Ecological regions versus hydrologic units: Frameworks for managing water quality

By James M. Omernik and Glenn E. Griffith

IN the mid-1970s, a flurry of research and assessment activity began on nonpoint-source pollution. Much of this activity was driven by legislative requirements, particularly Section 208 of the Clean Water Act, which required states to identify nonpoint sources of pollution and develop feasible methods to control these sources. Unfortunately, response to the law was piecemeal. Individual states used a variety of different methods to research and assess water quality problems, and most lacked a logical and useful spatial (geographical) framework to put the results into a meaningful perspective. State water quality assessments often used drainage basins or hydrologic units, and federal assessments used similar units or even political boundaries. Similarly, best-management-practice recommendations were commonly made for political units, drainage basins, or hydrologic units.

It soon became obvious that extrapolating results of nonpoint-source pollution research was difficult, and efforts to illustrate the extent of the problems for states and the nation were fuzzy, if not grossly distorted. As one review pointed out in 1985, the net effect of 10 years of nonpoint-source pollutant characterization and hundreds of "208" plans was hard to document (*35*). Chesters and Schierow (*2*) observed that, in spite of this decade of information acquisition, "...detailed information about small watersheds is not readily transferable to larger regions, including state and national levels."

Spatial frameworks have a profound influence on the effectiveness of the research, assessment, and management of many aquatic resource problems, particularly nonpoint-source pollution. The federal Clean Water Act of 1972 (Public Law 92-500), created a massive assessment and reporting burden for state and federal agencies concerned with the health of aquatic resources. Progress toward the restoration and maintenance of the physical, chemical, and biological integrity of the nation's water is, however, difficult to assess. Moreover, the specific conditions implied by that integrity, or at least the conditions that are attainable, may vary greatly from one region to another.

The United States is slowly moving beyond reliance on a technology-based, point-source-dominant, uniform-national-standards approach for water quality to an approach that recognizes the significance of land and water interactions, nonpoint-source pollution, and regional variations in attainable water quality. Water quality assessments need a regional framework that will help to achieve the following:

- ► Compare regional land and water patterns.
- ► Establish reasonable chemical and biological standards.
- ► Predict the effects of management practices and controls.
- ► Locate monitoring and special study sites.
- ► Extrapolate site-specific information to larger areas.

By using inappropriate spatial frameworks, some assessments may actually do more to obscure the nature and extent of a water quality problem than to clarify it.

Spatial frameworks based on ecological regions often can be more useful for assessing the health of aquatic systems than frameworks based only on hydrologic units, drainage basins, or administrative or political units. Methods of defining the spatial extent of specific water quality problems or components require a similar, although specially tailored, synoptic approach (*7, 19*).

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Background of frameworks

A watershed is defined as an area of land from which water drains to a single point or given place on a stream. Its boundary is usually delineated by following topographic divides. The term basin often is used for large watersheds, such as the Columbia River Basin or the Delaware River Basin.

Hydrologic units are similar to basins in that their boundaries are often based on topographic drainage divides. Some units are combinations of basins, some are segments of basins, and a few may include adjacent interstices that are unrelated to surface runoff. Hydrologic units of the U.S. Geological Survey (USGS) comprise the 21 major water resource regions and 222 subregions of the now defunct U.S. Water Resources Council, as well as 352 accounting units and 2,149 cataloging units (*25, 32*). Hydrologic unit maps and codes can provide a standardized base for locating, storing, retrieving, and exchanging hydrologic data; indexing and inventorying hydrologic information; and completing a variety of other applications (*25*).

Although such a framework is useful for many water resource management activities, there is a tendency to use basin and hydrologic-unit frameworks to summarize and illustrate ecological and water quality data (*1, 4, 5, 33,* and many state 305B reports). Hydrologic units and basins, like administrative and political units, simply do not correspond to patterns in vegetation, soils, land forms, land use, and other characteristics that control or reflect spatial variations in surface water quality. When these units are used as a primary framework to aggregate data, illustrate patterns, and suggest management options, the true spatial variations in quality are masked.

