Ecoregions, watersheds, basins, and HUCs: How state and federal agencies frame water quality

G.E. Griffith, J.M. Omernik, and A.J. Woods

ABSTRACT: Many state and federal agencies have adopted a "watershed approach" for water quality assessment and management, and the U.S. Environmental Protection Agency (EPA) recommends using hydrologic units for this purpose. Watersheds are important spatial units for studies of land-water relationships, but most hydrologic units are not watersheds. More importantly, watersheds, basins, or hydrologic units do not correspond to the spatial patterns of regional characteristics such as physiography, soils, vegetation, geology, climate, and land use that influence the physical, chemical, or biological nature of water bodies. For effective management strategies regarding protective water quality standards or restoration goals, these regional differences in ecological potentials should be considered. An ecoregion framework is an appropriate and necessary complementary tool for watershed assessment and management. Reference watersheds within ecoregions can be used to help set expectations, standards, and management practices. National, regional, and state examples illustrate the need to recognize the limitations of water quality assessments conducted solely within watershed or hydrologic unit frameworks.

Key Words: Aquatic ecosystems, ecoregions, hydrologic units, reference sites, water quality, watersheds.

Although progress has been made in improving water quality in some areas of the country over the past 20 years, many of our surface waters and freshwater ecosystems face serious problems. In the latest water quality report to Congress, the U.S. Environmental Protection Agency (EPA) suggests that of the waters surveyed by the states, 44% of rivers and streams and 49% of lakes are impaired or threatened for one or more of the designated beneficial uses such as fishing or swimming (U.S. EPA 1998a). Agriculture was listed as the leading source of impairment in these surface waters. While there are many shortcomings to the 305(b) water quality data collected from the states and reported to Congress, such as bias in site selection, differences in assessment methods, and emphasis on chemical and physical quality, if more comprehensive or statistically designed survey methods and biological criteria were used, reported levels of impairment would, in many cases, be higher (Paulsen et al. 1998, Yoder and Rankin 1998, Maxted 1997).

Other data sources indicate the critical nature of some U.S. water quality problems. When one considers the biologic elements of aquatic ecosystems, many of the trends are ominous. In California, 67% of the 115 native fish taxa are extinct, endangered, threatened, or declining (Moyle and Williams 1990; Moyle and Yoshiyama 1994). In the states of California, Oregon, Washington, and Idaho, at least 106 major populations of salmon and steelhead trout have been extirpated, and an additional 214 stocks of salmon, steelhead trout, and sea-run cutthroat trout are at high to moderate risk of extinction or are of special concern (Nehlsen et al. 1991). In Tennessee, more than 56 taxa (species, subspecies, or unique local races) of fish are endangered, threatened, or of special concern (Etnier and Starnes 1991). In Alabama, 10% of the fishes, 69% of the mussels, and 43% of the turtles are considered extinct, endangered, threatened, or of special concern (Lydeard and Mayden 1995). In the U.S., approximately 250 to 300 fish species, or about one-third of the U.S. freshwater fish fauna, and nearly 72% of the 297 native freshwater mussel species are endangered, threatened, or of special concern (Williams et al. 1989, 1992; Johnson 1995; Williams and Neves 1995; Stein and Flack 1997). In addition, 51 percent of U.S. crayfishes and 40 percent of amphibians are considered imperiled or vulnerable (Stein and Flack 1997).

Practices and patterns of agriculture, silviculture, grazing, industry, urbanization, and water resource management in general are well known to have caused serious modifications to habitat and degradation of water quality (National Research Council 1992; U.S. EPA 1998a; Water Environment Federation 1992). Species extinctions, contaminated sources of drinking water, nutrient enrichment, increased incidences of harmful microorganisms such as Pfiesteria piscicida, fish deformities, and fish consumption advisories all indicate the many critical water-related challenges to ensuring the health of our aquatic ecosystems and, in the long run, human beings. Meeting these challenges for improving water quality and addressing broader ecological issues and shifts in social values has been difficult for resource management agencies. Many agencies appear to be struggling with new mandates, more comprehensive approaches, and the ambiguities of ecosystem management. While there is an obvious need for holistic and integrative ecological approaches to assess and manage water quality, there is considerable debate and confusion about appropriate spatial frameworks to conduct such work.

Some researchers argue that watersheds provide the spatial framework necessary for ecosystem research, assessment and management (Lotspeich 1980; Montgomery et al. 1995; Smith 1994). The U.S. EPA (1995, 1997) has advocated managing by watersheds, and most of the ecosystem initiatives developed by state governments revolve around watershed-based approaches to water quality improvement (Brown and Marshall 1996). Yet, as Schramm and Hubert (1996) pointed out, ecosystem management is much more than watershed management. Understanding regional ecosystem differences is also critically important (Omernik 1995; Bailey 1996; Gallant et al. 1995). With the recently increased emphasis on watershed indicator and assessment activities, agencies, organizations, and individuals need to recognize the limitations of state and national assessments of water quality conducted within a watershed or hydrologic unit framework. Extrapolating water

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quality or ecological data to a watershed framework (e.g., U.S. EPA 1997) may be inappropriate and can lead to a misunderstanding of the spatial nature of ecosystems, natural resources, and the location of human activities or impacts (Omernik and Bailey 1997).

This paper discusses spatial frameworks that state and federal agencies commonly use in the assessment and management of watersheds and water quality. The objective is to clarify the definitions, differences, and proper uses of watershed, hydrologic unit, and ecoregion frameworks. Some of the benefits of employing a regional ecological framework are illustrated by examples from the Mid-Atlantic states, Ohio, and Florida.

