American Fisheries Society
Warmwater Streams Symposium, 1981, pp. 320–326

Use and Misuse of the Terms Watershed and Stream Order

ROBERT M. HUGHES[1] AND JAMES M. OMERNIK

Streams Branch, Freshwater Division, U.S. Environmental Protection Agency,
Corvallis, Oregon 97330

ABSTRACT

There are several problems with applications of the terms "watershed" and "stream order." Those problems are discussed within the context of a national watershed/stream classification we believe necessary for the rational management and scientific study of streams. Although topographic watersheds can be accurately defined in most of the United States, in about 40 percent of the country it is not possible for climatic and geomorphic reasons. Hence, watersheds are not always suitable or ideal units for research and management.

Because of the need for some quantitative measure of stream size for purposes of comparison, stream order (Horton 1945, Strahler 1957) is commonly used. However, that term now is being used in a much broader context than originally intended. In addition, small streams are frequently not mapped or are mapped incorrectly. We suggest using mean annual discharge per unit area, mean annual discharge, watershed area, and mean annual discharge range instead of stream order. Those terms provide a more meaningful characterization of key physical properties and biological capacities of streams.

INTRODUCTION

There is considerable misunderstanding surrounding the use of the term "watershed" as a defined unit for research, planning, and management, and there probably is even more confusion in using "stream order" to relate stream characteristics. We hope to put these problems in perspective and suggest ways to alleviate them. Our reasons for doing this stem from our interest and participation in the development of a national watershed/stream classification. We feel the confusion needs to be reduced, or perhaps eliminated, to facilitate communication of ideas about streams and the relationship of streams to spatial characteristics that affect them and ultimately to develop a watershed/stream classification. Because those misunderstandings are apparently not widely recognized, clarification is important, but difficult.

Our objectives in this paper are to discuss: (1) the usefulness and regional limitations of watersheds as planning, management, and research units and (2) the use and misuse of the term "stream order," for which we suggest alternative terms.

[1] On leave from Biology Department, Western Michigan University, Kalamazoo, Michigan 49008.

The term watershed is commonly used by administrators, planners, managers, and scientists from various disciplines to communicate an understanding of the relationships between surface water quality and the characteristics and conditions of drainage areas. The use of the term stems from a general acceptance that the physical and chemical state of a point in a stream reflects the characteristics of the topographic area upgradient from it; i.e., its watershed. For example, stream chemistry is a function of soil type, geology, and climate; and the flow, bed, and banks of a stream are functions of watershed size, precipitation, vegetational cover, slope, and geology. Biological characteristics are a function of all those factors.

If streams reflect their watersheds and if many watersheds have similar characteristics, then it should be possible to group watershed/stream systems in a number of categories. In general, each category should be based on similarities in soils, climate, and geology. It is important to recognize the relationships between watershed/stream classification and other efforts to classify spatial characteristics.

Presently, a major effort is underway to develop resource classifications to enable federal, state, regional, and local planners and managers to assess resources for a myriad of purposes (Ellis et al. 1977). However, the different agencies or groups that are developing the classifications generally have different interests relative to their different missions and, therefore, have different perspectives as to which spatial characteristics should be the focus of their systems. This is a serious obstacle for broad scientific understanding and multiple resource management.

Probably the most comprehensive work in the area of land and resource classification in the past few years has been the national ecoregion classification of Bailey (1976, 1978). However, that system lacks emphasis on watershed/stream relationships.

A national watershed/stream classification within Bailey's ecoregion classification would provide a basis for: (1) regionalizing water quality criteria, (2) determining the number of demonstration projects needed to test a particular control practice as well as providing some guidance as to where they should be geographically located, (3) extrapolating site specific water quality studies, (4) predicting stream response to various land use changes and controls of nonpoint source pollutants, and (5) deciding if the biophysical conditions in a given stream approximate what could be expected for a particular geographic area.

Two critical problems hinder the development of a national watershed/stream classification. First, not all areas are equally suited for a watershed/stream classification. Second, a better means of communicating stream size, importance, and character should be used in place of the present term stream order.