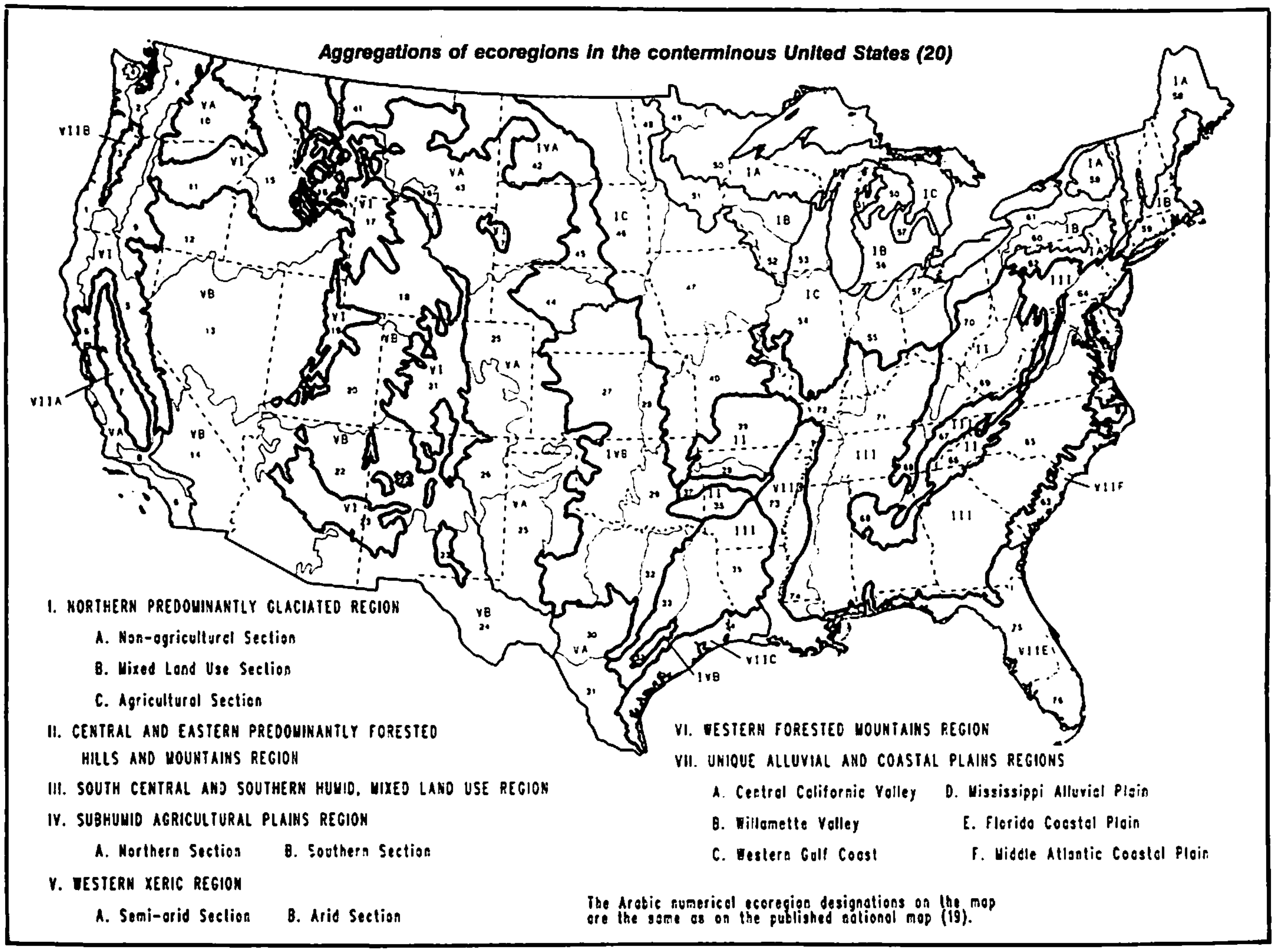
The major stimulus within the U.S. Environmental Protection Agency (EPA) to develop an ecoregional framework stemmed from the need to assess existing and attainable surface water quality (*7, 11, 19*). To address management needs, it was important that ecological regions reflect similarities in the type, quality, and quantity of water resources and the factors that have impacts on them. Because surface waters generally reflect the characteristics of areas they drain, the approach was based on patterns of terrestrial characteristics. The regions, therefore, are not exclusive to aquatic ecosystems but depict terrestrial ecosystems as well.

These ecoregions have been defined at several hierarchical levels for the conterminous United States. The broadest levels are named (see figure), and more detailed levels are identified by Arabic numerals. Even more detailed levels or subregions have been developed for the states of Colorado (*7*) and Oregon (*3*). Development of additional subregions is underway in some states and in the planning stage for others, largely in connection with the development of regional biological criteria and nonpoint-source management plans. Refinement of ecoregion boundary alignments and development of methods to address boundary width and fuzziness are a part of these projects.

Comparisons of frameworks

National scales. There are numerous national assessments of water quality that use convenient frameworks, such as hydrologic units, drainage basins, or political units. Some maps used to illustrate these assessments give a general idea of the national patterns of variation in quality, but not as clearly as if a framework of natural regions had been used, and most maps present misleading pictures.

