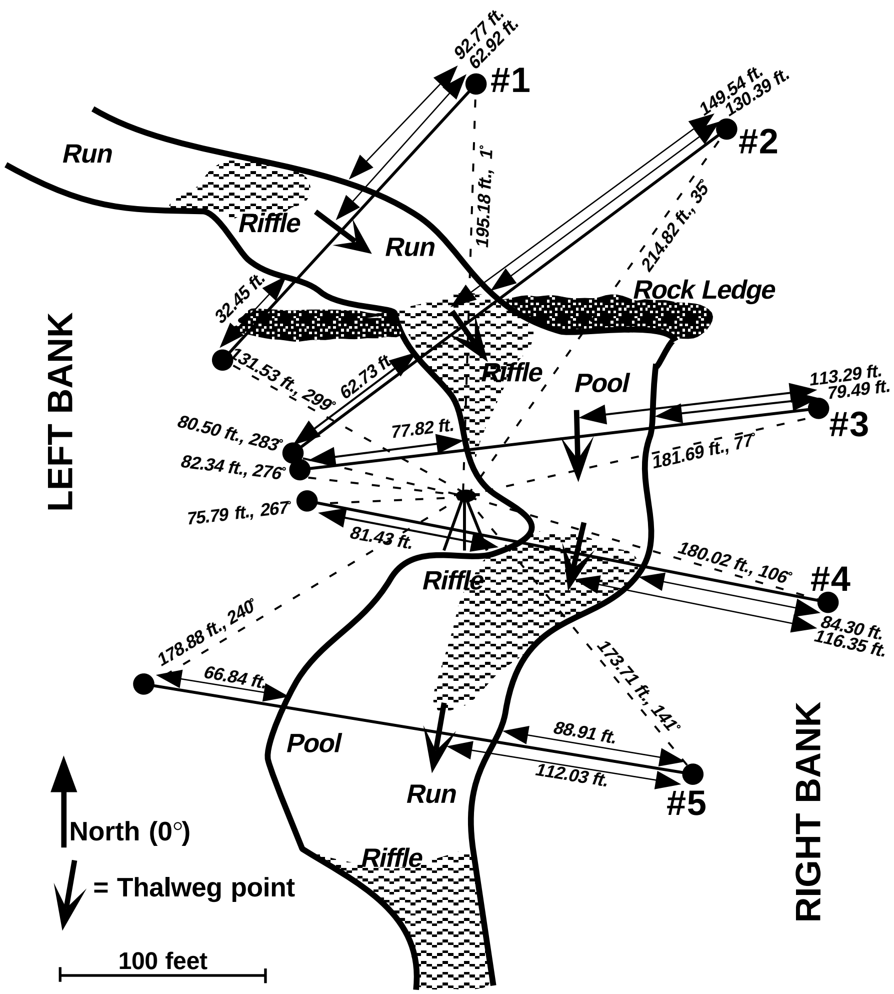


Figure 6.2 Sketch of a study site with notes and field measurements from a survey level and ruled tape. Recorded on this sketch are distances and angles off North for the endpoints of transects, and distances from the transect endpoints to the water edge and thalweg on each bank. Habitat features and other notes can be drawn on the sketch to complete a scale site map. A survey level is located in the middle of the illustration.

site sketch (Figure 6.2). The distance from one endpoint to the thalweg (point of greatest depth on a cross section), and the distances from each transect endpoint to the stream edges are measured using tape measures and are recorded on each transect. Finally, the site is mapped on graph paper in the office or using a computer drafting program. See Gordon et al. (1992), Harrelson et al. (1994), or an introductory manual on surveying or basic survey instrument techniques. Five or six transects should be adequate for developing a site map, and a subset of transects can be surveyed when more transects are used for cross section measurements. In such a case, use the first, last, and three or more intermediate transects.

- **Develop a longitudinal profile for the site.** A longitudinal (upstream–downstream) profile provides a view of the elevation change in the water surface and stream bottom through an assessment site. The profile should be based on the thalweg points on all transects. A site map provides the distances between the thalweg points of all or some transects. A subset of about five transects will provide an adequate basis for a longitudinal profile if all transects are not surveyed. Elevations for the water surface and stream bottom at the thalweg points are not available from the site map. To obtain the elevations, position a survey level so that the uppermost transect is visible and the instrument is higher than the water surface of this transect. Then, measure the elevations of the water surface and stream bottom using a level rod positioned at the thalweg point on each mapped transect as shown in Figure 6.3. The elevations from the level readings will increase moving downstream because the measurements are distances below the survey level height. Subtract all these values from an arbitrary elevation like 100 feet (survey level height) so the largest numbers are at the highest elevations. Make a longitudinal site plot (see Figure 6.4) using the final elevation values and distances between thalweg points from a scale site map (Figure 6.2). Figure 6.4 shows the pattern of elevation change at a site and the water surface and stream bottom slopes that are based on only the highest and lowest elevations in a slope formula:

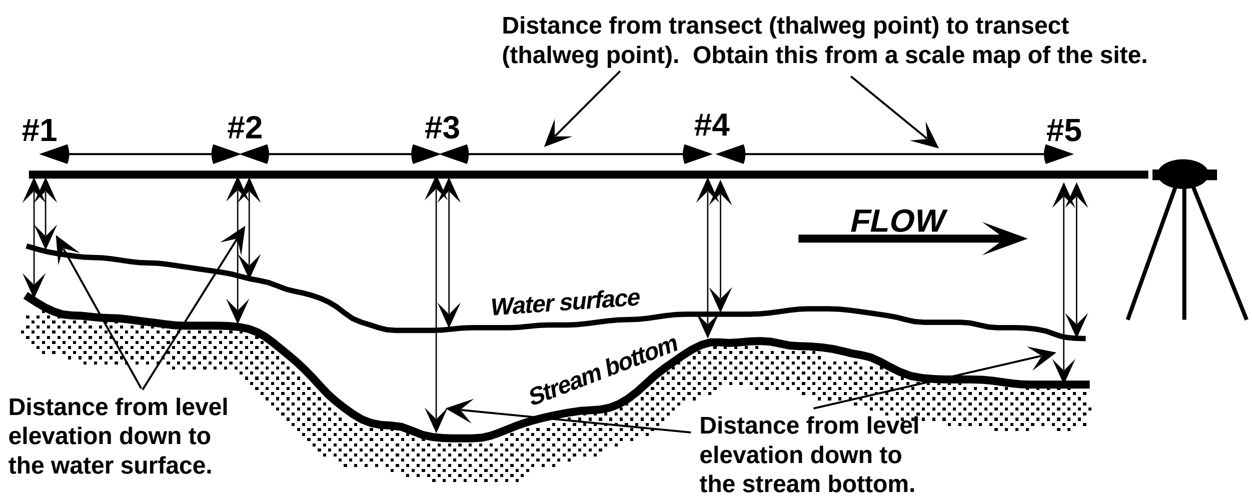


Figure 6.3 A diagram of longitudinal profile measurements using a survey level shown on the right. On the thalweg point of each transect, record the distance from the height of the survey level down to the water surface and stream bottom.

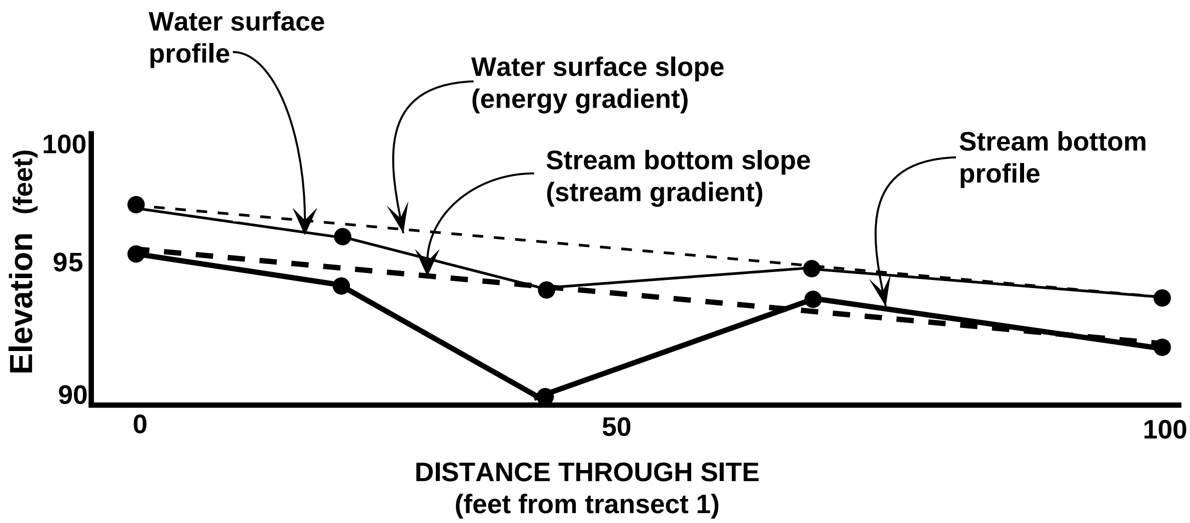


Figure 6.4 A longitudinal profile plot of the study site based on distance and elevation data from survey work described in Figure 6.3. Average water and stream bottom gradients are shown. The water surface slope is used as an estimate of the energy gradient in the Manning equation, and the stream bottom gradient is usually regarded as the slope of the stream in the site. The two slopes become equivalent at bankfull discharge and higher.

$$\text{Percent slope} = \text{Rise/run} \times 100$$

Where the rise/run value is: $\dfrac{\text{highest elevation} - \text{lowest elevation}}{\text{distance between elevation points}}$.

All measurements in the computation should be in the same units (meters or feet). Elevation change is also reported as gradient using unit per unit change; for example, feet per feet (or meters).

- **Complete final calculations and estimates.** Using the data from the site survey and a scale site map, compute the following basic descriptors of the assessment site:
  - Mean wet stream width: average of transect widths with water.
  - Mean bankfull width: average of bankfull channel widths.
  - Wetted perimeter: average of transect wetted perimeter measurements.
  - Stream depth: average of water depth measurements.
  - Maximum bankfull depth: the largest measurement obtained at the site.
  - Total reach area: measure the area (planimeter or computer) of the stream on the site map, or compute an estimate as the product of site length times mean stream width.

- Cross section area: compute an estimate for each transect as the product of mean depth times wet stream width, and then average transect cross-section areas for a mean site estimate.
- Water surface slope (energy gradient) and stream bottom slope (stream gradient), and stream gradient: computation described above.
- Channel roughness (Manning's *n*): see Box 6.1.

6.4 Notes

Harrelson et al. (1994) provides good instruction in the use of surveying equipment. This manual is available free from the U.S. Forest Service Stream Systems Technology Center (http://www.stream.fs.fed.us/ or telephone 970-498-1731).

Distances for cross-sectional and longitudinal profile surveys should be measured to 0.1 ft (0.03 m) and elevations should be measured to 0.01 ft (0.003 m).

Barnes (1967) provides stream site photographs, channel data, plan sketches, and cross section plots to visually estimate roughness.

Benchmarks are elevation reference points for transect and site surveys. Permanent basemarks can be a boulder, a tree spike, or a rebar (concrete reinforcing iron bar) well secured in the ground. Large embedded boulders can be marked with spray paint, a lightly chiseled X, a drilled hole with a bolt, or a combination of these marks. A tree spike monument can be made by driving a 40–80 penny spike partially into the base of a large tree that has stable roots. A rebar monument can be made by driving a 3–4 ft (90–120 cm) by 0.5 in (1–1.5 cm) diameter rebar into the ground to within 1–1.5 cm of the ground surface. Cover the rebar with a plastic cap or tag it with an aluminum survey marker tag. When repeated site surveys are not expected, a temporary benchmark can be any object that will remain stationary during fieldwork such as a flat rock, brick, or wooden stake.

The bankfull level of a stream is often hard to identify but this can be done reliably with experience interpreting indicators such as water marks or scour lines and changes in vegetation, slope, and bank materials. Consult detailed hydrology texts for guidance (Gordon et al. 1992; Rosgen 1996).

Transect measurements go with substrate, discharge, cover, velocity, bank condition; see corresponding chapters for more information.

Survey equipment is developing rapidly and we expect that laser devices and global positioning systems equipment will become widely available and commonly used in the next few years.

Box 6.1 Estimating channel roughness.

The Manning's equation results in a value (n) that explains the resistance to water flow caused by the stream channel. Manning's n values range from about 0.020 to 0.075 for large streams and rivers (Barnes 1967). High values are associated with channels that have more large rock, wood debris, and other flow-resisting material. The Manning's equation is:

$$n = \frac{1.486 R^{2/3} S^{1/2}}{v}$$

R = the hydraulic radius (ft) which is computed as the cross section area divided by wetted perimeter (can use average site values)
S = energy gradient (ft/ft) or water surface slope
v = the mean stream velocity (ft/s) which can be computed as the stream discharge divided by average cross section area

Example data and calculations for Cascadilla Creek near Ithaca, New York:

Transect	Mean depth (ft)	Stream width (ft)	Cross section area (ft^2)	Wetted perimeter (ft)	Hydraulic radius (ft)
1	0.64	24	15.36	25.8	0.60
2	0.73	14	10.22	15.5	0.66
3	1.80	24	43.20	27.6	1.57
4	1.40	23	32.20	25.8	1.25
5	1.30	26	33.80	28.6	1.18
Means			26.96		1.052

Water surface slope or energy gradient:
0.35 feet drop over 203.42 feet distance = 0.0017

Stream discharge at the time of survey = 23 ft^3/s

Mean stream velocity: $\frac{23\,ft^3/s}{26.96\,ft^2} = 0.85\,ft/s$

Manning's n calculation:

$$n = \frac{1.486(1.05^{2/3})(0.0017^{1/2})}{0.85} \qquad n = \frac{1.486(1.03)(0.041)}{0.85}$$

NOTE: Replace the coefficient 1.486 with 1.0 if using metric units.

Classification of Streams and Reaches

7

Kristin K. Arend

7.1 Introduction

7.1.1 Background

Stream channels form and are maintained by the interaction of streamflow and sediment regimes in a process that yields consistent average channel shape and size (Dunne and Leopold 1978). A reach is a section of a stream at least 20 times longer than its average channel width (Flosi and Reynolds 1994) that maintains homogenous channel morphology, flow, and physical, chemical, and biological characteristics. Streams and reaches are typically classified into types based on valley form, channel width, average depth and velocity, mean discharge, gradient, roughness of channel materials, sediment load and sizes, channel entrenchment, sinuosity, and other attributes (Rosgen 1994; Maxwell et al. 1995; Moore et al. 1995). Changes in land use or climate will initiate natural alterations in channel pattern, stream characteristics, and usually the stream or reach type.

Streams or segments of streams are often classified at one of three levels: broad classification of the entire stream, classification of a particular reach within the stream, or classification of macrohabitat within a reach. This chapter presents techniques for broad and reach classification; techniques for macrohabitat classification are presented in Chapter 8. Broad classification uses morphological criteria to characterize stream distribution within a watershed or region (Rosgen 1996). Identifying and describing stream reaches with a well-developed classification system provides a common frame of reference. The objectives for classifying stream reaches are to consistently characterize channel types, make comparisons among stream channels, and partition physical habitat among and within streams (Harrelson et al. 1994).

A comprehensive classification system provides insight into the formation and maintenance of stream channel attributes. Similar and different reaches within and between streams can then be compared. Furthermore, once the characteristics of representative reach types are known, they can be extrapolated to reaches of the same type for which measurements of many properties have not been made. This information could serve as a baseline for assessing a stream's current condition, estimating its probable form, monitoring or predicting the changes it may undergo over time and under different conditions, and developing sound restoration and management projects (Rosgen 1994; Maxwell et al. 1995). For example, knowledge of reach types can be useful when selecting fish habitat improvement projects to maintain the stability and function of the stream (Rosgen 1994).

7.1.2 Selection of Techniques

The three classifications presented here are based on channel geomorphology and the techniques link channel attributes and the surrounding landform. Classification systems developed by David Rosgen (1994, 1996), Galay et al. (1973), and Montgomery and Buffington (1983) were selected for this manual on the basis of applicability, practicality, and use by fisheries agencies. The techniques have been slightly modified to incorporate missing geomorphic or landform information, and to provide instructions for new users who lack experience making rapid judgments about classification.

The Rosgen technique (Rosgen 1994, 1996) is used by a number of state and federal agencies (e.g., the California Department of Fish and Game [Flosi and Reynolds 1994], Bureau of Land Management [Armantrout 1996]). This classification technique is based on quantitative channel morphology indices, and results in objective and consistent identification of stream types. The technique is suitable for a range of assessment objectives because streams can be classified to any of four levels of resolution. We present two of the four levels. Level I classification identifies stream types and will be most accurate when the user has experience interpreting maps and photographs and is familiar with the drainage basin being studied. Level II classification identifies reach types within each stream type. Level II classification requires field work, but measurements can be extrapolated from one stream reach to another of the same type, thereby covering a larger area but with a minimal increase in workload.

The classification technique of Galay et al. (1973) has not been widely used; however, it is a unique and practical classification system in which a checklist is used to document stream and reach types. Topographic maps and aerial photographs are used with this technique, which can be conducted entirely in an office. It is the least time consuming and expensive of the three techniques presented here. It is, however, the least rigorous technique because data quality depends on the accuracy and age of the maps and field verification is not required. This technique is not applicable to the headwaters of rivers.

The bed form technique, first proposed by Montgomery and Buffington (1983), is used regularly (e.g., the U.S. Forest Service [Maxwell et al. 1995]); it integrates well with channel geomorphic classification (see Chapter 8). This technique is comprehensive despite being less complex than the Rosgen technique. Classification is based on information from maps and photographs, but a site visit is required to verify reach boundaries and their classifications. Although more rigorous than the Galay technique, it too relies on the accuracy of the maps and photographs. Also, this technique does not resolve finer-scale bed forms (e.g., channel geomorphic units such as pools and riffles) and reach transitions in many streams (Bisson and Montgomery 1996).

7.2 Rosgen Technique

7.2.1 Rationale

The Rosgen stream classification technique can be used to identify an entire stream or a reach, and the technique is based on valley and channel morphology. The technique presented here is a modification of the first two levels of Rosgen's (1994, 1996) hierarchical system. Rosgen's levels III and IV involve precise measurement of reach properties to verify classification at levels I or II. We judged techniques for level III and IV classification are beyond the needs for most fisheries agency habitat assessments and, therefore, did not include them in this manual. The following technique is applicable to both ephemeral and perennial reaches: stream types are determined at points where the channel geometry is not affected by outside influences (e.g., road embankments, rip-rap, landslides, tributaries). A reach type may range in length from 20 meters to several kilometers, but should be at least two meander widths (or 20 bankfull channel widths) in length. Level I classification is based on work with maps and aerial photographs, but some field observations (e.g., the location of reach transitions and the presence of interesting features) and measurements (e.g., channel depth and bankfull elevation) are required. Level II classification depends on fieldwork.

Level I classification is necessarily broad, and integrates the landform and fluvial features of valley morphology with channel relief, pattern, shape, and dimension. Stream types are classified using (1) generalized descriptions of longitudinal profiles, valley and channel cross-section morphologies, and plan-view morphologies, (2) ranges for measurements of slope, entrenchment ratio, width-to-depth ratio, and sinuosity, and (3) descriptions of the landform, soils, and other features (Figure 7.1). Definitions and characteristics used for classifications are provided in Table 7.1. Using these criteria, the following nine stream types are identified: Aa+, A, B, C, D, DA, E, F, and G. For an individual stream type, the esti-

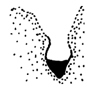
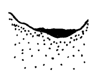
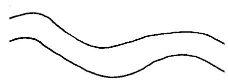
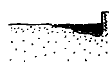
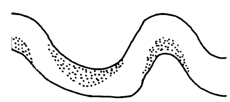
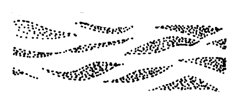
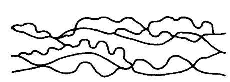
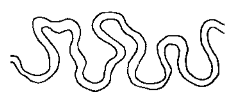
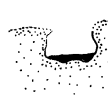
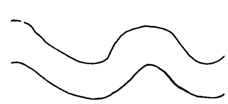
Stream type	General description	Longitudinal profile (slope)	Cross section	Plan view morphology	Landform, soils, features
Aa+	Very steep; deeply entrenched; debris transport; torrent	>0.10	 ER <1.4 W:D <12	 Sinuosity 1.0–1.1	Very high relief; erosional, bedrock, or depositional features; debris flow potential; deeply entrenched; vertical steps with deep scour pools; waterfalls
A	Steep, entrenched, cascading, step–pool; high energy and debris transport, depositional soils; very stable if bedrock or boulder dominated	0.04–0.10	 ER <1.4 W:D <12	 Sinuosity 1.0–1.2	High relief; erosional or depositional and bedrock forms; entrenched and confined; cascading reaches; frequently spaced, deep pools; step–pool bed morphology
B	Moderately entrenched, moderate gradient; riffle dominated; infrequently spaced pools; very stable plan and profile; stable banks	0.02–0.039	 ER 1.4–2.2 W:D >12	 Sinuosity >1.2	Moderate relief, colluvial deposition, and structural; moderate entrenchment and W:D ratio; narrow, gently sloping valleys; rapids predominate with scour pools
C	Low gradient; meandering riffle–pool; alluvial; broad, well-defined floodplains	<0.02	 ER >1.2 W:D >12	 Sinuosity >1.4	Broad valleys with terraces in association with floodplains; alluvial soils; slightly entrenched; well-defined meandering; riffle–pool bed morphology
D	Braided; longitudinal and transverse bars; very wide; eroding banks	<0.04	 ER n/a W:D >40	 Sinuosity n/a	Broad valleys; alluvium, steeper fans; glacial debris and depositional features; active lateral adjustment; abundance of sediment supply; convergence or divergence bed features; aggradational processes; high bedload and bank erosion
DA	Anastomosing; narrow, deep; extensive, well-vegetated floodplains and associated wetlands; gentle relief; highly variable sinuosities and W:D ratios; very stable banks	<0.005	 ER >2.2 W:D highly variable	 Sinuosity highly variable	Valleys broad, low gradient with fine alluvium or lacustrine soils; anastomosed; fine deposition; well-vegetated bars are laterally stable; broad wetland floodplains; very low bedload; high wash load sediment
E	Low gradient; meandering; riffle–pool; low W:D ratio; little deposition; very efficient and stable; high meander width ratio	<0.02	 ER >2.2 W:D <12	 Sinuosity >1.5	Broad valley or meadows; alluvial materials with floodplains; highly sinuous; stable, well-vegetated banks; riffle–pool morphology; very low W:D ratios
F	Entrenched; meandering; riffle–pool; low gradient; high W:D ratio	<0.02	 ER <1.4 W:D >12	 Sinuosity >1.4	Entrenched in highly weathered material; gentle gradients; high W:D ratio; meandering; laterally unstable with high bank erosion rates; riffle–pool morphology
G	Entrenched "gully"; step pool; low W:D ratio; moderate gradients	0.02–0.039	 ER <1.4 W:D <12	 Sinuosity >1.2	Gullies; step–pool morphology; moderate slopes; low W:D ratio; narrow valleys or deeply incised in alluvial or colluvial materials; unstable with grade control problems and high bank erosion rates

Figure 7.1 Guidelines for the Rosgen level II reach type classification. Modified from Rosgen (1996). ER = entrenchment ratio, W:D = width-to-depth ratio.

Table 7.1 Level I stream type classification criteria for the Rosgen technique.

Description	Criteria	Characteristics
Longitudinal profile channel morphology (slope and bed features)	slope >10% 4–10% <4% <2% <0.5% bed features scour pool step–pool riffle–pool	combination of slope and bed feature spacing of bed features influence of scour and deposition
Cross section morphology shape of the streambed, floodplain, and terraces	narrow, deep streams wide, shallow streams	degree of channel incision within the parent valley location and extent of floodplains occurrence and position of terraces presence of colluvial slopes presence of structural control features degree of channel entrenchment overall valley versus channel macro-dimensions
Plan-view morphology plan-view of the river pattern as it flows through the valley	relatively straight low sinuosity meandering tortuously meandering complex: multiple, braided, anastomosed	

mated or measured value of each classification criterion must fall within a specified range. However, the general geomorphologic characterization of a stream type may remain unaltered if there is only a minor inconsistency in criteria values.

Level II classification refines the level I stream types by identifying reaches nested within each of the nine level I categories. In level II, a stream type is verified by field measurements of entrenchment ratio, width-to-depth ratio, and sinuosity. Then, reaches are further classified using field measurements of the dominant channel material and stream slope. Bed and bank materials determine the form, plan, and profile of a stream, and these attributes are used in the Rosgen classification. Water surface slope also influences a channel's morphology and its sediment, hydraulic, and biological function, and this attribute is directly used in the level II classification. Bankfull width and mean bankfull depth are also measured for accurate calculations of entrenchment ratio and width-to-depth ratio. A level II reach type is designated by adding a number and sometimes a lowercase letter to the level I stream type designation (Table 7.2). Fieldwork for level I and level II classification can be conducted simultaneously.

Table 7.2 Guidelines for Rosgen's level II reach type classification. Modified from Rosgen 1996.

Stream type	Slope range	Channel material					
		Bedrock	Boulder	Cobble	Gravel	Sand	Silt or clay
A	>0.10	A1a+	A2a+	A3a+	A4a+	A5a+	A6a+
	0.04–0.099	A1	A2	A3	A4	A5	A6
	0.04–0.099	B1a	B2a	B3a	B4a	B5a	B6a
B	0.02–0.039	B1	B2	B3	B4	B5	B6
	<0.02	B1c	B2c	B3c	B4c	B5c	B6c
	0.02–0.039	C1b	C2b	C3b	C4b	C5b	C6b
C	0.001–0.02	C1	C2	C3	C4	C5	C6
	<0.001	C1c–	C2c–	C3c–	C4c–	C5c–	C6c–
	0.02–0.039	n/a	n/a	D3b	D4b	D5b	D6b
D	0.001–0.02	n/a	n/a	D3	D4	D4	D6
	<0.001	n/a	n/a	n/a	D4c–	D5c–	D6c–
DA	<0.005	n/a	n/a	n/a	DA4	DA5	DA6
E	0.02–0.039	n/a	n/a	E3b	E4b	E5b	E6b
	<0.02	n/a	n/a	E3	E4	E5	E6
F	0.02–0.039	F1b	F2b	F3b	F4b	F5b	F6b
	<0.02	F1	F2	F3	F4	F5	F6
G	0.02–0.039	G1	G2	G3	G4	G5	G6
	<0.02	G1c	G2c	G3c	G4c	G5c	G6c

7.2.2 Preparation

Level I

- Become familiar with stadiometers (map measurer) and planimeters.
- Acquire U.S. Geological Survey (USGS) topographic maps at 1:24,000 scale, land cover maps, watershed maps, a geologic map at 1:250,000 scale, soil or glacial maps (Duff et al. 1989).
- Acquire aerial photographs: Bisson and Montgomery (1996) suggest using low altitude photographs at the 1:12,000 scale or larger; Duff et al. (1989) suggest using photographs with a minimum scale of 1:2,000. Photographs should be taken when streams are at a base flow.
- Assemble cross section (transect) profiling equipment (see Chapter 6 for a list).
- Prepare a data recording sheet.

Level II

- Complete preparation for level I.

- Obtain permission to work on private land, if required.

7.2.3 Procedures

Level I

- **Delineation of valley types and landforms.** Overlay the drainage system of interest on a topographic map that has landforms identified (e.g., alluvial fans, glacial or fluvial terraces, floodplains, hanging valleys, other erosional or depositional features). Then, determine the elevation of terraces with respect to the elevations of the valley floor, using topographic elevation lines on the maps and field observations when needed.

- **Longitudinal profile (slope).** Use a stadiometer and a topographic map to measure the length of the main channel (L_C) from the outlet to the basin divide uphill of the most upstream point on the map. Identify the main channel at each bifurcation as the fork with the largest drainage area or the longest watercourse. Then, determine the upstream end of the channel by extending the main channel from the end of the mapped representation of the stream to the basin divide. Convert stadiometer units to kilometers using the map legend and a calculator. Measure elevation above mean sea level of the streambed at distances (m) 10% (E_{10}) and 85% (E_{85}) along the main channel from the outlet (see Chapter 6 for elevation procedure). Finally, calculate slope (m/km) as the change in elevation over the length of the main channel from the 10% and 85% points:

$$S_C = (E_{85} - E_{10})/0.75L_C$$

- **Bed features** (e.g., pools, riffles, rapids). Infer bed features from general slope categories estimated from topographic maps and from aerial photographs taken at base flow. Some field reconnaissance may be needed to verify bed features. Use the slope estimates and the criteria in Table 7.1 to characterize the longitudinal profile of the stream.

- **Cross section morphology.** Entrenchment ratio is estimated as the typical flood width divided by bankfull channel width. The bankfull stage is the height of water reached at flows primarily responsible for channel formation (Dunne and Leopold 1978). It is also the water height when the stream channel is filled to the top of the banks, equal to the floodplain surface (Gordon et al. 1992). Bankfull discharge, or the stream volume at bankfull stage, is determined in the field by: (1) the elevation of the top of the highest depositional features such as point and central bars, (2) a change in the size distribution of substrate or bank particles, (3) a break in the slope of the banks, (4) stains on rocks, and (5) root hairs exposed below an intact soil layer (Rosgen 1996). Rosgen defines the typical flood width (i.e., flood prone area) as the elevation corresponding to twice the maximum depth of the bankfull channel, which usually includes the active floodplain and low terrace. If available, refer to a valley profile or cross section profile for the reach that extends beyond the bankfull to the high flood level. Alternatively, make plots at representative reaches as described in Chapter 6, if cross section profile plots are not available. Visually compare the cross section of the reach with Figure 7.2 to classify the reach as entrenched, moderately entrenched, or slightly entrenched.

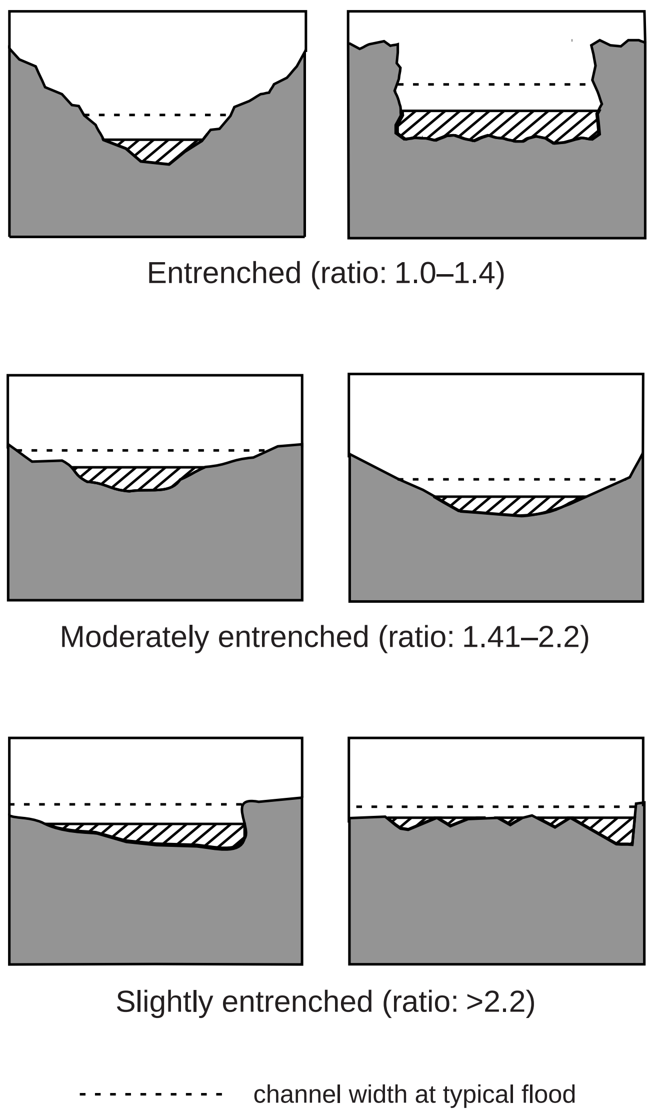


Figure 7.2 Example stream cross sections showing different entrenchment ratios with classification criteria from Rosgen (1996).

- **Cross section morphology.** Stream width-to-depth ratio (W:D) at bankfull discharge. Measure bankfull channel width and mean depth following the procedure outlined in Chapter 6 at representative reaches along the stream. Divide the bankfull channel width by the mean channel depth to calculate the W:D value; see Figure 7.1 for interpretation criteria.

- **Plan-view morphology.** Sinuosity (P) is estimated as the ratio of stream channel length to basin length. Use a metric ruler to measure the length (cm) of the basin (L_B) as the straight-line distance from the outlet to the point on the basin divide used to determine the main channel length (L_C). Convert the length to kilometers using the map legend and measure the length of the stream channel as described above for longitudinal profile (slope). Finally, calculate the sinuosity ratio as:

$$\text{Sinuosity } P = L_C/L_B$$

  Refer to Table 7.3 for criteria used to interpret the sinuosity ratio.

- **Stream classification.** Referring to the Rosgen level I classification criteria in Table 7.1, identify the most appropriate stream type shown and described in Figure 7.1.

Table 7.3 Rosgen level II measurements and interpretation criteria.

Criterion	Estimated or measured value	Interpretation
W:D ratio[a]	<12	low
	>12	moderate–high
Sinuosity[a]	<1.2	low
	>1.2	moderate
	>1.4	high
	>1.5	very high
Entrenchment ratio	1–1.4	entrenched
	1.41–2.2	moderately entrenched
	>2.2	slightly entrenched
Channel material	≥50.8 cm	large boulder
	25.4–50.8	small boulder
	6.35–25.4	cobble
	0.20–6.35	gravel
	0.062–2.0	sand
	<0.062	silt or clay

[a]Ratios for W:D ratio can vary by ±2.0 units; ratios for sinuosity and entrenchment ratio can vary by ±0.2 units.

Level II

- **Slope.** Measure water surface elevation along the longitudinal profile of the channel using the protocol described in Chapter 6. Measure the water surface elevation at the upstream end of two consecutive features of the same type (e.g., the top of one riffle and the top of the closest, downstream or upstream riffle). Then, calculate the vertical height change for that section of stream as follows:

  Vertical drop = (elevation of upstream feature) –
  (elevation of downstream feature) .

  Repeat the elevation measurements until a length of reach has been covered that is at least 20 bankfull channel widths or two meander widths. Sum the vertical drops of the sections to compute the overall vertical drop of the reach (the difference between the elevation measured for the most upstream bed feature and that measured for the most downstream bed feature). Next measure the length (m) of the entire stream reach covered as described in Chapter 6. Finally, calculate the percent stream slope as:

  Slope (%) = (vertical height/reach length) × 100.

- **Entrenchment ratio.** Follow the protocol described above for level I classification and refer to Table 7.3 for interpretation criteria.

- **Width-to-depth ratio.** Using the procedure described in Chapter 6, measure bankfull channel width and mean channel depth on six transects within the reach and refer to Table 7.3 for interpretation criteria.

- **Sinuosity.** Follow the protocol described above for level I classification and refer to Table 7.3 for interpretation criteria.

- **Channel material.** Characterize the reach substrate using the pebble count technique described in Chapter 9. Identify the median particle diameter (i.e., D-50 index diameters) using a cumulative size frequency plot (particle diameter for the 50 percentile point) described in Chapter 9 or by ranking the particles by size to find the middle observation. Alternatively, a histogram of material types (Table 7.3) can be used to determine the dominant particle size (i.e., the particle size having the greatest number of observations).

- **Final stream reach classification.** The level II field measurements are used to guide the level I stream classification. Using all the information, and the classification guidance in Tables 7.1 and 7.3, select the most appropriate stream type from Figure 7.1. The stream type designation can be refined with the classification information on stream slope and channel material in Table 7.2.

7.2.4 Notes

The stream and reach classification criteria included in hierarchical levels I–IV are directly related to the pattern, probable state, and stability of the stream; therefore, it is possible to interpret energy distribution and modes of adjustment (vertical, lateral, or both) for each stream type. For example, the width-to-depth ratio is an accurate predictor of the most probable state of a stream's channel pattern and a rapid and reliable indicator of channel instability (Rosgen 1996).

Rosgen (1996) provides guidelines for the appropriateness and effectiveness of management activities (e.g., construction of fish habitat improvement structures) based on the stream type. A table summarizing each stream type's sensitivity to disturbance, recovery potential, sediment supply, streambank erosion potential, and vegetation controlling influence provides useful information to managers who make decisions about restoration, forestry, mining, or disturbance activities. Information collected about reach properties (e.g., dominant channel materials) can be used to interpret biological function and stability within the river (Rosgen 1994).

7.3 Galay System

7.3.1 Rationale

Galay et al. (1973) introduced a technique for stream classification based on geomorphic setting and dominant channel processes. Classification criteria include: (1) major geomorphic setting (e.g., alluvial plains, deltas, alluvial fans, irregular bedrock channels), (2) degree of valley confinement of the river, (3) river channel pattern (i.e., sinuosity), (4) channel bars, (5) islands, (6) stability of the valley wall, and (7) special features. The Galay technique relies entirely on the use of maps and aerial photographs. Galay et al. (1973) suggest that additional classification criteria could be incorporated into the method. As described here, the classification is applicable to a variety of rivers and streams excluding headwaters.

7.3.2 Preparation

- Acquire USGS topographic maps at 1:24,000 scale, land cover maps, a geologic map at 1:250,000 scale, and soil or glacial maps (Duff et al. 1989).

- Acquire aerial photographs: Bisson and Montgomery (1996) suggest using low altitude photos at the 1:12,000 scale or larger; Duff et al. (1989) suggest using photographs with a minimum scale of 1:2,000. Photographs should be taken at base flow.

7.3.3 Procedures

- Determine if the river geomorphic setting is valley, alluvial plain, delta, alluvial fan, or irregular bedrock channels. See the glossary by Armantrout (1998) for definitions of these terms.
- Use topographic maps and aerial photographs to determine to what extent the river is confined to the valley for valley reaches only. Assign stream reaches to one of the entrenchment categories described in Table 7.4; a combination of categories is possible within a single stream.
- Determine the river channel pattern (sinuosity) by referring to aerial photographs and then assigning the stream reach to one of the channel pattern categories described in Table 7.4. Categories apply to the channel pattern at low flow stage, the conditions under which most maps and aerial photographs are taken.
- Identify channel bars (i.e., usually unvegetated channel deposits) in the reach by referring to aerial photographs and Table 7.4.
- Identify islands in the reach by examining aerial photographs and categories in Table 7.4. Islands are more permanent features than channel bars because islands typically remain above the water level at bankfull flows and have well-established vegetation.
- After reviewing aerial photographs, tentatively classify the valley wall of the reach as stable, some slumping, or extensive slumping.
- Describe special features, especially those that may have an effect on the appearance of the river channel (e.g., bedrock outcrops, boulder rapids, log jams, permafrost effects, river engineering works).
- Record classification information from the available choices in Table 7.5.

7.3.4 Notes

The Galay technique could incorporate other river and stream features such as: (1) the magnitude and distribution of land surface runoff (e.g., seasonal runoff, natural storage), (2) the extent to which ice shapes the channel, (3) channel stability relative to bank and bed materials, and (4) channel geometry, bed forms, rates of channel shift, rates of degradation and aggradation, and transport rates of bed load.

Table 7.4 Galay et al. technique for stream classification based on geomorphic setting and dominant channel processes.

Classification criteria	Description
Entrenchment	
Entrenched channel	Channel bordered on either side by banks higher than the highest flood level Is either actively degrading or has been doing so in the past
Partly entrenched channel	Channel bordered occasionally by discontinuous segments of floodplain It is common to have a combination of degradation with some lateral shifting and floodplain construction
Confined channel	Channel is either stable (vertically) or aggrading and the valley floor is predominantly a floodplain The channel alternately impinges on the left and right valley walls because the valley is far too narrow for the proper development of the river's meander pattern
Partly confined channel	Channel is confined by valley walls, fans, or slumps over short reaches, but there is sufficient room on the valley floodplain for the full development of some meanders
Channel pattern	
Straight channel	Very little curvature Usually due to structural controls; however, straight reaches occur in extremely flat channels in deltaic regions
Regular meanders	Repeatable meandering pattern Confined meanders typically have exceptional regularity
Tortuous meanders	Loops have a variety of shapes Characteristic feature: angle between the valley axis and the channel at cross-overs is frequently greater than 90° Prerequisites for development: low valley slope and relatively resistant floodplain deposits Also found in entrenched channels
Irregular meanders	Meander loops are discontinuous
Irregular channel	Abrupt changes in flow direction or sudden expansions and constrictions
Channel bars	
Point bars	Location: the inside of a river bend Process: become increasingly integrated into the active floodplain at the inside of the bend, as bank erosion at the outside of meander bends causes the river to shift laterally
Side bars	Location: adjacent to banks Usually present in a channel with straight or irregular patterns
Mid-channel bars	Take on a variety of appearances
Diagonal bars	Ridges common in gravel-bed channels Location: extend across part of a channel Water flow spills across the bar in the form of a riffle or small rapid

Table 7.4 Continued.

Classification criteria	Description
Islands	
Occasional islands	Infrequent Don't overlap
Frequent islands	Are prominent within the channel Occasionally overlap
Split channel	Continuous overlap of islands forming two or three channels over most of the reach
Braided channel	Islands generally overlap forming more than two flow channels Islands are unstable and resemble mid-channel bars There is a constant transition from channels with frequent mid-channel bars to truly braided channels

Notes:

(1) Use the term floodplain to describe the surface built up by the present river through lateral accretion and aggradation.
(2) It may not be possible to clearly distinguish low terraces and active floodplains without conducting field work; however, under extreme conditions, low terraces may be subject to flooding.

7.4 Bed Form System

7.4.1 Rationale

The Montgomery and Buffington (1983) classification technique identifies stream reaches as one of three kinds of valley reaches: colluvial, alluvial, or bedrock. As with the previous two techniques, the classification criteria are based on entrenchment, slope, and sinuosity. Maps and aerial photographs are used to identify reach boundaries by estimating stream gradients, degree of valley confinement, channel meander patterns, and significant changes in the predominant rock type. Although this technique can be completed in an office, a site visit is strongly recommended to verify the reach boundaries identified from the maps and photographs.

Classification of a valley reach is based on dominant types of sediment input and transport processes (Bisson and Montgomery 1996). In colluvial valleys, landslides from adjacent hillslopes deliver sediment and organic matter to the valley floor; whereas, in alluvial valleys, streamflow transports sediment along the valley floor (Bisson and Montgomery 1996). Bedrock valleys have little soil (Bisson and Montgomery 1996). Only colluvial reaches are found within colluvial valley segments and only bedrock reaches are found within bedrock valley segments. However, a reach in an alluvial valley segment can be identified as braided, regime, pool–riffle, plane-bed, step-pool, or cascade. The stream is separated into reaches based on average gradient and apparent degree of valley confinement. Changes in slope indicate where reach boundaries may

Table 7.5 River classification categories of Galay et al. (1973) that are evident from maps and aerial photographs. Select the combination of classes from those listed here where multiple entries in a column represent possible choices.

Landform	River channel pattern	Channel bars	Islands	Valley wall stability
Alluvial floodplain	Straight	Point		Stable, minor slump, extensive slump
	Regular meander	Side		Stable, minor slump, extensive slump
	Tortuous meander	Side, mid-channel, diagonal	Frequent, split, braided	Stable, minor slump, extensive slump
	Irregular meander			Stable, minor slump, extensive slump
	Irregular channel			Stable, minor slump, extensive slump
Delta	Straight	Point		Stable, minor slump, extensive slump
	Regular meander	Side		Stable, minor slump, extensive slump
	Tortuous meander	Point, mid-channel, side, diagonal	Occasional, frequent, split, braided	Stable, minor slump, extensive slump
	Irregular meander			Stable, minor slump, extensive slump
	Irregular channel			Stable, minor slump, extensive slump
Alluvial fan	Straight	Point		Stable, minor slump, extensive slump
	Regular meander	Side		Stable, minor slump, extensive slump
	Tortuous meander	Point, mid-channel, side, diagonal	Occasional, frequent, split, braided	Stable, minor slump, extensive slump
	Irregular meander			Stable, minor slump, extensive slump
	Irregular channel			Stable, minor slump, extensive slump
Bedrock channel	Straight	Point, mid-channel, side, diagonal	Occasional, frequent, split, braided	Stable, minor slump, extensive slump
	Regular meander	Point, mid-channel, side, diagonal	Occasional, frequent, split, braided	Stable, minor slump, extensive slump
	Tortuous meander	Point, mid-channel, side, diagonal	Occasional, frequent, split, braided	Stable, minor slump, extensive slump
	Irregular meander	Point, mid-channel, side, diagonal	Occasional, frequent, split, braided	Stable, minor slump, extensive slump
	Irregular channel			
Valley				
entrenched channel	Straight	Point	Split, braided	
	Regular meander	Side	Split, braided	
	Tortuous meander	Mid-channel, side, diagonal	Frequent, split, braided	
	Irregular meander		Split, braided	
	Irregular channel		Split, braided	
partly entrenched	Straight	Point		
	Regular meander	Side		
	Tortuous meander	Mid-channel, side, diagonal	Frequent, split, braided	
	Irregular meander			
	Irregular channel			
confined channel	Straight	Point		
	Regular meander	Side		
	Tortuous meander	Mid-channel, side, diagonal	Frequent, split, braided	
	Irregular meander			
	Irregular channel			
partly confined channel	Straight	Point		
	Regular meander	Side		
	Tortuous meander	Mid-channel, side, diagonal	Frequent, split, braided	
	Irregular meander			
	Irregular channel			

exist. Use maps and photographs to estimate elevation, channel width, valley floor width, and channel length to approximate slope and confinement. Also use aerial photographs, geological maps, and soils maps to accurately locate changes in channel shape and boundaries between geological formations. Criteria are broken into seven categories: (1) predominant bed material, (2) bedform pattern (sinuosity), (3) dominant roughness elements, (4) dominant sediment sources, (5) typical slope, (6) typical confinement, and (7) pool spacing. Table 7.6 defines each reach type according to these criteria.

Table 7.6 Characteristics of different types of stream reaches for bed form stream reach classification. From Bisson and Montgomery (1996).

			Alluvial					
Characteristics	Colluvial	Bedrock	Cascade	Step–pool	Plane–bed	Pool–riffle	Regime	Braided
Predominant bed material	Variable	Bedrock	Boulder	Cobble or boulder	Gravel or cobble	Gravel	Sand	Variable
Bedform pattern	Variable	Variable	None	Vertically oscillatory	None	Laterally oscillatory	Multilayered	Laterally oscillatory
Dominant roughness elements	Boulders, large woody debris	Streambed, banks	Boulders, banks	Bedforms (steps, pools), boulders, large woody debris, banks	Boulders and cobbles, banks	Bedforms (bars, pools), boulders and cobbles, large woody debris, sinuosity, banks	Sinuousity, bedforms (dunes, ripples, bars), banks	Bedforms (bars, pools)
Dominant sediment sources	Hilltops, debris flows	Fluvial, hillslope, debris flows	Fluvial, hillslope, debris flows	Fluvial, hillslope, debris flows	Fluvial, bank erosion, debris flows	Fluvial, bank erosion, inactive channels, debris flows	Fluvial, bank erosion, inactive channels	Fluvial, bank erosion, debris flows
Typical slope (%)	>20	Variable	8–30	4–8	1–4	0.1–2	<0.1	<3
Typical confinement	Strongly confined	Strongly confined	Strongly confined	Moderately confined	Variable	Unconfined	Unconfined	Unconfined
Pool spacing (channel widths)	Variable	Variable	<1	1–4	None	5–7	5–7	Variable

7.4.2 Preparation

- Obtain permission to survey on private land, if necessary.
- Select sites that allow for comparison of commonly occurring local reach types.
- Obtain low altitude aerial photographs at 1:12,000 scale or larger.
- Acquire topographic (1:24,000 scale), geological, and soils maps.
- Develop proficiency in the use of a stadiometer (map measurer), stereoscopic map reader, magnifying lens, or dissecting microscope.
- Collect 100-m and 30-m fiberglass tape; flagging; meter stick; optical, electronic, or sonic rangefinder; surveyor's rod or graduated wading staff (see Chapter 6).

7.4.3 Procedure

Office Procedures

- Working with maps, construct a longitudinal profile of the stream channel from the stream mouth or confluence toward the headwaters. Measure the distance along the blue stream line using a stadiometer or a finely graduated ruler. Be sure to calibrate graduations of the stadiometer or ruler against the map scale. Record the elevation and distance from the downstream starting point each time a contour line intersects the stream line. Plot the longitudinal profile of the stream by labeling the vertical plot axis "Elevation (m)" and the horizontal axis "Distance from mouth (km)." The stream source should be nearest the vertical axis as shown in the example plot (Figure 7.3).

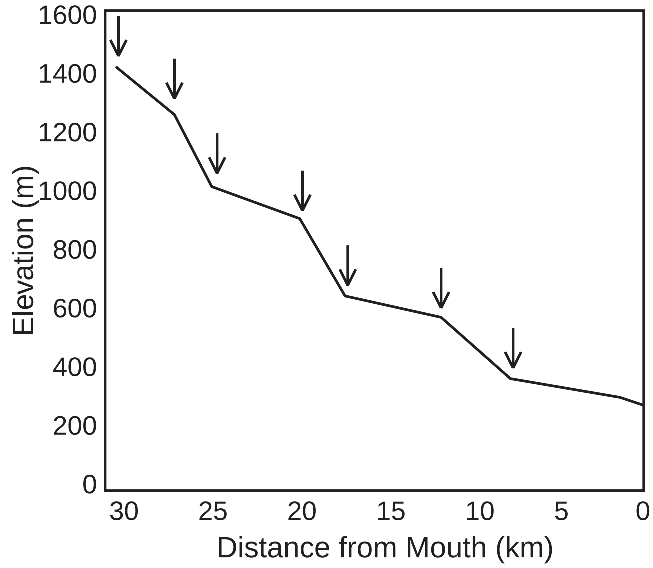


Figure 7.3 Example stream longitudinal profile with arrows indicating reach transitions.

- Identify reaches on the longitudinal profile by visually locating inflection points and marking them as seen in the example plot (Figure 7.3). The inflections are usually good indicators of reach transitions. Compute the average channel slope for each reach by measuring the elevations at both the upstream (E_u) and downstream (E_d) ends, then measure the reach length (L_r) as the distance between the downstream and upstream boundaries. To compute S or the average reach slope, use the equation:

$$S = \frac{E_u - E_d}{L_r} \quad .$$

- Approximate the level of valley confinement in each reach by examining the shape of the contour lines intersecting the stream. Although the channel width will not be shown on most topographic maps, the general shape and width of the valley floor indicate valley confinement. Figure 7.4 provides examples of topographic maps that indicate the general extent of stream confinement. When possible, approximate the degree of confinement for the reach by examining aerial photographs of the stream segments identified on the topographic maps. Use a stereoscopic map reader, magnifying lens, or dissecting microscope to view the unvegetated channel and estimate the channel width. Estimate the width of the valley floor from the topographic maps. Compare the width of the valley floor with the width of the stream channel to approximate the degree of confinement as:

  Strongly confined: valley floor width <2 channel widths;

  Moderately confined: valley floor width = 2–4 channel widths;

  Unconfined: valley floor width >4 channel widths.

- Consider whether the reach exhibits homogenous geological forms, dominant vegetation, soil composition, and climate. Compare average gradients and valley floor widths of each reach on the stream profile with geological, soils, vegetation, and climatological maps.

- Use boundaries evident on geological, soils, vegetation, and climatological maps to either verify the location of the reach boundaries or more accurately locate them.

- Finally, identify the reach type using the classification guidelines presented in Table 7.6.

Field Procedures

- Verify the accuracy of the reach type designation by inspecting the stream channel, adjacent valley floor, and hillslopes. Locate landmarks that indicate reach boundaries on maps if it is possible to get a panoramic view of the valley floor.

- Calibrate optical, electronic, or sonic rangefinders by measuring the distance between two points with a tape and adjusting the readings on the rangefinders to match the known distance. Use rangefinders and other survey equipment to measure attributes estimated from aerial photographs and topographic maps.

7.4.4 Notes

Maps may not provide very accurate information on sinuosity and channel braiding and they may not resolve key changes in stream gradient and valley confinement associated with reach transitions in small streams (Bisson and Montgomery 1996). Field measurements will be important in these cases. Also, the identification of finer-scale bed forms (e.g., channel geomorphic units such as pools and riffles) using aerial photographs may be difficult for many streams.

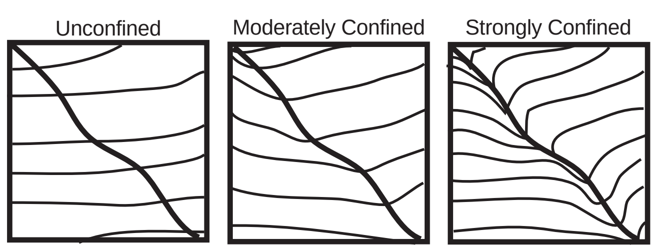


Figure 7.4 Example topographic map representations of streams considered to be unconfined, moderately confined, and unconfined.

Macrohabitat Identification

8

Kristin K. Arend

8.1 Introduction

8.1.1 Background

Macrohabitat identification is a method to efficiently describe, inventory, and assess streams for possible support of fisheries resources. A stream reach is divided into discrete habitats called channel geomorphic units (CGUs) which provide a framework for organizing and understanding habitat changes throughout a stream reach. The term CGUs is used throughout this chapter to convey the idea that macrohabitats are instream physical entities. Bed form, water velocity, the presence of flow control features, and other physical attributes form the basis for CGUs. Macrohabitat identification involves two steps: (1) determining the location and size of CGUs that compose a reach (henceforth called delineation); and (2) classifying the units into habitat types that are nested in levels of related groups and subgroups (henceforth called classification). The classification systems represent varying degrees of habitat resolution (i.e., the descriptive power of the CGU); therefore, the specific needs of an assessment can be met and compared across studies or cases (Hawkins et al. 1993).

Channel geomorphic units are relatively homogenous areas of a channel that differ in depth, velocity, and substrate characteristics from adjoining areas creating different habitat types in a stream channel. They are usually as long as the average wetted channel width or larger. Interactions between flow and streambed roughness are usually responsible for the creation of individual CGUs (Moore et al. 1995; Bisson and Montgomery 1996). They are easily recognized during periods of low flow in third-order and smaller streams; examples are different types of pools and riffles.

The physical characteristics of a stream are dependent upon the geological history and climate of a drainage basin, and watershed processes such as fluvial dynamics (Frissell et al. 1986; Poole et al. 1997). These characteristics determine both the type of reach (Chapter 7) and the sequence of CGUs in that reach (e.g., its pool–riffle morphology). Therefore, the site for macrohabitat identification is selected by dividing a stream into segments based on geology and local land attributes (Modde et al. 1991), contiguous reaches (e.g., Hankin and Reeves 1988), or reach types (Chapter 7). In turn, the presence, abundance, and sequence of the CGUs help determine the biotic community (Roper and Scarnecchia 1995) and fish life history types likely to be present (Frissell et al. 1986; Bisson and Montgomery 1996). As a result, a stream and its pattern of geomorphic channel units can be placed within the physical context of the stream's entire drainage basin, resulting in a greater understanding of ecological patterns in the stream (Frissell et al. 1986).

No one method for macrohabitat identification has been widely accepted. Many of the methods currently being used are based upon Bisson et al. (1982); however, inconsistent terminology and classification criteria make it difficult to compare studies. Most classification systems are hierarchically organized according to water depth and velocity, bed topography, water surface slope, position relative to the main channel, and features affecting hydrodynamics (e.g., logs, woody debris, boulders; Frissell et al. 1986). Similarities and differences in the combinations of these features allow the CGUs to be grouped in increasingly descriptive categories. Some systems use differences in geomorphic characteristics to differentiate between pools and riffles as primary units, and others prefer to base the classification on slow and fast water types. These base units are general categories under which more specific classes of habitat are organized.

Macrohabitat identification is a useful tool for the inventory and management of stream habitat. It contributes to understanding temporal and spatial changes in habitat within heterogenous stream segments. Macrohabitat identification is used to predict biotic response to changes in habitat availability and suitability, and to identify areas that might support fisheries resources (Bisson et al. 1982; Modde et al. 1991; Hawkins et al. 1993). Fish population estimates can easily be obtained by censusing the different habitats within a stream and sampling a subset of each habitat class for associated fishes (Hawkins et al. 1993). By examining fish responses to manipulations in the abundance and types of CGUs, restoration, enhancement, and fisheries management projects can be designed and evaluated (Hawkins et al. 1993; Flosi and Reynolds 1994). Monitoring projects can more accurately identify stream habitat changes over time that result from enhancement project alterations, management changes, and the cumulative impacts of land-use activities (Frissell et al. 1986; Hankin and Reeves 1988; Hawkins et al. 1993). By comparing stream segments that have similar CGU patterns, site-specific phenomenon (e.g., habitat improvement structures, stream bank failures) can be identified and streams in different drainages can be compared (Bisson and Montgomery 1996).

There are limitations to macrohabitat identification. Most macrohabitat identification methods currently in use are conducted in wadeable streams during base or late summer low flow. They are designed for natural, nonintermittent streams and channels free of human alteration (e.g., dredging, snag clearing). For large streams, the gradual transition between CGUs can make it difficult to distinguish changes. Field identifications can be influenced by observer experience, subjectivity, and inconsistency (Roper and Scarnecchia 1995; Bisson and Montgomery 1996). These points should be seriously considered; however, if standardized techniques and classification systems are adopted, field biologists are properly trained, and the selected techniques are appropriate for the objectives of the assessment (Bisson et al. 1982; Hawkins et al. 1993), macrohabitat identification is a reliable inventory and management tool.

8.1.2 Selection of Techniques

Macrohabitat identification has two components: (1) techniques for the delineation of a stream segment into distinct channel units, and (2) systems for the classification of these units into habitat types. Select a specific delineation technique and classification system before beginning an assessment. The two delineation techniques described in this chapter (channel feature and dimension technique, bed form differencing technique) differ in the way the CGUs are delineated, the number of measurements that need to be taken, and the degree of subjectivity. The three habitat classification systems presented are representative of systems currently in use. These systems may be used singly, in part, or as a combination of parts. Each is hierarchical and has a structure capable of maximum resolution to either three or four levels of complexity. They each distinguish and organize habitat classes differently and use different terminology. However, terminology has been standardized as much as possible, and selected terms are defined in the sections below and in the supporting material.

The channel feature and dimension technique for CGU delineation is compatible with the design of most classification systems, and experienced field staff can rapidly estimate or measure units. It uses systematic sampling and stream habitat sequence observations. The technique is convenient, fast, and relatively easy. The alternative CGU delineation technique, bed form differencing, is reproducible, spatially consistent, and also easy to apply. It is based on a single criterion, accumulated elevation change between bed forms, which is conceptually simple and intuitive (O'Neill and Abrahams 1987). Pools and riffles are delineated on the basis of streambed topography.

Three classification systems are presented: Hawkins system (Hawkins et al. 1993), Flosi and Reynolds system (Flosi and Reynolds 1994), and the Alaska Aquatic Resources Information Management System (AARIMS; Armantrout 1996). The Hawkins system is simple because it uses few habitat classes, subclasses, and levels. The Flosi and Reynolds system includes more levels of classification and more habitat classes than the Hawkins system, but it may overclassify habitats for some assessment objectives by offering too many categories. The AARIMS uses similar terminology as the Flosi and Reynolds system, and has almost as many classes. However, the AARIMS is organized in fewer levels and includes some unique regional habitat types. The AARIMS does not follow the CGUs described by Bisson et al. (1982), upon which most other systems are based.

For all three systems, the classification levels are nested and organized by increasing complexity. For example, a CGU classified as a scour pool at level II is further classified as wood, boulder, or bedrock at level III, depending on which object was responsible for its formation. This system is based on description and the terminology used to describe formative features is provided in detail. This should result in more consistent identification of channel units. Note that some habitat classes were changed by the author to avoid redundancy between levels and these changes can lead to inconsistencies with other systems. Finally, select and stay with one set of techniques, document methodology choices, and avoid adjusting or replacing techniques.

8.2 Delineation: Channel Feature and Dimension Technique

8.2.1 Rationale

The channel feature and dimension technique uses a set of channel shape and hydraulic measurements (modified from Bisson et al. 1982) to define channel geomorphic units (CGUs). The delineation of CGUs is based on the concept that distinct CGUs have characteristic gradient, water velocity, turbulence, substrate, and formative features. The boundaries of each CGU are determined using transect-based measurements of physical features periodically along the stream reach. A habitat area must meet two requirements to be considered a distinct CGU: (1) the measurements or presence of the physical characteristics (listed below) of adjacent units must clearly be different; (2) the largest dimensions of the channel unit should be equal to or greater than the average wetted width of the reach for mid-channel units (on a stream thalweg), or equal to half the average wetted width for CGUs defined along a stream margin (Bisson and Montgomery 1996). Therefore, a series of measurements are recorded along a stream reach and these are used to draw boundaries for CGUs covering the assessment area.

8.2.2 Preparation

- Field staff should have prior experience or at least 5 days of training in the identification of CGUs according to the criteria to be used in all macrohabitat identification work. If necessary, acquire permission to work on private land.

- Acquire the following surveying equipment: three-part telescoping surveyor's rod; level and clinometer; 1-m metric rule, calibrated rod, or pole; telescoping or folding tripod; materials for establishing the benchmark (see Chapter 6); colored plastic flagging and stakes for marking the assessment site and transect locations. Also obtain waders, a bearing compass, fiberglass metric tape and reel, and a notebook or appropriate data sheet.

8.2.3 Procedures

- Delineation should occur during periods of low flow unless multiple surveys are planned so that higher flows can be included (see Notes below). Cross section transects should be set up systematically along the thalweg (center line of main streamflow) of the channel in a reach that is approximately 35–40 mean stream widths long (Simonson et al. 1994). For streams greater than 5 m wide, space transects every two stream widths apart. For streams 5 m wide or less, transects may be spaced every three stream widths apart. See Chapter 6 for additional guidance on setting up transects. At each transect estimate or measure the habitat features described below.

  - **Wetted width**. By surveying or using a measuring tape along the transect, obtain the distance perpendicular to the midline channel. Include logs, boulders, stumps, or debris surrounded by water; do not include islands wider than 0.3 m (islands are any accumulation of inorganic sediment particles protruding above the water). Record distances to the nearest 0.1 m and sum the widths of all channels in multi-channel reaches. Repeat this procedure on each transect and calculate the arithmetic mean for the entire reach.

  - **Slope.** See Chapter 6 for the procedure to measure slope and obtain one estimate for each transect using adjacent transects as elevation points.

  - **Stream depth.** Using a calibrated rod, measure water depth (water surface to the stream bottom) to the nearest 0.03 m; read the depth on the downstream side of the rod to avoid inaccuracies due to the wave formed by the rod in moving water. Make depth measurements at three locations that are one-quarter, one-half, and three-quarters the distance across the transect. Calculate the average by dividing the total of the three measurements by 4 for trapezoidal channel shapes (to account for zero depths at the stream shore where the water surface meets the bank of channel) or by 3 for rectangular shapes.

  - **Turbulence.** Turbulence is present if there is a hydraulic jump sufficient to entrain air bubbles and create local patches of white water. Note turbulence at three locations that are one-quarter, one-half, and three-quarters the distance across the transect.

- **Water velocity.** Refer to Chapter 14 for procedures to measure velocity and obtain mean water velocity values at three locations that are one-quarter, one-half, and three-quarters the distance across the transect.
- **Dominant substrate.** Refer to Chapter 9 for categories of substrate types and substrate classification techniques. Record the dominant substrate at three locations that are one-quarter, one-half, and three-quarters the distance across the transect.

- After collecting the data, define distinct CGUs by delineating instream areas so that the physical characteristics of each CGU are clearly different than those of adjacent units. For channel CGUs, the greatest linear dimension should be equal to or greater than the average wetted width computed from field measurements. For channel margin CGUs, the greatest linear dimension should be equal to half the average wetted width.

- While in the field, sketch the stream segment and map the location of CGUs, significant flow controlling structures, and other habitat features drawn to scale. Record the maximum length and one (typical) or more widths of each CGU. Maximum CGU length should be oriented parallel to the main channel but not necessarily inclusive of the main channel. Length and width (mean or typical width) measurements can be used to approximate the areas of all CGUs for reporting reach summaries. After CGUs are defined, proceed with classifying the units into habitat types.

8.2.4 Notes

The decision to make visual estimates or take accurate measurements of channel and CGU dimensions depends upon how much time is available and how precise the measurements must be. However, document whichever procedure is selected.

If time and personnel permit, take measurements at a variety of flows, since discharge strongly influences the relative abundance of different CGUs (Bisson and Montgomery 1996).

Contour lines based on depth measurements can be drawn within the pools to estimate volume; wetted surface areas can be estimated by counting squares on gridded paper superimposed on the maps (see lake area estimates described in Chapter 16).

8.3 Delineation: Bed Form Differencing Technique

8.3.1 Rationale

O'Neill and Abrahams (1987) developed an objective technique for distinguishing pools and riffles in a stream segment. Streambed elevation changes are used to identify the locations of pool and riffle habitats (Figure 8.1). Undulations in the bed profile are measured and when the elevation change exceeds a segment specific tolerance value, a minimum or maximum elevation is designated. When a minimum or maximum value is followed by an opposing value, the previous minimum or maximum value is identified as a pool or riffle. Absolute minimum values delineate a pool and absolute maximum values delineate riffles. The procedure presented here is for pool–riffle sequences common to naturally formed stream channels, but the technique can be applied to altered streams by modifying the tolerance calculation and sampling interval length.

8.3.2 Preparation

- Field staff should have experience conducting elevation and distance surveying as described in Chapter 6 for longitudinal profile measurements. If necessary, acquire permission to work on private land.

- Acquire the following surveying equipment: three-part telescoping surveyor's rod, level, telescoping or folding tripod, materials for establishing the benchmark (see Chapter 6), colored plastic flagging and stakes for marking pool and riffle locations. Also obtain waders, fiberglass metric tape and reel, and a notebook or appropriate data sheet.

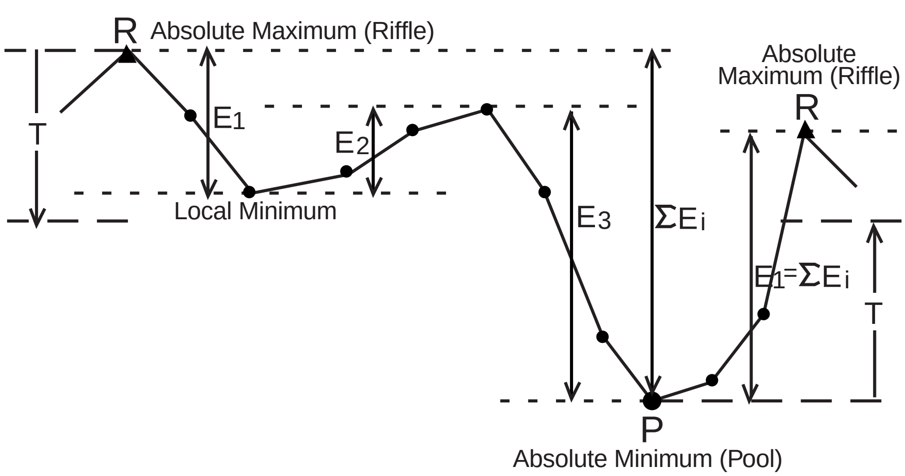


Figure 8.1 Hypothetical bed profile illustrating the approach and terminology for the bed form differencing technique (from O'Neill and Abrahams 1987).

8.3.3 Procedures

- Bed elevation surveys are most easily done at low flows when the riffle and pool features are easily recognized. Measure bed elevation by differential leveling (see Chapter 6) along the center of the channel at intervals approximately equal to mean channel width (estimate with a series of width measurements along the stream reach). The survey equipment readings will yield the inverse (from level height down) of elevation but subtracting from an arbitrary base level (e.g., 1,000 cm) will produce proper elevation readings. Shorten the measurement intervals if obvious errors occur because riffles and pools are close together. Working downstream, measure a series of increasing bed elevations (B_1, B_2, B_3, …). When the values begin to decrease, use the last high point as the starting location (first maximum or riffle) for data collection.

- Continue measuring a series of elevations, and perform the calculations as shown in Table 8.1. The values in Table 8.1 correspond to four examples shown graphically in Figure 8.2. Include enough observations in the series so that a distinct change in water surface elevation separating pool and riffle habitat is identified. Calculate the standard deviation (SD) of the resulting difference values ($B_1 - B_2$, $B_2 - B_3$, … [$B_{(i+1)} - B_i$]) as shown in Table 8.1. Set the tolerance value (T) at $0.75 \times$ SD if the sample spacing approximates the average stream width. Note the sign of the change in elevation with subsequent measurements. A series (E) of elevation changes is a set of consecutive difference values with the same sign. Number the series ($E_{1, 2, 3, \ldots}$) as in Table 8.1. Calculate the total elevation change for the series (ΣE_i) by summing the bed elevation differences. Compare the total elevation changes for each series against the tolerance value (T), and note those that are equal or larger than T. Mark these minimum or maximum points along the stream margin with flagging or a visible stake. If the next downstream minimum or maximum point is the same type (either lower or higher than the preceding), then the preceding point is a local minimum or maximum and of no further significance. When a minimum or maximum is followed by an opposing point that exceeds or equals T, a riffle or pool location is designated (Table 8.1, Figure 8.2). Leave markers for these points and remove the others.

- After pools and riffles are identified for a reach, classify the units into habitat types. Not all terms will be relevant, but subcategories of the pool and riffle habitats are provided for further characterization.

Table 8.1 Example calculations of the bed form differencing technique for identifying riffles and pools in streams. Cases correspond to plots in Figure 8.2 and the sample field measurements are the bed elevations (B_i) in arbitrary units such as centimeters from a given base mark.

Oberva-tion (i)	B (ith)	$B_{(i+1)} - B_i$	Sign of change	Series (i)	Series ΣE_i	$\lvert\Sigma E_i\rvert \geq T$?	Designation
				Example A			
1	39						Start or upstream bed form
2	29	–10	–	1			
3	9	–20	–	1			
4	6	– 3	–	1	–33	Yes	Absolute minimum; pool
5	12	6	+	2			
6	24	12	+	2			
7	35	11	+	2	29	Yes	Absolute maximum; riffle
	SD = 12.7			Net change =	– 4		
	T = 9.5						
				Example B			
1	46						Start or upstream bed form
2	37	– 9	–	1			
3	26	–11	–	1	–20	Yes	Local minimum
4	29	3	+	2	3	No	Less than T, not a bed form
5	19	–10	–	3	–10	Yes	Absolute minimum; pool
6	20	1	+	4			
7	24	4	+	4			
8	30	6	+	4			
9	42	12	+	4	23	Yes	Absolute maximum; riffle
	SD = 8.5			Net change =	– 4		
	T = 6.4						
				Example C			
1	45						Start or upstream bed form
2	31	–14	–	1	–14	Yes	Local minimium
3	37	6	+	2	6	No	Less than T, not a bed form
4	35	– 2	–	3	– 2	No	Less than T, not a bed form
5	36	1	+	4	1	No	Less than T, not a bed form
6	21	–15	–	5			
7	14	– 7	–	5	–22	Yes	Absolute minimum; pool
8	30	16	+	6			
9	42	12	+	6	28	Yes	Absolute maximum; riffle
	SD = 11.4			Net change =	– 3		
	T = 8.6						
				Example D			
1	43						Start or upstream bed form
2	32	–11	–	1			
3	22	–10	–	1	–21	Yes	Local minimium
4	25	3	+	2	3	No	Less than T, not a bed form
5	18	– 7	–	3	– 7	No	Less than T, not a bed form
6	22	4	+	4	4	No	Less than T, not a bed form
7	7	–15	–	5	–15	Yes	Absolute minimum; pool
8	12	5	+	6			
9	38	26	+	6	31	Yes	Absolute maximum; riffle
	SD = 13.2			Net change =	– 5		
	T = 9.9						

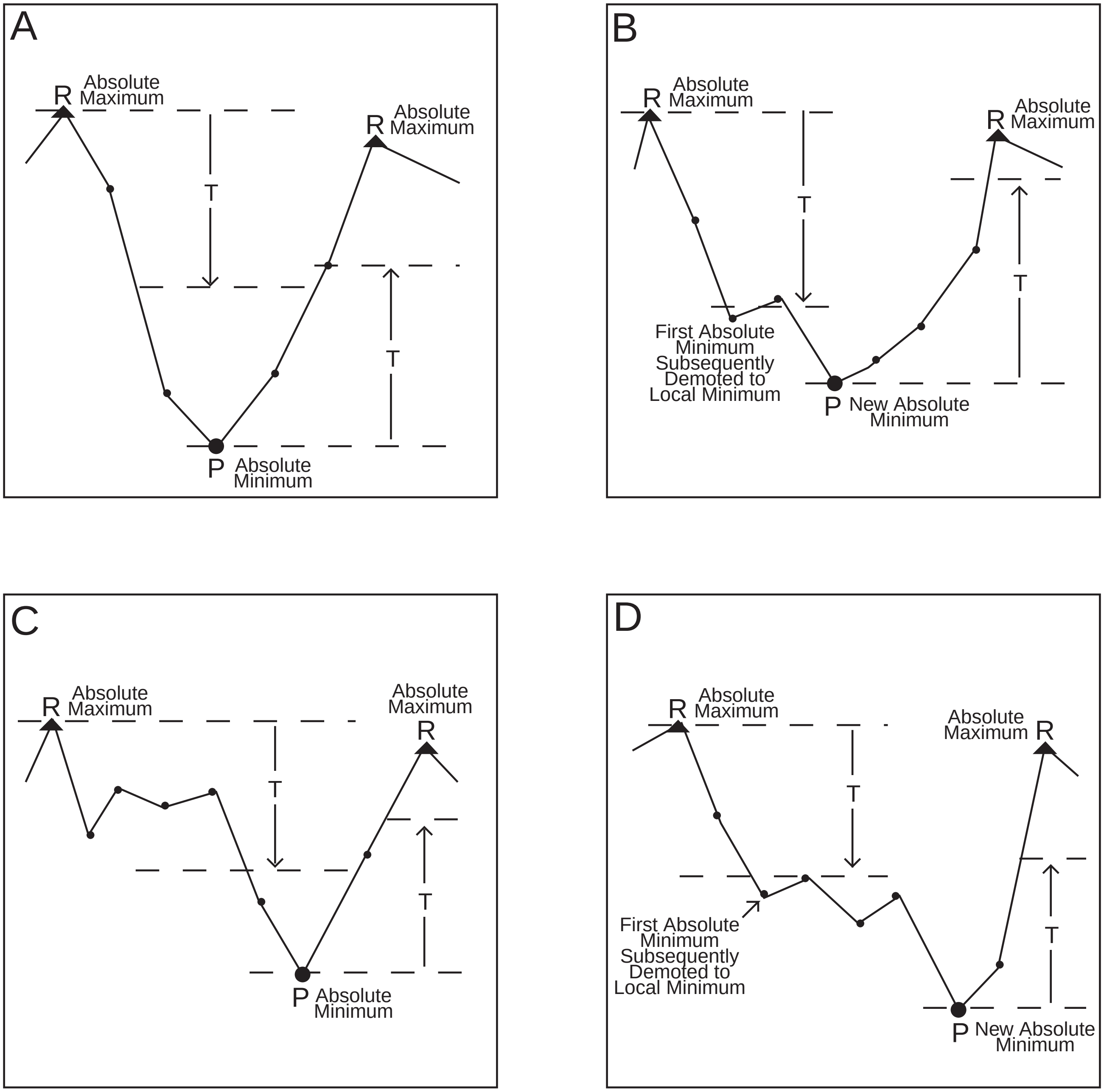


Figure 8.2 Example bed profiles showing the bed form differencing technique. Charts A, B, C, and D correspond with sample calculations in Table 8.1 (modified from O'Neill and Abrahams 1987).

8.3.4 Notes

With some field experience, it will not be necessary to use or retain a data sheet because the technique is easy to follow and key values will identify pools and riffles.

8.4 Macrohabitat Classification

8.4.1 Rationale

Three similar macrohabitat classification systems are provided in this section, and any one or a combination of systems can be used to classify CGUs or riffles and pools identified by the delineation techniques presented above. Select a classification system based on assessment objectives, desired level of detail, and regional usability. Habitat descriptors for fast water or riffles (Table 8.2) and slow water or pools (Table 8.3) are provided with illustrations (Figures 8.3 and 8.4) to guide the identification of habitat classes.

Hawkins et al. (1993) describe a three-level system that can be used to classify CGUs for riffle (fast water) and pool (slow water) habitat classes (Figure 8.5). Fast water habitats are subdivided based on differences in gradient, bed roughness, and step development (distinct breaks in bed slope) that result in turbulent or nonturbulent flow. Pool classes are distinguished according to location within the flood or active channel, longitudinal and cross-sectional depth profiles, substrate characteristics, and constraining features that impound water. Flosi and Reynolds (1994) developed a four-level classification system (Figure 8.6) where the first two levels are similar to the first two levels of the Hawkins system. The more detailed levels of the Flosi and Reynolds system are based on water surface gradient for riffles and stream channel structures and location for pools. At level IV, a wide range of habitat classes are provided making this the most detailed of the three systems. Finally, the AARIMS system (Alaska Aquatic Resources Information Management System; Armantrout 1996) has nearly as many habitat classes as the Flosi and Reynolds system but in three levels (Figure 8.7). Complex habitat classes are included at the second level of resolution, which makes the AARIMS system unique. A complex habitat is a combination of fast water, slow water, and standing water habitats, which are too small to be split apart well in most CGU delineations.

8.4.2 Preparation

- Before field observations, delineate the study reach into CGUs or riffles and pools for classifying habitat types.

- Determine which classification system and level of resolution will be used for habitat classifications.

Table 8.2 Fast water macrohabitats and their characteristics.

Habitat type	Turbulence	Velocity	Substrate	Slope	Stream reach type	Miscellaneous
Low gradient or riffle	moderate; little–no whitewater; high at points of channel constriction	moderate: 20–50 cm/s	gravel, pebble, cobble; totally–partially submerged	<4%	plane bed, pool–riffle, regime, braided	channel profile usually straight to convex
High gradient or rapid	considerable; whitewater	fast; >50 cm/s	cobble, boulder; course, exposed	4–7%	plane bed	steps and pocket pools common; planar longitudinal profile
Steep gradient or cascade	high; mainly whitewater	high	bedrock or accumulation of boulders	>7%	bedrock, cascade	series of small falls or steps and pools; stepped longitudinal profile
Falls	high; whitewater	free falling over vertical drop		≤100%	bedrock, cascade, step pool	formed from a full spanning flow obstruction
Steps		fast		10–100%		abrupt breaks in gradient; usually shorter than channel width; features include: bedrock, boulders, cobble bar, logs, culvert, dam, weir
Chutes	turbulent	swift	bedrock; little–none exposed	2–30%	bedrock, cascade, step pool	can be in narrow, steep slots in bedrock
Glides	nonturbulent	low–moderate; even	gravel, cobble, sand	0–1%		wide channel lacking a definite thalweg; usually at the transition between a pool and riffle; no major flow obstructions; lacks features associated with pools; moderately shallow (10–30 cm)
Run	nonturbulent	swift	gravel, cobble, boulder	low	pool–riffle, regime, braided	occurs over a definite thalweg flat plane with a uniform channel form; no major flow obstructions; moderately shallow; deeper than riffles
Sheets	nonturbulent	uniform	smooth bedrock	variable	bedrock, cascade, step pool	
Edgewater	nonturbulent	low–still	varies from cobbles to boulders			usually associated with riffles; along margins of stream

Table 8.3 Slow water macrohabitats and their characteristics.

Habitat type	Substrate	Formation	Features	Stream reach type	Miscellaneous
Pool		lateral constriction of channel or sharp drop in water surface profile	bend in channel, large-scale obstructions (e.g., boulder, log)		concave in shape; direction of flow varies widely; depth greater than riffles or runs
Straight scour	highly variable	mid-channel scour caused by flow constriction	laterally confined, hardened banks; boulders or woody debris obstructions	cascade, step pool, pool–riffle	hole encompasses >60% of wetted channel width; symmetrical cross section; deeper at head
Lateral scour	variable	partial channel obstruction constricts flow to one side of channel	undercut bank, channel bend, log, root wad, bedrock outcrop, boulder	step pool, pool–riffle, regime, braided	scour usually confined to <60% of wetted channel width; deepest along bank with obstruction
Backwater eddy	fine-grained (sand, gravel, cobble)	eddy scour down-stream of a large obstruction along channel margin	root wad, boulder, log	almost all reach types	deep; >30 cm
Trench	stable; mainly bedrock	scour due to tightly constrained channel	bedrock walls are highly resistant to erosion	bedrock-dominated	U-shaped cross section; very long and narrow; swift velocity; deep; uniform
Channel confluence		scour occurring at confluence of two or more channels	partical sorting, plunges, lateral obstructions	any type of reach	also called convergence; greater velocity and turbulence than most other pool types
Plunge	partical size highly variable	scour due to water falling vertically over a complete or nearly complete channel obstruction	logs, boulder, bedrock	small, steep headwater streams; bedrock, cascade, step pool	deep; >1 m
Step	boulder			high-gradient, mountain streams	pools separated by short riffles or cascades
Dammed	smaller gravels and sand	water impounded upstream due to a complete or nearly complete channel blockage	debris jam, beaver, landslide		temporary nature because fill up with sediments (rate depends on sediment source)
Secondary isolated	gravel, sand, silt	outside of wetted but within active channel; water prevented from entering secondary channel	gravel bars; any other feature preventing flow from main to secondary channel	pool–riffle, regime, braided	after freshets; may dry up or depend on intergravel flow during late summer
Alcove pocket water	typically sand and organic matter, but can be of any type	outside active channel, into a secondary channel or along margins; eddy scour near lateral obstruction	boulders, rubble, logs		length usually less than full channel width; low–still velocity
Abandoned channel		formed at low flow when bars deposited along main channel isolate water in secondary channels		pool–riffle, regime, braided	ephemeral or maintained by subsurface flow

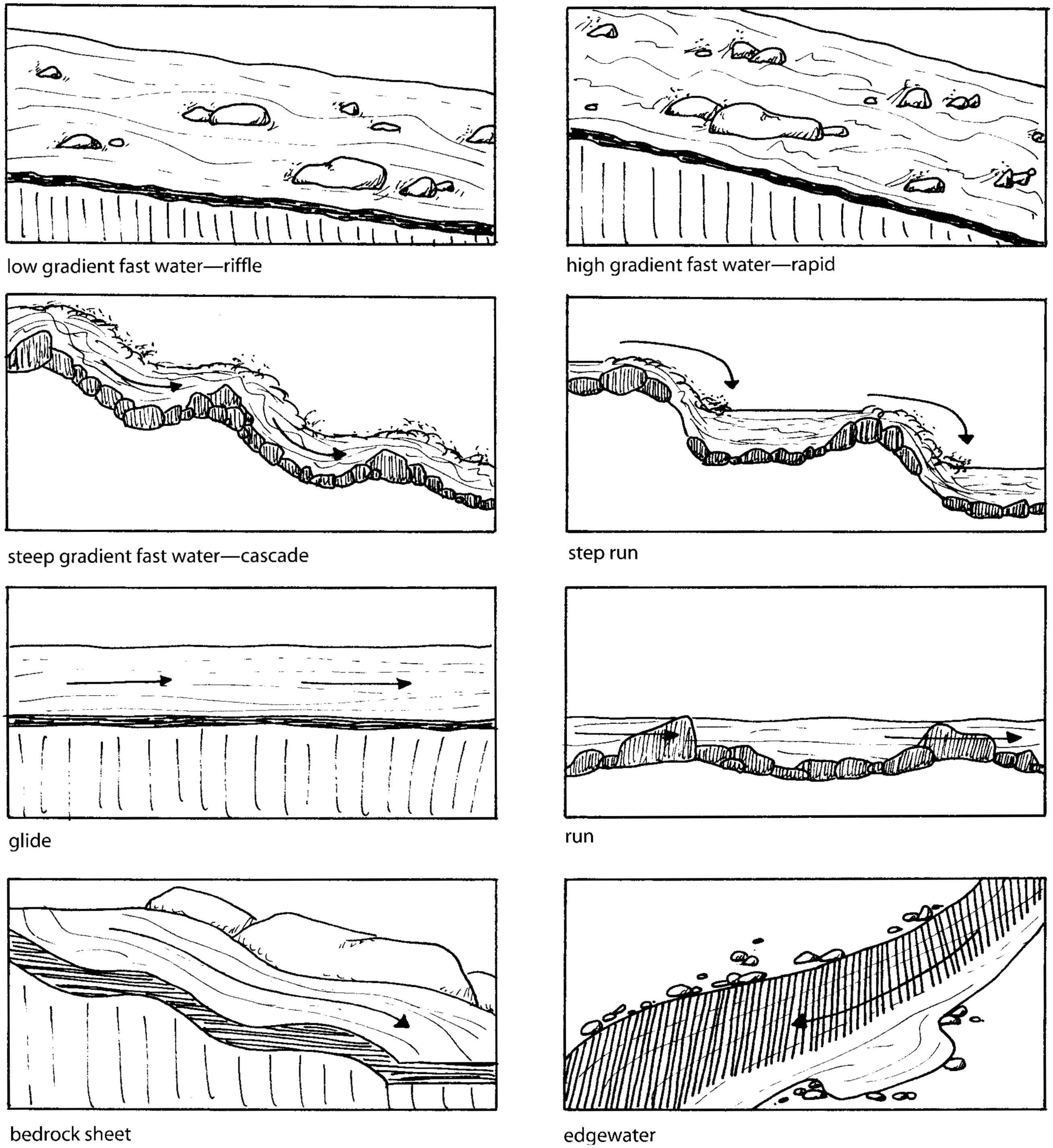
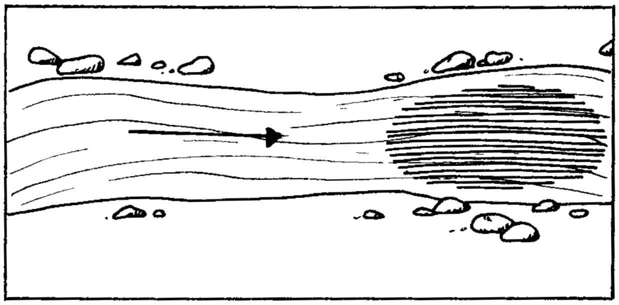
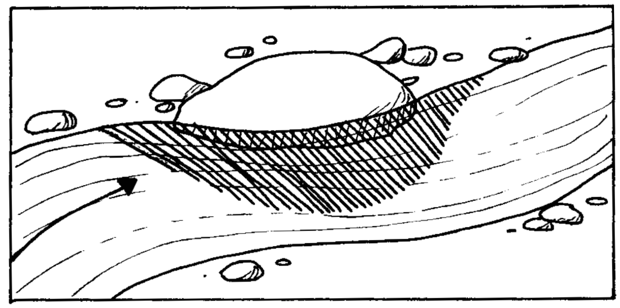


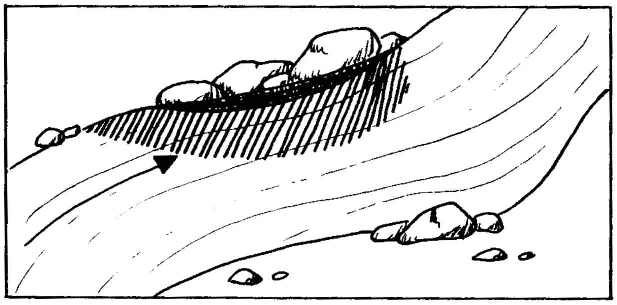
Figure 8.3 Illustrations of fast water habitat classes (from Flosi and Reynolds 1994).



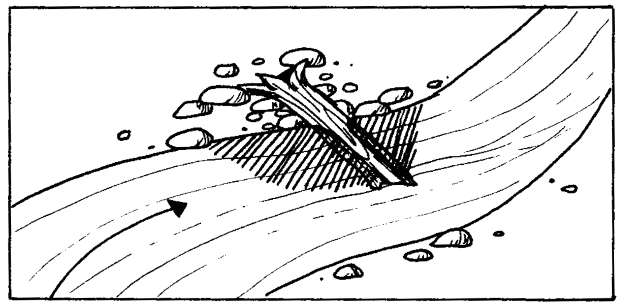
straight scour pool



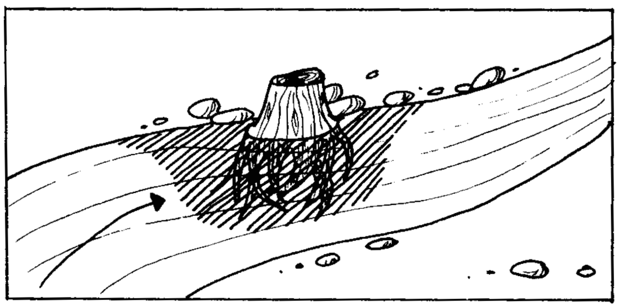
lateral scour pool—boulder formed



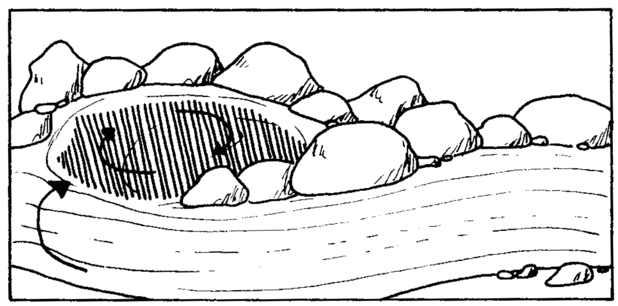
lateral scour pool—bedrock formed



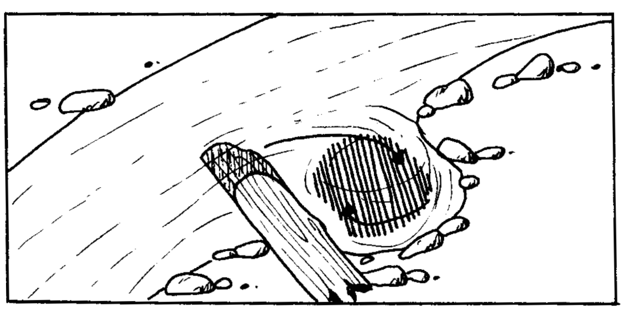
lateral scour pool—log enhanced



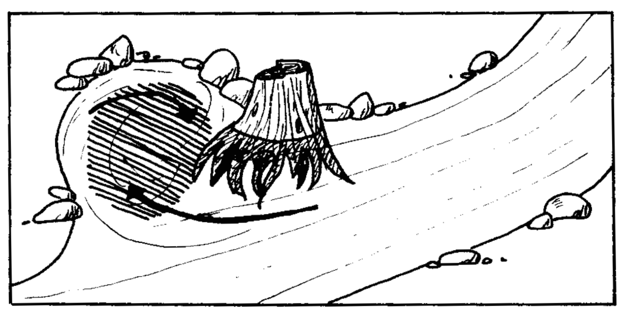
lateral scour pool—rootwad enhanced



backwater pool—boulder formed

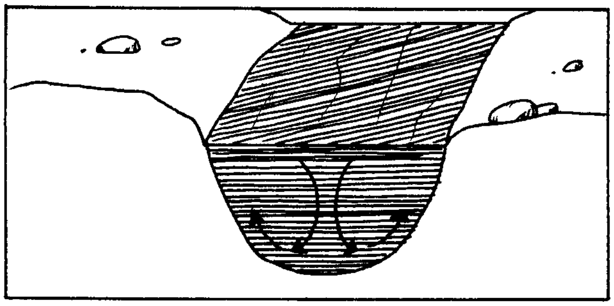


backwater pool—log formed

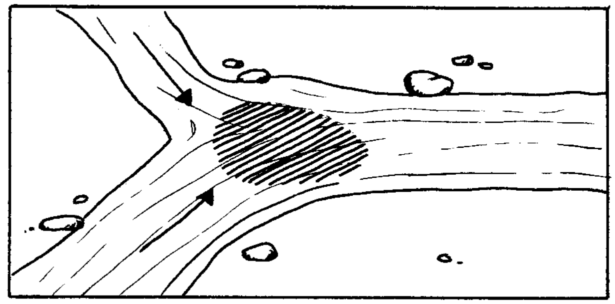


backwater pool—rootwad formed

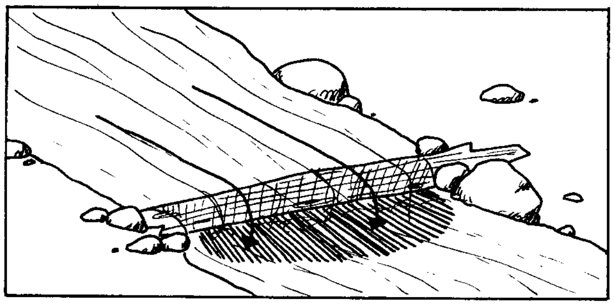
Figure 8.4 Illustrations of slow water habitat classes (from Flosi and Reynolds 1994).



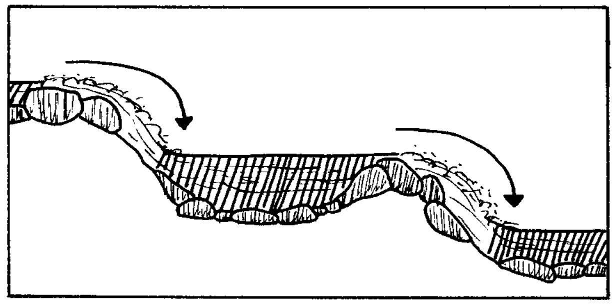
trench pool



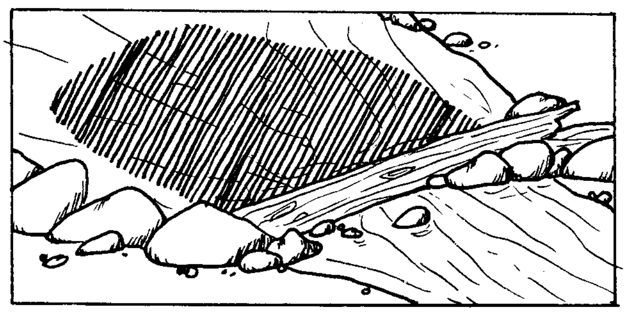
channel confluence pool



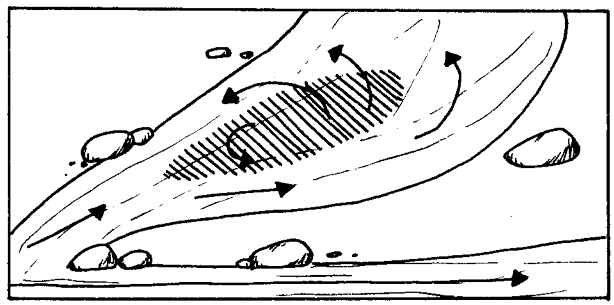
plunge pool



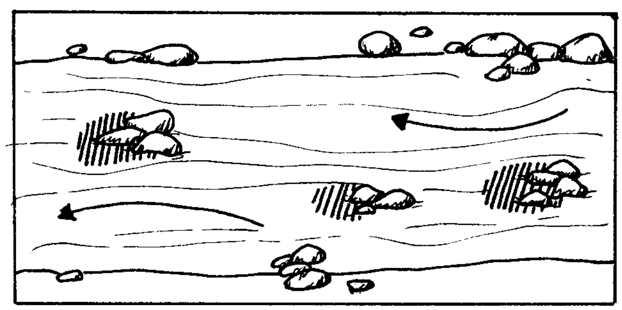
step pool



dammed pool



secondary channel pool



pocket water

Figure 8.4 Illustrations of slow water habitat classes, *continued* (from Flosi and Reynolds 1994).