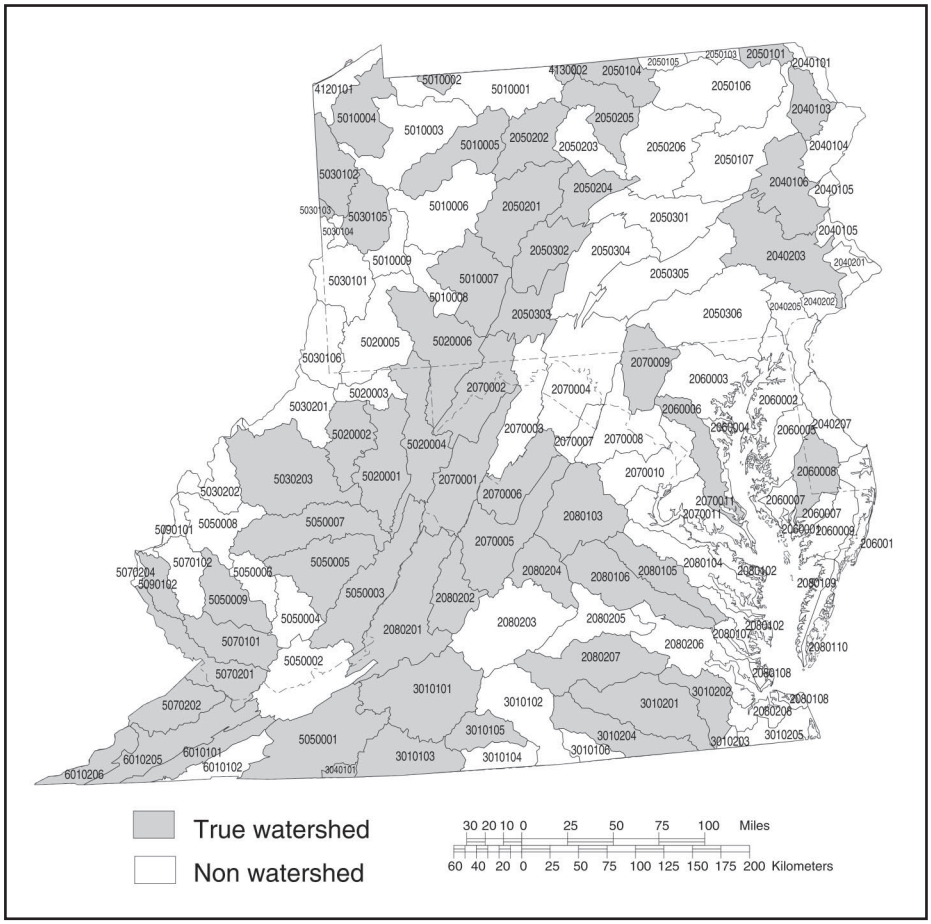

Figure 1. Only 46% of the 8-digit hydrologic units of the Mid-Atlantic region are true topographic watersheds.

Watersheds and basins

Almost everyone agrees on the definition of watersheds: topographic areas within which apparent surface water runoff drains to a specific point on a stream or to a waterbody such as a lake. While a confluence is often used as the watershed drainage point, there are an infininite number of points along the stream from which topographic watersheds could be delineated. Watersheds of large rivers are commonly called basins, e.g., the Snake River Basin within the Columbia River Basin, the Platte River Basin within the Missouri River Basin. Many states use basins as an organizational tool for monitoring and reporting water quality data, such as for their 305(b) reports to the U.S. EPA.

Watersheds have provided the spatial unit for framing countless scientific studies on land-water relationships and are critical to the understanding of physical and cultural effects on the quantity and quality of water at a given point. Because watersheds often integrate surface and subsurface flow of water upgradient from points at which measurements are made, they afford drainage basin-specific accountings to be made of characteristics such as point and nonpoint source pollutants, whose transport is associated with the movement of water. Watersheds are appropriate for studies of loads, where the entire watershed contributes to the water quality at a particular point. Significant long-term watershed research has been conducted at places such as Coweeta (N.C.), Hubbard Brook (N.H.), H.J. Andrews (Ore.), and San Dimas (Calif.), as well as many other watersheds across the country. Watershed networks, such as the U.S. Geological Survey (USGS) Hydrologic Benchmark Network and the USGS National Stream Quality Accounting Network, also have provided useful data for national and regional summaries of water quality characteristics and trends (Smith et al. 1987, 1993, 1997; Alexander et al. 1996). The important element in all of these studies is that the research was conducted in true watersheds.

Watersheds have been widely claimed to provide the necessary spatial mechanism for ecosystem research, assessment, and management (Lotspiech 1980; Lotspiech and Platts 1982; Maxwell et al. 1995; Montgomery et al. 1995; Smith 1994; U.S. Department of Interior, Fish and Wildlife Service 1995; U.S. EPA 1995; Water Environment Federation 1992; Williams and Rinne 1992). The U.S. EPA Office of Water has been advocating a "watershed approach" to state resource management agencies as "...a holistic framework for addressing complex pollution problems," (U.S. EPA 1998a). For "managing by watersheds," the Office of Water recommends using U.S. Geological Survey hydrologic units, claiming these units "provide a common national framework for delineating watersheds and their boundaries at a number of different geographic scales," (U.S. EPA 1995).

Hydrologic units

The hierarchical system of hydrologic units developed by the U.S. Geological Survey (Seaber et al. 1987) divides the United States and the Caribbean into 21 major regions, 222 subregions, 352 accounting units, and 2,149 cataloging units. The units are identified by unique hydrologic unit codes (HUCs) that provide a standardized base for locating, storing, retrieving, and exchanging hydrologic data.

There is a common misunderstanding that hydrologic units and watersheds are one and the same. Regardless of the hierarchical level, most hydrologic units are not true topographic watersheds. Many are downstream segments of larger watersheds, or collections of several adjacent small watersheds. It is impossible to divide the country into a finite number of true watersheds at any hierarchical level (Omernik and Bailey 1997). That is probably why HUCs were developed.

In several recent reports, the U.S. EPA has used the hydrologic cataloging units, sometimes called 8-digit HUCs, to summarize and illustrate geographical patterns in water quality or land cover characteristics (U.S. EPA 1997; Jones et al. 1997). In "An Ecological Assessment of the United States Mid-Atlantic Region: A Landscape Atlas," Jones et al. (1997) attempted to help readers "visualize and understand the changing conditions across the region, and how the patterns can be used as a context for community-level situations." Throughout the report, the HUCs are referred to as watersheds. However, less than half of the HUCs (57 of 123) that are completely or partly within the five state Mid-Atlantic Region are, in fact, true topographic watersheds (Figure 1). The authors of the atlas stated, "Strictly speaking, the USGS hydrologic accounting units are not watersheds in the classical sense of a topographically-defined catchment area." However, throughout the text and for nearly all of the figures, they refer to the units as "watersheds" and not as "hydrologic units" (Jones et al. 1997).

This misconception that hydrologic units are watersheds is also conveyed by the U.S. EPA Office of Water in its Index of Watershed Indicators (IWI) document and maps of the United States (U.S. EPA 1997). Also using eight digit HUCs, the Index of Watershed Indicators is stated to be a set of maps that present "a description of the condition and vulnerability to stressors of the 2111 watersheds in the continental United States" (U.S. EPA 1997). Again, however, most of the units on these maps are not true watersheds and many are small downstream segments of large basins covering diverse geographic regions. These reports (U.S. EPA 1997; Jones et al. 1997) imply that by summarizing a landscape indicator by HUCs, one can then make a link between the indicator and water quality. That link is difficult or impossible to make, however, when the HUC is not a watershed.