DISCUSSION

The Suitability of Watersheds as Measurement, Planning, and Research Units

Watersheds are extremely useful planning and study units in many parts of the United States. They are easy to define from topographic maps, and many of their major inputs and outputs are quantifiable. However, it is important to recognize some macrocharacteristics relevant to an understanding of watershed classification. For instance, only about 60 percent of the conterminous United States can be categorized as humid with effluent streams (effluent streams are defined as those where groundwater moves toward, and seeps into, stream channels) and topographic watersheds. In general, within areas in this category, any point on any stream reflects the characteristics of its topographic watershed. However, the relationships between areal phenomena and streams vary with watershed size and geographic region. Herein lies the reason for watershed/stream classification, to provide an understanding of the regional differences and similarities of those relationships.

In the remaining approximately 40 percent of the conterminous United States, it is difficult or impossible to delineate topographic watersheds (Fig. 1). That condition is primarily a result of the following geomorphic or climatic characteristics: (1) karstlands (typically, limestone and dolomite terrain with sinkholes, subsurface streams, and caverns); (2) areas with porous land surfaces, particularly lava flows or sand; (3) areas with extensive alluvial fan development; (4) areas with flat or nearly flat terrain, such as salt flats, swamps, and marshes; (5) arid areas where the water of ephemeral influent streams is lost by seepage to the water table; or (6) glaciated regions with numerous poorly defined areas of subsurface drainage where surface and subsurface watersheds differ.

Where any of those characteristics exist, topographically definable watersheds are generally less useful as management units because of the nebulous relationships between streams and the spatial characteristics that impact them.

Stream Characterization

There is a need to communicate quantitative comparisons of stream characteristics in order to study and manage watershed/stream systems, both within and among regions and regardless of the applicability of watersheds as research and management units. Presently, such a quantification is often attempted using stream order. Although stream order is a useful and easy means of communicating the relative sizes of streams within a drainage basin, we believe stream order is not applicable for many of the purposes for which it is being used.

Quantification of the linear geomorphic characteristics of streams began at the turn of the century with a European system that de-