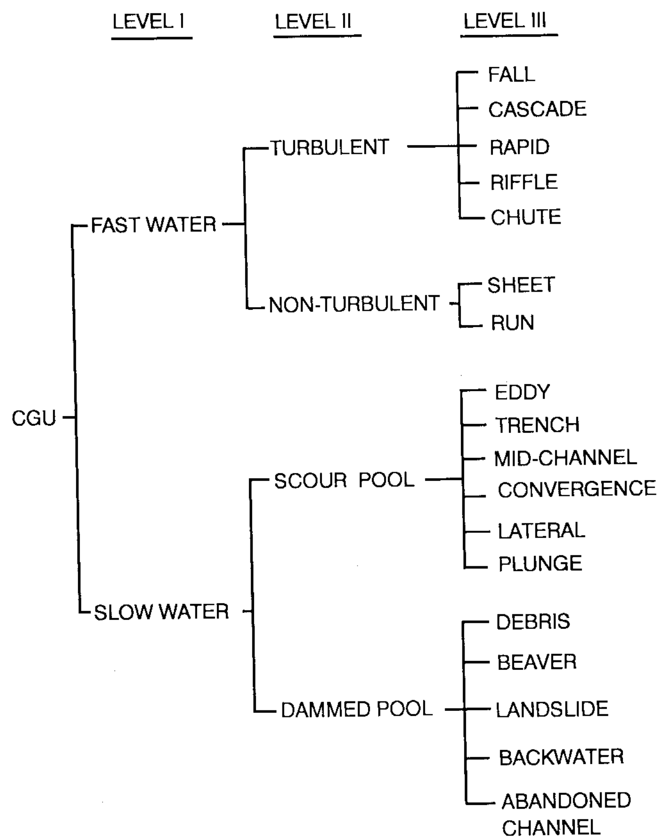


Figure 8.5 Dendrogram of the Hawkins habitat classification system (from Hawkins et al. 1993).

- Have the appropriate habitat type descriptions (Tables 8.2 and 8.3) and example illustrations (Figures 8.3 and 8.4) ready for use in the field. Prepare a check-off form that identifies the previously delineated habitats.

8.4.3 Procedure

- Classify each habitat by observation and measurements (e.g., maximum velocity, slope) as needed using Tables 8.2 and 8.3 and the sample habitat class illustrations (Figures 8.3 and 8.4) as guides. Record habitat types so that they correspond with information recorded in the delineation tasks. Label habitats on a sketch or scale map of the assessment reach.

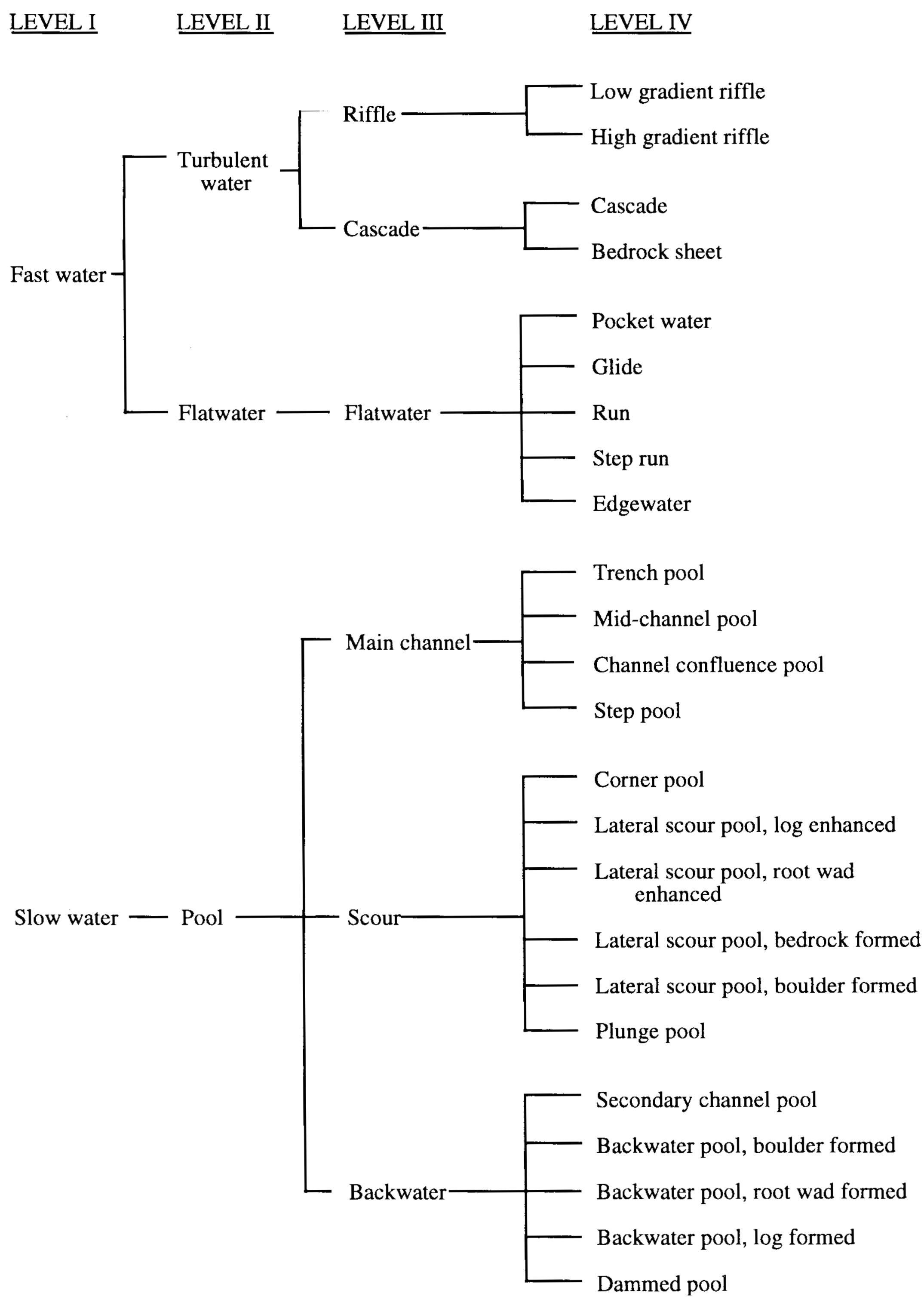


Figure 8.6 Dendrogram of the Flosi and Reynolds habitat classification system (modified from Flosi and Reynolds 1994).

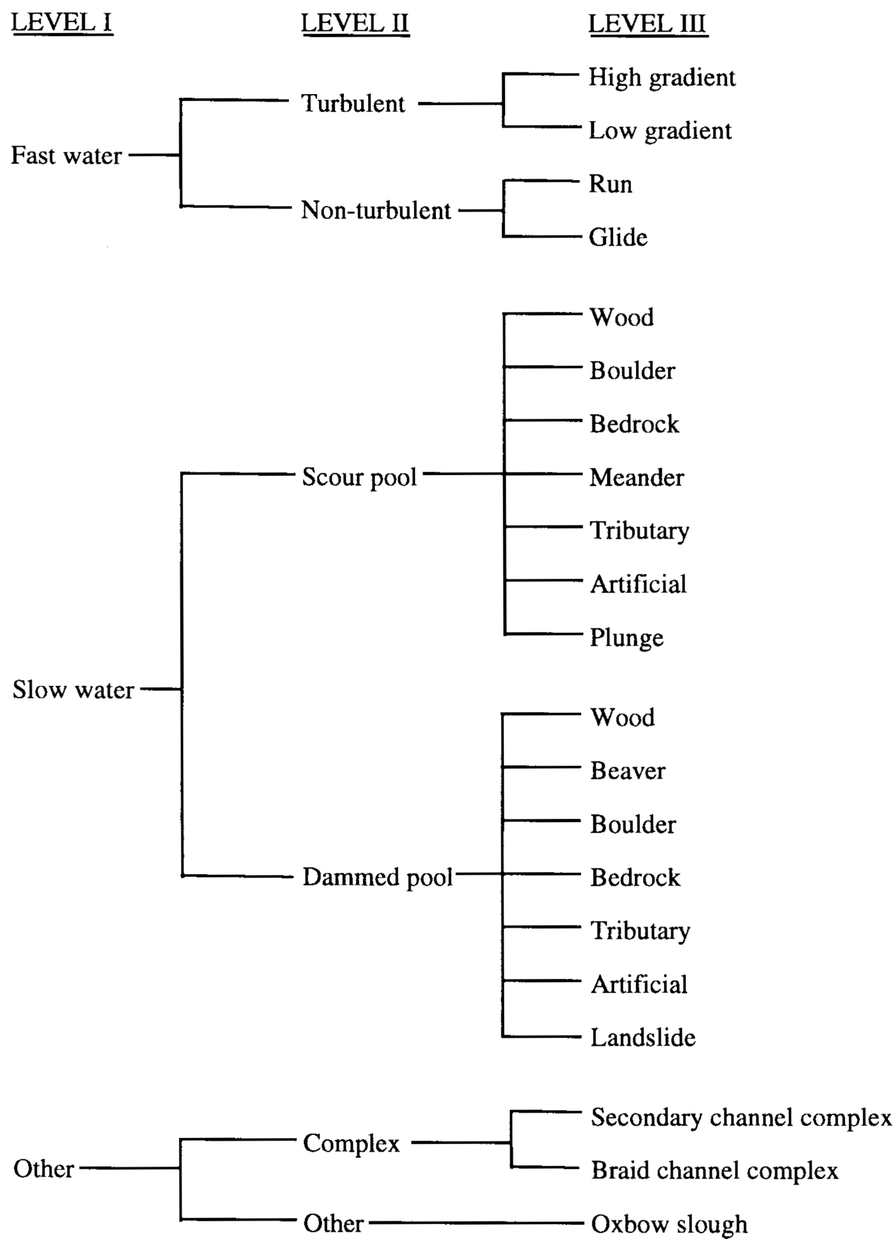


Figure 8.7 Dendrogram of the AARIMS habitat classification system (adapted from Armantrout 1996).

8.4.4 Notes

Not all of Flosi and Reynold's habitat classes are represented in the descriptive tables and illustrations because combinations of attributes are sometimes used to define a particular class and some consolidation of information was done for consistency across classification methods.

A fourth level of detail was included in the original AARIMS system (Armantrout 1996) but is not presented here because it was judged to be too detailed for broad use.

Substrate 9

Mark B. Bain

9.1 Introduction

9.1.1 Background

Substrate refers to the bottom material of a water body, and it is almost always documented in habitat surveys. There are three reasons for measuring substrate in any type of habitat assessment.

1. The composition of the substrate determines the roughness of stream channels, and roughness has a large influence on channel hydraulics (water depth, width, and current velocity) of stream habitat.
2. Substrate provides the micro-conditions needed by many fish species. For example, many species require specific substrates for spawning because eggs adhere to some surfaces. Also the interstitial water flow through the substrate maintains high oxygen levels around buried eggs (e.g., salmonids, see Chapman 1988).
3. Substrate provides clues to local and watershed influences on stream habitat quality. Land surface disturbances caused by forestry and agricultural practices alter surface water runoff and sedimentation rates, and these processes are reflected in the size composition of surface substrate (Meehan 1991).

As one of the most important aspects of fish habitat, substrate has often been measured or characterized using many techniques.

9.1.2 Selection of Techniques

A field technique is described that is especially relevant to each of the three functions associated with substrate. A rapid field technique (frequency of size classes) is described in section 9.2 to document simple substrate composition in a way that allows the data to be used in a variety of reports and further analyses. Although simplistic, substrate size-class composition will provide a means for consistently characterizing the general nature of stream substrate. A field technique is described in section 9.3 (embeddedness) for measuring the extent that interstitial spaces between coarse substrate particles are filled with fine material. This technique is especially relevant when habitat assessments target fish spawning habitat quality for species that bury eggs; notably salmonids. Finally, a technique is presented in section 9.4 (pebble count) that quantifies substrate size composition in a way that can be easily related to land use influences. This technique is commonly used when habitat assessments are oriented to watershed-scale conditions. The three techniques are ordered from the easiest and fastest to the most involved and informative. The pebble count method provides information that encompasses the other techniques, and when it is used all information commonly sought in substrate assessments is obtained.

9.2 Assessment of Composition: Frequency of Size Classes

9.2.1 Rationale

The goal of substrate assessments is to describe the dominant type or types of bottom material. Assessments are often done visually; for example, reporting that the littoral zone of a lake is largely sand. With little additional effort, a series of repeated observations can be used to develop a more quantitative assessment of substrate composition. The basic approach is to make a series of categorical observations of dominant substrate, and then treat those observations as data for statistical description. Statistical description of a series of substrate observations identifies the dominant material and the variability in the mixture of material that makes up the substrate.

It is necessary to categorize substrate types for making visual designations in the field. Substrate types have long been organized on a geometric size scale (the Wentworth scale, Wentworth 1922), in which each size category is twice as big as the preceding one. The Wentworth scale was grouped into familiar substrate types (e.g., sand, gravel, pebble) by Cummins (1962) and this modified Wentworth classification (Table 9.1) is frequently used in fish habitat studies because categories are easily distinguished for field surveys. Bain et al. (1985) described how the modified Wentworth classification can be used in a series of substrate observations to describe mean substrate size and substrate heterogeneity. This technique can also be used to directly measure the dominant substrate.

Table 9.1 Modified Wentworth classification of substrate types by size (Cummins 1962).

Substrate type	Particle size range (mm)	Sample codes
Boulder	>256	5
Cobble	64–256	4
Pebble	16–63	3
Gravel	2–15	2
Sand	0.06–1	1
Silt and clay	<0.059	0

9.2.2 Preparation

- Acquire one or more lead-core ropes or chains (1-m to 2-m lengths depending on habitat size) with 10-cm sections painted contrasting colors.

- Prior to fieldwork, develop a plan that specifies the number of observations to be made at a location, and the number of locations spaced across a study site. For example, in large streams a 2-m rope can be used to make 20 observations at a stream location, and 10 of these sample sets would yield a total of 200 observations.

9.2.3 Procedures

- **Make a series of substrate observations.** At each sampling location on the bottom of a stream or lake littoral zone, record the dominant substrate class in contact with each colored section of rope. The dominant substrate class will often vary by colored section, and dominant substrates can be rapidly judged for each section. Record the substrate types using the class codes in Table 9.1 and as shown in the sample data in Table 9.2. Repeat this procedure at predetermined intervals across the study site. The first location should be randomly selected and the others should follow at set intervals (e.g., every third meter across representative transects). In small streams, use a 1-m sampling rope to obtain 10 observations, and use the rope at least 10 times for a total of 100 observations. For large water bodies, a 2-m rope with 20 colored segments can be used; at least 10 samplings with the rope should be made across a study site.

- **Characterize the substrate for the study site.** Compute the mean of all substrate observations (e.g., $N = 100$ or 200) to estimate the average substrate size, the dominant substrate for the entire site, and the standard deviation to indicate substrate heterogeneity. Example statistics and their interpretations are given in Table 9.2 for single rope samples; a much larger series of numbers would be obtained and analyzed for a whole study site. The computations and interpretations would be the same but based on more observations.

Table 9.2 Sample coded substrate data from four sets of observations in different habitats with descriptive statistics and inferred substrate composition (from Bain et al. 1985). Actual field data for a study site would include 100 or 200 observations for each study site but the statistics and interpretations would be the same.

Substrate observations	Dominant (mode)	Mean	Standard deviation	Inferred substrate composition
5555511112111145555	Boulder	3.20	±1.96	Heterogeneous mix of sand and boulders
5555555555555555555	Boulder	5.00	±0.00	Homogeneous boulder
11112221111111122111	Sand	1.25	±0.44	Nearly homogeneous, fine
22233444325444433333	Pebble	3.25	±0.85	Intermediate mixture

9.2.4 Notes

This technique is simple, straightforward, and rapid to conduct. With some field experience, one person could quickly call out substrate codes and an assistant could record the observations. A set of observations can be completed in a minute or two after the rope is positioned on the substrate. Data derived from this technique should complement data on water depth, velocity, and other continuous habitat attributes. Although this is a rapid field technique, the level of resolution is sufficient to meet most management needs. Several numerical descriptive measures (subdominant substrates, range of types, and class frequencies) can be generated with the data collected in addition to those recommended above and in Table 9.2. The technique can be applied to lakes although it may be necessary to modify the gear (sampling rope or chain).

9.3 Assessment of Structure: Embeddedness

9.3.1 Rationale

Embeddedness is a substrate attribute reflecting the degree to which larger particles (boulder, cobble, pebble, and large gravel) are surrounded or covered by fine sediment such as sand, silt, or clay. Fine sediment can fill the interstitial spaces between large particles and block water flow important for quality substrate habitat to support benthic macroinvertebrates, small overwintering fish, some fish spawning, and egg incubation. Substrates with heavy interstitial filling are described as highly embedded and degraded in benthic habitat quality.

9.3.2 Preparation

- Conduct embeddedness assessment after substrate sizes have been described in qualitative or quantitative (section 9.2) terms. Observers should have experience in distinguishing between, gravel, cobble, and boulders. A reference sample (bag, large jar, or box) of particles in the size range for each substrate class (Table 9.1) is very helpful for training field staff to classify substrates by sight.

9.3.3 Procedures

- **Record a series of field observations.** Using the criteria in Table 9.3, classify the embeddedness of the channel in five or more representative habitats (riffle, run, pool) on the thalweg or midstream locations. If the site is being assessed with transects, embeddedness can be recorded for midstream or thalweg locations on each transect. Report the modal (most common) rating for the site.

9.3.4 Notes

This technique is simple to conduct although the visual assessment of embeddedness is not highly accurate. Therefore, this technique is intended to approximate the condition of substrate relative to fine sediment impacts, and this is often sufficient to meet many management evaluation needs. It is not known what level of embeddedness is optimal for many fish species, and consequently coarse assessments should be satisfactory. The technique cannot be applied to lakes since interstitial space and water flow are based on flowing water bed dynamics.

Table 9.3 Embeddedness rating for stream channel materials (from Platts et al. 1983). Fine sediment includes material less than 2 mm in diameter: sand, silt, and clay.

Level of embeddedness	Description
Negligible	Gravel, pebble, cobble, and boulder particles have <5% of their surface covered by fine sediment
Low	Gravel, pebble, cobble, and boulder particles have 5–25% of their surface covered by fine sediment
Moderate	Gravel, pebble, cobble, and boulder particles have 25–50% of their surface covered by fine sediment
High	Gravel, cobble, and boulder particles have 50–75% of their surface covered by fine sediment
Very high	Gravel, pebble, cobble, and boulder particles have >75% of their surface covered by fine sediment

9.4 Assessment of Size–Frequency Distribution: Pebble Counts

9.4.1 Rationale

Fisheries biologists have relied heavily on visual characterizations of substrate composition using the techniques described above. An alternative practical and rapid technique yields substrate measurements, which enhances the repeatability and comparability of substrate assessments. The Wolman pebble count procedure (Wolman 1954) has been modified (Potyondy and Hardy 1994) to produce this technique which is especially suited for relating land activities to stream habitat quality (Figure 9.1). To use this technique, the investigator records the measurement of a single dimension for each substrate particle and repeats this measurement for a series of particles collected at the stream site. Evaluation of pebble counts has supported its use as a rapid method for quantitative analyses superior in accuracy and assessment performance to visual characterizations (Kondolf and Li 1992; Bevenger and King 1995). The technique also yields particle size data that can be used to compute frequency distributions, summary statistics, and parameters used in hydraulic analyses.

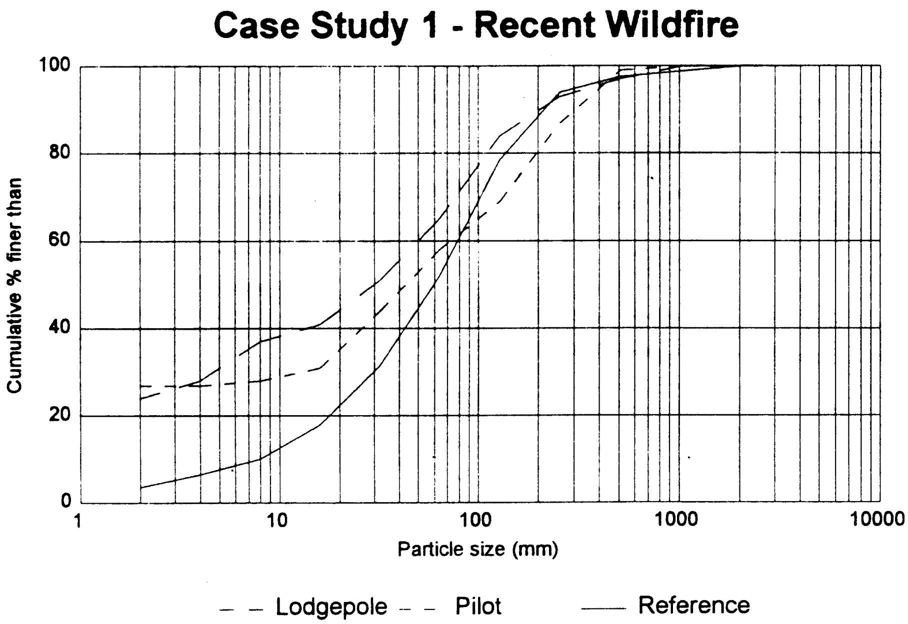
9.4.2 Preparation

- Obtain a hand ruler, caliper, and data sheet as shown in Figure 9.2.
- Inspect study site to obtain approximate stream width and site length.

9.4.3 Procedure

- **Design a sampling plan.** At the stream study site, set up about 12 zig-zag transects (see Figure 9.2) with bank intersection points spaced apart at a distance approximately twice the typical stream width (just visually estimate this spacing). Roughly estimate a distance interval to use on all transects (e.g., every second foot of length) to get about ten sampling points per transect. The total number of substrate observations should be 100, but there are no disadvantages to recording more observations. Twelve transects should ensure enough samples to account for variation in transect lengths.

- **Collect pebble measurements.** Proceed along all transects at a predetermined interval, pick a particle at toepoint, and measure the intermediate axis (see Figure 9.3 for a description) in millimeters (mm) using a ruler or caliper. The technique is illustrated in Figure 9.2 from Bevenger and King (1995). If boulders are too large to pick up, take an approximate measurement in the field by holding a ruler above the boulder assuming the two largest



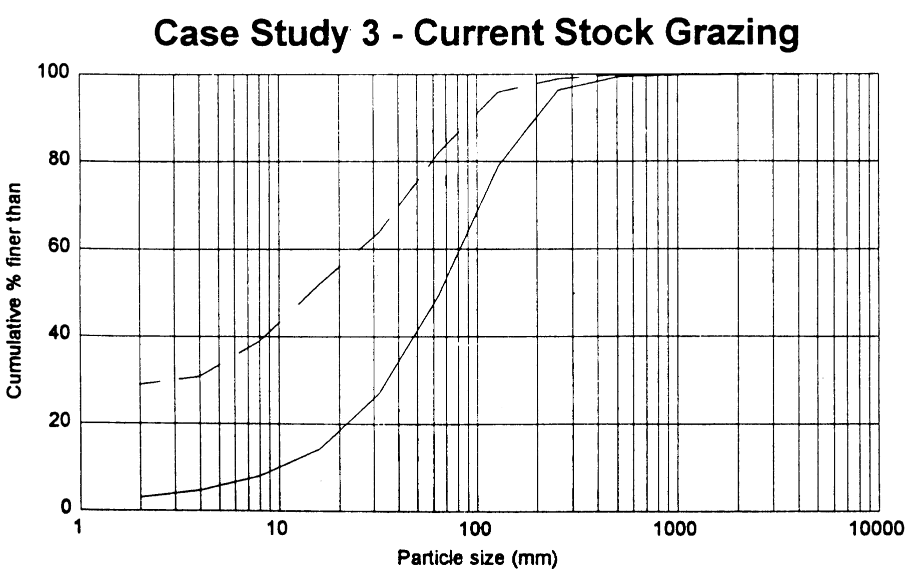


Figure 9.1 Particle size distributions from the pebble count technique for case study streams and reference sites (from Bevenger and King 1995).

dimensions are visible. For any particle under 2 mm on the intermediate axis, record the size as less than 2 mm. Include all channel areas on the transect that appear to be covered by water sometime during the year.

- **Prepare results.** Sort data points into rank order and plot every 10th percentile point as in Figure 9.1 to plot a cumulative frequency line. Percentile points on the plot correspond with vari-

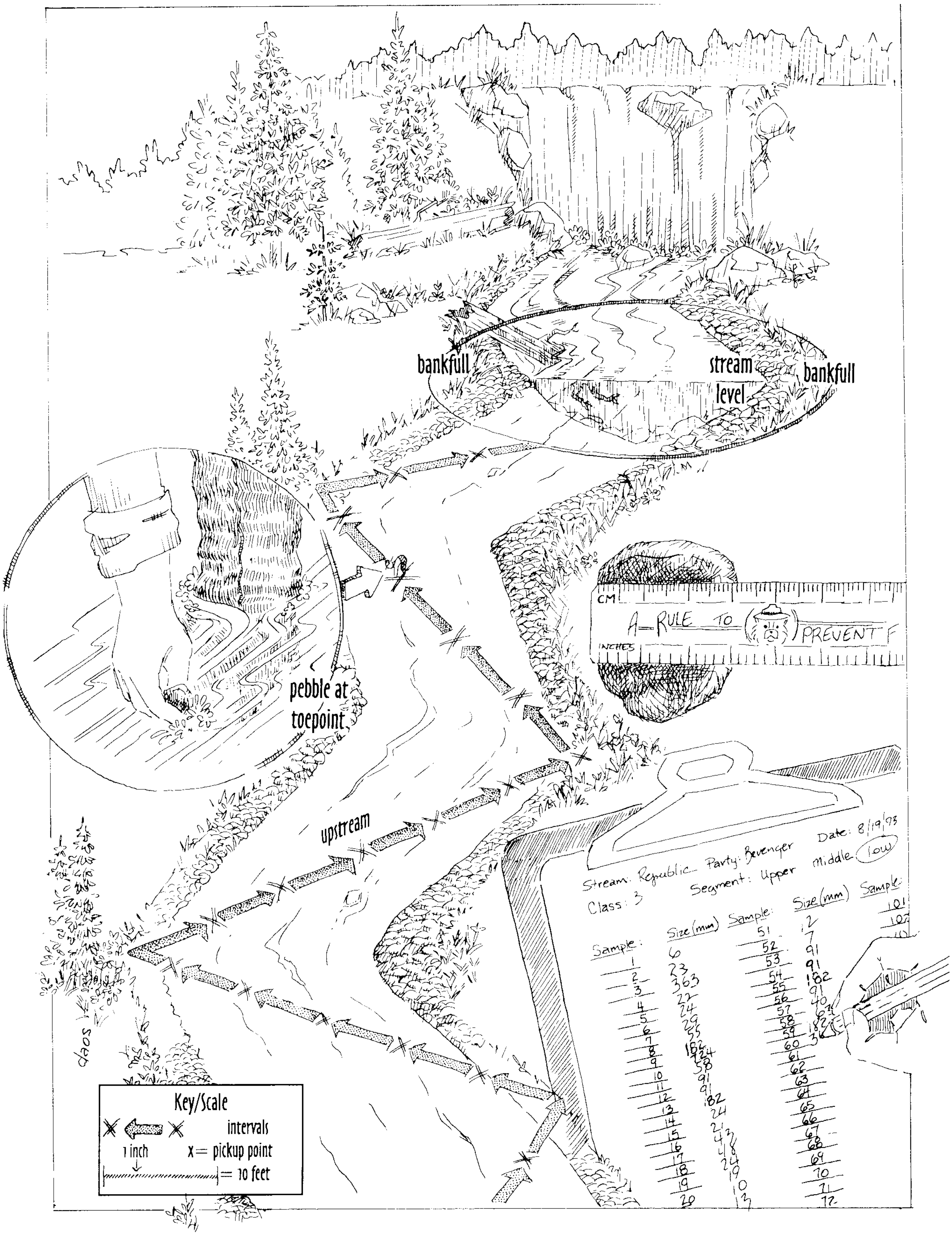
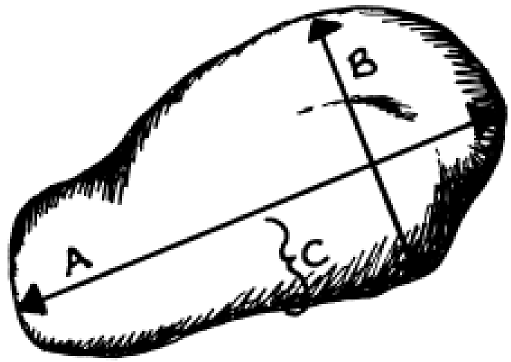


Figure 9.2 Pebble count technique (from Bevenger and King 1995).



A = longest axis (length)
B = intermediate axis (width)
C = shortest axis (thickness)

Figure 9.3 The intermediate axis of a particle, defined as neither the longest nor the shortest of mutually perpendicular axes, is measured to the nearest millimeter. The intermediate axis can be visualized as the dimension of the particle that controls whether or not it could pass through a sieve (from Harrelson et al. 1994).

ous measures (e.g., middle 50% size range, median, range, etc.) including the size of median (50th percentile) diameter used in many hydraulic formulae.

9.4.4 Notes

The accuracy of the pebble count technique depends on unbiased selection of particles, and that can be difficult to achieve consistently in some field situations. However, a clear sampling plan and careful particle selection often yields data that detect minor substrate composition differences among similar sites. This technique has been evaluated and used in the western mountain region of the United States; no information is available on its application in other regions. The technique cannot be applied to lakes since inference is based on flowing water sediment dynamics. The value of the data distribution for inference can be limited in naturally fine sediment coastal sand bed streams.

Cover and Refuge

10

Nathalie J. Stevenson and Mark B. Bain

10.1 Introduction

10.1.1 Background

Biologists consider the availability of cover in both lakes and streams to be important for maintaining many species and life stages of fish. Cover provides refuge (e.g., Tabor and Wurtsbaugh 1991) for fish from aquatic, terrestrial, and airborne (bird) predators as well as physical conditions such as high current velocities and bright sunlight. Organisms on which fish feed attach themselves to cover. Cover includes boulders and logs, aquatic vegetation, water turbulence, and concealing water depths (Armantrout 1998). While cover heavily influences the species, size, and life stage of fish found in a stream or lake habitat, cover and fish community relations are often complex. We present different techniques for documenting cover and refuge, and techniques for measuring the extent of cover.

10.1.2 Selection of Techniques

Many methods to assess cover have been developed, but they differ regarding what constitutes cover and how to best measure it. The techniques described here differ in fundamental ways as well. Section 10.2 presents techniques for measuring cover composition and abundance defined by single habitat attributes that provide cover and refuge for fish: deep water, turbulence, wood debris, and aquatic vegetation. The single-factor techniques are useful when one type of cover is of primary interest, for example, macrophyte beds in the littoral zone of lakes, or when one type of cover is the only one present, such as turbulence in fast-flowing, high montane streams. These techniques are also useful if habitat assessment is driven by the need to enhance or preserve one particular species of fish that depends on one or a few types of cover. Finally, the single-factor techniques can be used in concert with the more comprehensive cover assessment techniques described later. The result is a method that mixes general cover quantification with information on some specific cover features.

The techniques presented in sections 10.3 (Structural Complexity) and 10.4 (Cover Density) are used to evaluate cover indirectly by measuring physical structure features that are the consequence of cover. The technique used to assess structural complexity requires measuring topographic variability that is caused by cover objects. The technique used to assess cover density requires counting the number of objects that intersect a plane that extends between the water surface and the substrate. However, neither of these techniques identify the composition of cover in any assessed habitat. For a thorough assessment of cover, a combination of some or all of the techniques in section 10.2 could be used to document both the types and spatial extent of cover in a habitat.

10.2 Cover Composition and Abundance

10.2.1 Rationale

Stream morphology and water depth are positively correlated with abundance of certain fish species (Jowett et al. 1996) and life stages (Johnson et al. 1992; Aadland 1993; Carpenter and Maughan 1993). Depending on the water transparency, water depth provides surface concealment, and the availability of such water depth is considered as cover here. The techniques for measuring stream width and depth are covered in Chapter 6, and techniques for measuring transparency are covered in Chapter 17.

Turbulence is when water movement disturbs the surface and reduces the visibility of objects in water (Armantrout 1998). Turbulence is often important where little or no structural cover is present, but it is difficult to quantify the degree of turbulence needed to provide cover and refuge for particular species or sizes of fish. Consequently, we provide a simple but approximate technique for estimating the extent of turbulence. Large wood debris provides cover and usually improves both the quality and quantity of fish habitat (Lisle 1986; Everett and Ruiz 1993). Wood debris retards current velocity, adds structure, and increases the volume of usable habitat for some fish in small streams during periods of low flow (Lisle 1986). We include a technique for measuring the amount of wood debris in samples of habitat.

Many fish species are attracted to vegetation and rely on plant cover during some stage of their life. Studies that compare fish abundance in vegetated and unvegetated habitats have shown that abundance is usually much higher in vegetated areas for sunfish *Lepomis* spp., bass *Micropterus* spp., and northern pike *Esox lucius*. However, pelagic species, such as white bass *Morone chrysops*, gizzard shad

Dorosoma cepedianum, and inland silverside *Menidia beryllina*, are less abundant in highly vegetated habitats (Dibble et al. 1996). Very high vegetation density may cause decreased foraging efficiency for some important fishes. Some fish species are obligate plant spawners: at least 12 freshwater fish families use aquatic vegetation as nursery habitat for larvae, and at least 19 families of freshwater fish occupy vegetated habitats during at least one of their life stages (Dibble et al. 1996). Quantified relations between optimal fish species composition, biomass, density, and cover of aquatic vegetation are very limited despite many studies. However, intermediate (10–40% areal coverage) plant densities enhance fish diversity, feeding, growth, and reproduction (Dibble et al. 1996). The following technique yields broad measures of cover from structured visual estimation, since highly quantitative methods are not yet available for predicting habitat quality.

10.2.2 Preparation

- Measure and record representative stream widths and the maximum water depths that allow the substrate to be seen.

- Assemble waterproof measuring tapes, meter sticks, stakes and flagging for temporary transect marking, a field guide to common aquatic plants, and a small boat for deep water.

10.2.3 Procedures

- **Arrange transects and sections.** In shallow streams where most or all of the substrate is visible, set up 12 zig-zag transects with bank intersection points spaced apart by a distance approximately twice the typical stream width (visually estimate spacing). Create five or six sections per transect by roughly estimating a distance interval to use on all transects (e.g., every 2 m). There should be about 50 transect sections, but there are no disadvantages to including more. This zig-zag transect design is the same one recommended for substrate measurements in Chapter 9 and illustrated in Figure 9.2. To add cover observations, form five sections by making each section span the distance between every other substrate measurement point (about 10 per transect). For large streams and rivers, design transects in a similar way but do not sample the sections where the water is regularly so deep that the substrate is not visible from above. Record the sections where deep water provides cover as shown on the data sheet in Figure 10.1. In lakes and reservoirs, place transects perpendicular to the shoreline extending to the outer edge of the littoral zone. Subsection lengths and the number of transects should evenly cover the area of interest.

- **Estimate extent of turbulence in streams.** Visually estimate the percentage of the linear distance within each full transect section where the surface is broken. Turbulence is indicated by presence of spray, bubbles, white water, evident depressions, and elevations in the surface. For each full section, record (example in Figure 10.1) whether the water surface has negligible turbulence (<5% broken water surface), little turbulence (5–10% broken water surface), minor turbulence (11–40%), substantial turbulence (41–75%), or extensive turbulence (>75% broken water surface). Sum the number of sections and the distances counted in each turbulence class.

- **Enumerate wood debris.** For each full transect section, count and measure the diameter (to the nearest centimeter at the transect line) of all pieces of woody debris greater than one centimeter in diameter that intercept the transect line. Tally and record the number of wood pieces by diameter class (1–5, 6–10, 11–50, >51 cm) for each section (example in Figure 10.1). Sum the number of pieces in each size-class for all transect sections. Calculate the length of all transect sections and calculate the average number of pieces per section or linear length of transect.

- **Estimate extent of vegetation cover.** For each full transect section, estimate the approximate linear length with significant vegetation and record the dominant vegitation type: emergent, floating, or submerged (see Figure 10.1). Sum the linear distance (percents of section length) on all surveyed transect sections by vegetation class including no vegetation. Very common and dominant taxa should be noted.

10.2.4 Notes

This technique is based on general classes of cover (i.e., deep water, minor turbulence, abundant wood debris). Habitat assessments conducted in this way should result in data that can be used to estimate cover quality as there is little information available to relate cover characteristics and habitat value.

Turbulence and wood size classes are flexible and could be redefined for any specific habitat assessment program. Develop documentation for the specific criteria chosen.

The sampling design recommended here matches the one used for substrate assessment, so both sets of habitat attributes could be recorded simultaneously. See the pebble count technique (Chapter 9, section 9.4) for related information.

The characteristics of aquatic vegetation depend on season. Therefore, it is advised that the sampling season be standardized to improve comparability of data through time.

Water body: New Creek
Date:
Field investigators:
Study area location:

Number of transects: 12
Section length: 1 m
Number of sections surveyed: 46
Concealing water depth: 35 cm

Transect and section design notes:

		Turbulence				Wood				Vegetation		Notes
Tr. #	Sec. #	5-10	11-40	41-75	>75	1-5	6-10	11-50	>51	Dist. (m)	Class	and depth
1	1							2	1	0.4	Emergent	
1	2		1					1		0		
1	3			1						0		
1	4					3	2			0.3	Submerged	
1	5											Incomplete
2	1				1					0		
2	2									0		Deep water
2	3		1					1		0		
2	4	1				1				0.2	Submerged	
2	5					3	1			0.9	Submerged	
3	1	1								0		
3	2	1								0		Deep water
3	3		1							0		
3	4			1						0	Submerged	
3	5				1				1	0	Submerged	
3	6			1						0		
3	7					1	1			0.5	Emergent	
4	1	.	.	.	.	.	.	.	.	.	.	.
4	2	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.
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.	.	.	.	.	.	.	.	.	.	.	.	.
12	46	9	15	8	5	21	15	11	4	10.4	Submerged	8 Deep sections

Figure 10.1 Cover composition and abundance data sheet with some sample entries for a stream site assessment.

10.3 Structural Complexity

10.3.1 Rationale

Fish cover is provided by objects or structures that add topographic complexity to a flat habitat bottom. A measure of the deviation from a flat bottom would then be directly related to the amount of underwater structure. Luckhurst and Luckhurst (1978) provided a simple field technique to quantify deviation from a flat habitat. The technique compares the straight-line distance between fixed points with the bottom contour distance, including objects that add structure such as logs and boulders. The more structured the habitat, the greater the distance between two fixed points. This technique can be used when there is a variety of structures (including nonbiological debris such as tires) because the measurements detect anything that interrupts a flat habitat bottom. The technique has been adapted from its original form to be used along transects and sections in shallow habitats.

10.3.2 Preparation

- Select the length of transect sections to be used prior to actual field measurements. Because a ratio of lengths rather than absolute distances is used as final data, the transect section lengths can be changed from assessment site to site (not within sites or samples). Linear transect section lengths should be at least 2 m long so that distance changes due to cover objects on the transect can be easily measured.

- Obtain one or more chains or heavily weighted (lead-core) and flexible ropes, a standard length rope that corresponds to transect section lengths, and stakes and flags for marking transect positions and section endpoints.

10.3.3 Procedures

- **Arrange transects.** Locate a series of transects to representatively sample shallow-water (depths at which the substrate is visible) habitats at the lake or stream assessment site. The zig-zag transect arrangement described above (section 10.2.3) can be used or transects can parallel the shoreline: narrow streams (<5 m wide) should have a transect situated 1 m off each shore and one or two transects evenly spaced in midstream; for wide streams, add midstream transects parallel to shore but at increasing distances from shore in shallow water. Divide transects into equal-length sections that are at least 2-m long so that 15 or more sections are available for measurement.

- **Measure linear and contour lengths.** For each transect section, mark the section endpoints with stakes or flags on shore, or have two people stand the specified distance apart in the water. This is the linear distance between section endpoints. Position a chain or weighted (lead-core) rope along the transect section length and allow the chain to follow the substrate contours and hang over logs and other objects. Mark the transect section endpoints on the chain by grasping these points with the hand or attaching a clip of some kind. Remove the chain from the water and on shore measure the length between marks to obtain the contour length. Repeat the measurement of contour lengths along all transect sections.

- **Compute ratio values.** Calculate the ratio of contour length to linear length for each transect. Values close to one denote relatively simple topography, and higher values indicate topographically complex sites. The ratio for each transect section is the substrate ratio, and a mean of all sets of measurements provides a single measure of structural complexity for the assessment site.

10.3.4 Notes

This technique requires snorkeling in water deeper than 2 m because it is important to determine the exact endpoints of the contour measurements.

This technique is not descriptive of the type of cover (i.e., wood debris, vegetation, bank structures, etc.). Notes regarding the types of cover detected in the survey would make the technique more helpful.

10.4 Cover Density

10.4.1 Rationale

The cover density technique (Kinsolving and Bain 1990) enumerates objects that bisect a plane extending from the water surface to the habitat bottom for each transect section. It describes all of the instream cover and refuge regardless of whether it is wood debris, vegetation, boulders, or overhanging structures in the water. The technique is simple and does no more than provide counts of nonsubstrate objects. Large counts are associated with high cover density. The counting process can initially be confusing because rules determine what should be counted, but with experience the technique is rapid and easy to understand.

10.4.2 Preparation

- Obtain one or more heavily weighted (lead core) ropes to guide counting along a transect section, and some stakes and flagging for marking transect positions and section endpoints.

10.4.3 Procedure

- **Arrange transects.** Locate a series of transects to sample shallow water (depths at which the substrate is visible) habitats at the lake or stream assessment site. Use the zig-zag transect arrangement described in section 10.2.3 or the shoreline parallel transect arrangement described in section 10.3.3. Divide transects into sections that are equal length and at least 0.5 m long, so that 50 or more sections are available for cover counts. Transect section lengths can be about any length but they should be sized so that cover object counts are not so large as to be confusing (>25). Final results will be reported in counts per linear transect distance so varying the section lengths per site will not make sites incomparable.

- **Count cover objects per section.** Begin at one end of the transect section, and count the number of surfaces encountering a plane that extends from the water surface to the stream bottom. Counts can be done visually or by touching objects above the substrate in the plane. Exclude the actual stream bottom from your counts or any substrate particle including boulders. Rules for counting the number of surfaces are:

  - solid objects with a diameter greater than 10 cm, are counted as two surfaces;
  - objects with a diameter less than 10 cm are counted as a single surface;
  - objects located closer than 3 cm to each other are counted as one surface;
  - portions of a cover object that are geometrically separate (such as branches on a tree) are counted separately;
  - undercut banks are considered to be cover objects, and are therefore counted.

  Figure 10.2 shows an example of counting surfaces on a section plane. Record the number of object surfaces that intersect each section plane.

- **Compute site results.** After all sections are counted, compute cover density (mean counts per transect length, e.g., 0.7/m) by summing all counts, the number of sections counted, and the total linear length included in all counts. Other statistics can be computed such as the percent of sections with cover of some kind (nonzero counts) and variance of the counts as an index of cover dispersion.

10.4.4 Notes

Although the counting rules can be modified to fit assessment program needs, the rules cannot be changed among sites. Any counting rules need to be well documented. For instance, if adult salmonids are of special interest, the size limitations for adequate cover must be increased to match the size of the adult fish; whereas, if juvenile fish are of special interest, then the size limitations should be decreased because a juvenile fish can find adequate cover in small spaces.

This technique may not be very accurate in areas where there is either significant floating vegetation or where the stream or lake bottom is covered with fine but dense vegetation. In such cases, the rules would dictate that each increment would only be given a score of one, and underestimates of cover would therefore occur. In such cases it is recommended that surveyors use the technique to assess aquatic vegetation cover outlined in section 10.2.

This technique is not descriptive of the type of cover (i.e., wood debris, vegetation, bank structures, etc.). Notes about the types of cover detected in the survey could enhance this technique.

In the cover density technique, counts are not adjusted for variation in water depth among sections. Therefore, cover is not counted based on habitat volume. We assume deep water provides cover and counts are limited to shallow water so some of the potential shortcoming of ignoring depth should be reduced. Nevertheless, this technique may not satisfy assessment needs for habitat where cover per habitat volume is of special interest or target fish species respond strongly to cover depth distribution.

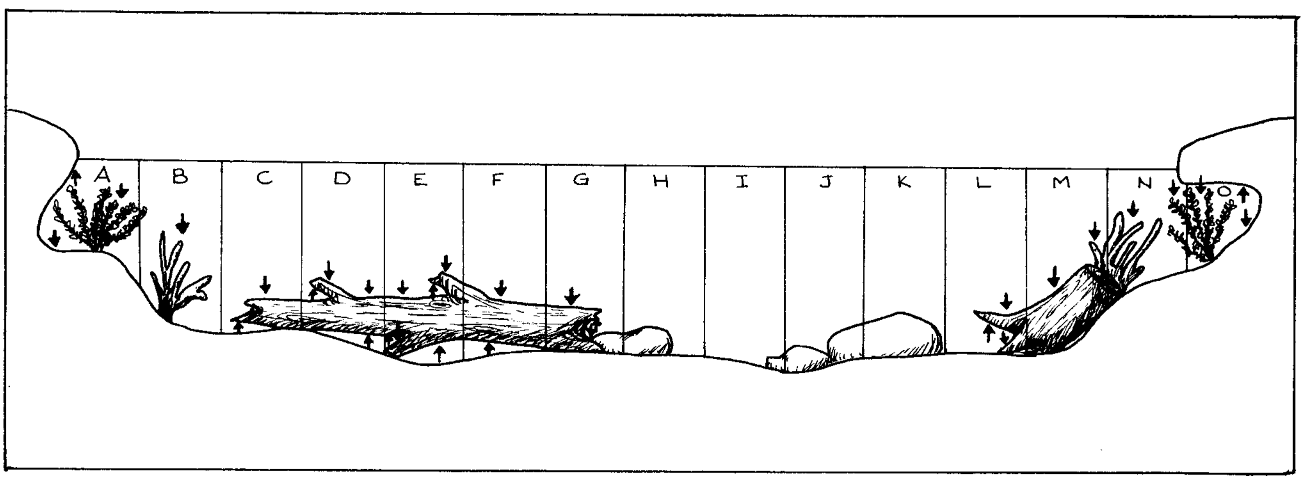

Figure 10.2 Example of counting surfaces on transect section planes for the cover density technique.

Streambank and Shoreline Condition

11

Nathalie J. Stevenson and Katherine E. Mills

11.1 Introduction

11.1.1 Background

Streambanks and lake shores are important transition zones between aquatic and terrestrial systems. When in good condition, these habitats are well vegetated, resistant to erosion, and provide cover and refuge for fish species in various life stages. Human impacts and natural disturbances reduce bank vegetation, erosion resistance, structural stability, and fish cover value. Shoreline fish cover is degraded when bank vegetation is lost and elevated erosion rates lead to undercut banks that collapse quickly when banks erode. Inputs of sediment and silt to lakes and streams reduces water transparency, smothers fish eggs and benthos, and fills pools and shallow water habitats. Bank condition is assessed by evaluating the attributes associated with erosion rates and structural stability: bank height, root depth, percent root density, bank angle, percent surface protection (bank cover), and the composition of substrate and soil. The techniques described below rate the condition of streambank and shoreline habitats, measure physical attributes indicative of condition, and document degradation of bank habitat by agricultural animal use.

11.1.2 Selection of Techniques

This chapter describes techniques for assessing streambank and shoreline condition visually and by using instruments. The technique for rating streambank and shoreline cover incorporates an evaluation of vegetation and rock cover associated with stable, low erosion habitats. Measurement of streambank angle and undercutting reflects erosion rates and stability, but this technique is especially relevant for documenting undercut habitats used by select species (e.g., salmonids). The technique for rating animal use damage has limited utility, but this form of habitat impact is important and pervasive in many parts of North America. The latter two specialized techniques are of interest in regions where undercut banks support key species or animal damage to stream habitat is a problem. A comprehensive evaluation of streambank and shoreline condition could be done by pairing a specialized technique with the more general cover assessment technique. Bank shape and animal damage can then be linked to information on erodible banks and shores.

11.2 Streambank and Shoreline Cover

11.2.1 Rationale

Streambank and shoreline stability is influenced by the erosion resistance role of plant roots and bank rock. Vegetation and large boulders stabilize banks and protect them from erosion when inundated: living root systems hold soil in place; increased roughness slows local water velocity; and surface vegetation can promote sediment deposition (Myers 1989). Trees and shrubs have deeper and larger root systems than grasses and forbs; however, a heterogeneous variety of plants provide greater bank stability than monotypic plant communities. With this technique both the amount of rooted vegetation and the amount of rocky ground cover are assessed using a measure of total bank cover to evaluate the susceptibility of banks to erosion. The basic method applies to both lentic and lotic waters, although the procedure is described for streams and modifications are suggested for lakes and reservoirs. Use this method to derive a total bank cover assessment that corresponds with erosion potential and stability. The methods used for lentic and for lotic environments are based on Pfankuch (1975) and Hamilton and Bergerson (1984).

11.2.2 Preparation

- Plan for the arrangement of transects along streambanks or lake shore. For streams, have an estimate of average stream width for selecting transect and segment lengths.

- Acquire measuring tape, stakes and flagging to define segments, and data recording sheets.

11.2.3 Procedures

- **Arrange stream site survey.** At base flow during summer or early fall, arrange one transect midway between the water edge and the floodplain (level land adjacent to the stream and inundated less than annually) running roughly parallel to the water edge. The length of the transect should be between five and seven times the average channel width of the stream. Once the transect has been established, mark 30 or more points with stakes or flagging along the transect length at regularly spaced intervals (e.g., every 5 m). These points define transect segments or the transect lengths between points.

- **Rate transect segments.** The observer should start at one end of the transect and determine ratings (1–4) for vegetation cover and rocky cover (ratings defined in Table 11.1) by transect segment (example on field form in Figure 11.1). Ratings for vegetation and rock cover should be recorded separately.

- **Calculate site results.** For each transect, compute mean bank scores separately for vegetation and rocky cover by multiplying the rating values by the number of observations and dividing the sum of products by the number of transect segments. Figure 11.1 shows a sample data sheet with entries and calculations for one transect. For each transect, take the whole value (drop fractions) of the mean scores for vegetation and rocky material ratings and sum them. Compare the sum to the total cover rating in Table 11.1. Enter the final total cover rating for the transect as in Figure 11.1. The right and left bank transects could be averaged or reported separately for the assessment site.

- **Modifications for lakes and reservoirs.** This technique can be easily adapted for use on lake and reservoir shorelines. Transects should be deployed to sample the area of interest or dispersed around the water body if the assessment is intended to represent the entire shoreline. Position the transect parallel to the shoreline within the zone between high and low lake levels. For reservoirs, position the transects along the summer pool level or in the zone between high and low summer pool levels. Do not apply the technique in the drawdown zone of seasonally regulated reservoirs because terrestrial vegetation cannot persist in this habitat. The field form shown in Figure 11.1 will need to be modified for the number of transects used.

11.3 Bank Shape

11.3.1 Rationale

Shoreline habitats are important for many fish species and life stages, and shoreline shape is related to bank erosion rates. Gradually sloping banks indicate stable lake and stream margins because they are less vulnerable to sloughing and they are formed by slow erosion and sediment deposition rates. Steep and undercut banks indicate accelerated erosion associated with intensive land use and shoreline disturbances like livestock grazing, although some bank undercutting is expected even in pristine waters. Undercut banks are valuable

Table 11.1 Rating criteria for vegetation cover, rocky cover, and total cover for transect segments along streambanks (modified from Hamilton and Bergersen 1984).

Rating value		Criteria and description
		Vegetation cover
4		Combined cover of trees, shrubs, grass and forbs is greater than 90% of the transect segment. Openings in this nearly complete cover are small and dispersed. Many plant species and age classes are represented. Growth is vigorous and the age or size structure of plants suggests continued ground cover. A deep, dense root mass is likely.
3		Plants cover 70–90% of the transect segment. Shrub species are more prevalent than trees. Openings in the tree canopy are larger than the space resulting from the loss of a single mature individual. Although plant growth appears good, few or no large and old trees and shrubs are present. A deep root mass may not seem continuous, and significant erosion is possible in the openings during high streamflow.
2		Plant cover ranges from 50 to 70% of the transect segment. Lack of vigor is evident in some individuals or species. Tree seedling reproduction is nil. Much of the transect segment lacks vegetation with the potential for a deep root mass. Serious erosion is likely at high streamflows.
1		Less than 50% of the segment is covered by vegetation. Trees are rare or absent, and shrub cover is sparse and clumped. Growth and reproduction vigor is generally poor. Root mass is likely to be discontinuous and shallow.
		Rocky material cover
4		Rock makes up 65% or more of the transect segment, and large boulders (longest axis >30 cm) are numerous.
3		The transect segment is 40–65% rocky material: mostly small boulders and cobble 15–30 cm across.
2		The transect segment is 20–40% rocky material. Although some small boulders may be present, most are 8–15 cm across.
1		Less than 20% of segment is stony material, mostly gravel 2.5–8 cm across.
		Total cover rating
≥4	Excellent	Nearly all of the streambank is covered by vegetation in vigorous condition or by boulders and cobble.
4	Good	Most of the streambank surfaces are covered by vegetation or rocky material the size of pebbles and larger. Areas not covered by vegetation are protected by materials that will limit erosion at high streamflows.
3	Fair	A substantial portion of the streambank surface is not covered by vegetation or rocky material. These areas are have poor resistance to erosion.
2	Poor	Little of the streambank surface is covered by vegetation or rocky material, and there is little or no resistance to erosion. Banks are clearly eroded each year by high streamflows.

Assessment Site:	
Recorder:	Date and time:
Streamflow condition:	

Streambank Cover Form

Right	Veg.	Rock
1	1	3
2	3	2
3	2	2
4	1	3
5	1	2
6	1	1
7	1	1
8	2	1
9	4	1
10	1	4
11	1	3
12	1	4
13	4	1
14	1	2
15	1	1
16	1	1
17	2	3
18	1	1
19	2	2
20	2	1
21	3	2
22	4	1
23	1	4
24	4	1
25	4	1
26	4	1
27	3	2
28	3	2
29	4	1
30	4	1
31	1	2
32	1	2
33		
34		
35		

Left	Veg.	Rock
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
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21		
22		
23		
24		
25		
26		
27		
28		
29		
30		
31		
32		
33		
34		
35		

Right Bank Vegetation		
Value	Obser.	Product
1	15	15
2	5	10
3	4	12
4	8	32
	32	69
Mean score =		2.15

Right Bank Rock		
Value	Obser.	Product
1	15	15
2	10	20
3	4	12
4	3	12
	32	59
Mean score =		1.84

Left Bank Vegetation		
Value	Obser.	Product
Mean score =		

Left Bank Rock		
Value	Obser.	Product
Mean score =		

Right Bank Total Cover Rating: Fair
Veg = 2 Rock = 1 Sum = 3

Right Bank Total Cover Rating:
Veg = Rock = Sum =

Notes on streambanks:

Figure 11.1 Sample streambank cover data sheet showing ratings for the right bank and the associated calculations.

habitats that conceal fish close to currents and often support high, localized fish biomass (Duff et al. 1989). Therefore, characterizing streambank and shoreline shape serves dual purposes of assessing potentially valuable fish habitat and assessing habitats that are sensitive to disturbances including landscape scale processes. Inferring the overall quality of shoreline habitats is possible when data on shoreline morphology is combined with other habitat assessment information like substrate quality, suspended sediment concentrations, and riparian vegetation. The technique described below will provide simple measurements of streambank and shoreline shape for use with other habitat assessment results.

11.3.2 Preparation

- Plan for the arrangement of transects along streambanks or sampling locations along lake shores. For streams, have an approximate estimate of average stream width for selecting transect and segment lengths.

- Acquire metal meter sticks, long straight edge devices, stakes and flagging to define sample points, data sheets, and a clinometer for measuring angles.

11.3.3 Procedures

- **Arrange stream site survey.** At base flow of summer or early fall, select a length of stream at least five to seven times the average channel width. Identify evenly spaced (e.g., every 5 m) measurement points that will provide 10 or more recordings per transect.

- **Measuring bank angle for sloping shorelines.** Using a clinometer and a straight edge, measure the angle at the water edge as shown in Figure 11.2. The angle is determined by placing the clinometer on the straight edge oriented along the bank slope at the water edge. Record the angle of the bank by subtracting the clinometer reading from 180°. For example, in Figure 11.2 the clinometer reads 35°, so the recording is 145°. Note that a vertical wall at the water edge would be recorded as 90°, so slopes less steep will be between 90° and 180°. Record water depth at the water edge as zero and undercut distance as zero (Figure 11.3) to be consistent with measurements for undercut banks explained below.

- **Measurements for undercut banks.** Three measurements are recorded for undercut banks: bank angle, undercut distance, and water depth at the overhang edge of the undercut. Again using a clinometer and a straight surface, measure the angle of the undercut as shown in Figure 11.4. Position the end of the straight edge at the furthest extent of the undercut as in Figure 11.3 and

Figure 11.2 Using a clinometer to measure a bank angle along a gradually sloping shoreline. The clinometer reading in this case is 35° so the recorded angle will be 145° (from Platts et al. 1987; Filipeck et al. 1994).

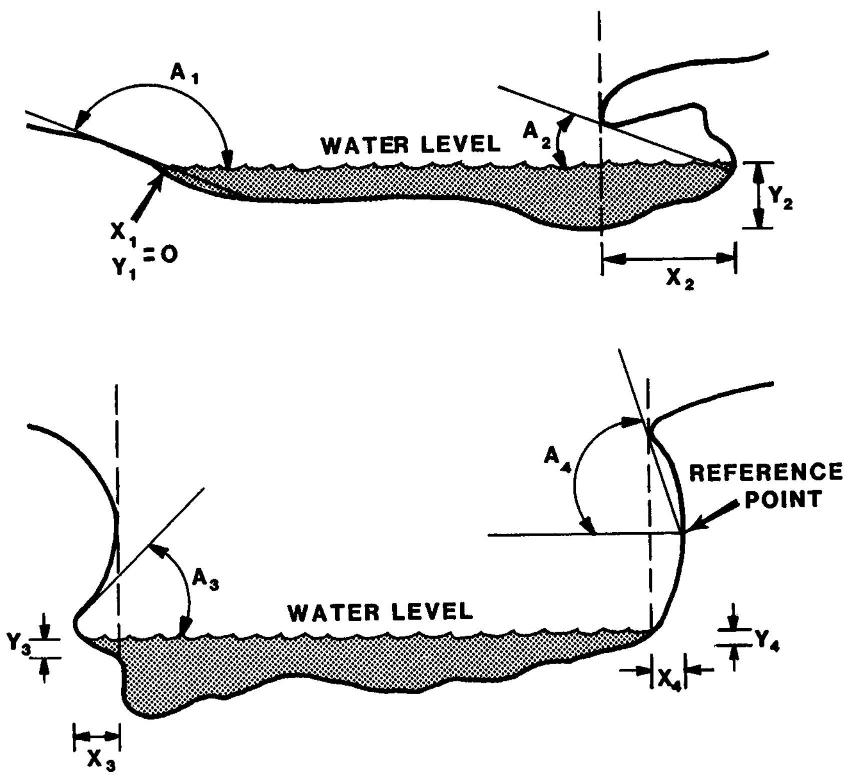


Figure 11.3 Hypothetical channel cross sections illustrating bank angle (A_i), undercut distance (X_i), and water depths (Y_i). (From Platts et al. 1987.)

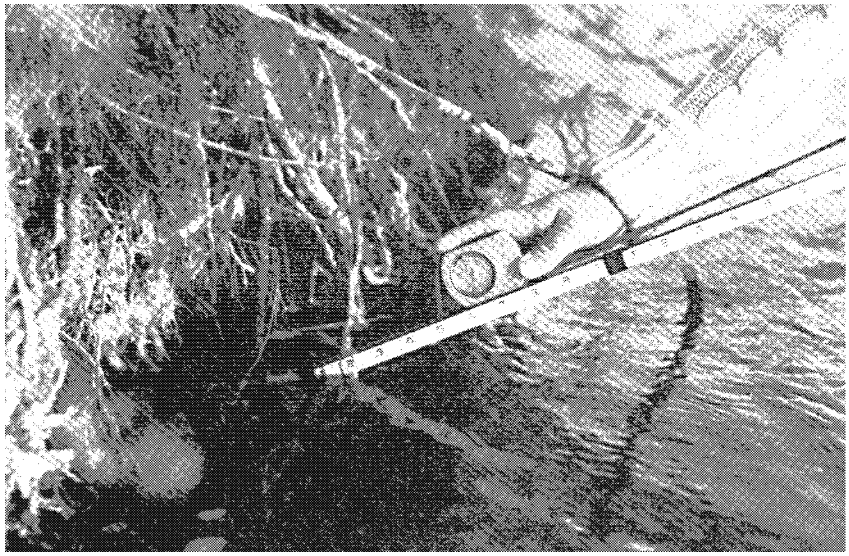


Figure 11.4 Using a clinometer to measure the angle of an undercut bank. The clinometer reading in this case is 45° and the angle is recorded as 45° (from Platts et al. 1987; Filipeck et al. 1994).

lift the straight edge to the underside of the undercut land surface. Measure this angle and record the same angle shown on the clinometer (i.e., do not subtract from 180°). Also record the distance between the land-inward end of the straight edge and the furthest outer edge of the undercut as in Figure 11.3 to obtain a measurement of undercut depth. Finally, record the water depth at the point directly beneath the outer edge of the undercut as in Figure 11.3. Note that undercut bank angles are always less than 90°.

- **Summarize results.** A series of bank measurements will usually include some sloping shorelines and undercut banks. All bank and undercut angles can be averaged to obtain a mean shore angle (range >0° to <180°). Water depths and undercut depths can be averaged for undercut bank measurements (angles <90°). These mean values describe the typical fish habitat associated with undercut banks.

- **Modifications for lakes and reservoirs.** This technique can be easily used on lake and reservoir shorelines. Measurement points should be deployed to sample the area of interest or dispersed evenly around the water body if the assessment is intended to represent the entire shoreline. For reservoirs, position the transects along the summer pool level or in the zone between high and low summer pool levels.

11.3.4 Notes

Evenly spaced bank measurements across an assessment site yield data on typical bank shape, but this sampling design may miss undercut bank habitat when it is sparse along a stream or lake. Measurements aimed at undercut bank habitat can be made but it should be noted on any field forms and database entries that these measurements were targeted at the particular habitat.

Platts et al. (1987) reported that year to year precision and accuracy are good for streambank angles greater than 90° because the 95% confidence intervals around the means are quite narrow. However, the 95% confidence intervals around the means of bank undercut are wide since the two points that define the undercut measurements are difficult to accurately determine in the field.

The actual bank angle should be recorded in the field, however, it may be useful to categorize the angles (or average values if applicable) to aid data interpretation. The following classification criteria are recommended: less than 90° indicates undercut banks; 90° to 135° indicates steeply sloping shorelines; and greater than 135° reflects gently sloping banks.

11.4 Shoreline Animal Damage

11.4.1 Rationale

Many streams flow through agricultural range or pasture land, and it is common for cattle, horses, and sheep to graze on streambanks. Intensive animal use of streamside areas often results in destabilized streambanks, sloughing and mass erosion of bank material, trampling of edge habitats, and consumption of riparian vegetation. The resulting habitat damage can be severe, and management intervention may be required to limit loss and restore bank habitat. The technique described below provides a rapid and easy way to qualitatively assess the effect of livestock use on the local streambanks. The technique was not intended for use in lake and reservoir habitat assessments.

11.4.2 Preparation

- Plan for the arrangement of transects along streambanks. Have an approximate estimate of average stream width for selecting transect and segment lengths.

- Acquire measuring tape, stakes and flagging to define segments, and data recording sheets.

11.4.3 Procedure

- **Arrange site survey.** Follow the procedure described in section 11.2.3 for locating transects divided into segments. The transect segments serve here as units of observation for rating the extent of animal damage to streambanks.

- **Rate animal damage by transect segment.** At each transect segment, note whether the land adjacent to the stream is used for livestock grazing; if so, assess the level of livestock use and associated damage, and record the rating values (Table 11.2).

- **Summarize results.** Animal damage ratings can be summarized with simple statistics (mean and range of ratings) for both banks or separately.

Table 11.2 Transect segment rating criteria for animal damage assessment (modified from Duff et al. 1989).

Rating value	Criteria and description	
4	Undamaged	Little or no evidence of streambank damage and evidence of animal use limited to 10–25% of the segment length. Little or no bank erosion or sloughing. Vegetative plant biomass at or near natural conditions.
3	Moderate damage	Streambank has evidence of animal damage in 26–50% of the segment length. Some erosion and sloughing evident. Less than half of potential plant biomass remains on site.
2	High damage	Streambank has evidence of animal damage over 51–75% of the segment length. Moderate to high bank erosion and sloughing during season of animal use and continuing during nonuse period. Annual recovery of vegetation structure limited to a minor portion of the segment.
1	Excessive damage	Streambank has evidence of animal damage over 76–100% of the segment length. Severe bank erosion and sloughing occurring over most or all to the segment streambank since root system and stem mass completely damaged. No evidence of bank recovery and erosion appears constant.

Riparian Vegetation 12

Katherine E. Mills and Nathalie J. Stevenson

12.1 Introduction

12.1.1 Background

A riparian zone is the area adjacent to a watercourse. Stream sides, river floodplain margins, and the edge habitat of lakes, ponds, and other bodies of water are all riparian zones. There are no clear criteria for delineating riparian zones, and Armantrout (1998) defines these habitats as terrestrial areas where the vegetation complex and microclimate conditions are products of the presence and influence of perennial or intermittent water. The extent of a riparian zone can be identified by changes in vegetation related to soil moisture. Riparian areas often support complex plant communities associated with diverse soil and hydrological variation (Platts et al. 1987), and typically including mature forest, low alder, brush, grasses, marshes, and agricultural pasture or fields. A variety of shrubs and long-lived tree species will grow in healthy riparian zones. Riparian vegetation is important to the input of nutrient and organic matter, the source of large woody debris, fish food and cover, the interception and storage of solar energy, reduction in solar heating, attenuation of flood flow scouring forces, and moderation of terrestrial nutrient inputs from agricultural sources (Myers 1989). An assessment of riparian vegetation composition and structure provides useful management information.

There are many techniques that evaluate vegetation to assess the status of riparian habitats; examples are Cowardin et al. (l979) for the U.S. Fish and Wildlife Service, Duff et al. (1989) for the Bureau of Land Management, Hansen et al. (1995) for Montana, and Swanson et al. (1988) for Nevada. Some methods directly assess vegetation, while others are based on soil and physical conditions.

Directly evaluating riparian vegetation requires examining community types, species composition, canopy cover, tree crown width, vegetation density, shadow characteristics, root depth and root density, and even areal coverage of each layer of vegetation. This chapter describes techniques that can be used to directly assess vegetation composition and structure in the riparian zone of streams, lakes, and reservoirs.

The most meaningful riparian assessments focus on relations between physical and biological factors influenced by the water–land transition landscape (Naiman et al. 1992). The techniques presented in this chapter characterize the basic structure of the riparian vegetation in height layers and stratify vegetation into understory (herbaceous plants and shrubs) and overstory (trees) layers. The understory has a majority of short-lived plants that revegetate annually; therefore, it provides a good indication of current soil and hydrological conditions. In contrast, trees in the overstory layer are long-lived and persistent plant community members that reflect long-term conditions.

12.1.2 Selection of Techniques

The assessment of riparian vegetation, like any plant assemblage analysis, can be complicated and time consuming. It is important to select the level of classification needed to meet management objectives. For example, would structure-level information be sufficient or are species-level data required? This chapter provides a general (section 12.2) vegetation characterization technique, as well as a more detailed (section 12.3) classification technique that focuses only on the area adjacent to the water body of interest. The techniques vary mainly in level of detail, measurement precision, and spatial scope. These techniques can be used to classify vegetation by category or by species. The technique provided in section 12.3 (water side vegetation assessment) requires identifying plant species and is appropriate for an in-depth description of vegetation composition and structure.

12.2 General Vegetation Characterization

12.2.1 Rationale

Vegetation structure reflects many important riparian site characteristics and functions, and riparian sites with diverse vegetation will have generally greater habitat value (Myers 1989). However, different vegetation types contribute to aquatic systems in different ways: large trees contribute wood, shade, and allochthonous inputs; shrubs stabilize banks and make it possible for solar radiation to penetrate the water. A general assessment of vegetation composition and vertical structure can be conducted quickly and easily by using the techniques described in this section. Using growth form (herbaceous, shrub, tree) to assess cover does not require expertise in identifying plant species.

12.2.2 Preparation

- Obtain field forms, one or more tape measures, a telescoping surveyors rod, and some stakes and flagging to mark transects.

12.2.3 Procedures

- **Arrange transects and points.** Locate five or more transects extending outward from the streambank or lakeshore bank (not the water edge) approximately 10 m or to the outer edge of the riparian zone (transition to uplands or vegetation unrelated to water body). Transects can be evenly spaced to cover the assessment site and should be perpendicular to the bank. For stream assessments place five or more transects on each side of the stream or river. Mark the transects as left or right bank on the data sheet (sample shown in Figure 12.1). Identify 100 points at even intervals on all the transects. Select a length interval that results in about 20 points per transect or 100 for the assessment site. Maintain the same spacing between points on all transects rather than forcing the same number of points on transects of different lengths.

- **Characterize vegetation composition.** For each transect, designate on a form (as in Figure 12.1) the classes of vegetation that constitute a majority of the cover (primary vegetation component) and the classes of vegetation that constitute significant but secondary components of cover. The classes of vegetation are listed in Figure 12.1 (forbs, grasses, shrubs, etc.). Forbs are broadleaved herbaceous plants, grasses are narrow leaved, and both lack woody stems above ground. Shrubs are woody plants that are typically bushy and less than 6 m tall at maturity (Cowardin 1979; e.g., speckled alder *Alnus rugosa* or buttonbush *Cephalanthus occidentalis*). Definitions for wetland classes are in Armantrout (1998).

- **Measure vegetation cover by height.** For each transect point, extend a telescoping survey rod from the ground up to the maximum extension of herbaceous plant height (this may vary but should not be more than 1.5 m). Record whether or not the rod hits herbaceous vegetation by placing an H in the box (Figure 12.1) for the sampling point. Record an H once per sample point even if herbaceous vegetation touches the rod at several points. Next, extend the rod upwards to the maximum extension of shrub height (usually about 6 m). Record whether or not the rod hits shrub vegetation by placing an S in the box (Figure 12.1) for the sampling point. Next, extend the rod up to tree height and record whether or not the rod hits tree vegetation by placing a T

Assessment Site:	
Recorder:	Date and time:
Streamflow/lake level condition:	

Riparian Vegetation Characterization

Transect	1	2	3	4	5	6	7	8	9	10
Bare soil										
Forbs										
Grasses, sedges, rushes										
Shrubs										
Trees with deciduous, broadleaf overstory										
Trees, with perennial overstorey										
Wetland vegetation: Bog										
Fen										
Marsh										
Agricultural vegetation: Row crops										
Grasses, forbs										
Pasture, grazed cover										

Entries: 1 = primary components of cover, 2 = secondary components of cover.

Site design notes:
Right bank transects:
Left bank transects:
Lake or reservoir site
Vegetation notes:

Point Intercept Recordings

Enter in each box:

- **H** for Herbaceous
- **S** for Shrub
- **T** for Tree
- **–** empty sample points

Right bank pts:
Herbaceous cover: H entries: % cover:
Shrub cover: S entries: % cover:
Tree cover: T entries: % cover:
Left bank pts:
Herbaceous cover: H entries: % cover:
Shrub cover: S entries: % cover:
Tree cover: T entries: % cover:

Figure 12.1 Example riparian vegetation characterization field form for designating primary and secondary vegetation by transect, and recording vegetation intercepts at sampling points.

in the box (Figure 12.1) for the sampling point. When tree height exceeds rod length, an observer could use the survey rod to visually estimate if tree vegetation intersects the sampling point. Finally, place a dash in the boxes for sampling points that had no vegetation recorded so the number of sampling points are clearly shown on the data sheet. Calculate the percentage of sampling points with each type of vegetation by dividing the number of entries (H, S, T separately) by the total number of point measurements taken (at least 100). The results are percent cover for each vegetation height category. Figure 12.1 shows a sample data sheet for recording frequency and percent cover calculations.

12.2.4 Notes

The end of the riparian zone may be inconsistently identified among field staff as there are no riparian delineation rules.

The vegetation classes (e.g., shrubs, trees) are broad so that there is less chance of observer error and field tasks are simplified. More detailed assessment would use height categories or record heights of plant intercepts with sampling points.

Sampling must be done during the summer because plant growth and coverage varies seasonally.

A spherical densiometer could be used to more precisely measure canopy cover for trees (described below).

12.3 Water Side Vegetation Assessment

12.3.1 Rationale

Some habitat assessment programs require more detailed information on riparian vegetation than can be obtained from the general characterization technique. Swanson et al. (1988) developed a vegetation classification system that integrates information on vegetation, soils, and hydrology, and can be applied easily and quickly. The Swanson et al. (1988) technique is based on observation, but when it is combined with the use of a spherical densiometer, quantitative vegetation cover data are obtained. Because of the densiometer, this technique presented is most accurate for plants more than 10 m in height. The technique described was adapted from Swanson et al. (1988) to simplify their riparian community classification and to eliminate material that is covered by techniques in other chapters of this manual. Although the Swanson et al. (1988) technique was developed for streams, we outline some minor steps that make it applicable to reservoir and lake shorelines.

12.3.2 Preparation

- Field staff should develop knowledge of the common riparian plant species, as well as basic soil types and formation processes present in the area.

- Obtain taxonomic guides to regional flora, sample bags and labels for unidentified species, a spherical densiometer, one or more tape measures, some stakes and flagging, and waterproof data sheets (sample in Figure 12.2).

- Modify a standard spherical densiometer as shown in Figure 12.3 so it records directional rather than 360° views (as in Platts et al. 1987).

12.3.3 Procedures

- **Identify sampling points.** Data are to be recorded at each end of a habitat assessment site. For streams, at each end of the site set up a transect across the stream channel with endpoints on each bank. Three locations should be identified and marked along this transect line: one 30 cm out from the right bank, one in midstream, and one 30 cm out from the left bank. For lakes, mark an observation point 30 cm off the shoreline bank at each end of the site or periodically around the lake.

- **Classify riparian vegetation.** Looking into the riparian zone from each shoreline sampling location, identify and record which of the following three riparian types best describes the habitat (see data sheet in Figure 12.2).

  Hydroriparian wetlands have hydric soils or substrates that are rarely or only briefly dry. Vegetation is predominantly obligate and preferential wet riparian plants.

  Mesoriparian areas have nonhydric soils and substrates that are dry seasonally. Vegetation is a mixture of obligate, preferential, and facultative riparian plants.

  Xeroriparian habitats are mesic to xeric; the average moisture is higher than the surrounding uplands due to occasional (less than one month a year) surface wetting or increased groundwater from the associated water body. Vegetation is preferential, facultative, and nonriparian plants.

  After identifying the riparian type, select the dominant class of trees, shrubs, and herbaceous plants (evergreen, deciduous, low, high, mixed) and record information on a data sheet (Figure 12.2). Finally, record the dominant plant taxa for trees, shrubs, and herbaceous vegetation layers. If multiple, similarly important taxa exist in a layer, then list them as codominant taxa using a hyphen to separate the species names.

- **Quantify cover by vegetation layer.** Use a modified spherical densiometer (Figure 12.3) to measure the extent of cover from tree, shrub, and herbaceous plant layers. At each bank location and midstream point, face the bank, upstream or downstream (upstream and downstream as separate observations) and hold

Assessment Site:	
Recorder:	Date and time:
Streamflow/lake level condition:	

Riparian Vegetation Classification

End of site : upstream __, downstream __, lakeshore at ____________				
Right Bank or ____________				
Hydroriparian		Trees	evergreen , deciduous , mixed	Taxa:
Mesoriparian		Shrubs	tall (> 1m) , low (≤ 1 m) , mixed	Taxa:
Xeroriparian		Herbaceous	tall (>30 cm) , low (≤30 cm) , mixed	Taxa:
		Other		
Left Bank				
Hydroriparian		Trees	evergreen , deciduous , mixed	Taxa:
Mesoriparian		Shrubs	tall (> 1m) , low (≤ 1 m) , mixed	Taxa:
Xeroriparian		Herbaceous	tall (>30 cm) , low (≤30 cm) , mixed	Taxa:
		Other		

End of site : upstream __, downstream __, lakeshore at ____________				
Right Bank or ____________				
Hydroriparian		Trees	evergreen , deciduous , mixed	Taxa:
Mesoriparian		Shrubs	tall (> 1m) , low (≤ 1 m) , mixed	Taxa:
Xeroriparian		Herbaceous	tall (>30 cm) , low (≤30 cm) , mixed	Taxa:
		Other		
Left Bank				
Hydroriparian		Trees	evergreen , deciduous , mixed	Taxa:
Mesoriparian		Shrubs	tall (> 1m) , low (≤ 1 m) , mixed	Taxa:
Xeroriparian		Herbaceous	tall (>30 cm) , low (≤30 cm) , mixed	Taxa:
		Other		

Spherical Densiometer

End of site : upstream __, downstream __, lakeshore at ________				
Right bank or:	Trees	points of	=	% cover
	Shrubs	points of	=	% cover
	Herbaceous	points of	=	% cover
Middle, upstream	Trees	points of	=	% cover
	Shrubs	points of	=	% cover
	Herbaceous	points of	=	% cover
Middle, downstream	Trees	points of	=	% cover
	Shrubs	points of	=	% cover
	Herbaceous	points of	=	% cover
Left bank	Trees	points of	=	% cover
	Shrubs	points of	=	% cover
	Herbaceous	points of	=	% cover

End of site : upstream __, downstream __, lakeshore at ________				
Right bank or:	Trees	points of	=	% cover
	Shrubs	points of	=	% cover
	Herbaceous	points of	=	% cover
Middle, upstream	Trees	points of	=	% cover
	Shrubs	points of	=	% cover
	Herbaceous	points of	=	% cover
Middle, downstream	Trees	points of	=	% cover
	Shrubs	points of	=	% cover
	Herbaceous	points of	=	% cover
Left bank	Trees	points of	=	% cover
	Shrubs	points of	=	% cover
	Herbaceous	points of	=	% cover

Figure 12.2 Example riparian vegetation classification field form for recording the composition of plant layers along a water course, and measuring canopy cover with a densiometer.

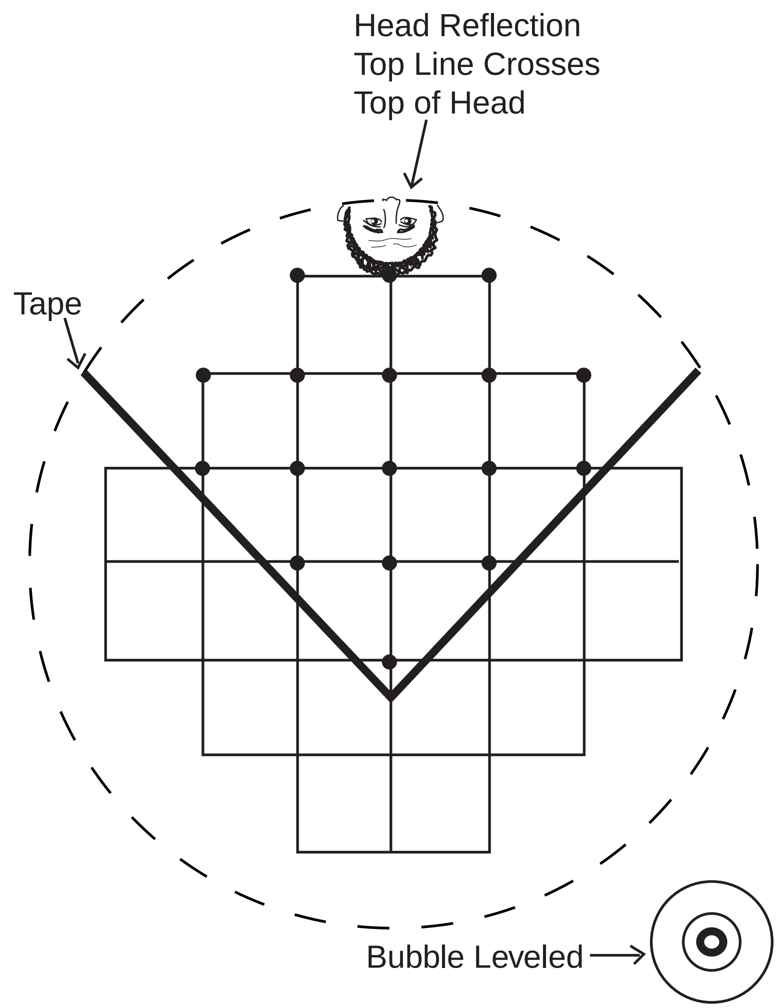


Figure 12.3 The concave spherical densiometer with placement of head reflection, bubble level, tape, and 17 observation points. Figure and device alterations are from Platts et al. (1987).

the densiometer about 30 cm above the land or water surface. The arm between the hand to the elbow should be horizontal to the water surface. The instrument should be held away from the observer with the bottom of the 'V' pointed towards the recorder so that his or her head reflection almost touches the top of the grid line. Level the densiometer with the bubble level in the viewfinder, and count the number of intercepts above the 'V' taped on the densiometer (Figure 12.3) hit by either herbaceous plants, shrubs, or trees. Record the number of intercepting points for each vegetation level (i.e., the frequency) on a data form (Figure 12.2). To calculate the percent cover, divide the total number of densiometer points recorded for each vegetation layer by the number sampled (often 17, 37, or 96 depending on the densiometer) and multiply by 100.

12.3.4 Notes

This technique avoids the problem of unclear riparian zone boundaries by assessing riparian areas from the water body perspective; water edge vegetation is evaluated.

In most plant communities, the taxa attain their maximal seasonal development at different times (Daubenmire 1959). If estimating cover by species, it may be necessary to sample multiple times in the growing season. Otherwise, sampling should occur during the summer when vegetation grouped by level is much less effected by seasonal growth patterns.

The curved, reflecting surface of a spherical densiometer typically has 37 intersections that form 24 squares, although some densiometers have 96 intersections. The curved surface results in observations from lateral as well as overhead positions, and consequently an overlap of readings would occur with the recommended sampling design. To account for this, Platts et al. (1987) devised a modification (taping the sphere surface) to isolate 17 intersections as observation points (Figure 12.3).

Barriers

13

Anne S. Gallagher

13.1 Introduction

13.1.1 Background

Physical barriers in streams and rivers are any structures or habitat conditions that create a potential obstacle to fish migration. Migratory fish rely on free passage through streams and rivers to spawn, reach rearing areas, seek food supplies, and satisfy other life requirements. Barriers can impede or even eliminate the movement of fish, disrupting their life cycle and limiting populations. Barriers can also influence stream life by disrupting flow, sediment transport, and thermal regimes. The effects that barriers can have on stream communities vary widely with the type and size of barrier.

Large dams have the greatest detrimental effect on streams, and their influence has been well documented (Ward and Stanford 1979; Baxter and Glaude 1980; Petts 1984; Williams and Wolman 1984). Small structures are often problematic because it is difficult to identify when a structure is actually a barrier to fish migration. Some fish will easily clear a 3-m waterfall, and yet a 1-m dam will pose a barrier to others. The ability to clear a barrier depends on its physical and hydraulic features, and the biology of the fish or fishes that need to pass by the structure. These factors can work separately or together to prevent fish from passing.

The techniques outlined below describe the steps necessary to quantify the potential of a barrier to block fish migration. Large artificial dams are discussed separately from other barriers because of the great difference in their size and effects. Habitat conditions that act as barriers to fish migration are treated separately because they do not involve any structure. Note that this chapter focuses on the ability of a barrier to limit fish movements. Barriers can have enormous influence on the ecology of streams and rivers, but these effects are not discussed here. To quantify biotic and abiotic changes in a stream due to a barrier (e.g., temperature changes, stream geomorphology changes), consult the other chapters in this book that address the specific factors of interest.

13.1.2 Selection of Techniques

The techniques below provide the means to identify and substantiate fish movement impediments that would be considered barriers. This set of techniques covers very different types of barriers: natural and small artificial structures, large dams, and stream habitat conditions. One or more techniques should be selected to fit the assessment situation. When unsure which technique is most appropriate, the relations between fish swimming and jumping performance in the first and third techniques can be used to determine which assessment is most relevant.

13.2 Assessing Natural and Small Artificial Barriers

13.2.1 Rationale

A structure is only a barrier to fish migration if fish cannot pass the structure. Fish can pass a structure in one of three ways: swim over it, jump over it, or bypass it through a fish ladder or similar facility. Fish can swim over some structures, such as cascades or low-lying dams, if the fish can swim faster than the water flowing over the structure. Fish can jump over a structure if: (1) the maximum jumping height of the fish is greater than the height of the structure, and (2) the pool of water below the structure is deep enough for the fish to reach maximum jump height. Maximum fish jumping height requires a depth of water 1.25 times the height of the structure, but no less than about 2.5 m (Reiser and Peacock 1985). Other factors can also affect barrier potential. Turbulent water below the structure can disorient fish and reduce jumping height. Abnormal temperatures or oxygen levels can reduce fish physiological performance and thus jumping heights. Finally, most migratory fish tire as they migrate, so the further a fish is along its migratory path, the less likely it will be able to jump high. Each of these factors must be considered when determining if a structure is a barrier.

Characteristics of barrier structures must be quantified to determine the likelihood of blocking fish movements. Effects of a structure increase with increasing structure size. Hydraulic features of a structure, such as speed and depth of water flow, are also important and vary with structure size. The dimensions of the barrier and its associated hydraulic features provide crucial information for judging how significant a structure is in blocking fish movement. The technique below provides steps to quantify fish performance and structure attributes to determine the likelihood that a structure is a fish barrier. This technique is appropriate for assessment of small natural and artificial structures.

13.2.2 Preparation

- Develop familiarity with barrier structures, standard measurements, and use of hydraulic measurement equipment necessary to fill out the data sheet.

- Develop thorough knowledge of fish species in the study area.

- Obtain a map of the stream, marked in river miles or kilometers. The map should include both the origin of the migrating fish and their final destination.

- Acquire measuring tapes; tools to measure the depth of plunge pools, such as a yardstick (shallow) or a weighted graduated cable (deep); and an instrument to measure water velocity (see Chapter 14, Streamflow, for different techniques and equipment). A boat may be needed for large waters.

- Duplicate a data recording sheet for field use (sample provided in Box 13.1).

13.2.3 Procedure

- **Basic description.** Review the types of barrier structures shown in Figure 13.1. Identify the potential barrier structure and record how far it is from the mouth of the stream. Draw a sketch of the stream reach and include the barrier and any prominent natural or constructed (e.g., bridges, roads) features.

- **Record dimensions.** The potential barrier must be measured under typical seasonal flow for the fish species of interest. For example, measure structure dimensions during typical spring flow conditions to determine if a dam blocks migration of spring run salmon. When assessing general characteristics of a structure for all fish, make measurements under late summer base flow conditions. This is usually the time of low stream discharge, after snow melt and before the leaf fall. Check flow records, if available, to confirm when flow is typically the lowest. Record the following for each potential barrier (see Figure 13.2 for a guide to where measurements should be taken).
  - Vertical height: height from the water surface at the plunge pool to the water level above the structure.
  - Stream width: streambank to streambank distance at the base of the structure.
  - Breadth of water flow: distance between a vertical line drawn where water begins to fall over the structure and a vertical line drawn at the base of the structure.
  - Gradient: determine by dividing the height of the barrier by the breadth of the water flow.

Box 13.1 Sheet for assessing natural and small artificial barriers.

Location ______________________ River mile from stream or river mouth __________

Date/time ______________________ Field crew ______________________

Type of structure ____

Special features ____

Measurements

height ____________	velocity (top) ____________	temperature ____________
width ____________	velocity (tail) ____________	dissolved oxygen ________
breadth ____________	culvert length ____________	pH ____________
gradient ____________	culvert height/diameter ______	salinity ____________
pool depth ____________	culvert width ____________	
cascade length ________	turbidity ____________	

Type of fish(es) ____

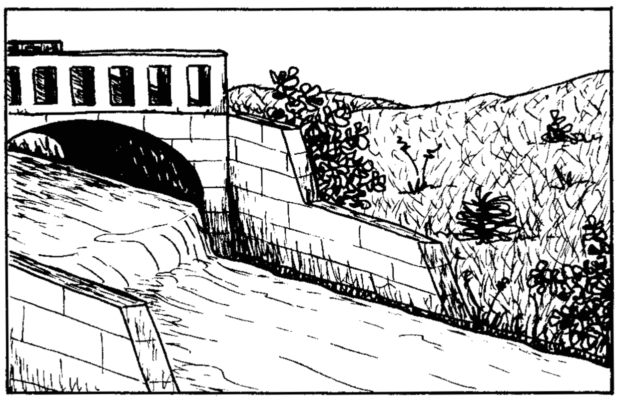
Maximum jumping height $(9l)^2/2\,g$, (g = 9.8 m/s^2, 32.2 ft/s^2) ______________________

		Yes	No
a.	Is the maximum jumping height of the fish higher than the structure?	☐	☐
b.	Is the darting speed of the fish faster than water flow over the structure?	☐	☐
c.	Is the darting speed of the fish faster than the tail water velocity?	☐	☐
d.	Is the depth of the plunge pool *either* greater than 1.25 times the height of the barrier or more than 2.5 m deep?	☐	☐
e.	Does the plunge pool water have laminar flow within one-third the height of the structure out from the base?	☐	☐
f.	Is the barrier less than halfway along the distance to the spawning ground?	☐	☐
g.	Are other environmental factors, like temperature and oxygen, within ideal range for the fish?	☐	☐
h.	Is the gradient of the cascade steep (>45°)?	☐	☐
i.	Is the culvert level rather than on a gradient?	☐	☐
j.	Is the culvert made from a rough material?	☐	☐
k.	Is the maximum darting distance of the fish greater than the length of the culvert?	☐	☐

Is the structure a barrier to fish migration? ☐ definitely ☐ probably ☐ possibly ☐ unlikely

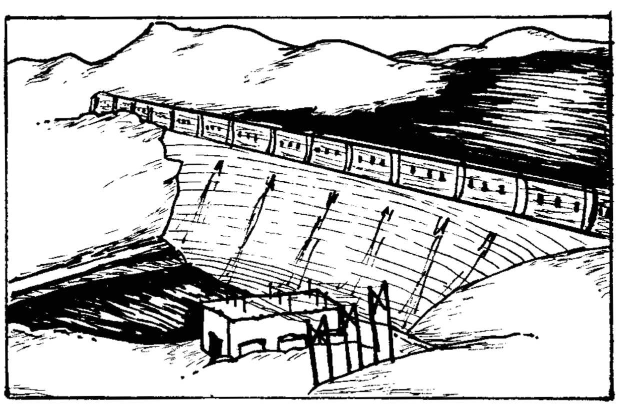
Waterfall

Cascade



Culvert

Log or debris dam



Artificial (constructed) dam

Beaver dam

Figure 13.1 Examples of natural barriers and small artificial barriers.

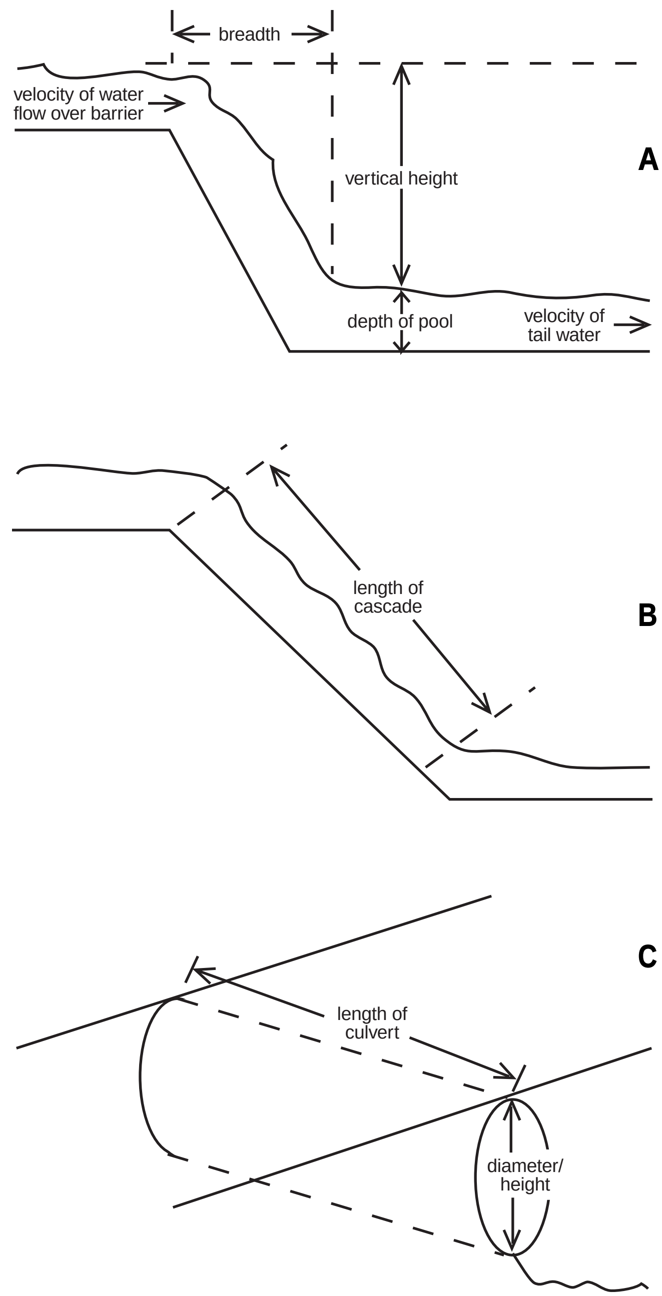


Figure 13.2 Dimensions and hydraulic features to be measured for falls (A), cascades (B), and culverts (C).