One example of the problems resulting from use of hydrologic or political units can be seen in a map produced by EPA (see



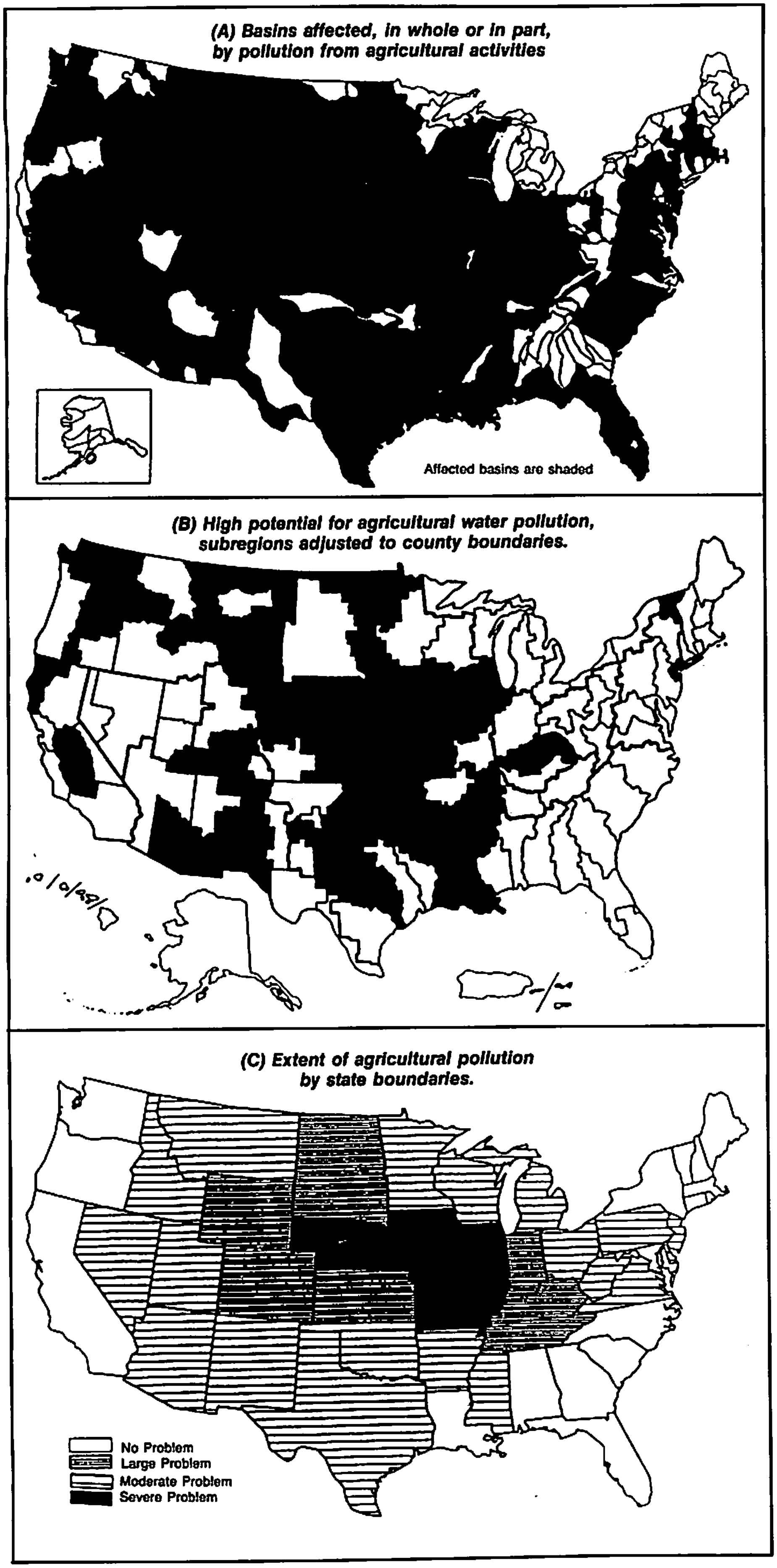
Aggregations of ecoregions in the conterminous United States (20) figure) in the late 1970s (*30*). This map has been reproduced several times in publications concerning agricultural nonpoint-source pollution (*6, 33, 35*). The framework uses 246 "EPA-designated hydrological drainage basins," some of which are actual basins or watersheds and some that are more like accounting units. These basins are used in an attempt to depict areas affected wholly or in part by agricultural nonpoint-source pollution. The map gives the impression that most of the nation is polluted by agricultural activities, even the large areas of deserts, forests, and high mountains where soils have never been touched by plow or tractor and where cattle grazing is largely absent.

Another map (see figure) uses "aggregated subareas," or hydrologic subregions that have been adjusted to county boundaries in an attempt to show areas with high potential for water quality degradation by agricultural pollution (*29*).