The U.S. Department of Agriculture and U.S. EPA currently recommend that the eight-digit HUC's serve as the common units for determining condition, reporting results, and targeting resources in the unified watershed assessment element of the administration's Clean Water Action Plan. Many states and agencies are also involved in projects to delineate and come to agreement on more detailed hydrologic units. Other federal agencies, including the Forest Service (Maxwell et al. 1995) and U.S. Fish and Wildlife Service (1995), have promoted the use of hydrologic unit based frameworks for aquatic ecosystem management. This promotion of HUCs has apparently influenced the work of conservation organizations as well. The Nature Conservancy (Master et al. 1998) has adopted a hydrological unit scheme that it claims are watersheds, and the World Wildlife Fund (Abell et al. 1998) uses "freshwater ecoregions" that are mostly basins and HUCs modified from the Maxwell et al. (1995) framework.

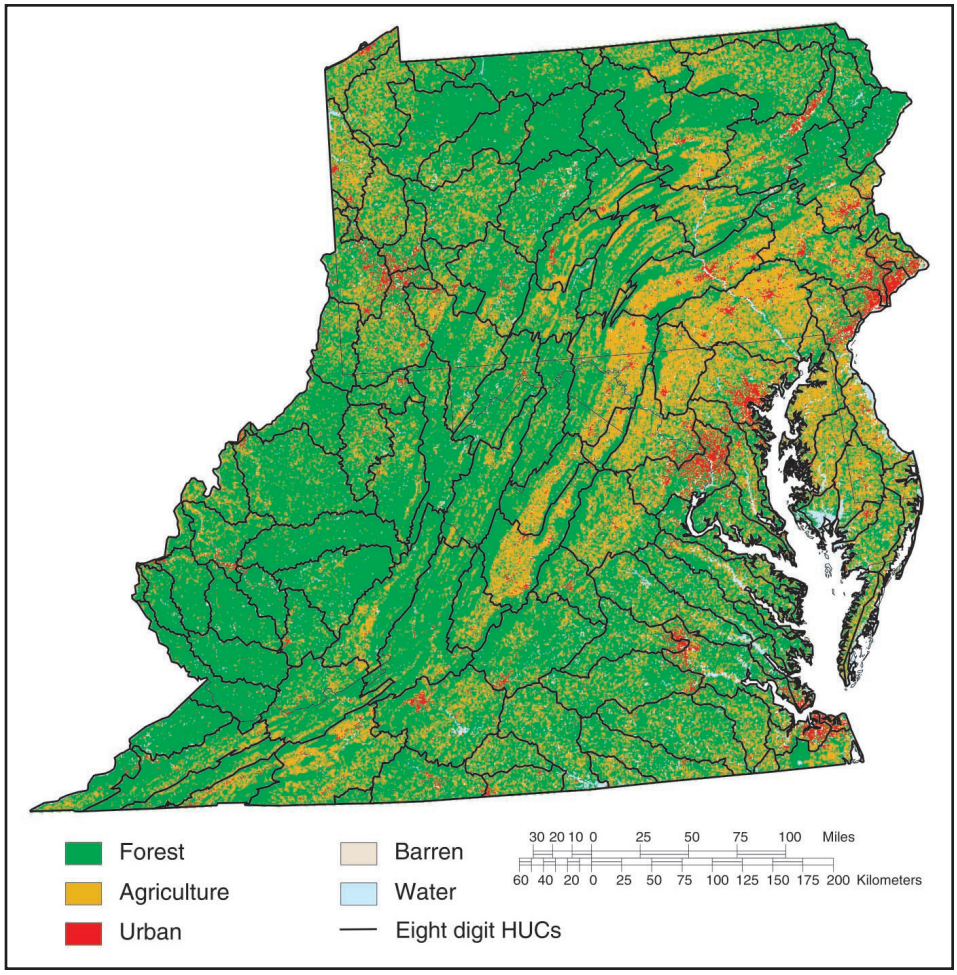

Figure 2. Hydrologic units and landcover in the Mid-Atlantic Region.

Problems with watershed/HUC frameworks

Obtaining a geographically representative description of water quality at state and national levels is a continuing challenge. It is especially difficult to provide a description or illustration that facilitates interpretation of the factors and processes that influence water quality conditions . More important than misstating that HUCs are watersheds is the problem that neither HUCs nor watersheds appear to be appropriate units for reporting or extrapolating data to illustrate spatial patterns in environmental conditions. Especially at state and national scales, these units seldom correspond to patterns of the characteristics that cause or reflect spatial differences in water quality and other environmental resources. For example, the patterns of general land cover (or soils, or geology, or vegetation, etc.) in the Mid-Atlantic Region show little spatial correspondence to HUCs (Figure 2).

Where the intent of an atlas or collection of maps is to show spatial patterns of environmental resources, such as with both the "landscape atlas" (Jones et al. 1997) and the IWI maps (U.S. EPA 1997), it is critical to use units that best depict these patterns and that allow more accurate interpretations of the spatial distributions. Although one could use any spatial unit such as counties or similar sized polygons for such an atlas, the effectiveness of portraying the patterns of the landscape characteristics is greatly diminished by using a system of units that lack spatial correspondence with the themes of the maps. For example, in its Agricultural Atlas of the United States, the U.S. Department of Commerce, Bureau of Census (1995) has shown patterns of