- Depth of pool in front of barrier.
- Velocity of water flow over the barrier; measure at a point just before the water begins to fall over the structure.
- Velocity of the tail water; measure where water begins to flow out of the plunge pool.
- Cascade length: measure as shown in Figure 13.2 or compute the length as the square root of the sum of the height of the

barrier squared and the breadth of the water flow squared. This formula derives cascade length as the hypotenuse (c) of a triangle with the height (a) and breadth (b) of the barrier as its sides:

$$c = (a^2 + b^2)^{1/2}.$$

- **Characterize the fish.** Identify which fish species could have movements blocked by the potential barrier. Information on the average size and the maximum jumping height of the migrating fish must be available to complete this section. Table 13.1 provides maximum jumping heights for some common salmonid fishes. Maximum jumping height (h) can be estimated for other species using the formula of Reiser and Peacock (1985):

$$h = v^2/2\,g\,;$$

h = maximum jumping height;
v = fish darting speed (see below);
g = acceleration due to gravity (9.8 m/s^2).

Fish darting speed (v) is the maximum swimming speed attained in a 2–3 s period. It is estimated as 8–12 times average fish length (l). The healthier the fish, the higher the number. Use 9 unless expert knowledge of the status or age of the fish suggests a different value. If the standard darting speed value is used, the maximum jumping height becomes

$$h = (9l)^2/2\,g\,.$$

See Box 13.2 for an example calculation.

- **Summarize results.** Answer each of the questions listed in Box 13.3 that pertain to the potential barrier. These questions are on the sample field form, Box 13.1, in abbreviated form. Review the answers to all relevant questions. If any of the first four ques-

Table 13.1 Maximum jumping heights of some migratory fishes as reported in Reiser and Peacock (1985).

Species	Maximum jumping height (m)
Oncorhynchus tshawytscha chinook salmon	2.4
Oncorhynchus kisutch coho salmon	2.2
Oncorhynchus nerka sockeye salmon	2.1
Oncorhynchus gorbuscha pink salmon	1.2
Oncorhynchus keta chum salmon	1.2
Salmo salar Atlantic salmon	3.3
Oncorhynchus mykiss steelhead	3.3
Salmo trutta brown trout	0.8
Oncorhynchus clarki cutthroat trout	0.8
Thymallus arcticus grayling	0.9

Box 13.2 Example fish jumping height calculation.

Calculation of jumping height (h) for a fish whose length (l) is 0.35 m.

$$h = v^2/2\,g$$

where v is estimated as 8 to 12 times the fish length, depending on the health of the fish. For this example,with no knowledge of the health of the specific fish in question, assume its maximum swimming speed is 9 times its body length per second.

$$\begin{aligned} h &= (9l)^2/2\,g \\ &= (9 \times 0.35)^2/2(9.8) \\ &= 0.51 \text{ m} \end{aligned}$$

tions (a–d) were answered "no," the structure poses a definite barrier to fish migration. If one or more of questions e–k were answered "no," the structure is a possible barrier to fish migration. Consider which question(s) were answered "no" and weigh their relative importance to the specific structure and fish in the stream reach. If all of the above questions were answered "yes," then the structure is an unlikely barrier to fish migration.

13.2.4 Notes

The technique outlined above requires some judgements that can heavily influence final conclusions. Barrier assessment accuracy and confidence depends on the analyst's knowledge about the biology of the fish being studied. Keep in mind that different species of fish will react differently to specific environmental conditions. In question e of Box 13.2, for example, turbulent versus laminar flow can be difficult to determine, and there are no absolute rules on when water is calm enough to allow normal fish movement. However, previous experience with the fish species will aid assessment of fish response to turbulent water. Similarly, in questions f and g, it may be time consuming if not impossible to determine precisely where swimming performance significantly declines, or the exact oxygen level that will limit swimming power. Consequently, knowledge of the particular limitations of the fish species and stream setting can guide judgements on whether the structure is a barrier.

13.3 Assessing Large Artificial Dams

13.3.1 Rationale

Large artificial dams usually block fish migrations because of their size and construction; however, many dams that prohibit fish move-

Box 13.3 Questions used to determine if a structure is a barrier to fish migration.

a. Is the maximum jumping height of the fish higher than the height of the structure?
b. Is the darting speed of the fish faster than the velocity of the water flow over the structure?
c. Is the darting speed of the fish faster than the velocity of the tail water?
d. Is the depth of the plunge pool either greater than 1.25 times the height of the barrier or more than 2.5 m deep?
e. Does the plunge pool water return from turbulent to laminar flow within one-third the height of the structure out from the base of the structure? One third the height of the structure is a rough estimate given to help you judge if the water is calm enough to allow the fish to reach maximum jumping height.
f. For anadromous fish, is the barrier less than halfway along the travel distance of the fish between the mouth of the river and the spawning ground? For catadromous fish, is the barrier less than halfway from the headwaters to the mouth of the river? Again, half the distance is a rough estimate. The closer a fish gets to its spawning ground, the lower its maximum jumping height is likely to be.
g. Are other environmental factors that could affect fish jumping abilities, such as temperature or oxygen, within the ideal range required by the migrating fish?

For cascades

h. Does the cascade have a steep gradient (>1) rather than a low gradient (<1)? A slope of 1 is a rough estimate. A low gradient is harder to jump over, because the depth of the cascade is harder to clear. However, a low gradient cascade may be swum over if the length of the cascade is not very long and the water flow is not faster than the fish.

For culverts

i. Is the culvert level rather than on a gradient? Culverts on a gradient have faster water velocity.
j. Is the culvert made from a rough material (e.g., not metal) that will slow water flow?
k. Is the maximum darting distance of the fish (= darting speed of fish per second × 2–3 seconds) greater than the length of the culvert?

ment have fishways or fish passage facilities, such as a fish ladders or locks. The barrier potential of the dam then depends on the ability of the fish to use the fishway successfully. The effectiveness of fishways is highly variable. Many migrating fishes are sensitive to hydraulic changes in and near the fishway, so the presence of a fishway does not ensure that fish migrations are unimpeded (Bell 1986). Fishways must be carefully constructed to promote fish passage; the approach to a fishway is equally important. Changes in hydrology or topography of a fishway approach may discourage fish from getting to the vicinity of the fishway. Operators of dams and fishways may have data on whether the facility is used successfully by migrating fish, what fish species use the facility, and what percentage or how many fish successfully pass. In addition to this information, physical attributes can be used to assess fishway effectiveness and identify problems.

13.3.2 Preparation

- Contact dam and fishway operators to obtain available data and information.

- Acquire maps of the dam site, facility design specifications, and operating or licensing information.

13.3.3 Procedures

- **Basic description.** Record distance from the mouth of the stream or river to the dam. Obtain a facility design drawing, site map, or aerial photographs to locate the dam and document the site configuration.

- **Record dimensions.** Follow the technique above (section 13.2) if the dam does not have a fish passage facility. If the dam has a fish passage facility, contact the operators to obtain the following information:

  - What is the discharge regime of the facility, both seasonally and daily?
  - What fish are targeted by the facility?
  - Is the facility used successfully by these fish?
  - When do these fish use the facility?
  - What percentage or how many of the fish successfully pass?

  Dimensions of the dam may vary depending on the daily and seasonal discharge regime. For example, downstream water surface elevation is often dependent on dam discharge rate. Dam dimensions should be estimated based on typical flow conditions when the target species reaches the dam during migration. Assess dimensions during several discharge regimes for dams that have fluctuating discharges or to test the general barrier characteristics. These data can be used to compare the effectiveness of fish passage facilities during different discharge periods. Measure, estimate, and record the following (data are often available from the dam operators):

  - height, width, breadth of dam, width of the spillway, and velocity of the tail water (for descriptions of some measurements, see section 13.2.3);
  - the type of fishway, upstream and downstream;
  - dimensions of the fishway, including gradient, length, velocity, and configuration;
  - topography leading into the fishway, including any structures used to corral the fish toward the fishway.

- **Evaluate the barrier potential.** Barrier status will depend on the data from the fish passage facility. These data should indicate the type and number of fish passing through the facility as well as the time when they pass. Expert knowledge of the fish being studied will aid this evaluation by providing an expectation of migration patterns without the dam. Fish passage data may reveal that the dam acts as a barrier but not all of the time (e.g., fish only pass through the fishway under certain conditions). These data can then be compared with the physical characteristics of the dam and fishway to find common traits of dams where the fishways are not effective.

13.3.4 Notes

The cautionary notes in section 13.2.4 also apply to the large dam technique above. Assessing large dams requires judgements that can heavily influence final conclusions about fish passage effectiveness. Assessment accuracy depends on the analyst's knowledge about the biology of the fish being studied and the design of fishways. Information from dam and fishway operators will be key in any assessment. Although there may not be much information about fish passage for dams and fishways built more than a century ago, a lot is known about passage at newer facilities.

13.4 Assessing Stream Habitat Conditions as Potential Barriers

13.4.1 Rationale

In addition to physical structures, habitat conditions can serve as barriers to fish migration. For example, stream channelization often produces habitat conditions with either very elevated water velocity or broad, shallow channels that limit or block fish movements. Habitat conditions should be quantified to complete a thorough assessment of fish barriers.

13.4.2 Preparation

- Develop familiarity with stream habitat conditions, standard measurements, and use of equipment necessary to fill out the data sheet.

- Develop thorough knowledge of fish species in the study area.

- Obtain a map of the stream, marked in river miles or kilometers. The map should include both the origin of the migrating fish and their final destination.

- Acquire measuring tapes and an instrument to measure water velocity (see Chapter 14, Streamflow, for different techniques and equipment). A boat may be needed for large waters.

- Duplicate a data recording sheet for field use (sample provided in Box 13.1).

13.4.3 Procedure

- **Basic description.** Record how far the habitat survey is from the mouth of the stream. Draw a sketch of the stream reach and record prominent natural or constructed (e.g., bridges, roads) features.

- **Assess water velocities.** Perform the following steps (adapted from Reiser and Peacock 1985; Bell 1986) if elevated water velocity is suspected of restricting fish movements.

  - Measure and record representative water velocities through a channel section of stream, and record the length of the stream where water velocities are high.
  - Identify which fish could encounter the potential barrier conditions, and determine their average size (total length, l). For the fish of interest, identify cruising swimming speeds (maintained for extended period of time) as 2–4 times l per second. If cruising speed of the fish is greater than the typical water velocities, then water velocity is not likely to pose a barrier to fish movements.
  - Identify sustained swimming speeds (maintained for several minutes) as 4–7 times l per second. If sustained swimming speed of the fish is greater than the water velocity, multiply the swimming speed by 5–8 min to get the total distance the fish can travel at that speed. If this distance is longer than the length of the stream section with increased velocity, then the water velocity is not likely to pose a barrier to fish movements.
  - Identify darting speeds (maintained for a few seconds) as 8–12 times l per second. If darting speed of the fish is greater than the water velocity, multiply the speed by 2–3 s to get the total distance the fish can travel at that speed. If this distance is longer than the length of the stream section with increased velocity, then the water velocity is not a likely barrier to fish movements.

- **Assess water depths.** Measure the length of stream and water depths along the thalweg, where low water levels might restrict fish movements. Identify which migratory fish will encounter the potential barrier conditions, estimate their body dimensions, and consider the probable responses to shallow water. Judge if water depths could prohibit swimming or pose conditions strongly avoided by the fish. Use knowledge of these fish to determine if they can pass through the water at available depths.

- **Evaluate the potential barrier conditions.** Make a final determination of the potential barrier effect of poor habitat conditions. This will often rely on judgements, but use the data on water velocities and depths to justify and support a conclusion.

13.4.4 Notes

Assessing stream habitat conditions as fish migration barriers is not as common as the two techniques described above. However, natural habitat barriers are increasingly common in regions where there is a growing human population. Where flooding is being minimized by stream channelization, the loss of natural meanders increases the water velocity during high flow periods when many fish move for spawning. Dry periods also impact fish passage when water withdrawals substantially reduce streamflows in heavily populated or intense agricultural areas. The habitat assessment technique presented here addresses these problems by specifying measurements that can be used with fish swimming and morphology data, to provide informed judgements about habitat conditions posing migration barriers.

Streamflow

14

Anne S. Gallagher and Nathalie J. Stevenson

14.1 Introduction

14.1.1 Background

Streamflow or discharge is the quantity of water passing through a cross section of a stream channel per unit time. Stream velocity (recorded in m/s) and the cross-sectional area (m^2) produce volume per unit time (m^3/s). Water velocity or current speed is a component of discharge and is recorded as a rate (m/s) for a point in a stream. While discharge estimates depend on velocity measurements, fish and other stream organisms often respond to water velocity in their immediate vicinity or microhabitat (e.g., Growns and Davis 1994; Hart 1996). Techniques for measuring water velocity can be used for point estimates in stream microhabitats, or in a series of cross-sectional measurements for estimating discharge.

Discharge is a product of the hydrologic cycle; therefore, it varies with topography, geology, climate, season, vegetation, and drainage area. Streams with land surface runoff and tributary inflows tend to have highly variable flow, whereas streams with substantial groundwater input (channel seepage and springs) have more stable flows. Drainage basins with intense human land use (agriculture, urban areas) and little riparian vegetation tend to have streams with highly variable discharge that quickly responds to precipitation; forested basins and streams with heavily vegetated riparian zones typically have more constant streamflow. Headwater streams vary in discharge based on local basin conditions and recent precipitation. Large streams and rivers drain large land areas and tend to have average basin conditions and moderately variable streamflow.

Changes in stream discharge affect water depths, substrate composition, suspended sediment loads, and nutrient and sediment transport. Streamflow directly affects habitat composition, and variability in streamflow largely determines habitat stability. Habitat composition and stability in turn affect the biotic components of a stream, especially fish community composition. Discharge can also affect riparian vegetation, which provides important fish cover and erosion control. Discharge determines the extent of stream channel inundation and the duration of inundation influences riparian soil moisture, soil oxygen concentration, and vegetation composition and distribution (Auble et al. 1994).

14.1.2 Selection of Techniques

Two techniques for determining stream discharge are outlined in this chapter: one involves fieldwork and one uses available streamflow data and applies them to habitat assessment sites. These techniques provide a choice of field or office procedures, as well as a choice of precise, point-in-time discharge estimates or approximations of discharge rates at any time or time period. The first technique is used to measure discharge in the field and includes three ways to measure stream velocity. Measure discharge in the field when precise measurements are needed for other assessment procedures. The second technique relies on extensive stream discharge monitoring data of the U.S. Geological Survey (USGS) and explains how to apply this information to a habitat assessment site. Available discharge data works well for approximating discharges that are defined over time (e.g., annual or monthly means, baseflow levels). In general, the field technique will be most useful for matching discharge to other habitat assessment data, and use of USGS data will be useful for characterizing discharges over time.

14.2 Cross Section Measurement

14.2.1 Rationale

Streamflow or discharge is the volume of water passing through a stream per unit time, so a simple way to estimate discharge is to multiply a cross-sectional area by the average velocity of the water. However, water in a channel flows at different speeds depending on its location. Friction from the streambed and from the air reduces velocity, and velocity of water moving through habitats within streams (e.g., riffles, runs, pools) varies markedly. It is, therefore, necessary to divide a stream cross section into subsections and determine the discharge of each subsection. The total of all the incremental section discharges equals the total stream discharge.

14.2.2 Preparation

- Assemble a tape measure or tag line, stakes, and a water velocity measurement device (meter, float and stop watch, or velocity head rod).

▶ Calibrate or test water flowmeter before fieldwork using the instructions specific to each device.

14.2.3 Procedures

- Stretch a tape measure (small streams) or metal tag line (marked wire line) across the stream, perpendicular to streamflow. Anchor the tape measure between two stakes. The tape measure should be level and taut. Unless discharge across a pool is specifically needed, it is best to measure discharge across a section of smoothly moving water, such as a riffle or run. Measure the width of the stream, from water's edge to water's edge. Divide this distance by 20–25 to set the approximate measurement (depth, velocity) interval. These interval widths do not have to be consistent. Closer intervals should be used for deeper or swifter parts of the channel or where there is a change in topography. Larger intervals can be used in shallow areas or where the depth and flow variability are relatively low. No subsection should contain >5% of the total discharge. Starting at the left bank (looking downstream), record the following for each subsection (see Figure 14.1, also sample field form in Box 14.1):
    - distance from the left bank along the tape measure,
    - water depth recorded from a measuring rod or flowmeter rod (zero at ends of the transect),
    - water velocity (measured in one of several ways outlined below).

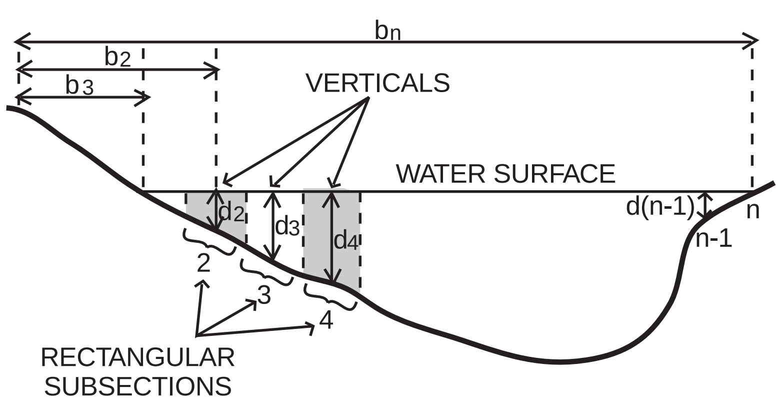


Figure 14.1 Cross section of a stream showing sampling locations for water depth (*d*) and velocity. Note that the interval represented is half the distance between adjacent measurement points except the first, and last interval, to the water edge.

Box 14.1 Discharge Measurement Form.

Assessment site:	
Recorder:	Date and time:
Streamflow condition:	

Distance from left bank endpoint (ft;m)	Water depth (ft;m)	Water velocity (ft/s;m/s)	Cell width (ft;m)	Cell area (ft^2;m^2)	Cell discharge (ft^3/s;m^3/s)	Notes
	0	0	–	–	–	water edge
	0	0	–	–	–	water edge
			Sum is the stream width	Sum is the cross section area	Sum is the stream discharge	

Once velocity measurements have been made, calculate the total stream discharge for each subsection according to the equation below or use the field form (Box 14.1) as a computation worksheet.

$$Q_n = d_n \times \left(\frac{b_{n+1} - b_{n-1}}{2} \right) \times v_n$$

Q_n = discharge for subsection n,
d_n = depth at subsection n,
b_n = distance along the tape measure from the initial point on the left bank to point n,
v_n = mean velocity of subsection n.

If any section has >5% of the total discharge (calculated in next step), subdivide that section into smaller incremental widths and take additional measurements. Calculate the total discharge (Q) for the cross section by adding all of the Q_n's to get total stream discharge (Q_{total}).

Choose a water velocity measurement method that best fits the cost limitations and accuracy requirements.

- **Flowmeter.** Mount the flowmeter probe on a wading rod. Set the water depth on the wading rod; it will automatically set the flowmeter to 0.6 of the water depth (mean velocity for a position). Hold the probe facing into the current. Stand downstream and far enough back to avoid interfering with the flow of water passing the meter. Depending on the flowmeter, wait at least 30 s for the velocity reading to stabilize. See Figure 14.2 for a picture of this method being done with a mechanical flowmeter. Take either one or two meter readings at each location, depending on the water depth, as described below:

  - For water depths (d) < 0.75 m, measure velocity once at 0.6 d from the water surface (e.g., if water is 0.5 m deep, measure velocity at 0.3 m from the water surface). A flowmeter wading rod (Figure 14.2) will automatically set the flowmeter to the correct depth.

  - For depths >0.75 m, measure velocity twice, at 0.2 d and 0.8 d. Average these two readings to determine the velocity for that cross section. If the water is too deep for a wading rod, lower the current meter to the proper depth on a graduated cable from a boat or bridge-mounted cable winder. If a wading rod is used, set the depth on the rod to 0.33 and 1.33 of the water depth, which will set the meter to 0.2 d and 0.8 d, respectively (e.g., if water is 1 m deep, set the rod to 0.33 m and 1.33 m. The wader rod will set the meter at 0.6 × the set depth, which equals 0.2 m [= 0.2 d] and 0.8 m [= 0.8 d]).

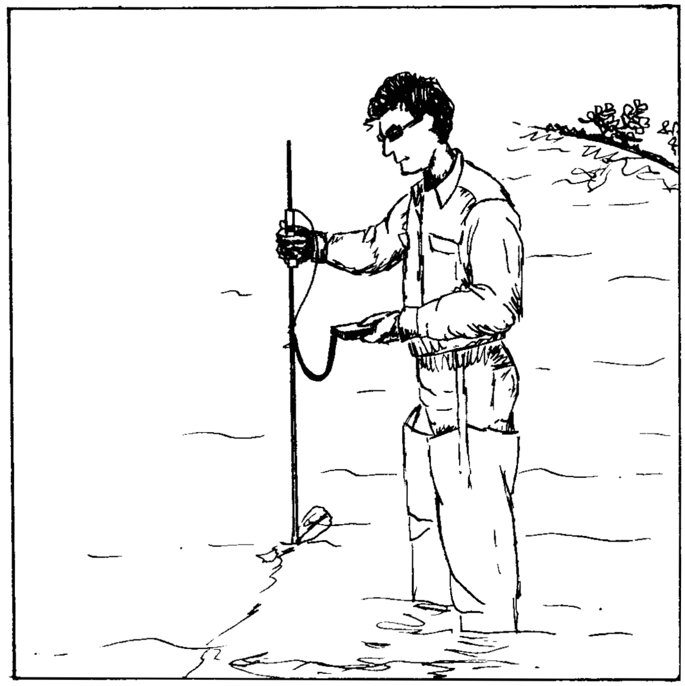


Figure 14.2 Measuring water velocity with a meter (mechanical type) and wading rod.

- **Velocity head rod.** Hold the velocity head rod (Figure 14.3) in the current so that the sharp edge is facing upstream and record the height (h_0) of the water passing the rod. Pivot the rod around 180° so that the flat side of the rod is facing upstream. This creates an obstruction which causes the height of the water surface to rise on the rod (Figure 14.4). Record the height (h_j) of the water on the flat side. Use Box 14.2 to convert the velocity head ($h_j - h_0$) to mean water velocity for measurement location.

Velocity Head Rod

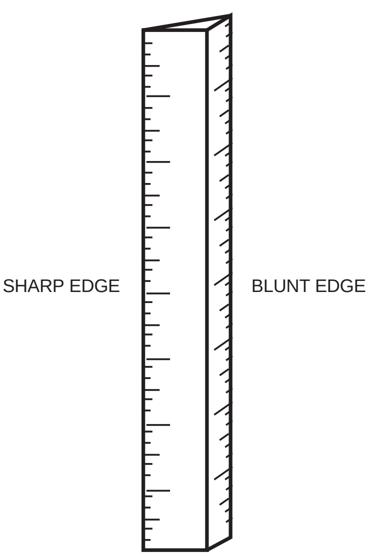


Figure 14.3 Velocity head rod.

- **Float method.** This technique estimates stream velocity for the whole stream cross section so the field form (Box 14.1) does not apply. Measure and mark two points along the bank at least three channel widths apart. Toss an orange (alternatively use any neutrally buoyant object) in the water and time how long it takes to float between the two points. Repeat this several times and average the travel times to get a mean surface velocity of the water. Multiply this number by a velocity adjustment coefficient to get the mean velocity of the entire cross section. This coefficient varies between 0.8 and 0.95, depending on the roughness of the channel: the smoother the channel, the higher the coefficient. Select a value, however, if in doubt, use 0.85 as the coefficient. Once mean velocity (ft/s, or m/s) is estimated, multiply that times the cross-sectional area (ft^2 or m^2) to compute the stream discharge (m^3/s).

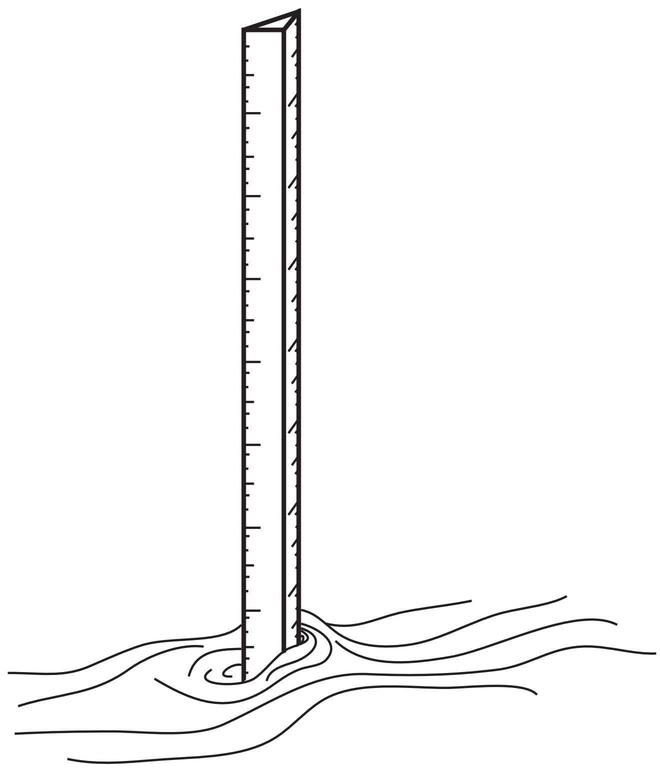


Figure 14.4 Hydraulic head formed on the flat side of the velocity head rod.

14.3 Stream Gauge Data

14.3.1 Rationale

The USGS provides discharge data on a continuous basis as part of their stream-gauging program (Wahl et al. 1995). Data from both active stations and discontinued stations are stored in a computer database that holds mean daily discharge data for nearly 18,500 locations and more than 400,000 station years of records (Wahl et al. 1995). These data are published on a water year basis for each state, which is the 12-month period from October 1 through September 30, and is designated by the calendar year in which it ends. These reports are usually published 6–12 months after the end of the water year so that the data can be reviewed; however, more than half of the currently operating stations make provisional data available as it is collected. Figure 14.5 shows sample output from one of these stations. The raw data are also available.

Box 14.2 Water velocity for different values of change in head.

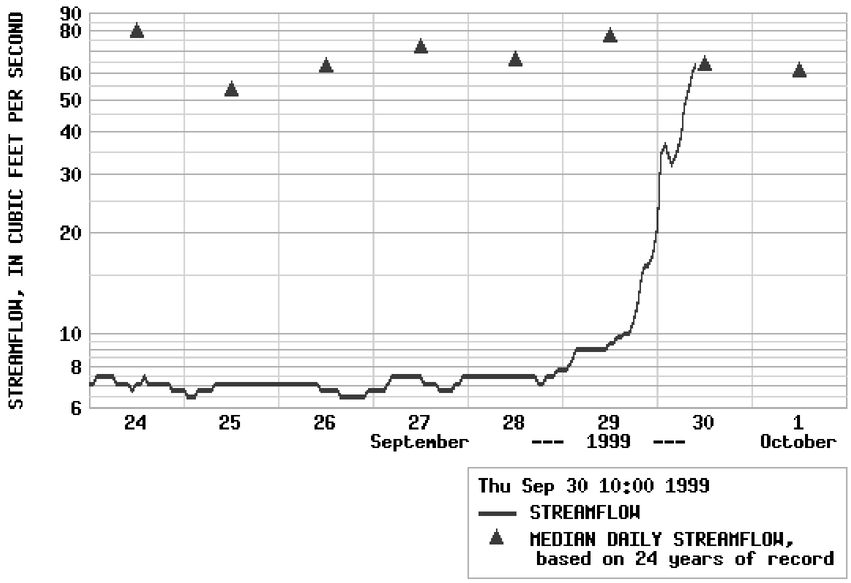
ft	cm	ft/s	m/s
0.05	1.5	1.79	0.54
0.10	3.1	2.54	0.78
0.15	4.6	3.11	0.95
0.20	6.1	3.59	1.09
0.25	7.6	4.01	1.22
0.30	9.1	4.39	1.34
0.35	10.7	4.74	1.45
0.40	12.1	5.07	1.55
0.45	13.7	5.38	1.64
0.50	15.2	5.67	1.73

USGS

PROVISIONAL DATA SUBJECT TO REVISION

03021350-- FRENCH CREEK NR WATTSBURG, PA

Streamflow -- updated Thu Sep 30 06:00 1999 -- download presentation-quality graph



STATION.--03021350 FRENCH CREEK NEAR WATTSBURG, PA

LOCATION.--Lat 42`00'55", long 79`46'58", Erie County, Hydrologic Unit 05010004, on right bank at downstream side of bridge on Tanner Road, 1,200 ft east of State Highway 74, 1.1 mi west of Pennsylvania-New York border, 1.5 mi northeast of Wattsburg, and 2.4 mi above confluence with West Branch French Creek.
DRAINAGE AREA.--92.0 mi^2.
PERIOD OF RECORD.--October 1974 to current year.
GAGE.--Water-stage recorder. Datum of gage is 1,304.84 ft above sea level (U.S. Army Corps of Engineers bench mark).
REMARKS.--U.S. Army Corps of Engineers satellite telemeter at station.
COOPERATION.--Funding for the operation of this station is provided by the U.S. Army Corps of Engineers, the Pennsylvania Department of Environmental Protection, and the U.S. Geological Survey.

Daily Mean Flow Statistics for 09/30 based on 24 years of record

Figure 14.5 Sample data reported from a gauge station reporting real-time data via the internet.

14.3.2 Preparation

- Acquire a computer with Internet access.

14.3.3 Procedures

- If the stream under investigation has a USGS gauging station on it, use their data. Access the USGS home page (http://water.usgs.gov/) and select "water data" and then either: real-time water data for continuously reporting stations, or National Water Information System (NWIS) for archived data on all gauging stations.
- If the stream under investigation does not have a USGS gauging station, data from a gauged stream can be interpolated to estimate discharge of the ungauged stream. Calculate the drainage area of the ungauged stream (see Chapter 4 for instructions on determining drainage areas). Identify a gauged stream from a drainage basin with similar aspect and elevation. Calculate the drainage area of the gauged stream. Calculate what fraction of the drainage basin from the gauged stream is the drainage basin of the ungauged stream. Assume that discharge of the ungauged stream is the same fraction of discharge from the gauged stream. See Box 14.3 for an example.

Box 14.3 Sample calculation for prorating USGS gauge data to an ungauged habitat assessment site.

Date: 6 December 1997

Habitat assessment site	**Nearby gauged stream site**
	01318500 Hudson River at Hadley, NY
discharge = to be estimated (x)	discharge = 2,032 ft^3/s
drainage area = 1,287 $mile^2$	drainage area = 1,664 $mile^2$

$$\frac{\text{drainage area (ungauged)}}{\text{drainage area (gauged)}} = \frac{\text{discharge (ungauged)}}{\text{discharge (gauged)}}$$

$$\frac{1,287}{1,664} = \frac{x}{2,032}$$

x = 1,572 ft^3/s is the estimated mean daily discharge on 6 December 1997 at the habitat assessment site.

Note: USGS data are most commonly reported in English units as shown in this example. Convert final result to metric.

15 Temperature

Anne S. Gallagher

15.1 Introduction

15.1.1 Background

Water temperature strongly influences the composition of aquatic communities, and is probably the most commonly recorded habitat attribute. Many fish survive or thrive only within a limited temperature range. Physiological functions are commonly influenced by temperature, some behaviors are linked to temperature, and temperature is closely associated with many life cycle changes. Temperature indirectly influences oxygen solubility, nutrient availability, and the decomposition rate of organic matter; all of which affect the structure and function of biotic communities. As water warms, oxygen and nutrient availability decrease, whereas many physiological and material decomposition rates increase. These temperature-moderated processes can influence the spatial and temporal distribution of fish species and aquatic organisms. Thus, knowledge of aquatic thermal regimes is important for predicting species composition, activity levels, behaviors, and life cycle events.

Water temperature varies with time of day, season, and water depth. The extent of such temperature variations will largely depend on the size and mobility of the water body. Heat gain and loss occurs more rapidly in streams, which are usually shallow and mobile, as compared to lakes, which are more concentrated, stable water masses. Although temperatures are particularly dependent on direct solar radiation, they are also influenced by water velocity, climate, elevation, stream order, amount of streamside vegetation providing shade, water source, temperature and volume of groundwater input, the dimensions of the stream channel, and human impact. Streams are usually not thermally stratified, but large rivers can get much colder as depth increases (Dodge et al. 1981; Simonson et al. 1993).

Large bodies of water have large heat storage capacity. Deep lake waters can store heat, and lakes mix very slowly compared to streams. Lake temperatures near the surface may fluctuate diurnally, and deeper water temperatures may vary seasonally. Lake shape, orientation, and volume (Chapter 16) determine the likelihood of sharp depth-related thermal changes that define a thermocline, the depth where there is a rapid decrease in water temperature of more than 1°C per meter (Wetzel and Likens 1990; Minnesota Department of Natural Resources 1993).

15.1.2 Selection of Techniques

The two techniques described below cover multiple ways of measuring temperature and determining thermal regimes in streams, rivers, and lakes. Point-in-time or single measurements are useful for quick temperature assessments, but thermal variation in some waters (e.g., shallow streams) will limit the utility of the values. Long-term temperature monitoring characterizes the thermal regime and could identify time periods or seasons of key importance. There are many devices for measuring temperature, and specific choices should be determined by management needs, study requirements, time constraints, and budgets. The techniques described here are the ones most commonly used in management investigations.

15.2 Point-in-Time Measurements

15.2.1 Rationale

Single measurements are good for quickly obtaining information that characterizes the general nature of the water temperature regime; for example, coldwater, coolwater, or warmwater habitat. Thermometers and thermistors give immediate results. These small devices can be used by hand in shallow waters or with long-probe meters to assess the vertical temperature profile of a lake. Maximum–minimum thermometers require slightly more work because they must be retrieved after some length of time, usually 24 h, but they provide information on both average temperature and temperature variability.

15.2.2 Preparation

- Acquire one or more of the following temperature recording instruments: a hand-held thermometer, a meter with a thermal probe (often part of a meter that records multiple water parameters), a thermistor, or a maximum–minimum thermometer.

- Temperature measurement equipment should be calibrated at least once each field season. Depending on the objectives of the study and the importance of the data, equipment should be calibrated more often.

15.2.3 Procedure

- **Shallow water measurements.** Stream temperature should be measured mid-channel and out of direct sunlight. For broadly representative values, do not measure near any large objects that project above the water surface, as they may elevate readings, or near subsurface springs or seeps, as they may lower readings. Measure temperature in the late afternoon, during the time of maximum daily temperature. If there has been any precipitation within 48 h, this may influence the reading. For a general water temperature measurement, hold thermometer just below the water surface for at least 60 s per reading. To record temperature extremes in shallow habitats, anchor a maximum–minimum thermometer in the stream and leave it for a given time period (generally 24 h). When retrieving the device, record the current temperature, date, and time along with the maximum and minimum measurements shown for the sampling period.

- **Deep water measurements.** When measuring in water deeper than a few meters (e.g., lakes, reservoirs), use a temperature recording meter with a cable-connected probe. Measure temperature at the surface, at 1 m below the surface, and at 2 m below. Continue measuring in 2-m increments until the lake bottom is reached. A thermocline is being detected when temperature readings drop more than 2°C per 2-m increment, and these water strata should be described in 1-m increments.

- **Substrate pore measurements.** The water temperature in the interstitial space of substrate can be most easily recorded with a durable thermistor that can penetrate the substrate of a stream or lake. Alternatively, drive a perforated polyvinyl chloride (PVC) tube into the substrate and measure interstitial flow with a handheld thermometer. Avoid leaving the tube in place between repeat readings, as the interstitial water will equilibrate with the rest of the stream.

15.2.4 Notes

Data from maximum–minimum thermometers can provide a good estimate of average daily temperature. Crisp (1990) computed mean daily temperature calculated from hourly readings over a 24-h period, and compared these means to those estimated with maximum and minimum values: mean = 0.5(maximum + minimum). Both sets of means were very similar (within 0.5°C in 96% of the cases) indicating that the mean of 24 h maximum–minimum values will closely approximate mean daily temperature.

15.3 Temperature Monitoring

15.3.1 Rationale

Measurements recorded over weeks or months result in a complete picture of the thermal regime. Thermal recording devices can be left in the field for a long time, which reduces the number of necessary site visits, but the devices are more costly than regular thermometers.

15.3.2 Preparation

- Acquire data loggers (small thermal recording digital devices) with waterproof, submersible cases and appropriate software for available computers. Alternatively, use water quality monitors (e.g., Hydrolab, Yellow Springs Instruments) that are designed to measure several variables, including pH, dissolved oxygen, salinity, and nutrient levels, as well as temperature. The monitors require protective housing while left in the field and cables long enough to reach the habitat being measured. Find a way to anchor data loggers or monitor probes in the water. A perforated PVC pipe tied to an iron bar used as a stake works well in shallow water.

- Prior to positioning field instruments, the recording devices should be calibrated against a laboratory thermometer or other reliable equipment.

15.3.3 Procedures

- **Install and retrieve data loggers.** These small, battery-operated recorders (Figure 15.1) take regular temperature readings over a predetermined period of time. Set the data logger for either the length of time to monitor or the time interval between readings. Put the data logger in a waterproof, submersible case and anchor it in the water so it is completely submerged. Refer to section 15.2.3 above for guidance on placement sites. At the end of the monitoring period, retrieve the data logger and download the data to a computer. Portable computers are useful for immediate inspection of the data.

- **Using water quality monitors.** The procedure for using water quality monitors is the same as for data loggers, so refer to the preceeding paragraph. They measure variables at regular intervals, and the data can be downloaded to a computer. This technique commands more attention to secure and waterproof field installation because monitors are larger and more vulnerable to damage.

15.3.4 Notes

Basic water quality data, including temperature, can often be obtained from past studies or agency monitoring efforts; refer to Chapter 18 for some sources. By using available data, it is often possible to characterize the annual thermal regime of a stream or lake. In addition, the thermal conditions of a target water body can sometimes be approximated using long-term data sets developed for nearby, similar waters.

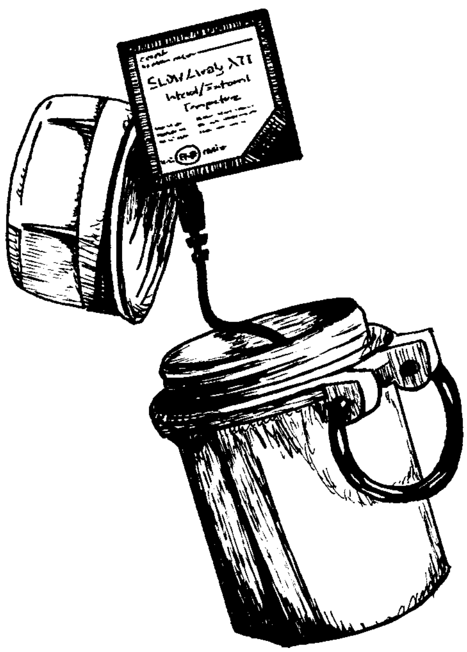


Figure 15.1 Thermal data logger commonly used for monitoring temperature in shallow waters.

Lake Morphology 16

Anne S. Gallagher

16.1 Introduction

16.1.1 Background

Lake morphometry refers to the measurement of lake shape and size and comprises surface area, depth, volume, length, width, and shoreline development (shoreline shape). Each of these dimensions is useful for predicting and explaining some biological, chemical, and physical aspects of a lake. For example, the surface area of a lake controls the amount of sunlight a lake can absorb, and this in turn controls the energy available for primary productivity. Also, lake depth determines the illuminated water volume: relatively deep lakes have low rates of photosynthesis per volume. Shoreline development determines the amount of water edge and littoral habitat relative to lake surface area. This morphological property can influence the trophic nature of the lake: the longer the shoreline, the greater the amount of productive shallow-water habitat.

Biologists often compare lakes using only surface area measurements. Cole (1975) reported a direct relationship between surface area and mean lake depth and volume in an analysis of morphometric data from 500 lakes. Larger lakes are usually deeper than smaller ones and have greater volume. However, this relationship does not hold true for small lakes, and notable exceptions exist with large lakes. For example, Lake Chad in central Africa covers more than 16,500 km^2 in surface area, yet its mean depth is a mere 1.5 m, and its volume is only 25 km^3 (Cole 1975). By comparison, Lake Ontario has a similar surface area (19,000 km^2), but its volume is 1,638 km^3 (www.glc.org/docs/greatplace/gplakes.txt). Although lakes can usually be classified by one metric, such as surface area, lake morphometry that includes several dimensions is more useful for characterizing a lake and explaining fisheries attributes.

The size and shape of a lake is often determined by the geological origin of the basin. For example, cirque lakes tend to be shaped like an amphitheater with steep walls because of ice scouring in deep valleys, and meteoric lakes are the size and shape of the meteor that created a depression. The geology of a lake is important not only because it can control the size and shape of a lake, but also because it can influence biological characteristics. Some geological phenomena, such as glacial or volcanic activity, are restricted to certain climates, elevations, or geographic areas. Lakes of a given origin may only be found in some physical locations and lakes clustered in these areas will tend to have a similar origin, age, and colonization pattern. The origin of a lake can control lake substrates and water chemistry. For instance, volcanic lakes tend to have high pH because the lava forming the lake bed is alkaline, whereas lakes formed by erosional processes (e.g., fluvial lakes) will have water chemistry that reflects local rock and soil composition. Finally, lake origin can also affect water flow through a lake or the exchange rate of the water mass.

16.1.2 Selection of Techniques

The techniques described in this chapter provide a set of criteria for comparing morphological and physical features of lakes. These techniques require little fieldwork; however, because they rely largely on information from maps, the accuracy of the assessment depends on accurate and current maps. Three procedures for using map information span a range of technologies. The most accurate procedure involves using geographic information systems (GIS), but it is more expensive and more training-intensive than the two alternative procedures. The overlay technique is the simplest, least expensive method, but it can have a significant margin of error. An intermediate approach requires the use of a polar planimeter. The selection of a technique will depend on available technology and the required accuracy of the final results.

16.2 Lake Dimensions

16.2.1 Rationale

The size and shape of a lake provide the most basic aquatic habitat measures. Measurement of lake dimensions creates a framework for understanding lake processes and a means for comparing attributes among lakes. The technique described here involves using either GIS or two alternative measuring devices. Geographic information systems should be used when available, but the alternative measuring devices are often acceptable and do not require special training.

16.2.2 Preparation

- Acquire U.S. Geological Survey (USGS) topographic maps at 1:24,000 scale (preferred, or use 100,000 scale) and a lake bathymetric map with contour lines of equal depth. If a bathymetric map is not available, the information can be obtained from field depth measurements. Lind (1974) provides details for constructing a bathymetric map. Gubala et al. (1994) described a more advanced technique of constructing a high-resolution bathymetric map using GIS framework by linking a depth sounder to a digital global positioning system unit.

- Gain access to a GIS unit with a digitizer, software, and a trained technician. Alternatively, obtain a polar planimeter or a 100 dot-per-square-inch transparent overlay with a map measurer (Figure 16.1) and ruler.

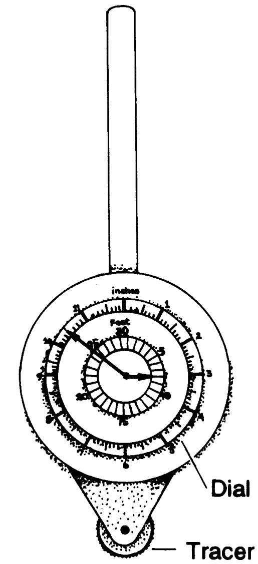


Figure 16.1 Diagram of a map measurer.

16.2.3 Procedures

- **Lake surface area.** Lake surface area is defined as the surface water area, excluding islands. Measure lake surface area in one of three ways.

  1. Digitize the outline of the map using GIS, which calculates the area estimate.

  2. Outline the mapped lake with a polar planimeter. A polar planimeter calculates the area of any plane from the movements of a tracer point along a line enclosing a lake. Place the planimeter in a position on the map that allows the tracer point to be moved on the mapped edge of the lake. Record the vernier units (zero at start) on the planimeter once the tracer point encircles the lake. Convert the vernier units to an area measurement based on the scale of the map and conversion units that came with the planimeter.

  3. A 100 dot-per-square-inch transparent overlay can be used to estimate lake area. Place the grid transparency over the lake. Count the number of dots falling within the shore boundary line and one-half of the number of dots falling on the boundary line. Check Table 16.1 for the correct conversion factor, based on the map scale in the legend. Multiply the total number of dots counted by this conversion factor to obtain the surface area of the lake in square kilometers.

- **Basic lake dimensions.** Lake length is the longest straight line that can be drawn across the lake, from shore point to the furthest shore point. Measure this distance using a ruler and convert it to kilometers (refer to the map legend). Lake width is calculated by dividing the lake area by its length. Lake perimeter can be measured two ways: (1) use GIS as described above and

Table 16.1 Conversion factors for 100 dot-per-square-inch transparent overlay grid. Count the number of dots falling within the boundary line of the lake and one-half of the number of dots falling on the boundary line. Convert the number of dots into lake area using the scale of the map.

Scale of map	Distance conversion	Per dot area conversion
1:24,000	1.6 in = 1 km	0.003889 km^2
1:100,000	0.3937 in = 1 km	0.06423 km^2
All other	x in = 1 km	$0.009956/x^2$

request the perimeter of the lake or length of the shoreline vector, or (2) measure the lake perimeter with a map measurer. A map measurer works by rolling the edge of the measurer along the outline of the lake to record the actual distance traveled. Convert the map measurer reading to kilometers using the map legend and the scale on the measurer. The mean depth of the lake is determined by dividing the volume of the lake (procedure below) by its surface area (procedure above).

- **Lake shape.** An index of shape or shoreline development is a comparative value that relates the length of the lake perimeter to the circumference of a circle with the same area as the lake. For lakes that are nearly circular, this number approaches 1; elongate lakes or lakes with irregular shorelines have much higher values. Once the lake perimeter and area values are obtained as described above, calculate the shoreline development index with the following equation:

  $$\text{Shoreline development index} = \frac{P}{2(A\pi)^{1/2}}$$

  P = perimeter of the lake shoreline;
  A = surface area of the lake;
  π = 3.1416

- **Lake volume.** The volume of a lake is determined by summing the volume of water at each depth increment defined by the contour lines on a bathymetric map. Measure the surface area, a_i, defined by each depth contour line on the bathymetric map (Figure 16.2), following the directions for surface area estimates above. Include the entire area at depth i and lower, rather than just the area between depth i and depth $i + 1$. For example, if the contour lines on the bathymetric map are marked in intervals of 20 m and the lake is 160 m deep, proceed as follows: measure the area at 0 m depth (total lake surface area); measure the area within the 20-m depth contour line; measure the area within the 40-m depth contour line; and so on through 160 m. If there are two or more areas enclosed by a contour line of the same depth, measure each area separately and sum the areas to get the total

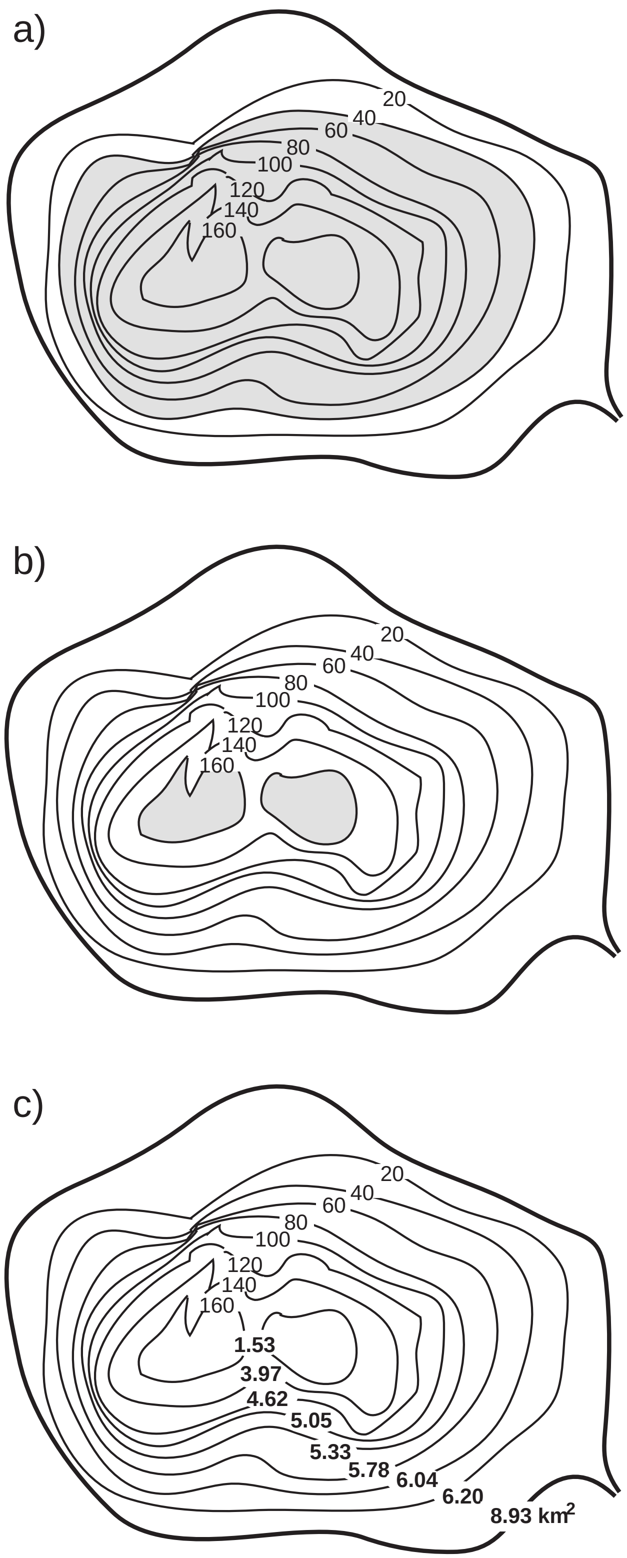


Figure 16.2 Measurement of area at each depth from a bathymetric map: A, area at the 40-m depth interval; B, sum of areas at the 160-m depth interval; C, bathymetric map marked with area at each depth interval.

area for that depth interval. See Figure 16.3 for an illustration and construct a plot like this for the study lake. Mark the left *y*-axis with the depth corresponding to each contour line. Mark the right *y*-axis with the surface area, a_i , at each contour depth *i* (for this example, *i* runs from 0 to 160 in 20-m increments; a_i = the area at depth *i*). Mark the distance between depth lines on the cross-sectional view of the lake as in Figure 16.3. Each distance, h_i equals the water depth at depth interval *i* minus the water depth at depth interval $i + 1$. For example, if the fourth depth line ($i = 4$) is 60 m and the fifth depth line ($i + 1 = 5$) is 80 m, then $h_4 = 20$ m, or 0.02 km. Calculate the total lake volume according to the following equation:

$$\text{Total lake volume} = \Sigma\ (h_i/3)\ [a_i + a_{i+1} + (a_i \cdot a_{i+1})^{½}]$$

See Box 16.1 for an example of this computation.

16.2.4 Notes

Divide a lake into sections if a lake map is larger than a 100-dot-per-square-inch transparent overlay or it exceeds the range of a planimeter. Then, measure each section independently and sum the results to obtain total values.

The overlay procedure will yield more precise results by increasing the grid density on the overlay transparency.

If islands are mapped, measure their areas and subtract the total area of the islands from that of the lake total.

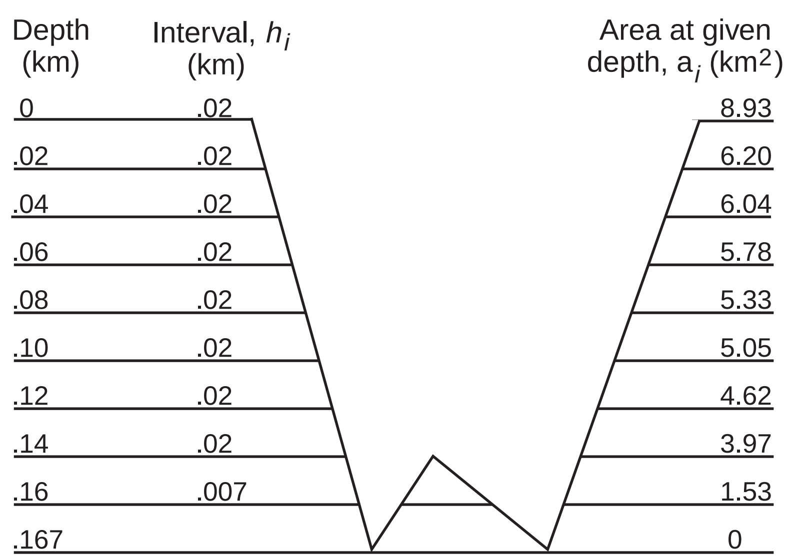


Figure 16.3 Cross-sectional diagram of lake depth and area corresponding to the illustration in Figure 16.2.

Box 16.1 Example computation of lake volume estimates.

See Figures 16.2 and 16.3 for diagrams showing the source of the data for the following calculations.

Interval i	Depth h_i (km)	Interval area a_i (km^2)	Area next interval a_{i+1} (km^2)
0	0.02	8.93	6.20
1	0.02	6.20	6.04
2	0.02	6.04	5.78
3	0.02	5.78	5.33
4	0.02	5.33	5.05
5	0.02	5.05	4.62
6	0.02	4.62	3.97
7	0.02	3.97	1.53
8	0.007	1.53	0.00

Using the above figures, follow the equation for total lake volume:

Total lake volume = $\Sigma\ (h_i/3)\ [a_i + a_{i+1} + (a_i \bullet a_{i+1})^{½}]$

$= 0.02/3 \bullet (8.93 + 6.20 + [8.93 \bullet 6.20]^{½})$
$+ 0.02/3 \bullet (6.20 + 6.04 + [6.20 \bullet 6.04]^{½})$
$+ 0.02/3 \bullet (6.04 + 5.78 + [6.04 \bullet 5.78]^{½})$
$+ 0.02/3 \bullet (5.78 + 5.33 + [5.78 \bullet 5.33]^{½})$
$+ 0.02/3 \bullet (5.33 + 5.05 + [5.33 \bullet 5.05]^{½})$
$+ 0.02/3 \bullet (5.05 + 4.62 + [5.05 \bullet 4.62]^{½})$
$+ 0.02/3 \bullet (4.62 + 3.97 + [4.62 \bullet 3.97]^{½})$
$+ 0.02/3 \bullet (3.97 + 1.53 + [3.97 \bullet 1.53]^{½})$
$+ 0.007/3 \bullet (1.53 + 0.00 + [1.53 \bullet 0]^{½})$

$= 0.150 + 0.122 + 0.118 + 0.111 + 0.104 + 0.097 + 0.086 + 0.053 + 0.004$
$= 0.845\ km^3$

16.3 Lake Geology

16.3.1 Rationale

Lake geology describes two features—lake genesis and lake physiography—that can determine many physical, chemical, and biological attributes of the water body. Lake genesis is the geological origin or physical action that created the lake. Lakes can be formed by long-term geological processes (e.g., glacial or tectonic activity), short-term physical activity (e.g., landslides), or anthropogenic activity (e.g., artificial dams). Lake physiography is the physical location of the lake, which is described by its latitude, longitude, and elevation.

16.3.2 Preparation

- Acquire a USGS topographic map of the lake (scale 1:24,000 for smaller lakes, 1:100,000 for larger lakes). This map can be supplemented with other areas maps and aerial photographs.

- Determine if a water level gauging facility is located on the lake or obtain supplies to establish a water level benchmark. A boat may be needed to obtain readings from a water level gauge or benchmark depending on locations.

16.3.3 Procedures

- **Lake formation.** Determine the geological or physical origin of the lake, based on knowledge of the geology of the surrounding area. Table 16.2 shows lake classification based on formation processes. The same force is often responsible for all natural lakes in a given geographic area, so if several lakes are being examined in one area, they usually will have been formed by the same process.

Table 16.2 Classification of lake formation processes.

Class	Formation process	Common associations
Glacial	Movement of glaciers	High latitudes and elevations
Cirque lakes	Ice scouring of steep valley forming a depression Tend to be shaped like an amphitheater with steep walls except at the outlet	
Moraine lakes	Deposition of debris and drift from glacier scouring	
Kettle lake	Depression following the melting of buried ice	
Fluviatile	River activity	Large streams, rivers
Volcanic	Dam or depression formed by lava flow or collapse of a volcano or lava	Areas of volcanic activity
Tectonic	Uplift of earth’s surface or drop of earth’s crust	Fault lines and areas
Wind	Deposits of sand or silt carried by wind	
Solution	Dissolution of soluble, carbonate rock by percolating water	Carbonate rock areas
Shoreline	Wave action of a larger water body	Large lake or sea margins
Landslide	Mass movement of soil, rock, and debris	
Organic	Buildup of peat and other organic matter	
Meteoric	Meteor impact	
Beaver	Beaver dam construction	On or near streams
Anthropogenic	Artificial (constructed) dams	

- **Identify lake location.** See Chapter 5 for techniques to identify lake location.

- **Measure lake level.** Monitor lake level fluctuations by recording the height of the water in relation to a water level gauge or benchmark. Lake levels are often available from stage or lake level recording facilities. When such a facility does not exist, a benchmark can be established by one of three procedures.

  1. Permanently mount a gauge (ruled plate or metal strip) on an existing solid structure such as a dam or bridge support. The gauge should be marked in depth increments of interest for the habitat assessment. Ensure that the gauge extends lower than the anticipated low water mark and higher than the expected high water mark.

  2. A rock face on the lake shoreline or in the lake (such as on a permanent island) can serve as a fixed point for lake level measurements. In these cases, paint a small circle on the rock about one meter above the high water mark. Drill a hole several centimeters deep in the center of the circle. Measure water level from the height of the hole down to the surface of the water.

  3. A large tree can be used in place of a rock face, and the same procedure can establish a fixed point for lake level measurements. Trees are, however, less dependable over long periods of time than bedrock and concrete dams.

17 Water Transparency

Mark B. Bain and Kristin M. Hynd

17.1 Introduction

17.1.1 Background

Fisheries biologists almost always document some aspect of water clarity in assessments of lake and stream habitats, although their reasons for measuring water clarity are highly diverse. For streams, biologists are most often measuring the sediment load suspended in the water. For lakes, measuring algal production in surface waters and measuring the depth of light penetration to define the extent of the littoral zone are the usual goals. All common techniques record some property of light transmission in water (i.e., the optical properties).

Sediments entering a stream can remain in the water column as suspended sediments or settle onto the bottom as deposited sediments. All streams contain some suspended and deposited sediments naturally. Several factors may increase the sediment load of a water body to a level that is detrimental to biological communities. The primary sources of inorganic sediment in streams are the erosion of uplands, lateral movement of channels into streambanks, and downcutting of streambeds (Waters 1995). Excessive sedimentation usually occurs as the result of human activity, including but not limited to agriculture, logging, mining, and urban development. Suspended sediments are fine particles, primarily clays, silts, and fine sands, that require only low velocities and minor turbulence to remain suspended (Allan 1995). Dissolved sediments have entered into solution, and these will not settle out of the water even if allowed to stand still. The techniques discussed in this chapter vary in their ability to distinguish between suspended and dissolved material, but either may be adequate for habitat assessment purposes.

17.1.2 Selection of Techniques

The two techniques described below can precisely record light transmission in lake water, and often identify the type of material involved. The technique should be chosen based on the availability of equipment and assessment information needs. The most common technique uses a Secchi disk: a 20-cm circular plate painted with a standard pattern that is lowered into water until it disappears from view and then raised until it reappears (Orth 1983). This is one of the simplest techniques for measuring transparency, but it is prone to variable accuracy and is a measurement device that is affected by anything that reduces light transmission in water including surface water reflection. This technique is not described in detail because of its limitations, but the widespread measurement of Secchi transparency has been useful in monitoring lake and reservoir water conditions.

17.2 Turbidity

17.2.1 Rationale

Turbidity is a measure of the extent to which light penetration in water is reduced from suspended solids (Armantrout 1998). Turbidity (also nephelometry, detecting transmitted light with instruments) has a history of use (e.g., Tebo 1955) as a rapid and indirect measure of suspended sediments. The terms turbidity and suspended solids are often used interchangeably. Turbidity is easy to measure rapidly and produces more accurate light transmission readings than can be obtained with a Secchi disk. Also, the U.S. Environmental Protection Agency (1986) quality criteria for water specifies that suspended solids and turbidity should not be elevated to a level where the depth limit for photosynthetic activity (e.g., in lakes) is reduced by more than 10% of the seasonal norm. Turbidity measurements are therefore consistent with many state and federal water quality regulatory programs.

Suspended sediment is the major contributor to turbidity, however, other materials also contribute to the reduction of transmitted light. Turbidity may be caused by pollution derived color, optically active dissolved and colloidal material, organic detritus and pollution, plankton, and other microscopic organisms. Even in the absence of these confounding factors, turbidity measurements can be influenced by suspended sediment grain size, composition, density, and indices of refraction (Earhart 1984). Therefore, when using turbidity as a general measure of water clarity, it should be understood that all factors affecting light transmission are captured in the readings.

17.2.2 Preparation

- Acquire a field nephelometric turbidity meter. These meters measure light transmission through sample cuvettes of standard and sample water. They are fairly inexpensive (US$600–900), small, and available in rugged field models.

- Prepare data recording sheets.

17.2.3 Procedures

- **Samples and meter readings.** Obtain a surface water sample, agitate the sample, and fill a meter cuvette. Follow meter instructions to obtain light transmission values in nephelometric turbidity units (NTU). Repeat for three to five samples collected at representative and well-spaced locations in the habitat being assessed. Record each single measurement; data can be reported as a mean or as a range of values.

17.2.4 Notes

This technique is simple and straightforward to conduct. Results can be obtained in the field and data are available immediately. The level of resolution is sufficient to meet most management evaluation needs. As with all physicochemical water measurements, the values obtained reflect conditions at the time of sampling. Although NTU readings will be accurate for the samples processed, the cause of turbidity will not always be evident.

In many field investigations, biologists have extended the meaning of turbidity readings by developing regression equations relating NTU values to suspended solid concentrations (mg/L). This practice may work well under very limited time periods and water conditions (Kunkle and Comer 1971); however, a consistent direct relationship between turbidity and the weight of inorganic sediments per volume of water is unlikely to be valid, because optical properties of water are not fully determined by the mass of solids in water (Earhart 1984).

17.3 Total Suspended Solids

17.3.1 Rationale

Any measure of water transparency captures effects of a variety of suspended and dissolved materials. Suspended sediments are fine particles kept in suspension by turbulence. Dissolved material is in solution, and will not settle out of the water. Dissolved substances may color water and otherwise alter transparency, but dissolved solids are routinely measured by specific conductance (see Chapter 18, Interpreting Chemical Data). A technique that separates the water transparency effects of suspended and dissolved material, and quantifies these components, would be an advancement over nephelometric turbidity meters.

A technique for specifically measuring total suspended solids (TSS in mg/L) is described here (also see APHA 1998). It has been used for many years (e.g., Cline et al. 1982), often under the older name of total nonfilterable residue (as in APHA 1980). Habitat assessments are often aimed at inorganic sediment inputs to lakes and streams; however, suspended solids may contain substantial organic matter. The TSS technique can be expanded to distinguish between organic and inorganic suspended solids (Lemly 1982). Measuring total suspended solids is done in a laboratory, but much of the sample processing can be done in the field.

17.3.2 Preparation

- Acquire field items for initial processing on-site: ruled sample bottles, hand pump and vacuum flask, filter folder and filters (2.0 μm or smaller pore size, standard glass-fiber filter), and storage bags for used filters. Bottles and filter disk bags should be labeled before sampling.

- Laboratory processing requires a drying oven (muffle furnace for expanded technique), desiccator, and sensitive balance.

17.3.3 Procedures

- **Field sampling.** Obtain three to five water samples (select a volume that yields 2.5–200 mg of residue; collect plenty and adjust) spanning the habitat being assessed. Filter each sample in the field with hand vacuum pumps and unbreakable filter funnels so that only the small disks are retained for laboratory work. Water samples or filter disks can be stored for up to 1 week at 4°C for further laboratory processing.

- **Laboratory processing.** Laboratory processing starts with vacuum filtering a well-mixed water sample through a glass-fiber filter (unless samples were filtered in the field). Determine dry filter weights before using. Following filtration, each filter is dried in an oven at 103–105°C for 1 h and then reweighed. Repeat this step if residue is heavy and possibly not well dried. Total suspended sediments are reported in milligrams (sediment on filter paper) per liter of water (APHA 1998). Calculate results:

  mg total solids/L = $([A - B] \times 1000)$/sample volume in mL;

  A = weight of filter and dried residue in mg
  B = weight of filter in mg

- **Advanced laboratory processing.** To distinguish between organic and inorganic suspended solids, the glass-fiber filters are placed in a furnace at 550°C (1 h) after the initial filtering, drying, and weighing. At this high temperature organic solids are burned so the loss of mass represents the mass of organic sediments. When using the expanded technique, report results for organic suspended solids, inorganic suspended solids, and total suspended solids in mg/L.

17.3.4 Notes

Although TSS analyses are much more complicated and time consuming than using a turbidity meter, this technique provides accurate data on material in lake and stream waters. The types of materials contributing to water turbidity are identified, and sources will often be evident from this information. Details of the analyses and further methodology recommendations are described in APHA (1998) and Hach Company (1992).

The TSS technique could be used in combination with the rapid, meter-based techniques for turbidity and specific conductance (for dissolved solids, see Chapter 18) to obtain a complete information set on suspended and dissolved material, and their effect on overall water clarity. As a guide for interpretation of TSS data, the middle 50% of U.S. streams and rivers range from 18 to 193 mg/L in total suspended solids (Smith et al. 1987).

Interpreting Chemical Data

18

Mark B. Bain

18.1 Introduction

The chemical and material composition of water influences the species composition and abundance of fish. More than a third (36%, U.S. Environmental Protection Agency 1997) of U.S. streams and rivers do not support intended uses because of water quality degradation. The leading causes of impairment are excessive levels of bacteria, sediment, nutrients, and oxygen-depleting substances from agricultural runoff, municipal point source pollution, and habitat alterations (e.g., dams, riparian zone modification). For lentic waters, the U.S. Environmental Protection Agency (1997) reports that more than a third (37%) of ponds, reservoirs, and lakes (excluding the Great Lakes) do not support intended uses because of excessive levels of nutrients, sediment, and oxygen-depleting substances caused by agricultural runoff, municipal point source pollution, and urban runoff. This chapter focuses on the most common physical and chemical data that can be used to assess the quality of water. Other chapters cover related attributes such as temperature (see Chapter 15, Temperature) and sediments (Chapter 17, Water Transparency).

The chemical and material composition of surface water in lakes, rivers, and streams can be organized into five basic components (Figure 18.1): dissolved gases, dissolved inorganic ions and compounds, particulate inorganic compounds, dissolved organic compounds, and particulate organic material. The gases include dissolved oxygen, which is essential for aquatic life and is often affected by land runoff and organic pollution. Dissolved inorganic ion concentrations (minerals), are often measured and reported in habitat assessments because the values for a set of related measurements (pH, hardness, alkalinity, total dissolved solids, and specific conductance) are indicative of biological productivity and vulnerability to

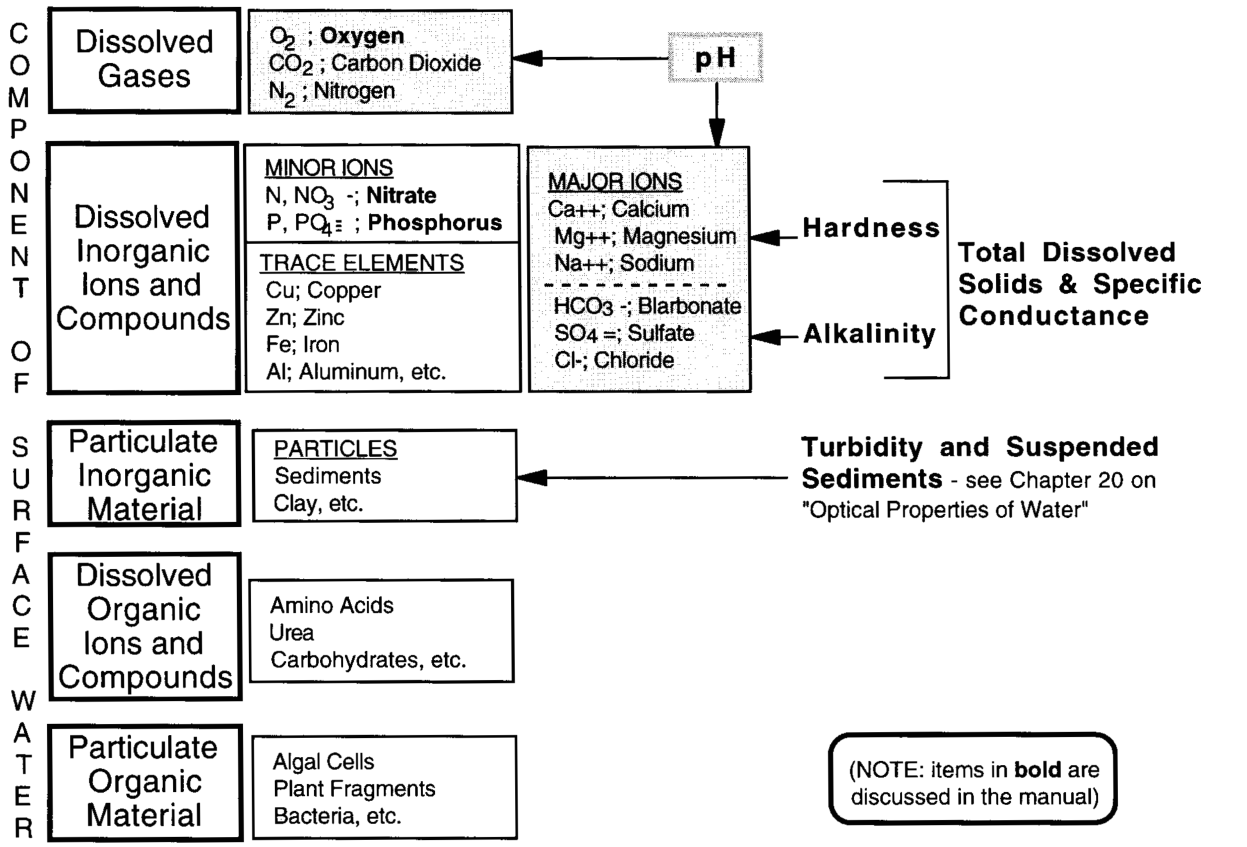


Figure 18.1 Organization of the major components of surface water.

acidification. Nutrients, or minor ions in terms of concentrations, are measured to determine primary productivity and evidence of eutrophication. Finally, particulate (nondissolved) inorganic material is a measure of sedimentation, a major form of habitat degradation.

This chapter is designed to assist fisheries biologists obtain water quality data, and interpret the data for commonly available parameters. Most habitat assessment methods include the use of water quality data. Data on metals, pesticides, herbicides, and other contaminants are beyond the scope of fisheries habitat investigations, and the analysis and interpretation of those data are complex and often controversial. Similarly, biological contamination, such as elevated bacteria concentrations, is not covered in this manual because it is largely a topic of public health (i.e., water consumption and contact).

18.2 Sources of Water Quality Data

18.2.1 Field Sampling and Laboratory Processing

Procedures for sampling and analyzing water are well established and documented. Many state, provincial, and federal agencies have standardized procedures (e.g., U.S. Environmental Protection

Agency 1982, 1983; U.S. Geological Survey 1982; Pritt and Raese 1992; Fishman et al. 1994; Maloney et al. 1994), and are easily obtained (National Environmental Information Service 1997). Commercial water testing companies routinely adhere to the standards and practices specified by the U.S. Environmental Protection Agency (USEPA). Some professional and scientific organizations (American Water Works Association, Water Environment Federation) have maintained recommended methods for sampling and analysis, and these have been in place for decades (e.g., APHA 1980, 1998, and other periodic versions). Some excellent and easy-to-understand independent reference books and manuals (e.g., Lind 1974) on water quality analysis can be purchased. In addition, field and laboratory kits for many water quality parameters are widely available and frequently used in habitat analyses. These kits have well-explained procedures, sampling supplies, and prepackaged reagents. Prepacked reagents and detailed procedures are also available (e.g., Hach Company 1992) for full-precision laboratory analyses.

There is no need to repeat the techniques on water sampling and analysis in this manual with such extensive information already available in several forms; however, some guidance is presented below on how to obtain water quality data for aquatic habitats or adjacent waters, and later criteria are presented (section 18.3) for interpreting water quality data. Keep in mind that standard techniques may already be defined for an agency or a closely related agency in the same level of government. Finally, water quality parameters change rapidly, often from day to day, and with changes in watershed activities, season, time of day, hydrology, and streamflow. More than a single day of sampling is needed to make inferences about water quality for any particular aquatic habitat.

18.2.2 Established Databases

Many state, provincial, and federal agencies maintain large and long-term databases of water quality measurements. Water quality databases will provide more information than could be collected in typical agency habitat surveys because the period of record is usually many years. These databases should be consulted for habitat assessments even when new data are collected so that inferences on water quality can be made from a long-term perspective (explained in section 18.4).

The USEPA maintains a very large water quality database called STORET (Box 18.1) that is the same database used by state water and environmental management agencies. The data in the STORET system came from a variety of sites where water sampling was completed once or often by numerous agencies and organizations. The STORET data comes with agency codes, station codes, latitude, longitude, hydrologic unit codes, date, time of sampling, and about 900 water parameters. Data are obtained from the STORET system by making a specific query, but the method for data queries changes as the system is improved (see Box 18.1).

Box 18.1 Introduction to the STORET water quality database (edited from the USEPA World Wide Web site: http://www.epa.gov/OWOW/STORET/index.html).

EPA United States Environmental Protection Agency

Office of Water

Watershed Protection

Welcome to STORET, EPA's largest computerized environmental data system.

STORET (short for STOrage and RETrieval) is a repository for water quality, biological, and physical data and is used by state environmental agencies, EPA and other federal agencies, universities, private citizens, and many others.

Obtaining Water Quality Data

Until the Legacy Data Center (LDC) and the STORET Warehouse are web-enabled, please call STORET User Support at 800-424-9067 if you wish to retrieve data from STORET. Before calling, be familiar with the available options and decide how you want your data retrieved.

First, you will need to specify your geographic area of interest. Data can be retrieved

- by state or state and county,
- by Hydrologic Unit Codes (HUC),
- by a latitude and longitude and a distance (radius) from that point, or
- by a polygon with the vertices being latitudes and longitudes.
  NOTE: data cannot be retrieved by river name or site (location) name

Next, you will need to know what data you want and how you want it displayed. Data can be displayed

- by an inventory of all the parameters sampled at each station,
- by a composite of all the parameters sampled in all the stations retrieved, or
- by a list of the raw data at each station for selected or all parameters.

Last, you should decide how you want to receive the data. Data can be sent to you

- in hard copy via mail to your snail mail address,
- electronically via File Transfer Protocol (FTP) to a user-specified site, or
- electronically via email, if the file is small.

STORET User Support will discuss these various options with you before initiating a retrieval. Depending on the data available in STORET, retrievals may be limited to certain dates or to certain waterbody types, such as groundwater, lakes, streams, etc.

There is no charge for the information unless the retrieval is for a large area of interest.

STORET User Support
800-424-9067
8:00 a.m. – 4:00 p.m. Eastern
Monday–Friday

The U.S. Geological Survey (USGS) maintains the WATSTORE (Water Data Storage and Retrieval System, Box 18.2) database of water quantity and water quality values for surface and groundwater. The water quality data are extensive and long term (e.g., covering decades). Unlike the STORET system, the data came largely from USGS investigations and monitoring programs, and the sampling sites usually correspond with stations that periodically or continuously monitor streamflow and lake stage.

Many agency databases can be accessed through the Internet. This trend in distributing water quality data is relatively new, and methods for obtaining the data are developing rapidly. A few computer products are available (e.g., CD-ROM) that contain water quality databases (e.g., Alexander et al. 1996) and data from the STORET and WATSTORE systems, but Internet access will probably replace these products in the near future.

Box 18.2 Introduction to the WATSTORE database (edited from the USGS World Wide Web site listed for WATSTORE).

U.S. Geological Survey

Water Data Storage and Retrieval System (WATSTORE)

This section serves as a guide for retrieving data from the Water Data Storage and Retrieval System (WATSTORE). The WATSTORE consists of several files in which water data are grouped and stored by common characteristics and data-collection frequencies. Files are maintained for the storage of (1) surface water, quality of water, and groundwater data measured daily or more frequently, (2) annual peak values and peaks above a base flow for streamflow stations, (3) chemical analyses for surface- and groundwater sites, (4) geologic and inventory data for ground-water sites, and (5) water use summary data. In addition, an index file of sites for which data are stored in the system is maintained in WATSTORE.

The Water Quality File contains results of more than 1.8 million analyses of water samples collected at over 300,000 sites are stored in the Water Quality File. The samples describe the chemical, physical, biological and radiochemical characteristics of both surface and groundwaters. Some analyses contain data for as many as 185 different parameters. However, the average numbers of parameters per analysis is less than 40.

The World Wide Web address for this WATSTORE is:

http://h2o.er.usgs.gov/public/nawdex/wats/intro.html
or
http://water.usgs.gov/public/nawdex/wats/intro.html

For comments and questions, contact: wgreen@usgs.gov

18.3 Common Water Quality Parameters

18.3.1 Dissolved Oxygen

Dissolved oxygen (DO) enters water from photosynthesis and the atmosphere, and it is used in respiration (from fish to bacterial breakdown of leaves, wood, animals, etc.). Adequate dissolved oxygen is essential to aquatic biota and historically has been one of the most frequently measured indicators of water quality (Hem 1970). Dissolved oxygen concentration in surface waters varies greatly with temperature because the saturation level for oxygen in water decreases as water temperature increases (Table 18.1). In unpolluted, turbulent waters, the dissolved oxygen concentration depends primarily on water temperature. Depletion of dissolved oxygen in streams is caused by algal and bacterial respiration associated with phytoplankton blooms; discharges from municipal and industrial wastewater treatment facilities; leaks and overflows from sewage lines and septic tanks; stormwater runoff from agricultural and urban land; and decaying vegetation, including aquatic plants from the stream itself and detrital terrestrial vegetation (Smith et al. 1993).

Table 18.1 Solubility of oxygen in pure water at mean sea level air pressure (Lind 1974).

Temperature (°C)	Dissolved oxygen (mg/L)
0	14.16
1	13.77
2	13.40
3	13.05
4	12.70
5	12.37
6	12.06
7	11.76
8	11.47
9	11.19
10	10.92
11	10.67
12	10.43
13	10.20
14	9.98
15	9.76
16	9.56
17	9.37
18	9.18
19	9.01
20	8.84
21	8.68
22	8.53
23	8.38
24	8.25
25	8.11
26	7.99
27	7.86
28	7.75
29	7.64
30	7.53
31	7.42
32	7.32
33	7.22
34	7.13
35	7.04

The USEPA (U.S. Environmental Protection Agency 1976, 1986) specifies a minimum dissolved oxygen concentration of 5 mg/L as a quality criterion for maintaining aquatic biota. Many states use a less protective minimum limit of 4 mg/L, and some states specify other values due to regional and seasonal conditions. Using the large USGS and USEPA databases described above, Smith et al. (1987) computed that the middle 50% of U.S. waters range from 8.7 to 10.5 mg/L (median 9.8) dissolved oxygen and therefore have adequate levels of oxygen for fish and other aquatic life. During the 1970s, the trend in dissolved oxygen concentration was fairly stable (Smith et al. 1987; Lettenmaier et al. 1991), and this stability prevailed in the 1980s (Smith et al. 1993). One explanation for the stability is that the investment in point-source pollution controls has kept pace with population increases and economic development (Smith et al. 1993).

The following descriptions could be used to interpret dissolved oxygen values in many water quality databases or in new samples:

Description	DO mg/L
Biotic crisis	≤3
Minimum limit in many states	<4
USEPA minimum limit	5
Adequate for fish	>5
Median of U.S. sites	9.8
Middle 50% U.S. sites	8.7–10.5

It is often informative to compare actual dissolved oxygen levels to the saturation level (Table 18.1) at the same temperature; expressed as percent saturation. When this percentage is low (<80–90%) it is evidence of elevated oxygen use, which is often associated with decomposition of organic matter.

18.3.2 Hydrogen Ion Concentration

Potentia hydrogenii (pH) or hydrogen ion activity is a negative $\log_{10}$ expression of hydrogen ion (H^+) concentration in moles per liter; pH = 7 is neutral. Restated, pH = $-\log_{10}$ [H^+], where [H^+] is the hydrogen ion activity. Pure rainwater has a pH of 5.6 because some CO_2 dissolves in pure water forming a weak solution of carbonic acid. Industrial emissions contribute other compounds (e.g., SO_2) to the atmosphere resulting in precipitation with high hydrogen ion concentration (that is, low pH or acid rain). There is an extensive body of scientific literature on acid effects on aquatic biota that emerged from more than a decade of intense study of the acid precipitation threat to North American waters.

The USEPA (U.S. Environmental Protection Agency 1976, 1986) classifies waters suitable for biota as pH 6.5–9. Severe stress to aquatic life is evident at pH levels below 4 units. Using the large USGS and USEPA water quality databases, Smith et al. (1987) computed that the middle 50% of U.S. waters range in pH from 7.3 to 8.1 (median 7.8) in the 1970s. Through the 1980s, pH levels have been increasing in most U.S. waters, especially in the northeastern states, suggesting a reduction in acidity of precipitation (Lettenmaier et al. 1991). The following descriptions could be used to interpret pH values in water quality databases or for new samples:

Description	pH
Stressed	<4
Suitable for biota	6.5–9.0
Most productive	6.5–8.5
Median for U.S. sites	7.8
Middle 50% U.S. sites	7.3–8.1

18.3.3 Alkalinity

Alkalinity is a measure of negative ion (such as hydroxide [OH^-], carbonate [CO_3^{2-}], bicarbonate [HCO_3^-] and others; Figure 18.1) concentrations expressed in ppm or mg/L $CaCO_3$. The level of alkalinity determines the buffering capacity or ability to neutralize acid (H^+ ions), and therefore is important for identifying habitats that are vulnerable to acidification. Well-buffered waters are usually associated with soluble sedimentary rock, especially limestone, and are often productive for fish. Finally, well-buffered waters provide a more stable chemical environment not only because of the acid neutralizing capacity of negative ions, but also because these ions complex with metals and other potentially stressful compounds.

The USEPA (U.S. Environmental Protection Agency 1976, 1986) specifies a minimum alkalinity of 20 mg/L $CaCO_3$ as a quality criteria for maintaining healthy aquatic biota. When waters naturally have alkalinity below 20 mg/L, the level should not be reduced by human actions. Lind (1974) classified waters as poorly, moderately, and well buffered (shown below), and these ranges provide easy categorical descriptors of alkalinity levels. Smith et al. (1987) computed that the middle 50% of U.S. waters range from 42 to 162 mg/L (median 104) alkalinity indicating that most waters are moderately to highly buffered. Through the 1980s, alkalinity levels have been increasing in most U.S. waters, especially in the northeastern states, possibly due to reductions in acidity in precipitation and increases in atmospheric deposition of sulfates (Lettenmaier et al. 1991). The following descriptions could be used to interpret alkalinity values in water quality databases or for new samples:

Description	Alkalinity (mg/L)
Minimum acceptable	20
Poorly buffered	<25
Moderately buffered	25–75
Highly buffered	>75
Median for U.S. Sites	104
Middle 50% U.S. sites	42–162

18.3.4 Hardness

Hardness is a measure of positive ion (primarily Ca^{2+}, and Mg^{2+}; Figure 18.1) concentration expressed as mg/L $CaCO_3$. The term "hardness" originated from the fact that water with high concentrations of positive ions is associated with difficulty in getting lather formation from soap (ions complex organic molecules of soap). Alkalinity and hardness are directly related since each measures differently charged ions of the same dissolved materials. Consequently, alkalinity and hardness usually covary through time and among sites. Moderate to high levels of hardness tend to be associated with soluble sedimentary rock, good fish productivity, and a stable chemical environment. Furthermore, organisms such as mollusks and crayfish need calcium for shells and exoskeleton mass.

The USEPA (U.S. Environmental Protection Agency 1976, 1986) classifies waters from soft to very hard to provide easy categorical descriptors of hardness levels. Using the USGS and USEPA databases, Smith et al. (1987) computed that the middle 50% of U.S. waters range from 27 to 157 mg/L (median 68) in the summed concentration of calcium, magnesium, and sodium, or total hardness, indicating that most waters range from soft to hard. Unlike alkalinity levels, changes in hardness have varied across U.S. waters because the concentration of dissolved materials in water is influenced by many human and natural processes (Smith et al. 1993). The following descriptions could be used to interpret hardness values in water quality databases or for new samples:

Description	mg/L $CaCO_3$
Soft	0–75
Moderately hard	75–150
Hard	150–300
Very hard	>300
Median for U.S. sites	68
Middle 50% U.S. sites	27–157

18.3.5 Total Dissolved Solids

Total dissolved solids (TDS) is a measure of the total concentration of dissolved substances (weight of material left in filtered water after evaporation), and therefore an indirect measure of ion concentration. Total dissolved solids is very easily approximated by specific conductance or conductivity (ability to pass an electric current through water). Pure water has very high resistance to electron flow (high ohms) and conductivity is the inverse: measure of electron flow in μmhos/cm or μS/cm (recent sources use the latter). When TDS is high in limestone outcrop regions, it is usually due to ions of calcium, sulfate, and carbonates. Water is low in TDS and dominated by silica in sand or granite dominated regions. In arid regions, evaporation concentrates sodium and chlorides, raising TDS and conductivity. As described for alkalinity and hardness that measure ion concentrations, dissolved materials tend to be positively correlated with biological productivity, promote stable chemical environments, and indicate a watershed with soluble bedrock.

Specific conductance is one of the most commonly recorded water characteristics because it is easy (insert meter probe in water), fast (immediate reading provided), and often practical (meters are inexpensive, durable, and require minimal care or calibration). Lind (1974) reports that TDS can be estimated as 0.65 times specific conductance (SC). The relation between conductivity and TDS is linear ($TDS = k \cdot SC$) but k varies from 0.55 and 0.75 so a regional relation should be developed for accurate TDS predictions (Allan 1995).

The USEPA (U.S. Environmental Protection Agency 1976, 1986) specifies a maximum TDS of 250 mg/L as a quality criterion for water supplies. Smith et al. (1993) classified waters as having low, medium, and high levels (below) of TDS based on an analysis of the U.S. water quality databases. Through the 1970s and 1980s, TDS levels have been increasing in most U.S. waters, especially in the eastern states, and this trend has been attributed to numerous human activities (Smith et al. 1987; Lettenmaier et al. 1991).

The following descriptions could be used to interpret TDS values in water quality databases or for new samples:

Description	TDS (mg/L)
USEPA maximum for water supply	250
New York state maximum	500
Low concentration	<100
Medium concentration	100–500
High concentration	500–1,000
Very high concentration	>1,000

18.3.6 Nitrate

Nitrate is one of two important nutrients (the other, phosphorus, is described later) that are required by plants and algae for growth. Nitrate levels are elevated by agricultural pollution (fertilizer runoff) and sewage (breakdown of proteins) where nitrate (NO_3) is the end product of oxidation of proteins; the other principal inorganic ions, nitrite and ammonia (NO_2, NH_4^+ ions), are transitory. Automobile exhaust and industrial emissions have significantly elevated nitrate levels in the atmosphere. Artificially high nitrate concentrations in surface waters results in public health concerns about human drinking water and the potential for eutrophication, especially in coastal waters where nitrate is often far more limiting to plant growth than phosphate. Direct effects on fish are not evident until levels are so high (>90 mg/L N; U.S. Environmental Protection Agency 1976, 1986) they are rarely seen even in polluted waters.

A widely applied concentration limit for nitrate (expressed as nitrogen) in water supplies is 10 mg/L (U.S. Environmental Protection Agency 1976, 1986) for public health reasons. These levels are far higher than seen in almost all natural surface waters; forested watersheds yield water with nitrate concentrations one hundredth of this level. Smith et al. (1993) use a nitrate concentration of 1 mg/L N as indicative of agricultural and urban runoff effects. Using the USGS and USEPA water quality databases, Smith et al. (1987) computed that the middle 50% of U.S. waters range in nitrate from 0.20 to 0.89 (median 0.41) mg/L. In the 1970s, nitrate levels in surface waters across North America were rising due to increased runoff of fertilizer from agricultural areas and atmospheric deposition (Smith et al. 1987), but the time trend analysis by Lettenmaier et al. (1991) indicated a mix of factors have been responsible.

The following values could be used to interpret nitrate concentrations in water quality databases or for new samples:

Description	NO_3 mg/L N
Undisturbed stream in a forested basin	0.1
Agriculture and urban influenced	>1
USEPA quality limit	≤10.0
No direct effects on fish	≤90.0
Median for U.S. sites	0.41
Middle 50% U.S. sites	0.20–0.89

18.3.7 Phosphorus

In surface freshwaters, phosphorus (P) occurs largely as phosphate (PO_4) and is the component of water chemistry that limits plant production. Phosphorus is vital to all life for synthesizing adenosine triphosphate (ATP), which is the energy carrier in all cells. It is not abundant in natural systems where it is rapidly used up by living things; however, many human activities greatly increase the availability of phosphorus as phosphate, which accelerates growth of aquatic plants and results in eutrophication. Waste discharge from sewage-treatment and food-processing plants and other industrial facilities is the largest source of phosphate in streams. Nonpoint sources of phosphorus include agricultural and urban runoff and, in certain regions, the runoff and groundwater flow from areas that contain natural deposits of phosphate minerals (Hem 1970).

Problematic algae or plant growth usually does not occur if phosphate concentrations remain under 0.1 ppm or mg/L (Winger 1981) and the U.S. Environmental Protection Agency (1976, 1986) uses this as the quality criterion for flowing waters. For lakes and reservoirs, the U.S. Environmental Protection Agency (1976, 1986) maximum quality limit is 0.5 mg/L. These levels are set to prevent eutrophication and nuisance plant growth. Using the USGS and USEPA water quality databases, Smith et al. (1987) computed that the middle 50% of U.S. waters ranged in phosphorus from 0.6 to 0.29 mg/L (median 0.13) in the 1970s. Smith et al. (1987) and Lettenmaier et al. (1991) also reported that phosphate levels were stable during the 1970s despite substantial increases in fertilizer use during that decade. During the 1980s the decline continued as a result of significant reductions in point-source loads and some reduction in nonpoint-source loads (Smith et al. 1993).

The following descriptions could be used to interpret total phosphorus values in water quality databases or for new samples:

Description	Total P mg/L
Undisturbed stream in a forested basin	0.005–0.05
USEPA quality limit; flowing waters	≤0.1
USEPA quality limit; lentic waters	≤0.5
Median of U.S. sites	0.41
Middle 50% U.S. sites	0.06–0.29

18.4 Summarizing Water Quality Data

Single measurements of most water quality parameters are highly variable due to temperature, season, stream discharge, and recent watershed activities (e.g., forest fires, land clearing, farming practices, construction, etc.). Therefore, inferences about water quality from point measurements taken during habitat assessments will be limited. Single water quality values may be informative when used in the context of a longer time series of data, or in comparison to nearby waters sampled under the same conditions. When using a time series of water quality data, it is recommended that summary statistics be used that are robust for highly variable distributions: nonparametric statistics such as medians and interquartile ranges (25–75%). Many of the water quality criteria provided above were based on median and interquartile values computed from large databases. Another useful data summary technique is to compute the frequency of violations in quality criteria such as those presented in the preceding sections. For example, using a 10-year, 35-value record of total phosphorus, one could compute the number of samples exceeding the USEPA stream quality criteria of 0.10 mg/L P. When 15% of the samples exceed quality criteria, degraded water quality is indicated. That 15% rate might be different for lethal conditions such as dissolved oxygen below 4 mg/L or pH less than 4. Finally, all available data and information should be reviewed for each aquatic habitat before classifying a habitat as degraded.

Trends in Methods for Assessing Freshwater Habitats

Appendix

Mark B. Bain, Thomas C. Hughes, and Kristin K. Arend

Fishery management has traditionally focused on population-level rates and processes. However, in the past two decades fisheries and natural resource agencies have increasingly employed habitat-based approaches for resource inventory and assessment. Habitat is now the basis of many forms of species management, mitigation planning, environmental regulation, and impact assessment. In comparison with fish populations, habitat has the advantages of being relatively stable through time, easily defined in intuitive physical terms, and a tangible resource for negotiations and decision making. However, the validity of habitat-based management rests on accurate definitions and measurements. As habitat management has become established, a wide range of agencies have developed numerous methods.

The American Fisheries Society (AFS), working with the U.S. Fish and Wildlife Service, developed a project to evaluate the array of habitat assessment methods being used by agencies with fishery management responsibilities. The project sought to provide a basis for defining a select set of standard data collection techniques and analytic procedures. This report is part of that effort, and our specific objectives were to

1. Assemble methods in use by state, provincial, federal, and private organizations to assess aquatic habitats in the inland waters of North America;
2. Assess and synthesize the techniques used in these methods; and
3. Summarize the common uses and attributes of established methods.

This appendix previously appeared in Fisheries *24(4): 16–21.*

A.1 Methods

Agencies with fishery management activities in North American state, provincial, and federal governments were surveyed by telephone from the fall of 1995 through the winter of 1996. We identified initial contact offices using the *National Wildlife Federation Conservation Directory* (1995) and the *American Fisheries Society 1994–1995 Membership Directory*. Typically, the main contact person available to answer questions was a research biologist or chief of fisheries. In many agencies, multiple people were responsible for assessing aquatic habitat. In these cases, we tried to contact all agency personnel knowledgeable about habitat assessment methods. Private consulting companies, chosen from advertisements in *Hydro Review*, *Fisheries*, and other sources, also were surveyed. Companies that advertised fisheries expertise and research in environmental sciences were emphasized in our survey. We asked all agencies and organizations to provide documentation for their established habitat assessment methods.