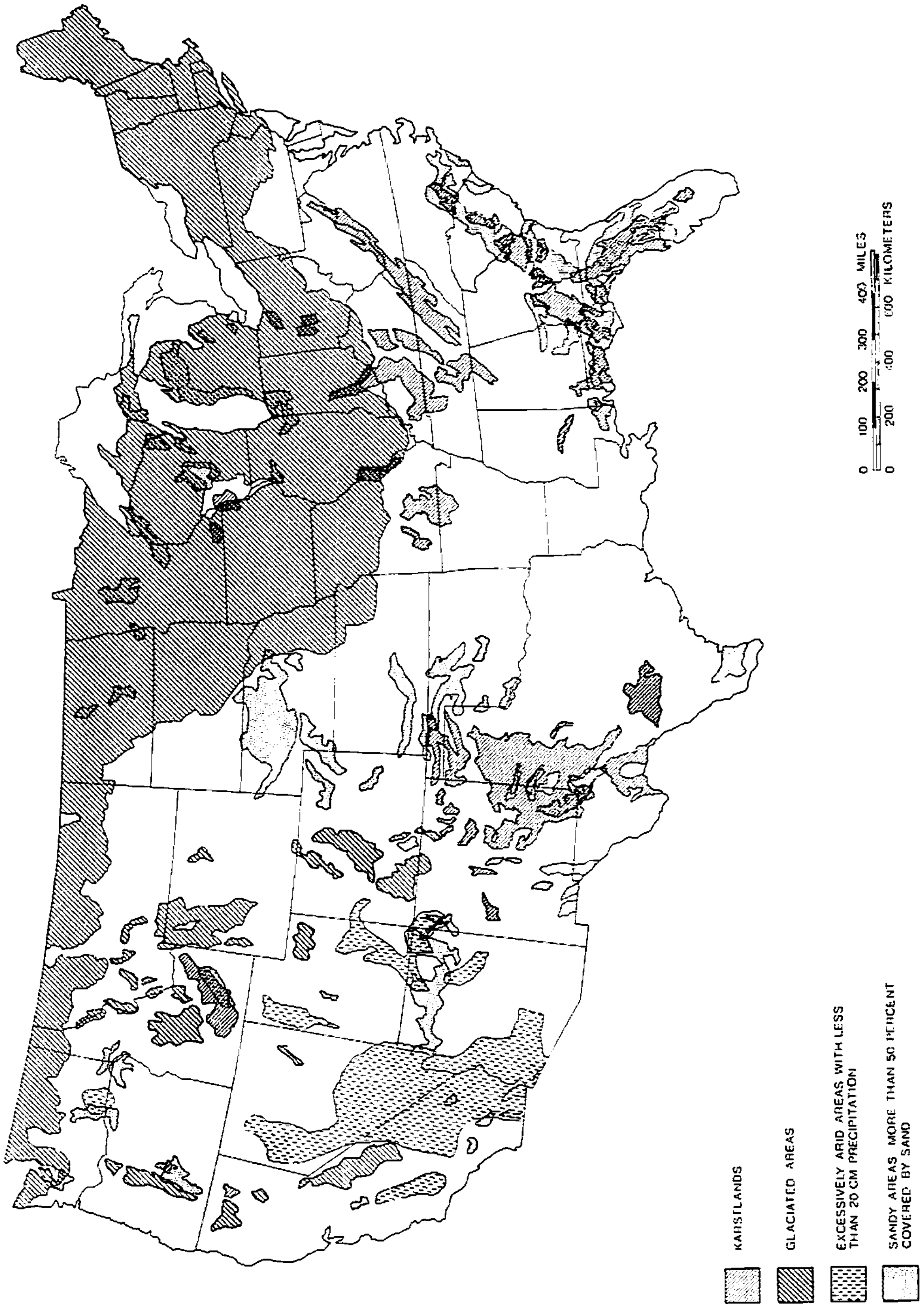

FIG. 1. Characteristics that hinder or preclude watershed delineation (after U.S. Geological Survey 1970).

fined the main stem as first order all the way to its origin then ordered tributaries so that unbranched tributaries had the highest order. Horton (1932, 1945) reversed the sequence so that unbranched tributaries were given the lowest order. Strahler (1952) modified the European–Horton system so that the main stem was ordered in the same way as the other sections. Strahler's system is now widely used. It designates unbranched tributaries as first order, streams receiving 2 or more first order streams as second order, streams receiving 2 or more second order streams as third order, and so on. Thus, streams receiving 2 or 20 third order tributaries could be fourth order.

However, stream order is often used for much more than for quantifying *linear* geomorphic characteristics. For lack of a better system, Kuehne (1962), Lotrich (1973), and Platts (1979) used stream order to classify fish communities in single watersheds, Warren (1979) suggested using it to help classify stream communities in his rationale for a watershed/stream classification, and Vannote et al. (1980) used it to represent size and width of stream reaches. We believe such usage is outside the purpose for which the term was conceived (Strahler 1975) and hence may cause misunderstanding. Although there are correlations between stream order and some areal and even relief (third dimension) geomorphic characteristics (Strahler 1975, Morisawa 1968), stream order is *not* universally applicable for comparing stream sizes, watershed areas, or watershed relief, much less the biotic characteristics of streams.

Stream order has little meaning in many parts of the United States where topographic watersheds are difficult or impossible to define. In karst regions and on porous land surfaces, large streams may arise from springs and disappear. In glaciated regions, large streams may originate from lakes, springs, or wetlands. In both regions, stream order is not even a useful scaling mechanism because such streams may have discharges many times greater than those of higher order streams in the same drainage basin.

Much of the misuse of the term can be traced to the seemingly simple process of determining stream order, especially for first order streams. Strahler (1952, 1957) originally proposed that ephemeral streams should be first order because they carry flood waters, when most discharge and stream and valley development occur. Leopold et al. (1964) suggested that first order streams should be the smallest ones delimited on a 1:24,000 map. Hynes (1970) has suggested that first order streams should be perennial streams or only those that develop biota. However, neither Strahler (1975) nor Morisawa (1968) mentioned the map scales to be used or whether the streams to be ordered should be perennial, intermittent, or ephemeral.

Stream order is comprehended differently because of the varying methods and map scales used for determining first order streams. For example, Oak Creek at Corvallis, Oregon, could be unordered or rated from first to fourth order depending on the map scale used. If all ephemeral stream channels, as determined on the ground, were considered, the stream would be rated at least fifth order.