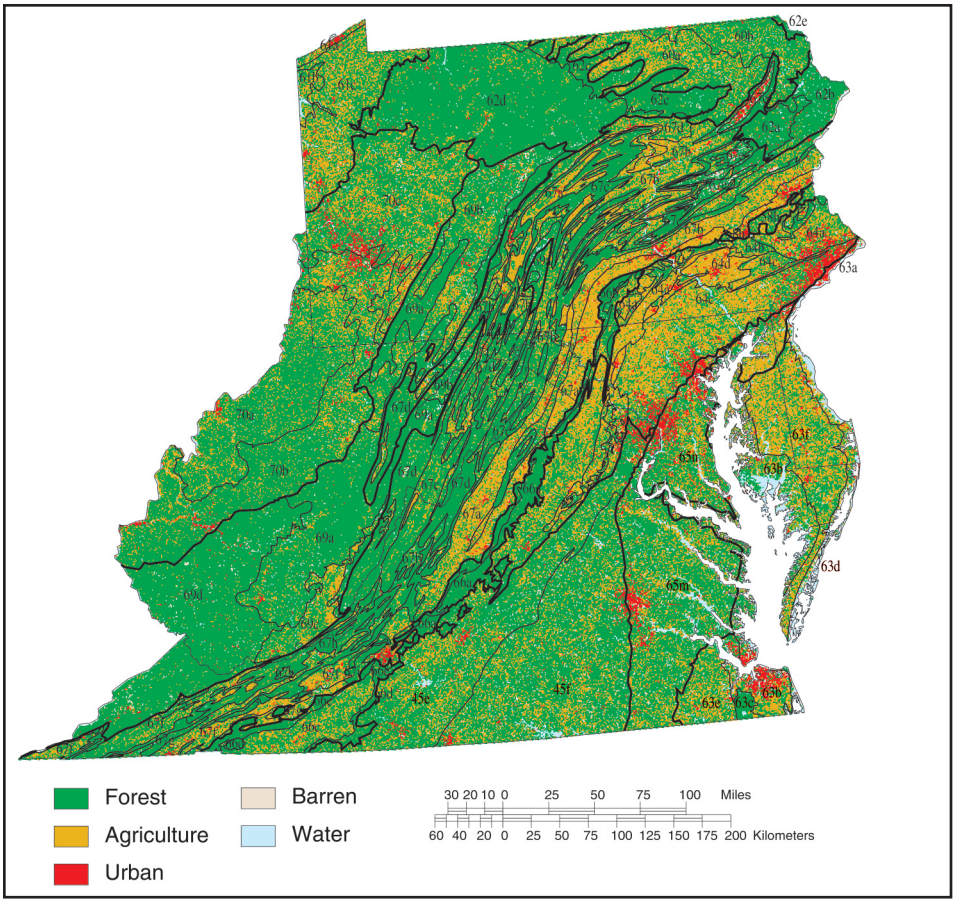

Figure 3. Ecoregion boundaries and landcover in the Mid-Atlantic Region.

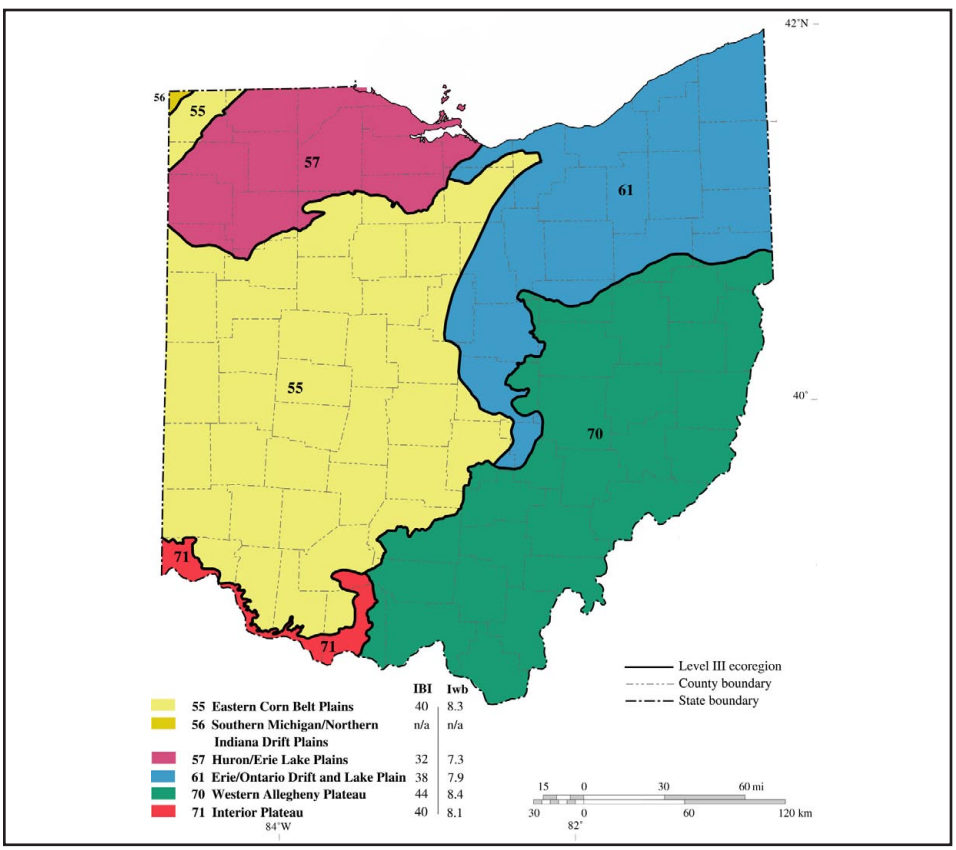

Figure 4. Level III ecoregions of Ohio (Omernik 1987; revised by Woods et al. 1998). Biological criteria for fish (IBI, Iwb) by ecoregion in the Warmwater Habitat Use designation for wading sites (Yoder and Rankin 1995).

agricultural characteristics (e.g., crop types, densities of different farm animals, use of agricultural chemicals) using the county units by which the data are collected. However, recognizing that reporting (via maps) by county units did not show the true patterns of these characteristics, dot distribution maps also were created to show more accurate patterns by using land use maps as a framework and placing the dots where the phenomena were most likely to occur. Hence, maps of vegetables show the small areas of intensive agriculture in southern California and Arizona, whereas the same data mapped using county units show the vegetable farming to cover vast non-agricultural desert areas in both states.

Using HUCs to show patterns of landscape characteristics has similar limitations to using counties to show patterns of agricultural characteristics. The problem with HUCs may be even greater, but more subtle. Many people who use HUCs, such as Jones et al. (1997) who defended their use of HUCs because "watersheds are natural units defined by the landscape," imply that the units are logical for showing landscape patterns. Aggregating resource data by basins or HUCs results in a highly variable set of data within each unit that can mask or homogenize spatial patterns and regional differences. Quantitative analyses comparing HUCs and ecoregions can be found in Brown and Brown (1994), Omernik and Griffith (1991) and Bryce et al. (1999).

Watersheds, basins, or hydrologic units do not correspond to areas within which there is similarity in the mosaic of geographic characteristics (e.g. physiography, soils, vegetation, geology, climate, and land use) that regionally influence the physical, chemical, or biological nature of water bodies (Omernik and Griffith 1991; Omernik 1995; Omernik and Bailey 1997). The desire among certain groups or agencies to have a freshwater framework and a terrestrial framework illustrates the problems of separating aquatic components from the terrestrial; such a separation is difficult to do in ecology (Willson et al. 1998), and seems counter to the need for holistic spatial frameworks for ecosystem management.