All documents received were first reviewed to determine if the method was within the scope of our study, and if the documents were detailed enough to judge method attributes. We then analyzed relevant method documents in one of two categories and conducted a full review of established habitat assessment methods with thorough documentation. A detailed form was used to structure summary information and observations of the method: its purpose, input and output variables, analytical approach, validity, and use. We conducted abbreviated reviews using a short version of the review form when the documentation was generalized or sparsely developed, or when the method only somewhat addressed habitat assessment. The abbreviated re view form only summarized information regarding method purpose, nature of habitat assessment, and use.

We included only fully reviewed methods in the tabulation and evaluation of common properties and trends in habitat assessment. While we counted the abbreviated reviews as evidence that some agencies conduct habitat assessment, we did not attempt to characterize method attributes because the documents lacked substantial portions of the information available from the fully reviewed methods. Also, the abbreviated methods did not include procedures or analyses that expanded the range of coverage provided in the fully reviewed methods.

A.2 Results and Discussion

We contacted biologists and fishery managers in 62 U.S. states and Canadian provinces. More than half (37) of these government fishery agencies used one or more established habitat assessment methods. Most (27) of these agencies used one or more methods that we fully reviewed because they were well developed and thoroughly documented. Many (19) state and provincial fishery agencies conducted habitat assessments as a significant management task, but they used ad hoc (developed at the time of need) methods. A minor portion (6) of the agencies reported that they did not conduct habitat assessments.

We contacted national, regional, and special program offices of 19 federal government agencies with fishery and aquatic resource management responsibilities in Canada, Mexico, and the United States. Most (16) of these agencies used one or more established habitat assessment methods, primarily the methods we fully reviewed. The other agencies used ad hoc procedures or had no established habitat assessments methods.

Most (12 of 15) of the private U.S. and international companies contacted conducted habitat assessments. However, all of these organizations reported that they used various methods depending on the involved government agencies and their requests. All of the methods mentioned by contacts as common and established were methods we had already obtained. Therefore, no further information was provided that would add to our evaluations. One exception was the Rosgen Method (Rosgen 1994) by Wildland Hydrology. The Rosgen Method was included as a fully reviewed method because it was an element of several other methods and was a method repeatedly mentioned by agency contacts as important in their work.

Our agency and organization survey clearly indicated that habitat assessment methods were well established in most fishery and environmental management agencies. Consequently, we believed that various approaches and procedures would be involved be cause of the range of organizational aims and operating styles. Also, some agencies used several established methods, indicating internal diversity of habitat assessment practices. After our contact survey, we received a large number of method documents, roughly a 1-m high pile of papers. Of these, we identified 52 method documents for review: 38 for a full level (identified in References for Agency Methods below) and 14 for a more cursory summary.

Of the 38 fully reviewed methods, most (31) targeted habitats in or associated with lotic (running water) systems. However, a significant portion (11) of the methods dealt exclusively with lentic (standing water) systems or these methods assessed all types of inland aquatic habitat. We considered all the methods to be directed at assessment, and almost half (17) specifically addressed monitoring of habitat long-term. More methods were oriented primarily to assessing general aquatic environmental quality (23) than to assessing habitat as part of fishery evaluations and status investigations (15). The reported purpose of the habitat assessment methods varied substantially (summarized in Figure A.1), but the dominant purpose for having an organizational method was to standardize measurement techniques and data. Only two methods aimed to assess instream flow, despite the significance of this fishery management practice. Other common purposes for developing habitat assessment methods were providing support for larger environmental assessment programs, having a tool for quantifying and evaluating habitat, and setting salmonid stocking allocations.

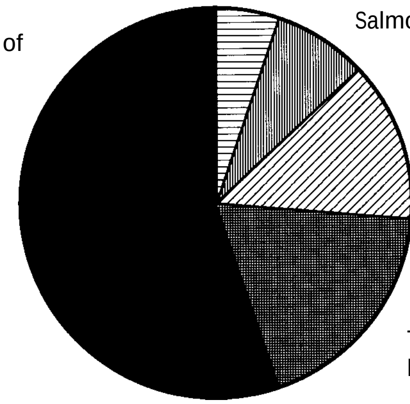


Figure A.1 References for agency methods, depicting the purpose of the 38 aquatic habitat assessment methods reviewed in this study. Statements in the method documentation were used to group the methods into five classes.

The 31 methods aimed at streams and rivers shared many application attributes and limitations. Although most of these methods were developed for the specific jurisdiction of the source agency, most appeared suitable for use throughout much broader geographic scales. In contrast to broad geographic utility, the lotic habitat methods were narrowly focused in terms of habitat applicability. Al most all of the method documents acknowledged the restriction that sampling methods were limited to streams that can be waded. Few methods are truly applicable to large rivers without substantial modification of procedures. Many (10) methods aimed to collect information relevant to all fish species present at an assessment site. Five methods were oriented to the stream community (in the broad sense of multiple taxonomic groups), and eight were aimed at sport fish, largely salmonids. Finally, eight methods had no orientation to a taxonomic group.

The area or site of assessment was highly variable among stream and river habitat methods. Approximately half of the methods varied by application because they depended on site characteristics for identifying sampling area. Six methods specified that study area size (stream length) was to be a multiple of average stream width (10–40 times). This practice is based on the natural frequency of pool and riffle sequences in stream channels. Other methods took an entirely different approach and specified fixed assessment site lengths (40–1,000 m). Consequently, very different approaches are being em ployed to define how much stream or river habitat needs to be measured. Likewise, fundamental differences existed among methods in terms of how study areas should be located. For almost half of the methods, study areas or sites were selected on the basis of being representative. Random siting of study areas was common, but so was ad hoc site selection. Finally, a few methods employed many sites in order to assess habitat at a watershed or regional scale.

The 31 stream habitat assessment methods included a broad range of variables, and many measures differed in minor ways. Some methods were found to make multiple measurements of similar habitat features. The habitat measures were grouped across methods to summarize (Table A.1) the types of data being collected. Physical attributes of stream habitat were heavily emphasized in the 31 methods. All methods included measures of channel size and shape (width, depth, etc.), and almost all methods included water movement (current speed, velocity, discharge, etc.), substrate, cover, and riparian zones (bank and floodplain characteristics). However, stream size (e.g., stream order, drainage area) and watershed attributes (e.g., land use) were often not included, probably because these measures were difficult to obtain without extensive map work. Water quality measurements were included in approximately half the methods (Table A.1) with biological attributes sampled less often. When biological attributes were assessed, fish species composition and relative abundances were most commonly recorded, with macroinvertebrates often included. Fish population estimates were not common, nor were data on fish behaviors (spawning, feeding, etc.) by habitat type.

The 11 methods for assessing lake and reservoir habitats were fairly consistent in capabilities and input measurements. Like the stream methods, most lake habitat methods were intended for the state or province of origin but have broader applicability. The methods were often designed for any type of lake, and we judged most of them to be flexible in application to lentic systems, al though survey respondents generally did not specify the way sampling sites were selected for a lake or reservoir. All or nearly all lake methods included measures of lake shape (morphometry), littoral zone features (aquatic vegetation, substrate), water quality, and fish species presence (Table A.1). Assessment methods often included measurements of shoreline or riparian conditions. This shallow-water and shoreline orientation differs from the traditional limnological orientation to deepwater and mid-lake sampling. For example, just 3 of the 11 methods included pelagic zone measurements. Similarly, zooplankton have been the dominant taxa of interest in traditional lake studies, but plankton data were important in only one method. Most methods incorporated relative or catch-per-unit-effort measures of fish abundance, but population structure and fishery variables were not common. Overall, lake habitat assessment methods appeared more consistent than the highly diverse and more numerous stream habitat methods.

Although a variety of computations, statistical calculations, and models were used in the assessment methods, the most common analysis approaches were simple data summaries and calculations of

Table A.1 Attributes measured in the habitat assessment methods for lotic and lentic waters.

Habitat attribute	Number of methods
Lotic waters	31
Physical structure	
Channel dimensions	31
Substrate	29
Water movement	27
Riparian zone	24
Cover	22
Stream size	15
Watershed attributes	8
Water quality	
Temperature	18
Chemistry	14
Biological attributes	
Fish species numbers	16
Fish abundances	11
Invertebrates	10
Fish population size	8
Fish behaviors	6
Fish habitat use	6
Lentic waters	
Physical structure	
Lake morphometry	11
Littoral habitat	9
Submerged vegetation	9
Substrate	9
Riparian zone	7
Pelagic habitat	3
Water quality	
Chemistry	10
Temperature	10
Biological attributes	
Fish species numbers	10
Fish abundances	9
Fish population structure	5
Fishery status	5
Benthos	3
Zooplankton	1

descriptive statistics (Figure A.2). Computations of habitat indices and ratings were used in many methods, and habitat mapping was an important form of analysis. Statistical and dynamic (e.g., hydraulic) models are prominent features of some well-known habitat analysis methods (e.g., Bovee 1982 [IFIM], Binns 1982 [habitat quality index]), but these kinds of analyses were not often built into habitat methods. Most of the habitat assessment methods do not include specialized tools or aids because sophisticated analyses were not common. The primary data analysis tools were database systems (Figure A.3), with frequent use of custom computer programs, reporting forms, and worksheets. Databases and computer programs for data storage were probably undercounted in our summary be cause some method documents did not address data handling.

Like the measurements and inputs included in the methods, outputs or products of the habitat assessments were highly varied. Outputs were summarized in three groups: numbers and statistics, ratings and indices, and predictions. Numerical summaries and basic descriptive statistics were the most common types of products (Figure A.4) with a focus on habitat attribute values and biota (mostly fish diversity). These reporting numbers reflect data inputs since physical habitat values were most often recorded, and fish species numbers were regularly recorded. Areas by habitat type and statistics on water chemistry were in cluded in some of the method outputs. Composite in dices were commonly reported but mainly for habitat quality, whereas respondents reported few indices of biotic health (community composition) and fish population status (Figure A.4). Predictions were an important habitat assessment output (Figure A.4), with fish resource numbers (stocking units, population potential, relative abundances) far more commonly reported than predictions of habitat units.

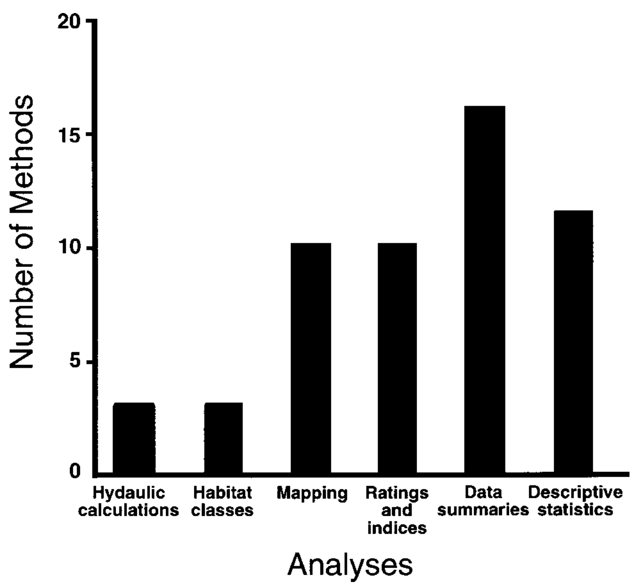


Figure A.2 Approaches used to analyze data collected in the reviewed methods for aquatic habitat assessments.

The reporting format for approximately half of the methods was a database or the enhancement of an existing data base. Identifying the presence, location, or amount of habitat by habitat type or class was employed in reporting results from 16 methods. The practice of reporting on available habitats with a numerical description of their characteristics was used in reporting results from more than half (22) of the methods. Overall, analyses often in volved simple computations and statistics, which were usually presented in computer (database) and quantitative (habitats with descriptors) form.

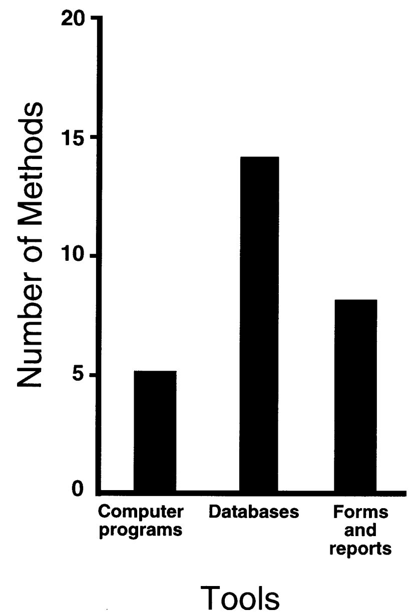


Figure A.3 Tools used to analyze data for the habitat assessment methods.

A.3 Conclusions

Most state, provincial, and federal agencies with fishery management responsibility have been using some type of established method for aquatic habitat assessment. However, a substantial portion (~30%) of the agencies have been relying on ad hoc procedures. The dominant purpose for most methods was to standardize habitat measurements and field sampling techniques. Many of the methods had long lists of habitat attributes that could be measured, and many measurements appeared similar even within single assessment methods. Analysis procedures primarily in volved simple computations and statistics, which were usually conducted using a computer database. Databases also were the dominant format for reporting habitat assessment results. In dices, ratings, and predictions of habitat quality are means of making habitat assessment results concise and easily interpreted, but these assessment outputs were not in widespread use. The general trend in habitat assessment aims, various measurements, generally straightforward analyses, and role of databases suggest that many agencies may have first addressed habitat management on an ad hoc basis and later moved to control a proliferation of measurements and field techniques before finally striving to cope with data storage and re-

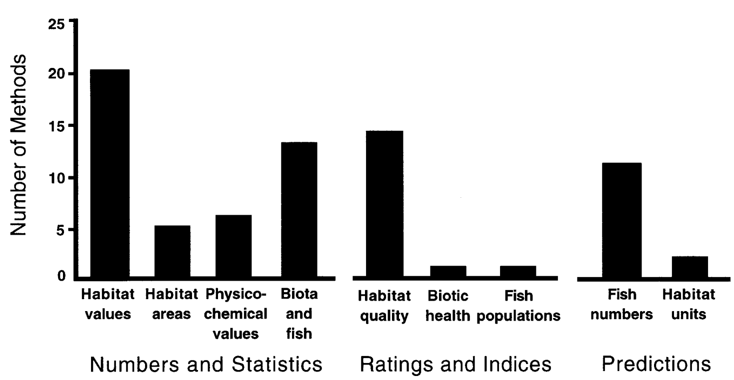


Figure A.4 Types of output information from the aquatic habitat assessment methods that were grouped by major category.

porting. If true, we anticipate that most agencies are in an active period of advancing their efforts, and we should see changes in most methods.

Most fishery biologists probably think of habitat assessment as a stream and river management activity, but we found that one-fourth of the assessment methods were directed at lakes and reservoirs. These lentic habitat methods strongly characterized the littoral zone, shallow-water physical structure, and riparian attributes. Such an orientation contrasts with traditional limnology, which is most often focused on pelagic waters, chemistry, and plankton. For stream habitat assessment, most methods were aimed at physical habitat, but substantial effort also was devoted to water chemistry and the biota. Furthermore, the aims of most stream and lake methods appeared broader than fishery management.

One issue emerged that divided habitat assessment methods into distinct and contrasting groups: sampling design in terms of the size of the area needed and the way study sites should be located. We found specific but inconsistent approaches being used in study design. Determinations of stream site size were being based on principles of geomorphology (e.g., multiples of stream width), field investigator judgment (ad hoc), and past experiences (fixed site sizes). Also, study sites were located on the basis of representativeness, random selection, and investigator judgment. The survey found there were some efforts to expand the scope of habitat assessment by using mul tiple sites for watershed or regional assessment of habitat resources. Because of the sharply contrasting approaches used in study design, this aspect of habitat assessment warrants investigation to provide managers with guidance on tradeoffs associated with the different decisions. Field studies have been reported to identify adequate stream lengths for fish community characterization, but this is just one aspect of the larger study design issue. As agencies seek to report on habitat re sources beyond the site-specific scale, sampling design considerations will become critical in the utility of data now being accumulated.

References

Aadland, L. P. 1993. Stream habitat types: their fish assemblages and relationship to flow. North American Journal of Fisheries Management 13:790–806.

Alexander, R. B., A. S. Ludtke, K. K. Fitzgerald, and T. L. Schertz. 1996. Data from selected U.S. Geological Survey National Stream Water-Quality Monitoring Networks (WQN) on CD-ROM. U.S. Geological Survey, Open-File Report 96-337, Reston, Virginia.

Allan, J. D. 1995. Stream ecology. Chapman and Hall, New York.

Angermeier, P. L., and I. J. Schlosser. 1995. Conserving aquatic biodiversity: beyond species and populations. Pages 402–414 *in* J. L. Nielsen, editor. Evolution and the aquatic ecosystem: defining unique units in population conservation. American Fisheries Society Symposium 17, Bethesda, Maryland.

APHA (American Public Health Association), American Water Works Association, and Water Pollution Control Federation. 1980. Standard methods for the examination of water and wastewater, 15th edition. APHA, Washington DC.

APHA (American Public Health Association), American Water Works Association, and Water Environment Federation. 1998. Standard methods for the examination of water and wastewater, 20th edition. APHA, Washington DC.

Armantrout, N. B. 1990. Aquatic habitat inventory. U.S. Bureau of Land Management, Eugene, Oregon.

Armantrout, N. B. 1996. Alaska Aquatic Resources Information Management System (AARIMS). U.S. Bureau of Land Management, Anchorage, Alaska.

Armantrout, N. B., compiler. 1998. Glossary of aquatic habitat inventory terminology. American Fisheries Society, Bethesda, Maryland.

Atwood, W. W. 1940. The physiographic provinces of North America. Ginn and Company, Boston, Massachusetts.

Auble, G. T., J. M. Friedman, and M. L. Scott. 1994. Relating riparian vegetation to present and future stream flows. Ecological Applications 4:544–554.

Bailey, R. G. 1978. Description of ecoregions of the United States. U.S. Forest Service, Intermountain Region, Ogden, Utah.

Bailey, R. G. 1983. Delineation of ecosystem regions. Environmental Management 7:365–373.

Bailey, R. G. 1995. Descriptions of ecoregions of the United States. U.S. Forest Service, Intermountain Region, Miscellaneous publication number 1391, Ogden, Utah.

Bailey, R. G. 1998. Ecoregions map of North America: explanatory note. U.S. Forest Service, Miscellaneous Publication 1548, Washington, DC.

Bailey, R. G., P. E. Avers, T. King, and W. H. McNab. 1994. Ecoregions and subregions of the United States (map). U.S. Geological Survey, Washington, DC.

Bailey, R. G., and H. C. Hogg. 1986. A world ecoregions map for resource reporting. Environmental Conservation 13:195–202.

Bailey, R. G., R. D. Pfister, and J. A. Henderson. 1978. Nature of land and resource classification—a review. Journal of Forestry 76:650–655.

Bain, M. B., J. T. Finn, and H. E. Booke. 1985. Quantifying stream substrate for habitat analysis studies. North American Journal of Fisheries Management 5:499–500.

Bain, M. B., T. C. Hughes, and K. K. Arend. 1999. Trends in methods for assessing freshwater habitats. Fisheries 24(4):16–21.

Baker, J. A., and S. A. Foster. 1992. Estimating density and abundance of endemic fishes in Hawaiian streams. Hawaii Department of Land and Natural Resources, Honolulu.

Baker, J. R., D. V. Peck, and D. W. Sutton. 1997. Environmental monitoring and assessment program, surface waters field operations manual for lakes. U.S. Environmental Protection Agency, EPA/600/R-97/003, Washington, DC.

Barnes, H. H., Jr. 1967. Roughness characteristics of natural channels. U.S. Geological Survey, Water-Supply Paper 1849, Reston, Virginia.

Baxter, R. M., and P. Glaude. 1980. Environmental effects of dams and impoundments. Canada Department of Fisheries and Oceans, Bulletin 205, Ottawa, Ontario.

Bell, M. 1986. Fisheries handbook of engineering requirements and biological criteria. U.S. Army Corps of Engineers, North Pacific Division, Fish Passage Development and Evaluation Program, Portland, Orgeon.

Bevenger, G. S., and R. M. King. 1995. A pebble count procedure for assessing watershed cumulative effects. U.S. Forest Service Research Paper RM-RP-319, Fort Collins, Colorado.

Binns, N. A. 1982. Habitat quality index procedures manual. Wyoming Game and Fish Department, Laramie, Wyoming.

Bisson, P. A., and D. R. Montgomery. 1996. Valley segments, stream reaches, and channel units. Pages 23–42 *in* R. F. Hauer and G. A. Lambert, editors. Methods in stream ecology. Academic Press, San Diego, California.

Bisson, P. A., J. L. Nielson, R. Palmason, and L. E. Grove. 1982. A system of naming habitat types in small streams, with examples of habitat utilization by salmonids during low stream flow. Pages 62–73 *in* N. B. Armantrout, editor. Acquisition and utilization of aquatic habitat inventory information. American Fisheries Society, Western Division, Bethesda, Maryland.

Bovee, K. D. 1982. A guide to stream habitat analysis using the in stream flow incremental methodology. U.S. Fish and Wildlife Service, FWS/OBS-82/26, Washington, DC.

Busch, W. D. N., and P. G. Sly. 1992. The development of an aquatic habitat classification system for lakes. CRC Press, Boca Raton, Florida.

Carpenter, J., and O. E. Maughan. 1993. Macrohabitat of Sonora chub (*Gila ditaenia*) in Sycamore Creek, Santa Cruz County, Arizona. Journal of Freshwater Ecology 8:265–280.

Chapman, D. W. 1988. Critical review of variables used to define fine sedi-

ment in redds of large salmonids. Transactions of the American Fisheries Society 117:1–21.
Chesser, W. L. 1975. Physiographic map of the earth. Brigham Young University, Provo, Utah.
Cline, L. D., R. A. Short, and J. V. Ward. 1982. The influence of highway construction on the macroinvertebrates and epilithic algae of a high mountain stream. Hydrobiologia 96:149–159.
Coghill, K. 1996. Stream survey protocol for the Tongass National Forest. U.S. Forest Service, Juneau, Alasaka.
Cole, G. A. 1975. Textbook of limnology. C. V. Mosby, St. Louis, Missouri.
Commission for Environmental Cooperation. 1997. Ecological regions of North America: toward a common perspective. Commission for Environmental Cooperation, Montreal, Quebec.
Cowardin, L. M., V. Carter, F. C. Golet, and E. T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. U.S. Fish and Wildlife Service, FWS-OBS-79/31, Washington, DC.
Crisp, D. T. 1990. Simplified methods of estimating daily mean stream water temperature. Freshwater Biology 23:457–462.
Cummins, K. W. 1962. An evaluation of some techniques for the collection and analysis of benthic samples with special emphasis on lotic waters. American Midland Naturalist 67:477–504.
Dana, P. H. 1998. Coordinate systems overview. University of Texas, Department of Geography, Austin.
Daubenmire, R. 1959. A canopy-coverage method of vegetational analysis. Northwest Science 33:43–64.
Dibble, E. D., K. J. Killgore, and S. L. Harrel. 1996. Assessment of fish-plant interactions. Pages 357–372 *in* L. E. Miranda and D. R. DeVries, editors. Multidimensional approaches to reservoir fisheries management. American Fisheries Society Symposium 16, Bethesda, Maryland.
Dodge, D. P., G. A. Goodchild, J. C. Tilt, and D. G. Waldriff. 1981. Manual of instructions: aquatic habitat inventory surveys. Ontario Ministry of Natural Resources, Fisheries Branch, Official Procedures Manual, Toronto.
Dolloff, C. A., D. G. Hankin, and G. H. Reeves. 1993. Basinwide estimation of habitat and fish populations in streams. U.S. Forest Service, Blacksburg, Virginia.
Duff, D., F. Mangum, and R. Maw. 1989. Fisheries habitat surveys handbook. U.S. Forest Service, Intermountain Region, Report FSH 2609.23, Ogden, Utah.
Dunne, T., and L. B. Leopold. 1978. Water in Environmental Planning. W. H. Freeman and Company, New York.
Dupuis, T., D. Guignion, R. MacFarlane, and R. Redmond. 1994. A technical manual for stream improvement on Prince Edward Island. Morell River Management Co-op, Charlottetown, Prince Edward Island, Canada.
Earhart, H. G. 1984. Monitoring total suspended solids by using nephelometry. Environmental Management 8:81–86.
Espegren, G. D. 1996. Development of instream flow recommendations in Colorado using R2CROSS. Colorado Water Conservation Board, Denver.
Everett, R. A., and G. M. Ruiz. 1993. Coarse woody debris as a refuge from predation in aquatic communities. Oecologia 93:475–486.
Fajen, O. F., and R. E. Wehnes. 1982. Missouri's method of evaluating stream habitat. Pages 117–123 *in* N. Armantrout, editor. Acquisition and utilization of aquatic habitat inventory information. American Fisheries Society, Western Division, Bethesda, Maryland.

Federal Interagency Committee on Water Resources. 1961. Notes on hydrologic activities, Bulletin 11: river basin maps showing hydrologic stations. U.S. Government Printing Office, Washington, DC.

Fenneman, N. M. 1931. Physiography of western United States. McGraw-Hill, New York.

Fenneman, N. M. 1938. Physiography of eastern United States. McGraw-Hill, New York.

Filipeck, S., D. J. Ebert, B. K. Wagner, J. A. Clingenpeel, W. M. Bivin, B. G. Cochran, and D. Patton. 1994. The basin area stream survey (BASS) system manual: a guide to evaluating the biological , physical and chemical aspects of streams and rivers. Arkansas Game and Fish Commision and U.S. Forest Service, Research Technical Report, Little Rock, Arkansas.

Fishman, M. J., J. W. Raese, C. N. Gerlitz, and R. A. Husband. 1994. U.S. Geological Survey approved inorganic and organic methods for the analysis of water and fluvial sediment, 1954–94: U.S. Geological Survey, Open-File Report 94-351, Reston, Virginia.

Flosi, G., and F. L. Reynolds. 1994. California salmonid stream habitat restoration manual. California Department of Fish and Game, Technical Report, Sacramento.

Frissell, C. A., W. J. Liss, C. E. Warren, and M. D. Hurley. 1986. A hierarchical framework for stream habitat classification: viewing streams in a watershed context. Environmental Management 10:199–214.

Galay, V. J., R. Kellerhals, and D. I. Bray. 1973. Diversity of river types in Canada. Pages 217–250 *in* Fluvial processes and sedimentation. Proceedings of hydrology symposium. National Research Council of Canada, Ottawa.

Gordon, N. E., T. A. McMahon, and B. L. Finlayson. 1992. Stream hydrology: an introduction for ecologists. John Wiley and Sons, New York.

Gregory, K. J., and D. E. Walling. 1973. Drainage basin form and process, a geomorphological approach. John Wiley and Sons, New York.

Growns, I. O., and J. A. Davis. 1994. Longitudinal changes in near-bed flows and macroinvertebrate communities in a western Australian stream. Journal of the North American Benthological Society 13:417–438.

Gubala, C. P., C. Branch, N. Roundy, and D. Landers. 1994. Automated global positioning system charting of environmental attributes: a limnologic case study. Science of the Total Environment 148:83–92.

Hach Company. 1992. Water analysis handbook. Hach Company, Loveland, Colorado.

Hadley, R. F. and S. A. Schumm. 1961. Sediment sources and drainage basin characteristics in upper Cheyenne River basin. U.S. Geological Survey, Water-Supply Paper 1531-B, Reston, Virginia.

Hagstrom, N. T., W. B. Gerrish, E. A. Machowski, and W. A. Hyatt. 1989. A survey of Connecticut streams and rivers—Farmington River, Park River, and Stony Brook drainages. Annual Performance Report FF-66-R-1, Connecticut Department of Environmental Protection, Hartford.

Hamilton, K., and E. P. Bergersen 1984. Methods to estimate aquatic habitat variables. Colorado State University, Cooperative Fish and Wildlife Research Unit, Fort Collins.

Hankin, D. G., and G. H. Reeves. 1988. Estimation total fish abundance and total habitat area in small streams based on visual estimation methods. Canadian Journal of Fisheries and Aquatic Sciences 45:834–844.

Hansen, P. L., R. D. Pfister, K. Boggs, B. J. Cook, J. Joy, and D. K. Hinckley. 1995. Classification and management of Montana's riparian and wetland sites. University of Montana, Montana Forest and Conservation Experiment Station, Miscellaneous Publication Number 54, Missoula.

Hanson, L. 1998. Physiographic provinces of the United States. Salem State College, Department of Geological Sciences, Salem, Massachusetts.

Harrelson, C. C., C. L. Rawlins, and J. P. Potyondy. 1994. Stream channel reference sites: an illustrated guide to field technique. U.S. Forest Service, Rocky Mountain Forest and Range Experiment Station, General Technical Report RM-245, Fort Collins, Colorado.

Hart, D. D. 1996. Fine-scale field measurements of benthic flow environmental inhabited by stream invertebrates. Limnology and Oceanography 41:297–308.

Harvey, C. A., and D. A. Eash. 1996. Description, instructions, and verification for Basinsoft, a computer program to quantify drainage-basin characteristics. U.S. Geological Survey, Water-Resources Investigations Report 95-4287, Reston, Virginia.

Hawkins, C. P., and 10 coauthors. 1993. A hierarchical approach to classifying stream habitat feature. Fisheries 18(6):3–12.

Hem, J. D. 1970. Study and interpretation of chemical characteristics of natural water. U.S. Geological Survey, Water-supply Paper 1473.

Horton, R. E. 1932. Drainage basin characteristics. Transactions of the American Geophysical Union 13:350–361.

Horton, R. E. 1945. Erosional development of streams and their drainage basins: hydrophysical approach to quantitative morphology. Bulletin of the Geological Society of America 56:275–350.

Hubert, W. A., and E. P. Bergersen. 1998. Define the purpose of habitat analysis and avoid the activity trap. Fisheries 23(5):20–21.

Hughes, R. M., D. P. Larsen, and J. M. Omernik. 1986. Regional reference sites: a method for assessing stream potentials. Environmental Management 10:629–635.

Hughes, R. M., E. Rexstad, and C. E. Bond. 1987. The relationship of aquatic ecoregions, river basins and physiographic provinces to the ichthyogeographic regions of Oregon. Copeia 2:423–432.

Hunt, C. B. 1967. Physiography of the United States. W. H. Freeman, San Francisco, California.

Hunter, C. J. 1991. Better trout habitat. Island Press, Washington, DC.

Hynes, H. B. N. 1975. The stream and its valley. Internationale Vereinigung für theoretische und angewandte Limnologie Verhandlungen 19:1–15.

Inter-agency Committee on Water Resources, Subcommittee on Hydrology. 1961. Notes on hydrologic activities, Bulletin 11 - river basin maps showing hydrologic stations. U.S. Government Printing Office, Washington, DC.

Jensen, M. E., I. Goodman, N. L. Poff, P. Bourgeron, J. R. Maxwell, C. J. Edwards, and D. Cleland. *In Press.* Use of ecological classification and mapping units in the characterization of aquatic systems for ecosystem management. Journal of the American Water Resources Association.

Johnson, J. H., Dropkin, D. S. and Shaffer, P. G. 1992. Habitat use by a headwater stream fish community in north central Pennsylvania. Rivers 3:69–79.

Jowett, I. G., J. Richardson, and R. M. McDowall. 1996. Relative effects of instream habitat and land use on fish distribution and abundance in tributaries of the Grey River, New Zealand. New Zealand Journal of Marine and Freshwater Research 30:463–475.

Kaufmann, P. R. and E. G. Robison. 1995. Physical habitat assessment. Section 6 *in* D. J. Klemm, and J. M. Lazorchak, editors. Environmental monitoring and assessment program. Surface waters: field operations

and methods for measuring the ecological condition of wadeable streams. U.S. Environmental Protection Agency Report 620/R-94/004, Cincinnati, Ohio.
Kershner, J. L., H. L. Forsgren, and W. R. Meehan. 1991. Managing salmonid habitats. Pages 599–606 *in* W. R. Meehan, editor. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society, Special Publication 19, Bethesda, Maryland.
Kinsolving, A. D., and Bain, M. B. 1990. A new approach for measuring cover in fish habitat studies. Journal of Freshwater Ecology 5:373–378.
Kondolf, G. M., and S. Li. 1992. The pebble count technique for quantifying surface bed material size in instream flow studies. Rivers 3:80–87.
Koppen, W. 1931. Grundriss der klimakunde. Walter de Gruyter Company, Berlin, Germany.
Krueger, C. C., and D. J. Decker. 1993. The process of fisheries management. Pages 33–54 *in* C. C. Kohler and W. A. Hubert, editors. Inland fisheries management in North America. American Fisheries Society, Bethesda, Maryland.
Kunkle, H. S., and G. H. Comer. 1971. Estimating suspended sediment concentrations in streams by turbidity measurements. Journal of Soil and Water Conservation 26:18–20.
Lemly, A. D. 1982. Modification of benthic insect communities in polluted streams: combined effects of sedimentation and nutrient enrichment. Hydrobiologia 87:229–245.
Leopold, L. B., M. G. Wolman, and J. P. Miller. 1964. Fluvial processes in geomorphology. W. H. Freeman, San Francisco, California.
Lettenmaier, D. P., E. R. Hooper, C. Wagoner, and K. B. Faris. 1991. Trends in stream quality in the continental United States, 1978–1987. Water Resources Research 27:327–339.
Likens, G. E. and F. H. Bormann. 1974. Linkages between terrestrial and aquatic ecosystems. Bioscience 24:447–456.
Lind, O. T. 1974. Handbook of common methods in limnology. C. V. Mosby, Saint Louis, Missouri.
Lisle, T. E. 1986. Effects of woody debris on anadromous salmonid habitat, Prince of Wales Island, southeast Alaska. North American Journal of Fisheries Management 6:538–550.
Lobeck, A. K. 1948. Physiographic provinces of North America. Hammond Company, Maplewood, New Jersey.
Luckhurst, B. E., and K. Luckhurst. 1978. Analysis of the influence of substrate variables on coral reef fish communities. Marine Biology 49:317–323.
Lyons, J. 1989. Correspondence between the distribution of fish assemblages in Wisconsin streams and Omernik's ecoregions. American Midland Naturalist 122:163–182.
Maine State Planning Office. 1987. The Maine lakes study: a statewide inventory of Maine lakes. Maine State Planning Office, Augusta.
Maloney, T. J., A. S. Ludtke, and T. L. Krizman. 1994. Quality-assurance results for routine water analysis in U.S. Geological Survey laboratories, water year 1991. U.S. Geological Survey, Water-Resources Investigations Report 94-4046, Reston, Virginia.
Maryland State Archives. 1999. Maryland physiography. Maryland State Archives, Annapolis.
Maxwell, J. R., C. J. Edwards, M. E. Jensen, S. J. Paustian, H. Parrott, and D. M. Hill. 1995. A hierarchical framework of aquatic ecological units in North America (Nearctic Zone). U.S. Forest Service, North Central For-

est Experiment Station, General Technical Report NC-176, St. Paul, Minnesota.

McMahon, T. E., A. V. Zale, and D. J. Orth. 1996. Aquatic habitat measurements. Pages 83–120 *in* B. R. Murphy and D. W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Meador, M. R., C. R. Hupp, T. F. Cuffney, and M. E. Gurtz. 1993. Methods for characterizing stream habitat as part of the National Water Quality Assessment Program. U.S. Geological Survey, Open File Rep. 93-408, Raleigh, North Carolina.

Meehan, W. R. 1991. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Special Publication 19, American Fisheries Society, Bethesda, Maryland.

Miller, J. A. 1990. Alabama, Florida, Georgia, and South Carolina: ground water atlas of the United States. U.S. Geological Survey, Hydrologic Investigations Atlas HA-730-G, Reston, Virginia.

Miller, R. R. 1958. Origin and affinities of the freshwater fish fauna of western North America. Pages 187–222 *in* C. L. Hubbs, editor. Zoogeography. American Association for the Advancement Science, Washington, DC.

Minnesota Department of Natural Resources. 1993. Manual of instructions for lake survey. Minnesota Department of Natural Resources, Special Publication No. 147, St. Paul.

Mississippi Department of Wildlife Conservation. 1986. Guidelines for standardized lake and reservoir surveys. Mississippi Department of Wildlife Conservation, Jackson.

Missouri Department of Conservation. Undated. Stream habitat assessment device. Missouri Department of Conservation, Jefferson City.

Modde, T., R. C. Ford, and M. G. Parsons. 1991. Use of a habitat-based stream classification system for categorizing trout biomass. North American Journal of Fisheries Management 11:305–311.

Montgomery, D. R., and J. M. Buffington. 1983. Channel classification, prediction of channel response, and assessment of channel condition. University of Washington, Department of Geological Sciences and Quaternary Research Center, Report FW-SH10-93-002, Seattle.

Moore, K., K. Jones, and J. Dambacher. 1995. Methods for stream habitat surveys, version 5.1. Oregon Department of Fish and Wildlife, Corvallis.

Myers, L. H. 1989. Riparian area management: inventory and monitoring of riparian areas. U.S. Bureau of Land Management, Technical Report 1737-3, Washington, DC.

Naiman, R. J., D. G. Lonzarich, T. J. Beechie, and S. C. Ralph. 1992. General principles of classification and the assessment of conservation potential in rivers. *In* P. J. Boon, P. Calow, and G. E. Petts, editors. River Conservation and Management. John Wiley and Sons, London.

National Environmental Information Service. 1997. Index to U.S. EPA test methods. Baton Rouge, Louisiana.

National Wildlife Federation. 1995. Conservation directory. 40th edition. Washington, DC.

Natural Resources of Canada. 1999. Geodetic survey - software and related data products online demonstration. Natural Resources Canada, Geodetic Survey Division, Information Services Unit Geodetic Survey, Ottawa, Ontario.

New Brunswick Department of Natural Resources and Energy. Undated. Fishlake system. Department of Natural Resources, Fredericton, New Brunswick.

Newbury, R. W., and M. N. Gaboury. 1994. Stream analysis and fish habitat design, a field manual. Newbury Hydraulics Ltd., The Manitoba Habitat Heritage Corporation, Gibsons, British Columbia.

Olcott, P. G. 1995. Connecticut, Maine, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont: Ground water atlas of the United States. U.S. Geological Survey, Hydrologic Investigations Atlas HA-730-M, Reston, Virginia.

Omernik, J. M. 1987. Aquatic ecoregions of the conterminous United States. Annals of the Association of American Geographers 77:118–125.

Omernik, J. M., and R. G. Bailey. 1997. Distinguishing between watersheds and ecoregions. Journal of the American Water Resources Association. 33: 935–949.

Omernik, J. M., and G. E. Griffith. 1991. Ecological regions verses hydrological units: frameworks for managing water quality. Journal of Soil and Water Conservation 46:334–340.

O'Neill, M. P., and A. D. Abrahams. 1987. Objective identification of pools and riffles. Water Resources Research 20:921–926.

Oregon Department of Fish and Wildlife. 1992. Quantitative reservoir habitat surveys 1992, aquatic inventory project. Oregon Department of Fish and Wildlife, Portland.

Orth, D. J. 1983. Aquatic habitat measurements. Pages 61–84 *in* L. A. Nielsen and D. L. Johnson, editors. Fisheries techniques. American Fisheries Society, Bethesda.

Petts, G. E. 1984. Impounded rivers. John Wiley & Sons, New York.

Pfankuch, D. J. 1975. Stream reach inventory and channel stability evaluation. U.S. Forest Service, Publication Ri-75-002, Missoula, Montana.

Pflieger, W. L. 1971. A distributional study of Missouri fishes. University of Kansas Publication, Museum of National History 20:225–570.

Pflieger, W. C. 1975. Fishes of Missouri. Missouri Department of Conservation, Jefferson City.

Plafkin, J. L., M. T. Barbour, K. D. Porter, S. K. Gross, and R. M. Hughes. 1989. Rapid bioassessment protocols for use in streams and rivers. U.S. Environmental Protection Agency, EPA/440/4-89-001, Washington, DC.

Platts, W. S., C. Armour, G. D. Booth, M. Bryant, J. L. Bufford, P. Cuplin, S. Jensen, G. W. Lienkaeemper, G. W. Minshall, S. B. Monsen, R. L. Nelson, J. R. Sedell, and J. S. Tuhy. 1987. Methods for evaluating riparian habitats with applications to management. U.S. Forest Service, General Technical Report INT-221, Ogden, Utah.

Platts, W. S., W. F. Megahan, and G. W. Minshall. 1983. Methods for evaluating stream, riparian, and biotic conditions. U.S. Forest Service, Intermountain Forest and Range Experiment Station, General Technical Report INT-138, Ogden, Utah.

Poole, G. C., C. A. Frissell, and S. C. Ralph. 1997. In-stream habitat unit classification: inadequacies for monitoring and some consequences for management. Water Resources Bulletin 33:879–896.

Potyondy, J. P., and T. Hardy. 1994. Use of pebble counts to evaluate fine sediment increase in stream channels. Water Resources Bulletin 30:509–520.

Powell, J. W. 1896. Physiographic regions of the United States. Pages 1–100 *in* National Geographic Society. The physiography of the United States; ten monographs. American Book Company, New York.

Pritt, J. W., and J. W. Raese. 1992. Quality assurance/quality control manual, National Water Quality Laboratory. U.S. Geological Survey, Open-File Report 92-495, Reston, Virginia.

Rankin, E. T. 1989. The qualitative habitat evaluation index [QHEI]: rationale, methods, and application. Ohio Environmental Protection Agency, Columbus.

Reiser, D. W. and R. T. Peacock. 1985. A technique for assessing upstream fish passage problems at small-scale hydropower developments. Pages 423–432 *in* F. W. Olson, R. G. White, and R. H. Hamre, editors. Symposium on small hydropower and fisheries. American Fisheries Society, Western Division, Bethesda, Maryland.

Rohm, C. M., J. W. Geise, and C. C. Bennett. 1987. Evaluation of an aquatic ecoregion classification of streams in Arkansas. Journal of Freshwater Ecology 4:127–140.

Roper, B. B., and D. L. Scarnecchia. 1995. Observer variability in classifying habitat types in stream surveys. North American Journal of Fisheries Management 15:49–53.

Rosgen, D. L. 1994. A classification of natural rivers. Catena 22:169–199.

Rosgen, D. L. 1996. Applied river morphology. Wildland Hydrology, Pagosa Springs, Colorado.

Seaber, P. R., F. P. Kapinos, and G. L. Knapp. 1994. Hydrologic unit maps. U.S. Geological Survey, Water-Supply Paper 2294, Denver, Colorado.

Scruton, D. A., T. C. Anderson, C. E. Bourgeois, and J. P. O'Brien. 1992. Small stream surveys for public-sponsored habitat improvement and enhancement projects. Canadian Report of Fisheries and Aquatic Sciences No. 2163.

Shreve, R. L. 1967. Infinite topologically random channel networks. Journal of Geology 75:178–186.

Simonson, T. D., J. Lyons, and P. D. Kanehl. 1993. Guidelines for evaluating fish habitat in Wisconsin streams. U.S. Forest Service, North Central Forest Experiment Station, General Technical Report NC-164, St. Paul, Minnesota.

Simonson, T. D., J. Lyons, and P. D. Kanehl. 1994. Quantifying fish habitat in streams: transect spacing, sample size, and a proposed framework. North American Journal of Fisheries Management 14:607–615.

Smith, R. A., R. B. Alexander, and K. J. Lanfear. 1993. Stream water quality in the conterminous United States — status and trends of selected indicators during the 1980's. U.S. Geological Survey, Water Supply Paper 2400, Reston, Virginia.

Smith, R. A., R. B. Alexander, and M. G. Wolman. 1987. Water-quality trends in the nation's rivers. Science 235:1607–1615.

Stalnaker, C., B. L. Lamb, J. Henriksen, K. Bovee, and J. Bartholow. 1995. The instream flow incremental methodology: a primer for IFIM. U.S. National Biological Service, Biological Report 29, Washington, DC.

Sternberg, R. B. 1978. Minnesota stream survey manual. Minnesota Department of Natural Resources, Special Publication 120, St. Paul.

Strahler, A. N. 1964. Quantitative geomorphology of drainage basins and channel networks. Pages 39–76 *in* V. T. Chow, editor. Handbook of applied hydrology, McGraw-Hill, New York.

Swanson, S., R. Miles, S. Leonard, and K. Genz. 1988. Classifying rangeland riparian areas; the Nevada task force approach. Journal of Soil and Water Conservation 43:259–263.

Tabor, R. A., and W. A. Wurtsbaugh. 1991. Predation risk and the importance of cover for juvenile rainbow trout in lentic systems. Transactions of the American Fisheries Society 120:728–738.

Tebo, L. B. 1955. Effects of siltation, resulting from improper logging, on the bottom fauna of a small trout stream in the southern Appalachians. The Progressive Fish-Culturist 17:64–70.

Texas Bureau of Economic Geology. 1998. The physiography of Texas. Texas Geological Survey, University of Texas, Austin.

Trautman, M. B. 1981. The fishes of Ohio. Ohio State University Press, Columbus.

Trewartha, G. T. 1968. An introduction to weather and climate. McGraw-Hill, New York.

University of Montana. 1999. Idaho hydrologic unit codes. University of Montana, School of Forestry, Riparian and Wetland Research Program, Missoula, Montana.

U.S. Department of Agriculture. 1963. Atlas of river basins of the United States. Soil Conservation Service, Washington, DC.

U.S. Department of Agriculture. 1970. Atlas of river basins of the United States. Soil Conservation Service, Washington, DC.

U.S. Environmental Protection Agency. 1976. Quality criteria for water. U.S. Environmental Protection Agency, Washington, DC.

U.S. Environmental Protection Agency. 1982. Handbook for sampling and sample preservation of water and wastewater. U.S. Environmental Protection Agency, EPA-600/4-82-029, Washington, DC.

U.S. Environmental Protection Agency. 1983. Methods for chemical analysis of water and wastes. U.S. Environmental Protection Agency, Washington, DC.

U.S. Environmental Protection Agency. 1986. Quality criteria for water 1986. U.S. Environmental Protection Agency, Office of Water Regulations and Standards, EPA 440/5-86-001, Washington, DC.

U.S. Environmental Protection Agency. 1994. USEPA Reach File Version 3.0, Alpha release (RF3-Alpha) technical reference. U.S. Environmental Protection Agency, Office of Wetlands, Oceans and Watersheds, Washington, DC.

U.S. Environmental Protection Agency. 1996. Level III ecoregions of the continental United States. U.S. Environmental Protection Agency, Office of Information Resources Management, Washington, D.C.

U.S. Environmental Protection Agency. 1997. The quality of our Nation's water: 1994. U.S. Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds, Washington, DC.

U.S. Fish and Wildlife Service. 1980. Habitat evaluation procedures (HEP). U.S. Fish and Wildlife Service, Ecological Services Manual 102, Washington, DC.

U.S. Geological Survey. 1973. Catalog of information on water data, 1972 edition. U.S. Geological Survey, Office of Water Data Coordination, Reston, Virginia.

U.S. Geological Survey. 1982. Chemical and physical quality of water and sediment. Chapter 5 *in* National handbook of recommended methods for water-data acquistion. U.S. Geological Survey, Office of Water Data Coordination, Reston, Virginia.

U.S. Geological Survey. 1997. Omernik ecoregions data. U.S. Geological Survey, EROS Data Center, Sioux Falls, South Dakota.

U.S. Geological Survey. 1998. Physiographic divisions. U.S. Geological Survey, Water Resources Division, Portland, Oregon.

U.S. Geological Survey. 1999a. Geographic names information system. U.S. Geological Survey, Reston, Virginia.

U.S. Geological Survey. 1999b. Physical divisions of the central region. U.S. Geological Survey, Biological Resources Division, Central Regional Office, Denver, Colorado.

U.S. National Bureau of Standards. 1983. Codes for the identification of hydrologic units in the Unites States and the Caribbean outlying areas. U.S. Department of Commerce, Federal Information Processing Standards Publication 103, Washington, DC.

U.S. Water Resources Council. 1970. Water resources regions and subregions for the national assessment of water and related land resources. U.S. Department of the Interior, Washington, DC.

Wahl, K. L., W. O. Thomas, Jr., and R. M. Hirsch. 1995. Stream-gaging program of the U.S. Geological Survey. U.S. Geological Survey, Circular 1123, Reston, Virginia.

Ward, J. V., and J. A. Stanford. 1979. The ecology of regulated streams. Plenum. New York.

Warren, C. E. 1979. Toward classification and rationale for watershed management and stream protection. U.S. Environmental Protection Agency, EPA/600/3-79/059, Corvallis, Oregon.

Waters, T. F. 1995. Sediment in Streams. American Fisheries Society, Monograph 7, Bethesda, Maryland.

Wentworth, C. K. 1922. A scale of grade and class for elastic sediments. Journal of Geology 30:377–392.

Wetzel, R. G., and G. E. Likens. 1990. Limnological analyses. Springer-Verlag, New York.

Whittier, T. R., R. M. Hughes, and D. P. Larsen. 1988. Correspondence between ecoregions and spatial patterns in stream ecosystems in Oregon. Canadian Journal of Fisheries and Aquatic Sciences 45:1264–1278.

Wiken, E. 1986. Terrestrial ecozones of Canada. Environment Canada, Ecological Land Classification Series Number 19, Hull, Quebec.

Williams, G. P. and M. G. Wolman. 1984. Downstream effects of dams on alluvial rivers. U.S. Geological Survey, Professional Paper 1286, Reston, Virginia.

Willis, D. W., and B. R. Murphy. 1996. Planning for sampling. Pages 1–15 *in* B. R. Murphy and D. W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

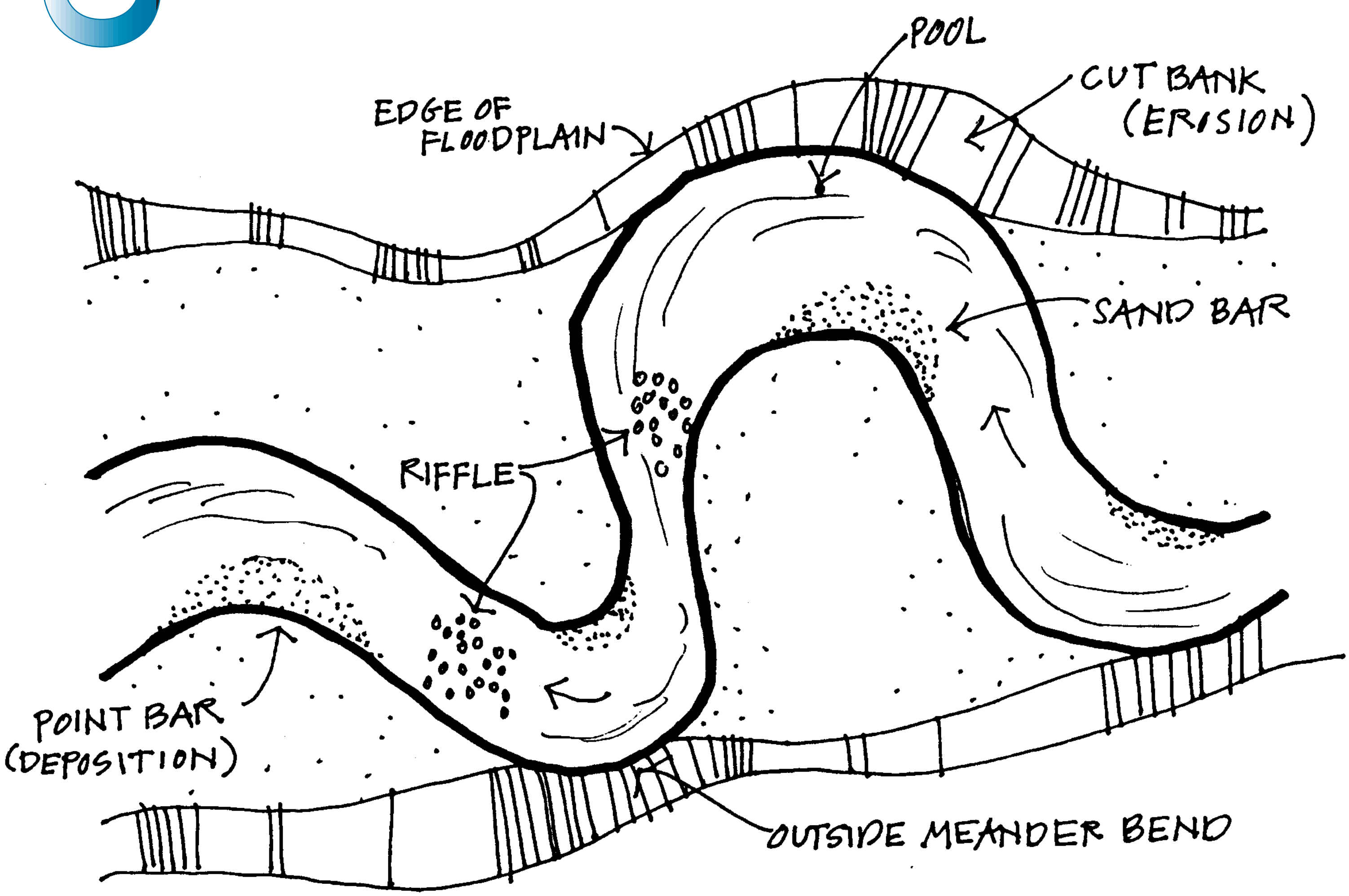
Winger, P. V. 1981. Physical and chemical characteristics of warmwater streams: a review. Pages 32–44 *in* L. A. Krumholz, editor. The warmwater streams symposium, American Fisheries Society, Southern Division, Bethesda, Maryland.

Wolman, M. G. 1954. A method of sampling coarse river-bed material. Transactions of the American Geophysical Union 35:951–956.

Vermont Fish and Wildlife Department. 1988. Winhall River tributaries Atlantic salmon habitat survey, Appendix I: stream survey methodology. Vermont Fish and Wildlife Department, Job Performance Report, Project No. F-12-R-21, Montpelier.

Glossary

Aquatic Habitat Inventory Terminology



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Glossary

of Aquatic Habitat Inventory Terminology

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This glossary is dedicated

to the memory of

Dr. William T. Helm.

Contents

Preface

An aquatic system is dependent upon the hydrological cycle that provides the water supply for the system through the amount, timing, and pattern of precipitation. Water from precipitation moves as surface or groundwater by gravity until it eventually reaches the ocean or enters the atmosphere as water vapor through evaporation or transpiration by plants. Condensation of water vapor at high altitudes results in precipitation and the hydrology cycle repeats itself.

The pattern of water movement on or under the surface of the earth is largely determined by the geomorphology where the porosity and permeability of substrates determine the flow of surface water as well as the infiltration and flow rate of groundwater. Surface patterns of standing and flowing water develop in response to landscape features that, in turn, help to form those features through erosion and deposition. Water, as surface or groundwater, governs the type and extent of vegetative cover in an area that results in a variety of aquatic and terrestrial habitats. Vegetation modifies the movement and erosive power of water that alters landscape features.

The interaction of climate, geomorphology, and vegetation produces a variety of aquatic features, ranging from rivers and lakes to wetlands and springs. The surface features do not exist as separate entities, but represent the most visible features of the much more extensive integrated aquatic system. Our attention is given most often to the largest, most visible features of an aquatic system although they may represent only a small fraction of the overall system.

Recently, humans have played an increasing role in the distribution and uses of water that have altered most major aquatic ecosystems on earth. Changes to both surface and subsurface aquatic systems have altered the natural hydrologic processes, landscape features, and even climate. Often humans fail to consider the interactions of the entire hydrologic cycle, climate, geomorphology, and vegetation, as well as the impacts on various habitats and organisms that use such habitats.

Background and Coverage

Existing aquatic and terrestrial systems are the result of dynamic interactions between water, climate, geology, vegetation, and human influences with time. Aquatic systems occur in a variety of types that range from flowing systems (e.g., rivers and streams) to standing water (e.g., wetlands, marshes, ponds, lakes, and reservoirs). Although influenced by various factors, aquatic systems exhibit consistent patterns so that they can be described and classified.

With growing demands for the multiple-use of aquatic resources, the importance of aquatic resource inventories and knowledge of the complex interactions of hydrology, hydraulics, and geomorphology is extremely important to understanding the overall effect of biological, chemical, and physical factors on an entire ecosystem.

While hydrologic processes and aquatic habitats exhibit consistent patterns, terminology and methods for aquatic habitat inventories vary among organizations, agencies, and disciplines. The resulting confusion and misunderstanding limit exchange and comparison of data. Researchers and managers are hindered from sharing data because terminology and methods are not standardized. With the rapid development of computer programs, the need for standardization of inventory systems has grown in concert with increased opportunities for data analysis at the local and landscape scale.

Realizing the need for standardization, the American Fisheries Society developed this glossary of aquatic habitat terminology.

Under the chair of Dr. William Helm, the Western Division of the American Fisheries Society prepared the first draft of a "Stream Inventory Glossary" which was based on terminology from the Western United States and Canada. It was then expanded to cover flowing, standing, and groundwater terminology used throughout North America. Some terms and definitions that are used in other countries and are frequently found in the literature were added for completeness.

This glossary has been developed to encourage consistent and standard use of the terms used by workers who conduct inventories and analyses of aquatic habitats. Standardization of terms and definitions provides a common language for habitat work and ensures the applicability and accuracy of inventory methods.

This document was prepared with a broad perspective on aquatic habitat terminology. Because of the interactive and integrative nature of aquatic systems with the landscape, many terms from the disciplines of meteorology, hydrology, hydraulics, and geomorphology have been included. Inventory and analysis of aquatic ecosystems have evolved from a localized approach to a watershed or landscape perspective and so are intertwined with ecology, meteorology, hydrology, hydraulics, and geology.

Some terms used by different professions and in different geographic regions have developed more than one definition. Where there are differences in meaning between the biological and physical science definitions, both definitions are provided for clarification. A conscious decision was made not to include all terms and definitions that are applicable to vegetation, ecology, physiology, soils, and fish sampling, but to include terms that are often used in inventories of aquatic habitats.

This glossary is part of a larger effort of the American Fisheries Society to produce a manual of standard methods for conducting aquatic habitat inventories and assessments. For this reason, many terms in this glossary do not provide details on how the information related to these terms is collected or used since those details will be described in detail in the techniques manual.

Balon's (1982) concerns about committees and nomenclature were carefully considered in the compilation of this glossary. Balon questioned the use of committees in standardizing nomenclature when he stated: "How much useful contribution, for example, can be expected from committees on 'standardization of nomenclature'? Nearly in all cases I know about, conclusions reached in such committees ratify parochial dogmas, many disproved [a] long time ago, rather than contribute to knowledge. Consequently, by false restriction of choices they retard future contributions." He concluded by stating, "It is not the nomenclature that matters but the clear definitions of the contents given to terms, a truism most frequently misunderstood."

Although this glossary is intended to standardize definitions of terms that are applicable to aquatic systems, no restrictions apply to the evolution and development of new terms that better describe such systems. American Fisheries Society members also intend to apply adaptive management to this glossary where, periodically, the terms in the glossary will be reviewed and refined, or updated, with the best information available at that time.

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The present glossary of terms and definitions used in conducting inventories of aquatic habitats is the cumulative effort of all persons who provided editorial comments for clarity and consistency and who helped to integrate terms and definitions from various sources listed in the reference section. Appreciation is extended to Mike Aceitano, John Anderson, Richard O. Anderson, Carl Armour, John Bartholow, Ken Bates, David H. Bennett, Joseph Bergen, Eric Bergersen, Ray Biette, N. Allen Binns, Peter Bisson, Michael Bozek, Richard E. Bruesewitz, C. Fred Bryan, Mason Bryant, John W. Burris, Dieter N. Busch, Jean Caldwell, Tom Chamberlin, James Chambers, Chris Clancy, Don Cloutman, Bruce Crawford, David Cross, Peter Delaney, Don Duff, Mark P. Ebener, Russell H. England, David Etnier, Otto Fajen, C. Michael Falter, David Fuller, Barb Garcia, Ronald Garvaelli, Leonard J. Gerardi, Gareth A. Goodchild, Robert S. Gregory, Bob Griffith, Steve Gutreuter, James Hall, Jim Henriksen, George Holton, Wayne Hubert, Mark Hudy, Philip J. Hulbert, Leroy J. Husak, Jack Imhof, Don Jackson, Alan Johnson, Gary B. Kappesser, John Kauffman, Jeff Kershner, John F. Kocik, Tom Lambert, Bill Layher, Steve Leonard, Gerald E. Lewis, Ron Lewis, John Lyons, Mike Maceina, O. Eugene Maughan, Daniel B. McKinley, Michael R. Meador, Keiteh Meals, Larry Mohn, Samuel C. Mozley, Donald Orth, Lewis L. Osborne, Vaugh L. Paragamian, Ron Ptolemy, Mike Purser, Charles F. Rabeni, Ron Remmick, John Rinne, Robert M. Ross, Gordon W. Russell, Robert N. Schmal, Monte E. Seehorn, Paul Seelbach, Mark Shaw, Brian Shuter, E. G. Silas, Dennis Smith, G. D. Taylor, William Thorn, Dennis Tol, Bill Turner, Harold H. Tyus, Richard A. Valdez, Bruce R. Ward, J. C. Wightman, and Richard S. Wydoski. In addition to these individuals, a number of anonymous contributors and reviewers assisted in the compilation and editing of this glossary.

Final editing, design, and production was handled by Beth Staehle, Robert Rand, and Janet Harry in the American Fisheries Society Editorial Office.

Symbols and Abbreviations

The following symbols and abbreviations may be found in this book without definition. Also undefined are standard mathematical and statistical symbols given in most dictionaries.

°C	degrees Celsius
cm	centimeter
d	day
dL	deciliter
E	east
e	base of natural logarithm (2.71828…)
e.g.	(exempli gratia) for example
et al.	(et alii) and others
etc.	et cetera
°F	degrees Fahrenheit
ft	foot (30.5 cm)
ft^3/s	cubic feet per second (0.0283 m^3/s)
g	gram
gal	gallon (3.79 L)
h	hour
ha	hectare (2.47 acres)
in	inch (2.54 cm)
i.e.	(id est) that is
k	kilo (10^3, as a prefix)
kg	kilogram
km	kilometer
L	liter (0.264 gal, 1.06 qt)
lb	pound (0.454 kg, 454g)
lm	lumen
log	logarithm
m	meter (as a suffix or by itself); milli (10^{-3}, as a prefix)
mi	mile (1.61 km)
min	minute
N	normal (for chemistry); north (for geography); newton
N	sample size
oz	ounce (28.4 g)
P	probability
pH	negative log of hydrogen ion activity
ppm	parts per million
qt	quart (0.946 L)
S	siemens (for electrical conductance); south (for geography)
s	second
U.S.	United States (adjective)
USA	United States of America (noun)
W	watt (for power); west (for geography)
yd	yard (0.914 m, 91.4 cm)
µ	micro (10^{-6}, as a prefix)
°	degree (temperature as a prefix, angular as a suffix)
%	per cent (per hundred)
‰	per mille (per thousand)

Terms and Definitions

a

abandoned meander channel See *abandoned meander channel* under *channel pattern*.

abiogenic Not derived from living organisms.

abioseston Nonliving components of the seston. See *seston* and *tripton*.

abiotic Nonliving components in the environment.

ablation (1) Wearing away of the surface of rocks or of glaciers by the kinetic energy of running or dropping water. (2) All the processes, such as melting or evaporation, by which ice or snow becomes transformed into water or water vapor.

ablation moraine See *ablation moraine* under *moraine*.

ablation till The coarse material that accumulates on top of a melting glacier.

ablation zone Lower part of a glacier where annual water loss exceeds snow accumulation.

absorption The selective uptake of fluids or substances that are in solution. Absorption may occur in organic matter or by cells in living organisms.

abstraction (1) Permanent removal of surface flow from a stream channel. (2) Shifting of a stream from one basin to another.

abutment The two support ends of a bridge that connect it to the adjoining land mass or road fill.

abyssal depth (1) Maximum depth of a lake or sea. (2) Great depth in oceans or lakes where light does not penetrate. Generally applied to the marine environment.

abyssal zone The bottom stratum of water. Generally applied to the marine environment.

accelerated erosion See *accelerated erosion* under *erosion*.

acclimatize (1) To adapt to a new temperature, altitude, climate, environment, or situation. (2) To become habituated to an environment where a plant or animal species is not native.

accretion (1) Gradual accumulation of flow from seepage of water. (2) The accumulation of sand, silt, and gravel in a stream channel. (3) Process, driven by tectonics, whereby the continental margin grows by addition of ocean crust and sediment at a subduction zone.

accumulation zone Part of a glacier where snow accumulation exceeds melting and evaporation.

acid drainage Runoff water with a pH less than 7.0, with total acidity exceeding total alkalinity, often associated with discharge from mining or reclamation operations.

acidic deposition The process by which acids are deposited into the environment through rain, sleet, or snow, when the pH of the precipitation is less than 7.0.

acidification An increase in the acidity of an ecosystem, caused by natural processes or acid deposition.

acidity (1) Quantitative capacity to neutralize a base to a designated pH. (2) A measure of hydrogen ion concentration, with a pH less than 7.0. See *pH*.

acid rain In general, rain having a pH of less than 7.0 can be considered acidic. Acid rain, as used in the literature, has a pH that is low enough (e.g., 5.6) to potentially threaten the life or well-being of vegetation or aquatic systems. See *pH*.

acquic moisture regime A seasonal moisture condition in soil that is virtually free of dissolved oxygen because the soil is saturated by ground-water or by water of the capillary fringe.

acre-foot See *acre-foot* under *dimensions*.

active channel (1) Short-term geomorphic feature, defined by the bank break, that marks a change to permanent vegetation. (2) The portion of a channel in which flows occur frequently enough to keep vegetation from becoming established. An active channel is formed and maintained by normal water and sediment processes.

active erosion See *erosion*.

active slope Slope of a hill or mountain, typically exceeding 45%, where detrital materials accumulate behind obstructions from valley incision processes.

active valley wall processes All currently active processes causing the movement of materials on valley walls or relic terraces, even if they do not reach the stream channel.

bench processes Processes that extend onto a bench or terrace but do not reach the active floodplain or valley flat.

floodplain processes Processes that extend out onto the floodplain or flat valley.

mountain processes Processes restricted to mountainsides without a connection to the valley bottom.

active water table Condition in which the soil saturation zone fluctuates and results in periodic anaerobic soil conditions.

actual shoreline Line formed by the water interface wherever it covers the bed of a body of water at the mean high water level.

acute meander See *acute meander* under *meander*.

adaptation Ability of an organism to adjust to changes in environmental conditions including biological, chemical, and physical factors.

adfluvial (1) Life history strategy in which adult fish spawn and juveniles subsequently rear in streams but migrate to lakes for feeding as subadults and adults. (2) Pertaining to flowing water. (3) Movement toward a river or stream. See *fluvial*.

adjacent See *adjacent* under *wetlands*.

adsorbed water Water that condenses or accumulates on a surface.

adsorption Adhesion of an extremely thin layer of gas molecules, dissolved substances, or liquids to a solid surface that they contact.

aeolian lake See *aeolian lake* under *lake*.

aerated pond or lagoon See *aerated pond or lagoon* under *pond*.

aeration To enhance the oxygen concentration of water.

aerial photography See *aerial photography* under *remote sensing*.

aerobic (1) Zone in a body of water where free oxygen is present. (2) Life processes occurring only in the presence of molecular oxygen.

aestival lake See *aestival lake* under *lake*.

aestival pond See *aestival pond* under *pond*.

affluent Water flowing to a standing water body.

aggradation Geologic process in which inorganic materials carried downstream are deposited in streambeds, floodplains, and other water bodies resulting in a rise in elevation in the bottom of the water body. Compare with *degradation*.

aggraded channel See *aggraded channel* under *channel geometry*.

aggregate Granular mineral materials such as sand and gravel. See also *aggregate* under *large organic debris*.

aggregate stability Erodibility of soil in terms of its tendency to separate when wetted.

a-jacks See *a-jacks* under *habitat enhancements*.

albedo Reflecting power of a surface, expressed as the reflected fraction of the radiation incident at the surface.

alcove See *alcove* under *slow water, pool, scour pool* under the main heading *channel unit*.

algal bloom Proliferation of one or several species of phytoplankton to high cell densities during favorable environmental conditions.

algal wash Shoreline drift composed mainly of filamentous algae.

alkali A substance which neutralizes an acid, usually a base such as metallic hydroxide.

alkali lake See *alkali lake* under *lake*.

alkaline In general, any water or soil with a pH greater than 7.0. More commonly used for a pH greater than 7.4 that promotes accumulation of salts and affects the physiology of plants and animals. See *pH*.

alkalinity Acid-neutralizing capacity of water usually due to carbonates, bicarbonates, and hydroxides; expressed as mg/L of $CaCO_3$.

allochthonous Exogenous food organisms, organic matter, and nutrients originating outside and transported into an aquatic system.

allogenic Refers to origination that is external to a system.

alluvial Related to material deposited by running water.

alluvial cone Material carried by ephemeral streams from higher elevations and accumulating at the mouth of a gorge as a moderately steep conical formation that slopes equally in all directions.

alluvial dam A dam formed by the accumulation of sediment that blocks the channel of a stream.

alluvial deposit Clay, silt, sand, gravel, or other sediment carried by flowing waters and deposited when the water velocity drops below that required to keep the material in suspension or move the bed load. Synonymous with *alluvial fill*.

alluvial fan Fan-shaped area of deposits of sediments formed by a stream where it exits a valley onto a floodplain and results from an abrupt decrease in water velocity.

alluvial fill Alluvial material that accumulates as a result of a reduction in water velocity, thereby allowing the alluvial material to settle. Synonymous with *alluvial deposit*.

alluvial flat (1) An alluvial valley and the relatively low-gradient stream reaches associated with it. (2) Term used to refer to an isolated alluvial valley that is bound upstream and downstream by steeper-gradient canyon stream segments.

alluvial plain An expanse of land formed, at least in part, by deposited materials through which an alluvial stream meanders. Usually applied to the gentle slope in a coastal plain.

alluvial soil A soil consisting of recently deposited sediment and showing no horizon development or other modification of the deposited material.

alluvial stream Named after the silts, clays, sands, and gravels of river origin that compose the bed, banks, and floodplains of streams. Alluvial streams tend to be large, composed of bed materials conveyed from upstream, and are characterized by a distinctive S-shaped channel pattern that is free to shift slowly (i.e., meander) in the valley. See also *alluvial stream* under *stream*.

alluvial terrace A relatively level plain or step that is formed by the deposition of alluvial sediments in floodplains when water velocities are reduced as the river subsides from a high flow event.

alluvial valley A valley form which resulted from deposition of relatively large stores of alluvium by fluvial erosion processes.

alluvial valley floor Unconsolidated stream-laid deposits forming the valley floor.

alluvion A gradual increase of land on a shore or streambank by the action of water, from natural or artificial causes.

alluvium A general term for all deposits resulting, directly or indirectly, from the sediment transport of streams that is deposited in streambeds, floodplains, lakes, and estuaries. See also *alluvium* under *valley segments*.

alpha-mesosaprobic zone See *alpha-mesosaprobic zone* under *saprobien system*.

alternate bar See *alternate bar* under *bar*.

ambient General conditions in the environment.

amictic See *amictic* under *mixing*.

amplitude See *amplitude* under *meander*.

anadromous A life history strategy of fishes, that includes migration between fresh- and saltwater, in which reproduction and egg deposition occurs in freshwater while rearing to the adult stage occurs in the ocean. Compare with *catadromous*, *diadromous*, *oceanadromous*, *potamodromous*.

anaerobe An organism that lives where free oxygen is absent.

anaerobic (1) Environmental conditions where free oxygen is absent. (2) Life processes that occur in the absence of molecular oxygen.

analytical watershed Term applied to a drainage basin for analyzing cumulative impacts on natural resources.

anastomizing channel See *anastomizing channel* under *channel pattern*.

anchialine pool See *anchialine pool* under *pond*.

anchor ice Ice formed on substrate or objects beneath fresh- or saltwater surfaces when the water becomes supercooled.

angle of repose Maximum slope or angle at which a material will remain stable without sliding or slumping.

annual maximum daily discharge See *annual maximum daily discharge* under *discharge*.

annual maximum instanteous discharge See *annual maximum instanteous discharge* under *discharge*.

annual mean discharge See *annual mean discharge* under *discharge*.

annual minimum daily discharge See *annual minimum daily discharge* under *discharge*.

anoxic Lack of oxygen.

antagonism Interaction of two or more substances (e.g., chemicals) such that the action of any one of them on living cells or tissues is lessened.

antecedent soil moisture Degree of wetness of soil at the beginning of a runoff or storm period, expressed as an index or as the total volume of water stored in the soil.

anthropogenic See *anthropogenic* under *streambank material*.

antidune See *sand wave*.

antinode See *antinode* under *wave*.

aphotic Depth of a body of water where light does not sufficiently penetrate to allow photosynthesis.

aphotic zone Stratum of a water body below which sufficient light is not present to allow photosynthesis.

aphytal (1) Refers to an area that lacks plants. (2) The plantless (profundal) zone of a lake bottom.

apparently stable channel See *apparently stable channel* under *channel pattern*.

apparent velocity See *interstitial velocity*.

apron (1) A protective structure in a stream used to prevent erosion around an artificial structure. (2) A pavement constructed at the lower side of a dam wall to protect the foundation from erosion.

aquamarsh See *aquamarsh* under *wetlands*.

aquatic Term applied to growing, living in, frequenting, or pertaining to water.

aquatic bed Wetlands and deeper water habitats dominated by plants that grow principally on or below the surface of the water for most of the growing season in most years. See also *aquatic bed* under *wetlands*.

aquatic ecosystem Any body of water, such as a wetland, stream, lake, reservoir, or estuary that includes all organisms and nonliving components, functioning as a natural system. See *aquatic system*.

aquatic habitat A specific type of area with environmental (i.e., biological, chemical, or physical) characteristics needed and used by an aquatic organism, population, or community.

aquatic system Any body of water, including lakes, reservoirs, streams, springs, or estuaries with associated living organisms and all nonliving components that function as a natural system. See *aquatic ecosystem*.

aquic Soils that have continuous or periodic saturation and reduction. These conditions are indicated by redoximorphic features.

aquiclude A poorly permeable underground bed, formation, or group of formations, often saturated, that impedes groundwater movement, and does not yield water freely to a well or spring. However, an aquiclude may transmit appreciable water to or from adjacent aquifers, and where sufficiently thick, may constitute an important groundwater storage unit.

aquic moisture regime A mostly reducing seasonal soil moisture regime that is free of dissolved oxygen due to saturation by groundwater or its capillary fringe.

aquifer An underground bed or layer of sand, earth, gravel, or porous stone that contains water or permits its passage.

arched roots Roots produced on plant stems in a position above the normal position of roots that serve to brace the plant during and following periods of prolonged inundation in water.

archival reach See *archival reach* under *reach*.

arc of the sun See *arc of the sun* under *solar radiation*.

area See *area* under *dimensions*.

area–capacity curve A graph showing the relation between the surface area of the water in a reservoir, the corresponding volume, and elevation.

argillorheophilic See *argillorheophilic* under *benthos*.

arm A long and relatively narrow water body extending inland from the main body of a lake or reservoir, and usually associated with a major tributary. Generally the term "arm" is applied to a water area that is greater in length and narrower in width than a bay or a cove. See *bay*, *cove*, *embayment*.

armoring (also armouring) (1) Formation of an erosion-resistant layer of relatively large particles on the surface of a streambed or streambank, resulting from removal of finer particles by erosion, which resists degradation by water currents. (2) Application of materials to reduce erosion.

arroyo A water-carved channel or gully in an arid area, usually rather small with steep banks and flat bottom, dry much of the time due to infrequent rainfall and the shallowness of the cut which does not penetrate below the level of permanent groundwater. In Mexico, the term "arroyo" often refers to permanent streams as well.

artesian well A well which continues to flow without a pumping mechanism as a result of groundwater pressure.

articulated concrete mattress See *articulated concrete mattress* under *habitat enhancements*.

articulation (1) Connection between two or more bodies of water. (2) Ratio of total area of inlets and bays to the total area of a lake or reservoir.

artificial beach Shore of a water body where the substrate or physical contours have been altered by human design or activity for recreational or aesthetic purposes.

artificial channels See *artificial channels* under *habitat enhancements*.

artificial control A weir or other constructed structure which serves as the control for streamgaging stations, fish passage facilities, streambed retention, or protection against erosion.

artificial holes See *artificial holes* under *habitat enhancements*.

artificial meander See *artificial meander* under *habitat enhancements*.

artificial recharge Recharge of groundwater aquifers by pumping or seepage of water introduced by human activity.

artificial reef See *artificial reef* under *habitat enhancements*.

artificial riffle See *artificial riffle* under *habitat enhancements*.

artificial substrate A device placed in the water that provides living space for aquatic organisms; most often used for biomonitoring.

artificial wetland See *artificial wetland* under *wetlands*.

aspect Direction a slope faces with respect to the cardinal compass points.

assimilation Ability of a water body to absorb materials and substances to purify itself.

assimilation capacity (1) Capacity of a natural water body to receive wastewaters, without deleterious effects, or toxic materials, without damage to aquatic life or humans that consume the water. (2) To incorporate and convert waste waters without deleterious effects. (3) Biological Oxygen Demand (BOD), within prescribed dissolved oxygen limits.

association (1) Plant and animal communities of a particular kind that are consistently found together. (2) A group of plant and animal species.

astatic Water bodies in which surface levels fluctuate.

perennial astatic Water body that rises and falls but does not dry up every year.

seasonal astatic Water body that dries up annually.

attenuation (1) Reduction in light intensity in water because of absorption and scattering by water molecules, suspended particles, and dissolved substances. (2) Reduction of the peak of a hydrograph by natural or artificial water storage.

attribute See *habitat component* and *attribute* under *remote sensing*.

aufwuchs Attached microscopic organisms growing on the bottom or other substrates.

autochthonous Endogenous materials such as nutrients or organisms fixed or generated within the aquatic system.

autotrophic Organisms that manufacture their own food using carbon dioxide or other inorganic substances. See also *autotrophic* under *trophic*.

available water capacity Ability of a soil to hold water in a form available to plants that is generally expressed in inches of water per inch of soil depth.

avalanche See *avalanche* under *landslide*.

avalanche cone See *avalanche cone* under *landslide*.

avalanche track See *avalanche track* under *landslide*.

average annual discharge See *average annual discharge* under *flow*.

average annual inflow See *average annual inflow* under *flow*.

average depth See *average depth* under *dimensions*.

average linear velocity See *average linear velocity* under *groundwater*.

average width See *average width* under *dimensions*.

AVHRR See *AVHRR* under *remote sensing*.

avulsed lands Lands that have been uncovered by a relatively sudden change in alignment of a river channel or by a comparable change in some other water body. Such lands remain as uplands or islands after the change.

avulsion An abandoned stream channel resulting from movement of the channel to a new route or direction.

azimuth An angle measured clockwise from a meridian, going north to east. See also *azimuth* under *remote sensing*.

▶ b

backbar channel See *backbar channel* under *channel pattern*.

backflow Reversal in the direction of water flow through a conduit or channel in the direction opposite to normal flow.

backflow billabong See *backflow billabong* under *billabong*.

backshore Zone of a typical beach profile above mean high water. Also used for the zone covered with water only during exceptionally severe storms.

backslope Steep slopes formed by bank erosion from flowing water.

backswamp See *backswamp* under *wetlands*.

backwash (1) Water thrown backward by the motion of a boat or other water craft. (2) Flow of water returning to a water body that occurs after the passing of a wave.

backwater (1) Water backed up or retarded in its course as compared with its normal or natural condition or flow. (2) A naturally or artificially formed arm or area of standing or slow-moving water partially isolated from the flow of the main channel of a river. (3) An area off the main water body of lakes, reservoirs, and bayous. (4) In stream gaging, a rise in stage produced by a temporary obstruction such as ice or weeds, or by flooding of the stream below. The difference between the observed stage and that indicated by the stage-discharge relation is reported as backwater. (5) Seasonal or permanent water bodies found in the lowest parts of floodplains, typically circular or oval in shape. (6) The plural (*backwaters*) is often used to refer to the upper, more riverine portion of a reservoir. See also *backwater* under *slow water*, *pool*, *dammed pool* with the main heading of *channel unit*.

backwater curve (1) Term is used in a general sense to denote calculated or measured water surface profiles, or for the profiles where the water depth has been increased by placement of an obstruction such as a dam or a weir. (2) A water surface profile in a section of stream in which there is a gradual transition in the depth of flow upwards or downwards relative to the channel bottom. (3) Change in elevation in a reservoir with increasing distance from the dam.

backwater deposits Overbank deposits of fine sediments deposited in slack water of a floodplain or outside natural levees.

backwater effect The effect of a dam or other obstruction in raising the upstream water surface.

backwater flooding Overbank inundation (i.e., flooding) that occurs during high runoff from a nearby stream.

badlands Generally barren, rough, and broken land that is strongly dissected or gullied by a fine drainage network with a very high drainage density. Most common in semi-arid regions where streams have entrenched into soft erodible materials.

baffle See *baffle* under *habitat enhancements*.

bajada A broad, gently inclined, piedmont slope formed by lateral coalescence of a series of alluvial fans with a broadly undulating transverse profile, resulting from the shape of the fans.

ballena A landform of round-topped ridgeline remnants of fan alluvium. Generally, the broadly rounded ridge shoulders meet to form a narrow crest and merge smoothly with the concave backslopes.

band See *band* under *remote sensing*.

band ratio See *band ratio* under *remote sensing*.

bank See *streambank*.

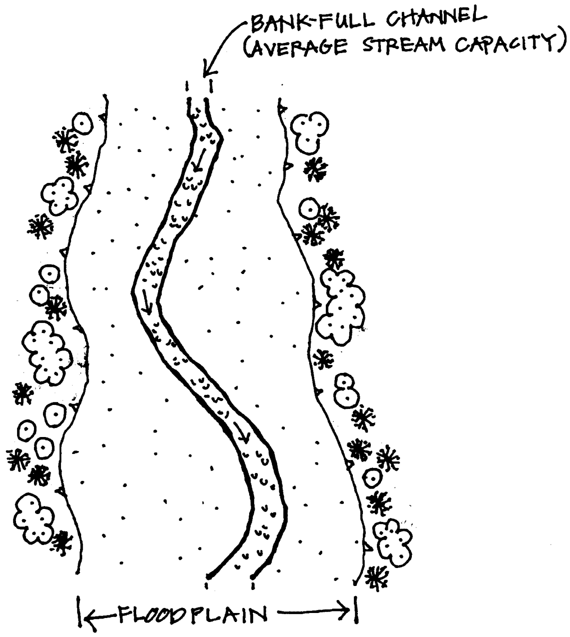
bank angle Angle formed by a downward sloping bank, measured in degrees from the horizontal such that a vertical bank is 90°. If the angle is variable, it is calculated by using the average of three measurements.

bank depth See *bank depth* under *dimensions*.

bank erosion Erosion of bank material caused by water current, wave action, or surface erosion.

bank-full depth Depth of water measured from the surface to the channel bottom when the water surface is even with the top of the streambank.

bank-full discharge Maximum streamflow that can be accommodated within the channel without overtopping the banks and spreading onto the floodplain. Generally the level associated with two- or three-year streamflow events.



bank-full stage (from Firehock and Doherty 1995)

bank-full stage Stream stage where stream reaches bank-full depth.

bank-full width Channel width between the tops of the most pronounced banks on either side of a stream reach.

bank height Distance between the channel bed and the top of the bank.

bank revetment See *bank revetment* under *habitat enhancements*.

bank sloughing Slumping of saturated, cohesive soils surrounding a water body that are incapable of free drainage during rapid drop in water level.

bank stability Pertains to the resistance of a bank to erosion.

failing bank A bank that is unable to maintain its structure because of active erosion.

stable bank A bank that, even with a steep slope, has no evidence of active erosion, breakdown, tension cracking, or shearing.

unstable bank A bank that shows active erosion or slumping.

bank stabilization See *bank stabilization* under *habitat enhancements*.

bank storage Water absorbed and stored in the voids in the soil cover in the bed and banks of a stream, lake, or reservoir, and returned in whole or in part as the surface drops.

bank width See *bank width* under *dimensions*.

bar A submerged or exposed ridge-like accumulation of sand, gravel, or other alluvial material formed in a lake or in the channel, along the banks, or at the mouth of a stream where a decrease in velocity induces deposition.

alternate bar Bars (i.e., depositions) that change from one side to the other of a winding thalweg.

braided bar Pattern of river bars with numerous interconnected small channels at lower flows that form in streams with high volumes of bed material.

channel junction bar Bar formed where two channels intersect.

cross-over bar See *transverse bar* under *bar*.

delta bar A bar formed immediately downstream of the confluence of a tributary and the main stream. Compare with *junction bar* under *bar*.

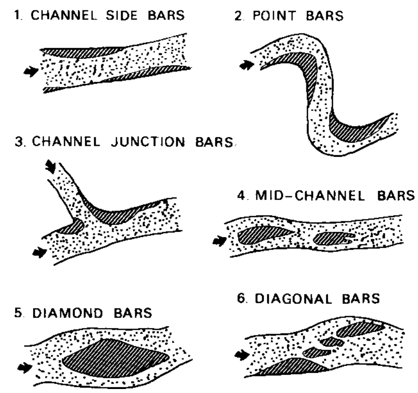
diagonal bar A bar that forms diagonally to a stream channel. Compare with *tansverse bar* under *bar*.

diamond bar A form of braiding in which the multiple interconnected channels form mid-channel bars.

diamond-braided bar Multiple diamond-shaped interconnected mid-channel bars that are characteristic of braided rivers.

dune bar Wave-like streambed formation that commonly occurs in relatively active channels of sand streambeds.

islands Exposed bars or land segments within the stream channel that are relatively stable and normally surrounded by water.

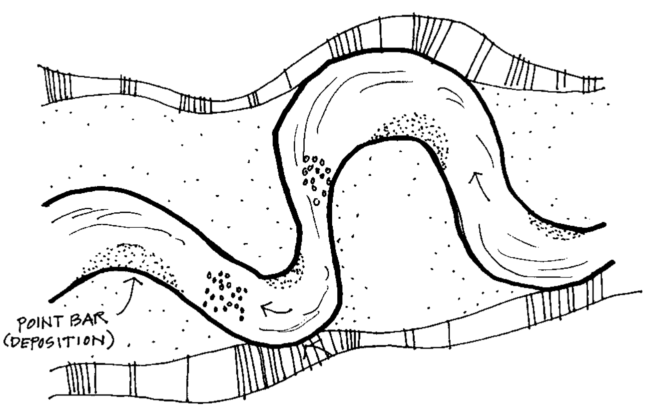


types of bars (adapted from Kellerhalls et al. 1995 with permission of ASCE)

junction bar A bar formed at the junction of two streams, usually because sediment transported by a tributary is deposited in the slower-moving water of the mainstream. Compare with *delta bar* under *bar*.

lee bar A bar caused by eddies and lower current velocities and formed in the lee of large immovable objects such as boulders or logs.

mid-channel bar Bar formed in the mid-channel zone, not extending completely across the channel. Also called a middle bar or mid-bar.



point bar (from Firehock and Doherty 1995)

point bar Bar found on the inside of meander bends.

reattachment bar Bar that extends from the downstream end of a recirculating eddy in large rivers and separated from the streambank by a recurrent channel. Compare with *separation bar* under *bar*.

separation bar Bar formed that extends from the upstream end of a recirculating eddy of large rivers. Compare with *reattachment bar* under *bar*.

side bar Bar located at the side of a river channel, usually associated with the inside of slight curves. Also called a lateral bar.

transverse bar Bar that extends diagonally across the full width of the active stream channel. Compare with *diagonal bar* under *bar*.

bar and channel A pattern found in younger floodplains and terraces, consisting of ridgelike bars of accumulated coarse sediments and channels of finer textures. Maintained by the competence of the stream, the features become less pronounced as higher lying bars erode.

bar presence Refers to the relative abundance of bars or islands in a river channel.

barrage Dams or weirs used for creating barriers to fish movements and facilitate capture of fish. Also used as a general term for dams or weirs.

barren shoal Shallow lake bottom with few or entirely devoid of aquatic plants.

barrier Any physical, physiographic, chemical or biological obstacle to migration or dispersal of aquatic organisms.

barrier beach An exposed ridge of deposits separated from the mainland by water.

barrier dam Low dam across a stream to divert water or to guide fish to the entrance of a fishway. Barrier dams may be used to block upstream migrations of fish.

barrier flat A relatively flat area, often with pools of water, separating the exposed or seaward edge of a barrier from the lagoon behind it.

barrier island A long broad sandy island lying parallel to a shore that is built up by the action of waves, currents, and winds and that protects the shore from the effects of the ocean.

bar screen A device for removing larger materials from effluent.

base flow See *base flow* under *flow*.

base level The level to which a stream channel profile has developed and below which significant erosion by water does not proceed.

baseline (1) Reference point for comparison of subsequent measurements. (2) Level of a receiving stream.

basin A topographic area of a watershed or geological land area that slopes toward a common center or depression where all surface and subsurface water drains. See *drainage area*.

basin dam A dam with a concave top that is built across the mouth of a gorge to prevent formation of an outwash fan.

basin slope See *basin slope* under *dimensions*.

bathile Term that pertains to the bed of a lake that is deeper than 25 m.

bathyal zone Pertaining to deep waters, especially between 183 and 1,830 m (100 and 1,000 fathoms).

bathylimnion See *bathylimnion* under *stratification*.

bathymetric map A map depicting the depth contours of the bottom of any water body.

bathymetry Refers to measurement of depth in a water body.

bay A water body that forms an indentation in a shoreline, larger than a cove, and typically wider than an arm. Also, a large embayment. See *arm*, *cove*, *embayment*.

bay head That portion of a bay which lies farthest inland from the main water body.

bay mouth Location where a bay joins a main water body.

bayou (1) A bay, inlet, backwater, river channel slough, oxbow lake, or channel in coastal marshes and sluggish creeks, or arm, outlet, or tributary of a lake or river. (2) Any stagnant or sluggish creek or marshy lake. Term is most often used in southeastern United States.

beach The gently sloping zone of demarcation between land and water of lakes or other large water bodies that is covered by sand, gravel, or larger rock fragments.

beach nourishment Aggradation of a beach from deposition of dredged or fill material placed to replenish eroded areas.

beach ridge A low, generally continuous area of dune material accumulated by the action of waves and currents that roughly parallel the shoreline and are not influenced by normal tides and storms.

beach terrace Flat benches, scarps, or terraces formed by waves from well-sorted sand and gravel of lacustrine or marine origin.