Even with map scale held constant at 1:24,000, problems would still exist. Maps are not all compiled under the same specifications and, more importantly, the mapped streams are the result of subjective interpretations by stereophotogrammetric compilers and field annotation personnel. For example, when studying nearly 1,000 watersheds throughout the United States for land use/water quality relationships, Omernik (1977) noticed significant differences in stream order indicated by 1:24,000 scale maps within areas of similar land use, physiography, and climate. The differences were often evident along neatlines (lines between adjoining maps), indicating obvious differences in map compilation.

Furthermore, most of the world, and even large parts of the United States, are not represented by 1:24,000 scale topographic maps. If stream information is to be exchanged between nations, consideration should be given to map data bases from other countries. When one views the differences in consistency and uniformity in scale and subjective interpretations involved in stream annotation and definition from an international perspective, the potentials for misuse are even more evident. Even if all the problems with definition and delineation were resolved, stream order would still be an inadequate means of explaining or comparing the physical and bio-

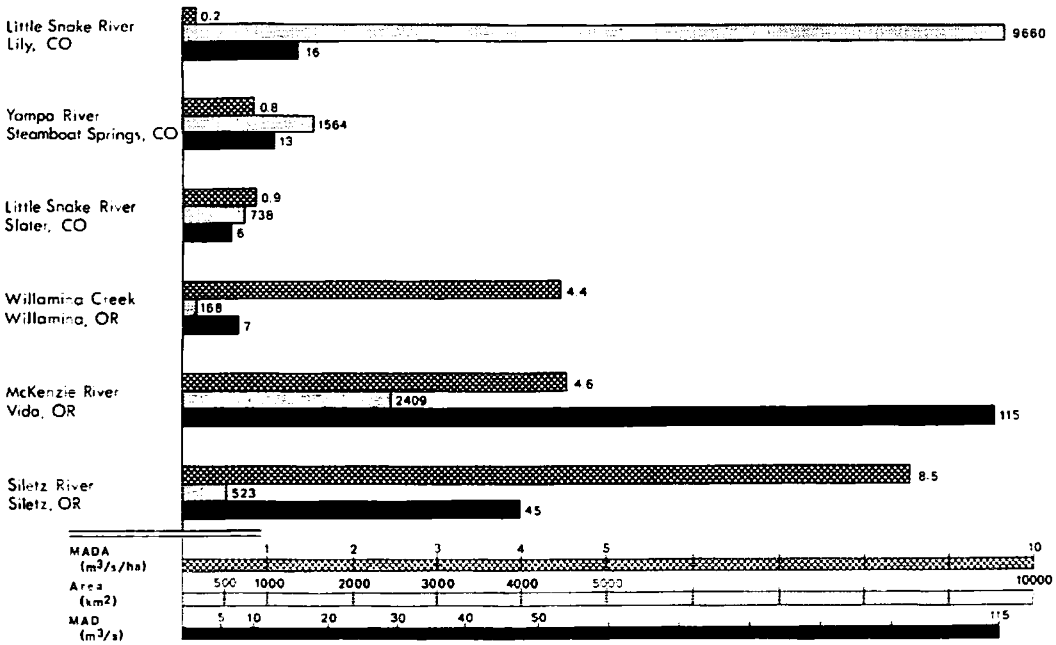

FIG. 2. Mean annual discharge per unit area (MADA), watershed area, and mean annual discharge (MAD) of 6 fifth order streams.

logical characteristics of streams, as we will attempt to show in the following section.

Alternatives to the Use of Stream Order

We recognize the need for quantification of stream characteristics in order to study and manage streams. Therefore, we suggest alternatives to stream order that have the potential for broader and more useful applications, are much more easily delineated, and characterize the sizes of watershed/stream systems. We suggest using the following watershed characteristics, in descending order of importance: mean annual discharge per unit area, mean annual discharge, watershed area if definable (if not, the characteristics that render it so), and mean annual discharge range. The discharge characteristics can be estimated from patterns of those characteristics in surrounding gaged watersheds. Such discharge characteristics are of primary importance to hydrologists, civil engineers, farmers, and ranchers, as well as to migratory fishes. Mean annual discharge per unit area is a means of relating discharge to basin area, thereby providing a means of comparing streams in different or similar climatic and geologic regions.