The value and application of regions

Why do we need a regional ecological framework? Management strategies regarding protective water quality standards or restoration goals can be more effective

if regional differences in ecological capabilities and potentials are considered. The quality and quantity of water at any point on a stream or lake reflects the aggregate of characteristics in the watershed upgradient from that point, but the critical task is to define areas or regions where this aggregate of characteristics that affect water quality is similar. Ecoregions can be defined as regions of relative homogeneity in ecological systems; they depict areas within which the mosaic of ecosystem components (biotic and abiotic as well as terrestrial and aquatic) is different than adjacent areas in a holistic sense. The goal of the U.S. EPA ecoregion work that began nearly 20 years ago was to develop a spatial framework for states to structure their regulatory programs more effectively, in tune with the regional potentials and resiliences of the land (Omernik 1987). Variation within regions should be less than variation between regions. Geographic phenomena such as soils, vegetation, climate, geology, land cover, and physiography that are associated with spatial differences in the quality and quantity of ecosystem components are relatively similar within ecoregions. It was suspected and subsequently learned that the quantity and quality of water tends to be similar within these ecological regions (Heiskary et al. 1987, Heiskary and Wilson 1989; Gallant et al. 1989; Hughes et al. 1994, Larsen et al. 1988, Rohm et al. 1987; Whittier et al. 1988).

Returning to the Mid-Atlantic example, the alignments of the U.S. EPA's hierarchical level III and IV ecoregions (Woods et al. 1996), which subsume patterns in the mosaic of characteristics that reflect differences in environmental resources, appear to correspond better to the patterns of land cover in many areas (Figure 3) than did the HUCs (Figure 2). Land capabilities, surface water characteristics, and management or restoration issues in the Blue Ridge ecoregion are different from those in the Ridge and Valley or the Piedmont or the Coastal Plain. Ecological regions can be more effective than HUCs or watersheds in depicting regional patterns in ecological conditions and water quality (Omernik and Bailey 1997; Bryce et al. 1999).

To use watersheds for assessing water quality and put the findings in some meaningful context, a regional ecological framework is an appropriate and necessary complementary tool. An ecoregion framework is intended to allow states to develop reasonable, regional goals and standards regarding water quality, non-point source pollution problems, lake management, and biological criteria. It is an important tool for comparing one place to another, for locating monitoring, reference, and special study sites, and allowing extrapolation for assessing and reporting on the status and trends of resources, such as a state's 305b report on water quality to EPA and Congress. Within ecological regions, sets of "reference" watersheds representative of different degrees of disturbance and other within-region variability can be used to set expectations, standards, and management practices (Hughes 1995). In Arkansas, for example, by examining least-disturbed watersheds within ecoregions, the state has set seasonal dissolved oxygen criteria and standards that better reflect regional potentials and capabilities than the traditional national standard (Giese et al. 1987; Rohm et al. 1987).

An ecoregional framework, together with regional reference data, also can be useful for developing more efficient sampling design strategies. Areas with quite similar aquatic systems can be represented by relatively few sample sites, while more variable regions may require a greater sampling density. After a better understanding of regionally attainable water quality is gained, the results of monitoring programs can be put in better perspective and allow more focused targeting for improvements and restoration. Sites with quality well below regional reference data are obvious candidates where improvements should be possible. Sites or streams with only minor deviations from reference conditions might get minimal benefits from additional expenditures. Streams with quality similar to or better than regional reference conditions would be worthy of special protection or anti-degradation efforts.

The authors' view is that watersheds are the study units, and ecological regions, rather than the watersheds, are the framework for extrapolation, reporting, and implementation of management practices and strategies. Agencies, such as the USGS, also have seen ecoregions as a logical classification device for their scientific studies. Ecoregions provided a useful organizing framework for site selection, analysis, and data interpretation for biological investigations in the Yakima River Basin (Cuffney et al. 1997). They have been used, along with other enviromental setting stratifiers, in several USGS National Water Quality Assessment (NAWQA) projects (Wentz et al. 1998; McMahon and Harned 1998).

State Examples

Ecoregions, watersheds, basins, and HUCs have been used by states to frame water quality. In the following pages, programs of two states, Ohio and Florida, are highlighted. These examples show how ecoregion frameworks can be successfully used by state resource management agencies.

Ohio. The Ohio Environmental Protection Agency (Ohio EPA) is a national leader in techniques for water quality monitoring and assessment. Although Ohio uses a basin and watershed approach to organize the monitoring and reporting of water quality data, it is also one of the states that is furthest along in the use of ecoregions, reference sites, and biological criteria for surface waters. Ohio is one of few that has consistently relied upon aquatic biological data to inform decision-makers, managers, and the public about the condition of its surface water resources.

In Ohio, level III ecoregions have been central to the Ohio EPA's use of biological, chemical, and physical information (Rankin et al. 1997). Six level III ecoregions in Ohio have been delineated by Omernik (1987) and refined by Woods and others (1998) (Figure 4). For over a decade, Ohio has used a combination of chemical, toxicological, and ecological (including biological criteria) approaches to monitor streams and to understand, model, and regulate water quality problems. "Least-disturbed" reference sites on some of the state's highest quality streams have been identified for each level III ecoregion. These sites have served as benchmarks for attainable conditions within an ecoregion and have been sampled by the Ohio EPA and the U.S. EPA to better understand fish and macroinvertebrate communities, as well as water quality (U.S. EPA 1990). Species richness, trophic composition, abundance, diversity, the presence of pollution-tolerant species, and the presence of diseased or abnormal individuals have been analyzed. Results have been used to calculate the values of three different biological indices, the Index of Biotic Integrity (IBI) for fish, the Index of Well Being (Iwb) for fish, and the Invertebrate Community Index (ICI) for macroinvertebrates. Using values from these three indices, the Ohio EPA has developed numeric biological criteria that are considered attainable for level III ecoregions in Ohio