A third map (see figure) uses state boundaries to show the spatial extent of the problem. The author of this map had a special purpose for using state boundaries, but graphically declaring that there is "no problem" of agricultural water pollution in the Pacific states, southeastern states, and northeastern states is a considerable exercise of cartographic license.

Although these three maps were obviously compiled with different methods, data, and assumptions, their basic intent was to illustrate similar areas. It is curious, then, that there is so much disagreement about where agricultural pollution occurs or has the potential to occur. And because of the wide discrepancies, a reader might reasonably suspect that any one of the maps is just as likely to misinform as inform. At the very least, one could delineate the areas where agricultural activities occur, as a limit on the spatial extent of the agricultural pollution problem.

A more logical and relatively easy way to paint this national-level picture would be to use the ecoregion framework developed for classifying water with regard to physical, chemical, and biological characteristics. To illustrate the extent of agricultural pollution, one would select one set of reference stream sites for areas representative of attainable conditions or quality (*12*) and another set of sites representative of perturbation due to



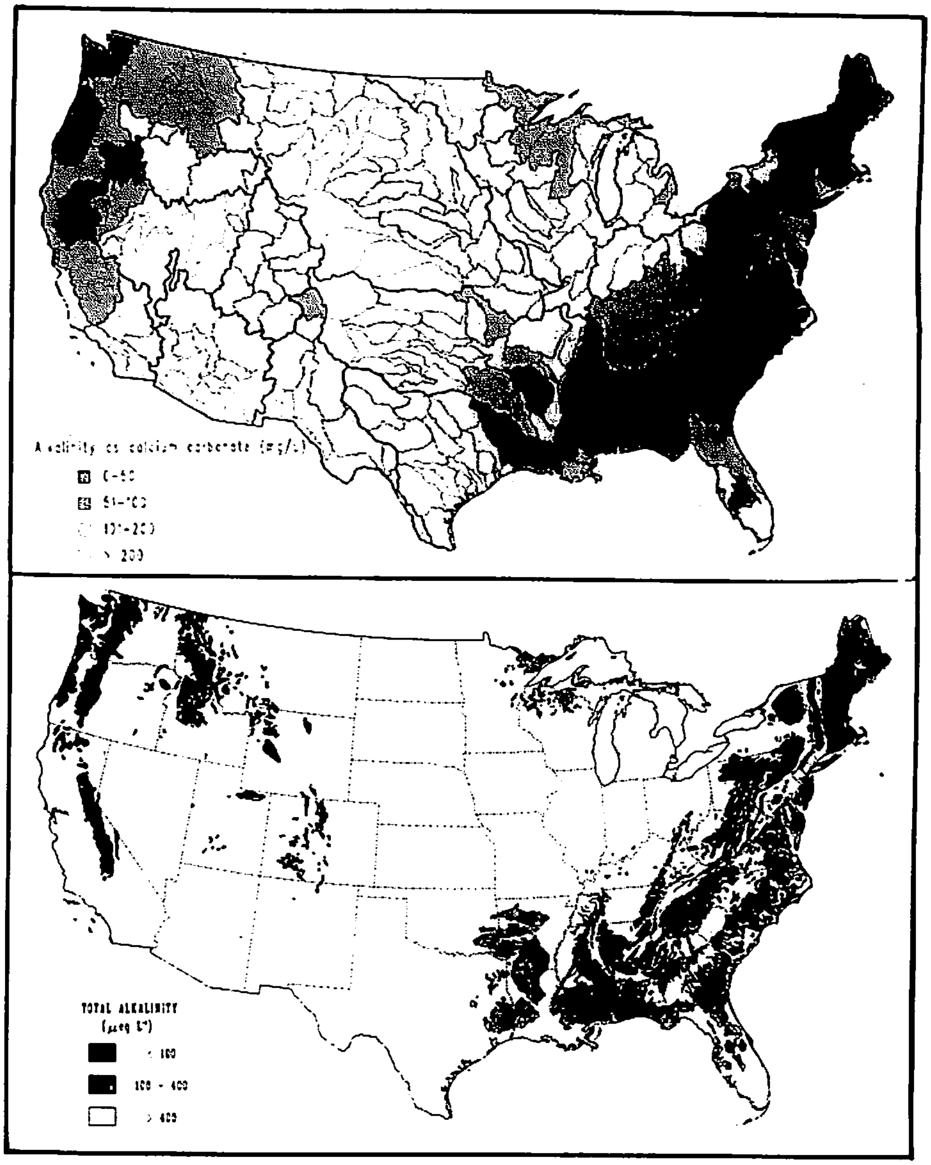
Three different frameworks used to illustrate the extent or potential extent of agricultural nonpoint-source pollution: (A) EPA-designated hydrological drainage basins (30), (B) aggregated subareas or water resource subregions adjusted to county boundaries (29), and (C) state boundaries (16).

agricultural practices, such as cattle feedlots, recent stream channelizations, excessive agricultural chemical use, inappropriate cultivation practices, and so forth. The two sets of sites for each region would provide data to illustrate means and ranges of perturbed and realistically attainable conditions. The ecoregions provide a framework that captures spatial homogeneity in ecosystems; human stresses; and the types, quality, and quantity of environmental resources, thereby allowing more meaningful extrapolation of the data to compile a national map.