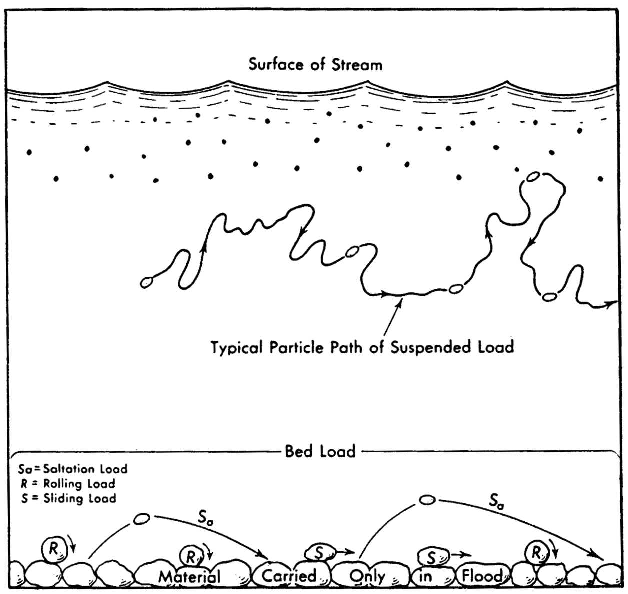
beaded stream A stream consisting of a series of small pools or lakes connected by short stream segments. Commonly found in a region of paternoster lakes, an area underlain by permafrost, or a recently glaciated area. See also *beaded stream* under *stream*.

beaver dam See *beaver dam* under *slow water, pool, dammed pool* under the main heading *channel unit*.

beaver pond See *beaver pond* under *pond*.

bed Bottom of a lake, pond, or other water body.

bedding Stratification of sedimentary material parallel to the original surface of deposition or inclined to it.



bed load (from Meehan 1991)

bed load (1) Substrate moving on or near a streambed and frequently in contact with it. (2) See *bed load* under *sediment load*.

bed load discharge Quantity of bed load passing a given point in a unit of time, expressed as dry weight. See *transport velocity*.

bed load transport rate A transport rate (Q_b) that is a function of the difference between the effective basal shear stress and the critical shear stress.

$$Q_b = kW(\tau' - \tau_{cr})^{1.5};$$

τ' = basal shear stress;
τ_{cr} = critical shear stress;
W = channel width;
k = a constant.

bed material Substrate mixture of a stream or lake bed that remains after moderate to high streamflow conditions. In alluvial streambeds, materials that are likely to be moved during moderate to high flows that lead to continued replacement through scour and deposition.

bed material load See *bed material load* under *sediment load*.

bedrock Solid rock, either exposed at surface or underlying surficial deposits. See also *bedrock* under *streambank material* and *valley segments*.

bedrock control The percentage of permanent and stable pools in a river reach that are formed by the presence of bedrock.

bedrock landslide See *bedrock landslide* under *landslide*.

bedrock type The parent material of bedrock (e.g., granite or sandstone) in a channel.

bed roughness A measure of the irregularity of a streambed as it contributes to resistance of flow. Commonly measured in terms of Manning's roughness coefficient. See *Manning's n*.

beheaded stream See *beheaded stream* under *stream*.

belt of meander See *belt of meander* under *meander*.

bench (1) Shelf-like areas in lakes and reservoirs with steeper slopes above and below, developed on horizontal or gently inclined rock layers where overlying softer and less resistant materials have been scoured away. (2) A series of level step-like areas remaining in a floodplain as a result of periodic deposition and erosion. See *terrace*.

benched gully side See *benched gully side* under *gully side form*.

benchmark A permanent object of known elevation that is generally located or placed where there is the least likelihood of being disturbed and used as a standard or reference for various physical measurements.

bench processes See *bench processes* under *active valley wall processes*.

bend A curve in the river channel. Term is most often used for an extended curvature of a large river or where the flow of a river changes direction.

beneficial use In water use law, reasonable use of water for a purpose consistent with the laws and best interest of people. Such uses vary by state law and include, but are not limited to: instream, out of stream, groundwater uses, domestic, municipal, industrial water supply, mining, irrigation, livestock watering, fish and aquatic life, wildlife, fishing, water contact recreation, aesthetics and scenic attraction, hydropower, and commercial navigation.

benthic organic matter Undifferentiated particles of organic matter desposited on the bottom of a water body.

fine benthic organic matter Benthic organic matter that is 0.45 μm–1 mm.

large benthic organic matter Benthic organic matter that is greater than 1 mm.

nonwoody benthic organic matter Benthic organic matter from other than woody vegetation, such as sedges or leaf litter.

benthic zone The bottom or bed of a water body.

benthos Bottom-dwelling organisms including plants, invertebrates, and vertebrate animals that inhabit the benthic zone of a water body.

argillorheophilic Benthos inhabiting mostly clay substrates, usually sessile and burrowing organisms.

lithorheophilic Benthos inhabiting solid substrates in flowing water, mainly composed of insects.

pelephilic Benthos inhabiting silty substrates in still waters.

pelorheophilic Benthos inhabiting silty areas in flowing water.

phytophilic Benthos inhabiting backwaters rich in plants.

psammorheophilic Benthos inhabiting sandy bottoms in flowing water, mainly composed of protozoans and small arthropods.

berm See *berm* under *habitat enhancements*. Also compare with *dike*.

beta-mesosaprobic zone See *beta-mesosaprobic zone* under *saprobien system*.

bight A broad, gradual bend or curve in a shoreline that is generally applied to the marine environment.

billabong An Australian term for an isolated pool of water.

backflow billabong A backwater in a floodplain of a river that forms a stagnant pool.

channel billabong A pothole or lagoon in the dry channel of a stream.

biocoenosis The plants and animals that comprise a community.

biocriteria See *biocriteria* under *biological indices*.

biofacies Sedimentary materials of organic origin.

biogenesis (1) Production of living organisms from other living organisms. (2) Materials produced by living organisms necessary for the continuation of life processes. The adjective "biogenic" applies to such production.

biogenic meromixis See *biogenic meromixis* under *mixing*.

biogeographic region Any region that is delineated by its biological and geographic characteristics.

biological accumulation Gradual biological process by which persistent substances accumulate in individual organisms, or through a succession of organisms from primary producers to top carnivores. Also referred to as bioaccumulation.

biological indices A measure of the health or condition of a water body based upon values for specific biological or physical parameters.

biocriteria Biologically based standards used to assess or regulate conditions of a water body.

biomonitoring Use of biological attributes of a water body to assess its environmental health or condition.

biotic condition index (BCI) The community tolerance quotient potential calculated for natural macroinvertebrate, physical, and chemical characteristics divided by the measured community tolerance quotient and multiplied by 100. Values above 90 are excellent, 80–90 are very good, 72–79 are fair, and below 72 are poor.

community tolerance quotient (CTQ) A value that represents a total of the tolerance quotients per sample divided by the number of taxa in the sample. Values generally range from 40 to 108, with the higher number indicating a more tolerant community. Stressed conditions may be shown depending upon the capability and potential of a stream.

diversity index A numerical value derived from the number of individuals per taxon (evenness) and the number of taxa present (richness).

dominance and taxa index (DAT) A diversity index that combines the number of taxa present and the relative dominance of one or more taxa in the samples. Dominance by one or more species (taxa) often indicates a habitat imbalance causing stress on the biological community. The number of species also reflects the condition of the aquatic habitat. A relative value scale for DAT is 18–26, excellent; 11–17, good; 6–10, fair; and 0–5, poor.

index of biotic integrity (IBI) A measure of the degree to which water resource quality deviates from that expected at relatively undisturbed sites. It is calculated based on data from the study of the entire fish community. Its measures, or metrics, fall into three broad categories: species composition, trophic composition, and fish abundance and condition.

tolerance quotient (TQ) A numerical value used to develop an index of the relative tolerance of a taxon to natural environmental levels of physical and chemical parameters found limiting to some species. Low numbers indicate nontolerant species and higher numbers indicate more tolerant species.

biological legacies See *biological legacies* under *large organic debris*.

biological oxygen demand (BOD) (1) The dissolved oxygen required to oxidize inorganic chemicals in water. (2) A measure of oxygen consumption during a fixed period of time. (3) The amount (milligram per liter) of molecular oxygen required to stabilize decomposable organic matter by aerobic biochemical action.

biomass (1) The total weight, at a given time, of living organisms of one or more species per unit area, or of all the species of a community. (2) The weight of a taxon or taxa per unit of surface area or volume of water expressed in units of living or dead weight, dry weight, ash-free weight, or nitrogen content.

biome An extensive complex or community of organisms occurring together. More specifically, a major ecological community such as a desert, grassland, or boreal forest.

biomonitoring See *biomonitoring* under *biological indices*.

biota Refers to all plant and animal life in an area or region.

biotic (1) Pertaining to life or living organisms. Also pertains to being caused by, produced by, or comprising living organisms. (2) Environmental components having their origins in living organisms.

biotic condition index (BCI) See *biotic condition index (BCI)* under *biological indices*.

bioturbation Disturbance of mud, water, or any other medium by the actions of organisms living in or on it.

biozone Zone capable of supporting living organisms.

bitter lake See *bitter lake* under *lake*.

bitters The saturated brine solution remaining after precipitation of sodium chloride during the solar evaporation process.

blanket bog See *blanket bog* under *wetlands*.

blind drain A ditch or trench, partly filled with large stones and covered with earth or brushwood. See also *french drain*.

blind lake See *blind lake* under *lake*.

bloom A period of vigorous plant growth, usually algae, or the aggregation of alga. See *algal bloom*.

blowdown See *blowdown* under *large organic debris*.

bluff A cliff, hill, or headland with a broad, steep face. See *cliff*.

boat basin A protected anchorage for small water craft with facilities for launching and loading.

boathouse An enclosed structure on land or over water to store (house) water craft.

boat ramp An artificial sloping structure on the shore of a water body used for boat launching.

bog See *bog* under *wetlands*.

bole See *bole* under *large organic debris*.

bolson An internally drained intermountain basin with nearly flat alluvial plain, playa-like depressions, and individual or coalesced alluvial fans.

bordering land Land bordering a water body.

borrowpit pond See *borrowpit pond* under *pond*.

bosque A small wooded area.

bottom The ground surface underlying a body of water.

bottomland A lowland, usually highly fertile, along a stream such as an alluvial floodplain. Also referred to as bottom land.

bottomset bed Flat-lying bed of fine sediment deposited in front of a delta that is buried by continuous growth of a delta.

bottom slope The change in the average elevation of a streambed between two cross sections, divided by the distance between them.

boulder A substrate particle larger than 25 cm (10 in) in diameter. Compare with other substrate sizes under *substrate size*.

boundary layer Layer where a fluid in contact with a solid surface is no longer influenced by that surface.

brackish Water with a salt content greater than freshwater but less than seawater.

braided Refers to a stream that divides into an interlacing network of several branching and reuniting channels separated from each other by islands or channel bars.

braided bar See *braided bar* under *bar*.

braided channel See *braided channel* under *channel pattern*.

branch A term sometimes applied to a small stream or tributary.

breaching Term applied to a break at the head of a side channel or side slough. May also be applied to a break in a berm, dike, levee, or revetment.

> **controlling breaching** Breaching condition in which the main stem discharges are equal to or greater than the main stem discharge required to directly govern the hydraulic characteristics within a side slough or side channel. This condition can be denoted as equalling the segment of the flow rating curve, beginning with the point of inflection and beyond.

> **initial breaching** The main stem discharge that represents the initial point when main stem water begins to enter the upstream end of a side channel or slough.

> **intermediate breaching** The range of main stem discharges representative of the conditions between the discharges that occur in *initial breaching* and *controlling breaching*.

breadth See *breadth* and *width* under *dimensions*.

breaker See *breaker* under *wave*.

breakline An area characterized by rapid changes in depth, water temperature, water chemistry, water clarity, structure, or cover.

breakwall See *jetty*.

breakwater Structural features placed in position to intercept waves and to dissipate their energy so as to protect shorelines. See *wave breaker*.

bridge A structure spanning a waterway that provides passage.

brine lake See *brine lake* under *lake*.

broken flow See *broken flow* under *flow*.

brook Small, natural freshwater stream. See *creek*.

brushline The edge of brushy cover near deep, more open water.

brushpile See *brushpile* under *habitat enhancements*.

buffer Vegetation strip maintained along a stream or lake to mitigate the impacts of actions on adjacent lands. Also called a buffer strip, leave strip, or streamside management zone.

bulk density The ratio of the mass of bed material to its volume.

bulkhead See *bulkhead* under *habitat enhancements*.

bund Synonymous with *berm* under *habitat enhancements*.

buoy A distinctively shaped and marked float, anchored to mark a channel, anchorage, navigational hazard, recreation area, or to provide a mooring place.

buoyancy Ability of an object to float in water.

buried channel (1) A channel that has been filled by unconsolidated deposits. (2) A water course that has been diverted through a pipe or culvert.

burn Term sometimes used for a small stream.

burst (darting) speed See *burst (darting) speed* under *swimming speed*.

butte An isolated, usually flat-topped geological formation with a top width less than the height of the formation; formed by differential erosion of substrates.

▶ C

caldera lake See *caldera lake* under *lake*.

caliche Layer near the surface (or exposed by erosion) that is more or less cemented by carbonates of Calcium and Magnesium precipitated from the soil.

calving (1) Erosion and collapse of sandbanks during a rapid drawdown of a reservoir, river, or lake that results from latent water storage.
(2) Breaking away of a mass of ice from its parent glacier, iceberg, or sea-ice formation.

canal An artificially created waterway.

canopy Overhead cover of branches and foliage of adjacent vegetation.

canopy closure The completeness of tree cover. See *canopy cover*.

canopy cover Percentage of ground or water covered by shade from the outermost perimeter or natural spread of foliage from plants. Small openings within the canopy are excluded if the sky is visible through them. Total canopy coverage may exceed 100% due to the layering of different vegetative strata. See also *foliar cover* and *stream surface shading*.

canopy density See *canopy cover*.

canopy layer Foliage layer in a plant community.

canyon A water-cut, deep chasm or gorge with steep sides, often with a stream at the bottom. Most characteristic of arid or semi-arid regions where downcutting by streams greatly exceeds weathering.

capacity Maximum amount of water, sediment, or debris that can be carried by a stream.

capacity : inflow ratio The storage capacity of a reservoir or lake expressed as a ratio to the mean annual inflow.

cape A piece of land jutting into a large water body.

capillary A tube or a fine bore channel. Channel in the material below the earth's surface through which water can move.

capillary fringe A zone immediately above the water table in which water is drawn upward.

capillary percolation Movement of water along a capillary channel.

capillary porosity Portion of soil porosity that remains filled with water at a defined level of drainage.

capillary stream Totality of water moving in a common direction along adjoining groundwater capillaries.

capillary water Water stored or moving through groundwater capillary system.

capillary waves See *capillary waves* under *waves*.

capture See *stream capture*.

carp mumblings Term used for small depressions about 0.64 cm (one-quarter inch) deep made by carp feeding in soft mud bottoms. Can be readily confused with small depressions that are made by other aquatic organisms.

carr See *carr* under *wetlands*.

carrying capacity The maximum biomass of aquatic organisms that can be sustained on a long-term basis by an aquatic ecosystem within existing environmental conditions. The maximum number (instead of biomass) is applied to terrestrial organisms.

cartesian See *cartesian* under *remote sensing*.

cartesian well Synonymous with *artesian well*.

cascade See *cascade* under *turbulent—fast water* under the main heading *channel unit*.

cascading The flow of water over one or a series of well-defined drops in stream.

catadromous Life history strategy, that includes migration between fresh- and saltwater, in which fish reproduce and spend their early life stages in saltwater, move into freshwater to rear as subadults, and return to saltwater to spawn as adults. Compare with *anadromous*, *diadromous*, *potamodromous*, *oceanadromous*.

catastrophic drift Term applied to the massive drift of bottom organisms that occurs under catastrophic or stress conditions such as floods or chemical toxicity.

catastrophic event A large-scale, high-intensity natural disturbance that occurs infrequently.

catchment The land area above a specified point from which water drains towards a stream, lake, reservoir, or sea.

catchment area The total area draining into a given stream, lake, or reservoir. See *drainage area*.

catchment basin The upslope land from which water drains by subsurface and surface routes into the lowest depression, especially for a reservoir or river. See *drainage basin*.

causeway A raised road or path made across low water or wet ground.

cave-in lake See *cave-in lake* under *lake*.

cell See *cell* under *remote sensing*.

cell size See *cell size* under *remote sensing*.

cemented bottom Compacted or possibly cohesive substrate of a stream or lake, with particles adhering so tightly that penetration or erosion is difficult.

centripetal stream See *centripetal stream* under *stream*.

channel A natural or artificial waterway that periodically or continuously contains moving water, has a definite bed, and has banks that serve to confine water at low to moderate streamflows.

channel bank The sloping land bordering a channel. Such a bank has steeper slopes than the bottom of the channel and is usually steeper than the land surrounding the channel.

channel billabong See *channel billabong* under *billabong*.

channel bottom The submerged portion of the channel cross section.

channel confluence pool See *channel confluence pool* under *pool*, *scour pool* under the main heading *channel unit*.

channel constrictor See *channel constrictor* under *habitat enhancements*.

channeled colluvium See *channeled colluvium* under *valley segments*.

channel-forming discharge Streamflow of a magnitude sufficient to mobilize significant amounts of the bed load.

channel geometry The geomorphic form of the stream channel in the landscape surface.

aggraded channel A channel that has accumulated bed load, raising the elevation of the stream channel.

confined channel Well-defined channel of sufficient stability to remain in the same location and plane.

degraded channel A downcut channel that has scoured accumulated bed load materials.

incised channel Deep, well-defined channel with narrow width : depth ratio and limited or no lateral movement. Often newly formed, and is a result of rapid down-cutting into the substrate.

channelization The mechanical alteration of a stream usually by deepening and straightening an existing stream channel or creating a new channel to facilitate the movement of water. See *confinement*.

channel junction bar See *channel junction bar* under *bar*.

channel maintenance or preservation flow The minimum streamflow to sustain biota. See *channel maintenance or preservation flow* under *flow*.

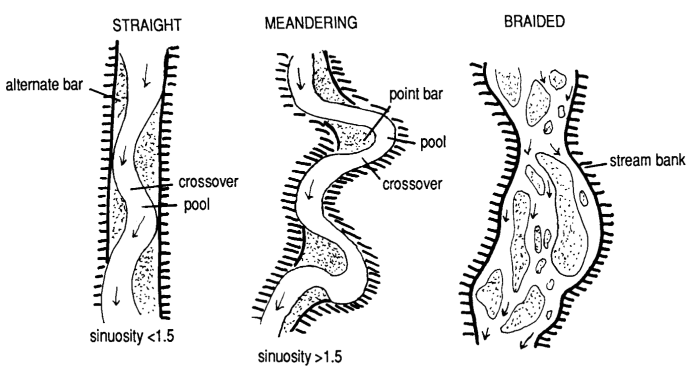
channel pattern The configuration of a stream as seen from above and described in terms of its relative form, including:

abandoned meander channel Former stream channel that was cut off from a river and typically lacks standing water during the entire year.

anastomizing channel Multiple channels that diverge and converge around many islands.

apparently stable channel Condition of river channel where signs of lateral channel instability do not exist.

backbar channel Channel formed behind a bar that is connected to the main channel but usually at a higher streambed elevation than the main channel.



channel patterns (from Kohler and Hubert 1993)

braided channel Multiple channels, often with banks poorly defined.

dendritic channel Pattern of streamflow when tributaries progressively branch to form a tree-like pattern.

deranged channel The opposite of dendritic channels, irregular, poorly differentiated from the main channel and each other. They enter the main channel from different angles. Commonly found in recently glacial areas and large alluvial floodplains.

eddy return channel Small channel formed by recirculating flow of an eddy, usually between a river and a depositional bar. Also referred to as a backwater.

irregular channel Irregular sinuous channel; channel displays irregular turns and bends without repetition of similar features.

irregular meander channel A channel with no repeating pattern.

main channel Primary watercourse containing the major streamflow. Also referred to as main stem.

main stem channel See *main channel* under *channel pattern*.

meander scrolls channel Depressions or rises on the convex side of bends formed as the channel migrated laterally down valleys and toward the concave bank.

meltwater channel Channel formed by glacial meltwater.

regular meander channel A clear repeated meander pattern formed in a simple channel that is well-defined by cutting outside of a bend.

secondary channel Channel that flows laterally but parallel to the main channel, containing less water, and may be intermittent or completely dry during periods of low streamflow.

serpentine channel See *regular meander channel* under *channel pattern*.

side channel A secondary channel containing a portion of the streamflow from the main or primary channel.

sinuous channel Having a series of curves, bends, and turns. See *sinuosity*.

straight channel Very little curvature within the reach.

tortuous meander channel A repeated pattern characterized by angles greater than 90°.

wandering meander channel A stream channel that migrates in a random pattern across a floodplain.

channel sensitivity Capacity of a stream channel to respond to physical disturbance.

channel stability A measure of the resistance of a stream to changes in its unique form, channel dimensions, and patterns that determines how well it adjusts to and recovers from the changes in quantities of flow or sediment.

channel storage Volume of water at a given time in the channel or over the floodplain of streams in a drainage basin or river reach.

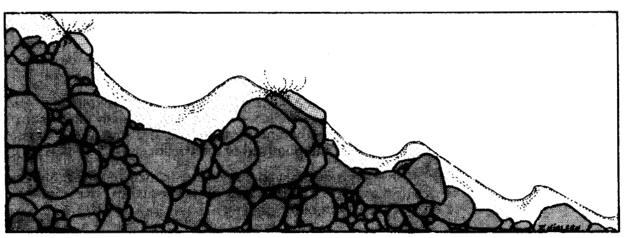
channel type A system for characterizing channels based on features such as channel and valley confinement, gradient, and erosional and depositional processes, such as:

Confinement	Gradient	Sediment process
Confined	>4%	Source
Moderately confined	1.5–4%	Transport
Unconfined	<1.5%	Response

Note: See Tables 1–3 for various systems for characterizing channel types.

channel unit Relatively homogeneous areas of a channel that differ in depth, velocity, and substrate characteristics from adjoining areas, creating different habitat types in a stream channel.

fast water—turbulent Channel with a gradient that exceeds 1%. A channel unit of this type possesses supercritical flow with hydraulic jumps sufficient to entrain air bubbles and create whitewater.



cascade (from Helm 1985)

cascade Highly turbulent series of short falls and small scour basins, with very rapid water movement as it passes over a steep channel bottom with gradients exceeding 8%. Most of the water surface is broken by short, irregular plunges creating whitewater, frequently characterized by very large substrates, and a well-defined stepped longitudinal profile that exceeds 50% in supercritical flow.

chute Rapidly flowing water within narrow, steep slots of bedrock.

falls Free-falling water with vertical or nearly vertical drops as it falls over an obstruction. Falling water is turbulent and appears white in color from trapped air bubbles.

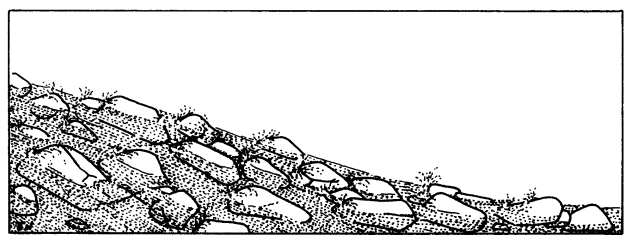
classic falls Well-defined falls over a sheer drop.

complex falls Falls with a series of drops, breaks, or channels.

curtain falls Falls with a broad, uninterupted face.

flume falls Falls within a narrow, confining channel.

ribbon falls Elongate, narrow falls.



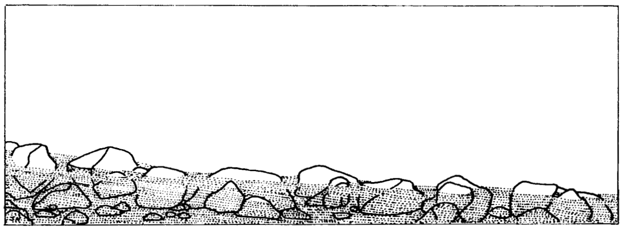
rapids (from Helm 1985)

rapids Moderately steep stream area (4–8% gradient) with supercritical flow between 15 and 50%, rapid and turbulent water movement, surface with intermittent whitewater

TABLE 1.—Channel Types of Paustian et al. (1983)

Type	Hydrology–slope	Sediment	Valley form
A	Precipitation headwaters	Sediment source	Upper slopes steep
B	Precipitation transition zone	Sediment transport	Slope–valley interface
C	Precipitation runoff	Sediment deposition	Valley bottom
D	Glacial runoff	High sediment load	Glacial outwash valleys
E	Tidal	Sediment deposition	Estuarine

with breaking waves, coarse substrate, with exposed boulders at low flows, and a somewhat planar longitudinal profile.



riffles (from Helm 1985)

riffles Shallow reaches with low subcritical flow (1–4% gradient) in alluvial channels of finer particles that are unstable, characterized by small hydraulic jumps over rough bed material, causing small ripples, waves, and eddies, without breaking the surface tension. Stable riffles are important in maintaining the water level in the pool immediately upstream of the riffle.

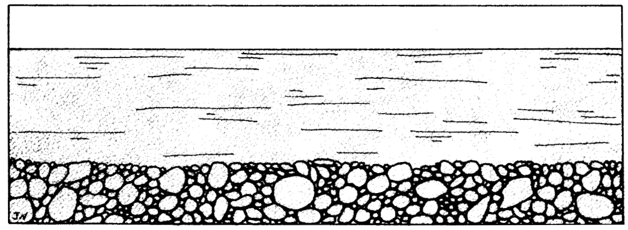
high gradient riffle A collective term for rapids and cascades. Steeper reaches of moderately deep, swift (greater than 4% gradient), and very turbulent waters. Generally, these riffles have exposed substrates that are dominated by large boulders and rocks. See *cascade* and *rapids* under *fast water—turbulent* under the main heading *channel unit*.

low gradient riffle Shallow reaches with swiftly flowing (gradients less than 4%), turbulent water with some partially exposed substrate, usually cobble or gravel.

step run Low gradient runs with small (0.5 to 2 m) riffle steps between runs.

fast water—nonturbulent Reaches that are deeper than riffles, with little or no supercritical flow. The water surface in such reaches has a smoother, laminar appearance.

run Swiftly flowing stream reach with a gradient greater than 4%, little to no surface agitation, waves, or turbulence, no major flow obstructions, approximately uniform flow, substrates of variable particle size, and water surface slope roughly parallel to the overall stream gradient.



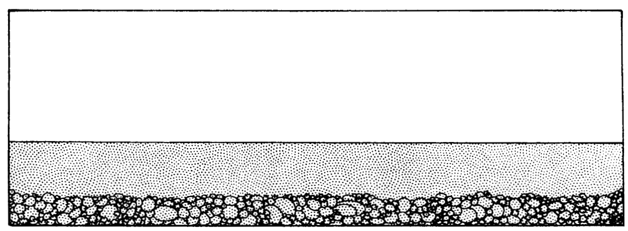
run (from Helm 1985)

sheet Shallow water reach that flows uniformly over smooth bedrock. Also referred to as a slipface.

slow water Stream channel with a gradient of less than 1% that is typically deeper than the reach average with a streambed composed of finer substrates and a smooth, unbroken water surface.

edgewater A shallow, quiet area along the margins of a stream with water velocity that is low or nonexistent. Edgewater areas are typically associated with riffles.

embayment An off-channel, pond-like water body that has a connection (sometimes narrow) to the stream channel.



glide (from Helm 1985)

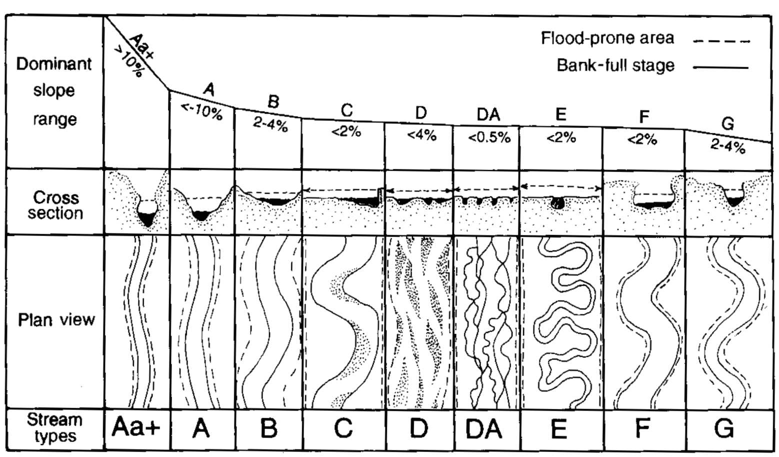
glide A shallow stream reach with a maximum depth that is 5% or less of the average stream width, a water velocity less than 20 cm (8 in) per second, and without surface turbulence.

pool Aquatic habitat in a stream with a gradient less than 1% that is normally deeper and wider than aquatic habitats immediately above and below it.

dammed pool Pool formed by impounded water from complete or nearly complete channel blockage caused by a beaver dam, log jam, rock slide, or stream habitat improvement structure. A dammed pool may form by substrate deposition at the confluence of a tribu-

TABLE 2.—Channel Types of Rosgen (1996)

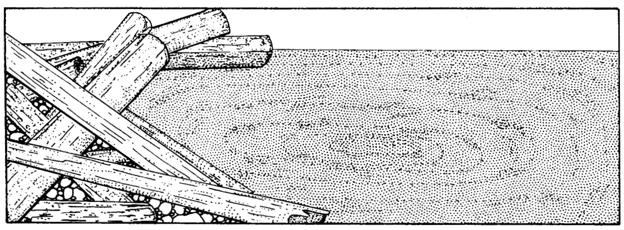
Type	Description	Slope	Landform
Aa	Very steep, deeply entrenched with debris transport.	>10%	High relief, deeply entrenched and erosional. Vertical steps with deep scour pools and waterfalls.
A	Steep, entrenched, step-pool with high energy and debris transport.	4–10%	High relief, entrenched and confined. Cascading reaches with frequently spaced deep pools in a step-pool bed morphology.
B	Moderately entrenched, moderate gradient, riffle-dominated, infrequently spaced pools with very stable banks and profile.	2–3.9%	Moderate relief, colluvial deposition and (or) residual soil, moderate entrenchment, and moderate width : depth ratio. Predominately rapids with occasional pools in a narrow, gently sloping valley.
C	Low gradient, meandering, point bar-, riffle-, pool-, alluvial channels with broad, well-defined floodplain.	<2%	Broad valley with terraces associated with the floodplain, alluvial soils, slightly entrenched, and well-defined meandering channel. Riffle-pool streambed morphology.
D	Wide channel with longitudinal and transverse bars with eroding banks.	<4%	Broad valley with abundant sediment in alluvial and colluvial fans, glacial debris, and other depositional features exhibiting active lateral adjustment.
Da	Anastomosing channels that are narrow and deep with stable banks, very gentle relief, highly variable sinuosity, and an expansive well-vegetated floodplain and associated wetlands.	<0.5%	Broad, low-gradient valleys with fine alluvium and (or) lacustrine soil. Anastomosing geologic control creating fine deposition with well-vegetated bars that are laterally stable and a broad wetland floodplain.
E	Low gradient, riffle-pool with very efficient and stable meandering rate, low width : depth ratio, and little deposition.	<2%	Broad valley-meadow. High sinuosity with stable well-vegetated banks and floodplain of alluvial material. Riffle-pool morphology with very low width : depth ratio.
F	Entrenched meandering riffle-pool with a low gradient and high width : depth ratio.	<2%	Entrenched in highly weathered material with gentle gradient and a high width : depth ratio. Riffle-pool morphology with meandering channel that is laterally unstable with high bank erosion.
G	Entrenched "gully" step-pool with moderate gradient and low width : depth ratio.	2–3.9%	Gully, step-pool morphology with moderate slopes, low width : depth ratio, narrow valleys that are deeply incised alluvial or colluvial material. Unstable with grade control problems and high bank erosion rates.



Channel type classification (from Rosgen 1994 with permission of Elsevier Science)

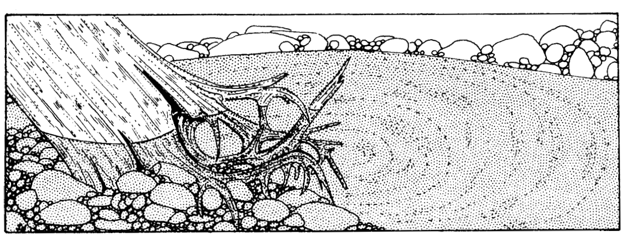
TABLE 3.—Channel Types of Montgomery and Buffington (1993)

Channel type	Description
Cascade	High gradient stream with large substrate where the flow is strongly three-dimensional and energy dissipation is dominated by tumbling jet-and-wake flow and hydraulic jumps.
Step-pool	A large series of steps created by larger substrate that separate pools with finer substrates.
Plane-bed	Lack of a well-defined bedform that is characterized by long reaches of relatively planar channel bed with occasional rapids.
Pool-riffle	Undulating channel bed with a sequence of bars, pools, and riffles.
Regime	Low-gradient, sandbed channel that exhibits a succession of bedforms with increasing flow.
Braided	Braided pattern of medial and longitudinal bars that are wide and shallow with a high sediment supply.



dammed pool (from Helm 1985)

tary stream with the main stem river when water velocity decreases.



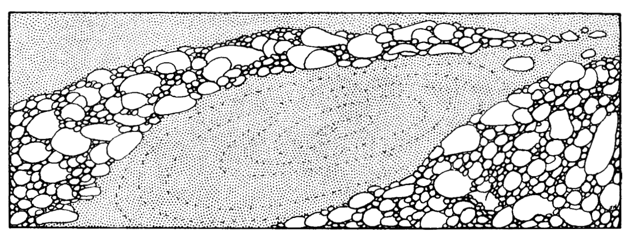
backwater (from Helm 1985)

backwater (1) A pool formed by water backing upstream from an obstruction, such as narrowing of the channel by a bedrock or boulder constriction. (2) Abandoned channel that remains connected to the active main stem river. (3) Secondary channel in which the inlet becomes blocked with substrate deposition when water velocities decrease as the river subsides but the outlet remains connected with the active main channel.

beaver pool Pool formed behind a dam created by beaver.

debris pool Pool formed behind an a channel obstruction created by an accumulation of woody debris.

landslide pool Pool created due to channel obstruction by materials transferred into the channel from adjacent slope or channel failures.



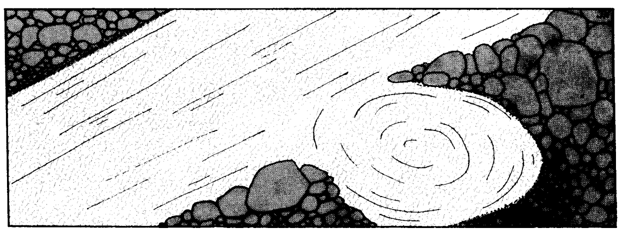
secondary channel (from Helm 1985)

secondary channel Relatively small pools formed outside the mainstream wetted channel, sometimes separated by formation of a bar deposited along the margin of the main channel. Also referred to as an abandoned channel or side channel pool.

side channel Elongated extension off the main channel that becomes a backwater under low streamflows when the inflow to the channel becomes blocked from sediment deposition.

slackwater pool Pool-like depressions on the floodplain with beds of rock or coarse material and higher current velocities flowing in a uniform direction that contain water only during high flow or after floodwaters recede, more transient in nature than secondary channel pools, and may contain water for only a few days or weeks.

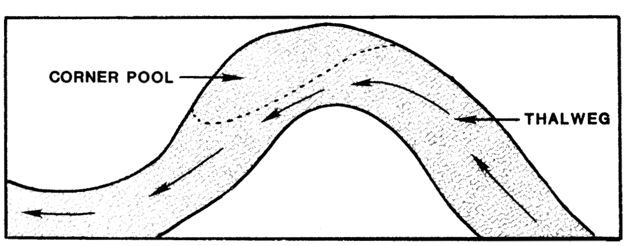
scour pool Pool created by the scouring action of current flowing against an obstruction, causing an increase in lift and drag forces, a result of flow deflection, constriction, or increased local turbulence induced by a nonalluvial obstruction.



alcove (from Helm 1985)

alcove A deeper area along the shoreline in a larger habitat where the stream is generally wide and shallow. Also referred to as a sidepool.

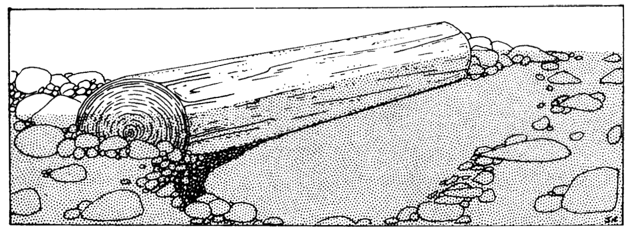
channel confluence pool (1) The location where two streams converge. (2) A pool created by scour where two channels meet that has more turbulence and higher water velocities than found in many other types of pools. Also referred to as a channel convergence pool.



corner pool (from Helm 1985)

corner pool Pool formed by lateral scour and transverse currents near the concave bank of a meander curve.

eddy A pool on the margin or off the main channel of a stream that is formed and maintained by strong eddy currents.

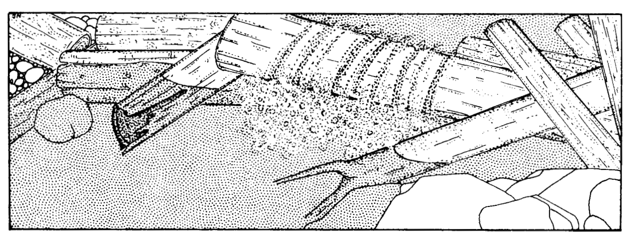


lateral scour pool (from Helm 1985)

lateral scour pool A pool formed by the scouring action of the flow as it is directed laterally or obliquely to one side of the stream by the configuration of the channel or a partial channel obstruction. Usually confined to less than 60% of the channel width.

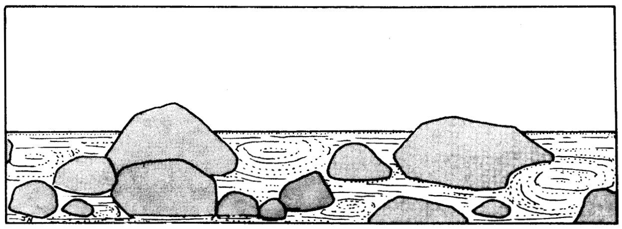
main channel pool A pool covering the entire channel; typically associated with one bedrock bank and a bend in the stream.

mid-channel pool A large pool formed by mid-channel scour that encompasses greater than 60% of the wetted channel with low velocity.



plunge pool (from Helm 1985)

plunge pool A pool created by water passing over or through a complete or nearly complete channel obstruction, and dropping steeply into the streambed below scouring out a basin in the stream substrate where the flow radiates from the point of water entry. This is an example of hydraulic control in a stream that determines how energy of moving water shapes a channel. Also referred to as a falls pool or plunge basin.

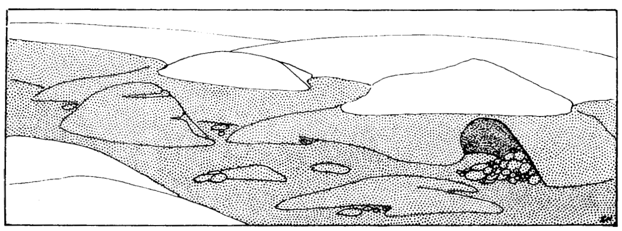


pocket water (from Helm 1985)

pocket water One or a series of small pools in a section of swiftly flowing water containing numerous obstructions such as boulders or logs which create eddies or scour holes in the channel substrate. Typically found in cascades and rapids.

residual pool The pool portion that lies below the elevation of the downstream outlet crest.

straight Straight, elongated pool in the center of a channel that is created by an upstream constriction.



trench (from Helm 1985)

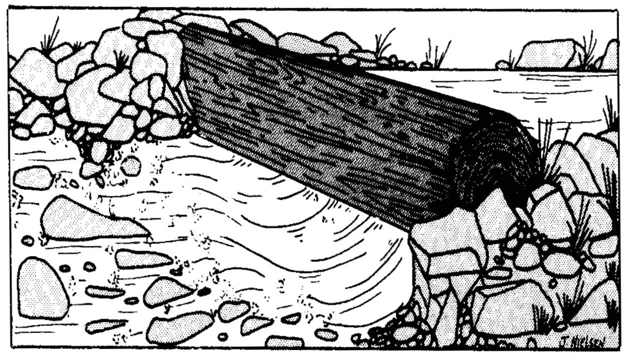
trench A relatively long, deep slot-like depression in the streambed, typically with a U-shaped channel, coarse-grained or bedrock substrates, and high water velocities. Such reaches are usually found in highly confined, often bedrock-dominated channels.

underscour pool Form of scour pool created by a log or other obstruction near the surface that causes the water to be deflected downward, scouring out a pool in the substrate. Also referred to as an upsurge pool.

channel width See *channel width* under *dimensions*.

charco See *charco* under *pond*.

check dam See *check dam* under *habitat enhancements*.



underscour pool (from Helm 1985)

chemical oxygen demand (COD) Represents the reduction capacity of organic and inorganic matter present, and is the amount of molecular oxygen required to stabilize the proportion of the sample which is susceptible to oxidation by a strong chemical oxidant.

chemical stratification Layering of water in a lake because of density differences or differential concentrations of dissolved substances with depth.

chemocline See *chemocline* under *stratification*.

chronic toxicity Sublethal toxicity of long duration that adversely affects an organism and may eventually lead to death. The sublethal toxicity is reflected through changes in productivity and population structure of a community.

chunk rock Formation of mixed sized, irregular-shaped rocks caused by gravity or erosion, usually found at the base of a bluff or cliff.

chute (from Helm 1985)

chute (1) A narrow, confined channel through which water flows rapidly. (2) A rapid or quick descent in a stream, usually with a bedrock substrate. (3) A short straight channel which bypasses a long bend in a stream, and is formed by the stream cutting across a narrow land area between two adjacent bends. See also *chute* under *fast water—turbulent* under *channel unit*.

cienagas See *cienagas* under *wetlands*.

cirque Rounded, bowl-like depressions in mountains that are created by weathering, erosion, and glacial action.

cirque lake See *cirque lake* under *lake*.

class See *class* under *remote sensing*.

classic falls See *classic falls* under *fast water—turbulent*, *falls* under the main heading *channel unit*.

clast An individual particle, detrital sediment or a sedimentary rock, initially produced by the disintegration of a larger mass of bedrock, classified according to size.

clay Natural earthy material which is plastic when wet, and consists essentially of hydrated silicates of aluminum, less than 4 µm. Compare with other substrate sizes under *substrate size*.

clay bottom Bottom composed of clay or clay-like material.

cleanwater association An association of organisms found in any natural, unpolluted environment that is characterized by species sensitive to environmental changes caused by contaminants or pollutants.

cliff The high steep face of a rocky mass overlooking a lower area; a precipice. See *bluff*.

climate The meteorological conditions including temperature, precipitation, wind, pressure, evaporation, and transpiration that prevail in and characterize a location.

climatic year A continuous 12-month period during which a complete annual cycle occurs. The U.S. Geological Survey uses the period October 1 through September 30 in the publication of its records of streamflow as a water year. See *water year*.

climax succession stage See *climax succession stage* under *succession*.

clinograde See *clinograde* under *stratification*.

clinolimnion See *clinolimnion* under *stratification*.

closed basin A basin without a surface outlet, from which water is lost only by evaporation or percolation.

closed lake See *closed lake* under *lake*.

clump A relatively dense aggregation of vegetation of the same species. See also *clump* under *large organic debris* and *remote sensing*.

cluster See *cluster* under *remote sensing*.

coarse load See *coarse load* under *sediment load*.

coarse particulate organic matter See *coarse particulate organic matter (CPOM)* under *organic particles*.

coarse woody debris See *large organic debris*; also a synonym for *large woody debris*.

coast Land next to the sea.

coastal delta floodplain See *coastal delta floodplain* under *floodplain*.

coastal lake See *coastal lake* under *lake*.

coastal plain A relative flat area, or plain, extending along a coast.

coastline Shape or pattern of an ocean coast.

cobble Stream substrate particles between 64 and 128 mm (2.5–5 in) in diameter. Compare with other substrate sizes under *substrate size*.

coefficient of storage See *coefficient of storage* under *groundwater*.

coffer dam Temporary structure constructed in a water body to provide a dewatered area for construction of structures such as bridges.

cohesion State in which particles of a single substance are held together by primary or secondary valence forces.

col A pronounced dip in a ridge, or between two peaks, connecting a neck of land; often formed at a divide where water courses flow in opposite directions.

cold monomictic See *cold monomictic* under *mixing*.

cold spring See *cold spring* under *spring*.

coldwater fishes A broad term applied to fish species that inhabit waters with relatively cold temperatures (optimum temperatures generally between 4–15°C (40–60°F). Examples are salmon, trout, chars, and whitefish. Compare with *coolwater fishes*, *warmwater fishes*.

coldwater lake See *coldwater lake* under *lake*.

collectors See *collectors* under *macroinvertebrates*.

colloidal Particles which are 10^{-7} to $5x10^{-6}$ mm in diameter, larger than most inorganic molecules, and that usually remain suspended indefinitely in the water column.

colluvial Gently inclined surface at the base of a slope that represents a transition zone between landforms. Colluvium is characterized by erosion and transport, and downslope sites of deposition. See also *colluvial* under *streambank material*.

colluvial soil Recently transported soil derived from material eroded and deposited locally through sheet flow. In its extreme form, such as avalanche or landslide, the soil comprises material of many sizes.

colluvium A general term for loose deposits of soil and rock moved by gravity (e.g., talus). See also *colluvium* under *valley segments*.

colonization The establishment of a species in an area not previously occupied by that species.

color The quality of water with respect to reflected or refracted light, measured as a wavelength pattern or hue.

community An assemblage of plants and animals occupying a given area; two or more populations of organisms interacting within a defined time and space.

community tolerance quotient (CTQ) See *community tolerance quotient (CTQ)* under *biological indices*.

compaction An increase in the density of a material by reducing the voids between the particles. The relative density of bed material, usually caused by sedimentation, mineralization, or imbrication.

compensation Creation or restoration of wetland areas that are equivalent to areas and functions of destroyed wetlands.

compensation level Depth in a water body at which the available light is reduced enough to cause photosynthesis to equal respiration. Also referred to as the compensation point.

competence Maximum size of particle that a stream can carry, which depends on water velocity and gradient. Also defined as the critical stress necessary for grain movement.

complex falls See *complex falls* under *fast water—turbulent*, *falls* under the main heading *channel unit*.

complexity Term used to describe the presence of a variety of habitat types within a defined area of a waterbody. Increased complexity provides habitat for a greater variety of organisms or life stages, and is usually an indicator of better habitat health.

compound meander See *compound meander* under *meander*.

concave bank See *concave bank* under *streambank*.

concretion A localized concentration of chemical compounds (e.g., calcium carbonate and iron oxide) in the form of a soil grain or nodule of varying size, shape, hardness, and color; concretions of significance in hydric soils are usually iron oxides and manganese oxides occurring at or near the soil surface, the result of fluctuating water tables.

conductivity A measure of the ability of a solution to carry an electrical current. Conductivity is dependent on the total concentration of ionized substances dissolved in the water and is measured as microsiemens per centimeter.

conduit A pipe, tube, or the structure for conveying water or other fluids.

confined See *confined* under *confinement*.

confined aquifer An aquifer that is restricted in size by impervious materials.

confined channel See *confined channel* under *channel geometry*.

confined meander See *confined meander* under *meander*.

confinement Degree to which the river channel is limited in its lateral movement by valley walls or relic terraces.

channelization Deepening an existing stream channel or creating a new stream channel by human activity to increase the rate of runoff or to lower the water table.

confined channel A stream that is in continuous or repeated contact at the outside of major meander bends.

entrenched channel A stream bend that is in continuous contact with bedrock valley walls or terraces.

frequently confined channel A stream that is frequently confined by the valley walls or terraces.

secondarily confined channel A stream channel that has cut down into deposited sediments because a controlling structure has been lost.

unconfined channel A stream channel that is not touching the valley wall or terrace and is capable of lateral migration.

confluence The location where two streams flow together to form one.

conglomerate Cemented material; rock consisting of rounded and waterworn gravel imbedded in a finer material.

conjugate points (conjugate principle points) See *conjugate points (conjugate principle points)* under *remote sensing*.

connate water Water trapped in deep geological sediments at the time the sediment was deposited.

connectivity Water exchange between the river channel and the associated floodplain.

consequent stream See *consequent stream* under *stream*.

conservation pool The minimum water level that is normally reserved behind a dam for a variety of purposes.

conservation storage Storage of water for later release for useful purposes (e.g., municipal water supply, power, or irrigation) in contrast with storage of water used for flood control.

constriction (1) A reduction in the channel width by a resistant structure. (2) Location where the river channel is prevented from migrating laterally within the valley, usually by a bedrock ridge protruding from the valley wall.

consumptive water use Occurs when water is removed and not returned.

contamination Presence of elevated levels of compounds, elements, physical parameters, or substances that make the water impure or unsuitable for use.

contents Volume of water in a reservoir. Unless otherwise indicated, reservoir content is computed on the basis of a level pool and does not include bank storage.

contiguous habitat Habitat able to provide the life needs of a species that is distributed in a continuous or nearly continuous pattern.

continuous gully See *continuous gully* under *gully*.

continuous stream See *continuous stream* under *stream*.

contour An imaginary line of constant elevation related to the surface of the earth.

controlling breaching See *controlling breaching* under *breaching*.

control station Any streamflow measurement site where a regulatory base flow has been established.

control structure Artificial structure designed to regulate and control the movement of water.

draft tube A conduit extended from a turbine.

drop inlet A water level control structure with a vertical tube connected to a horizontal tube that discharges through a dike or dam.

drum gate A circular gate at the entrance of a spillway.

gallery Area of a water intake structure behind a trash rack where water is distributed across the face of a screen to prevent fish and small debris from entering the water system.

gate Moveable structures used to control the movement, storage, and drainage of water.

flap gate Moveable gate at a right angle to a pipe that responds to a change in flow. The current opens the gate to drain and pushes the gate against the pipe to prevent re-entry of water.

radial gate A gate on pivotal arms.

roller gate Similar to a sliding gate but operating on rollers.

sliding gate Horizontal gate that is hoisted up or down between guides.

high tube overflow Horizontal tube on a small impoundment that can accommodate spill.

natural spillway Natural, undisturbed ground sufficiently firm to handle overflow from an impoundment.

ogee Spillway with an S-shaped weir.

outlet tower Structure that provides water control to a powerhouse inlet.

penstock Intake for a turbine.

ski jimp Spillway shaped like a ski jump.

spillway Part of a control structure designed to allow water to spill over a dam without weakening it.

stop log Box, logs, or planks with a drain pipe at the bottom that extends through the wall of an impoundment.

tin whistle Vertical riser tube connected to a horizontal tube through the wall of an impoundment. Stop logs are placed around the riser so that the water level is higher than the top of the riser allowing water to spill over the logs into the vertical tube.

trash rack Protective structure used to intercept logs and other debris.

turbine Rotary motor for converting the energy of falling water into electricity.

convex bank See *convex bank* under *streambank*.

conveyance loss Loss of water in transit from a conduit or channel due to leakage, seepage, evaporation, or evapo-transpiration.

convolution The sinuosity of a stream channel. The convolution index is the same as the sinuosity index.

cooling pond See *cooling pond* under *pond*.

cooling water Water used to cool operating equipment of a power plant or other industrial facility.

coolwater fishes A broad term applied to fish species that inhabit waters with relatively cool temperatures (optimum temperatures generally between 10 and 21°C (50 and 70°F). Compare with *coldwater fishes*, *warmwater fishes*.

copropel See *gyttja*.

coriolis effect (1) Force deflecting water currents as a result of the earth's rotation. The deflection is to the right in the Northern Hemisphere and to the left in the Southern Hemisphere.
(2) A force acting at right angles to horizontal path of particles in motion.

corner pool See *corner pool* under *slow water*, *pool*, *scour pool* under the main heading *channel unit*.

corrasion (1) The wearing down of underwater surfaces by chemical solutions. (2) The lateral and vertical cutting action of water courses, through abrasive power of their loads. (3) The wearing down of underwater surfaces through natural friction, as in the moving bed load of rivers. Sometimes referred to as abrasion.

counter dam A small wall built across the apron of the foot of a key dam to prevent it from being undermined by erosion.

course The direction of flow of water across the earth's surface.

cove A small indentation or recess in the shoreline of an aquatic system, sea, lake, or river; a sheltered area. See *arm*, *bay*, *embayment*.

cover Structural materials (boulders, logs, or stumps), channel features (ledges, vegetation), and water features (turbulence or depth) that provide protection for aquatic species. See also *cover* under *habitat enhancements*.

crater lake See *caldera lake* and *volcanic lake* under *lake*.

creek A small lotic system that serves as the natural drainage course for a small drainage basin. See *brook*.

creep Gradually and generally imperceptible downhill movement of soil and loose rock; a slow moving type of landslide.

creeping flow See *creeping flow* under *flow*.

crenocole An organism living only in spring environments.

crenogenic meromixis See *crenogenic meromixis* under *mixing*.

crenophile An organism that prefers spring environments but may be found in similar types of habitat.

crest (1) Top of a dike, spillway, or weir to which water must rise to pass over. (2) The summit or highest point of a wave. (3) Highest elevation reached by flood waters flowing in a channel.

crib See *crib* under *habitat enhancements*.

cribwell See *cribwell* under *habitat enhancements*.

critical depth Minimum depth that can occur as water flows over the top of a boulder, log, or crest of a spillway. Occurs slightly upstream of the brink.

critical flow State of water flow when one or more properties such as velocity undergoes a change.

critical location Location along a stream with a minimum concentration of dissolved oxygen.

critical reach See *critical reach* under *reach*.

critical slope Slope that sustains a uniform critical flow.

critical velocity See *critical velocity* under *velocity*. Also referred to as *critical flow*.

cross-ditch A ditch excavated across the road at an angle and depth sufficient to divert both road surface water and ditch water off or across the road.

cross-over bar See *cross-over bar* and *transverse bar* under *bar*. Definition is provided with *transverse bar* under *bar*.

cross-sectional area See *cross-sectional area* under *dimensions*.

crown The growing tip of a tree.

cryogenic lake See *cryogenic lake* under *lake*.

cryptodepression Portion of a lake below sea level.

cuesta Coastal plain ridge that is steepest toward the continent, due to the differential erosion of sedimentary deposits that gently dip seaward.

cultural eutrophication Accelerated addition of nutrients to a water body by human activities.

culvert A passage, usually a pipe, constructed beneath a road, railroad, or canal to transport water.

current Water moving continuously in one direction; the speed at which water is moving. See *velocity*.

curtain falls See *curtain falls* under *fast water—turbulent, falls* under the main heading *channel unit*.

cusps Triangular deposits of sand, or other current drift, spaced along a shore.

cut bank See *cut bank* under *streambank*.

cutoff lake See *cutoff lake* under *lake*.

cutoff wall A wall (usually concrete) installed downstream of culverts to keep water and materials in place.

cutting back Upslope movement of a stream channel due to erosion. See also *head cut*.

cycle of erosion progressive stages in erosion of a landscape.

▶ d

D_{50} See d_{50} or D_{50} under *sediment load*.

daily discharge See *daily discharge* under *discharge*.

dam A barrier obstructing the flow of water that increases the water surface elevation upstream of the barrier. Usually built for water storage or to increase the hydraulic head.

damaging flood A flood of magnitude exceeding the normal maximum discharge.

dam-break flooding See *dam-break flooding* under *flooding*.

dammed pool See *dammed pool* under *slow water, pool* under the main heading *channel unit*.

Darcy's law See *Darcy's law* under *groundwater*.

deadhead A log floating at or near the surface that presents a hazard to boating. See also *deadhead* under *large organic debris*.

dead lake See *dead lake* under *lake*.

deadman A structure of wood, metal, or concrete that is buried in the ground to serve as an anchor for cables or other lines.

dead storage The volume in a reservoir below the lowest controllable level.

dead water Water without measurable currents. Generally refers to water in a stream behind an obstruction.

debris Any material, organic or inorganic, floating or submerged, moved by water. Geologists and hydrologists have used this term in reference to inorganic material; more recently fishery workers have used the term in reference to organic material.

debris avalanche See *debris avalanche* under *landslide*.

debris fall See *debris fall* under *landslide*.

debris flow See *debris flow* under *landslide*.

debris jam or dam See *debris jam or dam* under *landslide*.

debris loading The quantity of debris located within a specific reach of stream channel due to natural processes or human activities.

debris pool See *debris pool* under *slow water, dammed pool* under *channel unit*.

debris slide See *debris slide* under *landslide*.

debris torrent See *debris torrent* under *landslide*.

deck Walking or work surface on an impoundment, dock, or boat.

deep-seated creep See *deep-seated creep* under *landslide*.

deep-seated failures See *deep-seated failures* under *landslide*.

deepwater habitat Permanently flooded lands lying below the deepwater boundary of wetlands. This boundary is 2 m (6.6 ft) below low water or at the edge of emergent macrophytes, whichever is deeper. Any open water in which the mean water depth exceeds 2 m (6.6 ft) at mean low water in nontidal and freshwater tidal areas, or below extreme low water at spring tides in salt and brackish tidal areas, or the maximum depth of emergent vegetation, whichever is greater.

deepwater zone An area of fairly great depth.

deflector See *deflector* under *habitat enhancements*.

degradation (1) Geologic process by which streambeds and floodplains are lowered in elevation by the removal of material.
(2) A decline in the viability of ecosystem functions and processes. Compare with *aggradation*.

degraded channel See *degraded channel* under *channel geometry*.

deliverability Likelihood that, as a result of one or more land-use practices or through cumulative effects, a given amount of wood, water, sediment, or energy will be delivered to fish habitat in streams.

delivered hazard Adverse changes in the amount or location of wood, water, sediment, or energy being delivered downstream that may affect fish, water quality, or capital improvements.

delta Flat plane of alluvial deposits between the branches at the mouth of a river, stream, or creek. See *alluvial fan*.

delta bar See *delta bar* under *bar*.

delta kame Deposit with the form of a steep, flat-topped hill located at the front of a retreating continental glacier.

delta lake See *delta lake* under *lake*.

dendritic channel See *dendritic channel* under *channel pattern*.

density (1) Number of individuals per unit of surface area or volume. (2) Mass per unit volume.

density current A flow of water maintained by gravity through a large body of water, such as a reservoir or lake, that retains its unmixed identity because of density differences.

density stratification See *stratification*.

deposit An accumulation of organic or inorganic material resulting from naturally occurring biological, chemical, or physical processes.

depositing substrate Bottom areas where solids are being actively deposited, often in the vicinity of effluent discharges.

deposition Settling of material from the water column and accumulation on the streambank or bed. Occurs when the energy of flowing water is unable to support the load of suspended material.

deposition zone Location along an erosion transport network where materials are deposited because water velocity and volume are insufficient to retain the materials in suspension.

depression Any relatively sunken part of the earth's surface, especially low-lying areas surrounded by higher ground, that may be natural or constructed.

depression storage Volume of water contained in natural depressions on the land surface (e.g., puddles).

depth See *depth* under *dimensions*.

depth : area ratio See *depth : area ratio* under *dimensions*.

depth integration See *depth integration* under *sediment load*.

depth of scour A relationship of the depth of scouring to the bed load transport rate:

$$d_s = \frac{Q_b}{u_b W p_s (1-p)};$$

d_s = depth of scour;
u_b = average bed load velocity;
Q_b = bed load transport rate;
W = width of stream;
p = particle size.

deranged channel See *deranged channel* under *channel pattern*.

desalinization Removal of salts from brackish or marine waters.

desert river See *desert river* under *river*.

desiccation Process of dehydration or drying up.

design high water level Elevation of the enveloped profile of the 50-year flood, or flood series, routed through the reservoir with a full conservation pool after 50 years of sediment, or the elevation of the top of the flood control pond, whichever is higher.

destratification See *destratification* under *stratification*.

detention reservoir An ungated reservoir for temporary storage of flood water.

detention storage Volume of water, other than depression storage, flowing on the land surface and that has not yet reached the channel.

detrital sedimentation Deposition of organic sediments.

detritus A nondissolved product of disintegration or wearing away. Pertains to small organic particles like leaves and twigs. Detritus may pertain to material produced by erosion, such as soil, sand, clay, gravel, and rock, carried down a watercourse, and deposited on an outwash fan or floodplain.

dewatering Removal of water from a site.

diadromous Life history strategy, that includes movement between fresh- and saltwater, where organisms exhibit two migrations to spend various life stages in different ecosystems. Compare with *anadromous*, *catadromous*, *oceandromous*, *potamodromous*.

diagonal bar See *diagonal bar* under *bar*.

diamond bar See *diamond bar* under *bar*.

diamond-braided bar See *diamond-braided bar* under *bar*.

diatom Microscopic algae with a silaceous skeleton that occurs as plankton or attaches to substrate.

diel Pertaining to a 24-hour period or a regular occurrence in every 24-hour period. See *diurnal*.

diffuser A structure at or near the end of an outfall designed to improve the initial dilution, dispersal, or mixing of discharged effluent.

diffusivity Rate at which a substance or temperature change will be transmitted through the water.

digger log See *digger log* under *habitat enhancements*. Compare with *digger log* under *large organic debris*.

digital classification See *digital classification* under *remote sensing*.

digital enhancement See *digital enhancement* under *remote sensing*.

digital terrain model See *digital terrain model* under *remote sensing*.

digitizing See *digitizing* under *remote sensing*.

dike An embankment for controlling water. Also used for any impoundment structure that completely spans a navigable water. Compare with *berm* under *habitat enhancements*.

dilution Reduction in the concentration, or strength, of a substance by increasing the proportion of water in the mixture.

dimensions The linear, areal, and volumetric features of an aquatic habitat as measured on both the horizontal and vertical scale.

acre-foot A unit for measuring the volume of water, equal to the quantity of water required to cover a surface area of one acre (0.4047 ha) to a depth of one foot (0.3048 m) and equal to 43,560 cubic feet, 325,851 gallons, or 1,233 cubic meters.

area Quantitative measurement of the surface of a body of water or drainage basin.

average depth Total of all depth measurements divided by the number of measurements taken at a site on a water body.

average width Total of all width measurements divided by the number of measurements taken at a site on a water body.

bank depth Vertical distance between the water surface and the floodplain.

bank width See *channel width* under *dimensions*.

basin slope Change in depth per unit of horizontal distance.

breadth See *width* under *dimensions*.

channel width Horizontal distance along a transect line from bank to bank at the bankful stage, measured at right angles to the direction of flow. Multiple channel widths are summed to represent total channel width.

cross-sectional area Area formed by the width and depth of a stream, channel, or waterway, measured perpendicular to the center line of flow.

depth Dimension of a water body measured vertically from the surface to the bottom.

depth : area ratio Area of a lake, by depth classification, expressed as a ratio to the total lake area.

drainage basin shape (R_f) Ratio of a basin's area (A) to the square of its maximum length (L):

$$R_f = A/L^2 .$$

hydraulic depth (D) Ratio of the cross-sectional area (A) divided by the width (W):

$$D = A/W .$$

hydraulic radius (R) Ratio of the cross-sectional area (A) divided by the wetted perimeter (P):

$$R = A/P .$$

lake volume An estimation of the total volume of a lake:

$$V = (h/3)\ (A_1 + A_2 + [A_1A_2]^{1/2})\ ;$$

h = vertical depth;
A_1 = area of the upper surface;
A_2 = Area of lower surface.

lake width Distance on the lake surface from shore to shore at right angles to the length.

length Distance along the thalweg of a stream channel or the longest straight axis between the shores of a lake.

maximum bank height Maximum vertical distance from the water surface to the top of the highest bank.

maximum depth Greatest depth of the body of water. In streams, the greatest water depth at the sample location.

maximum elevation Highest point in the sample area, or the highest point in a watershed.

maximum lake length Single line distance on the lake surface between the most distant points on the lake shore.

maximum width Greatest measurement from shore to shore along a line perpendicular to the thalweg of a stream or the greatest measurement across other bodies of water.

mean lake depth (Z) Volume (V) divided by the surface area (A):

$$Z = V/A\ .$$

Compare with *average depth* under *dimensions*.

mean lake width Quotient of the lake area divided by the maximum length.

mean stream length Length of a stream segment along a line extending from the point of origin in a stream along the center of the channel to the point where the measurement is terminated.

median depth Midpoint elevation between the maximum depth and the surface on a line from shore to shore.

median width Midpoint width between the start of measurements and the maximum measurements.

minimum bank height Minimum vertical distance from the water surface to the top of the lowest bank.

pool : riffle ratio Ratio of the surface area or length of pools to the surface area or length of riffles in a given stream reach, frequently expressed as the relative percentage of each category.

pressure head Relative pressure (excess over atmospheric pressure) divided by the unit weight of water, expressed in units of height.

radius of curvature (r_c) Radius of the curve that describes the symmetrical meander of a stream or river. Is often used to evaluate channel resistance to erosion or the migration rates of bends and meanders.

$$r_c = \frac{L_m K^{-1.5}}{13\,(K-1)^{½}}\ ;$$

L_m = meander wavelength;
K = sinuosity.

relative depth (Z_r) Maximum depth (Z_m) as a percentage of the mean diameter of a lake. With diameter expressed in terms of lake area (A), the formula is:

$$Z_r = \frac{88.6 \times Z_m}{A^{½}}\ .$$

relief ratio (R_r) Ratio of a basin's length and altitude change in the basin:

$$R_r = h/L\ ;$$

h = difference in elevation between the river mouth and the highest point in the drainage
L = maximum length of a basin

shoreline : area ratio Ratio of lake shoreline length to area of lake surface.

shoreline development (D_L) Ratio of a lake's shoreline length (L) to the circumference of a circle having the same area (A) as the lake:

$$D_L = \frac{L}{2(\pi A)^{½}}\ .$$

shoreline length Length of the perimeter of a lake.

sinuosity An index (K) of a stream's meander as a function of stream length or valley profile.

$$K = \frac{L_c}{L_v} = \frac{S_v}{S_c}\ ;$$

L_c = channel length;
L_v = valley length;
S_v = valley slope;
S_c = channel gradient.

stream width Distance between the two margins of flowing water in a stream at right angles to the flow.

top width Width of a stream at the water surface that varies with changes in flow.

valley floor width index (VFWI) Measure, in channel widths, of the variation in the width of a valley floor.

$$\mathrm{VFWI} = \frac{(W_{ac} + W_{fp})}{W_{ac*}}\ ;$$

W_{ac} = width of active channel;
W_{fp} = floodplain width;
W_{ac*} = average width of active channel for all reaches at each site.

volume development Comparison of the shape of a lake to the shape of an inverted cone equal to the lake's surface area.

wetted cross section Total cross-sectional area through which a river flows above the bed at a specific discharge.

wetted perimeter Length of the wetted contact between a stream of flowing water and the stream bottom in a vertical plane at right angles to the direction of flow.

wetted width Width of a water surface measured perpendicular to the direction of flow at a specific discharge. Widths of multiple channels are summed to represent the total wetted width.

width Measure of the cross section shape of a stream channel or across the narrow dimension of a lake, pond, or reservoir.

width : depth ratio An index of the cross section shape of a stream channel, at bankful level.

dimictic See *dimictic* under *mixing*.

dip A hollow or depression in a land form.

dipslope Conformation of land surface features with the shape of underlying bedded materials.

direct solar radiation See *direct solar radiation* under *solar radiation*.

direct toxicity Toxicity that has a direct—rather than indirect—effect on organisms, for example, chronic exposure to toxicants from contaminated food organisms.

discharge (1) Rate at which a volume of water flows past a point per unit of time, usually expressed as cubic meters per second or cubic feet per second. (2) Intentional or unintentional release of substances into a waterway or water body that can occur from spilling, leaking, pumping, pouring, or dumping. (3) Any addition of dredged or fill material into a waterway or water body.

annual maximum daily discharge Highest total daily discharge during the year.

annual maximum instantaneous discharge Highest discharge recorded in a year.

annual mean discharge Sum of total daily discharges for a year divided by the number of days in a year. Also, the total annual discharge divided by the number of seconds in a year.

annual minimum daily discharge Lowest discharge recorded for any single day during a one-year period.

daily discharge Total discharge from midnight to midnight for a continuous recording.

hydraulic discharge An estimate of water volume (Q) passing by a point on a stream or river:

$$Q = WDu\,;$$

W = width;
D = depth;
u = velocity of flow.

See *stream discharge* under *discharge* for an alternate meaning of Q.

instantaneous discharge Discharge at a particular point in time.

mean monthly discharge Average volume of water discharged per month during the given year. Expressed as hectares per meter.

monthly mean discharge Average volume of water discharged per day during the given month.

stream discharge An estimate of water volume (Q) passing a point on a stream or river:

$$Q = AVn\,;$$

A = cross section area of stream channel;
V = velocity of water;
n = Manning's bed roughness constant.

See *hydraulic discharge* under *discharge* for an alternative meaning of Q.

discharge area An area where water is released into surface water, groundwater, or the atmosphere.

disclimax Term applied to a situation where recurring disturbances, such as grazing or periodic burning, exert a predominant influence in maintaining the species composition and density of vegetation.

discontinuity layer See *discontinuity layer* under *stratification*.

discontinuous gully See *discontinuous gully* under *gully*.

dished out bank Streambanks that have a bank angle greater than 90°. See *streambank*.

dispersal Multi-directional spread, at any time scale, of plants or animals from any point of origin to another, resulting in occupancy of other areas in their geographic range. Differs from emigration or immigration where movements are one-way from or into an area, respectively.

dispersion (1) Separation or scattering of particles in water. (2) Active movement of individual organisms into adjoining areas.

dissolved load Quantity of material dissolved in a specified volume of liquid.

dissolved organic matter See *dissolved organic matter (DOM)* or *dissolved organic carbon (DOC)* under *organic particles*.

dissolved oxygen Concentration of oxygen dissolved in water, where saturation is the maximum amount of oxygen that can theoretically be dissolved in water at a given altitude and temperature. Expressed as milligrams per liter or as percent saturation.

dissolved solids Total of disintegrated organic and inorganic material that is dissolved in water. See *total dissolved solids*.

distorted meander See *distorted meander* under *meander*.

distributary See *distributary* under *stream*.

distribution Occurrence, frequency of occurrence, position, or arrangement of animals or plants within an area. May also be applied to a rate such as the number per unit of area or unit of time.

distrophic (dystrophic) See *distrophic* under *trophic*.

disturbance A force that causes changes in habitat or community structure and composition through (a) natural events such as fire, flood, wind, or earthquake; (b) mortality due to insect or disease outbreaks; or (c) human activities such as agriculture, grazing, logging, mining, road construction, etc.

ditch A long, narrow excavation in the ground (usually an open and unpaved channel, trench, or waterway smaller than a canal) for conveying water to or from a specific location for purposes such as drainage or irrigation.

diurnal (1) Refers to events, processes, or changes that occur every day. (2) May be applied to organisms that are active during the day. See *diel*.

diversion An artificial structure, such as a canal, embankment, channel, pipe, or other conduit, for taking water from a stream or other body of water to another location.

diversity Variation that occurs in plant and animal taxa (i.e., species composition), habitats, or ecosystems within a given geographic location.

diversity index Any of several numerical measures of animal or plant diversity in a given area. Often, the relationship of the number of taxa (richness) to the relative number of individuals per taxon (evenness) for a given community or area. See *diversity index* under *biological indices*. Also, see *habitat quality indices*.

divide Topographical boundary in a catchment area that is related to the highest elevation surrounding the area. The hydrological divide would include subsurface as well as surface runoff. See *drainage divide*.

dock A narrow walk or platform supported on posts or floats extending from the shore into a water body for the purpose of anchoring, docking, and landing boats, and for loading equipment and people into boats.

doline lake See *doline lake* under *lake*.

domain Region or area that is characterized by a specific feature, such as the type of vegetation, aquatic system, or wildlife.

domestic water supply Water from wells, streams, lakes, or reservoirs used for human consumption and other uses in homes.

dominance and taxa (DAT) See *dominance and taxa (DAT)* under *biological indices*.

dominant discharge Stream discharge level(s), usually the bank-full flow, that in aggregate is sustained over a long enough time period to form and maintain a relative equilibrium in a natural channel by dislodging, transporting, and distributing bed materials. Also referred to as a formative discharge.

downcutting Water erosion that deepens an existing channel or forms a new channel where one did not exist previously.

down log See *down log* under *large organic debris*.

downstream link See *downstream link* under *link*.

draft tube See *draft tube* under *control structure*.

dragline Equipment used to excavate and remove bottom materials from a water body. The materials are removed with a bucket that is pulled toward the piece of equipment with cables.

drain (1) To remove and carry away surface or subsurface water. (2) An artificial channel or pipe used to transport surface or subsurface water. See *canal; ditch*.

drainage (1) A watershed that contains all tributary rivers, streams, sloughs, ponds, and lakes that drain a given area. (2) The process of downward removal of surface and subsurface runoff water from soil either by gravity or artificial means.

drainage area Total land area, measured in a horizontal plane, enclosed by a topographic divide, from which direct surface runoff from precipitation normally drains by gravity into a wetland, lake, or river. Also referred to as a catchment area, watershed, and basin. In the case of transbasin diversions, the drainage area would include water from all diverted streams. See *catchment area*.

drainage basin The total surface land area drained by a stream or river from its headwater divides to its mouth. See *catchment basin*.

drainage basin density (D_d) Ratio of total drainage channel length (miles or kilometers, L) to total drainage basin area (square miles or square kilometers, A):

$$D_d = L/A.$$

Synonymous with *stream density*.

drainage basin shape See *drainage basin shape* under *dimensions*.

drainage divide The boundary formed along a topographic ridge or along a subsurface formation that separates two adjacent drainage basins.

drainage lake See *drainage lake* under *lake*.

drainage structure A structure to remove runoff water composed of metal, concrete, or wooden culverts, open-faced culverts, bridges, and ditches.

drainage system Natural or artificial channels that transport water out of a basin.

drainage texture Expression of the space between stream channels above a reference point in a stream. Determined by dividing the number of stream crossings by the length of a contour.

drained A condition where ground or surface water has been removed by artificial means to the point that an area no longer meets the hydrological criterion of a wetland.

draw A long, wide topographic feature formed by perennial or intermittent surface runoff, without reference to the presence or absence of water.

drawdown (1) Lowering of water levels stored behind a dam or other water control structure. (2) Change in reservoir elevation during a specified time interval. (3) Local decline of a water table due to water withdrawal.

dredge (1) Act of sampling or excavating material from the bottom of a water body. (2) Equipment used for sampling or excavation material from the bottom of a water body.

drift (1) Dislodgement of aquatic invertebrates and fish from a stream bottom into the water column where they move or float with the current. (2) Any detrital material transported by water current. (3) Materials deposited ashore by wind or water currents in a pond, lake, or reservoir. (4) Woody debris that has been modified by abrasion in a stream. Sometimes, this term refers to floating materials or surface water set in motion by the wind.

drift line A visible elongated collection of floating debris, detritus, or organic matter that results when opposing forces such as wind and current meet along a bank contour (i.e., parallel to the shoreline of a lake or the flow of a stream) that marks the height of an inundation event or streamflow.

drift organism Benthic organisms temporarily suspended in water and carried by the current of streams.

drop, drop structure See *check dam* under *habitat enhancements*.

drop inlet See *drop inlet* under *control structure*.

drop-off A vertical or steep descent in the bottom of a water body.

drowned valley Valley carved in land by a stream and later flooded by a rise in sea level.

drum gate See *drum gate* under *control structure*.

drumlin A tear-drop shaped landform that results from the deposit of glacial till or other drift with the tapered end pointing in the direction of the glacial movement.

dry dam A dam designed for flood control that does not provide permanent water storage.

dry ravel See *dry ravel* under *landslide*.

dry wash An intermittent streambed in an arroyo or canyon that contains rainwater for a very short time.

Duboy's equation An equation that calculates the force per unit of area exerted on the streambed at different flows or used to predict the capability of a system to move bed load material.

dug pond See *dug pond* under *pond*.

dune (1) Summit and sloping sides of a mound, hill, or ridge of loose, unconsolidated, granular windblown deposits. (2) In streams, bedforms that are generally transverse to the direction of flow with a triangular profile that advances downstream due to net deposition of particles from the gentle upstream slope to the steeper downstream slope. Dunes move down the stream at velocities that are small relative to streamflow.

dune bar See *dune bar* under *bar*.

dune lake See *dune lake* under *lake*.

dune pond See *dune pond* under *pond*.

duration curve A graphical representation (a curve) of the number of times given quantities such as streamflow occurred or a percentage of events within a time period. The event or quantity is arranged in order of magnitude along the ordinate with the time period expressed as a percentage along the abscissa.

duration of inundation or saturation Length of time that water remains above the soil surface when water fills most of the interspaces between soil particles.

duty of water In irrigation, the quantity of water required to satisfy the irrigation water requirements of land. It is expressed as the rate of flow required per unit area of land, the area which can be served by a unit rate of flow, or the total volumetric quantity of water in terms of depth, required during the entire or portion of the irrigation season. In stating the duty, the crop, the location of the land in question, and the soil type are usually specified.

dy Soft, fine-grained sediment (composed almost entirely of organic matter) in lakes, bogs, marshes, or swamps. Yellow-brown, flocculent, fibrous, undecomposed plant material with a low pH that is derived to a great extent from peat in a bog sedge mat or from other allochthonous sources.

dynamic equilibrium (1) Condition of a system where there is balanced inflow and outflow of material. (2) A migrating channel that is in equilibrium in terms of shape, pattern, and geometry.

dystrophic lake See *dystrophic lake* under *lake*.

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early succession stage See *early succession stage* under *succession*.

earth (1) Soft surface materials composed of soil and weathered rock. See *ground*, *soil*. (2) Name for the Planet Earth.

earth dam A barrier formed by the accumulation of earth that impedes the flow of water.

earthflow See *earthflow* under *landslide*.

earth islands See *earth islands* under *habitat enhancements*.

earthquake lake See *earthquake lake* under *lake*.

earth slump See *earth slump* under *landslide*.

ebullition Bubbling up of gases produced through the decay of organic matter in the substrate.

ecoclimate Climate (temperature, humidity, precipitation, winds, and solar radiation) that occurs in a particular habitat or ecosystem.

ecocline Gradual, continuous change in an environmental condition of an ecosystem or a community.

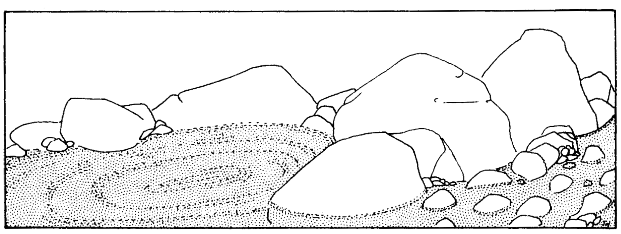
ecosystem Any complex of living organisms interacting with nonliving chemical and physical components that form and function as a natural environmental unit.

ecosystem function Any performance attribute or rate function with some level of biological organization (e.g., energy flow, detritus processing, or nutrient spiralling).

ecotone Transition zone between two or more ecosystems or communities.

ectogenic meromixis See *ectogenic meromixis* under *mixing*.

edaphic Pertaining to or affected by geology or soil rather than climate or water.



eddy (from Helm 1985)

eddy Circular current of water, sometimes quite strong, diverging from and initially flowing against the main current in streams. Eddies are usually formed where water flows past some obstruction or on the inside of river bends. Eddies often form backwater pools, alcove pools, or pocket water in rapids and cascades. See *eddy* under *slow water*, *pool*, *scour pool* under the main heading *channel unit*.

eddy flow Pattern of water movement created within an eddy.

eddy flux Continuous change and movement of water in an eddy.

eddy return channel See *eddy return channel* under *channel pattern*.

edge effect Ecotone or zone between two adjoining habitats or communities with different vegetation, climate, flow, or other features that contain an increased biological diversity and density of organisms.

edgewater Water that occurs at the interface between land and a water body. See also *edgewater* under *slow water* under the main heading *channel unit*.

effluent (1) Discharge of liquid into a water body or emission of a gas into the environment. Usually composed of waste material. For example, emission of combustion gases into the atmosphere from industry or manufacturing. (2) Also, may be used to describe a streamflowing out of a lake or reservoir.

effluent flow See *effluent flow* under *flow*.

effluent seepage Diffuse discharge of effluents into groundwater or surface water.

Ekman dredge Device for sampling macroinvertebrates in bottoms of water bodies with soft substrates.

Ekman spiral (1) Current drift that is deflected 45° from the direction of the wind by geostrophic deflection. (2) Sequence of direction shifts of current that is generated by wind, usually downward from a lake surface. Ekman spirals are progressively more clockwise in the Northern Hemisphere.

Ekman transport Refers to drifting currents or organisms in an Ekman spiral.

elevation Height above or below sea level at a given point on the earth's surface. Surface water level in lake or reservoir.

eluvial Of, related to, or composed of eluvium or fine weathered rock.

eluvium (1) Deposit of soil, dust, etc., formed by the decomposition of rock that is found at its place of origin. (2) Soil from which dissolved or suspended material has been removed by percolating water through the process of eluviation.

embankment An artificial deposit of natural material, such as a bank, mound, or dike, raised above the natural surface of the land, and erected along or across a wetted area to divert or hold back water, support a roadway, store water, or for other similar purposes. See *dike* and *streambank*.

embayment (1) An area of water that is enclosed by the topography of the adjoining land. (2) Portion of a stream flooded seasonally or permanently by a reservoir. See *arm; backwater* under *slow water, dammed pool* under the main heading *channel unit; bay; cove*.

embeddedness Degree that gravel and larger sizes of particles (boulders, cobble, or rubble) are surrounded or covered by fine sediment (e.g., less than 2 mm).

emergency spillway Wide outlet in the dam of a reservoir that allows excess water to be passed or spilled during periods of high runoff. Often intended to protect the structural integrity of the dam when storage capacity is high.

emergent macrophyte See *emergent macrophyte* under *macrophyte*.

emergent vegetation Rooted aquatic plants with some herbaceous vegetative parts that project above the water surface. Also referred to as emersed vegetation.

emergent wetland See *emergent wetland* under *wetlands*.

emulsion Mechanical mixture of two liquids that do not readily mix, such as oil and water.

endemic Species that is unique or confined to a specific locality or drainage.

end moraine See *end moraine* under *moraine*.

endorheic Interior drainage from which no or little surface water reaches the sea.

energy Capacity for work or available power. In streams, the capacity of the water to mobilize and move materials.

energy dissipation Loss of kinetic energy in moving water due to bottom friction, pools, large rocks, debris, and similar obstacles that impede flow.

potential energy (PE) Amount of energy in precipitated water that will be dissipated during its transit to sea level:

$$\mathrm{PE} = mgh\ ;$$

m = mass of water;
g = acceleration due to gravity;
h = elevation above sea level.

shear stress Ability of water to mobilize materials from the bed and banks in streams.

$$Y = \rho RS\ ;$$

ρ = density of water;
R = hydraulic radius;
S = channel slope.

stream power (SP) Stream power at a given location, expressed as joules per second per meter.

$$S\rho = \rho gQS\ ;$$

ρ = fluid density;
g = acceleration due to gravity;
Q = discharge;
S = average gradient of the channel.

total stream power Availability of energy at a given location along a stream in relation to temporal loss of potential energy:

$$P = \frac{m\Delta h}{\Delta t}\ ;$$

m = mass of water;
Δh = change in elevation above sea level;
Δt = change in time.

unit stream power Time-rate loss of potential energy per unit mass of water.

$$\omega = \rho gvs\ ;$$

ρ = fluid density;
g = acceleration due to gravity;
s = energy slope of flowing water (usually assumed to be similar to channel gradient);
v = velocity gradient.

energy dissipation See *energy dissipation* under *energy*.

energy efficiency Measure of work accomplished in comparison to energy expended.

enhancement (1) An improvement of ecological conditions over existing conditions for aquatic, terrestrial, or recreational resources. (2) Any change that is made for the improvement of a structural or functional attribute for a species or habitat. Some enhancement activities that result in a positive impact on a single species or specific component of an ecosystem may negatively impact others.

enhancement flow See *enhancement flow* under *flow*.

enrichment Process where discharge or runoff carries nutrients into a water body, enhancing the growth potential for bacteria, algae, and aquatic plants.

entrainment (1) Accumulation or drawing in of organisms by a current, such as at a power plant intake. (2) Progressive erosion of the lower layers in the thermocline that results in a corresponding lowering of the thermocline in a stratified lake.

entrenched channel See *entrenched channel* under *confinement*.

entrenched stream See *entrenched stream* under *stream*.

entrenchment Stream channel incision from fluvial processes.

entrenchment ratio Computed index used to describe the degree of vertical containment of a river. It is the channel width of a flood prone area at an elevation twice the maximum bank-full depth/bank-full width.

environment Combination of physical, chemical, climatic, and biotic conditions that influence the development, growth, structure, and vigor of an organism, population, or community.

eolian See *eolian* under *streambank material*.

epeirogenesis Wide-ranging tectonic events that can raise large crustal blocks in the earth's surface and sometimes create large basins where lakes can form. Similar to orogeny (i.e., mountain building) but slower.

ephemeral Short-lived or transitory.

ephemeral flooding See *ephemeral flooding* under *flooding*.

ephemeral flow See *ephemeral flow* under *flow*.

ephemeral lake See *ephemeral lake* under *lake*.

epibenthos Organisms living at the water–substrate interface.

epilimnion See *epilimnion* under *stratification*.

epilithic Refers to periphyton assemblages on stones. See *epilithic* under *periphyton*.

epilittoral See *epilittoral* under *littoral*.

epineuston (1) Microscopic organisms living on the upper surface of the air–water interface. (2) See *epineuston* under *neuston*.

epipelic Occurring on the surface of fine sediment. See also *epipelic* under *periphyton*.

epiphyte Plant that lives on another plant but is not parasitic.

epiphytic See *epiphytic* under *periphyton*.

epipleuston See *epipleuston* under *neuston* and *pleuston*.

epipotamon See *epipotamon* under *potamon*.

epipsammic See *epipsammic* under *periphyton*.

epirhithron See *epirhithron* under *rhithron*.

epizooic Refers to materials or organisms that live or dwell on the bodies of animals.

equilibrium drawdown Ultimate, constant drawdown that results in a steady rate of pumped discharge.

equitability Measure of the distribution of individuals among the species component in a diversity index. Also referred to as evenness.

erosion (1) Process of weathering or wearing away of streambanks and adjacent land slopes by water, ice, wind, or other factors. (2) Removal of rock and soil from the land surface by a variety of processes including gravitation stress, mass wasting, or movement in a medium.

accelerated erosion Rate of erosion that is much more rapid than normal, natural or geologic erosion, due primarily to human activities.

flow erosion Rapid downhill movement of solum (i.e., soil above the A and B horizons of the parent soil), along with some parent soil material, in a highly saturated condition.

fluvial erosion Erosion caused by flowing water.

geologic erosion Normal or natural erosion from geologic processes through time.

gully erosion (1) Rapid erosion, usually in brief time periods, that creates a narrow channel which may exceed 30 m in depth. (2) Formation of gullies in surficial materials or bedrock by a variety of processes including erosion by running water, weathering and the impact of falling rock, debris slides, debris flows, and other types of mass movement; erosion by snow avalanches.

interill erosion Uniform removal of soil from a small area by the impact of raindrops or by sheet flow.

natural erosion Wearing away of the earth's surface by ice, water, wind, or other agents under natural environmental conditions.

normal erosion Gradual erosion of land used by people that does not greatly accelerate natural erosion.

rill erosion Erosion resulting from movement of soil by a network of small, shallow channels.

saltation erosion Bouncing of small soil or mineral particles from the action of wind, water, or gravity.

sheet erosion Erosion of soil from across a surface by nearly uniform action of rain or flowing water. Sometimes includes rill and interill erosion.

splash erosion Dislodgement and transport of soil particles as a result of the impacts of raindrops.

surface creep erosion Dislodgement and movement of small particles of soil or minerals as a result of wind or gravity.

surface erosion Detachment and transport of surface soil particles by running water, waves, currents, moving ice, wind, or gravity. Surface erosion can occur as the loss of soil, in a uniform layer, in rills, or by dry ravel (broken or crumbled rock).

suspension erosion Movement of dislodged soil or mineral particles by moving water or above the ground by air movement.

erosion cycle Pattern of erosion in a given location that moves and deposits materials over time.

erosion feature Physical feature or geological landmark created from differential erosion of adjoining materials.

erosion lake See *erosion lake* under *lake*.

erosion remnant Material remaining after erosion of the surrounding landform.

erosion surface Land face that is being eroded.

escape ladder See *escape ladder* under *habitat enhancements*.

escapement Number of fish that survive natural and human-caused mortality to spawn.

escape ramp See *escape ramp* under *habitat enhancements*.

escarpment (1) Relatively continuous cliff or steep slope, produced by erosion or faulting, between two relatively level surfaces. Most commonly, a cliff produced by differential erosion. (2) A long, precipitous, cliff-like ridge of rock and other material, commonly formed by faulting or fracturing. See *scarp*.

essential elements Collection of habitat elements, such as water, food, and shelter, that are essential to the continued existence of a plant or animal species; used to describe critical habitat for endangered species.

estuarine See *estuarine* under *valley segments*.

estuarine zone Environmental system consisting of an estuary and the transitional area that are consistently influenced or affected by water from sources such as, but not limited to, salt marshes, coastal and intertidal areas, bays, harbors, lagoons, inshore waters, and rivers.

estuary That part of a river or stream or other body of water having unimpaired connection with the open sea, where the sea water is measurably diluted with freshwater derived from land drainage.

eulittoral See *eulittoral* under *littoral*.

euphotic zone Lighted region in a body of water that extends vertically from the surface to the depth at which light is insufficient to enable photosynthesis to exceed respiration of phytoplankton.

eupotamon Lotic side arms of a river connected at both ends.

euryhaline See *euryhaline* under *salinity*.

eurysaline See *eurysaline* under *salinity*.

eutrophic See *eutrophic* under *trophic*.

eutrophication (1) Natural process of maturing (aging) in a body of water. (2) Natural and human-influenced process of enrichment with nutrients, especially nitrogen (total nitrogen greater than 600 mg/m^3) and phosphorus (total phosphorus greater than 25 mg/m^3), leading to an increased production of organic matter. See also *cultural eutrophication*.

eutrophy State of the nutrient condition (especially nitrogen and phosphorus) in a water body. See *trophic*.

evaporation Loss of liquid water by transition to the gaseous phase.

evaporation pond See *evaporation pond* under *pond*.

evaporite Remains of a solution after most of the solvent (usually water) has evaporated.

evapotranspiration Movement of moisture from the earth to the atmosphere as water vapor by the evaporation of surface water and the transpiration of water from plants.

evorsion lake See *evorsion lake* under *lake*.

exorheic An area of open basins whose rivers ultimately reach the sea.

extinction coefficient (η) (1) Degree of light attenuation in water. (2) Availability of light with increasing depth as a negative exponential:

$$\eta = \frac{\log_e I_s - \log_e I_z}{z};$$

also given as:

$$\eta z = \log_e I_s - \log_e I_z;$$

I_s = light at the water surface;
I_z = light at depth z;
z = depth.

extinct lake See *extinct lake* under *lake*.

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fabric blanket See *fabric blanket* under *habitat enhancements*.

face Slope that drains directly into the length of a stream without an obvious route of surface flow. These areas drain either by subsurface flow, shallow surface runoff without channels, or very small ephemeral streams.

faceted gully side See *faceted gully side* under *gully side form*.

facultative wetland plants Plant species that usually occur in wetlands (estimated probability 67–99%), but occasionally found in uplands.

facultative wetland species See *facultative wetland species* under *wetland status*.

failing bank See *failing bank* under *bank stability*.

fall A free, precipitous descent of water. The plural (falls) may apply to a single waterfall or to a series of waterfalls. See *falls* under *fast water—turbulent* under the main heading *channel unit*.

fall overturn See *fall overturn* under *stratification*.

false color See *false color* under *remote sensing*.

false karst lake See *false karst lake* under *lake*.

fan See *alluvial fan*, *delta*.

fan apron Accumulation of relatively recent alluvial material covering an older fan or piedmont.

fan terrace An older, inactive alluvial fan that has partially eroded, with more recent accumulations of alluvial materials at the lower elevation.

farm pond See *farm pond* under *pond*.

fast water—nonturbulent See *fast water -— nonturbulent* under *channel unit*.

fast water—turbulent See *fast water—turbulent* under *channel unit*.

fathom A unit of measure equal to 1.83 m (6 ft).

fault A plane or zone of fracture in a geographic feature (usually rock) that marks where permanent displacement or shifting has occurred.

fault sag pond See *fault sag pond* under *pond*.

feature Any component of a community or ecosystem, obstruction, sample location, or other item plotted during aquatic biophysical mapping of streams and digitizing processes.

feeder Term that is applied to a tributary stream.

fen See *fen* under *wetlands*.

fence barrier See *fence barrier* under *habitat enhancements*.

fetch (1) An area where waves are generated by wind. (2) The distance waves travel in open water from their point of origin to the point of breaking. (3) The distance along open water or land over which wind blows without appreciable impedance or change in direction. (4) The distance across a lake from a given point to the upwind shore.

fill (1) Localized deposition of material eroded and transported by a stream from other areas, resulting in a change in bed elevation. Compare with *scour*. (2) Deliberate placement of (generally) inorganic material on submerged land or low shoreline of a stream or other body of water to increase the surface elevation.

film water Layer of water surrounding soil particles and varying in thickness from 1 to 100 or more molecular layers.

fine benthic organic matter See *fine benthic organic matter* under *benthic organic matter*.

fine load See *fine load* under *sediment load*.

fine particulate organic matter See *fine particulate organic matter* under *organic particles*.

fines Particulate material, less than 2 mm in diameter, including sand, silt, clay, and fine organic material.

fine sediment Fine-grained particles (2 mm or less in diameter) in streambanks and substrate. *See substrate particle-size table*.

fine woody debris Parts of woody vegetation, usually branches, twigs, leaves, roots, and smaller limbs.

finger lake See *finger lake* under *lake*.

firth Long, narrow indentations of a coastline.

fish attractors See *fish attractors* under *habitat enhancements*.

fish depth See *fish elevation*.

fish elevation Elevation of a fish above a streambed measured at the tip of the fish's snout. See *focal point*.

fish habitat Aquatic and riparian habitats that provide the necessary biological, chemical, and physical (i.e., environmental) requirements of fish species at various life stages.

fish habitat indices See *habitat quality indices*.

fish ladder Inclined waterway, commonly an artificial channel with stepped pools, installed at a dam or waterfall to allow passage of migratory fish over or around an obstruction. May also be referred to as a fishway, fish passageway, or fish pass.

fish sanctuary Resting, rearing, or spawning area for fish where they are protected by barriers or regulation from exploitation by sport or commercial fishers.

fish screen Screen placed at the entrance of a water diversion for irrigation or power generation to prevent entry of fish.

fish velocity See *fish velocity* under *velocity*. Also referred to as focal point velocity.

fixed logs See *fixed logs* under *large organic debris*.

fjord Long, narrow inlet or arm along a sea coast bordered by steep cliffs or slopes that are usually formed through glacial erosion and typified by the presence of a partially obstructing rise in bathymetry at the seaward opening.

flap gate See *flap gate* under *gate* and main heading *control structure*.

flashboard Temporary barrier (usually constructed of wood), of relatively low height that is placed along the crest of a spillway on a dam to adjust the water surface in the reservoir. Flashboards are constructed so that they can be readily added to increase water storage during low water years or removed to decrease water storage during high water years.

flash flood Rapid increase in streamflow due to surface runoff, usually caused by torrential upstream rainfall.

flash flow See *flash flow* under *flow*.

flat bank See *flat bank* under *streambank*.

flatland reservoir Impoundment built in relatively level terrain or in a wide floodplain and characterized by large shallow areas, often where a meandering river channel remains with its associated oxbows and sloughs.

flat meander See *flat meander* under *meander*.

flats Level landform composed of unconsolidated sediments, usually mud or sand, that may be elongated or irregularly shaped and continuous with the shore, that is covered with shallow water or may be periodically exposed. May also be called a marsh or shoal. See *wetlands*, *shoal*.

floater Tree or piece of timber that remains afloat in water.

floating aquatic vegetation Rooted or free aquatic plants that wholly or partially float on the water surface.

floating macrophyte See *floating macrophyte* under *macrophyte*.

floating meadow floodplain See *floating meadow floodplain* under *floodplain*.

floats See *floats* under *large organic debris*.

floc Tuftlike mass of floating material formed by flocculation or the aggregation of a number of fine suspended particles.

flocculation Coalescence of colloidal particles into a larger mass that precipitates in the water column.

flood (1) Rising and overflowing of a water body onto normally dry land. (2) Any flow that exceeds the bank-full capacity of a stream or channel and flows onto the floodplain. (3) May also refer to an exceptionally high tide in marine waters. See *flooding*.

flood basin Largest floodplain possible occurring within one drainage.

flood channels Channels that contain water only during high water conditions or flood events. Also referred to as overflow channels.

flood control pool Maximum storage capacity of a flood control reservoir.

flood control reservoir Reservoirs built to store water during high water years to abate flood damage. Extreme water level fluctuations usually characterize such reservoirs. See *reservoir*.

flood control storage Water stored in reservoirs to abate flood damage. See *flood control pool*.

flood frequency See *recurrence interval*.

flooding Condition where the surface of soil that is generally dry is temporarily covered with flowing water from any source including inflow from streams during high water years, runoff from adjacent slopes, or any combination of sources. See *flood*.

dam-break flooding Downstream surge of water caused by the sudden breaching of a dam on an impoundment in a stream channel, that may be caused by a landslide, the deposit of a debris flow, or a debris jam.

ephemeral flooding Inundation of the floodplain that is short-lived or transitory.

headwater flooding Situation where an area becomes inundated directly by surface runoff from upland areas.