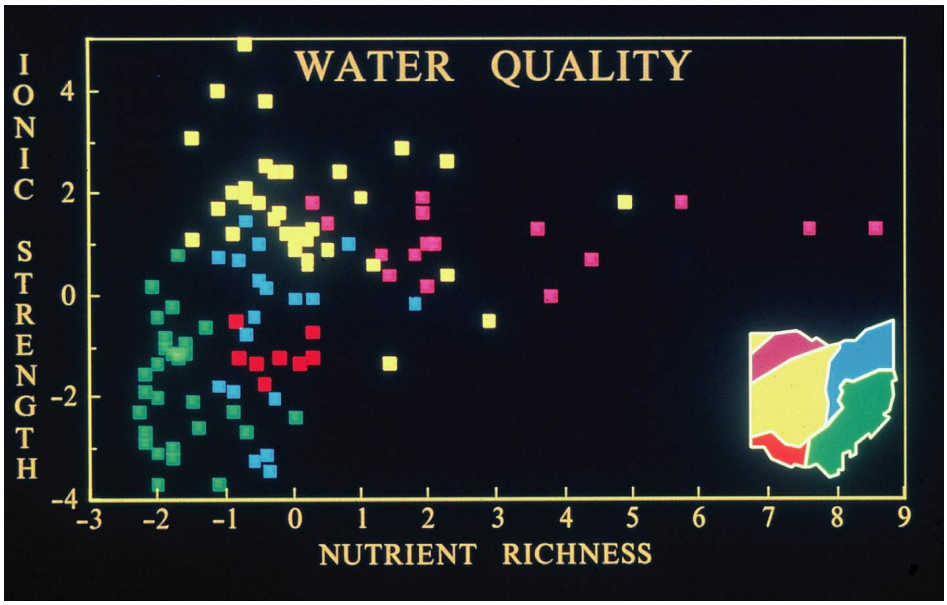

Figure 5. Ohio ecoregional patterns in nutrient richness and ionic strength variables in least-impacted watersheds as indicated by principal components axis I scores for each. Square color corresponds to site in an ecoregion of the same color on the index map (from Larsen et al. 1988).

and codified them in the Ohio Water Quality Standards (Figure 4) (U.S. EPA 1990; Yoder and Rankin 1995, 1998).

A correspondence has been shown between ecoregions and the spatial patterns of water quality in Ohio (Figure 5) (Whittier et al. 1987; Larsen et al. 1988). Figure 5 graphs the results of two principal components analyses of median stream values of ionic strength variables (conductivity, alkalinity, calcium, magnesium, and total hardness) and nutrient richness variables (total phosphorus; nitrate-, nitrite-, ammonia-, and Kjeldahl nitrogen; and total organic carbon) collected from the reference watersheds. The ecoregions can be distinguished by the clustering of the sites having similar chemical concentrations. Some of the largest differences in water quality occur between the streams of the flat, agriculturally-dominated Huron/Erie Lake Plain (57) and the hilly, forested Western Allegheny Plateau (70). These patterns are predictable because agriculture, particularly near-channel agriculture, can readily contribute sediments, nutrients, and pesticides to streams. The low-gradient streams of the Huron/Erie Lake Plain (57) are particularly susceptible to sedimentation and habitat destruction because they are sluggish and have long sediment retention times (Rankin 1995). Even the least-impacted streams (57) are warm, turbid, nutrient rich, and silt-bottomed with little instream cover. Streams of the Western Allegheny Plateau (70), on the other hand, are more rapidly flowing, usually cooler, less turbid, coarser-bottomed, and have lower ionic strength and nutrient levels than those of the Huron/Erie Lake Plain (57) (Whittier et al. 1987; Larsen et al. 1988).

In Ohio, similarity exists between the spatial patterns of level III ecoregions and fish assemblages. The spatial similarity mirrors the relationships between ecoregions and water quality that have already been discussed (Larsen et al. 1988; Whittier et al. 1987). The largest differences in fish communities occur between the streams of the Huron/Erie Lake Plain (57) and the

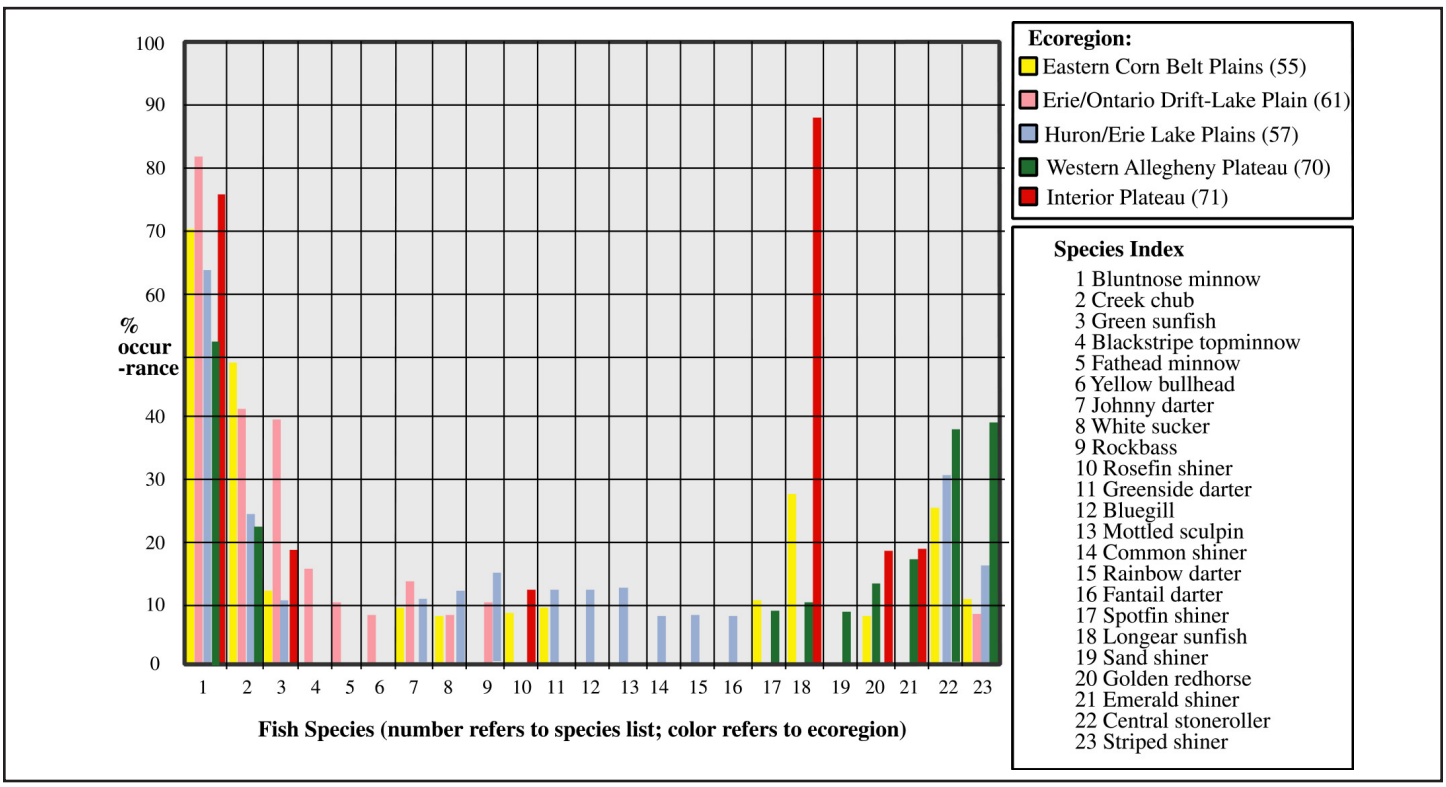

Figure 6. Dominant fish species. Fraction of samples in each Ohio ecoregion in which these species were dominant (from Whittier et al. 1987).