With respect to the term "attainable," it is important to separate attainable quality from that which is the result of misuse or pollution. Quality attainable in one region may not be attainable in another due to natural factors. It must also be recognized that it is not only impossible but unrealistic and inappropriate to compare water quality to "pristine" conditions, as they would have occurred before European settlement of North America. It is highly unlikely, for example, that the western Corn Belt will be returned to blackland prairie.

Another alternative, although more time consuming and requiring more data, would be to define and map single-purpose regions (*20*). For clarifying nonpoint-source pollution problems, this would involve overlaying the portions of the country in agriculture with information on factors known or believed to be contributing to agricultural nonpoint-source pollution, including agricultural chemical use, agricultural animal unit density, areas of concentrated animal production, and so on. The particular combination of factors, the types and intensities of agriculture, and their weightings would, of course, depend upon the specific problem to be illustrated. If the concern includes the streams affected by nonpoint-source pollution, then the streams draining the problem areas should be shown as linear features. Portions of drainage areas that are not contributing to the particular problem or are downgradient should not be shown. These approaches would present more accurate, useful illustrations of the problem areas and resources affected than those using hydrologic units or political units.

Another national example is the use of data from the USGS National Stream Quality Accounting Network (NASQAN), extrapolated to entire hydrologic accounting units to produce national water quality maps. Beginning with 1974 data, USGS published these maps annually to "describe the water quality of the entire country," to "show areal patterns of stream quality," and to "depict areal variability" (*1*). Again, what USGS intended to illustrate was quite different from what the maps actually showed when the data were extrapolated to hydrologic units. The NASQAN maps were intended to present "geographic patterns of water quality that reflect climate, geology, soil types, agricultural practices, human and animal populations, water pollution, and pollution-control practices" (*31*). However, because the data were extrapolated to the entire basin or hydrologic unit, the patterns illustrated are grossly distorted, and using the map to assess the actual associations of water quality with these influencing factors is difficult, if not impossible.



Hydrologic unit framework (top) typical of NASQAN water quality maps (1). Surface water alkalinity map (bottom), adapted from 1988 revision of a map (23). Note: 1 milligram per liter equals 20 microequivalents per liter.

NASQAN maps, such as the one for alkalinity, mask important water chemistry variations. In the Rocky Mountains, for example, where surface water alkalinity can be extremely low (*21*), the NASQAN map shows very high alkalinity because the data are from downstream, low-elevation mainstem sites that are, again, extrapolated to the entire watershed or hydrologic unit. Mapping techniques that consider the factors affecting water chemistry and that can incorporate the information to help extrapolate or delimit the parameter classes lead to maps that more accurately reflect what might actually be found in the field. Such techniques have been used to produce national maps of surface water alkalinity (*23*), phosphorus concentration in lakes (*22*), and stream nutrient concentrations attributable to nonpoint sources (*18*). Although not an ecoregion framework, the method of delineation on the maps involved similar synthesizing processes (*20*).

Smith and associates (*27*) concluded that the national water quality monitoring networks, such as NASQAN with its heterogeneous basins, are ill-suited for several types of needed studies on water quality. To increase our understanding of nitrogen transport from land to water or to distinguish atmospheric from terrestrial influences, for example, they suggest that long-term water quality sampling in smaller, more homogeneous basins should take place. While this will help, one must also understand the regional representativeness of the data. Regardless of the scale of interest—national, regional, or local—the areas within which there is relative similarity in resource type, quality, quantity, and associations must first be defined. This is necessary to guide the determination of which basins should be selected; basin size requirements (for example, small enough to be completely within the ecoregion and consistent with the relative homogeneity of geographic characteristics, such as physiography, land-use patterns, vegetation types, etc.); and ultimately, the representativeness and extrapolability of data collected.

Regional/state scale. Many states use a basin or hydrologic unit framework for reports on water quality, such as the biennial 305(b) reports submitted to Congress under the Clean Water Act. A basin reporting system, however, can lead to disjointed and misleading assessment documents (*3*). Several statewide case studies have evaluated the usefulness of ecoregions for examining regional variations in biological and environmental variables (*10, 11, 14, 17, 24, 36*). Minnesota, Ohio, and Arkansas have used an ecoregional framework in their 305(b) reports. Several other states, including Alabama, Florida, Indiana, Louisiana, Michigan, Mississippi, Oregon, and Texas, are planning to use ecoregions to set biological criteria, evaluate the impacts of nonpoint-source pollution on the health of surface waters, and/or to prepare their 305(b) reports.