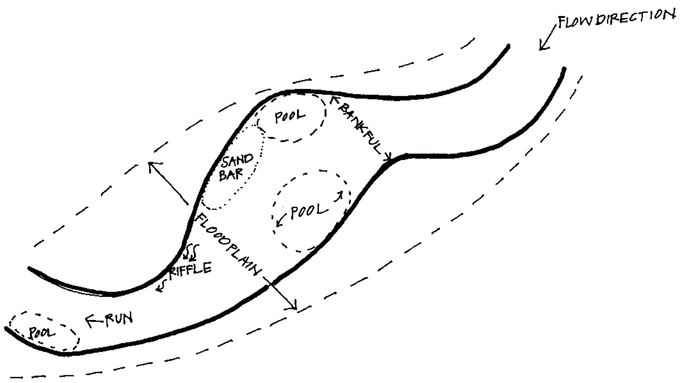
long-duration flooding Inundation from a single event ranges from seven days to one month.

periodically flooded Soils that are regularly or irregularly inundated from ponding of groundwater, precipitation, overland flow, stream flooding, or tidal influences that occur at intervals of hours, days, or longer.

permanently flooded Water regime where standing water covers a land surface during the entire year, except during extreme droughts.

flood level Elevation or stage of water surface in a stream during a particular event when the stream exceeds bank-full capacity.

floodplain (1) Area adjoining a water body that becomes inundated during periods of overbank flooding and that is given rigorous legal definition in regulatory programs. (2) Land beyond a stream channel that forms the perimeter for the maximum probability flood. (3) Strip of land bordering a stream that is formed by substrate deposition. (4) Deposit of alluvium that covers a valley flat from lateral erosion of meandering streams and rivers.



floodplain (from Firehock and Doherty 1995)

coastal delta floodplain Terminal lateral expansion of the alluvial plain where the river divides into numerous distributary channels as it enters an estuary or ocean.

floating meadow floodplain Flooded grassland forming vast floating mats of vegetation that may occur seasonally. May also apply to land areas that are semi-aquatic. See *wetlands*.

fringing floodplain Relatively narrow strip of floodplain between the walls of a river valley.

internal delta floodplain Floodplains created by geologic features that result from lateral spreading where the main channel divides and sheet flooding is common.

nonflooding floodplain Floodplain where overbank flooding occurs very rarely.

occasionally flooded Floodplain that is covered infrequently by standing water.

permanently flooded floodplain Floodplain that is permanently covered by water and that may contain floating, submerged, or rooted vegetation. See terms and definitions under *wetlands*.

seasonally flooded floodplain Floodplain that floods annually or seasonally.

floodplain processes See *floodplain processes* under active *valley wall processes*.

floodplain width Distance between the edge of the main stream channel and the land–water interface at maximum flood stage where flooding occurs an average of every two years.

flood pulse Periodic increase in riverine productivity that occurs when rivers inundate floodplains. Nutrients, phytoplankton, and zooplankton produced in the floodplain provide a "flood pulse" when connectivity between the floodplain and river occurs.

flood pulse concept The pulse of river discharge due to flooding. See *flood pulse*.

flood recurrence interval See *recurrence interval*.

flood river See *flood river* under *river*.

floodway (1) Part of a floodplain that is contained by levees and is intended for emergency diversion of water during floods. (2) Part of a floodplain that is kept clear of obstructions to facilitate the passage of floodwater.

flood zone Land bordering a stream that is subject to floods of about equal frequency.

flotation load Total organic debris that enters water.

flotsam Floating debris of natural or human origin that is transported downstream but often collects in eddies.

flow (1) Movement of water and other mobile substances from one location to another. (2) Volume of water passing a given point per unit of time. Synonymous with *discharge*.

average annual discharge Product of the average water velocity of an aquatic system times the cross-sectional area of that system.

average annual inflow Sum of the mean annual discharge for all streams entering a water body.

base flow Portion of the stream discharge that is derived from natural storage (i.e., outflow from groundwater, large lakes or swamps), or sources other than rainfall that creates surface runoff; discharge sustained in a stream channel, not a result of direct runoff and without regulation, diversion, or other human effects. Also called sustaining, normal, dry weather, ordinary, or groundwater flow.

broken flow Nonlaminar flow with numerous standing waves.

channel maintenance or preservation flow Range of flows within a stream from normal peak runoff and may include, but is not limited to, flushing flows or flows required to maintain the existing natural stream channel and adjacent riparian vegetation.

creeping flow Increased flow that spreads laterally across a low-relief, depositional floodplain.

duration flow See *duration curve*.

effluent flow Streamflow generated from groundwater.

enhancement flow Increased streamflow from reservoir releases that improves natural streamflow conditions for aquatic, terrestrial, recreational, and other resources.

ephemeral flow Streamflows in channels that are short-lived or transitory and occur from precipitation, snow melt, or short-term water releases.

flash flow Sharp peaks in streamflows on a hydrograph.

flushing flow Artificial or natural discharge of sufficient magnitude and duration to scour and remove fine sediments from the stream bottom that helps to maintain the integrity of substrate composition and the form of the natural channel.

generation flow Flow that results from water releases for power generation.

improvement flow Discharge that provides additional water for various uses, corrects the deterioration of water quality and utilization pressures, and results in increases in populations of aquatic organisms.

index flow Standard measure of discharge used to compare other streamflows.

influent flow Groundwater flows that recharge aquifers.

instantaneous flow Discharge measured at any instant in time.

instream flow Discharge regime for a stream channel.

instream flow requirements Streamflow regime required to satisfy the water demand for instream uses.

intergravel flow Portion of surface water that infiltrates a streambed and moves through the gravel substrate. Also referred to as interstitial flow.

intermittent flow Flows that occur at certain times of the year only when groundwater levels are adequate but may cease entirely in low water years or be reduced to a series of separated pools. Compare with *ephemeral flow* under *flow*.

interstitial flow See *intergravel flow* under *flow*.

laminar flow Uniform streamflow with no mixing or turbulence.

least flow Lowest flow established by agreement in a regulated stream that will sustain an aquatic population at agreed upon levels. This flow may vary seasonally. Compare with *minimum flow* under *flow*.

low flow See *minimum flow* under *flow*.

maximum flow See *peak flow* under *flow*.

mean annual flow Average annual streamflow, usually expressed as cubic meters per second (m^3/s).

mean annual runoff Mean annual flow divided by the catchment area (e.g, meters per hectare).

mean flow Average discharge at a given stream location, usually expressed in cubic meters per second or cubic feet per second. The discharge is computed for the period of record by dividing the total volume of flow by the number of days, months, or years in the specified period. Also referred to as average discharge, mean discharge, average daily flow (ADF), or average annual flow (QAA).

minimum flow (1) The lowest discharge recorded over a specified period of time. (2) Lowest flow established by agreement in a regulated stream that will sustain an aquatic population to agreed upon levels.

modified flow Discharge at a given point in a stream resulting from the combined effects of all upstream and on-site operations, diversions, return flows, and consumptive uses.

natural flow Stream discharge that occurs naturally through climate and geomorphology without regulation, diversion, or other modification by humans.

optimum flow Discharge regime that provides the maximum flow for any specified use in a stream.

peak flow Highest discharge recorded within a specified period of time that is often related to spring snowmelt, summer, fall, or winter flows. Also called maximum flow.

perennial flow Flows that are continuous throughout the year.

placid flow Flow that is slow, tranquil, and sluggish.

regulated flow Streamflows that have been affected by regulated releases, diversions, or other anthropogenic perturbations.

return flow Water, previously diverted from a stream, that is not consumed and returned to a stream or to another associated body of surface or groundwater.

rolling flow Streamflows with numerous unbroken waves.

seasonal flow Streamflows that exist only at certain times of the year, that may be derived from springs or surface sources, but usually are associated with seasonal precipitation patterns.

seven day low flow (Q7L) Lowest discharge that occurs for a seven consecutive day period during the water year.

seven day/Q10 (Q7/10) Lowest flow (i.e., a specific critical low flow) that occurs or is predicted to occur for seven consecutive days within a ten-year period.

sheet flow Fast, nonturbulent flow over a level streambed that approaches laminar flow.

shooting flow Swift, high energy streamflow with great erosive potential. Also referred to as supercritical flow. Compare with *tranquil flow*.

sluggish flow Slow streamflow that occurs when runoff is spread over a period of time.

stable flow Streamflow with a constant discharge.

steady flow Little fluctuation in discharge during a specified period of time.

stem flow Precipitation that is intercepted by plants and flows down a plant stem or tree trunk to the ground.

storm flow Sudden and temporary increase in streamflow, resulting during a heavy rainfall that may be accompanied by additional water from increased snow melt.

streamflow Flow of water, generally with its suspended load, in a well-defined channel or water course.

streamline flow Tranquil flow slower than shooting flow. See *tranquil flow* under *flow*.

subsurface flow Portion of streamflow moving horizontally through and below the streambed from groundwater seepage. It may or may not become part of the visible streamflow at some point downstream.

surface flow Visible portion of streamflow that occurs above the substrate within a channel.

survival flow Discharge required to prevent death of aquatic organisms in a stream during specified periods of time (e.g., seven days) when streamflows are extremely low.

swirling flow Streamflows characterized by eddies, boils, and swirls.

tranquil flow Slow streamflow with low energy that results in little erosion to streambanks and the stream bottom. Also referred to as *subcritical flow*. Compare with *shooting flow* under *flow*.

transition flow Interface where laminar and turbulent flows meet.

transverse flow Stream currents that operate at right angles to the main flow of the current. These currents are important in pool formation along the banks of meandering streams.

tumbling flow Flow characterized by cascades, usually over large boulders or rocky outcrops.

turbulent flow Streamflow characterized by an irregular, chaotic path, with violent mixing.

uniform flow Flow where water velocities are the same in both magnitude and direction from point to point in a cross section. Uniform flow is possible only in a channel where the cross section and gradient are constant. Compare with *laminar flow* under *flow*.

unsteady flow Flow in an open channel where the depth changes with time.

flow duration curve Graphical representation of the number of times or frequency that a flow of a given magnitude occurs.

flow erosion See *flow erosion* under *erosion*.

flow slides See *flow slides* under *landslide*.

flow stability A description of flow consistency at a given stream location.

flow till See *flow till* under *landslide*.

flume A chute constructed to transport materials with flowing water. See also *flume falls* under *fast water—turbulent*, *falls* under the main heading *channel unit*.

flush (1) Rapid release of water from a storage structure, such as a reservoir, that has a sufficient quantity of water to transport suspended and floating materials. (2) Sudden rush of water down a stream that occurs during a freshet (flash flood). (3) Action of periodic high flow to keep a site at a spring or wetland wet or moist. (4) Rinsing or cleansing of beaches by a flush of water at high tide.

flushing flow See *flushing flow* under *flow*.

flushing period Period of time required for the total volume of water to be flushed through a system.

flushing rate Time required for a volume of water equivalent to the reservoir volume to be discharged. The flushing rate is calculated by dividing the volume of the reservoir by the daily discharge.

fluvial Pertaining to or living in streams or rivers, or produced by the action of flowing water. See also *fluvial* under *streambank material*.

sediment production zone Area of active erosion where sediments are derived and moved downstream. Also referred to as drainage basin.

sink zone Area with low gradient and water velocity where substrates are deposited. Also referred to as the zone of deposition.

transportation zone Area where the erosion and deposition are generally in equilibrium so that the total eroded material does not increase or decrease but is transported downstream. Also referred to as the transfer zone.

fluvial erosion See *fluvial erosion* under *erosion*.

fluvial sedimentation Sediment created, transported, and deposited by flowing water.

flux Variation of substances, such as nutrients, per unit of time.

foam Collection of minute bubbles on the surface of a liquid formed by agitation or fermentation.

focal point Location, and the conditions at that location, occupied by an organism. Focal point measurements help to define microhabitat. See *microhabitat*.

fog Accumulation of minute water particles in a layer at or just above the ground surface that often occurs in river bottoms, depressions, or low lying areas.

foliar cover Percentage of ground or water covered by shade from the aerial portion of plants. Small openings in the canopy are excluded; foliar cover is always less than the canopy cover and is never greater than 100%. Synonymous with shading effect as measured with a vertical light source. See *canopy cover*.

foliar shading See *foliar shading* under *stream surface shading*.

ford Low-water stream crossing with bank access to allow wading or vehicular passage by people and crossing by livestock. The streambed must be composed of materials that are resistant to erosion. Streamflows must either be low enough to allow shallow crossings or the “ford” cannot be used during high-water periods.

forebay (1) A reservoir or canal from which water is taken to operate equipment such as a waterwheel or turbine. (2) The entry chamber of a dam through which water flows into an outlet works. (3) The area of a reservoir immediately upstream and adjacent to the structure that forms a reservoir.

foreshore (1) Land along the edge of a water body. (2) Portion of land between the high water mark and the low water mark.

forested wetland See *forested wetland* under *wetlands*.

fork The point at which a stream branches into two channels that may be of similar size and flow.

form Shape of a streambank that results from fluvial processes.

formative discharge See *dominant discharge*.

fossil water Water accumulated in an aquifer during a previous geologic time that has an extremely long recharge period.

foul Refers to materials or organisms that cling to a substrate so as to encumber it (i.e., to entangle or clog or render unsuitable for use).

fracture Rock mass that is separated into distinct fragments or masses. In streams, fractures create discontinuous surfaces, often with distinct boundaries.

fragipan Natural subsurface soil horizon with a high bulk density relative to the soil above that is brittle and appears cemented when dry but less so when moist. Generally such soils are mottled in color, only slowly permeable to water, and commonly exhibit bleached cracks that form polygons in horizontal section.

framework riffle Riffle composed of coarse substrates, often resistant to hydraulic erosion, that does not accumulate much sediment.

frazil ice Fine spicules of ice formed in water (i.e., slush) too turbulent to allow the formation of sheet ice or anchor ice.

Fredle index (f_i) An index of the quality of salmonid spawning gravel, obtained by dividing geometric mean diameter of particle size by the sorting coefficient:

$$f_i = \frac{d_g}{S_o};$$

d_g = geometric mean particle diameter (see *geometric mean particle diameter*);
S_o = sorting coefficient, $(d_{75}/d_{25})^{½}$; d_{75} is the particle diameter at the 75th percentile of cumulative particle weight (weight is cumulated from small to large particles), and d_{25} is the diameter at the 25th weight percentile).

freeboard (1) Vertical distance between the level of the surface of the liquid in a conduit, reservoir, tank, or canal, and the top of an open conduit, or levee that prevents waves or other movements by the liquid to overtop the confining structure. (2) Height of the sides in a boat above the water surface.

free-floating macrophyte See *free-floating macrophyte* under *macrophyte*.

free-flowing Stream or stream reach that flows unconfined and naturally without impoundment, diversion, straightening, rip-rapping, or other modification of the waterway.

free-living Plants or animals not attached to or parasitic on other plants or animals (i.e., capable of living and moving independently).

free log See *free log* under *large organic debris*.

free meander See *free meander* under *meander*.

free-swimming Organisms that are actively moving or capable of moving in water.

free water Water that drains freely by gravity.

french drain Blind drain composed of piping with holes that allows water to seep into the piping and drain from the site.

frequency of inundation or saturation Period that an area is covered by surface water or soil is saturated. It is usually expressed as the number of years the area is inundated or the soil is saturated during the portion of the growing season with prevalent vegetation.

frequently confined channel See *frequently confined channel* under *confinement*.

frequently flooded channel A channel that floods often (e.g., in most years).

freshet Rapid temporary rise in stream discharge and level caused by heavy rains or rapid melting of snow and ice.

freshwater See *freshwater* under *salinity*.

freshwater marsh See *freshwater marsh* under *wetlands*.

fringe marsh See *fringe marsh* under *wetlands*.

fringing floodplain See *fringing floodplain* under *floodplain*.

Froude number (F_r) Dimensionless number expressing the ratio of inertial to gravitational forces in a fluid:

$$F_r = \frac{V}{(gd)^{½}}$$

or

$$F_r = V^2/gD \;;$$

V = mean velocity (m/s);
g = acceleration due to gravity (m/s^2);
D = hydraulic depth (m);

Values of F_r less than 1 are termed subcritical, and are characteristic of relatively deep, slow streamflow. Values of 1 denote "critical flow." Values greater than 1 are termed supercritical, and are characteristic of shallow, fast water.

▶ g

gabion See *gabion* under *habitat enhancements*.

gaging station Particular location on a stream, canal, lake, or reservoir where systematic measurements of streamflow or quantity of water are made.

gaining stream See *gaining stream* under *stream*.

gallery See *gallery* under *control structure*.

gallery forest Strip of forest confined to a stream margin or floodplain in an otherwise unforested landscape.

gate See *gate* under *control structure*.

generation flow See *generation flow* under *flow*.

geographic information systems Systems for identifying locations geographically and organizing information about those locations in a relational process based on shared geographic location. Data are referenced with geographic coordinates and stored in digital format in a computer.

geologic erosion See *geologic erosion* under *erosion*.

geometric mean diameter particle (d_g) Measure of the mean particle size of substrate materials that is sometimes used as an index of spawning gravel quality; it is also referred to as the D_{50} size. It has been calculated in two ways:

$$d_g = d_1^{w1} \times d_2^{w2} \times \ldots\ d_n^{wn} \;;$$

$d_1, \ldots d_n$ = particle diameters in size percentiles 1, …, n;
$w_1, \ldots w_n$ = decimal weight fractions in size percentiles 1, …, n.

Alternatively,

$$d_g = (d_{16} \times d_{84})^{1/2} \;;$$

d_{16} = particle diameter at the 16th size percentile;
d_{84} = particle diameter at the 84th size percentile.

geometric registration See *geometric registration* under *remote sensing*.

geomorphic Pertains to the form or shape of the landscape and to those processes that affect the surface of the earth.

geomorphic surface Unit on the earth's surface with a characteristic form that indicates the unit was formed by a particular process in a particular geomorphic environment.

geomorphological processes Dynamic actions or events that occur at the earth's surface due to natural forces resulting from gravity, temperature changes, freezing and thawing, chemical reactions, seismic activity, and the forces of wind, moving water, ice, and snow. Where and when a force exceeds the strength of the earth material, the material is changed by deformation, translocation, or chemical reaction.

geomorphology Study of the origin of landforms, the processes that form them, and their material composition.

georeferencing Process of assigning map coordinates to image data.

geostrophic effect Deflection (coriolis) force of the earth's rotation.

geothermal Pertains to the internal heat of the earth. Frequently expressed as hot water springs, steam, and hot brines that seep to the surface or are forced into the air by hot groundwater generated by the internal heat of the earth. See *geyser*.

geyser Hot water spring that intermittently erupts as a fountain-like jet of water and steam.

glacial drift Rock debris transported and deposited by glacial ice or melt water.

glacial flour Inorganic material pulverized to silt- and clay-size particles by the movement of glaciers and ice sheets. Term is also used to describe suspended or deposited glacial silt.

glacial lake See *glacial lake* under *lake*.

glacier Body of ice formed by the compaction and recrystalization of snow that has definite lateral limits and exhibits motion in a definite direction.

rock glacier Tongue of rock fragments held together by interstitial ice that moves downslope, similar to a glacier.

valley glacier Glacier that is smaller than a continental glacier or an ice cap that flows mainly along well-defined valleys, often with many tributaries.

glaciofluvial Pertains to channelized flow of glacier meltwater as well as deposits and landforms formed by glacial streams.

glaciofluvial materials Materials such as sediments deposited by glacial streams either directly in front of, or in contact with, glacial ice.

glaciolacustrine materials Range of particles resulting from glacial action, deposited along the margins of glacial lakes or released into the lakes by melt water.

glaze Homogeneous, transparent ice layers that are formed from rain or drizzle when the precipitation comes in contact with surfaces at temperatures of 0°C (32°F) or lower.

gleization Process in saturated or nearly saturated soils that involves the reduction of iron, its segregation into mottles and concretions, or its removal by leaching. Gleizated soils tend to be grey in color when the iron has been reduced and reddish when the iron is oxidized.

glide See *glide* under *slow water* under the main heading *channel unit*.

global positioning system (GPS) System of satellites in permanent orbit above the earth that allow a receiver to triangulate their position on or above the earth's surface.

gorge (1) Small, narrow canyon with steep, rocky walls, especially one through which a streamflows. (2) Portion of the water drainage system situated between the catchment area and the outwash fan.

graben Portion of the earth's crust bounded on at least two sides by faults that have moved downward as a result of crustal activity to create an area that is lower than the adjoining landform.

graben lake See *graben lake* under *lake*.

graded bed Streambed with a series of sorted layers where the larger sizes of particles occur on the bottom and finer sizes on the surface.

graded stream See *graded stream* under *stream*.

grade-stabilization or control structure See *check dam* under *habitat enhancements*.

gradient (1) General slope, or the change in vertical elevation per unit of horizontal distance, of the water surface in a flowing stream. (2) Rate of change of any characteristic per unit of length. See *profile*.

gravel Substrate particle size between 2 and 64 mm (0.1 and 2.5 in) in diameter. Compare with other substrate sizes under *substrate size*.

gravel bed (1) Natural accumulation or deposition of gravel-size particles in areas of low water velocity, decreased gradient, or channel obstruction. (2) Gravel artificially placed in a water body for fish habitat, primarily for spawning.

gravel pit lake See *gravel pit lake* under *lake*.

gravel restoration See *gravel restoration* under *habitat enhancements*.

gravity flow See *gravity flow* under *landslide*.

gravity waves See *gravity waves* under *wave*.

graywater Drainage of dishwater, shower, laundry, bath, and washbasin effluents that contrast with "blackwater" such as toilet drainage.

greenway Protected linear open-space area that is either landscaped or left in a natural condition. May follow a natural feature or landscape, such as river or stream, or other types of right-of-ways.

grit Fine, abrasive particles, usually composed of coarse-grained siliceous rock (the size of sand or smaller) with a sharp, angular form and deposited as dust from the air or from impurities in water.

gross primary production See *gross primary production* under *production*.

ground Term applied to the solid surfaces of soil, weathered rock, and detritus on the earth. See *earth*, *soil*.

ground cover See *ground cover* under *remote sensing*.

ground moraine See *ground moraine* under *moraine*.

ground truthing See *ground truthing* under *remote sensing*.

groundwater (1) Water located interstitially in the substrate of the earth that is recharged by infiltration and enters streams through seepage and springs. (2) Subsurface water in a zone of saturation, standing in or passing though (groundwater flow) the soil and the underlying strata.

average linear velocity The average linear velocity (V) of groundwater flow is estimated by:

$$V = \frac{K\,(d_h/d_l)}{n_e}\;;$$

K = hydraulic conductivity (m/d);
d_h/d_l = hydraulic head;
n_e = effective porosity, the volume of interconnected pore space relative to the total volume.

coefficient of storage The coefficient of storage, S, is estimated by:

$$S = \rho g h(\alpha + n\beta)\;;$$

ρ = density of fluid;
g = gravitational constant;
h = saturated thickness of aquifer;
α = compressibility of the aquifer skeleton;
n = porosity;
β = compressibility of the fluid.

Darcy's law Darcy's law describes the liquid transporting properties of porous materials:

$$Q = KA(d_h/d_l)\;;$$

Q = flow rate (m^3/d);
K = hydraulic conductivity (m/d);
A = cross-sectional area through which flow occurs (m^2);
d_h/d_l = fluid head.

porosity Porosity, n, is estimated by:

$$n = S_y + S_r\;;$$

S_y = specific yield of groundwater;
S_r = specific retention (the volume of groundwater that does not drain under influence of gravity.

groundwater budget Summation of water movement into and out of the groundwater during a specified period of time.

groundwater dam Underground obstruction hindering the movement of groundwater.

groundwater discharge Seepage or flow of water from groundwater to surface waters.

groundwater interchange Pattern of recharge and discharge between groundwater and surface water.

groundwater level Elevation of water in groundwater in relation to the surface or another fixed point.

groundwater recharge Flow of water from the surface into groundwater.

groundwater runoff Flow of groundwater along a geologic gradient by gravity that is comparable to surface runoff.

groundwater table Surface below which rock, gravel, sand, or other substrates are saturated by a body of unconfined groundwater.

groyne (groin) See groyne under *habitat enhancement*.

gulch Small, narrow, often steep-sided stream valley that results from a secondary incision into a broader alluvial valley. See *ravine*.

gulf Portion of an ocean or sea that is partly enclosed by land.

gully Small valley, ravine, or an ephemeral stream channel that carries water during and immediately after rain that is generally longer than wide.

continuous gully Gully with many finger-like extensions into its headwaters area that gains depth rapidly downstream and maintains the depth to the mouth of the gully.

discontinuous gully Gully that begins as an abrupt headcut and may occur singly or as a chain of gullies following one another in a downslope direction.

gully erosion See *gully erosion* under *erosion*.

gully plug See *gully plug* and *check dam* under *habitat enhancements*.

gully side form Shape or profile of gully sides compared to right angles in the direction of flow.

benched Sides having a horizontal section (less than 5% or at least 30 cm wide) in an otherwise vertical wall.

faceted Sides with various combinations of vertical and sloping segments.

sloping Sides with a general slope less than 65% from horizontal.

vertical Sides with the general slope greater than 65% from horizontal.

guzzler Water entrapment and containment structure used primarily to provide water for wildlife and livestock in arid regions.

gyrals (gyres) Surface currents in very large lakes or seas that circulate in very large swirls.

gyttja Sediment mixture of particulate organic matter, often zooplankton fecal pellets, inorganic precipitates, and deposited matter that is less than 50% inorganic by dry weight. Consists of a mixture of humus material, fine plant fragments, algal remains, quartz grains, diatom fistulas, exoskeleton fragments, spores of pollen relics, and plankton.

▶ h

habitat Specific type of place within an ecosystem occupied by an organism, population, or community that contains both living and nonliving components with specific biological, chemical, and physical characteristics including the basic life requirements of food, water, and cover or shelter.

habitat component Single element (such as velocity, depth, or cover) of the habitat or area where an organism lives or occurs. Component is synonymous with attribute.

habitat diversity Number of different types of habitat within a given area.

habitat enhancements Actions taken to modify or enhance habitats to benefit one or more species.

a-jacks Structure with three arms fastened together, resembling a child's toy jack, made of concrete or metal and placed along a bank or shoreline to prevent erosion from waves, breakers, or current.

articulated concrete mattress Collection of concrete slabs wired together to form a large mattress that is used to stabilize a bank.

artificial channels Short channels designed for spawning or rearing fish that are located near but separate from stream channels.

artificial holes Cavities of tile, pipe, hollow logs, and similar structures of appropriate size that are plugged at one end and are for fish spawning.

artifical meander A human-constructed stream channel that resembles a natural meander.

artificial reef Structure of concrete, tires, or other solid material constructed to create cover for aquatic organisms in marine or large freshwater environments.

artificial riffle Stream reach where rocks are added to create a shallow area with turbulent flow.

baffle Any device that changes the direction and distribution of flow or velocity of water.

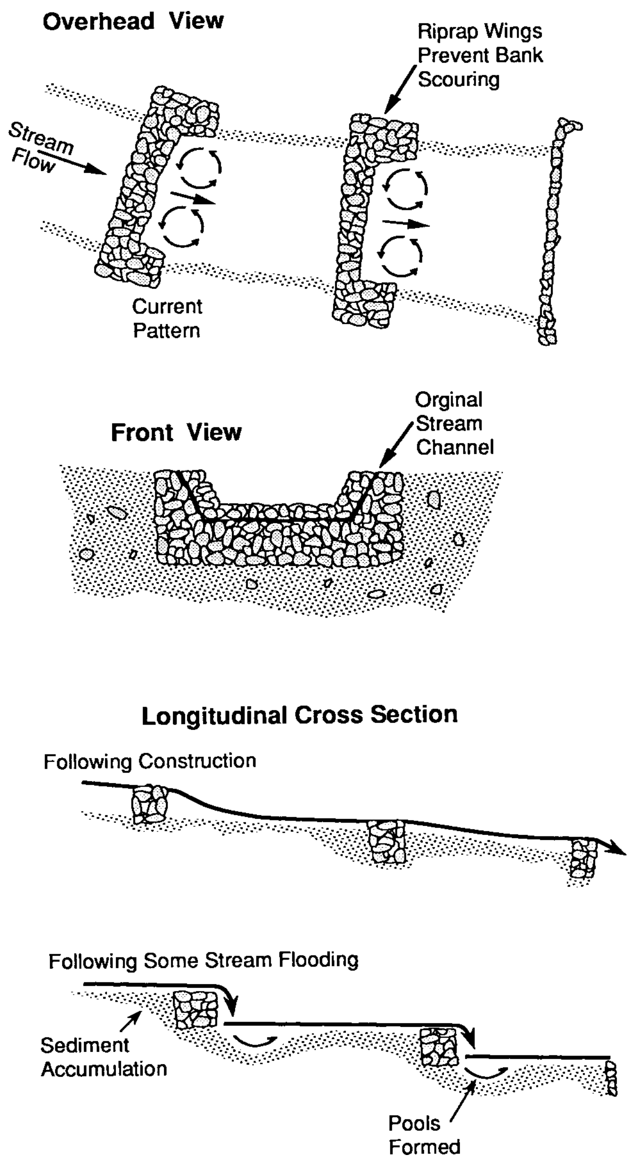
bank stabilization Placement of materials such as riprap, logs, gabions, and planting of vegetation to prevent bank erosion.

berm Natural or artificial levee, dike, shelf, ledge, groyne, or bench along a streambank that may extend laterally along the channel or parallel to the flow to contain the flow within the streambank. Also referred to as *bund*. See *dike*, *levee*.

brushpile Trees, brush, or other vegetation tied into bundles and placed in a water body as supplemental structure or cover.

bulkhead Wall of wood, metal, rock, or concrete used to support a slumping bank.

channel constrictor Type of structure, such as a notched drop structure or a double-wing current deflector, that forces the main flow of water through a narrow gap.



check dams (from Meehan 1991)

check dam Small dam of logs, rock, gabions, concrete, or other materials that completely spans the stream channel, slowing swift current and creating a plunge pool downstream from the sudden drop in channel elevation. Used to control soil erosion, headcutting in streams, and retard the flow of water and sediment in a channel.

cover Logs, boulders, brush, or other materials placed along the banks, on the bottom, or midwater, in a water body to create habitat for spawning or nursery areas.

crib Cubical structure constructed of logs, metal posts, boulders, or other materials that is filled with rocks to protect streambanks and enhance cover in streams, lakes, or reservoirs. See *gabion* under *habitat enhancements*.

cribwell Log crib that is anchored to the bank that is usually filled with rocks or dirt and planted with woody vegetation such as willows.

deflector Single or double wing dam or jetty constructed from boulders, logs, or gabions that is used to force the current in a different direction. See *gabion* and *jetty* under *habitat enhancements*.

digger log Type of current deflector that consists of a log anchored to a streambank that protrudes into or across the channel to deflect the flow and excavate a depression in the substrate.

drop, drop structure See *check dam* under *habitat enhancements*.

earth islands Islands of earth constructed in lakes, ponds, reservoirs, or other water bodies that provide habitat for birds or terrestrial animals and shallow-dwelling aquatic organisms.

escape ladder Ladder-like structure of wood or mesh that provides animal access to developed water sources.

escape ramp Structures (ramps) of rock, concrete, or wood that are placed along steep sides of ponds, canals, or conduits to permit animals access to water or to escape if trapped.

fabric blanket Flexible, mesh-like material (usually synthetic), that reduces erosion and through which vegetation can grow. Sometimes placed under channel structures or riprap to hold materials.

fence barrier Fence-like arrangement of logs, pilings, gabions, or other materials placed along a streambank.

fish attractors Brush, tires, plastic, stake beds, clay pipes, standing timber, or other structures used to create habitat for fish or other organisms.

gabion Wire cage or basket filled with rocks or stone used to stabilize banks and to enhance aquatic habitat.

grade-stabilization or control structure See *check dam* under *habitat enhancements*.

gravel restoration Placement of gravel in a stream or other water body as spawning habitat for fish.

groyne (groin) (1) Structure of wood, stone, or concrete projecting into water to prevent sand, pebbles, gravel, or other substrates or materials from being washed away by the current. (2) Structure usually constructed of logs or rocks and placed on a streambank to control the soil erosion or direction of water current.

gully plug (1) Refers to the construction of check dams in gullies. See *check dam* under *habitat enhancements*. (2) Also refers to filling of gullies with soil and planting vegetation.

half-log Log split lengthwise and anchored to the substrate (split side down) so that there is a gap between the log and the substrate that serves as cover for fish.

Hewitt ramp Type of check dam made of logs, wood planks, or rocks that creates a gradual incline downstream so that water can excavate a plunge pool in a stream with little gradient. See *check dam* under *habitat enhancements*.

hurdles Smaller branches woven together and pegged against a bank on a moderate slope to control bank erosion and promote growth of vegetation.

jack See *a-jacks* under *habitat enhancements*.

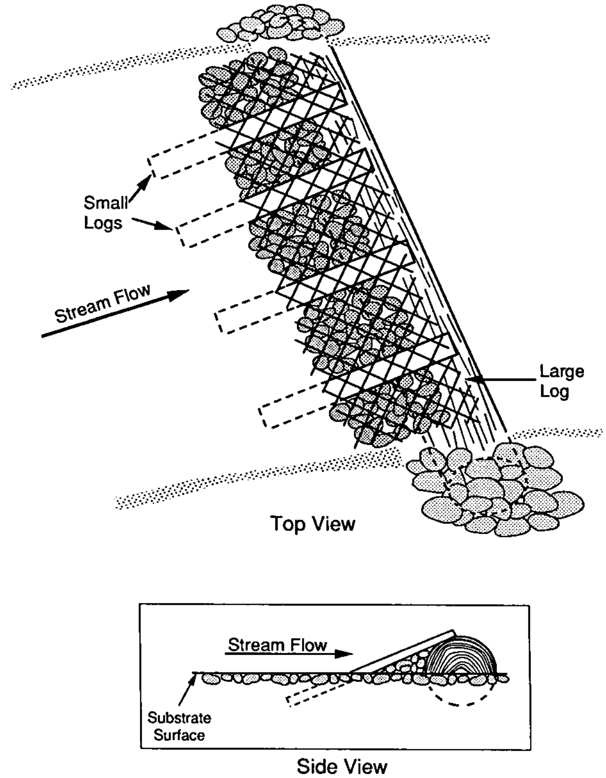
jetty Structure of rock, logs, pilings, gabions, or other materials that projects part way across a channel to direct the stream current.

k-dam Log structure with a "K" shape constructed in a stream channel as habitat for fish and other aquatic organisms.

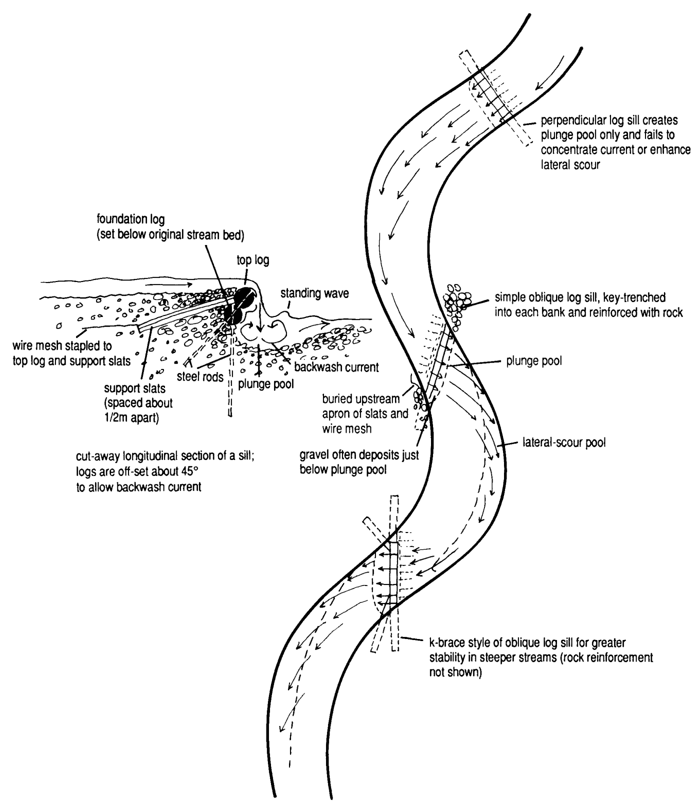
leg-type structure Concrete structure, supported by either two legs along one side or four legs at the corners, or a "+" in the middle, placed in a stream channel.

log sill See *check dam* under *habitat enhancements*.

low-head dam See *check dam* under *habitat enhancements*.



log sill (from Meehan 1991)



oblique log sill (from Kohler and Hubert 1993)

lunker structure Plank and log, free-standing, box-like structure with open sides that is installed just below the water at the toe of a bank to stabilize the bank and create habitat.

mudsill Logs placed perpendicular to the bank of a stream to prevent erosion.

off-channel pools Pools or ponds created in the riparian area adjoining a stream channel and connected with the channel, creating a protected area for rearing fish or other aquatic organisms.

retard See *fence barrier* under *habitat enhancements*.

revetment A facing or structure made of large, durable material, such as earth-filled sacks, trees, logs, stumps, gabions, or rocks placed on a streambank to deflect current. Term also refers to the materials used to construct the revetment. Similar to *riprap* under *habitat enhancements*.

riprap Hard materials, such as logs, rock, or boulders (often fastened together) used to protect a bank or another important feature of a stream, lake, reservoir, or other water body. Similar to *revetment* under *habitat enhancements*.

roller dam See *check dam* under *habitat enhancements*.

scour structure Structure of rocks, logs, gabions, or other materials placed along a streambank or in a stream channel to cause scouring and deposition of substrates.

sediment trap Artificial pool that is generally excavated or constructed for collecting or trapping sand, silt, or other substrates that are transported as the streambed load.

sill Low horizontal barrier of rock or other durable material in a stream. More particularly, a low barrier that is generally constructed of masonry across a gorge to control streambed erosion. Compare with *gully plug* and *check dam* under *habitat enhancements*.

spawning box Boxes filled with gravel that are placed in shallow water of a lake or reservoir as artificial spawning habitat for fish.

spawning marsh Artificial marshes constructed along a stream channel or margin of a lake or reservoir as spawning habitat for fish.

spawning platform A floating or suspended wooden platform placed in a lake or reservoir as spawning habitat for fish.

spawning reef An artificial reef of gravel, rock, or other material to serve as a spawning area for fish.

spiling Term applied to control soil erosion using stakes that are driven into the ground with branches woven between the stakes, or two rows of staggered posts with brush between them to help reduce soil erosion and promote growth of vegetation.

stake bed Artificial fish habitat created either by driving narrow wooden stakes vertically into a lake bottom before impoundment (or when the water level is low) or by attaching similar wooden stakes to a weighted frame that is lowered into place after impoundment.

structure Durable materials, such as large organic debris, boulders, rock, or concrete placed in a stream, lake, reservoir, or other water body to create habitat.

tetrapod Structure made from four legs of precast concrete joined at a central point, all at angles of 109.5° to each other, that functions similar to an a-jack. See *a-jack* under *habitat enhancements*.

timber crib Crib constructed of timber or planks in or along the margin of a water body to create habitat for aquatic organisms or to stabilize a bank.

tire reef Artificial structure made of discarded vehicle tires that are generally attached together and weighted to keep the reef on the bottom of a water body. Used to create fish habitat in fresh or saltwater. A type of *artificial reef* described under *habitat enhancements*.

training wall A low dam, that is normally constructed parallel or at an angle to a streambank, to divert flow in a specific direction.

trash collector Fence-like structure of heavy wire fastened to metal stakes or logs and placed across a stream to intercept and hold debris flowing downstream that creates a dam and a plunge pool. Used to protect bridge crossings, create pools as habitat for fish, and collect gravel for spawning habitat. Synonymous with debris catcher, grizzly, or trash catcher.

tree retards Trees placed along a streambank to reduce current and accumulate debris.

wedge dam Dam or weir constructed with the apex facing upstream.

weir See *check dam* under *habitat enhancements*.

wing dam See *jetty* under *habitat enhancements*.

Wisconsin bank cover Artificial ledge of wood that is supported by rock on the margin of a stream channel as cover for fish.

habitat fragmentation Division of existing habitats into separate discrete units from modification or conversion of the habitat by anthropogenic or natural activities.

habitat quality indices Numerical indices have been devised to give an overall rating of the quality or quantity of an aquatic or terrestrial habitat. In aquatic habitats, these indices often integrate many habitat elements such as streamflow regime, substrate, cover, and water quality and are frequently used in stream condition assessments or evaluations and to predict environmental impacts.

habitat type Aggregation of land or aquatic units having equivalent structure, function, and responses to disturbance and capable of maintaining similar animal or plant communities.

half-log See *half-log* under h*abitat enhancements*.

haline See *haline* under *salinity*.

haline marsh See *haline marsh* under *wetlands*.

halocline See *halocline* under *salinity*.

hanging garden Community of plants and animals that develops on steep slopes or cliffs where groundwater seeps onto the surface to form a confined ecosystem.

hanging valley (1) Valley formed by a tributary stream that has a noticeably higher elevation than the main channel at their confluence. (2) Valley that is high above a shore to a water body and was formed from rapid erosion of the land or displacement by a fault.

hardness Total concentration of calcium and magnesium ions expressed as milligrams per liter (mg/L) of calcium carbonate. Synonymous with total hardness.

hardpan A layer of earth that has become relatively hard and impermeable, usually through mineral deposits. A chemically hardened layer where the soil particles are cemented together with organic matter of SiO_2, sesquioxides, or $CaCO_3$.

hardwater Water with a large concentration of alkaline cations derived from carbonates, chlorides, and sulfates of calcium and magnesium that is generally found in areas of limestone substrate. Compare with *softwater*.

head Energy per unit weight of a fluid such as that resulting from a difference in depth at two points in a body of water. Includes pressure head, velocity head, and elevation head. See *hydraulic head*.

head cut Upstream migration or deepening of a stream channel that results from cutting (i.e., erosion) of the streambank by high water velocities.

headland Point of land, usually high and with a sheer drop, extending out into a water body, especially a sea.

head race Channel that delivers water to a water wheel and causes the wheel to turn.

headscarp See *headscarp* under *landslide*.

headwall Steep slopes at the upper end of a valley, water course, or the cliff faces around a cirque.

headwater flooding See *headwater flooding* under *flooding*.

headwaters (1) Upper reaches of tributaries in a drainage basin. (2) The point on a nontidal stream above which the average annual flow is less than five cubic feet per second. For streams that remain dry for long periods of the year, the headwaters may be established as the point on the stream where a flow of five cubic feet per second is equaled or exceeded 50% of the time.

headwater stream See *headwater stream* under *stream*.

heat budget (1) Amount of heat per unit of surface area necessary to raise a body of water from the minimum temperature of winter to the maximum temperature of summer. (2) Total amount of heat between the lowest and highest heat content.

summer heat income Amount of heat needed to raise a body of water from isothermal winter conditions of 4°C to maximum summer levels.

winter heat income Amount of heat needed to raise a body of water from its minimum levels to isothermal conditions at 4°C.

height See *height* under *wave*.

Henry's law At a constant temperature, the amount of gas absorbed by a given volume of liquid is proportional to the atmospheric pressure of the gas.

heterotrophic See *heterotrophic* under *trophic*.

Hewitt ramp See *Hewitt ramp* under *habitat enhancements*.

high gradient riffle See *high gradient riffle* under *fast water—turbulent, riffles* under the main heading *channel unit*.

highland reservoir Impoundment built on steep terrain with a narrow floodplain. Most of the shoreline is characterized by steep, rocky, or clifflike formations.

high moor See *high moor* under *wetlands*.

high tube overflow See *high tube overflow* under *control structure*.

holding pond See *holding pond* under *pond*.

hole Part of a water body or channel unit that is distinctly deeper than the surrounding area.

hollow Valley or landscape depression.

holomictic See *holomictic* under *mixing*.

homogeneous Refers to a water body that has a uniform chemical composition throughout.

homoiohaline See *homoiohaline* under *salinity*.

homothermous Refers to a water body that has the same temperature throughout.

hot brine Saline water exceeding 37°C (98°F).

hot spring See *hot spring* under *spring*.

hummock Rounded, undefined or chaotic pattern of steep-sided low hills and hollows.

hummocky moraine See *hummocky moraine* under *moraine*.

humus General term for the dark organic material of soils that is produced by the decomposition of vegetable or animal matter. The more or less stable fraction of soil from decomposed organic material, generally amorphous, colloidal, and dark-colored. Nonhumus organic material is generally of low molecular weight, easily degraded by microbes, and has a short retention time.

hurdles See *hurdles* under *habitat enhancements*.

hydraulic control point Top of an obstruction in a stream or a point in a stream where streamflow is constricted by any large, relatively immobile object (e.g., boulder, bedrock) that stabilizes the stream geometry and maintains long-term channel character.

hydraulic depth See *hydraulic depth (D)* under *dimensions*.

hydraulic discharge See *hydraulic discharge* under *discharge*.

hydraulic drop Point where the streamflow changes from subcritical to supercritical in a reach with rapid changes in flow.

hydraulic flushing rate Rate at which an entire volume of lake water is replaced. See *flushing rate*.

hydraulic gradient (1) Slope of water in a stream. (2) Drop in pressure head per unit length in the direction of the streamflow.

hydraulic head Height of the free surface in a water body above a given point beneath the surface, or the height of the water level at an upstream point compared to the height of the water surface at a given downstream location.

hydraulic jump Transition form of supercritical flow that usually results from a change in channel elevation, geometry, or gradient. It may be confined to a very short reach where the depth increases dramatically in a turbulent wavelike feature or in a more gradual or undulating increase.

hydraulic radius Ratio of the area of flow divided by the wetted perimeter of a cross section:

$$R = A/P\,;$$

A = area;
P = wetted perimeter of a cross section.

hydraulics Refers to the motion and action of water and other liquids.

hydraulic slope Change in elevation of water surface between two cross sections divided by the distance between them. Compare with *gradient*.

hydric Moist.

hydric soils Soils that are saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions in the upper layers.

hydrograph Graph that illustrates the relation of discharge, stage velocity, or other water component with time, for a given point on a stream.

hydrographic maps Maps of lakes with contour lines delineating depth.

hydrohaline See *hydrohaline* under *salinity*.

hydrologic balance Relationship between the quality and quantity of water inflow to, water outflow from, and water storage in hydrologic units such as an aquifer, drainage basin, lake, reservoir, or soil zone. It encompasses the dynamic relationships of precipitation, runoff, evaporation, and changes in surface and groundwater storage.

hydrologic budget Compilation of the total water input to and output from a lake, drainage, or watershed.

hydrologic control Natural or artificial structures or conditions that manage or control the movement of surface or subsurface flow.

hydrologic cycle Cycle of water movement from the atmosphere to the earth via precipitation through surface and groundwater to the oceans and return to the atmosphere via evaporation from water bodies and transpiration by plants. See *water cycle*.

hydrologic feature Refers to water-related features visible at the land surface, such as stream channels, seepage zones, springs, and soil moisture including soil moisture characteristics as deduced from vegetation characteristics.

hydrologic regime Water movement in a given area that is a function of the input from precipitation, surface, and groundwater and the output from evaporation into the atmosphere or transpiration from plants.

hydrologic zone Area that is inundated by water or has saturated soils within a specified range of frequency and the duration of inundation or soil saturation.

hydrometabolism Metabolism that occurs in free waters that is essentially all aerobic.

hydromorphic soil Soils that develop in the presence of water sufficient to create anaerobic conditions in the soil.

hydrophobic soils Soils that can repel water due to the presence of materials, usually of plant or animal origin, or condensed hydrophobic substances.

hydrophyte (1) Plants that grow in water or saturated soils. (2) Any macrophyte that grows in wetlands or aquatic habitats on a substrate that is at least periodically deficient in oxygen because of excessive water content.

hydropower reservoir Artificial water storage impoundments designed to retain water and redirect it through turbines to generate electricity.

hydrosaline See *hydrosaline* under *salinity*.

hydrothermal Refers to water on or within the earth that is heated from within the earth.

hydrothermal alteration Process where heated groundwater passes through cracks or pores in rock that may alter the water, mineral, and rock.

hydrothermal vein A cluster of minerals in a rock cavity that were precipitated by hydrothermal activity.

hygric See *hydric*.

hygrophyte Plants restricted to growing in or on moist sites. See *hydrophyte*.

hygroscopic water Water adsorbed by dry soil from an atmosphere of high relative humidity.

hypereutrophic See *hypereutrophic* under *trophic.*

hypertrophic See *hypertrophic* under *trophic.*

hypoeutrophic See *hypoeutrophic* under *trophic.*

hypolimnion See *hypolimnion* under *stratification.*

hypopleuston See *hypopleuston* under *pleuston.*

hypopotamon See *hypopotamon* under *potamon.*

hyporheic zone Latticework of underground habitats through the alluvium of the channel and floodplain associated with streamflows that extend as deep as the interstitial water in the substrate.

hyporhithron See *hyporhithron* under *rhithron.*

hypothermal Refers to water on or within the earth that is lukewarm or tepid.

hypotrophic See *hypotrophic* under *trophic.*

hypsographic curve Depth–area curve that describes the relationship of the cross-sectional area of a lake at a specific depth. A depth–volume curve is closely related and describes the volume of the lake at a specific depth.

▶ i

ice See *ice* under *streambank material.*

iceberg Large floating mass of ice.

icecap Ice covering an area that slopes in all directions from the center unless confined between steep slopes.

ice dam Dam created in the spring when broken sections of ice create a structure that blocks or retards the movement of water.

ice-disintegration moraine See *ice-disintegration moraine* under *moraine.*

ice jam Large blocks and pieces of ice that are jammed by a channel constriction or obstruction, usually occurring during spring breakup. If water cannot penetrate freely through the ice, a dam can form that may cause flooding, damage to human-built structures, or loss of human lives. See *ice dam.*

ice rafting Sections of ice that form and float downstream when ice covering a river breaks up.

ice scouring Abrasion or erosion of stream bottoms by ice that normally occurs from ice jams.

ice wedge Accumulation or piling of ice that is pushed forward by the flow of water or pressure from ice and gravity.

IFIM Abbreviation for instream flow incremental methodology. A method for relating changes in the physical characteristics of a stream to changes in flows.

illumination Amount of light radiation impinging on a surface, expressed as lux, watts per square centimeter, foot-candles or lumens per square meter.

illuviation Transport and deposition of soil components from a higher to a lower level by percolating water.

image See *image* under *remote sensing.*

imbrication Shingled or downstream overlapping of bed material due to water flow, most commonly as plate-shaped large gravel or cobble substrate materials.

impermeable Refers to a layer of material of sufficient composition, density, and thickness that it does not permit passage of a liquid or a gas.

impervious Refers to material through which water cannot pass or passes with great difficulty.

impoundment Natural or artificial body of water that is confined by a structure such as a dam to retain water, sediment, or wastes.

improvement flow See *improvement flow* under *flow.*

impurity A foreign, objectionable material that contaminates water.

incidental drift Casual or random drift of aquatic organisms.

incident light See *incident light* under *solar radiation.*

incised channel See *incised channel* under *channel geometry.*

incised stream See *incised stream* under *stream*.

index Measurement of feature of an organism, community, or habitat that is used as a reference for determining or monitoring change over time.

index flow Standard discharge that is used to compare with other discharges in a specific stream. See also *index flow* under *flow*.

index of biotic integrity (IBI) See index of biotic integrity (IBI) under *biological indices*.

index of refraction (1) Number indicating the speed of light in a given medium versus the speed in water or other specified medium. (2) Measure of the degree to which light is bent or scattered when passing through water or other substances.

indicator organisms (1) Organisms that respond predictably to various environmental changes, and whose presence, absence, and abundance are used as indicators of environmental conditions. (2) Any plant or animal that, by its presence, its frequency, or its vigor, indicates any particular property of a site.

indigenous A fish or other aquatic organism native to a particular water body, basin, or region.

indirect toxicity Toxicity that affects organisms by interfering with their food supply or modifying their habitat instead of acting directly on the organisms.

infiltration Process by which water moves from the earth or surface water into the groundwater system.

infiltration rate Rate at which standing water percolates downward into the substrate.

inflow Location where water from one source enters another water body. Also, the movement of water from one source into another water body.

influent flow See *influent flow* under *flow*.

influent seepage Water movement from the surface of the ground toward the water table. Also, refers to seepage of water into the streambed from a stream above the water table.

initial breaching See *initial breaching* under *breaching*.

initial dilution zone Area receiving water adjacent to a point source discharge, extending from the point of discharge 100 m in all directions from the water surface to the bottom. State and federal water quality objectives do not apply within an initial dilution zone.

inlet Long and narrow indentation of a shoreline or a narrow passage between two islands.

inner gorge Stream reach bounded by steep valley walls. Common in areas of stream downcutting or geologic uplift.

inshore On or very close to the shore. Also referred to as onshore.

insolation Exposure to sunlight. Solar radiation is measured as the rate of delivery or intensity per unit area on the horizontal surface of an object.

instanteous discharge See *instanteous discharge* under *discharge*.

instanteous flow See *instanteous flow* under *flow*.

instream Within the wetted perimeter of the stream channel.

instream cover Areas with structure (e.g., boulders, rocks, logs, etc.) in a stream channel that provide aquatic organisms with shelter or protection from predators or competitors. Also a place with low water velocity where organisms can rest and conserve energy.

instream flow See *instream flow* under *flow*.

instream flow requirements See *instream flow requirements* under *flow*.

insular Of or pertaining to an island or islands. Also applied to dwelling on an island, forming an island, or occurring alone.

insulated stream See *insulated stream* under *stream*.

intensity See *irradiance*.

interbasin transfer Transport of water from one watershed or river basin to another.

interception Physical interference of precipitation by vegetation.

intercratonic basin Basin formed in a relatively rigid and immobile area of the earth's crust.

interface Surface that forms a boundary between adjacent areas, bodies, or spaces. May also refer to the point of interaction between two independent systems.

interflow (1) Precipitation that infiltrates the soil and moves laterally until it resurfaces or is intercepted by an underground body of water. (2) Movement or inflow of water in a reservoir or lake between layers of water of different (higher or lower) density. See also *interflow* under *mixing*.

interfluve Elevated region that divides watersheds.

intergravel flow See *intergravel flow* under *flow*.

interill erosion See *interill erosion* under *erosion*.

intermediate breaching See *intermediate breaching* under *breaching*.

intermittent (1) Alternately starting and stopping. (2) Water that flows or exists sporadically or periodically.

intermittent flow See *intermittent flow* under *flow*.

intermittent lake See *intermittent lake* under *lake*.

intermittently exposed See *intermittently exposed* under *water regime*.

intermittently flooded See *intermittently flooded* under *water regime*.

internal delta floodplain See *internal delta floodplain* under *floodplain*.

internal progressive wave See *internal progressive wave* under *wave*.

internal seiche See *internal seiche* under *wave*.

interrupted stream See *interrupted stream* under *stream*.

interstitial flow See *intergravel flow* under *flow*.

interstitial space Spaces or openings in substrates that provide habitat and cover for benthos.

interstitial velocity Rate of subsurface water flow through the substrate (V_a), expressed as the volume of flow per unit of time through a unit area composed of solids and voids. Also referred to as apparent or intragravel velocity:

$$V_a = KS\,;$$

K = permeability (cm/h);
S = hydraulic gradient.

It can also be approximated from surface velocities by the equation:

$$V_a = \frac{(V_s)^2 n^2 K}{2.22 R^{4/3}}\,;$$

V_s = mean velocity of surface water;
n = roughness coefficient;
K = permeability;
R = hydraulic radius.

intertidal Zone between high and low tides.

intrusive body Igneous rocks which, while fluid, penetrated into or between other rocks but solidified before reaching the surface; includes very hard, coarse-grained rocks like granite, diorite, and gabbro.

inundation To be covered with standing or moving water.

inverse estuary Type of estuary where evaporation exceeds the freshwater inflow plus precipitation.

inverse stratification See *inverse stratification* under *stratification*.

invert (1) Refers to the upstream end of a culvert. (2) The bottom inside surface of a pipe or conduit. Occasionally the term refers to the bottom or base elevation of a structure.

iones Relic riverbeds.

irradiance Amount of electromagnetic energy received at a unit surface area per unit time, usually measured for the visible and near-visible portion of the light spectrum. Light passing through a water surface is progressively absorbed with increasing depth; light intensity at depth z (I_z) is:

$$I_z = I_o e^{-\eta z}$$

I_o = light intensity at the water surface;
η = extinction coefficient of light in water.

irregular acute meander See *irregular acute meander* under *meander*.

irregular channel See *irregular channel* under *channel pattern*.

irregular meander See *irregular meander* under *meander*.

irregular meander channel See *irregular meander channel* under *channel pattern*.

irregular meander with oxbow See *irregular meander with oxbow* under *meander*.

irrigation Movement of water through ditches, canals, pipes, sprinklers, or other devices from the surface or groundwater for providing water to vegetation.

island Discrete parcel of land completely surrounded by water. See *islands* under *bar*.

islet A small island.

isobath Imaginary line or area on map connecting all points of equal depth.

isocline Fold or strata that is so tightly compressed that parts of each side dip in the same direction.

isopleth Line on a graph or chart depicting a measurement of equal value. See *isobath*, *isotherm*.

isotherm Line on a chart or graph linking all points having identical water temperatures.

isthmus Narrow strip of land connecting two larger land areas.

▶ j

jack See *a-jack* under *habitat enhancements*.

jam Congested area caused by the accumulation of debris in flowing waters. See also *jam* under *large organic debris*.

jetsam Materials of human origin that accumulates along coastal areas.

jetty See *jetty* under *habitat enhancements*.

junction bar See *junction bar* under *bar*.

▶ k

kame A ridge-like or hilly local glacial deposit of coarse alluvium formed as a delta at the front of glaciers by meltwater streams.

karst Geologic features composed of limestone that are characterized by sinks, ravines, and underground streams. Any limestone or dolomitic region with underground geologic features.

k-dam See *k-dam* under *habitat enhancements*.

kelvin wave See *kelvin wave* under *wave*.

kettle lake See *kettle lake* under *lake*.

key dam Main or primary dam that is generally constructed across the lower part of a gorge.

knickpoint See *nick point*.

▶ l

lacustrian Lake-dwelling; term pertains to standing water bodies.

lacustrine Pertaining to lakes, reservoirs, wetlands, or any standing water body with a total surface area exceeding 8 ha (20 acres). See also *lacustrine* under *streambank material*.

lag deposits Coarser materials remaining after finer particle-sized materials are removed.

lagoon (1) Small, shallow, pond-like body of water that is connected to a larger body. (2) Shallow water separated from the sea by a sandbar or a reef. (3) Settling pond for wastewater treatment.

lag time An interval or lapse in time between events such as precipitation and peak runoff.

lahar See *lahar* under *landslide*.

lake (1) Natural or artificial body of fresh or saline water (usually at least 8 ha [20 acres] in surface area) that is completely surrounded by land. (2) Large floodplain feature, persistent, relatively unchanged over a period of years. See *lacustrine*.

aeolian lake Lake that forms in a basin scoured out by wind.

aestival lake Shallow lake, permanently flooded, that freezes.

alkali lake Lake where alkaline salts have accumulated from evaporation (i.e., closed basin) or in situations where freshwater inflow is insufficient to dilute the alkaline salts.

bitter lake Water body formed for salt extraction from seawater or other water body that contains a high concentration of salts in solution.

blind lake Lake that has neither an inflowing stream nor an outlet. Compare with *seepage lake* under *lake*.

brine lake Lake with water that is saturated or with high salt concentrations.

caldera lake Lake formed by subsidence in the roof of a partially emptied magmatic chamber. See *crater lake* and *volcanic lake* under *lake*.

cave-in lake See *kettle lake*, *sink lake*, *thaw lake*, *themokarst lake* under *lake*.

cirque lake Lake that occurs where valleys are shaped into structures resembling amphitheaters by the action of freezing and thawing ice. Usually found in the upper portion of a glaciated area or in mountains.

closed lake Lake that loses water only through evaporation.

coastal lake Lake formed by the enclosure of lagoons by wave action or an embayment formed by bars deposited by currents along a shoreline.

coldwater lake Lake with a fish community composed primarily of coldwater fishes.

crater lake See *caldera lake* and *volcanic lake* under *lake*.

cryogenic lake Lake formed inside an ice-wedge polygon that develops in permafrost from water seepage through cracks in the surface of the ground.

cutoff lake Artificial oxbow lake created by river channelization or levee construction that isolates the lake from the river. A cutoff lake may contain a water control structure to facilitate drainage into the river.

dead lake Body of standing water that cannot support plants or animals because of adverse chemical or physical features.

delta lake Lake formed upstream of an alluvial deposition.

doline lake Lake, usually with circular and conically shaped sinks, that is developed from the solution of soluble rock that gradually erodes the rock stratum.

drainage lake Lake that loses water through flows from an outlet. Sometimes separated into further categories by whether the lake has an inlet and outlet or is spring-fed with no inlet but an outlet.

dune lake Lake formed by deposition of sand or other material that is moved, primarily or partially, by wind.

dystrophic lake Lake with a high concentration of humic acid in the water that colors it brown, low pH, and peat-filled margins that develop into peat bogs. See *bog* under *wetlands*.

earthquake lake Lake formed in a depression created by an earthquake.

ephemeral lake Lake that contains water for short and irregular periods of time and usually contains water after a period of heavy precipitation.

erosion lake Lake formed in a depression by the removal or deposition of rock fragments or other organic material.

eversion lake Type of pothole formed by streambed abrasion. A category of fluvial lakes associated with torrential flow and cataracts where rocks cut a pothole into the stream bedrock through erosion by a swirling action generated through hydraulic pressure.

extinct lake A former lake as evidenced by fossil remains or stratigraphy, that no longer holds water due to climatic changes or changes in hydraulic processes.

false karst lake Lake in a depression caused by geologic piping that results in turbulent subsurface drainage channels in insoluble clastic rock.

finger lake Lake that is narrow and elongate in shape.

glacial lake Lake formed by glacial action such as scouring or damming.

graben lake Lake formed by geologic faulting processes where depressions occur between masses of either a single fault displacement or in multiple downward displacements resulting in troughs. See also *tectonic lake*.

gravel pit lake Lake formed by water accumulated in a pit from which gravel was excavated below the groundwater level.

intermittent lake Lake that has surface water only part of the time at different recurring intervals and durations.

kettle lake Lake formed in a depression by melting ice blocks deposited in glacial drift or in the outwash plain.

landslide lake Lake formed by dams or depressions created by the mass movement of soil, rock, and debris.

levee lake Shallow, often elongated body of water that lies parallel to a stream and is separated from it by a strip of higher land.

maar lake Lake occupying a small depression with a diameter less than 2 km, resulting from lava in contact with groundwater or from degassing of magma.

marl lake Lake with a high deposition or content of calcareous materials in the littoral zone.

montane freshwater lake Circumneutral lake found in mountains below timberline.

moraine lake Lake formed by the damming action of rock debris deposited by retreating glaciers.

open lake Lake with outflow from an outlet or from seepage.

oxbow lake Lake occupying a former meander of a river isolated by a shift in the stream channel.

paternoster lake A chain of small lakes in a glaciated valley formed by ice erosion.

pay lake Lake where the public pays a fee for swimming, fishing, and other recreational uses.

perched lake Lake formed by surface water from a perched groundwater table.

perennial lake Lake that always contains water.

playa lake An internally drained lake found in a sandy, salty, or muddy flat floor of an arid basin, usually occupied by shallow water only after periods of prolonged heavy precipitation. Sometimes refers to an ephemeral lake that forms a "playa" upon drying up.

plunge lake An excavated lake at the foot of a waterfall.

pluvial lake A former lake that existed under a different climate in areas that are now dry.

pothole lake Ponds, pools, lakes, and wetlands found in depressions (potholes) that were formed by glacial activity.

public lake Lake legally open to the public for recreational activities that may include boating, fishing, and swimming.

relict lake A remnant lake or a larger pluvial lake occupying a closed basin in arid regions.

reservoir A lake formed by impounding water behind a natural or constructed dam.

rift lake Lake formed along a geologic fault or fault zone.

saline lake Lake with a high concentration of salts such as carbonates, chlorides, or sulfates.

saltern lake Lake with a high concentration of sodium chloride.

salt karst lake Lake formed by the dissolution of evaporites.

seepage lake Lake without an outlet drained by seepage into groundwater. Compare with *blind lake* under *lake*.

sink lake Lake that forms in a depression created by underground solution of limestone.

small mountain lake A small lake (8 ha [20 acres]) formed in a natural topographic depression on a mountain.

soda lake Lake with a high concentration of $NaHCO_3$ and Na_2CO_3.

solution lake Lake formed by soluble rock slowly dissolved by percolating groundwater.

stratified lake Lake with distinctive strata caused by density differences (e.g., temperature, salinity).

tectonic lake Lake formed in depressions created by movement or damming action of surface plates.

thaw lake Lake formed in shallow depressions from unequal thawing of permafrost in arctic regions. Also termed *thermokarst*.

thermokarst lake Lake formed by coalescing of many cryogenic lakes, or by melting of large amounts of ice deep in permafrost.

two-story lake Lake with an upper layer of warm water supporting warmwater fishes and a lower (i.e., deeper) layer of cold water supporting coldwater fishes.

vernal lake A shallow lake resulting from seasonal precipitation and runoff that is dry for part of the year.

volcanic lake Lake formed by depressions in lava or volcanic cones or dams formed by lava that impounds water. See *caldera lake* and *crater lake* under *lake*.

warmwater lake Lake with a fish community composed primarily of warmwater fishes.

lake volume See *lake volume* under *dimensions*.

lake width See *lake width* under *dimensions*.

laminar flow See *laminar flow* under *flow*.

land Any part of the earth not covered by water.

landform Any physical, recognizable form or feature of the earth's surface that is produced by natural processes and has a characteristic or unique shape.

landsat See *landsat* under *remote sensing*.

landsat multispectral scanner (MSS) See *landsat multispectral scanner (MSS)* under *remote sensing*.

landsat thematic mapper (TM) See *landsat thematic mapper (TM)* under *remote sensing*.

landscape Contiguous heterogeneous natural or constructed land area with similar conditions over a larger geographic area.

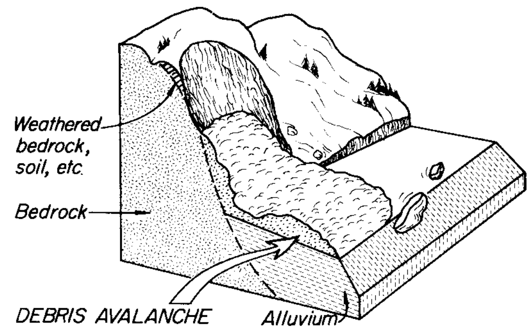
landslide Fall or slide of soil, debris, or rock on or from a slope. Any downslope mass movement of soil, rock, or debris on a landform. See also *landslide pool* under *slow water, pool, dammed pool* under the main heading *channel unit*.

avalanche Large mass of snow or ice, sometimes with rocks and vegetative debris that moves rapidly downslope.

avalanche cone Accumulated material, similar to a talus cone, deposited by a snow avalanche.

avalanche track Channel-like pathway of an avalanche, marked by eroded surfaces and bent or broken trees.

bedrock landslide Infrequent landslides of rock whose strength is much higher than the strength of their boundaries. These landslides usually occur as frequent small slides that produce irregular hillslopes with steep toes and head scarps.



debris avalanche (from Meehan 1991)

debris avalanche Rapid, shallow, downslope mass movement of saturated soil or surficial material (commonly including vegetation debris) that occurs on steep hillsides.

debris fall Fall or rolling soil or surficial material mass.

debris flow Rapid mass movement of material including vegetation, soil, mud, boulders, and weathered rock (i.e., a debris torrent) down a steep (greater than 5°) mountain slope or stream channel. See *debris torrent*.

debris flow tracks Erosion marks made by debris flows characterized by the lack of vegetation or young plants, deposits of soil, boulders, and rock, levees, or gullies.

debris jam or dam Accumulation of debris in a channel that may cause ponding of water or alluvial deposition upstream from the accumulation, and block fish movements.

debris slide Downslope sliding of a mass of soil or surface material that may be transformed into a debris flow.

debris torrent Rapid, turbulent movement of water, soil, alluvium, and organic matter down a stream channel during storms or floods. Torrents generally occur in small streams with scouring of the streambed and deposition of a large quantity of material at the lower end of the torrent. See *debris flow*.

deep-seated creep Slow, gradual, more or less continuous and permanent deformation of soil caused by gravity.

deep-seated failures Landslides involving deep regolith, weathered rock, or bedrock, as well as surface soil that may form large geologic features.

dry ravel Downslope movement of dry, noncohesive soil or rock particles by gravity in a form of soil creep.

earthflow Mass downslope movement of soil and particles of weathered rock smaller than sand that results when soils become saturated and unstable.

earth slump Downslope movement of a relatively intact mass of soil, colluvium, and vegetation along a clearly defined, concave surface that is parallel to the slope.

flow slides Rapid downslope movement of a cohesive soil mass that results from liquefaction of a bank in saturated silty and sandy soils.

flow till Debris flow resulting from melting ice that causes saturation of glacial debris and accumulates on a lower gradient, more stable surface.

gravity flow Downslope flow of a mixture of water and sediment caused by slumping.

headscarp Steep, upper portion of a landslide scar.

lahar Flash floods or avalanche consisting of semiliquid mud, rock, and ice that surge rapidly downslope from higher altitudes, and usually occur on the slopes of volcanoes.

landslide scar Part of a slope (commonly steep) that is exposed or visibly modified from downslope movement of soils and rock accompanying a landslide.

large persistent deep-seated failure Slump-earthflows involving large areas of hillside on landscapes that remain recognizable for a long period of time.

mass movement General term for a large downslope movement of soil and rock or for avalanches that result from natural or anthropogenic causes.

mass wasting Downslope movement, flow, or slumping of a large amount of coherent or aggregate material from weathering and erosion that reduces the steepness of slopes and deposits the material in lower areas.

mud slide Horizontal and vertical movement of mud caused by natural water saturation of the soil or from anthropogenic disturbance.

periglacial landslide Active valley wall processes characteristic of very cold regions such as next to active glaciers or alpine terrain.

rock avalanche Rapid, downslope flow of large masses of rock by rock falls and slides from bedrock areas.

rock creep Slow, gradual downslope progression of rock fragments.

rock fall Relatively free-falling and precipitous movement of newly detached fragments of bedrock (any size) from a cliff or other very steep slope.

rock slide Downslope movement of rock on or from a steep slope.

rotational failure Horizontal downslope movement of hillside material that results in an upward turn on the toe of the slide. See *slump*.

shallow-rapid landslide Shallow (1–2 m) landslide on a steep slope produced by failure (slipping, sliding) of the soil mantle including glacial till and some weathered bedrock that leaves an elongate, spoon-shaped scar.

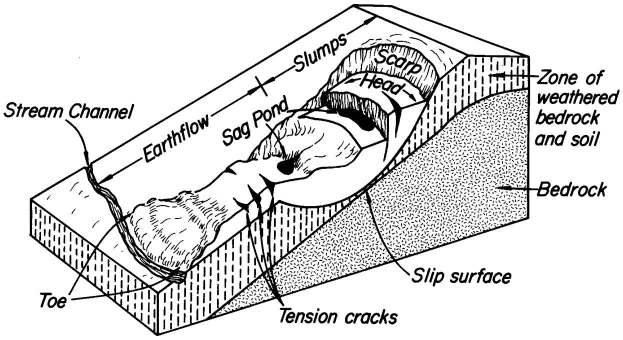
slab failure Broad, flat, somewhat thick rock that breaks off or falls as a single unit.

slide Mass movement of soil and rock where slope failure occurs along one or more slip surfaces. May become a debris flow or torrent flow if enough water is present in the mass.

slip erosion Downslope slide of a whole mantle rock. The large, spectacular forms are termed landslips, landslides, or debris avalanches.

slope failure Rupture and collapse or flow of surface materials, soil, or bedrock due to shear stress exceeding the strength of the material.

slump Deep, rotational landslide, generally producing coherent lateral and downward movement (back-rotation) of a mass of soil, rock, or other material that slips as a coherent



slump (from Meehan 1991)

mass. Also, a land area that sunk to create a boggy, marshy place.

slump–earthflow Landslide exhibiting characteristics of slumps and earthflows in which the upper part moves by slumping while the lower portion moves by flow.

small sporadic deep-seated failures Commonly smaller slumps that can result from storms or earth movement at irregular time intervals and can crumble or decay so that they are indiscernible.

snow avalanche See *avalanche* under *landslide*.

landslide lake See *landslide lake* under *lake*.

landslide pool See *landslide pool* under *slow water*, *pool*, under the main heading *channel unit*.

landslide scar See *landslide scar* under *landslide*.

landtype Unit on the earth's surface of a characteritistic geomorphic surface type and a particular lithological composition, indentifiable on a spatial scale of hectares or acres.

langmuir circulation See *langmuir circulation* under *wave*.

large benthic organic matter See *large benthic organic matter* under *benthic organic matter*.

large bole See *large bole* under *large organic debris*.

large impoundment An impoundment larger than 227 hectares (500 acres) in surface area.

large organic debris Large woody material (e.g., log or tree) with a diameter greater than 10 cm (4 in) and a length greater than 1 m (39 in). Synonymous with large woody debris (LWD), a term that is commonly used in the Pacific Northwest where organic debris generally is a log or tree.

aggregate Two or more large woody pieces at one location.

biological legacies Large trees, logs, snags, and other components of a forest that remain after logging for reseeding and that provide terrestrial or aquatic ecological structure.

blowdown Trees that have fallen from high wind.

bole Term referring to the trunk of a tree.

clump Irregular accumulation of debris along a stream channel that does not form major impediments to streamflow.

deadhead Log submerged and close to the water surface that is not embedded, lodged, or rooted in the stream channel.

digger log Log anchored to a streambank or channel bottom to form a scour pool.

down log Portion of a tree that has fallen or been cut and left on the forest floor.

fixed logs Log (or group of logs) that is firmly embedded, lodged, or rooted in a stream channel.

floats Accumulations of logs floating on the surface but prevented from moving downstream by an obstruction.

free log Log (or group of logs) that is not embedded, lodged, or rooted in the stream channel.

jam Wholly or partially submerged accumulation of woody debris from winds, water currents, or logging activities that partially or completely blocks a stream channel and obstructs streamflow.

large bole Bole 60 cm (24 in) or more in diameter.

log In general, a tree trunk, bole, or large limb, with or without the roots attached.

log dam Dam formed by the deposition of woody debris and stream sediments at an obstruction caused by a log or several logs in the stream channel.

root wad Root mass from a tree. Synonymous with butt ends.

scattered Single pieces of debris distributed at irregular intervals along a stream channel.

small bole Bole less than 60 cm (24 in) in diameter.

snag Generally applies to a standing dead tree. Sometimes applied to a submerged fallen tree in a large stream with the top exposed or only slightly submerged.

stable debris Large woody debris, usually anchored or embedded in the stream bottom or bank that is not dislodged during periods of high flows.

sweeper log Fallen tree with branches that accumulates floating logs and other debris and projects into the channel, creating a hazard for navigation.

volume Volume (V) of a piece of large woody debris can be calculated as:

$$V = \frac{\pi(D_1^2 + D_2^2)L}{8};$$

D_1 = diameter of debris at one end;
D_2 = diameter of debris at other end;
L = length.

woody debris Collection of materials in the water or substrate on the bank or shoreline that is primarily composed of wood.

large persistent deep-seated failure See *large persistent deep-seated failure* under *landslide*.

lateral channel movement Movement of a stream channel laterally across a valley floor either gradually through meandering or suddenly through avulsions.

lateral moraine See *lateral moraine* under *moraine*.

lateral scour pool See *lateral scour pool* under *slow water*, *pool*, *scour pool* under the main heading *channel unit*.

late succession stage See *late succession stage* under *succession*.

leachate Soluble substance that has been removed from other material by water percolation.

leaching Removal of soluble material in the ground by percolating water.

leak Escape or entry of water.

leakage The amount of water that leaks into or out of a storage area.

leaking Movement of water into or out of a storage area or stream.

least flow See *least flow* under *flow*.

leave strips Bands of trees or other vegetation left along stream, rivers, and roads as buffers from adjacent forest management and other human activities. See also *buffer*.

ledge Reef, ridge, shelf, or line of rock longer than wide found in the sea, lakes, or other bodies of water.

lee The downwind side of an object being affected by some physical process.

lee bar See *lee bar* under *bar*.

leeshore The shore protected from direct wind or a shore receiving wind only from the land.

leg-type structure See *leg-type structure* under *habitat enhancements*.

length See *length* under *dimensions* and *wave*.

lentic An aquatic system with standing or slow flowing water (e.g., lake, pond, reservoir, swamp, marsh, and wetland). Such systems have a nondirectional net flow of water. See *standing water*.

levee (1) Naturally formed elongate ridge or embankment of fluvial sediments deposited along a stream channel. (2) Artificial embankment along a water course or an arm of the sea to prevent flooding or restrict movement of water into or through an area. Compare with *berm* under *habitat enhancements*, *dike*.

levee lake See *levee lake* under *lake*.

level Surface elevation of a body of water relative to mean sea level.

Liebig's law of the minimum Growth and reproduction of an organism is hindered when a minimum quantity of an element or substance such as oxygen, carbon dioxide, or calcium is available.

limiting factor (1) Any condition that approaches or exceeds the limits of tolerance by an organism. (2) A habitat component (biological, chemical, or physical) whose quantity constraints or limits the size of a population.

limnetic (1) Open-water zone of a water body too deep to support rooted aquatic vegetation. (2) Zone of deep water between the surface and compensation depth.

limnic material Soils made up of inorganic or organic compounds that are deposited in water by precipitation, aquatic organisms, underwater or floating aquatic plants, or aquatic animals.

limnocrene A spring pool (generally large) with or without outlet.

linear extent of structure Percentage of sides in a water body that are cliffs or shoals.

link In drainage networks, stream reach of a particular order, or a stream at its origin.

downstream link Magnitude of a link at the next downstream confluence.

link magnitude In drainage networks, the number of links upstream from a given point in the network.

lithology Physical character of a rock or deposit that is defined by rock type or distribution of particle sizes.

lithorheophilic See *lithorheophilic* under *benthos*.

litter Leaves, needles, twigs and branches, and other small organic matter entering a water body. Also referred to as litter fall.

littoral Shallow shore area (less than 6 m [~20 ft] deep) of a water body where light can usually penetrate to the bottom and that is often occupied by rooted macrophytes.

epilittoral Shore area entirely above the water line that is unaffected by spray.

eulittoral Shoreline between the highest and lowest seasonal water levels.

littoroprofundal Zone below the lower edge of the macrophyte boundary.

lower infralittoral Zone of submerged vegetation.

middle infralittoral Zone of floating leaf vegetation.

sublittoral Portion of a shore from the lowest water level to the lower boundary of plant growth.

supralittoral Shore area above the water line that is subjected to spraying by waves.

upper infralittoral Zone of rooted vegetation.

littoral drift Material floating in the littoral zone of a lake.

littoral sediment Sediment deposited along the shore of a lake.

littoroprofundal See *littoroprofundal* under *littoral*.

loading Addition of specific quantities of substances or heat to a water body.

loess Fine, loamy soil or sand deposited by the wind.

log See *log* under *large organic debris*.

log dam See *log dam* under *large organic debris*.

log pond See *log pond* under *pond*.

log sill See *check dam* under *habitat enhancements*.

long-duration flooding See *long-duration flooding* under *flooding*.

longitudinal profile A plot of elevations with distances to depict stream channel characteristics.

longshore drift Movement of sediment along a beach from wash and backwash of waves that make oblique contact with the shore.

long wave See *long wave* under *wave*.

losing stream See *losing stream* under *stream*.

lotic Aquatic system with rapidly flowing water such as a brook, stream, or river where the net flow of water is unidirectional from the headwaters to the mouth.

lotic (riparian) wetland See *lotic (riparian) wetland* under *wetlands*.

lower bank See *lower bank* under *streambank*.

lower infralittoral See *lower infralittoral* under *littoral*.

lower valley wall tributary See *lower valley wall tributary* under *tributary*.

low flow See *low flow* under *flow*.

low gradient riffle See *low gradient riffle* under *fast water—turbulent*, *riffles* under the main heading *channel unit*.

low-head dam A low barrier that is placed in a waterway to retain or redirect flows. See also *check dam* under *habitat enhancements*.

lowland Land that is level and only slightly above the elevation of the water surface and that is periodically subject to flooding.

lowland reservoir Impoundment constructed in rolling hill country or on a stream with a moderate floodplain.

lowland stream See *lowland stream* under *stream*.

low moor See *low moor* under *wetlands*.

lunker structure See *lunker structure* under *habitat enhancements*.

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maar lake See *maar lake* under *lake*.

macroinvertebrate An invertebrate animal (without backbone) large enough to be seen without magnification and retained by a 0.595 mm (U.S. #30) screen. See *benthos*.

collectors Macroinvertebrates that feed on living algae, fine particulate matter, or decomposing particulate organic matter collected by filtering water or the surface of sediments.

predators Macroinvertebrates that feed on flesh or fluids of other animals.

scrapers Macroinvertebrates that feed on algae or microflora attached to the substrate or to plants.

shredders Macroinvertebrate herbivores and detritivores that feed on living and decomposing vascular plant tissue.

macroinvertebrate community indicators See *water quality indicators*.

macrophyte A plant that can be seen without the aid of optics.

emergent macrophyte Aquatic plants growing from submerged soils in water between 0.5 and 1.5 m (1.5–5 ft) deep.

floating macrophyte Floating aquatic vegetation growing from submerged substrates in water between 0.5 and 3.0 m (1.5–10 ft) deep.

free-floating macrophyte Aquatic vegetation at or near the surface not rooted in the substrate.

nonpersistent emergent Emergent hydrophytes whose leaves and stems die and decompose annually so that most portions of the plant above ground are easily transported by currents, waves, or ice.

rheophyte A plant associated with fast-flowing water.

submerged macrophyte General term for aquatic vegetation in the photic zone.

macroplankton See *macroplankton* under *plankton*.

madicolous habitat Thin sheets of water flowing over rock faces, found at the edge of rocky streams, at the sides of waterfalls, and on rocky chutes.

main channel See *main channel* under *channel pattern*. Also referred to as *main stem channel* under *channel pattern*.

main channel pool See *main channel pool* under *pool*, *scour pool* under the main heading *channel unit*.

main-lake point A peninsula that juts into the main body of a lake or reservoir and continues underwater.

main stem Principal, largest, or dominating stream or channel in any given area or drainage system.

major waterway Any river, stream, or lake that is extensively used by commercial or private watercraft.

mangrove swamp See *mangrove swamp* under *wetlands*.

Manning's *n* An empirical coefficient for computing stream bottom roughness. Used in determining water velocity in stream discharge calculations. In English units,

$$Q = \frac{1.486R^{2/3}S^{1/2}A}{n};$$

Q = discharge;
R = hydraulic radius;
S = energy gradient (parallel to water slope);
A = cross-sectional area.

Because Q = water velocity, (V) times area (A),

$$V = \frac{1.486R^{2/3}S^{1/2}}{n}.$$

In metric units, the coefficient 1.486 becomes 1.0.

marginal habitat Habitats that approach the limits to which a species is adapted. More generally, habitats with physical or biological factors that support only limited species or populations.

marina Area to dock boats and provide other services for small watercraft.

marine Of, or pertaining to, the ocean and associated seas. See also *marine* under *streambank material*.

marl Light gray, calcareous, generally friable, clay or clay-loam composed principally of carbonate derived from photosynthetic activity of algae and mollusk shells.

marl lake See *marl lake* under *lake*.

marsh See *marsh* under *wetlands*.

mass movement See *mass movement* under *landslide*.

mass wasting See *mass wasting* under *landslide*.

mat (1) Collection of floating debris, macrophytes, or algae. (2) Submerged artificial fish structure, particularly one made of brush and tree branches.

mature river See *mature river* under *river*.

mature stream See *graded stream* under *stream*.

maximum bank height See *maximum bank height* under *dimensions*.

maximum depth See *maximum depth* under *dimensions*.

maximum elevation See *maximum elevation* under *dimensions*.

maximum flow See *maximum flow* under *flow*.

maximum lake length See *maximum lake length* under *dimensions*.

maximum likelihood See *maximum likelihood* under *remote sensing*.

maximum wavelength See *maximum wavelength* under *wave*.

maximum width See *maximum width* under *dimensions*.

mean annual flow See *mean annual flow* under *flow*.

mean annual runoff See *mean annual runoff* under *flow*.

mean catchment slope Can be calculated by:

$$S_b = \frac{(\text{elevation at } 0.85L) - (\text{elevation at } 0.10L)}{0.75L};$$

L = maximum length of the catchment basin.

mean column velocity See *mean column velocity* under *velocity*.

mean cross section velocity See *mean cross section velocity* under *velocity*.

mean density of structural units Density of structures per unit of shoreline or bottom.

meander Sinuous course of a river having specific geometric dimensions that describe the degree of curvature. More particularly, one curved portion of a sinuous or winding stream channel, consisting of two consecutive loops, one turning clockwise and the other counterclockwise. See *sinuosity*.

acute meander Meander with sharp, hairpin turns.

amplitude Breadth or width of the meander.

belt of meander The approximate width of a stream valley.

compound meander Irregular meander pattern developed on streams with more than one dominant discharge.

confined meander Meander scrolls within a confined floodplain.

distorted meander Meanders where obstructions limit lateral movement and development of sinuosity.

flat meander An irregular meander in a stream with a flat streambed.

free meander Meander in unconsolidated alluvium that migrates freely to develop waveforms without constraint from valley walls, adjacent terrain, or distortion from heterogeneous alluvium.

irregular acute meander Meander with an irregular pattern of sharp hairpin turns.

irregular meander Deformed or irregular meanders of variable size within a meander belt.

irregular meander with oxbow Irregular meander that retained a remnant loop.

meander belt-width Normal width or distance between tangents drawn on the convex sides of successive belts.

meander length Wave length of the meander.

meander scar Evidence of old channel locations from the lateral migration of a meander.

paleopotamon A large, deep former river meander that is disconnected from the current river channel except at the highest flood flow.

parapotamon Dead arms that are permanently connected to a river channel at the downstream end.

plesiopotamon A former braided channel connected only during high flows.

point of inflection Location where the thalweg crosses from one bank to the other.

radius of curvature Degree of curvature of the meander loop.

regular meander Meander with regular intervals and a consistent pattern of sinuosity and loops.

simple meander Meander with one dominant meander belt-width and wavelength.

sinuous meander Meander with slight curvature within a stream reach of less than approximately two channel widths.

straight meander Meander with very little curvature.

tortuous meander Meander that has a more or less repeated pattern characterized by angles greater than 90°.

truncated meander Meander where confinement limits lateral movement and sinuosity with undeveloped loops.

unconfined meander Meander that migrates unrestricted across a floodplain.

meander belt-width See *meander belt-width* under *meander*.

meander length See *meander length* under *meander*.

meander line A survey line that represents the location of the actual shoreline of a permanent natural body of water, without showing all the details of its windings and irregularities.

meander scar See *meander scar* under *meander*.

meander scrolls channel See *meander scrolls channel* under *channel pattern*.

mean flow See *mean flow* under *flow*.

mean high water Average height of the high water over 19 years.

mean lake depth See *mean lake depth* under *dimensions*.

mean lake width See *mean lake width* under *dimensions*.

mean low water Average height of the low water over 19 years.

mean monthly discharge See *mean monthly discharge* under *discharge*.

mean sea level Average elevation of the surface of the sea for all tidal levels over 19 years. Altitudes or elevations are expressed as elevations above mean sea level.

mean stream length See *mean stream length* under *dimensions*.

mean stream slope The mean gradient or drop in stream surface elevation per unit length of stream.

$$S_c = \frac{\text{elevation at source} - \text{elevation at mouth}}{\text{length of stream}}.$$

medial moraine See *medial moraine* under *moraine*.

median depth See *median depth* under *dimensions*.

median lethal dose (LD50 or LD$_{50}$) Dose (internal amount) of a substance that is lethal to 50% of a group of organisms within a specified time period.

median lethal concentration (LC50 or LC50) The concentration of a substance that kills half of the test organisms in a specified period of exposure. Called the *median tolerance limit* in older literature.

median line Line that is equidistant from the nearest points on opposite shores that forms the center line of the channel.

median moraine See *median moraine* under *moraine*.

median tolerance limit (TLm or TL$_m$) See *median lethal concentration*.

median width See *median width* under *dimensions*.

melt Action by which a solid becomes a liquid.

meltout till See *meltout till* under *moraine*.

meltwater Water that originates from the melting of snow or ice.

meltwater channel See *meltwater channel* under *channel pattern*.

meltwater stream See *meltwater stream* under *stream*.

merge See *merge* under *remote sensing*.

meromictic See *meromictic* under *mixing*.

mesa High, nearly flat-topped and usually isolated area bounded by steep slopes.

mesic Pertaining to or adapted to an area that has a balanced supply of water (i.e., moderately wet).

mesocline See *mesocline* under *stratification*.

mesohaline See *mesohaline* under *salinity*.

mesolimnion See *mesolimnion* under *stratification*.

mesophytic Plant species that grow in locations where soil moisture and aeration conditions lie between extremes (i.e., occurring in habitats with average moisture conditions).

mesosaline See *mesosaline* under *salinity*.

mesotrophic See *mesotrophic* under *trophic*.

metalimnion See *metalimnion* under *stratification*.

metaphyton Algae aggregated in the littoral zone, neither attached to substrate nor planktonic.

metapotamon See *metapotamon* under *potamon*.

metarhithron See *metarhithron* under *rhithron*.

meteoric water Term applied to rainwater, snow, hail, and sleet.

microclimate The climatic factors operating in a terrestrial microenvironment (i.e., small or restricted area).

microenvironment All the external environmental conditions that may influence an organism's physiology or energetics in a small or restricted area.

microhabitat Specific locations where organisms live that contain combinations of habitat characteristics that directly influence the organisms at any life stage. See *niche*.

microplankton See *microplankton* under *plankton*.

mid-channel bar See *mid-channel bar* under *bar*.

mid-channel pool See *mid-channel pool* under *pool, scour pool* with the main heading of *channel unit*.

middle infralittoral See *middle infralittoral* under *littoral*.

middle stream See *middle stream* under *stream*.

mid-successional stage See *mid-successional stage* under *succession*.

milk White or chalky-colored appearance of suspended mineral particles in water.

mill pond See *mill pond* under *pond*.

mine discharge Water that is drained, pumped, or siphoned from a mine.

mineral spring Spring with water containing a significant amount of dissolved minerals.

mineral turbidity Turbidity resulting from the presence of fine mineral particles such as clay.

mineral water Water containing a significant amount of dissolved minerals.

minimum bank height See *minimum bank height* under *dimensions*.

minimum flow See *minimum flow* under *flow*.

minor discharge Any discharge of less than 50,000 gallons per day or a discharge that does not adversely affect the receiving waters.

mire Refers to slimy soil or deep mud but also may be applied to swampy ground, bogs, or marshes.

mitigation (1) Action taken to alleviate or compensate for potentially adverse effects on aquatic habitat that have been modified through anthropogenic actions. (2) In-kind mitigation may be substituted for compensation to replace a resource that has been negatively impacted with a similar resource (e.g., a stream for a stream). (3) Out-of-kind mitigation refers to replacement of one resource with another (e.g., a lake for a stream).

mixing Internal circulation in a water body.

amictic Lakes that do not mix because they are perennially sealed off by ice from most of the annual variation in temperature.

biogenic meromixis Lakes that do not mix because of salt accumulation in the hypolimnion from decomposition of organic matter in the sediment.

cold monomictic Lakes with water temperature never greater than 4°C that circulate only one time in summer at or below 4°C.

crenogenic meromixis Lakes that do not mix because of high salinity from saline springs at deep pockets in the basin.

dimictic Lakes with two periods of mixing—one in the spring and one in the fall.

ectogenic meromixis Lakes that do not mix because of density differences. See *meromictic* under *mixing*.

holomictic Lakes that are mixed throughout the water column by wind.

interflow Flow of water into a lake that is greater in density than the epilimnion or hypolimnion and remains as a plume at intermediate depths.

meromictic Lake in which dissolved substances create a density gradient with depth that prevents complete (top to bottom) mixing or circulation of water. Periodic circulation occurs only in waters above the chemocline.

mixing characteristics Frequency with which all or some part of water is mixed.

mixing depth Depth of body of water where mixing occurs.

mixing zone Area or location of a water body where individual masses of water are mixed.

monomictic Lake with one regular period of circulation per year.

oligomictic Lake with temperatures always greater than 4°C that exhibit only irregular circulation.

overflow The inflow of water at the surface of a lake that is less dense than the lake water.

partial meromixis A normally dimictic lake that skips a turnover, usually in spring, from dynamic processes such as decomposition.

polymictic Lake with frequent or continuous circulation.

turnover ratio Volume of water (as a percentage) that is affected by turnover in meromictic lakes.

underflow Flow of water into a lake that has a greater density than the water in the lake.

warm monomictic Waters that do not drop below 4°C and circulate freely in winter but stratify in summer.

warm polymictic Waters that circulate freely at temperatures well above 4°C.

mixing characteristics See *mixing characteristics* under *mixing*.

mixing depth See *mixing depth* under *mixing*.

mixing zone See *mixing zone* under *mixing*.

mixohaline See *mixohaline* under *salinity*.

mixolimnion See *mixolimnion* under *stratification*.

mixosaline See *mixosaline* under *salinity*.

modified flow See *modified flow* under *flow*.

modified universal soil loss equation An estimate of sediment yield for an individual storm event can be calculated from:

$$Y = 95(Qq)^{0.56}KLSCP\ ;$$

Y = single storm sediment yield, in tons;
Q = storm runoff in acre-feet;
q = peak discharge in cubic feet per second;
K = soil erodibility factor;
L = slope length factor;
S = slope steepness factor;
C = cover management factor;
P = supportive practices factor.

monimolimnion See *monimolimnion* under *stratification*.

monomictic See *monomictic* under *mixing*.

monsoon (1) Wind that affects the climate of a large area when it changes direction with the seasons. (2) Specifically applies to the seasonal wind in southern Asia that blows from southwest in summer and northeast in winter and is associated with episodes of heavy rainfall separated by periods of little or no rain.

montane Pertaining to mountains or mountainous areas.

montane freshwater lake See *montane freshwater lake* under *lake*.

monthly mean discharge See *monthly mean discharge* under *discharge*.

moor See *moor* under *wetlands*.

morainal See *morainal* under *streambank material*.

moraine Irregular, surficial geologic deposit of sand, rock, and debris left by a retreating glacier.

ablation moraine Moraine formed by melting ice that has a typically hummock form.

end moraine A ridge of glacial till that remains in equilibrium at the terminus of a valley glacier or at the margin of an ice sheet.

ground moraine Thin deposits left underneath a retreating glacier that may have a gently rolling or hummock-like appearance.

hummocky moraine Moraine composed of generally random knobs, ridges, hummocks, and depressions.

ice-disintegration moraine Moraine formed by accumulation of till and other materials on toe of stagnant ice.

lateral moraine Geologic deposits formed along the sides of a retreating glacier.

medial moraine A long strip of rock debris carried on or within a glacier from the convergence of lateral moraines where two glaciers join.

median moraine Geologic deposits along the central path of a glacier.

meltout till Material that collects on or under glacier ice of a stationary or stagnant glacier.

neoglacial moraine Term applied to a moraine that formed during the Neoglacial period and the more recent Little Ice Age.

recessional moraine Moraine created by accumulation of materials deposited by a melting glacier that marks a temporary halt in its general retreat.

terminal moraine Geologic deposits at the front lobe or foot of a glacier that marks the furthest point reached by a glacier.

moraine lake See *moraine lake* under *lake*.

morass See *morass* under *wetlands*.

morphoedaphic index (MEI) An index of the trophic state of a water body:

$$\text{MEI} = [(\text{TDS})/\bar{d}\,]^{1/2}\ ;$$

TDS = total dissolved solids;
$\bar{d}$ = mean depth.

morphology Physical attributes of a water body and the methods for measuring those attributes.

morphometry The physical shape of a water body, such as a stream, lake, or reservoir.

mosaic See *mosaic* under *remote sensing*.

moss–lichen wetland See *moss–lichen wetland* under *wetlands*.

mountain processes See *mountain processes* under *active valley wall processes*.

mouth Downstream terminus of a stream as it enters another water body.

moveable bed A streambed composed of materials that are readily transported by streamflow.

muck Soft fine-grained soil composed of silt, clay, or organic substrate material, typically dark in color, that consists of 20–50% highly decomposed organic matter with intermingled silt and clay.

mud (1) Wet, sticky earth composed of silt intermingled with clay that may contain organic material. (2) Term that is often applied to firm streambeds composed of soil.

mudbank Lateral sides of a streambank created by mud deposition.

mud cracks Cracks formed in mud as it dries and shrinks.

mud flats Shallow areas of a stream composed of silt and other fine particles that are periodically exposed at relatively even elevations.

mudflow Lateral flow of mud that has been wetted by precipitation.

mudsill See *mudsill* under *habitat enhancements*.

mud slide See *mud slide* under *landslide*.

multipurpose reservoir Artificial impoundment used for water storage where water releases are regulated for various uses including domestic water supply, irrigated agriculture, power generation, and navigation.

multispectral classification See *multispectral classification* under *remote sensing*.

multispectral imagery See *multispectral imagery* under *remote sensing*.

multispectral scanner (MSS) See *multispectral scanner (MSS)* under *remote sensing*.

muskeg See *muskeg* under *wetlands*.