Table 1 and Fig. 2 show examples of the areal and discharge characteristics of 6 "fifth order" streams. The streams were chosen because they have been gaged by the USGS for many years and we had the map coverage. With stream order held constant, note that: (1) the mean annual discharge per unit area of the Siletz River is 42 times greater than that of the Little Snake River at Lily, yet the watershed area of the Siletz is only about 5 percent that of the Little Snake; (2) the watershed area of the Little Snake River at Lily is 57 times greater than that of Willamina Creek, yet the mean annual discharge per unit area of the Little Snake is only about 4 percent that of the Willamina; and (3) compared with the Little Snake at Slater, the Little Snake at Lily has a mean annual discharge per unit area that is only one-fifth as much but a watershed area and a mean annual discharge that are 13 and 2.5 times greater, respectively. The range in mean annual discharge shows similar variability between different streams and different sites on the same stream. Thus, even as-

TABLE 1.—RANGE OF DIFFERENCES IN AREA AND DISCHARGE OF 6 FIFTH-ORDER STREAMS

Stream name, location, USGS gage	Order[1]	Mean annual discharge per unit area ($m^3/s/ha$)	Watershed area (km^2)	Mean annual discharge/mean annual discharge range[2] (m^3/s)
Little Snake River Lily, Colorado 09260000[3]	5	0.2	9,660	16/3–4,661
Yampa River Steamboat Springs, Colorado 09239500[3]	5	0.8	1,564	13/2–90
Little Snake River Slater, Colorado 09253000[3]	5	0.9	738	6/0.5–53
Willamina Creek Willamina, Oregon 14193000[4]	5	4.4	168	7/0.3–102
McKenzie River Vida, Oregon 14162500[4]	5	4.6	2,409	115/55–513
Siletz River Siletz, Oregon 14305500[4]	5	8.5	523	45/2–502

[1] Order was determined from solid blue lines on 1:24,000 scale USGS topographic maps, except for the McKenzie River for which only 1:62,000 scale maps were available.
[2] Mean annual discharge ranges were calculated from 17 years of data (1961–1978).
[3] U.S. Geological Survey. 1978. Water Resources Data for Colorado. Water Data Report CO-78-3.
[4] U.S. Geological Survey. 1978. Water Resources Data for Oregon. Water Data Report OR-78-1.

suming that stream order can be obtained in a consistent manner, important characteristics of watershed/stream systems show extreme variability. Cursory examination of several smaller streams across the country suggested the same variability.

There are 4 advantages of using discharge characteristics rather than stream order: (1) They relate information about the quantity of water flowing past a point on a stream and the size of the catchment. Although order is used commonly to convey an understanding of this information, it does not. (2) They provide uniformity in methods of derivation. Much of the misunderstanding surrounding the use of stream order results from the various (sometimes qualitative) methods of derivation and different availability and interpretation of source materials. (3) They reduce or eliminate the problems of characterizing ephemeral, intermittent, braided, and delta streams. Streams originating in lakes, springs, or wetlands can be meaningfully characterized because discharge and drainage area can be quantified; or when the watershed is undefinable, physical reasons can be given for why it is so. (4) They measure the physical entities of area and flow rather than place a number on a subjective evaluation of tributaries. This provides a means of comparing basic hydrological characteristics such as climate and substrate among watersheds throughout the nation. Therefore, a better understanding of watershed/stream phenomena and a much more predictive watershed/stream science are possible. For example, rather than say that a particular organism or community is typical of second order streams, biologists might say it is characteristic of streams with a mean annual discharge per unit area of 0.040–0.090 $m^3/sec/km^2$ and a mean annual discharge range of 2.2–502 m^3/sec.

There are 3 disadvantages of using discharge characteristics rather than stream order: (1) It may appear more cumbersome to use several values rather than one. (2) Estimates of discharge characteristics from gaged streams and determination of watershed areas may be more time consuming than determining stream order from maps. Such estimates may also include considerable error, especially when they involve very small watersheds, slowly flowing or intermittent streams, or poorly defined watersheds such as those described in the watershed delineation section. (3) As with all averages, mean annual discharge per unit area, mean annual discharge, and mean annual discharge range will only approximate the values actually seen from year to year.