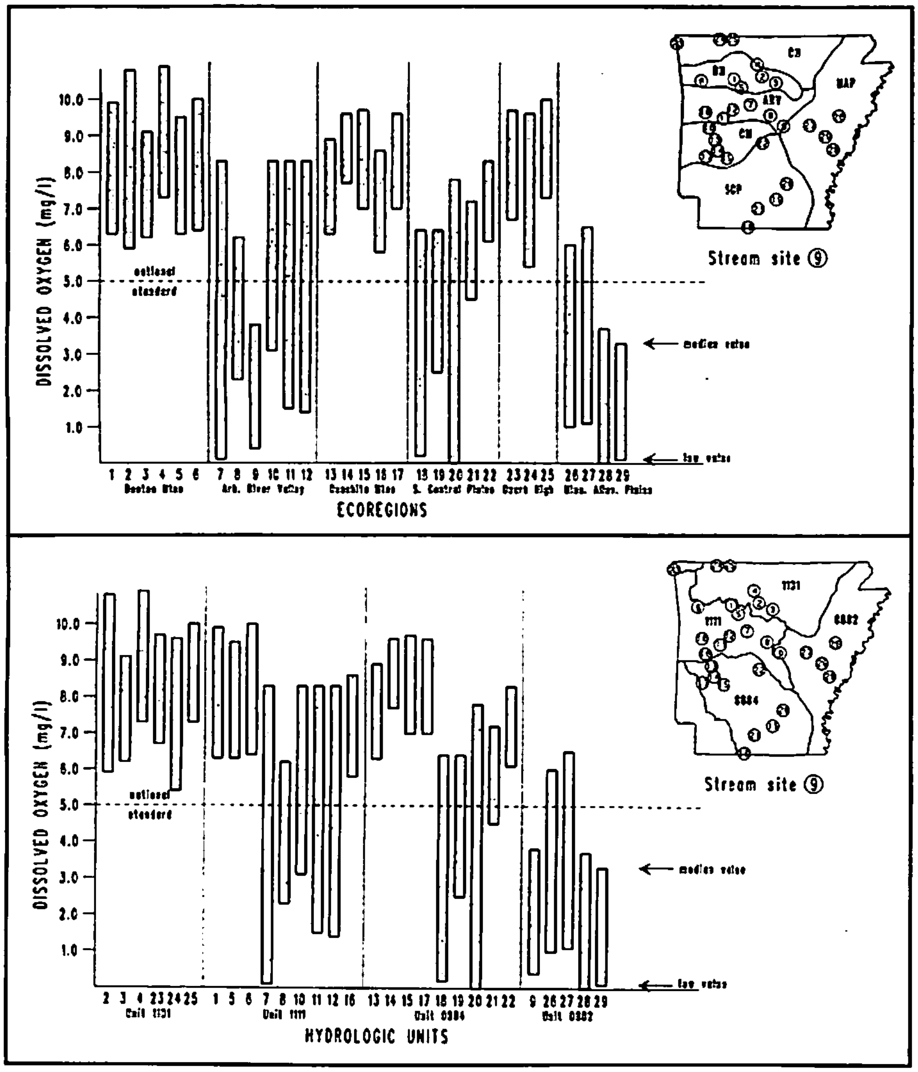
In Arkansas, six aquatic ecoregions were defined that have proved useful for evaluating and managing streams (*9, 24*). The state has used the ecoregion framework for developing and evaluating water quality standards, particularly those concerned with the designation of fisheries and dissolved oxygen criteria. Traditionally, water quality standards follow national guidelines, and the values established do not recognize regional variations in water quality. In portions of Arkansas, some of the high-quality, least-disturbed surface waters have natural water quality values that are substandard according to these national values. In other portions, the attainable quality is considerably higher than the national standard. To attempt to meet national quality goals in parts of the state where they are not realistically attainable would be a foolish expenditure of resources, and under-protecting higher quality resources in other areas would be mismanagement.