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nadir See *nadir* under *remote sensing*.

nannoplankton Planktonic organisms that are small enough to pass through a 0.03 mm mesh net. See also *nannoplankton* under *plankton*.

> **ultranannoplankton** Plankton that are less than 0.2 µm.

nannoseston See *nannoseston* under *seston*.

nasmode A spring complex or an area where a number of nearby springs originate from the same groundwater source.

native species Plant and animal species that occur naturally in aquatic and terrestrial habitats.

natural erosion See *natural erosion* under *erosion*.

natural flow See *natural flow* under *flow*.

natural levee Sediment deposited on a streambank as floodwaters subside that creates natural banks or ridges slightly above the floodplain.

natural spillway See *natural spillway* under *control structure*.

navigable Waterways used by humans for transportation or transport of goods. Legally applied to interstate waters: intrastate lakes, rivers, and streams that are used by interstate travelers for recreational or other purposes; intrastate lakes, rivers, and streams from which fish or shellfish are taken and sold in interstate commerce; and intrastate lakes, rivers, and streams that are used for industrial purposes by industries involved in interstate commerce.

nearshore Zone extending from a shore to a distance where the water column is no longer influenced by conditions on or drainage from land.

neck Narrow strip of land, such as an isthmus, cape, or strait.

needle ice Thin ice crystals formed on soil and rocks from frost-heaving.

negative heterograde See *negative heterograde* under *stratification*.

nekton Actively swimming organisms able to move independent of water current.

neoglacial moraine See *neoglacial moraine* under *moraine*.

neritic zone Relatively shallow water zone in oceans or seas that extends from the high-tide mark to the edge of the continental shelf.

net primary production See *net primary production* under *production*.

net seston See *net seston* under *seston*.

neuston Microscopic organisms associated with habitats at the interface of air and water. See *pleuston*.

epineuston Neuston living on the upper surface of water.

hyponeuston Neuston living on the underside of the surface water film.

neutral estuary Type of estuary where neither the freshwater inflow nor evaporation predominates (i.e., total freshwater inflow and precipitation equals evaporation).

niche (1) Ecological position of an organism within its community or ecosystem that results from the organism's structural adaptations, physiological responses, and specific behavior. An analogy is, the habitat is an organism's "address," while its niche is its "profession." (2) Ecological and functional role of an organism in a community, especially with regard to its food consumption. See *microhabitat*.

nick point (knickpoint) (1) Narrowing of a channel causing an increase in current velocity that results in an upstream accumulation of water and deposition. (2) Abrupt changes in slope at the confluence of streams or associated with geologic features.

nodal point See *nodal point* under *wave*.

node Refers to the ending points of a line that is used in GIS systems as a reference point along a stream.

nonclastic Crystalline chemical precipitates forming sedimentary deposits.

nonflooding floodplain See *nonflooding floodplain* under *floodplain*.

nonfoliar shading See *nonfoliar shading* under *stream surface shading*.

nonhydric Soils that develop under predominantly aerobic soil conditions.

nonmarine sediment Sediment that accumulates in rivers or freshwater lakes.

nonpersistent emergent See *nonpersistent emergent* under *macrophyte*.

nonpersistent wetland See *nonpersistent wetland* under *wetlands*.

nonpoint source Usually applied to pollutants entering a water body in a diffuse pattern rather than from a specific, single location that includes land runoff, precipitation, atmospheric deposition, or percolation.

nonsaturated zone Zone where the actual amount of oxygen or other material dissolved in water is less than saturation.

nonsensitive reservoir Reservoir where overall productivity is not decreased by low reservoir production rates.

nonwetland Area that is sufficiently dry so that hydrophytic vegetation, hydric soils, and wetland hydrology do not occur; includes uplands as well as former wetlands that are drained.

nonwoody benthic organic matter See *nonwoody benthic organic matter* under *benthic organic matter*.

normal erosion See *normal erosion* under *erosion*.

normal high water High water mark that occurs annually in a water body. In streams, it occurs at bank-full flows and is also called the peak annual flow (QFP).

nose velocity Water velocity immediately in front of a fish that is positioned into the current.

nuisance organism Term applied to an organism that is capable of interfering with the use or treatment of water.

nutrient Element or compound essential for growth, development, and life for living organisms such as oxygen, nitrogen, phosphorus, and potassium.

nutrient budget Gain and loss of all nutrients in a specific water body.

nutrient cycling Circulation of nutrient elements and compounds in and among the atmosphere, soil, parent rock, flora, and fauna in a given area such as a water body.

nutrient depletion Situation where the export of nutrients is greater than the import and where the reduction in the total amount of nutrients and their rate of uptake, release, movement, transformation, or export negatively affects organisms that inhabit a particular area.

nutrient loading Addition of nutrients into the water column via runoff, discharge, internal recirculation, groundwater, or atmosphere.

nutrient spiraling Cycling and downstream transport of nutrients from physical and biological activities in a stream.

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oasis Isolated, fertile area with vegetation in an arid region that is supplied with water from a well or spring.

obligate wetland species See *obligate wetland species* under *wetland status*.

obsequent stream See *obsequent stream* under *stream*.

obstruction Object or formation that partially or wholly blocks or hinders water flow and movement of organisms or that restricts, endangers, or interferes with navigation. Examples in aquatic habitats include geologic features, falls, cascades, chutes, beaver dams, and dams on impoundments.

occasionally flooded floodplain See *occasionally flooded floodplain* under *floodplain*.

oceanadromous Life cycle strategy of fish including migrations, reproduction, and feeding that occur entirely in saltwater. Compare with *anadromous*, *catadromous*, *diadromous*, *and potamodromous*.

off-channel pond See *off-channel pond* under *pond*.

off-channel pools See *off-channel pools* under *habitat enhancements*.

offshore Away from, moving away from, or at a distance from the shore.

offshore wind Wind blowing away from the shore.

ogee See *ogee* under *control structure*.

old river See *old river* under *river*.

oligohaline See *oligohaline* under *salinity*.

oligomictic See *oligomictic* under *mixing*.

oligopelic Bottom deposit containing very little clay.

oligosaline See *oligosaline* under *salinity*.

oligosaprobic zone See *oligosaprobic zone* under *saprobein system*.

oligotrophic See *oligotrophic* under *trophic*.

onshore In water, refers to a location on, moving onto, close to, or parallel to the shore. On land, refers to a location adjacent to a water body.

onshore wind Wind blowing toward the shore.

ooze (1) Soft, fine-textured bottom mud. (2) A condition where a substance flows, or is extruded, very slowly through openings.

opacity Degree of obstruction to light passage.

open basin Basin with a surface outlet.

open lake See *open lake* under *lake*.

open water (1) Water free of vegetation, stumps, or artificial obstructions that is away from the shoreline. (2) Water in a pond, lake, or reservoir that remains unfrozen or is not covered by ice during winter.

operating pool Amount of water retained in a reservoir for limited periods and released to operate turbines.

optimum flow See *optimum flow* under *flow*.

optimum level The most suitable degree of any environmental factor for the well-being, health, and productivity of a given organism.

organic See *organic* under *streambank material*.

organic debris Material of organic origin that ranges in size from fine particulate matter to large trees.

organic particles Particles that are of biological origin.

coarse particulate organic matter (CPOM) Living or dead organic material ranging in size from 1 mm (0.04 in) to 10 cm (4 in) that is often referred to as detritus.

dissolved organic matter (DOM) or dissolved organic carbon (DOC) Organic material that is smaller than 0.45 µm (i.e., passes through a 0.45 µm filter).

fine particulate organic matter (FPOM) Organic material ranging in size from 0.45 µm to 1 mm.

ultrafine particulate matter Matter smaller than 0.45 µm.

organism Any living thing composed of one or more cells.

orientation Position of an object or organism relative to the direction of streamflow or current in a lake, reservoir, or ocean.

orthograde See *orthograde* under *stratification*.

orthophotos See *orthophotos* under *remote sensing*.

oscillation Repeated, regular fluctuation above and below some mean value, or a single fluctuation between the maximum and minimum levels of such a periodic fluctuation. See also *oscillation* under *wave*.

outer beach Zone of a beach that is ordinarily dry and wetted only by waves during violent storms.

outfall Outlet of a water body, drain, culvert, or other structure.

outflow Water flowing out of a water body, drain, sewer, or other structure.

outlet (1) Opening or passage that allows water to flow from one place to another. (2) River or stream flowing from a water body. (3) Terminus or mouth of a stream where it flows into a larger water body such as a lake, reservoir, or sea.

outlet depth Midline depth of principal outlet.

outlet drain Drain that collects and transports the discharge of side drains.

outlet tower See *outlet tower* under *control structure*.

outslope Face of a fill or embankment that slopes downward from the highest elevation to the toe.

outsloping Sloping a road surface to direct water away from the cut side of the road.

outwash Material, chiefly sand or gravel, that is dislodged (i.e., washed) from a glacier by melt water.

outwash fan Detritus mass deposited at the foot of a glacier or mouth of a gorge by free-flowing water that is heavily loaded with sediment where velocity is suddenly reduced as a result of lower lateral constrictions.

outwash plain Flat area formed gradually by sediment carried to the site from a glacier and deposited by changes in carrying capacity of glacier meltwater.

overbank flooding Any situation where inundation occurs when the water level of a river or stream rises above the bank.

overbank storage Flood water from overbank flooding of a stream that remains in floodplain depressions where it is temporarily "stored" until it percolates into the stream or evaporates into the atmosphere.

overflow See *overflow* under *mixing*.

overflow channel Abandoned channel in a floodplain that carries water during periods of high runoff.

overhang Organic or inorganic materials that project over or into a water body.

overhead cover Plant foliage or overhanging material that provides protection to fish or other aquatic animals.

overlay See *overlay* under *remote sensing*.

oversaturation Concentrations of dissolved gases or other dissolved materials that exceed the predicted saturation level in water based on temperature and pressure.

overturn See *overturn* under *stratification*.

oxbow Bend or meander in a stream that becomes detached from the stream channel either from natural fluvial processes or anthropogenic disturbance.

oxbow lake See *oxbow lake* under *lake*.

oxygen deficit Difference between the observed oxygen concentration and the amount that would theoretically be present at 100% saturation for existing conditions of temperature and pressure.

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paleopotamon See *paleopotamon* under *meander*.

palustrine (1) Nontidal wetlands that are dominated by trees, shrubs, persistent or nonpersistent emergents, mosses, or lichens. (2) May also include wetlands (smaller than 8 ha) without vegetation, wetlands with water depths less than 2 m, and wetlands with salinity of less than 0.5 ppt. See also *palustrine* under *wetlands*.

parallel stream See *parallel stream* under *stream*.

parameter Any quantitative characteristic that describes an individual, population, or community or that describes the biological, chemical, and physical components of an ecosystem.

parapotamon See *parapotamon* under *meander*.

parent material Unconsolidated (more or less) weathered mineral or organic matter from which soil is developed.

partial meromixis See *partial meromixis* under *mixing*.

particle Individual fragment of organic or mineral material.

particle cluster Cluster of small particles that are grouped around one or more large particles and do not move until the large particle moves.

particle size Linear dimension, usually designated as "diameter," that characterizes the size of a particle.

particle size distribution Frequency distribution (expressed as d_n) of the relative amounts of particles in a sample that are within a specified size range, or a cumulative frequency distribution of the relative amounts of particles that are coarser or finer than a specified size.

particulates Any finely divided solid substance suspended in the water.

passage An avenue or corridor for fish migration either up or down a river system.

patch More homogeneous ecological islands that are recognizeably different from parts of an ecosystem that surround them but interact with the rest of the ecosytem.

paternoster lake See *paternoster lake* under *lake*.

pattern Configuration of a channel reach described in terms of its relative meander characteristics.

pavement Surface layer of resistant material in a streambed, such as stones and rocks, exposed after finer materials have been eroded away.

pay lake See *pay lake* under *lake*.

peak flow See *peak flow* under *flow*.

peat Unconsolidated, partially decomposed organic—mainly plant—material, deposited under waterlogged, oxygen-poor conditions. A layer of organic material containing plant residues that have accumulated in a very wet environment.

peat bog See *peat bog* under *wetlands*.

peatland General term for any land covered with a soil layer that contains a higher percentage of peat than adjoining areas.

pebble Small (2–64 mm), gravel-sized stone with rounded edges, especially one smoothed by the action of water. Compare with other substrate sizes under *substrate size*.

pebble beach Beach area dominated by small, gravel-sized, rounded stones.

pebble count Method of measuring the composition of streambed material by manual collection while wading a stream.

pediment Gradually sloping rock surface at the base of a steep slope, usually covered by thin alluvium. Also applied to a gentle sloping rock surface in front of an abrupt and receding hillslope, mountain slope, plateau, or mesa in an arid or semi-arid environment.

pelagic (1) Open water areas of lakes, reservoirs, or seas away from the shore. (2) Refers to organisms at or near the surface in water away from the shore. Compare with *limnetic*.

pelephilic See *pelephilic* under *benthos*.

pellicle Refers to a thin film or skim of material on the surface of water.

pelometabolism Metabolism in benthic sediments, primarily bacterial metabolism in anaerobic conditions.

pelorheophilic See *pelorheophilic* under *benthos*.

peneplain Low, large, nearly featureless land surface deposited by erosional processes operating over a long period of time.

peninsula Arm of land almost completely surrounded by water.

penstock See *penstock* under *control structure*.

peraquic moisture regime Soil condition where reducing conditions always occur due to the presence of groundwater at or near the soil surface.

percent fines Percentage of fine sediments, by weight or volume, that are less than 2 mm (0.08 in) in diameter in substrate samples. See *fine sediment*.

perched groundwater Groundwater that is separated from the main groundwater body by unsaturated, impermeable material.

perched lake See *perched lake* under *lake*.

perched stream See *perched stream* under *stream*.

percolation Downward movement of water through soil, sand, gravel, or rock.

perennial Stream, lake, or other water body with water present continuously during a normal water year.

perennial astatic See *perennial astatic* under *astatic*.

perennial flow See *perennial flow* under *flow*.

perennial lake See *perennial lake* under *lake*.

periglacial Pertains to active valley wall processes characteristic of very cold regions such as found next to active glaciers or in alpine terrain.

periglacial landslide See *periglacial landslide* under *landslide*.

perilithon Organisms (microscropic algae, protozoans, fungi, and bacteria) growing on the submerged portion of coarse rock substrates.

period See *period* under *wave*.

periodic drift Drift of bottom organisms that occur regularly or at predictable time periods such as diurnal or seasonal.

periodically flooded See *periodically flooded* under *flooding*.

periodicity Tendency to recur at regular intervals.

period of uninodal surface oscillation See *period of uninodal surface oscillation* under *wave*.

periphyton Attached microflora growing on the bottom, or on other submerged substrates, including higher plants.

epilithic Flora growing on the surface of rock or stones.

epipelic Flora living on fine sediment.

epiphytic Flora growing on the surface of macrophytes.

epipsammic Flora growing on or moving through sand.

permanently flooded Water regime where standing water covers the land surface during the entire year, except during extreme droughts. See various types of aquatic habitats in such areas under *wetlands*. See also *permanently flooded* under *flooding*, *floodplain*, and *water regime*.

permeability Measure of the rate at which water can penetrate and pass through a medium such as soil or other substrate. The rate depends on the composition and degree of compaction of the substrate.

persistent emergent hydrophytes Hydrophytes that normally remain standing, at least until the beginning of the next growing season.

pesticide Any chemical used to control populations of organisms that are undesirable to humans. The term "pesticide" is a generic term that is applied to chemicals used to control animals. More specific terms include "herbicide" (to control plants), "insecticide" (to control insects), and "lampricide" (to control sea lampreys).

pH Measure of the acidity and alkalinity of a solution, expressed as the negative $\log_{10}$ of the hydrogen-ion concentration on a scale of 0 (highly acidic) to 14 (highly basic). A pH of 7 is neutral.

PHABSIM Abbreviation for "physical habitat simulation method" that is used to translate changes in streamflow to changes in quantity and quality of habitat. For a range of measured and simulated flows, the distribution of depths, velocity, substrates, and cover types across a channel are converted to an index of physical habitat as preference curves for a given species and life stage.

photic zone See *euphotic zone*.

photogrammetry See *photogrammetry* under *remote sensing*.

photophobic Term applied to an organism that avoids light.

phototrophism Movement of organisms in response to light.

phreatophyte Deeply rooted plant that obtains its water supply from a more or less permanent subsurface zone of saturation.

physicochemical Term applied to the physical and chemical characteristics of an ecosystem.

phytophilic See *phytophilic* under *benthos*.

phytoplankton See *phytoplankton* under *plankton*.

picoplankton See *picoplankton* under *plankton*.

piedmont Deposit that is located or formed near the base of a mountain. Also applies to a physiographic province located between mountains and a coastal plain.

pier Structure constructed on pilings or that floats and that is used as a moorage for boats. See *pilings*.

piezometer Small diameter, nonpumping tube, pipe, or well used to measure the elevation of water table or potentiometric surface.

pilings Vertical columns, usually of timber, steel, or reinforced concrete, that are driven into the bottom of a water body to support a structure such as a pier or bridge.

pinnate stream See *pinnate stream* under *stream*.

piping Bank erosion caused by seepage of groundwater, with subsurface erosion that creates underground conduits, sometimes causing collapse of the surface.

piping depression pond See *piping depression pond* under *pond*.

pitch See *pitch* under *remote sensing*.

pixel See *pixel* under *remote sensing*.

placer Shallow deposits of gravel or similar substrate containing precious metals such as gold. The term is also applied to the site or form of mining.

placid Term refers to surface water that is quiet with no eddies or waves and that is usually associated with very slowly moving waters.

placid flow See *placid flow* under *flow*.

plain Any flat or gently sloping (elevation differences of less than 150 m [500 ft]) area formed from deposition of eroded substrates at low elevations and that may be forested or bare of trees.

plane bed Bed of fine sediments.

plankton Small plants and animals, generally smaller than 2 mm and without strong locomotive ability, that are suspended in the water column and carried by currents or waves that may make daily or seasonal movements in the water column.

macroplankton Planktonic organisms that are larger than 500 µm.

microplankton Planktonic organisms that range in size from 50 to 500 µm.

nannoplankton Planktonic organisms that range in size from 10 to 50 µm.

phytoplankton Planktonic plants that are composed primarily of diatoms and algae.

picoplankton Planktonic organisms that are smaller than 1 µm.

ultraplankton Planktonic organisms that range in size from 0.5 to 10 µm.

zooplankton Planktonic animals that are composed primarily of protozoans and small crustaceans.

plateau Flat areas that are elevated over the surrounding terrain.

playa lake See *playa lake* under *lake*.

plesiopotamon See *plesiopotamon* under *meander*.

pleuston Organisms adapted for life in the interface between air and water.

epipleuston Organisms living on the surface of the air–water interface.

hypopleuston Organisms living on the underside of the air–water interface.

plug A piece of material or an accumulation of material that prevents the movement of water or other fluids.

plume (1) Flow of dissolved or suspended material into a larger water body. (2) Mass of water discharged by a river, outfall, or some other source into a water body that is not completely mixed and retains measurably different characteristics from the rest of a water body.

plunge lake See *plunge lake* under *lake*.

plunge pool See *plunge pool* under *pool, scour pool* under the main heading *channel unit*.

plunging breaker See *plunging breaker* under *wave*.

pluvial Refers to rain or the action of falling rain.

pluvial lake See *pluvial lake* under *lake*.

pocket water See *pocket water* under *pool, scour pool* under the main heading *channel unit*.

pocosin See *pocosin* under *wetlands*.

poikilohaline See *poikilohaline* under *salinity*.

poincare wave See *poincare wave* under *wave*.

point Peninsula or land that projects from the shore into a water body. A stationary location used for reference such as the single source of a pollutant.

point bar See *point bar* under *bar*.

point of diversion Location where water is diverted for some use.

point of inflection See *point of inflection* under *meander*.

point source Material, usually pollutants, flowing into a water body from a single well-defined source such as a pipe or ditch.

pollute To contaminate land, water, air, plants, animals, or microorganisms with substances considered objectionable or harmful to the health of living organisms.

pollution Presence of matter or energy, usually of human origin, whose nature, location, or quantity, produces undesired environmental effects on natural systems.

polygon See *polygon* under *remote sensing*.

polyhaline See *polyhaline* under *salinity*.

polymictic See *polymictic* under *mixing*.

polysaline See *polysaline* under *salinity*.

polysaprobic zone See *polysaprobic zone* under *saprobien system*.

pond Natural or artificial body of standing water that is typically smaller than a lake (less than 8 ha [20 acre]), characterized by a high ratio of littoral zone relative to open water.

aerated pond or lagoon Natural or artificial basin where mechanical equipment is used to increase the supply of oxygen to decompose organic waste, increase aquaculture production, or improve aesthetics.

aestival pond Pond that exists only in summer.

anchialine pool Mostly small, irregular water exposures in barren lava with a surface level at the marine water table so the water is mixohaline from dilution by groundwater and salinity is usually 1–10‰.

beaver pond Pond containing water impounded behind a dam built by beaver.

borrowpit pond Pond formed by the accumulation of water in an area excavated by mining for sand, gravel, or boulders used in construction.

charco Small pond formed by a soil dam that is usually round with a basin shaped like an inverted cone that is filled by groundwater.

Often found in the desert of southwestern United States.

cooling pond Pond with water used to cool equipment in a power plant or other industrial facility.

dug pond Pond formed by excavation, without a dam, and supplied with water from runoff or seepage.

dune pond Pond in a basin formed from the blockage of a stream mouth by sand dunes that move along a shoreline of an ocean.

evaporation pond Shallow ponds filled with water that are allowed to evaporate to recover suspended or dissolved materials such as salts or other minerals.

farm pond Pond created for agricultural purposes (i.e., irrigation or water for livestock), culture of commercial fishes, or for recreation (including sportfishing, swimming, and boating).

fault sag pond Pond in a small depression along an active or recent geologic fault that is supplied by groundwater.

holding pond Pond or reservoir constructed for settling and storage of sediments, for aerating or aging water for a fish hatchery, or for storing wastes or polluted runoff.

lagoon See *lagoon*.

log pond Pond used for storing logs, generally attached to saw or veneer mills. See *mill pond*.

mill pond Impoundment created by damming a stream to produce a head of water for operating a mill or for storage of logs. Synonymous with *log pond*.

off-channel pond Pond that is not part of the active channel but is supplied with water from overbank flooding or through a connection with the main stream by a short channel. These ponds are generally located on flood terraces and are called wall-based channel ponds when located near the base of a valley wall.

piping depression pond Pond that forms in a small depression resulting from subsurface piping.

quarry Pond formed in the depression created by excavation of rock or coal (as well as clay in some instances) and generally supplied with groundwater.

sag pond Small body of water occupying a depression or sag formed by active or recent geologic fault movements.

salt chuck pond A log pond in seawater. Compare with *salt chuck*.

sedimentation pond Impoundment created to trap suspended sediments. See *settling pond* and *stilling pond* under *pond*.

settling pond Impoundment used to precipitate materials that accumulate on the bottom and are removed periodically. See *sedimentation pond* and *stilling pond* under *pond*.

stilling pond Deep depression constructed in a streambed on the outwash fan that is used to catch detritus and sediments. See *sedimentation pond* and *settling pond* under *pond*.

tank Artificial pond to hold water for livestock, wildlife (sometimes including fish) and other uses.

vernal pond Small (usually less than 1 ha), temporary pond that forms from melting snow and rainfall in late winter or early spring.

wall-based pond See *off-channel pond* under *pond*.

pondage Term applied to storage capacity or water that is held for later release above the dam of a hydroelectric plant to equalize daily or weekly fluctuations of streamflow or to permit irregular releases of water through turbines to accommodate the demand for electricity.

ponded Water that is impounded from anthropogenic or natural blockage or obstruction. Also referred to as ponding.

pool Small depression with standing water such as found in a marsh or on a floodplain. Also see *pool* under *slow water* under the main heading *channel unit*.

pool digger Rock or log structure designed to scour a plunge pool on its downstream side or a lateral scour pool.

pooled channel See *pooled channel* under *stream*.

pool feature Condition or object that causes the formation of a pool including logs, trees, roots, stumps, brush, debris, channel meanders, sediment deposition, beaver dams, culverts, bridges, or other artificial or natural structures.

pool margin Outer edge of a pool as identified by bed topography.

pool quality Estimate of the ability of a pool to support target fish species, based on measurements such as length, width, depth, velocity, and cover.

pool : riffle ratio See *pool : riffle ratio* under *dimensions*.

poorly drained Condition where water is removed from the soil so slowly that the soil is saturated periodically during the growing season and remains wet for long periods (e.g., more than 7 d).

pore space Unoccupied interstices in the substrate.

porosity (1) Existence of interstices or "pores" in soil or rock, and the ratio of the volume of pores to the total volume of solids plus voids. (2) Also refers to the ease or speed that water can move into or through the substrate. See also *porosity* under *groundwater*.

positive estuary Coastal indentures where there is a measurable dilution of seawater by land drainage so that freshwater inflow plus precipitation is greater than evaporation.

positive heterograde See *positive heterograde* under *stratification*.

potable Water that is suitable or safe for drinking according to established health standards.

potamodromous Life-cycle strategy of a fish that includes migrations, spawning, and feeding entirely in freshwater. Compare with *anadromous*, *catadromous*, *diadromous*, *oceanadromous*.

potamology Study of the biological, chemical, geological, and physical aspects of rivers.

potamon Portion of a stream that includes the thalweg (or deepest part of the channel) and is nearly always defined as lotic. Also applied to that portion of a stream that contains water even if discharge becomes intermittent.

epipotamon Upper layer of the potamon region.

hypopotamon Bottom layer of the potamon region.

metapotamon Intermediate layer of the potamon region.

potamon plankton Plankton living in freshwater lotic habitats.

potential energy See *potential energy* under *energy*.

pothole lake See *pothole lake* under *lake*.

power pool See *operating pool*.

prairie pothole Ponds, pools, lakes, and wetlands found in depressions (potholes) that were formed by glacial activity. A local term used in the Great Plains of central United States and Canada. See *pothole lake* under *lake*.

precipitate Solid that settles from water through physical or chemical changes.

precipitation Water, hail, sleet, and snow that falls to earth from its origin as atmospheric moisture.

predators See *predators* under *macroinvertebrate*.

preservation Protection and maintenance of intact and functional natural areas and ecosystems. Compare with *restoration*.

pressure A force per unit of area.

pressure head See *pressure head* under *dimensions*.

pristine Term used to describe a natural location or habitat unaffected by anthropogenic disturbances.

problem area wetland See *problem area wetland* under *wetlands*.

process water Water used in manufacturing or processing including the production or use of any raw material, intermediate product, finished product, by-product, or waste product. See *effluent*.

production (1) Process of producing organic material. (2) Increase in biomass by individuals, species, or communities with time (e.g., the total amount of fish tissue produced by a population of fish within a specified period of time).

gross primary production Total rate of photosynthesis including the organic matter used up in respiration during the measurement period.

net primary production Rate of storage of organic matter in plant tissues in excess of the respiratory use by the plants during the measurement period.

secondary production Total energy storage at the consumer and decomposer trophic levels. Consumers and decomposers utilize food materials that have already been produced and convert this matter in different tissues with energy loss to respiration. Efficiency of conversion in secondary production decreases with trophic levels.

productivity (1) Rate of formation of new tissue or energy use by one or more organisms. (2) Capacity or ability of an environmental unit to produce organic material. (3) Recruitment ability of a population from natural reproduction.

profile Graphical or other representation of shape or relationship. Compare with *stream profile*.

profundal Deep, bottom-water area beyond the depth of effective light penetration including all of the lake or sea floor beneath the upper margin of the hypolimnion.

progressive wave See *progressive wave* under *wave*.

prolonged speed See *prolonged speed* under *swimming speed*.

promontory High point of land or rock overlooking or projecting into a water body.

protected area Area administratively set aside as a buffered or structured area that is shielded from damage from anthropogenic disturbances.

psammon Refers to the beach zone along an ocean or an organism growing in or moving through sand on the beach.

psammorheophilic See *psammorheophilic* under *benthos*.

public lake See *public lake* under *lake*.

public water Water that is navigable by federal test or court decree, legally accessible over public lands, or impressed with prescriptive rights vested in the public.

public water system System providing piped water for public consumption.

puddle Small (several inches to several feet in its greatest dimension), shallow (usually a few inches in depth) pool of water that is ephemeral and often dirty or muddy.

pump chance Water body, usually small, that is accessible to equipment collecting water for fire control.

pumped storage reservoir Reservoir used to store water for use during peak periods of electricity production. During periods of low demand for electricity, water is pumped into the storage reservoir for later release through turbines to generate electricity during periods of peak demand.

pycnocline See *pycnocline* under *stratification*.

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quaking bog See *quaking bog* under *wetlands*.

quarry See *quarry* under *pond*.

quick sand Soft or loose sand, sometimes of measurable depth, saturated with spring or stream water that yields when weight is placed on it.

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radial See *radial* under *stream*.

radial gate See *radial gate* under *gate* and main heading of *control structure*.

radio telemetry See *radio telemetry* under *remote sensing*.

radius of curvature See *radius of curvature* under *dimensions* as well as under *meander*.

raft (1) Collection of timbers or bamboo, tied together or enclosed within a boom, for transport by floating. (2) Also, a large number of closely spaced timbers that can free float on water.

rain-on-snow event Event that occurs in late winter, spring, and early summer when snowpacks are partially or completely melted during rainstorms causing flooding.

rain shadow Area of reduced precipitation on the leeward side of mountains that results from the interception of storms by the mountains.

raised bog See *raised bog* under *wetlands*.

rapids See *rapids* under *fast water—turbulent* with the main heading of *channel unit*.

raster See *raster* under *remote sensing*.

raster data See *raster data* under *remote sensing*.

ravine Narrow, steep-sided valley that is commonly eroded by running water.

raw water Untreated surface or groundwater that is available for use but may or may not be potable.

reach (1) Any specified length of stream. (2) Relatively homogeneous stretch of a stream having a repetitious sequence of physical characteristics and habitat types. (3) Length of channel where a single gage affords a satisfactory measure of the stage and discharge. (4) Portion of a stream that extends downstream from the confluence of two streams or rivers to the next encountered confluence. (5) According to the Environmental Protection Agency, that portion of a river reach extending downstream from the confluence of two rivers (or from the uppermost end of a river) to the next encountered confluence.

archival reach Reach whose boundaries and properties have been modified by natural or other events since an original survey was conducted. Original data is compared with new data to evalute changes.

critical reach Stream segment that is essential for development and survival of a particular aquatic organism, or a particular life stage of an aquatic organism.

representative reach Stream segment that represents a larger segment of the stream with respect to area, depth, discharge, slope, or other physiochemical or biotic characteristics.

specific reach Stream segment that is uniform with respect to selected habitat characteristics or elements (discharge, depth, area, slope, population of hydraulic units), species composition, water quality, and condition of bank cover.

reaeration Supply of oxygen to oxygen-depleted water.

rearing habitat Areas in a body of water where larval and juvenile fish find food and shelter to live and grow. Also referred to as nursery habitat.

reattachment bar See *reattachment bar* under *bar*.

receiving site Water collection sites where water is collected by subsurface flow from higher elevations and precipitation.

receiving waters Any body of water into which untreated or treated wastes, or polluted waters, are discharged.

recessional moraine See *recessional moraine* under *moraine*.

recharge Process by which water is added to an aquifer.

recharge area Area where water infiltrates into the ground and joins the aquifer through hydraulic head.

recharge zone Area through which water is added to an aquifer.

reclamation (1) Most recently defined as any action that results in a stable, self-sustaining ecosystem that may or may not include introduced species. (2) Traditionally defined as the process of adapting natural resources to serve a utilitarian human purpose. Historically this term included the conversion of riparian or wetland ecosystems to agricultural, industrial, or urban uses.

recovery Ability of a disturbed system to re-establish habitats and plant or animal communities that were present prior to the disturbance.

recreational pool The "normal" surface elevation of a reservoir with fluctuating water levels that is generally a stable level established by the water controlling agency to maximize recreational uses during spring, summer, and fall (i.e., open water period). Compare with *summer pool*.

rectangular drainage See *rectangular stream* under *stream*.

rectangular stream See *rectangular stream* under *stream*.

rectification See *rectification* under *remote sensing*.

recurrence interval Expected or observed time intervals between hydrological events of a particular magnitude described by stochastic or probabilistic modes (log-log plots). The average interval of time within which a given event, such as a flood, will be equalled or exceeded one time.

redd Nest excavated in the substrate by fish for spawning where fertilized eggs are deposited and develop until the eggs hatch and larvae emerge from the substrate.

reducers Organisms, usually bacteria or fungi, that break down complex organic materials into simpler compounds.

reef Ridge of rocks, sand, soil or coral projecting from the bottom to or near the surface of the water.

reference wetland See *reference wetland* under *wetlands*.

reflectance See *reflectance* under *remote sensing*.

reflected solar radiation See *reflected solar radiation* under *solar radiation*.

refracted solar radiation See *refracted solar radiation* under *solar radiation*.

refraction See *refraction* under *wave*.

refugium (1) Habitats that support sustainable populations of organisms that are limited to fragments of their previous historic and geographic range. (2) Habitats that sustain organisms during periods when ecological conditions are not suitable elsewhere. For example, trout in alpine areas use the deeper pools in a stream during winter or fish use a lake with high dissolved oxygen levels to escape adjacent hypoxic swamps and marshes. (3) Waters where threatened or endangered fishes are placed for safe-keeping or where a portion of the population is maintained to prevent extinction.

regime (1) Seasonal pattern of streamflow during a year. (2) Balance or equilibrium of erosion and deposition in a channel with time so that the stream channel maintains its overall characteristics.

regimen Characteristics of a stream with respect to velocity and volume changes in a channel capacity to transport sediment and the amount of sediment transported with time.

regolith Unconsolidated mantle of weathered rock, soil, and surficial materials overlying solid rock.

regular meander See *regular meander* under *meander*.

regular meander channel See *regular meander channel* under *channel pattern*.

regulated flow See *regulated flow* under *flow*.

regulated zone Area in a reservoir between conservation pool and flood control pool.

regulation Control of the volume and timing of streamflow at a specific location.

rehabilitation (1) Action taken to return a landform, vegetation, or water body to as near its original condition as practical. (2) Term implies making land and water resources useful again (primarily for humans) after natural or anthropogenic disturbances. This term differs from restoration that implies a return to predisturbance conditions and functions in natural aquatic or terrestrial systems. See *restoration*.

rejuvenated river See *rejuvenated river* under *river*.

relative depth See *relative depth* under *dimensions*.

relative thermal resistance Ratio of the density difference between water at the top and bottom of a water column with a definite thickness, to the density difference between water at 5°C and 4°C. "Thermal resistance" also refers to mixing, or the amount of work done by meteorological or anthropogenic events to mix a water column.

relict Remnant of a biotic community or population that was formerly widespread.

relict lake See *relict lake* under *lake*.

relief (1) Change in elevation of a land surface between two points. (2) Configuration of the earth's surface including such features as hills and valleys.

relief ratio See *relief ratio* under *dimensions*.

remote sensing (1) Acquisition of information from a distance, generally by transmissions that involve electromagnetic energy and sometimes by gravity and sound. (2) Measurement or acquisition of data on an object by satellite, aerial photography, and radar that are some distance from the object.

aerial photography Images on film or in digital format taken above the surface of a planet.

attribute Nongraphic information associated with a point, line, or polygon.

AVHRR Advanced very high resolution (1.1 × 1.1 km or 4 × 4 km) radiometer data with small-scale imagery produced by a NOAA polar orbiting satellite.

azimuth Principal plane in a clockwise angle on a tilted photograph.

band Set of values for a specific portion of the electromagnetic spectrum of reflected light, emitted heat, or some other user-defined information, created by combining or enhancing the original bands.

band ratio Method in which ratios of different spectral bands from the same image or from two registered images are used to reduce certain effects such as topography or to enhance subtle differences of certain features.

cartesian Coordinate system in which data are organized on a grid and points on the ground are referenced by their x- and y-coordinates.

cell Pixel or grid cell with a 1° × 1° area of coverage.

cell size Area represented by one pixel, measured in map units.

class Set of pixels in a GIS file that represents areas that share some condition.

clump Contiguous group of pixels in one class that is also called a raster region.

cluster Natural groupings of pixels when plotted in a spectral space.

conjugate points (conjugate principal points) Positions on an aerial photograph that are principal points on adjacent photos of the same flight line. Conjugate points are used to justify or align photographs for creation of a larger photographic mosaic.

digital classification Process for using algorithms to group pixels with similar spectral signatures.

digital enhancement Manipulating digital information to increase or improve features of interest for interpretation.

digital terrain model Analysis of pixel or topographic information to produce a three-dimensional representation of the landform. Also called digital elevation model.

digitizing Process that converts nondigital data into numerical data that is usually stored in a computer.

false color Use of one color to represent a characteristic or feature or a color substituted for the true color on an image.

geometric registration Process of aligning data resolution scales so that information can be visually or digitally superimposed.

ground cover (1) Vegetation and litter on or slightly above the ground surface. (2) The percentage of area bearing such cover.

ground truthing Field verification of data gathered away from the site by remote sensing or by some other method.

image Picture or representation of an object or scene on paper or computer display screen. Remotely sensed images are digital representations of the earth.

landsat Satellite system that provides imagery used for remote sensing inventory and analysis. Also refers to a series of earth-orbiting satellites gathering multispectral scanner or thematic mapper imagery.

landsat multispectral scanner (MSS) Satellite-borne sensor capable of recording reflectance energy from the surface of the earth in four wavelength bands for a 180 × 180 km scene.

landsat thematic mapper (TM) Satellite sensor capable of recording reflected and emitted energy from the surface of the earth in seven bands or divisions of the visible and infrared spectrum.

maximum likelihood Classification decision rule based on the probability that a pixel belongs to a particular class. The basic equation assumes that the probabilities are equal for all classes, and that the input bands have normal distribution.

merge The process of combining information from one or more sources or the restructuring of an existing database to create a new database that retains the original data.

mosaic (1) Pattern of vegetation across a landscape. (2) Composite image created by joining smaller images, usually aerial photographs, into a single composite.

multispectral classification Process of sorting pixels into a finite number of individual classes or categories of data that are based on data files in multiple bands.

multispectral imagery Satellite imagery with data recorded in two or more bands.

multispectral scanner (MSS) Landsat sensor system that generates spectral data from reflected light in the visible light spectrum.

nadir Point where a vertical line from the center of the camera lens intersects the plane of the photograph.

orthophotos Images based on aerial photographs that are true to scale and free of distortion. Orthophotos resemble aerial photographs but are really accurate maps.

overlay Process in which data from different themes or plots are placed over a base map or in a series to show spatial interactions.

photogrammetry Gathering of information on physical objects and the environment by recording and interpreting images and phenomena.

pitch Rotation of a camera around the y- or exterior x-axis.

pixel Abbreviation for "picture element" that is the smallest division of an image.

polygon Closed figure usually with three or more sides. Also refers to a set of closed lines defining an area.

radio telemetry Use of transmitters attached to an animal to send signals to a remote receiver that is used to track the animal.

raster Pattern of scanning lines that cover an area where images are projected.

raster data Data that are organized in a grid of columns and rows and usually represent a planar graph or geographic area.

rectification Transformation of an image to a horizontal plane to correct tilt and to convert to a desired scale.

reflectance Measure of the ability of a surface to reflect energy as a ratio of reflected and incident light. Reflectance is influenced by the nature of the reflected surface and the pattern of light.

remote survey Measurement or acquisition of information by a recording device that is not in physical contact with the object under study. More precisely, recording of environmental images using electromagnetic radiation sensors and their interpretation.

resolution (1) Spatial: Ability to reproduce an isolated object or to separate closely spaced objects or lines that are usually measured in lines per millimeter. (2) Temporal: How often a sensor records imagery of a specific geographcal area. (3) Spectral: The number and dimension of wavelength intervals in the electromagnetic spectrum recorded by the sensor. (4) Radiometric: Sensitivity of a detector to differences in signal strength.

satellite imagery Passive images of natural radiation detected in visual or infrared wavelengths.

scan line Strip of land within the view of a remote sensor as it passes over a surface.

scanning Transfer of analog data, such as photographs, maps, or other viewable images into a digital (raster) format.

sensor Device that gathers energy, converts it to a digital value, and presents it in a form suitable for obtaining information about the environment.

signature Set of statistics that define a training sample or cluster that is used in a classification process. Each signature corresponds to a GIS class that is created with a classification decision rule.

SLAR Abbreviation for "Sideways Looking Airborne Radar." A form of remote sensing where an aircraft sends out and receives long wavelength radiation, and interference in the return pattern is analyzed for physical features of the area surveyed. An antenna is fixed below an aircraft and pointed to one side to transmit and receive the radar signal.

sonar Method using echolocation to detect and locate objects, including living organisms, below the surface of water.

spectral signature (spectral reflectance curve) Characteristic wavelength patterns associated with vegetation, structures, water, or other features.

SPOT Series of earth-orbiting satellites operated by the Centre National d'Etude Spatiales of France.

supervised classification Computer-implemented classification based on pattern recognition of assigned class signatures.

supervised training Any method of generating signatures for classification in which the analyst is directly involved in a pattern recognition process. Supervised training usually requires an analyst to select training samples from the data that represent patterns to be classified.

swath width Total width of the area on the ground covered by the scanner in a satellite system.

synthetic aperture radar (SAR) Use of a side-looking, fixed antenna sensor to create a synthetic aperture. The sensor transmits and receives as it is moving, and the signals that are received during a time interval are combined to create an image. SAR sensors are mounted on satellites and the NASA space shuttle.

thematic data Raster data that are qualitative and categorical. Thematic layers often contain classes of related information, such as land cover, soil type, slope, and hydrology that can be displayed on maps illustrating the class characteristics.

thematic mapper Advanced satellite sensor system in Landsat 4 and 5 that incorporates radiometric and geographic design improvements relative to the older MSS system.

theme Data set used for mapping information on a particular subject. Individual theme information can be displayed and related to other themes.

training Process of defining the criteria by which patterns in image data are recognized for classification.

unsupervised classification Computer-automated method of pattern recognition where some parameters are specified by the user to define statistical patterns that are inherent in the data.

vector A line in space characterized by direction and magnitude. In GIS systems, vectors are used to create a file of points that can be connected from point to point to create line segments.

vector data Data that represent physical elements such as points, lines, and polygons. In a remote sensing database, only verticals of vector data are stored (rather than every point that makes up the element).

vector format A GIS database file where information is used to code lines and polygons to express size, direction, and degree of connection between data points.

remote survey See *remote survey* under *remote sensing*.

repose bank See *repose bank* under *streambank*.

representative reach See *representative reach* under *reach*.

reregulating reservoir Reservoir for reducing diurnal fluctuations in volume from the operation of an upstream reservoir for power production.

reservoir (1) Generally, natural or artificial impoundment where water is collected, stored, regulated, and released for human use. (2) An underground porous, permeable substrate that contains accumulated water. See *reservoir* under *lake* and *small impoundment*.

reservoir river See *reservoir river* under *river*.

residence time Amount of time that some material, such as large woody debris, pesticide, or sedimentary material, remains in one location.

resident fish Fish species that remain in one water body (i.e., nonmigratory species).

resident species Organisms normally found in a single habitat, ecosystem, or area.

residual depression storage Depression storage that exists at the end of a period of heavy rainfall.

residual depth Term corresponding to a minimum streamflow that just barely flows through pools that is calculated by subtracting water depth at a riffle crest from water depth in the upstream pool.

residual detention storage Detention storage existing at the end of a period of heavy rainfall.

residual pool See *residual pool* under *slow water*, *pool*, *scour pool* under the main heading *channel unit*.

residual volume of fine sediment Fraction of a scour pool volume (V^*) occupied by fine sediment.

$$V^* = \frac{V_f}{(V_f + V_r)};$$

V_f = fine sediment volume;
V_r = residual pool volume.

resilience Capacity of species or ecosystems to recover after a natural disturbance or anthropogenic perturbation.

resistance Capacity of an ecosystem to maintain natural function and structure after a natural disturbance or anthropogenic perturbation.

response segment Reach or segment of a stream channel where localized inputs of wood, water, energy, and sediments causes changes in form to that reach of the stream channel.

resolution See *resolution* under *remote sensing*.

restoration (1) Reestablishment of predisturbance riparian or stream functions and related biological, chemical, and physical processes in an ecosystem. (2) Actions taken to return a habitat, an ecosystem, or a community to its original condition after damage resulting from a natural disturbance or an anthropogenic perturbation. (3) Sometimes used to describe reestablishment of fish stocks or populations that were eliminated or reduced from anthropogenic actions. See *rehabilitation*.

restrictive layer Soil layer that restricts the movement of water because of its density or composition.

resurgent water Water that resurfaces or reappears.

retard See *fence barrier* under *habitat enhancements*.

retarding reservoir See *detention reservoir*.

retention Portion of the gross storm rainfall that is intercepted, stored, or delayed, and thus fails to reach a concentration point by either surface or subsurface routes during the time period under consideration.

retention time Length of time that water is stored within a drainage system or water body.

return flow See *return flow* under *flow*.

revetment A facing or structure made of hard material such as boulders or logs along a streambank or shoreline that reduces erosion. See *riprap* under *habitat enhancements*.

Reynolds number (R_e) Dimensionless value expressing the ratio of inertial to viscous forces acting on a fluid or a particle in the fluid:

$$R_e = \frac{VD}{v};$$

V = velocity of the fluid or particle (m/s);
D = a relevant dimension (pipe diameter, particle length, etc.) (m);
ν = kinetic viscosity (10^{-6} m^2/s).

rheocrenes Perennial seeps and springs that flow only a short distance over a rock surface or in indistinct channels.

rheophilus Current-loving organisms.

rheophyte See *rheophyte* under *macrophyte*.

rhithron Reach of stream that extends from the headwaters downstream to where the mean monthly summer temperature reaches 20°C, dissolved oxygen levels are always high, flow is fast and turbulent, and the bed is composed of rocks or gravel with occasional sandy or silty patches. The rhithron is subdivided into three zones covering a range of water courses.

epirhithron Upper reaches of the rhithron region that are characterized by rapids, waterfalls, and cascades.

hyporhithron Lower reaches of the rhithron region that are characterized by an increase in backwaters with mud and debris bottoms.

metarhithron Middle reaches of the rhithron region that are characterized by a more gentle gradient and higher percentage of pools.

ribbon falls See *ribbon falls* under *fast water—turbulent*, *falls* under the main heading *channel unit*.

riffle crest Shallowest continuous line (usually not straight) across the channel close to where a water surface becomes continuously riffled.

riffles See *riffles* under *fast water—turbulent* under the main heading *channel units*.

riffle stability index An index to determine the size class percentage of riffle material moved during channel forming flows. Determined by comparing the largest, commonly occurring size of particles moved by the force of a frequent flood event to the cumulative particle size distribution of bed materials in a riffle

rift lake See *rift lake* under *lake*.

rift valley Long, narrow valley resulting from subsidence (i.e., settling) of strata between more or less parallel geologic faults.

rill One of the first and smallest channels formed by surface runoff.

rill erosion Mild water erosion caused by overland flow producing very small and numerous channels. See also *rill erosion* under *erosion*.

rilling Removal of soil by water from very small but well-defined, visible channels or streamlets where there is substantial overland flow.

riparian area (1) Of, pertaining to, situated or dwelling on the margin of a river or other water body. (2) Also applies to banks on water bodies where sufficient soil moisture supports the growth of mesic vegetation that requires a moderate amount of moisture. Also referred to as riparian zone, riparian management area, or riparian habitat.

riparian ecosystem Ecosystem located between ecocline of aquatic and terrestrial environments. See *ecocline*.

riparian rights Entitlement to water on or bordering a landowner's property including the right to prevent diversion of water upstream.

riparian vegetation Vegetation growing on or near the banks of a stream or other water body that is more dependent on water than vegetation that is found further upslope.

riparian vegetation erosion control rating System for ranking the relative effectiveness of riparian vegetation to control bank erosion.

ripping The process of breaking up or loosening compacted soil to improve aeration and assure development of root systems from seeds or planted seedlings.

ripple See *ripple* under *wave*.

riprap See *riprap* under *habitat enhancements*. Compare with *revetment* under *habitat enhancements*.

rithron See *rhithron*.

river Large, natural or human-modified stream that flows in a defined course or channel, or a series of diverging and converging channels.

desert river River in an arid area that is characterized by flash floods and no tributaries. Desert rivers increase in alkalinity and conductivity as they flow downstream and may terminate in salt marshes or lakes.

flood river River with extremes of annual fluctuation in streamflow.

mature river River system where erosion and deposition are in balance.

old river River where depositional processes dominate.

rejuvenated river An old or mature river where gradient changes result in a temporary reversal of normal succession processes.

reservoir river River with an extensive area of lakes, swamps, and floodplain depressions that stores or holds water.

sandbank river River that conveys floodwaters but frequently ceases to flow or even dry out seasonally.

savanna river Floodbank or sandbank river characterized by high silt loads and low pH and conductivity.

tropical river River in the tropics that functions similar to a reservoir river and is characterized by black water with low pH, low conductivity, low silt load, and high humus load.

tundra river River in an arctic or subarctic region with streamflows that fluctuate with the freezing cycle.

young river Generally used in reference to the headwaters where erosional processes are most active.

riverbank Elevated edges of a channel that control lateral movement of water.

river channel Natural or artificial open conduits that continuously or periodically contain moving water. Also applied to a connection between two water bodies.

river continuum Ecological succession that occurs from the headwaters to the mouth in a river and that is associated with an increase in nutrients and organic matter.

riverine (riverain) (1) Habitats that are formed by or associated with a river or stream. (2) Wetlands and deeper water habitats within a channel that are influenced strongly by the energy of flowing water. (3) Also applied to vegetation growing in a floodplain, in close proximity to water courses with flowing water, or on islands in a river.

riverine wetland See *riverine wetland* under *wetlands*.

rivulet Refers to a small stream.

rock Mass of stone of any size, consolidated or unconsolidated, of various mineral composition.

rock avalanche See *rock avalanche* under *landslide*.

rock creep See *rock creep* under *landslide*.

rock fall See *rock fall* under *landslide*.

rock-fill dam (1) Dam composed of large, broken, and loosely placed rocks that allows water to percolate and continue to flow downstream. (2) Dam with an impervious core of composted rock and soil with large rocks (i.e., riprap) on the upstream face or surface.

rock glacier See *rock glacier* under *glacier*.

rock slide See *rock slide* under *landslide*.

roller dam See *roller dam* under *habitat enhancements*.

roller gate See *roller gate* under *gate* and main heading *control structure*.

rolling flow See *rolling flow* under *flow*.

root wad See *root wad* under *large organic debris*.

rotational failure See *rotational failure* under *landslide*.

roughness Pertains to the irregularity of a substrate surface.

roughness coefficient See *Manning's n*.

roughness element Any object or structure (e.g., bedrock outcrops, large woody debris, and boulders) that obstructs streamflow in a channel and influences the pattern of bed load transport and deposition in a stream reach.

rubble Stream substrate particles between 128 and 256 mm (5–10 in) in diameter. Compare with other substrate sizes under *substrate size*.

run See *run* under *fast water—nonturbulent* under the main heading *channel unit*.

runoff (1) Natural drainage of water away from an area. (2) Precipitation that flows overland before entering a defined stream channel. (3) Total discharge of stream within a specified time from a specific area that includes both surface and subsurface discharge and is generally measured in cubic feet (cubic meters) or acre feet (hectare meters) of water.

runoff curve Graphic estimator of runoff potential in a drainage basin based on precipitation, soils, vegetation, and land use.

run-of-the-river flow Flow through a dam that is minimally regulated by the dam and approximates the flow that would occur in the absence of a dam.

run-of-the-river reservoir Narrow reservoir that is held to the width of the natural river channel in which short-term water input approximates equal short-term outflow.

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saddle Narrow, submerged isthmus of land surrounded by deeper water which may connect a point and an island, hummock, or another land mass.

sag pond See *sag pond* under *pond*.

salinas Inland desert basins that are light-colored from salt.

saline (1) Soil or water containing sufficient soluble salts to interfere with the growth of most plants. (2) See *saline* under *salinity*.

saline marsh See *saline marsh* under *wetlands*.

saline lake See *saline lake* under *lake*.

salinity Relative concentration of salts, mainly sodium chloride, in a given water, expressed as the weight per volume or weight per weight. The terms “haline” and “saline” are often used interchangeably, but differ based on the origin of the salts. Haline refers to ocean-derived salts and saline refers to land-derived salts.

euryhaline (1) Waters with a salinity between 30.1 and 40‰ (parts per thousand) from ocean-derived salts. (2) Organisms that are able to live in waters with a wide range of ocean-derived salts.

eurysaline (1) Waters with a salinity between 30.1 and 40‰ from land-derived salts. (2) Organisms that are able to live in waters with a wide range of land-derived salts.

freshwater Water with salinity of less than 0.5‰ dissolved salts.

haline Refers to saline conditions from ocean-derived salts.

halocline Well-defined vertical salinity cleavage or boundary in a water body.

homoiohaline Refers to saline conditions in oceans that are either stable or with narrow fluctuations.

hydrohaline Waters with a salinity greater than 40‰ from ocean-derived salts. Also referred to as hyperhaline.

hydrosaline Waters with salinity greater than 40‰ from land-derived salts. Also referred to as hypersaline.

mesohaline (1) Waters with salinity between 5.1 and 18‰ from ocean-derived salts. Also referred to as metahaline. (2) Saltwater organisms that are able to live in waters with medium salinities.

mesosaline (1) Waters with salinity between 5.1 and 18‰ from land-derived salts. Also referred to as metasaline. (2) Organisms that are able to live in waters with a medium range of salinities from land-derived salts.

mixohaline Waters with salinity between 0.5 and 30‰ from ocean-derived salts.

mixosaline Water with salinity between 0.5 and 30‰ from land-derived salts.

oligohaline (1) Waters with salinity between 0.5 and 5.0‰ from ocean-derived salts. (2) Saltwater organisms that are able to live in waters with low salinities.

oligosaline (1) Waters with salinity between 0.5 and 5.0‰ from land-derived salts. (2) Organisms that are able to live in waters with a low range of salinities from land-derived salts.

poikilohaline Salt concentrations that fluctuate widely.

polyhaline Waters with salinity between 18.1 and 30‰ from ocean-derived salts.

polysaline Waters with salinity between 18.1 and 30‰ from land-derived salts.

saline Waters with salinity that is greater than 30‰.

seawater Waters with salinity of about 35‰ dissolved salts.

stenohaline Organisms that are able to live in waters with a narrow range of ocean-derived salts.

stenosaline Organisms that are able to live in waters with a narrow range of land-derived salts.

saltation erosion See *saltation erosion* under *erosion*.

salt chuck General term for the estuarine areas at the mouth of rivers. Compare with *salt chuck* under *pond*.

saltern lake See Saltern Lake under *lake*.

salt flat Land area with little or no elevational changes and with a surface layer of salts that remains after prolonged flooding and desiccation.

salt karst lake See *salt karst lake* under *lake*.

salt marsh See *salt marsh* under *wetlands*.

salt water intrusion Invasion of saltwater into fresh surface or groundwater systems, usually as a result of freshwater depletion that provides access for saltwater.

sand Substrate particles between 0.062 and 2 mm (0.00003–0.01 in) in diameter. Compare with other substrate sizes under *substrate size*.

sandbank river See *sandbank river* under *river*.

sand dune See *sand wave*.

sand splay Deposits of flood debris that are usually composed of coarse organic matter and sand particles in the form of splays or scattered debris.

sand wave Series of generally sinusoidal waves that form on the sandy bottom of a river from the interaction of flowing water and the substrate when the Froude number is close to or greater than one. Sand waves are often transitory, vary in height, and may migrate along the river bottom. Also referred to as an *antidune* or *sand dune*.

saprobic Term applied to living on dead or decaying organic matter.

saprobicity Sum of all metabolic processes that can be measured either by the dynamics of metabolism or analysis of community structure.

saprobien system System of classifying organisms according to their response to organic pollution in slow moving streams.

alpha-mesosaprobic zone Zone of active decomposition, that is partly aerobic and partly anaerobic, in a stream that is heavily polluted with organic wastes.

beta-mesosaprobic zone Zone of a stream that is moderately polluted with organic wastes.

oligosaprobic zone Stream reach that is slightly polluted with organic wastes and contains the mineralized products of self-purification from organic pollution with none of the organic pollution remaining.

polysaprobic zone Zone of a grossly polluted stream containing complex organic wastes that are decomposing primarily by anaerobic processes.

saprolite See *saprolite* under *streambank material*.

sapropel Neutral humus or a thick layer of old, stratified and saturated organic matter that is nearly completely mineralized.

satellite imagery See *satellite imagery* under *remote sensing*.

saturated Condition where all easily drained voids (i.e., interstices or pores) between soil particles are temporarily or permanently filled with water. This condition results in significant saturation if it continues for one week or more during the growing season. See also *saturated* under *water regime*.

saturated zone (1) Area of land that is completely soaked by water where the substrate is saturated to the surface for extended periods during the growing season. (2) Zone of water with the maximum concentration of dissolved gases, elements, or other materials.

savanna river See *savanna river* under *river*.

scan line See *scan line* under *remote sensing*.

scanning See *scanning* under *remote sensing*.

scarp (1) Line of cliffs formed by the faulting or fracturing of the earth's crust or by erosion. (2) To form or cut into a steep slope. See *escarpment*.

scattered See *scattered* under *large organic debris*.

scour Localized erosion of substrate from the streambed by flowing water when water velocities are high.

scour chain Steel chains implanted in the streambed to measure scour and sediment deposition within a period of time.

scour pool See *scour pool* under *slow water, pool* under the main heading *channel unit*.

scour structure See *scour structure* under *habitat enhancements*.

scrapers See *scrapers* under *macroinvertebrate*.

scrub–shrub wetland See *scrub–shrub wetland* under *wetlands*.

seasonal astatic See *seasonal astatic* under *astatic*.

seasonal flow See *seasonal flow* under *flow*.

seasonally flooded See *seasonally flooded* under *floodplain* and *water regime*.

seasonally flooded floodplain See *seasonally flooded floodplain* under *floodplain*.

seawater See *seawater* under *salinity*.

secchi disk A disk 20 or 50 cm (~ 8 or 20 in) in diameter with alternating white and black quarters that is lowered into a water column with a calibrated chain or rope used to visually measure the depth of light transparency in water.

The depth is determined directly from the calibrations on the chain or rope.

secondarily confined channel See *secondarily confined channel* under *confinement*.

secondary channel See *secondary channel* under *channel pattern* and *slow water*, *pool*, *dammed pool* under the main heading *channel unit*.

secondary current cells Generally applied to stream currents that move at right angles to the main current, primarily in meandering streams, and are responsible for the formation of concave banks and point bar deposition. Also referred to as helical flow or transverse flow.

secondary production See *secondary production* under *production*.

sediment Fragmented material from weathered rocks and organic material that is suspended in, transported by and eventually deposited by water or air.

sedimentary Substrate that is formed by the deposition of water-borne mineral fragments, organic debris, or mineral precipitates that become cemented and pressed into a solid form (i.e., rocks).

sedimentation (1) Action or process of forming and depositing sediments. (2) Deposition of suspended matter by gravity when water velocity cannot transport the bed load.

sedimentation pond See *sedimentation pond* under *pond*.

sediment budget An account of the sediment types, amounts, sources, movement, routes to specific locations, storage, and disposition of sediment in a basin.

sediment discharge Mass or volume of sediment (usually mass) passing a stream transect in a unit of time, and that is generally expressed as tons per day of suspended sediment discharge, bed load discharge, or total sediment discharge.

sediment load General term that refers to sediment moved by a stream in suspension (suspended load) or at the bottom (bed load). Sediment load is not synonymous with either discharge or concentration.

bed load Sediment that moves on or near and frequently in contact with a streambed by rolling, sliding, and sometimes bouncing with the flow. Bedload sediments are composed of particles greater than or equal to 0.062 mm (~0.01 in) in diameter.

bed material load Portion of the stream sediment load that is composed of particle sizes present in appreciable quantities in the streambed.

coarse load Portion of the bed load that is more difficult to move by flowing water than sediment because it requires higher water velocities with enough power to move larger substrate materials.

d_{50} or D_{50} Size of particle diameters that contains 50% fine sediments. The percentage of fines can be set from 1 to 100%.

depth integration Method of sampling at all points throughout the sample depth so that a water–sediment mixture is collected proportional to the stream velocity at each point. This procedure yields a discharge weighted sample.

fine load Portion of the total sediment load that is composed of particles smaller than the particles present in appreciable quantities in the bed material. Similar to *washload* under *sediment load*.

suspended load Portion of the total sediment load that moves in suspension, free from contact with the streambed, and made up of small sediment particles. The density and grain size of the sediment particles are dependent upon the amount of turbulence and water velocity. Only unusually swift streams are turbulent enough or have water velocities high enough to lift particles larger than medium-sized sand from their beds. See also *bed load* and *washload* under *sediment load*.

washload Portion of the sediment load that can be carried in large quantities and is limited only by availability in the watershed. The washload contains sediments that are finer than the smallest 10% of the bed load and usually less than 0.062 mm (~ 0.002 in) in diameter. Compare with *fine load* under *sediment load*.

sediment production zone See *sediment production zone* under *fluvial*.

sediment rating curve A graph that illustrates the relationship between sediment discharge and stream discharge at a specific stream cross section.

sediment storage Mineral and organic matter that is transported by a stream or river and deposited at locations where it remains in a relatively stable state.

sediment transport Process by which individual particles of bed material are lifted from the streambed and transported by water velocity.

sediment transport rate Mass or volume of sediment (usually mass) that passes a stream cross section in a specific unit of time.

sediment trap See *sediment trap* under *habitat enhancements*.

sediment yield Quantity of sediment produced from a specific area in a specified period of time.

seep Small groundwater discharge that slowly oozes to the surface of the ground or into a stream. A seep oozes water slowly and differs from a spring that visibly flows from the ground.

seepage (1) Movement of water through the substrate without the formation of a definite channel. (2) Loss of water by infiltration from a canal, reservoir, other water body, or field.

seepage lake See *seepage lake* under *lake*.

seiche See *seiche* under *wave*.

self-maintaining system An aquatic ecosystem that can perform all of the natural ecological functions without human intervention or a dependence on engineered structures.

semipermanently flooded See *semipermanently flooded* under *water regime*.

sensitive reservoir Reservoir where high production rates decrease restoration or recovery. See *eutrophic* under *trophic*.

sensitive slope Any slope that is prone to mass erosion or wasting.

sensitivity Susceptibility of a watershed, stream, or lake to damage from natural processes or human activities.

sensor See *sensor* under *remote sensing*.

separation bar See *separation bar* under *bar*.

seral stages See *seral stages* under *succession*.

serial discontinuity Concept where dams shift biological and physical characteristics of streams and rivers from the predicted pattern related to the river continuum concept.

serpentine channel See *serpentine channel* under *channel pattern*.

sessile Organisms that are attached to a substrate but do not penetrate it and are unable to move about freely.

seston All organic and inorganic material greater than 60 μm in size that is suspended in the water column.

- **nannoseston** Seston that passes through a plankton net.
- **net seston** Seston that does not pass through a plankton net.

settleable solids Matter in the water column that does not stay in suspension when the water is immobile and sinks to the bottom or floats to the surface.

settling pond See *settling pond* under *pond*.

seven day low flow (Q7L) See *seven day low flow (Q7L)* under *flow*.

seven day/Q10 See *seven day/Q10* under *flow*.

sewage Refuse liquids including human body wastes or wastes carried off by sewers.

shade density Inverse of the percentage of direct light passing through crowns such that complete shading yields a value of 100%.

shallow Term applied to water that is usually less than 2 m (less than 6.5 ft) in depth. See *shoal*.

shallow-rapid landslide See *shallow-rapid landslide* under *landslide*.

shape index An index of the width and depth of a stream habitat. Values less than 9 generally indicate pools, greater than 9, riffles:

$$\text{shape index} = (w/d)^{(d/d\max)};$$

w = width;
d = mean depth;
d_{max} = maximum depth along a cross section.

shear stress Force per unit area that is parallel to a surface. See also *shear stress* under *energy*.

sheen An iridescent appearance on a water surface.

sheet Migrating accumulations of bed load one or two grain-diameters thick that alternate between fine and coarse particles. See also *sheet* under *fast water—nonturbulent* under the main heading *channel unit*.

sheet erosion Erosion of soil from sloping land in thin layers or sheets that may be imperceptible, particularly when caused by wind, or denoted by numerous fine rills. See also sheet erosion under *erosion*.

sheet flow Flow of water over the ground in a more or less continuous sheet. If the flow is large, it is termed a sheet flood. See also *sheet flow* under *flow*.

sheetwash Flow of rainwater that covers the entire ground surface with a thin film and is not concentrated in streams.

shelf Sandbank or submerged area of rock in a water body or bedrock underlying an alluvial deposit.

Shelford law of tolerance When one environmental factor or condition is near the limits of tolerance at either a minimum or maximum level or state, that one factor or condition will determine whether or not a species will be able to maintain itself under those specific environmental conditions.

shoal Shallow area that is usually a sandbank, sandbar, or a rocky, swift section of stream. See *shallow*.

shoalwater substrate Composition of the bed in a shallow (shoal) area of a river, sea, or other water body.

shooting flow See *shooting flow* under *flow*.

shore Land along the edge of a water body.

shoreline Interface between land and water or the intersection of land and permanent water.

shoreline : acreage ratio See *shoreline : acreage ratio* under *dimensions*.

shoreline development See *shoreline development* (D_l) under *dimensions*.

shoreline length See *shoreline length* under *dimensions*.

shredders See *shredders* under *macroinvertebrate*.

side bar See *side bar* under *bar*.

side channel See *side channel* under *channel pattern*. Also, see *side channel* under *slow water, pool, dammed pool* with the main heading of *channel unit*.

signature See *signature* under *remote sensing*.

significant wave height See *significant wave height* under *wave*.

siliceous Term applied to material containing silica or silica dioxide.

sill (1) Elevated area of the bottom at the mouth of a port or harbor, or at the outlet of a water body such as a lake or estuary. (2) Bottom of a stop-log gate structure or dam crest that controls water level with flash boards. Compare with *sill* under *habitat enhancements*.

silt (1) Fine soil that is between 0.004 and 0.062 mm (0.00002 – 0.0003 in) in diameter. (2) Also applied to a soil or substrate containing a very high proportion of silt particles. Compare with other substrate sizes under *substrate size*.

siltation Settling of fine suspended sediments in water where water velocity is reduced.

silting Process of depositing silt when water velocities and transport capabilities of a stream are reduced. Also applied to conditions that accompany the deposition of excessive amounts of silt.

silt load Quantity of silt being transported in a specified quantity of water.

simple meander See *simple meander* under *meander*.

sink (1) Depression or low-lying, poorly drained area or hole formed where the underlying rock dissolves and waters collect in the depression or where water disappears through evaporation.

(2) Area where the input of mass or energy exceeds the output or production. (3) Location where streamflow disappears into the bed material of the stream. (4) To move downward in the water column.

sinker Term applied to logs or large limbs that do not remain afloat in water either because of intrinsic density or through water-logging.

sinkhole Depression, often steep-sided, that is created by subsidence where subterranean minerals or substrate dissolves and results in the collapse of an underground passage or piping.

sinking current Downward movement of sea or lake water that has become denser through cooling or increased salinity, or moves downward as the result of an onshore wind.

sink lake See *sink lake* under *lake*.

sink zone See *sink zone* under *fluvial*.

sinter General term applied to chemical sediments deposited by mineral springs.

sinuosity (1) Ratio of channel length between two points in a channel to the straight line distance between the same two points. (2) Ratio of channel length to valley length. Channels with sinuosities of 1.5 or more are called "meandering," while those close to 1.0 are called "straight." (3) See also *sinuosity* under *dimensions*.

sinuous channel See *sinuous channel* under *channel pattern*.

sinuous meander See *sinuous meander* under *meander*.

site Area described or defined by biotic, climatic, water, and soil conditions that forms the smallest planning unit with a defined boundary.

skid road In forestry practices, any road or trail used for hauling logs from the logging site to a landing where logs are loaded on trucks or other conveyances for transport.

ski jump See *ski jump* under *control structure*.

slab failure See *slab failure* under *landslide*.

slack water Quiet, still pool-like area of water in a stream usually on the side of a bend where water current is low. See *slackwater* under *slow water*, *pool*, *dammed pool* under the main heading *channel unit*.

SLAR See *SLAR* under *remote sensing*.

slick (1) Glassy smooth flow of water that is sometimes used interchangeably with glide. See *glide* under *slow water* in *channel unit*. (2) A thin, shiny layer of material on the surface of the water usually referring to oil or other petroleum-based product.

slide See *slide* under *landslide*.

sliding beads Procedure used to measure substrate movement in a streambed that involves burying numbered beads on a cable. The beads slide to the end of the cable when substrate is dislodged from high water velocities associated with peak flows that scour the streambed. The number of beads that are dislodged provide a measure of the depth of streambed scour. See *scour*.

sliding gate See *sliding gate* under *gate* and main heading of *control structure*.

slip erosion See *slip erosion* under *landslide*.

slope Incline of any part of the earth's surface. Land with an incline or oblique direction in reference to the vertical or horizontal plane. See also *gradient*.

slope break Pattern on a slope where gradient changes abruptly.

slope failure See *slope failure* under *landslide*.

slope processes Mass movement by debris slides and surface wash that results in transport of fine sediments downslope by overland flow.

slope stability Measure of slope resistance to erosion, slumping, sliding, or other unstable conditions.

slope wash Motion of water and sediments down a slope caused by sheet flow.

sloping gully side See *sloping gully side* under *gully side form*.

slough (1) Low swamp or swamp-like area in a marshy or reedy pool, pond, inlet, or backwater with marsh characteristics such as abundant vegetation. (2) Channel where water flows sluggishly or slowly through low swampy ground on a delta or floodplain. (3) Marshy tract located in a shallow, undrained depression or a sluggish creek in a bottomland. (4) Tidal channel in a salt marsh. (5) Lower reach of a tributary that has been ponded by sediment and debris at the confluence with the main channel.

slow water See *slow water* under *channel unit*.

sludge Deposit of a semifluid mass such as mud, ooze, sediment, or organic matter in the bottom of a water body.

sluggish flow See *sluggish flow* under *flow*.

slump See *slump* under *landslide*.

slump-earthflow See *slump-earthflow* under *landslide*.

small bole See *small bole* under *large organic debris*.

small impoundment Small reservoir (generally 8 ha [20 acres] or less in surface area) used for water storage and control on a stream. See *reservoir*.

small mountain lake See *small mountain lake* under *lake*.

small-sporadic deep-seated failures See *small-sporadic deep-seated failures* under *landslide*.

snag (1) Standing dead tree. (2) Submerged fallen tree in a stream, sometimes with an exposed or only slightly submerged tree top. (3) See also *snag* under *large organic debris*.

snagging Removing or cutting snags on land or in water.

soda lake See *soda lake* under *lake*.

softwater Freshwater with low alkalinity, conductivity, or salinity that is generally found in areas with sandstone substrate or headwater streams. Compare with *hardwater*.

soil Portion of the earth's surface that consists of earth, disintegrated rock, and humus and that is capable of supporting vegetation. See *earth*, *ground*.

soil creep Gradual downslope movement of soil by gravity.

soil drainage Pattern of water drainage from soils, generally applied to saturated soil.

soil erosion Removal of soil through erosion by wind, precipitation, surface water, or other natural processes.

soil pore Area, interstice, or space within soil that is occupied by either air or water where the degree of porosity is dependent upon the arrangement of individual soil particles.

soil water potential Amount of work required to transport a given quantity of water from the surface into groundwater.

solar arc See *solar arc* under *solar radiation*.

solar radiation Electromagnetic energy from the sun at all wavelengths. More particularly, radiation with wavelengths between 0.2 and 4.5 μm that emanate from the sun and can be measured by instruments (e.g., actinometer, pyranometer, radiometer, or solimeter). The fraction of incident light or electromagnetic radiation that is reflected by a surface or body is known as albedo. Net radiation is the algebraic sum of the upward and downward vertical components of long- and short-wave radiation.

arc of the sun Change in the angle of the sun on a given day in degrees from when sunlight first strikes water. The arc of the sun on August 1st at the same location is used as a standard.

direct solar radiation Radiation that reaches a water surface in an unobstructed straight line.

incident light Visible light reaching a water surface.

reflected solar radiation Radiation that does not penetrate a water surface but is reflected from the surface.

refracted solar radiation Radiation that penetrates a water surface and is either bent or deflected from its original path.

solar arc Measure of canopy angle in degrees that is based on the measurement of the angles formed from the line of sight to the visible horizon.

total solar radiation Sum of direct, reflected, and refracted radiation reaching a given point.

solifluxion, solifuction Slow, downhill flow of soil or soil layers saturated with water that is typical of sites subjected to periods of alternate freezing and thawing. Solifluxion over frozen ground is termed gelifluxion that may develop into a sudden mass flow of mud and earth.

soligenous fen See *soligenous fen* under *wetlands*.

solitron A single, isolated peak or trough of a wave in water.

solum Upper part of a soil profile that is influenced by plant roots.

solute Substance that will dissolve or go into solution.

solution lake See *solution lake* under *lake*.

sonar See *sonar* under *remote sensing*.

sorted Geological term pertaining to the variability of particle sizes in a clastic sediment or sedimentation rock. Materials with a wide range of particle sizes are termed poorly sorted while materials with a small range of sizes are termed well sorted.

sorting coefficient Measure of the distribution or variability of particle sizes in substrate that is usually expressed as the square root of d_{75}/d_{25}. The terms d_{75} and d_{25} are diameters where 75% and 25% of the cumulative size-frequency distributions are larger than a given size. A substrate with a large sorting coefficient is termed well sorted.

sound Water body that is usually broad, elongated, and parallel to the shore between the mainland of a continent and one or more islands.

sounding Process of measuring the depth of water, as in a lake or reservoir, either with a sounding line (chain or cord with gradations) or by transmitting a sound wave into water to reflect off the bottom and read on a depth finder.

spawning box See *spawning box* under *habitat enhancements*.

spawning marsh See *spawning marsh* under *habitat enhancements*.

spawning platform See *spawning platform* under *habitat enhancements*.

spawning reef See *spawning reef* under *habitat enhancements*.

spawning substrates Substrates of suitable size and composition in rivers, lakes, or other water bodies that are used by fish and and other aquatic animals for deposition of eggs and sperm.

specific gravity Ratio that denotes the density of an object or fluid compared to the same volume of distilled water at 4°C.

specific reach See *specific reach* under *reach*.

spectral signature See *spectral signature/spectral relectance curve* under *remote sensing*.

spiling See *spiling* under *habitat enhancements*.

spilling breaker See *spilling breaker* under *wave*.

spillway See *spillway* under *control structure*.

spit Narrow strip of land that projects into a water body.

splash apron Concrete or rock structure placed at the outlet of a culvert, drop structure, channel, or ford to intercept water and reduce velocity to prevent scouring.

splash dam Temporary or permanent structure in a stream channel used to store logs and water until sufficient water is present from precipitation, runoff, and storage to transport the logs downstream when the splash dam is opened.

splash erosion See *splash erosion* under *erosion*.

SPOT See *SPOT* under *remote sensing*.

spring Site where groundwater flows naturally from a rock or soil substrate to the surface to form a stream, pond, marsh, or other type of water body.

cold spring Spring with a mean annual water temperature that is appreciably below the mean annual atmospheric temperature for a specific area.

hot spring Thermal spring with a mean water temperature that exceed the normal temperature of a human body (37°C or 98.6°F).

spring breakup (1) Breakup of ice on rivers and lakes during the spring thaw. (2) Period in spring when snow and ice that are formed during winter are melting. (3) In some parts of the United States, this term refers to the "mud season" when earth or clay roads may be impassable.

springbrook Short, spring-fed stream with substrates of organic mud and sand that often contains thick growths of watercress.

spring creek Stream that derives most of its flow from a spring and is characterized by a relatively constant flow and water temperature.

spring overturn See *spring overturn* under *stratification*.

spring source area Lands that contribute water to a spring by infiltration and percolation through the soil or other substrates.

sprungschicht See *metalimnion* and *thermocline* under *stratification*.

stability Ability of a bank, streambed, or slope to retain its shape and dimensions when exposed to high streamflows and varying temperature conditions.

stability rating An index of the resistance or susceptibility of the stream channel and banks to erosion.

stable bank See *stable bank* under *bank stability*.

stable debris See *stable debris* under *large organic debris*.

stable flow See *stable flow* under *flow*.

stage (1) Elevation of a water surface above or below an established reference point. (2) Quantification of a discharge expressed as a percent of mean annual discharge or some other reference flow. (3) Depth of water at any point in a stream that is generally calibrated so that discharge can be estimated with a weir.

stage class See *stage class* under *succession*.

stagnant Layer of inert water with little or no circulation of water and low dissolved oxygen.

stagnation point Point at the leading edge of an object where the water velocity of the oncoming flow is zero where the water collides with the object.

stagnation pressure Pressure differential between a zone of high velocity water flow and a zone of lower velocity such as along rock riprap. Such pressure differential or stagnation pressure is often sufficient to dislodge large, heavy objects such as boulders and large rocks.

stake bed See *stake bed* under *habitat enhancements*.

standard fall velocity Average velocity that a particle would finally attain if falling in quiescent distilled water at a temperature of 24°C.

standard sedimentation diameter Diameter of a sphere that has the same specific gravity and the same standard fall velocity as a given particle.

standing crop Quantity of living organisms present in the environment at a given time that is usually expressed as the dry total weight of biomass of a specific taxon or community. Generally synonymous with *standing stock* but often refers to the harvestable portion of the *standing stock*. See *standing stock*.

standing stock Dry total weight of biomass of a specific taxon or community of organisms that exists in an area at a given time. See *biomass*.

standing timber Trees, usually dead, that were left uncut in a reservoir basin before impoundment to serve as habitat for fish and invertebrates.

standing water Water that remains in one location such as a marsh, pond, lake, or swamp. See *lentic*.

standing wave See *standing wave* under *wave*.

static head Distance from a standard datum (artificially defined reference point) of the water surface on a column of water that can be supported by the static pressure at a given time.

station (1) Exact place of occurrence of an individual or species within a given habitat. (2) Permanent or semi-permanent sample area. (3) A circumscribed area that contains all the environmental conditions required by an individual or group of individuals.

status See *status* under *trophic*.

steady flow See *steady flow* under *flow*.

steep bank See *steep bank* under *streambank*.

stem flow See *stem flow* under *flow*.

stenobathic Refers to an organism that is restricted to living at a certain depth in a water column.

stenohaline See *stenohaline* under *salinity*.

stenosaline See *stenosaline* under *salinity*.

stenotherm Organisms that have a narrow temperature tolerance.

stenotypic organism An organism with a narrow range of tolerance to a particular environmental factor.

step run See *step run* under *fast water—turbulent* under the main heading *channel unit*.

still Water is considered to be still when it is motionless, free from turbulence, without waves or perceptible current.

stilling basin Deep pool located in or below the spillway of a dam that dissipates the energy of the water in the spillway.

stilling pond See *stilling pond* under *pond*.

stocking Release of bird, fish, or wildlife species into a given habitat that were obtained through captive propagation or were captured from the wild elsewhere.

stone Naturally formed hard substance consisting of mineral or earth materials such as rock formations, weathered rock in the form of boulders, or gravel (pieces of rock that have become rounded from scouring in a streambed). Compare with other substrate sizes under *substrate size*.

stop log See *stop log* under *control structure*.

storage (1) Water that is artificially impounded in surface or underground reservoirs for future use. (2) Water that is naturally detained in a drainage basin as groundwater, channel storage, and depression storage. The term "drainage basin storage" or simply "basin storage" is sometimes used in reference to the total amount of naturally stored water in a drainage basin.

storage coefficient Coefficient that expresses the relation of storage capacity in a reservoir to the mean annual flow of a single stream or all streams that are direct tributaries to the reservoir.

storage ratio Net available water storage divided by the mean annual flow for a basin within a period of one year.

storage reservoir Reservoir designed to retain water during peak water periods for release and use downstream at another time when streamflows are low. See *reservoir*, *storage*.

storm event Major episode of atmospheric disturbance that is often associated with heavy precipitation, lighting, and thunder.

storm flow See *storm flow* under *flow*.

story One of several distinct layers of plant growth such as tall trees, large shrubs, low shrubs, and ground cover.

straight See *straight* under *slow water, scour pool* under *channel unit*.

straight channel See *straight channel* under *channel pattern*.

straight meander See *straight meander* under *meander*.

strait Narrow passage of water connecting two larger water bodies.

strath terrace Terrace composed of ancient alluvial material that is deposited as a mantle over a base of bedrock.

stratification Arrangement of water masses into distinct, horizontal layers that are separated by differences in density associated with water temperature and dissolved or suspended matter.

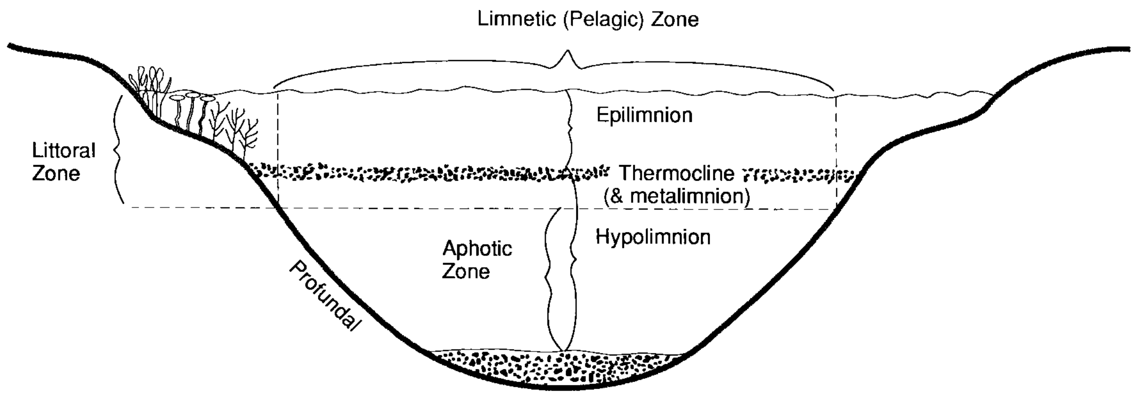
bathylimnion Deepest part of a lake that is located below the clinolimnion.

chemocline Density gradient, or pycnocline, from differences in salt concentration.

clinograde Oxygen profile in which the hypolimnion has less dissolved oxygen than the epilimnion.

clinolimnion Layer or region of a water body where the rate of heating decreases exponentially.

destratification Process that interrupts the boundary between water strata and induces mixing between strata.



stratification layers (adapted from Thorp and Covich 1991)

discontinuity layer See *thermocline* under *stratification*.

epilimnion Uppermost layer of water in a lake characterized by an essentially uniform temperature where relatively thorough mixing occurs from wind and wave action to produce a less dense but oxygen-rich layer of water. In a thermally stratified lake the epilimnion extends from the water surface down to the metalimnion.

fall overturn Physical phenomenon that involves the thorough mixing of water that occurs in temperate-zone water bodies during the fall season. The sequence of events leading to the fall overturn includes: (a) cooling and increased density of surface waters producing convection currents from top to bottom; (b) circulation of the total water volume by wind actions and density differences resulting in a uniform water temperature that allows complete mixing of nutrients and chemicals throughout the entire water mass.

hypolimnion Poorly oxygenated and illuminated lower layer or region in a stratified lake that extends from the metalimnion to the bottom and is essentially removed from major surface influences. Water in the hypolimnion is denser and colder than strata higher in the water column.

inverse stratification Water body with colder water in a stratum over warmer water.

mesocline See *thermocline* under *stratification*.

mesolimnion Term used in place of thermocline. See *thermocline* under *stratification*.

metalimnion Stratum between the epilimnion and hypolimnion that exhibits a marked thermal discontinuity with a temperature gradient equal to or exceeding 1°C per meter. See *mesocline*, *thermocline*.

mixolimnion Upper strata of a lake that exhibits periodic circulation. See *epilimnion* under *stratification*.

monimolimnion Deeper stratum or layer of a lake that remains perennially stagnant and rarely circulates, especially the layer below the chemocline in a meromictic lake.

negative heterograde Term applied to a vertical profile of water with minimum oxygen levels.

orthograde Oxygen profile where the oxygen level below the epilimnion remains at or near saturation.

overturn Period of mixing or circulation of water in a previously thermally stratified water body. See *fall overturn* under *stratification*.

positive heterograde Profile where an oxygen profile remains well above saturation.

pycnocline Layer or region in saltwater where a marked change occurs in the density of a water column that acts as a partial barrier to exchange between the upper and lower water columns.

spring overturn Physical phenomenon that may involve the thorough mixing of water in temperate-zone water bodies during the early spring. The sequence of events leading to spring overturn includes: (a) melting ice cover; (b) warming surface waters; (c) changing densities in surface waters that produce convection currents from top to bottom; and

(d) circulation of the entire water volume by wind action, resulting in a uniform water temperature that allows complete mixing of nutrients and chemicals throughout the entire water mass.

sprungschicht Term that is synonymous with thermocline or metalimnion.

thermal stratification Vertical temperature stratification in north temperate lakes resulting in: (a) virtually uniform water temperature in the epilimnion; (b) rapid and marked gradient change in temperature with depth in the metalimnion; and (c) cold and nearly uniform water temperature in the hypolimnion, from the bottom of the metalimnion to the bottom of a water body.

thermocline Stratum between the epilimnion and hypolimnion that exhibits a marked temperature gradient equal to or exceeding 1°C per meter. Synonomous with mesolimnion or metalimnion.

turnover Refers to the thorough mixing of water in a lake by wind action that occurs when density differences of a thermally stratified water column disappear and temperatures become uniform. See fall turnover and spring turnover.

stratified Refers to a series of water layers that form from density differences of water temperatures. See *thermocline* under *stratification*.

stratified flow Layered flow that results from a difference in density due to temperature, dissolved, or suspended materials between the inflowing and receiving water.

stratified lake See *stratified lake* under *lake*.

stratified stream segment Portion of a stream that is relatively homogeneous based on geomorphology, streamflow, geology, and sinuosity. This term also refers to a series of short reaches with a common morphology.

streaks Surface areas parallel to direction of the wind that coincide with lines of surface convergence and downward movement of water. See also *langmuir circulation* under *wave*.

stream Natural water course containing flowing water, at least part of the year, together with dissolved and suspended materials, that normally supports communities of plants and animals within the channel and the riparian vegetation zone.

alluvial stream Stream where the form of the streambed is composed of appreciable quantities of sediments that are transported and deposited in concert with changes in streamflow.

beaded stream Stream connecting a series of small ponds or lakes.

beheaded stream Stream that has been separated from a portion of its headwater tributaries. See *stream piracy*.

centripetal stream Streams that converge in the central part of a basin.

consequent stream Stream that flows in the same direction as local geologic strata.

continuous stream Stream where the flow along its course is not interrupted in space or time.

distributary Division of stream channels, as on a delta or alluvial fan, that flow away from the main channel, usually into a larger stream, lake, or other receiving water body. Distributary streams form where deposition exceeds erosion.

entrenched stream Stream that has eroded into the substrate and is confined by walls resistant to erosion.

gaining stream Stream or stream reach that receives water from the zone of saturation.

graded stream Stream that has achieved a state of equilibrium between the rate of sediment supply, transport, and deposition throughout long reaches.

headwater stream Stream that has few or no tributaries, and has steep, incised channels that are often associated with active erosion, seeps, and springs. Headwater streams are referred to as first order streams. See *seep*, *spring*, *stream order*.

incised stream Stream that has, through degradation, cut its channel into the bed of a valley.

insulated stream Stream or stream reach that neither contributes to nor receives water from the zone of saturation because it is separated by an impermeable bed.

interrupted stream Stream without a continuous flow where reaches with water may be perennial, intermittent, or ephemeral.

losing stream Stream or stream reach that contributes water to the zone of saturation.

lowland stream Stream that flows across low gradient terrain, has a bed composed of fine substrate materials, and is located in the lower part of a drainage network downstream from mountains.

mature stream See *graded stream* under *stream*.

meltwater stream Channelized flow of glacial melt water.

middle stream Refers to a stream reach that is located in the center of a stream course between headwaters and the mouth, has beds of diverse substrates, variable habitat patterns, and usually has equilibrium or balance between scouring and deposition. See *deposition*, *scour*.

obsequent stream Stream that flows in a direction opposite of the general trend in local geologic strata.

parallel stream Stream that flows in close proximity to and in the same direction as another stream but separated by a divide.

perched stream Stream that may be classified as either "losing" or "isolated" and is separated from the underlying groundwater by a zone of aeration. See *losing stream* and *isolated stream* under *stream*.

pinnate stream Stream pattern characterized by a series of small tributaries distributed along the stream gradient of the main stem.

pooled channel An intermittent stream with significant surface pool area and without flowing surface water that is supplied by groundwater.

radial Pattern of stream channels flowing out from a central point such as a volcanic cone.

rectangular stream A system of streams in which each straight segment of stream takes one of two characteristic perpendicular directions that follow perpendicular landforms.

superimposed stream A stream whose course, once established, is maintained by erosion cutting deeper into the landform.

trellis stream Stream pattern in which tributary streams join the main stream at or near right angles and are fed by elongated secondary tributaries parallel to the main stream so that the whole system resembles a vine on a trellis.

streambank Ground bordering a channel above the streambed and below the level of rooted vegetation that often has a gradient steeper than 45° and exhibits a distinct break in slope from the stream bottom. The portion of the channel cross section that restricts lateral movement of water during normal streamflow. Right and left banks are determined while looking downstream.

concave bank Bank that is indented such that the top and bottom of the bank are higher and is often characterized by bank erosion. Generally, a concave bank is located on the outside of a river curve or bend of a meandering stream.

convex bank Bank that is inverted such that the top and bottom of the bank are lower and is often characterized by sediment deposition at a point bar. Generally, a convex bank is located on the inside bank on a river curve or bend, especially on a meandering stream.

cut bank Streambank that is actively eroding and has a steep face.

flat bank Streambank where the riverbed slopes gently to the level of rooted vegetation.

lower bank Bank that is periodically submerged between the normal high water line to the water's edge during the summer low flow period.

repose bank Bank with an angle of repose (usually 34–37°) in unconsolidated material.

steep bank Bank that is nearly vertical and is consolidated by the cement action of minerals, compaction, and roots from riparian vegetation.

undercut bank Bank with a cavity below the water line that is maintained by scour from substrates and high water velocities. See *scour*.

unstable bank Streambank boundary of the channel that is actively failing through erosion or slumping, that is recognized by clumps of sod and earth along the base of the bank, and that is expressed as a percentage of the total length of both banks for the reach. See *erosion* and *earth slump* under *landslide*.

upper bank Portion of a bank in the topographic cross section of the channel from the break in the general slope of the surrounding land to the normal high water line.

streambank material Substrates that compose banks along stream courses. The following terms classify bank material according to composition, origin, and method of formation.

anthropogenic Materials created or modified by humans, including those associated with mining of minerals, waste disposal, and erosion control. See *revetment*, *riprap*.

bedrock Rock outcrop or rock covered by a thin mantle (less than 10 cm) of consolidated material.

colluvial Product of mass movement of materials (usually angular and poorly sorted) that reached their present position by direct influence of gravity such as slides or talus slopes. See *landslide*.

eolian Materials (usually silt or fine sand) that are transported and deposited by wind.

fluvial Materials (usually rounded, sorted into horizontal layers, and poorly compacted) that are transported and deposited by streams and rivers.

ice Frozen water from seeps or glaciers, or atmospheric conditions. See *glacier*, *seep*.

lacustrine Fine-textured sediments that have settled to the bottom from suspension in bodies of standing freshwater or that have accumulated at the margins of lakes or reservoirs through wave action. May be fine textured with repetitive layers.

marine Sediments that have settled from suspension in brackish or saltwater of estuaries or oceans.

morainal Poorly sorted (angular to subangular) material transported in front of, beneath, beside, or within a glacier and deposited directly by the glacier. May be highly compacted and have significant clay content.

organic Materials resulting from vegetative growth, decay, and accumulation in closed basins or on gentle slopes where the rate of accumulation exceeds that of decay.

saprolite Weathered bedrock that decomposed in situ, principally by chemical and weathering processes.

undifferentiated Multiple layers of different types of material.

volcanic Unconsolidated volcanic or igneous (pyroclastic) sediments that accumulate from volcanic eruptions or fine volcanic dust carried by winds and deposited some distance from the volcano.

streambank stability Index of firmness or resistance to disintegration of a bank based on the percentage of the bank showing active erosion and the presence of protective vegetation, woody material, or rock. See *stable* and *unstable* under *bank stability*, and *cut bank* and *unstable bank* under *streambank*.

streambed Substrate plane, bounded by banks, of a stream bottom. Also referred to as the stream bottom.

stream capacity (1) Total volume of water that a stream can transport within the high water channel. (2) Maximum sediment load a stream can transport at a given velocity and discharge.

stream capture Upstream connection of one stream by erosion into the drainage basin of another stream that results in changes of drainage patterns. See *stream piracy*.

stream channel (1) Long, narrow depression shaped by the concentrated flow of a stream and covered continuously or periodically by water. (2) Bed and banks formed by fluvial processes where a natural stream of water runs continually or intermittently. See *channel*.

stream classification Systems used to group or identify streams possessing similar features using geomorphic structure (e.g., gradient and confinement), water source (e.g., spring creek), associated biota (e.g., trout zone), or other characteristics. A hierarchical classification. Two approaches are commonly used: a management-related classification that is based almost entirely on value to fish populations, and a geomorphic-habitat classification system.

stream corridor Perennial, intermittent, or ephemeral stream and riparian vegetative fringe that occupies the continuous low profile of the stream valley.

stream density Abundance of streams that is expressed as kilometers of stream per square kilometer of landscape or terrain. Synonymous with *drainage density*. See *landscape*, *terrain*.

stream discharge See *stream discharge* under *discharge*.

stream–estuary ecotone Transitional area from a stream mouth and lower limit of marsh vegetation that extends to the upper limit of tidal influence. See *ecotone*.