The mean annual discharge and mean annual discharge range of streams allow estimates of mass transport, organic processing capability, and habitat quality and can order stream sections in the biophysical river continuum discussed by Vannote et al. (1980). Transport of organic and inorganic material is a function of discharge, especially peak discharge when the banks are submerged and velocities are high enough to move large particles. Minimum discharges have been used by Orsborn (1976) to classify watersheds by their water holding capacities. Organic processing rates are functions of water temperature and the evenness of discharge. High winter discharges, such as those in western Oregon streams, flush coarse particulate organic materials downstream to accumulate in pools and estuaries where decomposition is generally slower. That reduces the energy and nutrient base for organisms in the feeder streams. A lack of freshets produces silted substrates and poor spawning and rearing habitat for many aquatic organisms. Third and seventh orders are occasionally used by stream ecologists to characterize changes in light, temperature, and the food base as one moves downstream from headwaters to midreaches to lower reaches in a river system. But mean annual discharge is a much more quantifiable causal measure that can be related to changes in production–respiration ratios, functional groups, width, and depth.

REFERENCES

BAILEY, R. G. 1976. Ecoregions of the United States (map). U.S. Dept. Agric., For. Serv. Intermtn. Region, Ogden, Utah.

———. 1978. Description of the ecoregions of the United States. U.S. Dept. Agric., For. Serv. Intermtn. Region, Ogden, Utah.

ELLIS, S. L., C. FALLAT, N. REECE, AND C. RIORDAN. 1977. Guide to land cover and use classification systems employed by western governmental agencies. FWS/OBS-77/05. Fort Collins, Colo.

HORTON, R. E. 1932. Drainage basin characteristics. Trans. Amer. Geophys. Union 13:350–361.

———. 1945. Erosional development of streams and their drainage basins: hydrological approach to quantitative morphology. Bull. Geol. Soc. Amer. 56:275–370.

HYNES, H. B. N. 1970. The ecology of running waters. Univ. of Toronto Press, Toronto, Ont.

KUEHNE, R. A. 1962. A classification of streams illustrated by fish distribution in an eastern Kentucky creek. Ecology 43(4):608–614.

LEOPOLD, L. B., M. G. WOLMAN, AND J. A. MILLER. 1964. Fluvial processes in geomorphology. W. H. Freeman Co. San Francisco, Cal.

LOTRICH, V. A. 1973. Growth, production and community composition of fishes inhabiting a first-, second-, and third-order stream of eastern Kentucky. Ecol. Monogr. 43:377–397.

MORISAWA, M. 1968. Streams, their dynamics and morphology. McGraw-Hill Book Co., New York, N.Y.

OMERNIK, J. M. 1977. Nonpoint source-stream nutrient level relationships: a nationwide study. EPA-600/3-77-105. Corvallis Environmental Research Laboratory. U.S. Environ. Prot. Agency. Corvallis, Ore.

ORSBORN, J. F. 1976. Drainage basin characteristics applied to hydraulic design and water-resources management. Pp. 141–171. *In* Proceedings of the geomorphology and engineering symposium. State University of New York at Binghamton. 24–25 September 1976.

PLATTS, W. S. 1979. Relationships among stream order, fish populations, and aquatic geomorphology in an Idaho river drainage. Fisheries 4(2):5–9.

STRAHLER, A. N. 1952. Hypsometric (area-altitude) analysis of erosional topography. Bull. Geol. Soc. Amer. 63(4):1117–1142.

———. 1957. Quantitative analysis of watershed geomorphology. Trans. Amer. Geophys. Union 38:913–920.

———. 1975. Physical geography. John Wiley & Sons. New York, N.Y.

U.S. GEOLOGICAL SURVEY. 1970. The national atlas of the United States of America. Washington, D.C.

VANNOTE, R. L., G. W. MINSHALL, K. W. CUMMINS, J. R. SEDELL, AND C. E. CUSHING. 1980. The river continuum concept. Can. J. Fish. Aquat. Sci. 37:130–137.

WARREN, C. E. 1979. Toward classification and rationale for watershed management and stream protection. EPA-600/3-79-059. Environmental Research Laboratory. U.S. Environ. Prot. Agency. Corvallis, Ore.