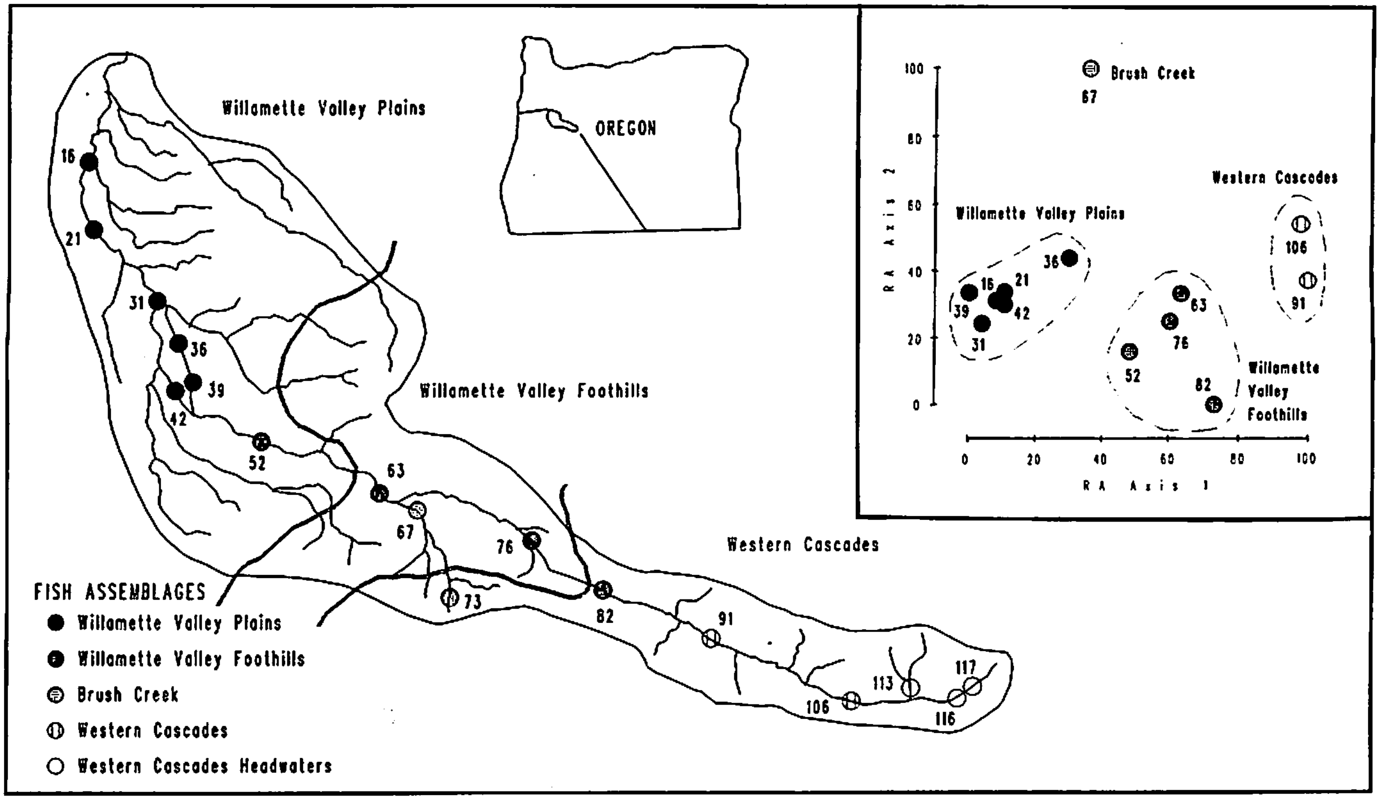
Streams within each of the six ecoregions of Arkansas contain physical, chemical, and biological features that are characteristically similar within ecoregions and distinctively dissimilar among the ecoregions (*9*). Analyzing these streams with a basin or hydrologic unit framework, however, tends to lump dissimilar land areas and water types together (see figures).

Streams representative of the Boston Mountains, Ouachita Mountains, and Ozark Highlands all have minimum dissolved oxygen levels well above the existing water quality standard of five parts per million, so such a standard might allow unnecessary degradation. Conversely, streams in the Mississippi Alluvial Plains, Arkansas River Valley, and South Central Plains have low dissolved oxygen levels considerably below five parts per million. In these and other low-dissolved-oxygen reference streams, however, the State of Arkansas has collected significant numbers of fish species, including black bass, that are particularly sensitive to habitat disruptions. The Arkansas Department of Pollution Control and Ecology has set seasonal dissolved oxygen criteria to protect the biotic integrity of streams in each ecoregion. Based on ecoregions and watershed size, the state has determined that some critical season minimum dissolved oxygen requirements are as high as six parts per million, while in other regions they are as low as three parts per million (*9*).

Local scales. The local level (covering relatively small areas) is the scale where watersheds are used most frequently. Watersheds are the most common spatial units for studying impacts of land management activities on water quality and for framing guidelines for controls and remediation.

Median and low values for dissolved oxygen in regionally representative Arkansas streams by ecoregion (top) and hydrologic unit (bottom). Data from USGS, Water Years 1983-1988.