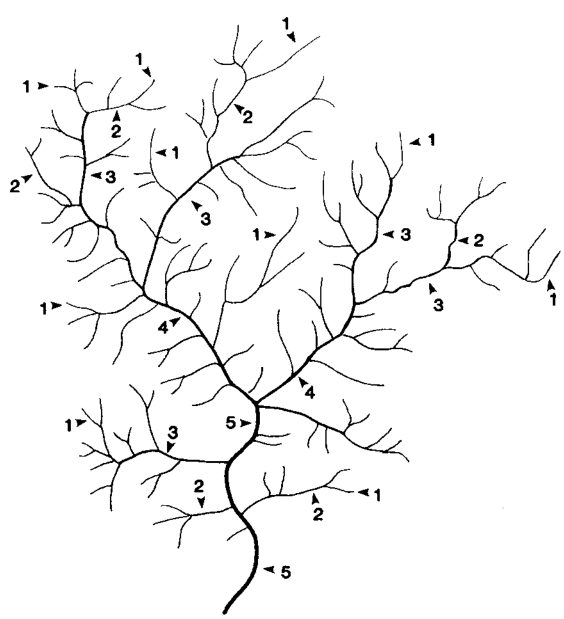
streamflow See *streamflow* under *flow*. See also *discharge*.

stream–forest ecotone Area of a stream that is directly influenced by riparian vegetation, including the streambank and upland area adjacent to the stream. Its size depends on stream width, type of vegetation, and physical characteristics of the adjoining uplands. See *ecotone*, *streamside management zone*.

stream frequency The number of streams per square kilometer of area.

streamline Direction of water movement at a given instant.

streamline flow See *streamline flow* under *flow*.



stream order (from Helm 1985)

stream order Hierarchical ordering of streams based on the degree of branching. A first-order stream is an unforked or unbranched stream. Two first-order streams flow together to form a second-order stream, two second orders combine to make a third-order stream, etc.

stream pattern See *channel type*.

stream piracy Transfer of a stream from one basin to another as a result of geomorphic changes, usually by erosion through a common divide. See *stream capture*.

stream power Energy or ability of a stream to move substrates and scour streambanks that is based on gravity, slope, discharge, and water velocity. See also *stream power* under *energy*.

stream profile Graphical presentation of elevation versus distance of a stream channel or shape of a cross section. In open channel hydraulics, it is a plot of water surface elevation against channel distance.

stream reach See *reach*.

stream shore water depth Water depth at a stream shoreline or at the edge of a bank overhanging a shoreline.

streamside management zone The land, together with the riparian vegetation, that is in immediate contact with a stream and sufficiently close to have a major influence on the total ecological character and function of the stream. See *stream–forest ecotone*.

stream surface shading Percentage of the stream surface area that is shaded.

foliar shading Shading attributable to riparian vegetation.

nonfoliar shading Shading from debris, undercut banks, and surrounding terrain.

stream transport capability Ability of a stream to move sedimentary materials and organic material during periods of peak flow. This ability is influenced by water volume (i.e., discharge), water velocities, channel slope, timing of the peak flows, and the presence or absence of obstructions in the channel.

stream width See *wetted width* under *dimensions*.

structure (1) Any object, usually large, in a channel that influences streamflow. (2) Features that create a diversity of physical habitat within a stream, lake, or reservoir. (3) Organization of taxa into various functional or trophic groupings in a biological community. Compare with *structure* under *habitat enhancements*.

stump field Area in the bottom of an impoundment where stumps remain after trees were cut and removed before impoundment.

subbasin Surface area of a watershed drained by a tributary to a larger stream that is bounded by ridges or other hydrologic divides and is located within the larger watershed drained by the larger stream. Also referred to as subdrainage.

subdrainage See *subbasin*.

sublittoral See *sublittoral* under *littoral*.

submerged Refers to under a water surface.

submerged macrophyte See *submerged macrophyte* under *macrophyte*.

subsidence Lowering of surface elevations caused by loss of support and subsequent settling or caving of substrate strata.

substrate (1) Mineral and organic material forming the bottom of a waterway or water body. (2) The base or substance upon which an organism is growing. Also referred to as substratum.

substrate size The following table includes the average diameter of various substrates in millimeters and inches.

	Diameter of particle	
Name of particle	Millimeters	Inches
Large boulders	>1,024	40–160
Small boulders	256–1,024	10–40
Stone	256–600	10–24
Rubble (large cobble)	128–256	5–10
Cobble (small cobble)	64–128	2.5–5
Pebble	2–64	0.08–2.5
Coarse gravel	32–64	1.3–2.5
Fine gravel	2–32	0.08–1.3
Sand	0.062–2.0	–
Silt	0.004–0.062	–
Clay	<0.004	–

subsurface flow Water that moves horizontally below the earth's surface. See also *subsurface flow* under *flow*.

subsurface inflow Water moving horizontally through the upper soil layers into a water body.

subsurface outflow Water moving horizontally through the upper soil layers away from a water body.

subsurface runoff Term for the portion of runoff that percolates through the soil by gravity as groundwater before emerging to the surface as seepage or springs.

subterranean stream Part of a stream reach that flows underground.

succession Changes in species composition of plants and animals in an ecosystem with time, often in a predictable order. More specifically, the gradual and natural progression of physical and biological changes, especially in trophic structure of an ecosystem, toward a climax condition or stage.

climax succession stage Culminating stage in plant succession for a given site where the vegetation has reached a highly stable condition.

early succession stage Stage in forest or other plant community that includes species that colonize early, or a stage of young growth including seedlings, saplings, and pole-sized trees.

late succession stage Plant community that has developed mature characteristics. Also referred to as the climax stage.

mid-successional stage Succession in a plant community between the early colonizers and transition to a mature community.

seral stages Series of relatively transitory plant communities that develop with ecological succession from bare ground to the climax stage.

stage class Any distinguishable phase of growth or development of a population or community.

summer heat income See *summer heat income* under *heat budget*.

summerkill Complete or partial dieoff of a fish population during summer when extended cloud cover prevents sunlight from allowing photosynthesis of plants. The death of rooted aquatic plants depletes dissolved oxygen in warm water and fish die by suffocation or from toxins produced by certain species of decaying algae.

summer pool Water level in a reservoir, usually maintained at a stable level during the summer months. Compare with *recreational pool*.

sump A pit, well, or depression where water or other liquid is collected.

superimposed stream See *superimposed stream* under *stream*.

supervised classification See *supervised classification* under *remote sensing*.

supervised training See *supervised training* under *remote sensing*.

supralittoral See *supralittoral* under *littoral*.

surf Waves or swells that break upon the shore of a water body. Generally this term applies to ocean environments.

surface Interface between water and the atmosphere.

surface area Area of a water body at the interface between water and the atmosphere.

surface creep erosion See *surface creep erosion* under *erosion*.

surface elevation Height of the surface above mean sea level.

surface erosion See *surface erosion* under *erosion*.

surface film Surface tension of water due to air–water (molecular) interactions that provides support for certain plants and animals so they can live at the air–water interface.

surface flow See *surface flow* under *flow*.

surface impoundment Natural topographic depression, artificial excavation, or dike arrangement containing water that is constructed above, below, or partially in the ground (or in navigable waters) and may or may not have a permeable bottom and sides.

surface runoff Portion of the runoff that flows over the surface without infiltrating into the groundwater.

surface seiche See *surface seiche* under *wave*.

surface water Standing water above the substrate or water that flows exclusively across a land surface and includes all perennial and ephemeral water bodies.

surface water inflow Water flowing into a water body from one or more stream channels.

surface water outflow Water flowing out of a water body in one or more stream channels.

surface wave See *surface wave* under *wave*.

surfactant Chemical agent that improves the emulsifying, dispersing, spreading, or wetting abilities of other chemicals such as herbicides and pesticides.

surge An episode of uneven flow and strong momentum such as a swell due to a sudden change in pressure or a rapid destabilizing physical event. See *swell*.

survival flow See *survival flow* under *flow*.

suspended load See *suspended load* under *sediment load*. Compare with *bed load* and *washload* under *sediment load*.

suspended sediment discharge Quantity, usually expressed as mass or volume, of suspended sediment passing a stream cross section in a given unit of time.

suspended sediments Sediments that are carried in suspension in the water column by turbulence and water velocity or by Brownian movement so that they are transported for a long time without settling to the bottom. See *suspended load*.

suspended solids Particles of unfiltered, undissolved solid matter such as wood fibers or soil that are present in water. See *total dissolved solids (TDS)*.

suspension erosion See *suspension erosion* under *erosion*.

suspensoids Colloidal particles that remain in suspension under most conditions and combine or react with liquid only to a limited extent.

sustained (cruising) speed See *sustained (cruising) speed* under *swimming speed*.

swale A moist or marshy depression or topographic low area, particularly in prairies.

swamp See *swamp* under *wetlands*.

swash Landmark rush of water from a breaking wave up the slope of a beach.

swath width See *swath width* under *remote sensing*.

sweeper log See *sweeper log* under *large organic debris*.

swell See *swell* under *wave*.

swimming speed Speed that fish or other aquatic organisms travel when swimming that varies from essentially zero to over six m/s (19.7 ft/s), depending upon species, size, and activity. Swimming speed of fish is often expressed as body length per second. Three categories of swimming performance are generally recognized:

burst (darting) speed Speed that a fish can maintain for a very short time, generally 5–10 seconds, without fatigue. Burst speeds are used by fish in feeding, escape from predators, or to pass barriers such as cascades or falls during migration, and represent the maximum swimming speed for a species.

prolonged speed Speed that a fish can maintain for a prolonged period of time (minutes but usually less than 1 hr) that ultimately results in fatigue. A fish is under some degree of stress when it swims at its prolonged speed. Prolonged speeds in fish typically involve anaerobic metabolism.

sustained (cruising) speed Speed that a fish can maintain for an extended period of time (hours) without fatigue or stress during normal movements between two sites. Cruising speeds in fish typically involve aerobic metabolism.

swimming velocity See *swimming speed*.

swirling flow See *swirling flow* under *flow*.

synergism Interaction of two or more substances (e.g., chemicals) such that the action of any one of them on living cells or tissues is increased. Compare with *antagonism*.

synthetic aperture radar (SAR) See *synthetic aperture radar (SAR)* under *remote sensing*.

synusia Any component of a community that is composed of one or more species, belonging to the same life-form, having similar environmental requirements, and occurring in similar habitats.

system Regularly interacting or interdependent group of items or things forming a unified whole. In stream applications, it includes a watershed or basin. For examples, see *basin*, *drainage*, *ecosystem*, *watershed*.

▶ t

taiga Northern, subarctic coniferous forest (composed of sparse stands of small spruces and firs) in Asia, Europe, and North America that is typically open or interspersed with bogs and forms a transition zone between denser forest to the south and tundra to the north.

tail Transition between habitat types that is usually shallow where the water velocity increases (e.g., the downstream section of a pool, glide, or other habitat type). Synonymous with tailout or flat.

tailings Mining waste from screening or processing mineral ore. Tailings may contain suspended solids, heavy metals, radioactive materials, acids, and other contaminants that can leach into a water course.

tailrace (1) Channel with highly turbulent water, usually confined by concrete or riprap, in the tailwater of a reservoir. (2) Channel that carries water from a water wheel.

tailwater Flowing water below a dam that is released from an upstream impoundment. Often releases from the hypolimnion in the reservoir provides clear, cold water in the tailwater that can support coldwater sport fisheries.

talus (1) Slope with numerous, loosely aggregated rocks. (2) The sloping accumulation of rock fragments at the base of a cliff.

tank See *tank* under *pond*.

taxon Any formal taxonomic unit or category of organisms (e.g., species, genus, family, order). The plural of taxon is taxa.

tectonic lake See *tectonic lake* under *lake*.

telluric water Surface water derived from sources other than direct precipitation on a site (e.g. seep or spring). See *seep*, *spring*.

temporarily flooded See *temporarily flooded* under *water regime*.

tenaja Pools in seasonal streams that may support a flora similar to vernal pools upon desiccation.

terminal moraine See *terminal moraine* under *moraine*.

terrace Relatively level or gently inclined land surface that is elevated above an active stream channel in a steplike arrangement of a slope or lake bed. Terraces are remnants of floodplains or perched shorelines at low water levels. See *bench*.

terrace tributary See *terrace tributary* under *tributary*.

terracing Dikes constructed along the contour of agricultural land to contain runoff and sediment, thereby reducing erosion. See *dike*.

terrain Comprehensive term describing the landscape with respect to its features. See *landscape*.

terrestrial Belonging to, or living on, the ground or earth.

terrigenous sediments Sediments produced from soil, ground, earth, or weathered rock that are derived directly from the neighboring land.

tetrapod See *tetrapod* under *habitat enhancements*.

texture Size, shape, and arrangement of particles in a substrate.

thalweg Path of a stream that follows the deepest part of the channel.

thalweg depth Vertical distance from the water surface to the deepest point of a channel cross section.

thalweg velocity See *thalweg velocity* under *velocity*.

thaw lake See *thaw lake* under *lake*.

thematic data See *thematic data* under *remote sensing*.

thematic mapper See *thematic mapper* under *remote sensing*.

theme See *theme* under *remote sensing*.

thermal Related to or caused by heating or warm temperatures.

thermal bar Narrow transition zone of nearly 4°C in the vertical isotherm between an open water mass and the stratified area of a water body.

thermal refuge Zone in a water body that maintains oxygenated water and temperatures adequate for fish survival.

thermal stratification See *thermal stratification* under *stratification*.

thermocline See *thermocline* under *stratification*.

thermokarst Depression created in permafrost by melting of ground ice with a subsequent settling of the soil.

thermokarst lake See *thermokarst lake* under *lake*.

throughfall All the precipitation that eventually reaches a forest floor including direct precipitation and drip from foliage but minus stem flow.

tidal flat Level land that is regularly inundated by ocean tides, often with muddy substrate.

tidal inlet An opening along the shoreline where water extends at high tide.

tidal marsh See *tidal marsh* under *wetlands*.

tide Alternate rising and falling of the surface of an ocean (including bays and gulfs connected to an ocean) that generally occurs twice daily from the gravitational pull of the moon and sun on the earth.

till Unmodified substrate material deposited by glaciers and ice sheets.

timber crib See *timber crib* under *habitat enhancements*.

tin whistle See *tin whistle* under *control structure*.

tire reef See *tire reef* under *habitat enhancements*.

toe The base of a slope along a bank or other geographic feature where a gentle incline changes abruptly to a steeper gradient.

toe of the bank The point at the base of a streambank where the bank becomes more level as it forms the channel bed.

toe undercutting Erosion by a stream at the toe of an underwater slope that may result in bank failure.

toe width The width of the exposed toe along a slope.

tolerance Relative capability of an organism to endure or adapt to unfavorable environmental conditions.

tolerance association Association of organisms capable of withstanding adverse environmental conditions within a habitat. This association is often characterized by a reduction in the number of species and, in the case of organic pollution, an increase in individuals representing certain species.

tolerance limit Concentration of a substance that can be endured by an organism for a specified period of time.

tolerance quotient (TQ) See *tolerance quotient (TQ)* under *biological indices*.

tolerance range Range of one or more environmental conditions (i.e., the highest and lowest values) in which an organism can function and survive.

top of the bank Point on a bank that corresponds to the high water mark for normal streamflows.

topography Configuration of a surface including its relief and the position of its natural and artificial features.

topset bed Horizontal sedimentary bed formed at the top of a delta over the existing streambed.

top width See *top width* under *dimensions*.

torrent Refers to a violent high streamflow condition that is created by heavy rainfall or rapid snowmelt and is characterized by a near bank-full discharge or greater, increased velocity, standing waves, and high sediment load in alluvial or meltwater streams. See *alluvial stream* and *meltwater stream* under *stream*.

tortuous meander See *tortuous meander* under *meander*.

tortuous meander channel See *tortuous meander channel* under *channel pattern*.

total dissolved solids (TDS) Measure of inorganic and organic materials dissolved in water that pass through a 0.45 µm filter, expressed as mg/L. Sometimes used as an indicator of potential production in habitat quality indices. Also referred to as filterable residue (FR). See *conductivity;* compare to *suspended solids*.

total sediment discharge Total quantity of sediment passing a stream crosssection during a prescribed unit of time.

total solar radiation See *total solar radiation* under *solar radiation*.

total storage Volume of water in a reservoir at any stage from full pool to dead storage.

total stream power See *total stream power* under *energy*.

total suspended solids (TSS) Organic and inorganic material left on a standard glass filter of 0.45 µm after a water sample is passed through the filter. Also referred to as filterable residue (FR).

toxicant (1) A substance that, through its chemical or physical action, kills, injures, or impairs an organism. (2) Any environmental condition that results in a harmful biological effect.

toxicity Quality, state, or degree of a harmful effect in organisms that results from alteration of natural environmental conditions.

training See *training* under *remote sensing*.

training wall See *training wall* under *habitat enhancements*.

tranquil flow See *tranquil flow* under *flow*.

transect (1) A line on the ground along which observations are made or data are collected at fixed intervals. (2) A line across a region selected to show spatial relationships of landforms, vegetation, or other features. (3) A straight line across a stream channel, perpendicular to the flow, along which habitat features such as depth or substrate are measured at pre-determined intervals.

transitional habitat Habitat serving as a boundary between two dissimilar habitat types.

transition flow See *transition flow* under *flow*.

transition region Stream reach where the flow changes from laminar to turbulent.

transition zone Narrow or broad zone where a change occurs from wetlands to nonwetlands.

translation See *translation* under *wave*.

transmissivity Rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. Transmissivity values can be expressed as square meters per day (m^2/d) or square meters per second (m^2/s).

transparency Ability of water to transmit visible light.

transpiration Process in plants where water is released as vapor (primarily through the stomata, or pores, in leaves) into the atmosphere.

transportation zone See *transportation zone* under *fluvial*.

transport capacity Ability of a stream to transport a suspended sediment load that is expressed as the total weight of sediment.

transport velocity Velocity required to move sediment of different sizes in a stream.

Transport velocities for various sizes of streambed materials

Diameter		Transport velocity	
mm	in	cm/s	ft/s
0.005–0.5	0.00002–0.002	15–20	0.49–0.66
0.25–2.5	0.01–0.10	30–65	0.98–2.13
5.0–15	0.2–0.6	80–120	2.62–3.94
25–75	1.0–3.0	140–240	4.59–7.87
100–200	4.0–7.8	270–390	8.86–12.80

transverse bar See *transverse bar* under *bar*.

transverse flow See *transverse flow* under *flow*.

transverse rib Lines of large clasts across a channel that are usually one or two diameters wide.

trash collector See *trash collector* under *habitat enhancements*.

trash rack See *trash rack* under *control structure*.

tree retards See *tree retards* under *habitat enhancements*.

trellis stream See *trellis stream* under *stream*.

trench See *trench* under *slow water, pool, scour pool* under the main heading *channel unit*.

tributary Stream that flows into or joins a larger stream. Synonymous with feeder stream or side stream. Tributary types are based on watershed geomorphology.

lower valley wall tributary Characterized by moderately steep gradients that occur at the slope break between valley wall and valley floor.

terrace tributary Stream flowing across terraces to the main stem, originating from springs or from tributaries draining valley slopes.

upper valley wall tributary Possess very steep gradients, high water velocities, and flow in a stepwise profile of alternating pools and cascades.

wall-based tributary Flow along the base of a valley wall and into the main stem channel. May flow parallel to the main stem for a short distance.

tripton Nonliving, nondetritus fragments in water.

trophic Related to the processes of energy and nutrient transfer (i.e., productivity) from one level of organisms to another in an ecosystem.

autotrophic Water body where all organic compounds are produced through photosynthesis rather than imported from external sources.

dystrophic Shallow lake with colored water, high humic and total organic matter content, low nutrient availability, high oxygen demand, and limited bottom fauna. Oxygen is continually depleted and pH is usually low. The stage between a eutrophic lake and a wetland in lake succession.

eutrophic Water body that is rich in nutrients, organic materials, and productivity. During the growing season, chlorophyll concentrations are typically 10–100 mg/m^3.

heterotrophic Water body where all organic compounds are derived from sources that are external to the water body.

hypereutrophic Water body receiving very high nutrient enrichment, usually from human activities such as agricultural runoff and sewage effluent. Specifically, phosphorus levels are greater than 100 mg/m^3, and chlorophyll levels are greater than 40 mg/m^3.

hypertrophic See *hypereutrophic*.

hypoeutrophic Water body with less than the desired nutrients and productivity.

hypotrophic See *hypoeutrophic*.

mesotrophic Water body with productivity intermediate between oligotrophic and eutrophic with chlorophyll levels typically at 4–11 mg/m^3 during the growing season.

oligotrophic Water body characterized by low dissolved nutrients and organic matter, dissolved oxygen near saturation, and chlorophyll levels typically at less than 4 mg/m^3 during the growing season.

status Position of an organism with respect to energy flow within an aquatic ecosystem.

trophogenic region Area of a water body where organic production from mineral substances takes place on the basis of light energy and photosynthetic activity.

tropholytic region Deep area of a water body where decomposition of organic matter predominates.

tropical river See *tropical river* under *river*.

trough (1) A long depression or hollow. (2) Small human-built structure of metal, wood, or concrete used to hold water (e.g., watering trough for livestock). See *trench* under *pool* under the main heading *channel unit*.

true color Color of water resulting from dissolved substances rather than from colloidal or suspended matter.

truncated meander See *truncated meander* under *meander*.

tumbling flow See *tumbling flow* under *flow*.

tundra Zone of low vegetation found above the tree line in the arctic or in mountainous areas but below zones of perpetual ice and snow (i.e., snowbanks or glaciers).

tundra brook Narrow, shallow stream with low dissolved solids, water temperature usually less than 8° C, and variable flows that are supplied from snow and ice melt.

tundra river See *tundra river* under *river*.

turbidity (1) Refers to the relative clarity of a water body. (2) Measure of the extent to which light penetration in water is reduced from suspended materials such as clay, mud, organic matter, color, or plankton. Measured by several nonequivalent standards such as nephelometric turbidity units (NTU), formazin turbidity units (FTU), and Jackson turbidity units (JTU).

turbidity current A mass of mixed water and sediment that flows downward (sometimes rapidly) along the bottom of an ocean or lake because it is denser than the surrounding water.

turbine See *turbine* under *control structure*.

turbulence Streamflows in which the velocity at a given point varies erratically in magnitude and direction and disrupts reaches with laminar flow. Turbulence causes disturbance of the water surface and produces uneven surface levels which results in poor visibility because air bubbles are entrained in the water.

turbulent flow See *turbulent flow* under *flow*.

turnover (1) Complete mixing of nutrients and oxygen in a lake that occurs when stratification breaks down due to changes in water temperature, water density, and wind action. (2) Time interval between the use and replacement of one or more nutrients in a nutrient pool. See *fall turnover*, *spring turnover*, *turnover*, and *thermal stratification* under the main heading of *stratification*.

turnover ratio See *turnover ratio* under *mixing*.

tussock Clumps or thick tufts of vegetation forming a more solid surface in a wetland.

two-story lake See *two-story lake* under *lake*.

U

ultrafine particulate matter See *ultrafine particulate matter* under *organic particles*.

ultranannoplankton See *ultranannoplankton* under *nannoplankton*.

ultraplankton See *ultraplankton* under *plankton*.

unchanneled colluvium See *unchanneled colluvium* under *colluvium* in *valley segments*.

unconfined aquifer Underground water not held in a confined area as a result of impervious materials that allow movement and interchange of water with adjoining areas.

unconfined channel See *unconfined channel* under *confinement*.

unconfined meander See *unconfined meander* under *meander*.

unconsolidated bottom Bottom in wetlands and deepwater habitats with at least 25% of the area covered by particles smaller than stones and less than 30% covered by vegetation.

unconsolidated bottom wetland See *unconsolidated bottom wetland* under *wetlands*.

unconsolidated deposits Sediments with particles that are loosely arranged and are not cemented together that include alluvial, glacial, volcanic, and landslide deposits.

unconsolidated shore wetland See *unconsolidated shore wetland* under *wetlands*.

undercut bank See *undercut bank* under *streambank*.

underflow See *underflow* under *mixing*.

underground water See *subsurface flow*.

underscour pool see *underscour pool* under *slow water*, *pool*, *scour pool* with the main heading of *channel unit*.

undertow (1) Any strong current below the surface of a water body that moves in a different direction than the surface current. (2) A seaward subsurface flow or draft of water from waves breaking on an ocean beach.

undifferentiated See *undifferentiated* under *streambank material*.

uniform flow See *uniform flow* under *flow*.

unit stream power See *unit stream power* under *energy*.

universal soil loss equation An equation that predicts the amount of soil lost in an average year:

$$A = RKLSPC\ ;$$

A = the soil loss in mass per unit area per year;
R = rainfall factor;
K = slope erodibility factor;
L = length of the slope;
S = percent slope;
P = conservation practice factor;
C = cropping and management factor.

unsaturated Conditions when water can hold additional dissolved gases or other materials or where the subsurface aquifers are able to hold additional water.

unstable areas Land areas that have a higher probability of increased erosion, landslides, and channel adjustment disturbances during climatic or physical events such as major storms or landslides.

unstable bank See *unstable bank* under *bank stability* and *streambank*.

unsteady flow See *unsteady flow* under *flow*.

unsupervised classification See *unsupervised classification* under *remote sensing*.

upland (1) Refers to the terrestrial habitat above a water body or any area that is not typically influenced by saturated soil or by standing or moving water. (2) Zone sufficiently above and away from flowing or standing water that is dependent on precipitation for its water supply.

uplift High land area produced by movements that raise or upthrust underlying rocks in the earth's crust.

upper bank See *upper bank* under *streambank*.

upper infralittoral See *upper infralittoral* under *littoral*.

upper valley wall tributary See *upper valley wall tributary* under *tributary*.

upstream Direction from which a river or stream flows.

upwelling Movement of a water mass from the bottom to the surface.

urban runoff Storm water from city streets that usually transports litter and organic wastes in addition to water from precipitation.

useable storage Volume of water in a reservoir that is normally available for domestic water, irrigation, power generation, and other purposes.

UTM (universal transverse mercator) Grid system for establishing a fixed point between 84° N and 80° S using exact measurements. The planet earth is divided into 60 grids, each 6° longitude by 8° latitude. Line 1 begins at 180° longitude. Line 2 would be at 174°, etc. Latitude lines are designated by letters C through X, but omitting I and O to reduce confusion. Each grid zone is further subdivided into a finer grid of 100,000 square meters. Starting at 180°, the 100,000 m grid blocks are labelled from A to Z, again omitting I and O. Every 18° the lettering starts over. The 100,000 m squares are also lettered from A to V, south to north, beginning at 80° S, again omitting I and O. The sequence repeats every 2,000,000 m, so that the nearest similar grid reference is 101 km or 63 miles. Grid coordinates can be derived to within 10 m.

V

vadose zone Subsurface zone in a water table where the interstices or spaces in a porous substrate are only partially filled with water.

valley Elongated, low, and flat area of a landscape, between higher terrain features such as uplands, hills and mountains where runoff and sediment transport occur through downslope convergence.

valley fill Accumulation of deposits that partially or completely fill a valley.

valley flat Area in a valley bottom (i.e., floodplain) that becomes inundated under high streamflows. See *floodplain*.

valley floor width index See *valley floor width index* under *dimensions*.

valley glacier See *valley glacier* under *glacier*.

valley line Longitudinal profile of a streambed in a water course. Compare with *thalweg*.

valley morphology System for classifying valleys based on physical features and profiles.

type I A V-shaped, confined valley, often structurally controlled and associated with faults. Elevation relief is high and slopes in the bottom are moderately steep or greater than 2%.

type II Valley with moderate relief and slopes that is relatively stable; gradients less than 4%.

type III Valley that is primarily depositional, with characteristic debris-colluvial or debris-alluvial fan landforms and slopes in the bottom that are moderately steep or greater than 2%.

type IV Valley with classic meandering pattern, entrenched or deeply incised, and confined landforms such as canyons or gorges with gentle elevation relief and valley floor gradients less than 2%.

type V Valley that is glacially scoured with U-shaped trough and valley floor slopes less than 4%.

type VI Fault-line valley that is structurally controlled and dominated by colluvial slope building processes. Valley floor gradients are often less than 4%

type VII Valley with a steep to moderately steep landform that is characterized by highly dissected fluvial slopes, typically with deeply incised stream channels, high drainage density, and a very high sediment supply.

type VIII Valley with multiple river terraces that are positioned laterally along broad valleys with a gentle elevation.

type IX Glacial outwash plains and dunes formed by deposition in areas with a high sediment supply.

type X Valley that is very wide with a gentle elevation relief and composed of mostly alluvial materials. Typically this type of valley is found in coastal plains as broad lacustrine or alluvial flats.

type XI Valley with large river deltas and tidal flats composed of alluvial materials.

valley segments Valley networks with similar geologic features that are formed through geomorphic processes.

alluvium Valley that is characterized by fluvial transport of sediment over a predominantly alluvial valley fill.

bedrock Valley with little soil or sediment and dominated by bedrock.

colluvium Valley where colluvial fills accumulate and are periodically eroded during rare hydrologic events.

channeled colluvium Valleys that contain low order streams immediately downstream from unchanneled colluvial valleys.

unchanneled colluvium Headwater valley segments lacking recognizable stream channels.

estuarine Valley with a transition zone between terrestrial and marine environments.

valley wall Portion of a valley slope that is located above a valley flat and relic terraces. In some situations where fans or deltas have been formed, the valley wall is absent.

varves Sedimentary layers of a lake bed that are deposited at regular intervals, usually one or two times per year. More particularly, the differential sediment deposited in glacial lakes by glacial streams; coarser layers are deposited in summer and finer layers are deposited in winter.

vector See *vector* under *remote sensing*.

vector data See *vector data* under *remote sensing*.

vector format See *vector format* under *remote sensing*.

vegetation Refers to plant life or total plant cover of an area.

vegetation density The extent of an area covered by vegetation that is generally expressed as a percentage of a specific area. Also, the percentage of an area at the surface, midwater, and bottom along a vertical transect or at other fixed points in a water body that is occupied by aquatic plants.

vegetation layer Subunit of a plant community where all component species exhibit the same growth form (e.g., trees, saplings, or herbs).

vegetation–soil rating Used to evaluate the impacts of consumptive and nonconsumptive animal activity on riparian vegetation and impacts to soils from erosion.

vegetative cover In aquatic systems, vegetation that provides cover for protection of fish and other aquatic organisms (e.g., algal mats, macrophytes, and overhanging riparian vegetation).

velocity Speed at which water travels downstream. More specifically, the time rate of motion calculated as the distance traveled divided by the time required to travel that distance and expressed as cm/s, m/s, or ft/s.

critical velocity (1) Maximum water velocity in which a fish can sustain its position for a specified length of time. For example, the maximum forward swimming speed that a fish can sustain over a specified distance or length of time. (2) Velocity in a channel when flow changes from laminar to turbulent.

fish velocity or focal point velocity Velocity at the location occupied by a fish that is measured at the fish's snout. Synonymous with snout velocity or facing velocity.

mean column velocity Average velocity of water measured on an imaginary vertical line at any point in a stream. A measurement at 60% of the maximum depth for depths less than 76 cm (30 in), measured from the surface, closely approximates the average velocity for the water column. In water depths greater than 76 cm (30 in), the average of measurements made at 20% and 80% of the depth approximates the mean column velocity.

mean cross section velocity Mean velocity of water flowing in a channel at a given cross section that is equal to the discharge divided by the cross section of the area.

swimming velocity See *swimming speed*.

thalweg velocity Mean velocity of a water column in a stream that is measured along the thalweg.

vernal lake See *vernal lake* under *lake*.

vernal pond See *vernal pond* under *pond*.

vertical gully side See *vertical gully side* under *gully side form*.

vertical stability Indication of the net effect of deposition or scour of a streambed in a specific reach over a long period of time that is described as degrading or aggrading.

vertical velocity profile A parabolic line that describes water velocity in a vertical plane of a stream channel at a given location. The velocity along the line varies from zero at the bottom to a maximum value near the surface.

very long duration Duration of inundation for a single flood event that is greater than one month.

viscosity Adhesive quality of a liquid including water that exhibits resistance to friction.

viscous water Water to which a thickening agent has been added to reduce surface runoff.

v-notch (1) Narrow ravine or valley with steep sides and a V-shaped cross section that usually contains a watercourse. (2) Type of weir with a V-shaped notch used for gaging discharge in small streams.

volcanic See *volcanic* under *streambank material*.

volcanic lake See *volcanic lake* under *lake*.

volume Mass or quantity of water enclosed within a specific water body that is reported as cubic meters (m^3), cubic feet (ft^3), or acre-feet (ac-ft). See also *volume* under *large organic debris*.

volume curve Graph with depth on the vertical axis and percentage volume along the horizontal axis.

volume development See *volume development* under *dimensions*.

W

wadi Channel of a water course that is dry except during periods of rainfall.

wake Track of waves from objects such as a boat moving through the water.

wall-based pond See *wall-based pond* under *pond*.

wall-based tributary See *wall-based tributary* under *tributary*.

wandering meander channel See *wandering meander channel* under *channel pattern*.

warm monomictic See *warm monomictic* under *mixing*.

warm polymictic See *warm polymictic* under *mixing*.

warmwater fishes A broad term applied to fish species that inhabit waters with relatively warm water temperatures (optimum temperatures generally between 15–27°C (60–80°F)). Compare with *coldwater fishes*, *coolwater fishes*.

warmwater lake See *warmwater lake* under *lake*.

wash (1) Dry bed of an elongated depression or channel that is formed by water in an intermittent stream. Often associated with an arid environment that is characterized by flash flooding, high bed load movement, and sparse vegetation. (2) A general pattern of erosion, movement, or exposure to moving water.

washing Removal of fines from surface substrate materials by wave action or flowing water.

washload See *washload* under *sediment load*. Compare with *suspended load* under *sediment load*.

wastewater Water carrying dissolved or suspended solids generated by human activities.

water Colorless, odorless, tasteless, slightly compressible liquid, composed of two atoms of hydrogen and one of oxygen, that is a major constituent of all living matter. Occurs as several forms including rain, sleet, snow, and ice that cycles through atmospheric, surface, and subsurface transport. Generic word used in place of lake, reservoir, river, or other water body. See *water body*.

water balance A record of outflow from, inflow to, and storage in a hydrologic unit such as an aquifer or drainage basin. See *aquifer*, *drainage basin*.

water bar Shallow ditch excavated across a road at an angle to collect and divert surface water from a roadway to prevent erosion of the road bed. Also referred to as cross ditch.

water body Any natural or artificial pond, lake, stream, river, estuary, or ocean that contains permanent, semi-permanent, or intermittent standing or flowing water.

water budget The balance of all water moving into and out of a specified area within a specified period of time.

water column Portion of water in a water body extending vertically from a given point on the surface to any depth; generally used to locate, describe, or characterize the chemical and physical constituents at a given depth or depth range.

water course Natural or artificial channel with perennial or intermittent water and definable bed and banks.

water cycle Large-scale circulation of water between the atmosphere and earth that involves the processes of precipitation, condensation, runoff, evaporation, and transportation. See *hydrologic cycle*.

waterfall See *falls* under *fast water—turbulent* under the main heading *channel unit*.

water level fluctuation Annual vertical fluctuation of the surface in a water body including reservoirs and lakes.

water logging (1) Generally refers to the saturation of soil with water which causes inadequate aeration may be detrimental to plants. (2) Process or condition where the water table reaches or rises above the ground surface or its capillary fringe is near to the surface.

water mark Visible line on upright structures along a water body of debris accumulation, sediment deposits, or stain that represents the maximum height of water.

water pressure Pressure in water created by gravity resulting from elevational differences. See *head*.

water quality Term used to describe biological, chemical, and physical characteristics of an aquatic environment, usually in relation to the uses of water.

water regime Refers to the presence and pattern of surface water at a given location.

intermittently exposed Surface water is present throughout the year except in years of extreme drought.

intermittently flooded Substrate is usually exposed but covered with surface water for variable periods of time.

permanently flooded Water covers the land surface throughout the year in all years and where vegetation includes obligate hydrophytes.

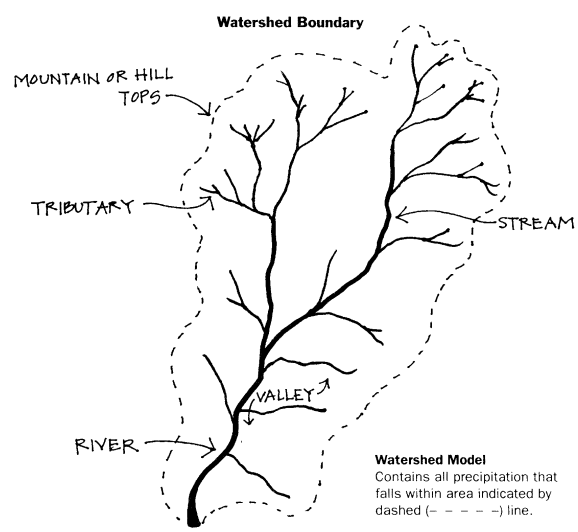
saturated Substrate is saturated to the ground surface for extended periods of time during the growing season but surface water is seldom present.

seasonally flooded Surface water is present for extended periods of time, especially early in the growing season, but is absent by the end of the season for most years. Generally occurs in areas where the water table is near the surface.

semipermanently flooded Surface waters persist throughout the growing season in most years where the water table is at or near the surface in all years.

temporarily flooded Surface water is present for brief periods during the growing season but the water table is usually well below the ground surface.

water right Authorization by prior ownership, contract, purchase, or appropriation, to use water for designated purposes.



watershed (from Firehock and Doherty 1995)

watershed (1) Region or area drained by surface and groundwater flow in rivers, streams, or other surface channels. A smaller watershed can be wholly contained within a larger watershed. (2) The divide between two catchment areas. See *drainage area*.

water spreading Diversion of streamflow, generally from a watercourse onto a gently sloping and porous ground to conserve water, maintain or increase plant growth, reduce flood peaks, and replenish or recharge groundwater.

water-stable aggregate Soil aggregate that is stable to the action of water.

water storage The retention of water in a specified location by natural or artificial means.

water table Depth below which the ground is saturated with water; generally expressed as linear depth below the soil surface to the upper layer of groundwater.

waterway River, canal, or other navigable channel that is used as a route or way of travel or transport.

water year See *climatic year*.

water yield Total outflow from all or a part of a drainage basin through surface runoff or subsurface aquifers within a given time (i.e., a year). Also referred to as annual water yield.

wave A vertical disturbance on the surface of a stream, river, lake, or sea in the form of a ridge or swell that is usually caused by wind.

antinode Where the maximum vertical movement occurs during a rocking motion in a water body.

breaker Collapse of waves in front of asymmetrical wave.

capillary waves Refers to water that is flowing in small waves. See *ripple* under *wave*.

gravity waves Short surface waves with a wavelength greater than 6.28 cm.

height Perpendicular distance between a wave crest and trough.

internal progressive wave Horizontal water movements associated with shearing flow at the metalimnion–epilimnion interface.

internal seiche Layers in a lake of differing density that oscillate relative to one another. See *seiche* under *wave*.

Kelvin wave Rotary wave in a lake that is always parallel to a shoreline.

langmuir circulation Elongate spirals of water that rotate about a horizontal axis parallel to the water surface and wind direction. See *streaks*.

length Distance between two successive wave crests.

long wave Wave with a length that is long in comparison to, and much greater than, the water depth. A long wave is nondispersive and travels at a speed that is independent of its wavelength.

nodal point Point where no vertical movement occurs during a rocking motion in water.

oscillation Fluctuating wave in deep water where each particle of water vacillates for a short distance as the wave moves forward and creates a wave motion that is very different from regular wave motion.

period The elapsed time between the arrival of two successive wave crests at any point.

period of uninodal surface oscillation (t) Defined as:

$$t = 2L/(gz)^{1/2};$$

L = the length of the basin at the surface;
z = mean depth of the basin;
g = acceleration of gravity (980.6 cm/s).

plunging breaker The forward fall of a wave becomes convex and the crest curls over but collapses with insufficient depth to complete a vortex.

Poincare wave Wave occurring only in very large lakes where a cellular system of gyres or circular currents with alternating upward and downward oscillations of wave centers results in the wave direction rotating clockwise once every wave cycle.

progressive wave See *surface wave* under *wave*.

refraction Process where a series of waves in shallow water that are moving at an angle to the shoreline change direction to become parallel with the bottom contours.

ripple Waves less than 6.28 cm long that move with a slight rise and fall or ruffling of the water surface. See *capillary waves* under *wave*.

seiche Rhythmic motions of a lake, bay, or other water body resulting in fluctuations in water level that are generally caused by wind but may be caused by geologic processes such as earthquakes or tectonic movements of plates. A seiche is formed by a long, standing wave that oscillates from the surface to some depth of a lake or landlocked sea that varies in period from a few minutes to several hours.

significant wave height Average height from trough to crest of one-third of the largest waves.

spilling breaker The forward collapse of a wave that spills downward over the front of another wave.

standing wave Permanent, nonmoving water created by deflection of swiftly flowing water by large woody material, large boulders, or the bank. Also applied to the wave associated with a hydraulic jump.

surface seiche Long standing wave that attains maximum amplitude at the surface and shoreline and results in oscillating water levels along the shore of a water body.

surface wave Vertical movement of water from wind action on the surface of a water body.

swell Long, massive, and crestless wave (or succession of waves) that is generally produced by wind and often continues after its cause. The distance between swells is much longer than the distance between waves in a general wave pattern.

translation Horizontal (i.e., forward) movement of water that is covered with surface waves and that is characteristic of shallow water.

wave velocity Speed of wave travel that is calculated by dividing the wave length by the period of time between waves.

wave breaker Structure that is designed and constructed of solid materials to intercept and dissipate the energy of waves in areas such as the entrance to a harbor. See *breakwall*.

wave cut platform Gently sloping surface produced by wave erosion that may extend some distance into a lake or sea from the base of a cliff.

wave velocity See *wave velocity* under *wave*.

weathering In situ decomposition and disintegration of bedrock from both chemical and physical processes.

wedge dam See *wedge dam* under *habitat enhancements*.

weed Troublesome or noxious plant, often exotic or introduced, that grows profusely in the wild and often is well-adapted to quickly invade and thrive in disturbed areas.

weighted usable area (WUA) (1) An index of the capacity of a stream reach to support a particular species and life stage; expressed as the actual area or the percentage of suitable habitat area that is available per unit length of a stream at a given flow. (2) Total surface area having a certain combination of hydraulic and substrate conditions multiplied by the composite suitability index of use by fish or other aquatic species for the specific combination of conditions at a given flow.

weir (1) Notch or depression in a levee, dam, embankment, or other barrier across or bordering a stream that regulates or measures the flow of water. (2) Barrier constructed across a stream to guide fish into a trap. See also *weir* under *habitat enhancements*.

well Hole dug or drilled into the earth to obtain water, or a natural spring source of water that is in a deep depression.

well head Outlet, or fountainhead, to move water to the surface of the earth.

wetland boundary Point on the land surface where a transition or shift occurs from wetlands to nonwetlands or aquatic habitat.

wetland hydrology Total of wetness characteristics in an area that is inundated by water or has saturated soils for sufficient duration to support hydrophytic vegetation. Such permanent or periodic inundation by water or prolonged soil saturation generally results in anaerobic soil conditions.

wetlands Land areas that are wet at least for part of the year, are poorly drained, and are characterized by hydrophytic vegetation, hydric soils, and wetland hydrology. See *wetland hydrology*.

adjacent Wetlands separated from other aquatic habitats by constructed dikes or barriers, natural river berms, beach dunes, or similar features.

aquamarsh Water body where the original open water area is nearly or completely obscured by emergent and floating aquatic vegetation.

aquatic bed Class of wetland and deepwater habitat dominated by plants that grow principally on or below the surface of the water for most of the growing season in most years.

artificial wetland Wetlands created, intentionally or accidentally, by the anthropogenic activities of humans.

backswamp An extensive, marshy, depressed area in floodplains between the natural levee borders of channels and valley sides or terraces.

blanket bog Large upland areas, typically in cold, wet climates, where extensive accumulations of undecomposed peat cover waterlogged, nutrient-poor ground. Also referred to as blanket mire.

bog (1) Wet, spongy land that is usually poorly drained, highly acidic, and nutrient-rich, and is characterized by an accumulation of poorly to moderately decomposed peat and surface vegetation of mosses and shrubs. (2) A peatland dominated by ericacenous shrubs, sedges, and moss with a saturated water regime, or a forested peatland dominated by evergreen trees and larch.

carr Wetland on organic soil with greater than 25% cover of shrubs, typically dominated by willow.

cienagas Wetland associated with spring and seep systems in isolated arid basins of the Southwest.

emergent wetland Class of wetland habitat characterized by erect, rooted, herbaceous hydrophytes, excluding mosses and lichens, that are present for most of the growing season.

fen Low-lying peatland that is partially covered with relatively fast moving, nutrient-rich, neutral to basic water that is rich in calcium. Fens are often dominated by sedges and rushes that form peat when they die and decay.

forested wetland Wetland habitat characterized by woody vegetation (conifer and deciduous species) that is 6 m (20 ft) tall or taller, and that occurs near springs, seeps, or areas with natural high water tables.

freshwater marsh Area with continuously water-logged soil that is dominated by emergent herbaceous plants but without a surface accumulation of peat.

fringe marsh Saturated, poorly drained area, intermittently or permanently water covered, that is close to or along the edge of a land mass.

haline marsh Saturated, poorly drained seashore area that is intermittently or permanently water covered and covered with aquatic and grass-like vegetation.

high moor Type of bog where vegetation and peat are low in nutrients, minerals, and nitrogen and that is located in sites with a cool, humid climate (as in higher latitudes) where heavy precipitation has leached most of the nutrients from the soil and caused waterlogging for much of the year, creating a blanket bog or blanket peat.

lotic (riparian) wetland Lotic wetlands are associated with flowing water found along streams, rivers, and drainages. They have a defined channel, an associated floodplain, continuously transport water, and include seeps, springs, beaver ponds, and wet meadows.

low moor Type of bog or swamp composed of peat or mulch soil, formed in eutrophic or mesotrophic waters that are relatively rich in minerals (generally the drainage from a surrounding catchment area into a basin that may have been a former lake).

mangrove swamp Swampy or tidal area dominated by tropical trees or shrubs of the genus *Rhizophora* with exposed interlacing adventitious roots above ground.

marsh Water-saturated, poorly drained wetland area that is periodically or permanently inundated to a depth of 2 m (6.6 ft) and that supports an extensive cover of emergent, nonwoody vegetation, without peat-like accumulations.

moor An open, uncultivated tract of land with a peat-like soil that supports low vegetation, typically of coarse grass and sedges, in low elevations and with sphagnum and cotton "grass" at higher and wetter elevations. At its wettest, a moor is similar to a bog.

morass Tract of low, soft, wet ground.

moss–lichen wetland Wetland dominated by mosses (mainly peat moss) and lichens with little tall vegetation.

muskeg A bog composed of deep accumulations of organic material in wet, poorly drained boreal areas (often with permafrost), that is usually dominated by *sphagnum* mosses, often contains tussocks, and has shrubby plants, and small, scattered trees.

nonpersistent wetland Wetland dominated by plants that fall on the surface or below the water surface at the end of the growing season when there is no obvious sign of emergent vegetation.

palustrine Nontidal wetland that is dominated by trees, shrubs, persistent emergents, mosses, or lichens.

peat bog Bog with a dominant underlying material of peat. See *bog* under *wetlands*.

pocosin Local term for swamp or bog in the coastal plain of the southeastern United States.

problem area wetland Wetland that is difficult to identify because it may lack indicators of wetland hydrology and hydric soils; usually dominated by plant species that are characteristic of nonwetlands.

quaking bog Dense, interwoven accumulation of organic matter and living organisms that floats on open water in the littoral zone of dystrophic lakes.

raised bog A bog containing an accumulation of organic matter, but low in plant nutrients, with excellent capillarity that raises the water level in the mat. As a result, the central portion of the bog extends above the natural groundwater level.

reference wetland Wetland within a relatively homogeneous biogeographic region that is representative of a specific hydrogeomorphic wetland type.

riverine wetland Any wetland or deepwater habitat contained within a stream channel.

saline marsh Saturated, poorly drained inland area, intermittently or permanently water covered, containing various dissolved salts, and with aquatic and grass-like vegetation. See *saline* under *salinity*.

salt marsh Low areas adjacent to saline springs or lakes covered by salt-tolerant vegetation or similar areas near a sea that are periodically flooded by seawater but not exposed to daily tides. See *tidal marsh* under *wetlands*.

scrub–shrub wetland Wetland that includes areas dominated by low, woody vegetation less than 6 m (20 ft) tall that are stunted because of existing environmental conditions.

soligenous fen Peatland formed in waters draining, at least partially, areas of high mineral content.

swamp Tree- or tall shrub-dominated wetlands that are characterized by periodic flooding and nearly permanent subsurface water flow through mixtures of mineral sediments and organic materials without peat-like accumulation.

tidal marsh Low, flat marshland often traversed by interlaced channels and tidal sloughs that are subject to oceanic tides; vegetation consists of salt-tolerant bushes and grasses. See *salt marsh* under *wetlands*.

unconsolidated bottom wetland Wetlands that have bottoms with at least 25% cover of particles smaller than stones and a vegetative cover of less than 30%.

unconsolidated shore wetland Wetlands that have unconsolidated substrates with less than 75% of the area covered by rocky material, less than 30% of the area covered by vegetation other than pioneering plants, and water regimes that include irregular flooding or saturation.

wet meadow Meadows characterized by wet soils that are normally waterlogged within a few inches of the ground surface and slow surface and subsurface flows. Channels are typically poorly defined or nonexistent and vegetation is dominated by grasses and riparian-dependent species.

wooded swamp Wetland dominated by trees (i.e., a forested wetland).

wetland soil Soil that is saturated for prolonged periods of time and that is accompanied by anaerobic conditions. Hydric soils that are sufficiently wet to support hydrophytic vegetation are also considered to be wetland soils.

wetland status Refers to wetland species that have exhibited an ability to develop to maturity and reproduce in an environment where all or portions of the soils within the root zone become, periodically or continuously, saturated with water during the growing season.

facultative wetland species Species usually occurring in wetlands but occasionally found in nonwetlands.

obligate wetland species Species that almost always occur under the natural conditions of wetlands.

wetland vegetation Vegetation that occurs in areas with hydric soils and wetland hydrology. See *wetland*, *wetland hydrology*.

wet line Length of sounding line between a water surface and the bottom of a water body.

wet meadow See *wet meadow* under *wetlands*.

wetted cross section See *wetted cross section* under *dimensions*.

wetted perimeter (1) Distance along the bottom and sides of a cross section in a body of water in contact with water that is roughly equal to the width plus two times the mean depth. (2) See also *wetted perimeter* under *dimensions*.

wetted width See *wetted width* under *dimensions*.

wet water Water to which a surfactant has been added to reduce the surface tension.

white water Occurs where flows are sufficiently fast and turbulent to entrain numerous air bubbles in the water, giving the water a whitish cast.

width See *width* under *dimensions*.

width : depth ratio See *width : depth ratio* under *dimensions*.

windfall Trees or parts of trees felled by high winds. See *blowdown* under *large organic debris*.

windrow (1) A row or line of material swept together by the wind. (2) An accumulation of road fill or surfacing material left on the road shoulders from poor grading. (3) Woody materials from timber sales or land-clearing activities that are shoved into elongated piles.

windthrow See *blowdown* under *large organic debris*.

wind turbidity Turbidity resulting from agitation of bottom sediments from wind action, usually in shallow areas where waves mobilize fine sediments.

windward shore The shore toward which the wind blows.

wing dam See *check dam* under *habitat enhancements*.

wing wall (1) Part of a dam that is constructed into the bank. (2) Extension of a bridge abutment that is constructed to retain fill material in the road bed to prevent it from entering the watercourse.

winter heat income See *winter heat income* under *heat budget*.

winterkill The death of fishes or other organisms in a water body during a prolonged period of ice and snow cover. Death is usually caused by oxygen depletion due to the lack of photosynthesis.

Wisconsin bank cover See *Wisconsin bank cover* under *habitat enhancements*.

wooded swamp See *wooded swamp* under *wetlands*.

woody debris See *woody debris* under *large organic debris*.

WUA Acronym for weighted usable area. An index of physical habitat for a specific species.

▶ x

xeric Locations lacking in water due to limited rainfall.

xerophytic Plant species that are typically adapted for life in conditions where a lack of water is a limiting factor for growth and reproduction. These species are capable of growth in extremely dry conditions as a result of morphological, physiological, and reproductive adaptations.

▶ y

yield To produce or give forth a product or the quantity of a product by a natural process or cultivation. The harvest, actual or estimated, of living organisms, expressed as numbers, weight, or as a proportion of the standing crop, for a given period of time. Also refers to the amount of water produced from a given drainage or watershed. See *drainage*, *watershed*.

young river See *young river* under *river*.

▶ Z

zone (1) Area characterized by similar flora or fauna. (2) Belt or area to which certain species are limited.

zone of aeration Soil and capillaries above the water table that are exposed to air from the atmosphere. See *capillary* and *soil*.

zone of influence Area contiguous to a ditch, channel, or other drainage feature that is directly affected by it.

zone of saturation The soil zone that is located below the permanent water table.

zooplankton See *zooplankton* under *plankton*.

References

Aird, P. L. 1994. Conservation for the sustainable development of forests worldwide: a compendium of concepts and terms. Forestry Chronicle 70:666–674.

Allan, J. D. 1995. Stream ecology: structure and function of running waters. Chapman and Hall, London.

Allee, W. C., A. E. Emerson, O. Park, T. Park, and K. P. Schmidt. 1949. Principles of animal ecology. Saunders, Philadelphia. (Reprinted 1967.)

Alonso, C. V., and S. T. Combs. 1990. Stream bank erosion due to bed degradation—a model concept. Transactions of the American Society for Applied Engineering 33:1239–1248.

Amoros, C. 1991. Changes in side-arm connectivity and implications for river system management. Rivers 2:105–112.

Angermeier, P. L., and J. R. Karr. 1986. Applying an index of biotic integrity based on stream-fish communities: considerations in sampling and interpretation. North American Journal of Fisheries Management 6:418–429.

Armantrout, N. B., editor. 1982. Acquisition and utilization of aquatic habitat inventory information. American Fisheries Society, Western Division, Bethesda, Maryland.

Armantrout, N. B. 1983. A flexible integrated aquatic habitat inventory and monitoring system. Pages 428–431 *in* J. F. Beel and T. Atterbury, editors. Renewable resource inventories for monitoring changes and trends: an international conference. Oregon State University, College of Forestry, Corvallis.

Armour, C. L., K. P. Burnham, and W. S. Platts. 1983. Field methods and statistical analyses for monitoring small salmonid streams. U.S. Fish and Wildlife Service, Office of Biological Services, FWS/OBS/83/33, Washington, D.C.

Arnette, J. L. 1976. Nomenclature for instream assessments. Pages 9–15 *in* C. B. Stalnaker and J. L. Arnette, editors. Methodologies for the determination of stream resource flow requirements: an assessment. U.S. Fish and Wildlife Service, Office of Biological Services, Washington, D.C.

Bair, E. S. 1995. Hydrogeology. Pages 285–310 *in* A. D. Ward and J. Elliot, editors. Environmental hydrology. Lewis Publishers, Boca Raton, Florida.

Balon, E. K. 1982. About the courtship rituals in fishes, but also about a false sense of security given by classification schemes, 'comprehensive' reviews and committee decisions. Environmental Biology of Fishes 7:193–197.

Bancroft, B., and K. Kelsey. 1994. "In-stream" management techniques to enhance fish habitat. Pages 61–69 *in* N. B. Federicton, editor. Proceedings of a symposium on riparian management. Canadian Forest Service, Maritime Region, Nova Scotia.

Barraclough, C. L. No date. Glossary of terms used in aquatic inventory. Prepared by Aqua-Tex Scientific Consulting, Ltd., for British Columbia Department of the Environment, Resource Inventory Committee, Victoria.

Bates, R. L., and J. A. Jackson. 1980. Glossary of geology, 2nd edition. American Geological Institute, Washington, D.C.

Bayha, K. 1981. Glossary of terms pertinent to instream flow work. (Mimeographed draft manuscript.) Cooperative Instream Flow Service Group, Western Energy and Land Use Team, U.S. Fish and Wildlife Service, Fort Collins, Colorado.

Bayley, P. B. 1991. The flood pulse advantage and restoration of river- floodplain systems. Regulated Rivers Research & Management 6:75–86.

Bell, M. C. 1986. Fisheries handbook of engineering requirements and biological criteria. U.S. Army Corps of Engineers, North Pacific Division, Fish Passage Development and Evaluation Program, Portland, Oregon.

Bell, M. C. 1990. Fisheries handbook of engineering requirements and biological criteria. U.S. Army Corps of Engineers, North Pacific Division, Fish Passage Development and Evaluation Program, Portland, Oregon.

Benda, L., T. J. Beechie, R. C. Wissmar, and A. Johnson. 1992. Morphology and evolution of salmonid habitats in a recently deglaciated river basin, Washington State, USA. Canadian Journal of Fisheries and Aquatic Sciences 49:1246–1256.

Beschta, R. L. 1978. Inventorying small streams and channels on wildland watersheds. Pages 104–113 *in* Proceedings of a national workshop on integrated inventories of renewable natural resources. U.S. Forest Service General Technical Report RM-55.

Beschta, R. L., and W. L. Jackson. 1979. The intrusion of fine sediments into a stable gravel bed. Journal of the Fisheries Research Board of Canada 36:204–210.

Beschta, R. L., S. J. O'Leary, R. E. Edwards, and K. D. Knoop. 1981. Sediment and organic matter transport in Oregon Coast Range streams. Water Resources Institute Publication WRRI-70, Corvallis, Oregon.

Beschta, R. L., and W. S. Platts. 1986. Morphological features of small streams: significance and function. Water Resources Bulletin 22:369–379.

Binns, N. A., and F. M. Eiserman. 1979. Quantification of fluvial trout habitat in Wyoming. Transactions of the American Fisheries Society 108:215–228.

Bisson, P. A., and D. Montgomery. 1996. Valley segments, stream reaches, and channel units. Pages 23–52 *in* R. F. Hauer and G. A. Lamberti, editors. Methods in stream ecology. Academic Press, New York.

Bisson, P. A., J. L. Nielsen, R. A. Palmason, and L. E. Grove. 1982. A system of naming habitat types in small streams, with examples of habitat utilization by salmonids during low streamflow. Pages 62–73 *in* N. B. Armantrout, editor. Acquisition and utilization of aquatic habitat inventory information. American Fisheries Society, Western Division, Bethesda, Maryland.

Boehne, P. L., and R. A. House. 1983. Stream ordering: a tool for land managers to classify western Oregon streams. U.S. Department of the Interior, Bureau of Land Management, Technical Note T/N:OR-3, Portland, Oregon.

Bovee, K. D. 1978. The incremental method of assessing habitat potential for coolwater species, with management implications. Pages 340–346 *in* R. L. Kendall, editor. Selected coolwater fishes of North America. American Fisheries Society, Special Publication 11, Bethesda, Maryland.

Bovee, K. D., and T. Cochnauer. 1977. Development and evaluation of weighted criteria, probability-of-use curves for instream flow assessments: fisheries. U.S. Fish and Wildlife Service, Federal Interagency Energy/Environment Research and Development Program, Office of Research and Development, U.S. Environmental Protection Agency, FWS/OBS-77-63, Fort Collins, Colorado.

Brussock, P. P., A. V. Brown, and J. C. Dixon. 1985. Channel form and stream ecosystem modes. Water Resources Bulletin 21:859–866.

Bryant, M. D., P. E. Porter, and S. J. Paustian. 1990. Evaluation of a stream channel-type system for southeast Alaska. U.S. Forest Service General Technical Report PNW-267.

Bryant, M. D., B. E. Wright, and B. J. Davies. 1992. Application of a hierarchical habitat unit classification system: stream habitat and salmonid distribution in Ward Creek, southeast Alaska. U.S. Forest Service Research Note PNW-508.

Chamberlin, T. W. 1980. Aquatic system inventory (biophysical stream surveys). British Columbia Ministry of Environment, Assessment and Planning Division, Technical Paper 1, Victoria.

Chamberlin, T. W. 1980. Aquatic survey terminology. British Columbia Ministry of Environment, Assessment and Planning Division, Technical Paper 2, Victoria.

Cherry, J., and R. L. Beschta. 1989. Coarse woody debris and channel morphology: a flume study. Water Resources Bulletin 25:1031–1036.

Cheslak, E. F., and A. S. Jacobson. 1990. Integrating the instream flow incremental methodology with a population response model. Rivers 1:264–288.

Chutter, F. M. 1972. An empirical biotic index of the quality of water in South African streams and rivers. Water Research 6:19–30.

Cole, G. A. 1983. Textbook of limnology, 3rd edition. C. V. Mosby, St. Louis, Missouri.

Collotzi, A. W. 1977. A systematic approach to the stratification of the valley bottom and the relationship to land use planning. Internal paper. U.S. Forest Service, Bridge-Teton National Forest, Jackson Hole, Wyoming.

Collotzi, A. W. 1986. GAWS: general aquatic wildlife system. Proceedings of the annual meeting of the Colorado-Wyoming Chapter, American Fisheries Society 21:113–114. (Fort Collins, Colorado.)

Collotzi, A. W., and D. K. Dunham. 1978. Inventory and display of aquatic habitats. Pages 533–542 *in* A. Marmelstein, editor. Classification, inventory, and analysis of fish and wildlife habitat. U.S. Fish and Wildlife Service, Office of Biological Services, FWS/OBS-78/76, Washington, D.C.

Committee on Restoration of Aquatic Ecosystems. 1992. Restoration of aquatic ecosystems. Committee on Restoration of Aquatic Ecosystems, National Research Council. National Academy Press, Washington, D.C.

Cooperrider, A. Y., R. J. Boyd, and H. R. Stuart. 1986. Inventory and monitoring of wildlife habitat. U.S. Department of the Interior, Bureau of Land Management, Denver.

Cowardin, L. M., V. Carter, F. Golet, and E. J. Laroe. 1979. Classification of wetlands and deepwater habitats of the United States. U.S. Fish and Wildlife Service, Office of Biological Services, FWS/OBS-79-31.

Cronquist, A. 1961. Introductory Botany. Harper and Row, New York. 892 pp.

Crouch, R. J. 1987. The relationship of gully sidewall shape to sediment production. Australian Journal of Soil Research 25:531–539.

Cuplin, P., C. Armour, R. Corning, D. Duff, and A. Oakley. 1974. Fisheries and aquatic habitat inventory and analysis techniques. U.S. Department of the Interior, Bureau of Land Management, Technical Note, Denver, Colorado.

Deason, W. O. 1975. Environmental glossary. U.S. Department of the Interior, Bureau of Reclamation, Washington, D.C.

DeLeeuw, A. D. 1982. Guide to aquatic survey terminology and data entry procedures and codes. Canadian Ministry of Environment, Aquatic Studies Branch, Vancouver.

Densmore, A. L., R. S. Anderson, B. G. McAdoo, and M. A. Ellis. 1997. Hillslope evolution by bedrock landslides. Science 275:369–372.

Dodge, D. P., G. A. Goodchild, I. MacRitchie, J. C. Tilt, and D. G. Waldriff. 1984. Manual of instructions: aquatic habitat inventory surveys. Canadian Ministry of Natural Resources, Fisheries Branch, Official Procedural Manual Policy Fl.2.03.01., Ottawa.

Dolloff, C. A., D. G. Hankin, and G. H. Reeves. 1993. Basin wide estimation of habitat and fish populations in streams. U.S. Forest Service, Southeast Forest Experiment Station General Technical Report SE-83, Asheville, North Carolina.

Duff, D. D. 1982. General aquatic wildlife system (GAWS). *In* R. Wiley, D. Bartschi, A. Binns, D. Duff, J. Erickson, and B. Platts, editors. Proceedings of the Rocky Mountain stream habitat management workshop. American Fisheries Society, Western Division, Jackson Hole, Wyoming.

Dunham, D. K., and A. Collotzi. 1975. The transect method of stream habitat inventory—Guidelines and applications. U.S. Forest Service, Ogden, Utah.

Dunster, J., and K. Dunster. 1996. Dictionary of natural resource management. University of British Columbia Press, Vancouver.

Government Institutes, Inc. 1991. Natural resources glossary. Government Institutes, Inc., Rockville, Maryland.

Elliot, W. J., and A. D. Ward. 1995. Soil erosion and control practices. Pages 117–204 *in* A. D. Ward and J. Elliot, editors. Environmental hydrology. Lewis Publishers, Boca Raton, Florida.

Enviro Control, Inc. 1980. Reach file phase II report: a standardized method for classifying status and type of fisheries. Draft Report to U.S. Fish and Wildlife Service, Western Energy and Land Use Team, Fort Collins, Colorado.

ERDAS (Earth Resources Data Analysis System). 1993. ERDAS field guide, 3rd edition. ERDAS, Inc., Atlanta.

Estes, C. C., and D. S. Vincent-Lang. 1984. Aquatic habitat and instream flow investigations. Draft Report 3. Alaska Power Authority, Anchorage, Alaska.

Fajen, O. F., and R. E. Wehnes. 1982. Missouri's method of evaluating stream habitat. Pages 117–123 *in* N. B. Armantrout, editor. Acquisition and utilization of aquatic habitat inventory information. American Fisheries Society, Western Division, Bethesda, Maryland.

Fausch, K. D., C. L. Hawkes, and M. G. Parsons. 1988. Models that predict standing crop of stream fish habitat variables: 1950–85. U.S. Forest Service General Technical Report PNW-GTR-213.

Fausch, K. D., J. Lyons, J. R. Karr, and P. L. Angermeier. 1990. Fish communities as indicators of environmental degradation. Pages 123–144 *in* S. M. Adams, editor. Biological indicators of stress in fish. American Fisheries Society, Symposium 8, Bethesda, Maryland.

Federal Interagency Committee for Wetland Delineation. 1989. Federal manual for identifying and delineating jurisdictional wetlands. U.S. Army Corps of Engineers, U.S. Environmental Protection Agency, U.S. Fish and Wildlife Service, and U.S. Department of Agriculture, Soil Conservation Service, Washington, D.C.

Ferguson, R. I., K. L. Prestegaard, and P. J. Ashworth. 1989. Influence of sand on hydraulics and gravel transport in a braided gravel bed river. Water Resources Research 25:635–643.

Ferren, W. R., Jr., P. L. Fiedler, R. A. Leidy, K. D. Lafferty, and L. A. K. Mertes. 1996. Wetlands of California: part II: classification and description of wetlands of the central and southern coastal watersheds. Madrono 43:125–182.

Firehock, K., and J. Doherty. 1995. A citizen's streambank restoration handbook. Save Our Streams, Izaak Walton League of America, Inc., Gaithersburg, Maryland.

Ford-Robertson, F. C., editor. 1971. Terminology of forest science technology practice and products. The Multinational Forestry Terminology Series 1 (English language version). Society of American Foresters, Bethesda, Maryland.

Forest Ecosystem Management Assessment Team. 1993. Forest ecosystem management: an ecological, economic, and social assessment. U.S. Forest Service, Portland, Oregon.

Foth, H. D. 1984. Fundamentals of soil science. Wiley, New York.

Fredriksen, R. L., and R. D. Harr. 1979. Soil, vegetation, and watershed management of the Douglas-fir region. Pages 231–260 *in* P. E. Heilman, H. Anderson, and D. M. Baumgartner, editors. Forest soils of the Douglas-fir region. Washington State University, Cooperative Extension Service, Pullman.

Frick, G. W. 1980. Environmental glossary. Government Institutes, Inc., Washington, D.C.

Frissell, C. A., and W. J. Liss. 1986. Classification of stream habitat and watershed systems in south coastal Oregon. Progress Report. Oak Creek Laboratory of Biology, Department of Fisheries and Wildlife, Oregon State University, Corvallis.

Gas, I. G., P. J. Smith, and R. C. L. Wilson, editors. 1972. Understanding the Earth, 2nd edition. The Massachusetts Institute of Technology Press, Cambridge.

Gomez, B., and M. Church. 1989. An assessment of bed load sediment transport formulae for gravel bed rivers. Water Resources Research 25:1161–1186.

Gordon, N. D., T. A. McMahon, and B. L. Finlayson. 1992. Stream hydrology. Wiley, New York.

Gosse, J. C., and W. T. Helm. 1982. A method for measuring microhabitat components for lotic fishes and its application with regard to brown trout. Pages 138–149 *in* N. B. Armantrout, editor. Acquisition and utilization of aquatic habitat inventory information. American Fisheries Society, Western Division, Bethesda, Maryland.

Grant, G. E., and F. J. Swanson. 1995. Morphology and processes of valley floors in mountain streams in western Cascades Oregon. Pages 83–101 *in* J. E. Costa, A. J. Miller, K. W. Potter, and P. R. Wilcock, editors. Natural and anthropogenic influences in fluvial geomorphology. American Geophysical Union, Geophysical Monograph 89, Washington, D.C.

Grant, G. E., F. J. Swanson, and M. G. Wolman. 1990. Pattern and origin of stepped-bed morphology in high-gradient streams, Western Cascades, Oregon. Geological Society of America Bulletin 102:340–352.

Gray, D. H., and A. T. Leiser. 1982. Biotechnical slope protection and erosion control. Van Nostrand Reinhold, New York.

Greentree, W. J., and R. C. Aldrich. 1976. Evaluating stream trout habitat on large-scale aerial color photographs. U.S. Forest Service Research Paper PSW-123/1976.

Ham, D. 1996. Aerial photography and videography standards: application for stream inventory and assessment. Resource Inventory Committee, Fisheries Branch, Ministry of Environment, Lands and Parks, Victoria.

Hamilton, K., and E. P. Bergersen. 1984. Methods to estimate aquatic habitat variables. Prepared by the Colorado Cooperative Fishery Research Unit, Fort Collins, for the U.S. Department of the Interior, Bureau of Reclamation, Denver, Colorado.

Hankin, D. G., and G. H. Reeves. 1988. Estimating total fish abundance and total habitat area in small streams based on visual estimation methods. Canadian Journal of Fisheries and Aquatic Sciences 45:834–844.

Hansen, E. C., G. R. Alexander, and W. H. Dunn. 1983. Sand sediment in a Michigan trout stream. Part I. A technique for removing sand bedload from a stream. North American Journal of Fisheries Management 3:355–364.

Hansen, P. L., and five coauthors. 1995. Classification and management of Montana's riparian and wetland sites. Montana Forest and Conservation Experiment Station, Miscellaneous Publication 54.

Hasfurther, V. R. 1985. The use of meander parameters in restoring hydrologic balance to reclaimed stream beds. Pages 21–40 *in* J. A. Gore, editor. The restoration of rivers and streams: theories and experience. Butterworth, Stoneham, Massachusetts.

Hawkins, C. P., and 10 coauthors. 1993. A hierarchical approach to classifying stream habitat features. Fisheries 18(6):3–12.

Heede, B. H. 1976. Gully development and control: the status of our knowledge. U.S. Forest Service Research Paper RM-169.

Heede, B. H. 1980. Stream dynamics: an overview for land managers. U.S. Forest Service, General Technical Report RM-72.

Helm, W. T., J. C. Gosse, and J. Bich. 1982. Life history, microhabitat and habitat evaluation systems. Pages 150–153 *in* N. B. Armantrout, editor. Acquisition and utilization of aquatic habitat inventory information. American Fisheries Society, Western Division, Bethesda, Maryland.

Helm, W. T. 1985. Aquatic habitat inventory: glossary and standard methods. American Fisheries Society, Western Division, Bethesda, Maryland.

Herrington, R. B., and D. K. Dunham. 1967. A technique for sampling general fish habitat characteristics of streams. U.S. Forest Service Research Paper INT-41.

Hilsenhoff, W. L. 1977. Use of arthropods to evaluate water quality of streams. Wisconsin Department of Natural Resources Technical Bulletin 100, Madison.

Hilton, S., and T. E. Lisle. 1993. Measuring the fraction of pool volume filled with fine sediment. U.S. Forest Service Research Note PSW-RN-414.

Hogle, J. S., T. A. Wesche, and W. A. Hubert. 1993. A test of the precision of the habitat quality index model II. North American Journal of Fisheries Management 13:640–643.

Hubert, W. A., and S. J. Kozel. 1993. Quantitative relations of physical habitat features to channel slope and discharge in unaltered mountain streams. Journal of Freshwater Ecology 8:177–183.

Hunt, C. E., and V. Huser. 1988. Down by the river: the impacts of federal water projects and policies on biological diversity. Island Press, Covelo, California.

Hynes, H. B. N. 1970. The ecology of running waters. University of Toronto Press, Toronto.

Hynes, H. B. N. 1983. Groundwater and stream ecology. Hydrobiologia 100:93–99.

Independent Scientific Group. 1996. Return to the river: restoration of salmonid fishes in the Columbia River ecosystem. Development of an alternative conceptual foundation and review and synthesis of science underlying the Columbia River Basin Fish and Wildlife Program of the Northwest Power Planning Council, Portland, Oregon. Prepublication Draft. NWPPC 96-6.

Johnson, S. W., and J. Heifetz. 1985. Methods for assessing effects of timber harvest on small streams. NOAA (National Oceanic and Atmospheric Administration) Technical Memorandum NMFS (National Marine Fisheries Service) F/NWC-73.

Joweth, I. 1993. A method for objectively identifying pool, run, and riffle habitats for physical measurements. New Zealand Journal of Marine and Freshwater Research 27:241–248.

Judson, S., K. S. Deffeyes, and R. B. Hargraves. 1976. Physical geology. Prentice-Hall, Englewood Cliffs, New Jersey.

Junk, W. J., P. B. Bayley, and R. E. Sparks. 1989. The flood pulse concept in river floodplain systems. Canadian Special Publication of Fisheries and Aquatic Sciences 106:110–127.

Kappesser, G. B. 1993. Riffle stability index. Draft Report. U.S. Forest Service, Idaho Panhandle National Forest, Coeur d'Alene, Idaho.

Karr, J. R. 1981. Assessment of biotic integrity using fish communities. Fisheries 6(6):21–27.

Karr, J. R., P. R. Yant, and K. D. Fausch. 1987. Spatial and temporal variability of the index of biotic integrity in three midwestern streams. Transactions of the American Fisheries Society 116:1–11.

Kauffman, J. B., R. L. Beschta, N. Otting, and D. Lytjen. 1997. An ecological perspective of riparian and stream restoration in the western United States. Fisheries 22(5):12–24.

Kaufmann, P., and E. G. Robison. 1993. A quantitative habitat assessment protocol for field evaluation of physical habitat in small wadable streams. Draft version. Department of Forest Engineering and Department of Fisheries and Wildlife, Oregon State University, and U.S. Environmental Protection Agency, Environmental Research Laboratory, Corvallis.

Kellerhalls, R., M. Church, and D. I. Bray. 1976. Classification and analysis of river processes. Journal of the Hydraulics Division, American Society of Civil Engineers, 102:813–829.

Kent, C., and J. Wong. 1982. An index of littoral zone complexity and its measurement. Canadian Journal of Fisheries and Aquatic Sciences 39:847–853.

Kershner, J. L., W. M. Snider, D. M. Turner, and P. B. Moyle. 1992. Distribution and sequencing of mesohabitats: are there differences at the reach scale? Rivers 3:179–190.

Kinsolving, A. D., and M. B. Bain. 1990. A new approach for measuring cover in fish habitat studies. Journal of Freshwater Ecology 5:373–378.

Kohler, C. C., and W. A. Hubert, editors. 1993. Inland fisheries management in North America. American Fisheries Society, Bethesda, Maryland.

Kondolf, G. M., G. F. Cada, and M. J. Sale. 1987. Assessing flushing-flow requirements for brown trout spawning gravels in steep streams. Water Resources Bulletin 23:927–935.

Kondolf, G. M., and E. R. Micheli. 1995. Evaluating stream restoration projects. Environmental Management 19:1–15.

Lanka, R. P., W. A. Hubert, and T. A. Wesche. 1987. Relations of geomorphology to stream habitat and trout standing stock in small Rocky Mountain streams. Transactions of the American Fisheries Society 116:21–28.

Leonard, P. M., and D. J. Orth. 1986. Application and testing of an index of biotic integrity in small, coolwater streams. Transactions of the American Fisheries Society 115:401–414.

Leopold, L. B., and T. Maddock, Jr. 1953. The hydraulic geometry of stream channels and some physiographic implications. U.S. Geological Survey, Professional Paper 252, Washington, D.C.

Leopold, L. B., M. G. Wolman, and J. P. Miller. 1964. Fluvial processes in geomorphology. Freeman, San Francisco.

Lienkaemper, G. W., and F. J. Swanson. 1987. Dynamics of large woody debris in streams in old-growth Douglas-fir forests. Canadian Journal of Forest Research 17:150–156.

Lisle, T. 1987. Using "residual depth" to monitor pool depths independently of discharge. U.S. Forest Service, Pacific Southwest Forest and Range Experiment Station, Research Paper PSW-394, Berkeley, California.

Lisle, T. 1987. Overview: channel morphology and sediment transport in steepland streams. Proceedings of the symposium on erosion and sediment transport in the Pacific Rim. International Association of Hydrologic Sciences 165:287–297.

Lisle, T. E. 1995. Particle size variation between bed load and bed material in natural gravel bed channels. Water Resources Research 31:1107–1118.

Lisle, T. E., and S. Hilton. 1992. The volume of fine sediment in pools: an index of sediment supply in gravel-bed streams. Water Resources Bulletin 28:371–383.

Lotspeich, F. B., and F. H. Everest. 1981. A new method for reporting and interpreting textural composition of spawning gravel. U.S. Forest Service Research Note PNW-369.

Lyons, J. 1992. Using the index of biotic integrity (IBI) to measure environmental quality in warmwater streams of Wisconsin. U.S. Forest Service General Technical Report NC-149.

Maciolek, J. A. 1978. Insular aquatic ecosystems: Hawaii. Pages 103–120 *in* A. Marmelstein, editor. Classification, inventory, and analysis of fish and wildlife habitat. U.S. Fish and Wildlife Service, Office of Biological Services, FWS/OBS-78/76, Washington, D.C.

Marmelstein, A. 1978. Classification, inventory, and analysis of fish and wildlife habitat. U.S. Fish and Wildlife Service, Office of Biological Services, FWS/OBS-78/76, Washington, D.C.

Matthews, J. E. 1969. Glossary of aquatic ecological terms. U.S. Department of the Interior, Federal Water Pollution Control Administration, Ada, Oklahoma.

McCain, M., L. Decker, and K. Overton. 1990. Stream habitat classification and inventory procedures for northern California. U.S. Forest Service, Pacific Southwest, Region 5, FHR #1, San Francisco.

Meehan, W. R., editor. 1991. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Special Publication 19, Bethesda, Maryland.

Mish, F. C., editor 1985. Webster's ninth new collegiate dictionary. Merriam-Webster, Inc., Springfield, Massachusetts.

Montgomery, D. R., and J. M. Buffington. 1993. Channel classification, prediction of channel response, and assessment of channel condition. Washington Department of Natural Resources, Report TFW(Timber-Fish-Wildlife)-SH10-93-002, Olympia.

Morisawa, M. 1968. Streams: their dynamics and morphology. McGraw-Hill, New York.

Murphy, M. L., and five coauthors. 1987. The relationship between stream classification, fish and habitat in southeast Alaska. U.S. Forest Service, Alaska Region, Wildlife and Habitat Management Note 12, Juneau.

Myers, T. J., and S. Swanson. 1991. Aquatic habitat condition, stream type, and livestock bank damage in northern Nevada. Water Resources Bulletin 27:667–677.

Nawa, R. K., and C. A. Frissell. 1993. Measuring scour and fill of gravel streambeds with scour chains and sliding-bead monitors. North American Journal of Fisheries Management 13:634–639.

Nelson, R. W., G. C. Horack, and J. E. Olson. 1978. Western reservoir and stream habitat improvement handbook. U.S. Fish and Wildlife Service, Office of Biological Services, Western Land Use and Energy Team, Fort Collins, Colorado.

Oberdorff, T., and R. M. Hughes. No date. Modification of an index of biotic integrity based on fish assemblages to characterize rivers of the Seine Basin, France. NSI (Northrop Services, Inc.) Technology Services Corporation, Corvallis, Oregon.

Odum, E. P., and H. T. Odum. 1959. Fundamentals of ecology. Saunders, Philadelphia.

Olson, J. E., E. A. Whippo, and G. C. Hovak. 1981. Reach file phase II report: a standardized method for classifying status and type of fisheries. U.S. Fish and Wildlife Service, Office of Biological Services, FWS/OBS-81/31, Washington, D.C.

Orth, D. J. 1983. Aquatic habitat measurements. Pages 61–84 *in* L. A. Nielsen and D. L. Johnson, editors. Fisheries techniques. American Fisheries Society, Bethesda, Maryland.

Osborn, J. F. 1982. Estimating spawning habitat using watershed and channel characteristics (a physical systems approach). Pages 154–160 *in* N. B. Armantrout, editor. Acquisition and utilization of aquatic habitat inventory information. American Fisheries Society, Western Division, Bethesda, Maryland.

Osborne, L. L., and six coauthors. 1992. Influence of stream location in a drainage network on the index of biotic integrity. Transactions of the American Fisheries Society 121:635–643.

Overton, C. K., J. D. McIntyre, R. Armstrong, S. L. Whitwell, and K. A. Duncan. 1995. User's guide to fish habitat: descriptions that represent natural conditions in the Salmon River Basin, Idaho. U.S. Forest Service General Technical Report INT-GTR-322.

Parsons, S., and S. Hudson. 1985. Channel cross section surveys and data analysis. U.S. Department of the Interior, Bureau of Land Management, Report TR-4341-1, Denver, Colorado.

Paustian, S. J., D. Perkison, D. A. Marich, and P. Hunsicker. 1983. An aquatic value rating procedure for fisheries and water resource management in southeast Alaska. Pages 17-1 to 17-29 *in* Managing Water Resources for Alaska's Development. Water Resources Association, Alaska Section, Fairbanks.

Payne, N. F., and F. Copes, technical editors. 1986. Wildlife and fisheries habitat improvement handbook. U.S. Forest Service, Wildlife and Fisheries Administrative Report (unnumbered), Washington, D.C.

Pennak, R. W. 1978. The dilemma of stream classification. Pages 59–66 *in* A. Marmelstein, editor. Classification, inventory, and analysis of fish and wildlife habitat. U.S. Fish and Wildlife Service, Office of Biological Services, FWS/OBS-78/76, Washington, D.C.

Pfankuch, D. J. 1975. Stream reach inventory and channel stability evaluation. U.S. Forest Service, Northern Region, Missoula, Montana.

Platts, W. S. 1974. Methodology for classifying aquatic environments in mountainous lands for entry into land use planning. Presented at the William F. Sigler Symposium, Utah State University, Logan.

Platts, W. S., W. F. Megahan, and G. W. Minshall. 1983. Methods for evaluating stream, riparian, and biotic conditions. U.S. Forest Service, Intermountain Forest and Range Experiment Station, Ogden, Utah.

Press, F., and R. Siever. 1978. Earth. Freeman, San Francisco.

Rabe, F. W., C. Eizinga, and R. Breckenridge. 1994. Classification of meandering glide and spring stream natural areas in Idaho. Natural Areas Journal 14:188–202.

Rahel, F. J., and W. A. Hubert. 1991. Fish assemblages and habitat gradients in Rocky Mountain—Great Plains streams: biotic zonation and additive patterns of community change. Transactions of the American Fisheries Society 120: 319–332.

Rassam, G. N., J. Gravesteijn, and R. Potenza. 1988. Multilingual thesaurus of geosciences. Pergamon Press, New York.

Rechard, P. A., and R. McQuisten. 1968. Glossary of selected hydrologic terms. Wyoming Water Resources Research Institute, Water Resources Series 1 (Revised), University of Wyoming, Laramie.

Renard, K. G., J. M. Laflen, G. R. Foster, and D. K. McCool. 1994. The revised universal soil loss equation. Pages 105–124 *in* R. Lal, editor. Soil erosion research methods. Soil and Water Conservation Society, St. Lucie Press, Ankeny, Iowa.

Rinne, J. N. 1985. Physical habitat evaluation of small stream fishes: point vs transect, observation vs capture methodologies. Journal of Freshwater Ecology 3:121–131.

Robison, E. G., and R. L. Beschta. 1990. Coarse woody debris and channel morphology interactions for undisturbed streams in southeast Alaska, USA. Earth Surface Processes and Landforms 15:149–156.

Roseboom, D. 1994. Case studies on biotechnical stream bank protection. Proceedings of the annual meeting of the Forestry Committee, Great Plains Agriculture Council, Manhattan, Kansas. Great Plains Agriculture Council Publication 149:57–65.

Rosgen, D. L. 1994. A classification of natural rivers. Catena 22:169–199.

Rosgen, D. 1996. Applied river morphology. Wildland Hydrology, Pagosa Springs, Colorado.

Rosgen, D., and B. L. Fittante. 1986. Fish habitat structures—a selection guide using stream classification. Pages 163–179 *in* J. G. Miller, J. A. Arway, and R. F. Carline, editors. Proceedings, 5th trout stream habitat improvement workshop. Pennsylvania Fish Commission, Harrisburg.

Ruttner, F. 1953. Fundamentals of limnology. University of Toronto Press, Toronto.

Schumm, S. A. 1993. River response to baselevel change: implications for sequence stratigraphy. Journal of Geology 101:279–294.

Sedell, J. R., J. E. Richey, and F. J. Swanson. 1989. The river continuum concept: a basis for the expected ecosystem behavior of very large rivers. Canadian Special Publication of Fisheries and Aquatic Sciences 106:49–55.

Shera, W. P., and D. J. Grant. 1980. A hierarchical watershed coding system for British Columbia. Canadian Ministry of Environment, Research Analysis Branch of Technology, Paper 3, Vancouver.

Sherrets, H. D. 1989. Wildlife watering and escape ramps on livestock water developments: suggestions and recommendations. U.S. Department of the Interior, Bureau of Land Management, Technical Bulletin 89-4, Boise, Idaho.

Shirazi, M. A., and W. K. Seim. 1979. A stream system evaluation—an emphasis on spawning habitat for salmonids. U.S. Environmental Protection Agency Report EPA-800/3-79-109, Corvallis, Oregon.

Shirazi, M. A., W. K. Seim, and D. H. Lewis. 1981. Characterization of spawning gravel and stream system evaluation. Pages 227–278 in Proceedings, conference on salmon spawning gravel: a renewable resource in the Pacific Northwest? Washington State University, Water Research Center Report 39, Pullman.

Simonson, T. D., J. Lyons, and P. D. Kanehl. 1994. Quantifying fish habitat in streams: transect spacing, sample size, and a proposed framework. North American Journal of Fisheries Management 14:607–615.

Stauffer, J. C., and R. M. Goldstern. 1997. Comparison of three qualitative habitat indices and their applicability to prairie streams. North American Journal of Fisheries Management 17:348–361.

Stone, E., III. 1996. B.L.M. balloon photography. U.S. Department of the Interior, Bureau of Land Management, Technical Paper, Oregon State Office, Portland.

Storer, T. I., and R. L. Usinger. 1957. General zoology. McGraw-Hill, New York.

Strahler, A. N. 1957. Quantitative analysis of watershed geomorphology. Transactions of the American Geophysical Union 38:913–920.

Stream Enhancement Research Committee. 1980. Stream enhancement guide. Canadian Ministry of Environment, Department of Fisheries and Oceans, Vancouver.

Stream Systems Technology Center. 1993. Would the real bankful stand up! Stream Notes (April 1993), Stream Systems Technology Center, Fort Collins, Colorado.

Sullivan, K., T. E. Lisle, C. A. Dolloff, G. E. Grant, and L. M. Reid. 1987. Stream channels: the link between forests and fishes. Pages 39–97 *in* E. O. Salo and T. W. Cundy, editors. Streamside management: forestry and fishery interaction. University of Washington, Institute of Forest Resources, Contribution 57, Seattle.

Swanson, F. J., and six coauthors. 1987. Mass failures and other processes of sediment production in Pacific Northwest forest landscapes. Pages 9–38 *in* E. O. Salo and T. W. Cunday, editors. Streamside management: forestry and fishery interaction. University of Washington, Institute of Forest Resources, Contribution 57, Seattle.

Terrene Institute. 1994. Riparian road guide: managing roads to enhance riparian areas. Terrene Institute, Washington, D.C.

Thorp, J. H., and A. P. Covich. 1991. Ecology and classification of North American freshwater invertebrates. Academic Press, San Diego, California.

U.S. Army Corps of Engineers. 1987. Corps of Engineers wetland delineation manual. U.S. Army Corps of Engineers, Environmental Laboratory Wetlands Research Program, Technical Report Y-87-1, Vicksburg, Mississippi.

U.S. Fish and Wildlife Service. 1980. Ecological services manual—habitat evaluation procedures (HEP). U.S. Fish and Wildlife Service, Division of Ecological Services, Ecological Services Manual ESM102, Washington, D.C.

U.S. Fish and Wildlife Service. 1981. Ecological services manual—standards for the development of habitat suitability index models. U.S. Fish and Wildlife Service, Division of Ecological Services, Ecological Services Manual ESM103, Washington, D.C.

U.S. Forest Service. 1985. Fisheries habitat evaluation handbook (monitoring). U.S. Forest Service, Region 6, FSH 2609.23, Portland, Oregon.

U.S. Forest Service. 1990. Fish habitat assessment handbook. Draft report. U.S. Forest Service, Region 5, San Francisco.

U.S. Geological Survey. 1977 with updates. National handbook of recommended methods for water-data acquisition. U.S. Geological Survey, Reston, Virginia.

Valett, H. M., S. G. Fisher, and E. H. Stanley. 1990. Physical and chemical characteristics of the hyporheic zone of a Sonoran desert stream. Journal of the North American Benthological Society 9:201–215.

Van Pelt, J., M. J. Woldenberg, and R. W. H. Verwer. 1989. Two generalized topological models of stream network growth. Journal of Geology 97:281–299.

Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell, and C. E. Cushing. 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences 37:130–137.

Wakeley, J. S., and L. J. O'Neil. 1988. Techniques to increase efficiency and reduce effort in applications of the habitat evaluation procedures (HEP). U.S. Army Corps of Engineers, Environmental Impact Research Program, Technical Report EL-86-33, Washington, D.C.

Ward, J. V., and J. A. Stanford. 1995. Ecological connectivity in alluvial river ecosystems and its disruption by flow regulation. Regulated Rivers 11:105–119.

Washington Forest Practice Board. 1992. Standard methodology for conducting watershed analysis. Washington Forest Practice Board Manual Version 1,10. Washington Forest Practice Board, Washington State Department of Natural Resources, Olympia.

Webster, J. R., S. W. Golladay, E. F. Banfield, D. J. D'Angelo, and G. T. Peters. 1990. Effects of forest disturbance on particulate organic matter budgets of small streams. Journal of the North American Benthological Society 9: 120–140.

Welcomme, R. L. 1985. River fisheries. FAO (Food and Agriculture Organization of the United Nations) Fisheries Technical Paper 262.

Welcomme, R. L. 1989. Floodplain fisheries management. Pages 209–233 *in* J. A. Gore and G. E. Petts, editors. Alternatives in regulated river management. CRC Press, Boca Raton, Florida.

Wesche, T. A. 1973. Parametric determination of minimum stream flow for trout. University of Wyoming, Water Resources Research Institute, Water Resources Series 37, Laramie.

Wesche, T. A. 1985. Stream channel modifications and reclamation structures to enhance fish habitat. Pages 103–163 *in* J. A. Gore, editor. The restoration of rivers and streams: theories and experience. Butterworth, Stoneham, Massachusetts.

Wesche, T. A. 1993. Watershed management and land-use practices. Pages 181–203 *in* C. C. Kohler and W. A. Hubert, editors. Inland fisheries management in North America. American Fisheries Society, Bethesda, Maryland.

Wetzel, R. G. 1975. Limnology. Saunders, Philadelphia.

White, R. J., and O. M. Brynildson. 1967. Guidelines for management of trout stream habitat in Wisconsin. Wisconsin Department of Natural Resources Technical Bulletin 39.

Williams, O. R., R. B. Thomas, and R. L. Daddow. 1988. Methods for collection and analysis of fluvial sediment data. U.S. Forest Service Report WSTG-TP-00012, Washington, D.C.

Winget, R. N., and F. A. Mangum. 1979. Biotic condition index: integrated biological, physical and chemical stream parameters for management. U.S. Forest Service, Intermountain Region, Ogden, Utah.

Winters, R. K., editor. 1977. Terminology of forest science technology practice and products. Addendum One. Society of American Foresters, Bethesda, Maryland.

Wood-Smith, R. D., and J. M. Buffington. 1996. Multivariate geomorphic analysis of forest streams: implications for assessment of land use impacts on channel condition. Earth Surface Processes and Landforms 21:377–393.

Yeou-Koung T., and W. E. Hathhorn. 1989. Determination of the critical locations in a stochastic stream environment. Ecological Modelling 45:43–61.

Young, M. K., W. A. Hubert, and T. A. Wesche. 1991. Selection of measures of substrate composition to estimate survival to emergence of salmonids and to detect changes in stream substrate. North American Journal of Fisheries Management 11:339–346.

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