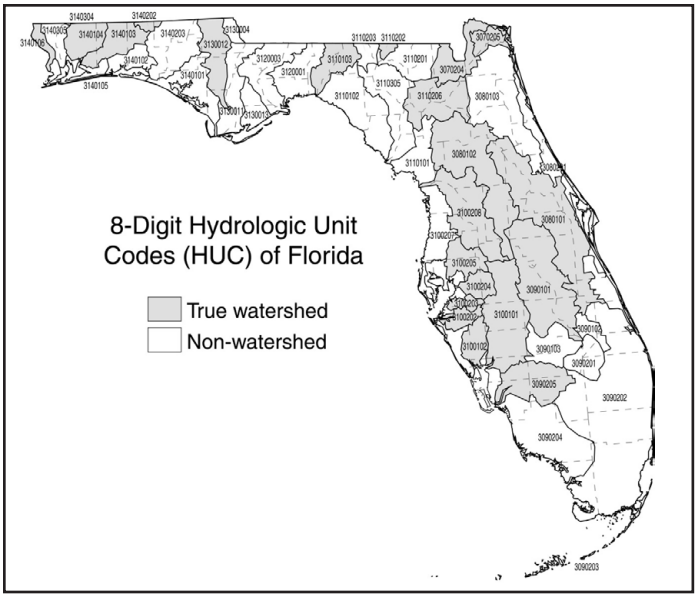

Figure 7. Eight-digit hydrologic units of Florida. Only 40% are true topographic watersheds.

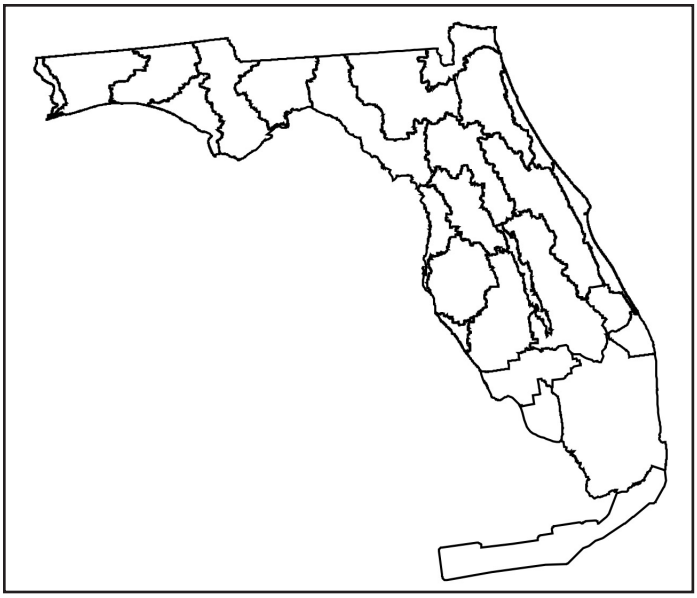

Figure 8. Florida DEP's basin-based ecosystem management areas.

Western Allegheny Plateau (70). These two ecoregions also differ the most in terms of land use and physiography. Dominant fish species in the "least-disturbed" streams of Ohio's 6 level III ecoregions are shown in Figure 6. The streams of the Huron/Erie Lake Plain (57) support relatively depauperate fish assemblages that are tolerant to sedimentation and turbidity (Larsen et al. 1988). In contrast, the fish communities of the Western Allegheny Plateau (70) are less tolerant of sedimentation and turbidity and have greater species richness (Larsen et al. 1988).

In the 1990s, collaborative projects between states, the US EPA, and other federal agencies have refined and subdivided level III ecoregions in more than 20 states. As part of this effort, the six level III ecoregions of Ohio (Omernik 1987) were refined and subdivided into 23 level IV ecoregions (Woods et al. 1998). Each level IV ecoregion is smaller and more homogeneous than the level III ecoregion that it nests within. The ecological influences of field drainage tiling, aquifer discharge rates, mining effluent, soil drainage class, and stream type are better represented by this new, larger-scale ecoregion mapping than they were at the level III scale. For example, the Huron/Erie Lake Plain (57) has been subdivided into four level IV ecoregions: 1) a level and depressional area with very poorly-drained soils; 2) a nearly flat, poorly-drained section; 3) a well–drained sand dune and beach ridge portion; and 4) a region directly underlain by limestone. In another example, the Western Allegheny Plateau (70) has been newly divided into several level IV ecoregions including: 1) a rugged area of high-gradient streams without acidity problems; 2) a less rugged section without acidified streams; 3) an area with clayey regolith, unstable hillsides, and high stream turbidity; and 4) portions characterized by coal mining and acidified streams. These more detailed level IV ecoregions will help researchers and managers stratify and explain some of the variation seen in level III ecoregions. The ecoregion framework can be used to report, research, assess, manage, monitor, and extrapolate water quality and other ecological information.

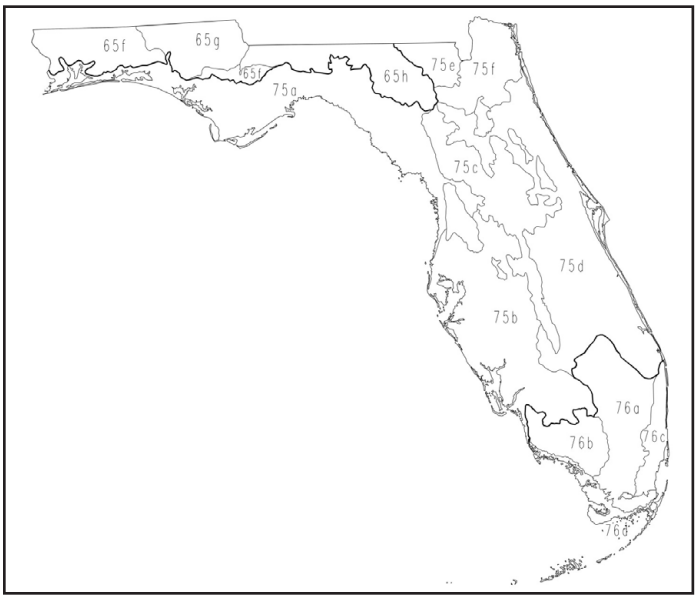

Figure 9. Level III and IV ecoregions of Florida.