Reciprocal averaging ordination of sites by fish species in the Calapoola River watershed, Oregon. The inset shows the correspondence between fish assemblages in the rivers and ecoregions.

College courses are given in "watershed studies"; the word watershed or basin appears in the titles of several organizational units of government regulatory agencies; and agriculture and forest management units often follow watershed boundaries.

Obviously, it is critical to define the topographic drainage of any point on a stream when one is attempting to determine reasons, both natural and anthropogenic, for the quality at that point. Streams reflect the characteristics and impacts of the areas they drain. In the 60 percent of the conterminous United States where topographic drainage areas are definable and streams are effluent (where groundwater generally feeds streams, compared to "influent," where streams tend to feed the groundwater), watersheds afford a convenient frame for these assessments (*13*). Watersheds are less useful where topographic drainage areas are difficult or impossible to define and in arid areas with influent streams (*13*).

The question, therefore, is not whether watersheds, basins, or hydrologic units are useful, but when and how they should be used. "Natural" regions, within which there is similarity in characteristics that affect the quality and health of streams, should be determined first. Then the drainage areas relative to the points on the streams where water quality is being assessed should be determined. In some regions of karst topography, eolian sandy soils, continental glaciation, and arid lands, however, watersheds can only be approximated, and they will have less utility (*13*). Portions of drainage areas occupying different natural regions are likely to contribute differently to the streams in question, and management activities are likely to have different effects.

One local-scale example of this ecoregional influence can be seen in the Calapooia watershed in western Oregon. This 372-square-mile watershed can be divided into three distinct ecoregions: the Willamette Valley plains, the transitional foothills region, and the Western Cascades (*3*).

In the summer of 1983, in an effort to discern changes in the river as it passed from one ecoregion to another, fish from 17 sites were sampled, as well as physical and chemical habitat and macroinvertebrate data (J. Giattina, personal communication, EPA, Chicago; *15*). Similar biological communities presumably would be found in areas of similar habitat, and that variation, in turn, would correspond to observable patterns of change in terrestrial features of the watershed. Giattina used a reciprocal averaging ordination technique (*8*) to classify the sites by their fish assemblages. This technique produces a two-dimensional representation of the similarities among the sites. The accompanying figure shows the second of two ordinations with the distinct headwater sites removed to give a better separation of the remaining sites.

Results of the Calapooia study indicate that the ecoregion framework serves as a useful model for predicting stream reaches having similar fish and macroinvertebrate assemblages: the redside shiner, squawfish, and snail assemblages in the valley plains region; the torrent sculpin, speckled dace, and caddisfly assemblages in the foothills; and the trout, Paiute sculpin, and caddisfly and mayfly assemblages in the Cascades. While there is community change along a river continuum, distinct assemblages can be delineated, and these tend to correspond to broad-scale geographic features within a watershed. Whereas the size of the Calapooia (in terms of stream order, channel width, drainage area, or discharge) does not increase significantly as the river flows from one ecological region to the next, community structure is distinctly different. This has obvious implications for best management practices, use designations, water quality standards, biocriteria, and so forth. Managers and researchers need to view streams in a broader spatial perspective. Although the longitudinal linkages emphasized in the river continuum concept are important (*34*), lateral linkages with regional characteristics must also be examined. Assessing just a reach or the channel or the riparian zone or even the drainage basin may not be sufficient if the context of the broader ecoregion influences are not considered as well.

A more logical framework

Spatial frameworks can be powerful and influential tools, but they need to be carefully analyzed to determine their utility and shortcomings. This is true for the graphic display of spatial information and, more importantly, for the assessment and management of resources as well. A spatial framework that is readily available and widely used is not necessarily a good choice for the management and reporting of resources if its use produces misleading results. Too often frameworks are used for purposes other than those for which they were developed or intended.

The idea of the drainage basin as a suitable framework for the study and organization of the facts of physical and human geography has a long tradition (*26, 28*), one not easily overcome. The river basin can, in fact, be an optimal unit of water resources planning, development, and management. Such units are appropriate for certain integrated plans and policies, for assessing upstream and downstream conflicts among water users, and for hydrologic studies where it is necessary to consider the contributions of the entire watershed. While river basin units are appropriate for some types of hydrologic data, rarely do the spatial differences in the quality and quantity of environmental resources correspond to topographic divides.

The results of several statewide studies indicate the appropriateness of using ecoregions to develop quantitative regional chemical and biological goals and standards. Ecoregions stratify the naturally occurring spatial variation that exists across basins, states, and nations. This regional stratification can increase monitoring efficiency, improve data interpretation and trend detection, and provide a more logical framework than hydrologic units or political boundaries for assessing and reporting on water quality issues.

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