Florida. Florida's diversity of water resources is matched by its diversity of water-related institutions that conduct water quality monitoring and assessments. The state has relatively large environmental protection and fish and wildlife agencies, often with strong field district offices, and has powerful water management districts that are aligned along political/hydrological boundaries. Florida's agencies also use a variety of statewide spatial frameworks for water quality management and assessments, including basins, hydrologic units, ecoregions, lake regions, bioregions, and ecosystem management areas.

The 305(b) report on water quality produced by the Florida Department of Environmental Protection (FL DEP) is one of the most detailed in the country, consisting of multiple volumes and many maps and graphics. Similar to most other states, the agency uses a watershed and basin framework to organize and assess water quality, with 4,534 watersheds in 52 major basins or hydrologic units (Paulic et al. 1996).

These 8-digit hydrological units have been selected by many Florida agencies and divisions as the standard basin management unit for monitoring and assessments and implementing the watershed protection approach. Unfortunately, upon closer examination of these 52 "basins" and considering the extent of a few of these hydrologic units in the neighboring states of Georgia and Alabama, most are not true basins or watersheds at all (Figure 7). Only 21 of the 52 units (40%) could be considered true watersheds. With Florida's complex hydrology and flat terrain, the significance of these watersheds for explaining the source and quality of water often is diminished.

Florida also is a national leader in implementing concepts of ecosystem management in their regulatory and environmental protection language and activities, and the FL DEP has an ecosystem management framework (Figure 8). These ecosystem management areas are essentially the major basins of the state, but in some cases are modified by political boundaries, roads, or canals. Management areas also include the Lake Wales Ridge soil region from the STATSGO generalized soils coverage. As the FL DEP (Barnett et al. 1995) defined them, "Ecosystem Management Areas are broad areas...often based on drainage basins or watersheds, that are big enough to allow major hydrological and ecological connections to be addressed on a regional scale."

There are many problems with using a basin or watershed framework for assessing streams and lakes in Florida. Topographic watershed boundaries in Florida are not distinct and frequently can be hydrologically misleading. Florida's hydrology is complex; the groundwater system does not coincide with the surface drainage system, and differences often vary from year to year. But most importantly, differences in lake or stream or ecological characteristics do not coincide with basins or hydrologic units.

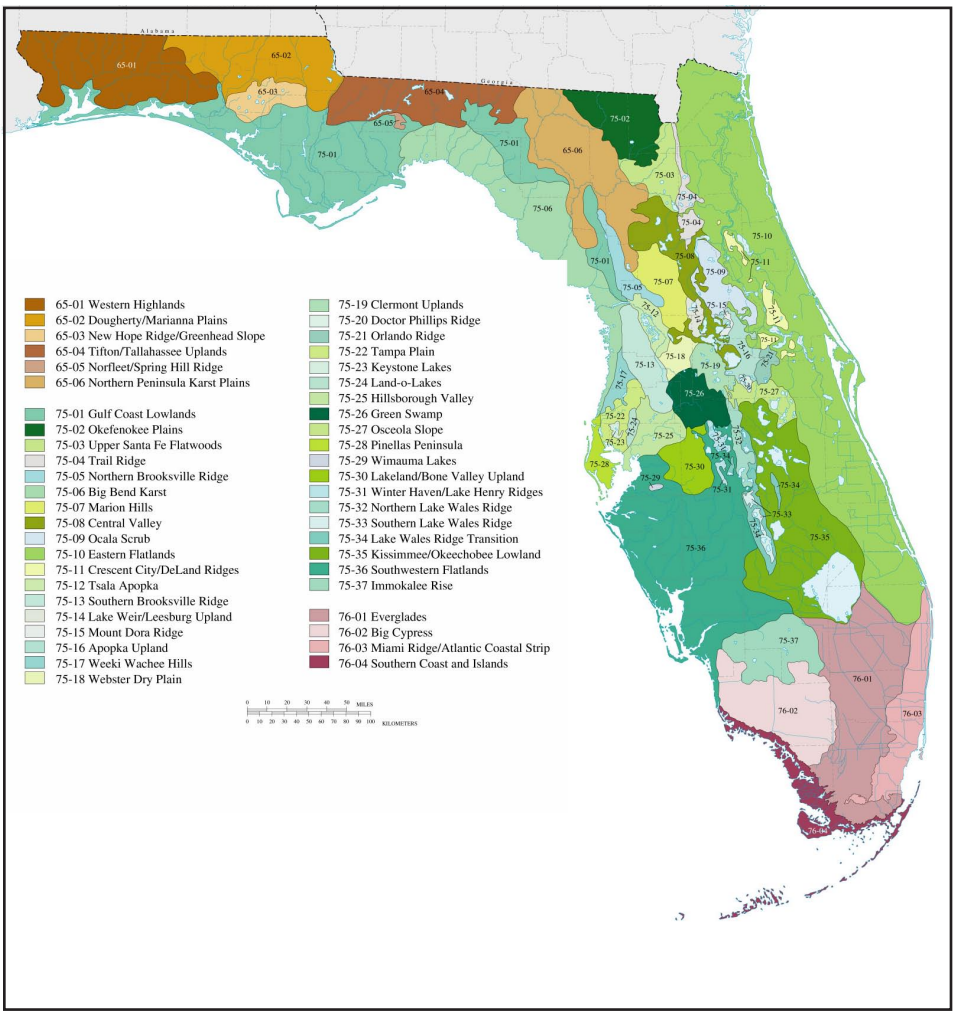

Figure 10. Florida lake regions.

Ecological regions of Florida were defined to help the FL DEP select regional stream reference sites and develop biological criteria for streams (Griffith et al. 1994; Barbour et al. 1996). Thirteen level IV ecoregions were delineated (Figure 9) and more than 80 stream reference sites were sampled. The ecoregions were useful in selecting the reference sites and were originally thought to be needed to discriminate between stream macroinvertebrate communities statewide. Data indicated that the communities could be lumped into three bioregions: the Panhandle (ecoregions 65f, 65g, 65h, and most of 75a), the peninsula (ecoregions 75b, 75c, 75d and part of 75a), and northeastern Florida (ecoregions 75e and 75f) (Barbour et al. 1996). [Ecoregions of the South Florida Coastal Plain (76a,b,c,d) were excluded from this study because they had few natural streams]. The results of this particular stream biocriteria effort and the aggregation of regions highlight the fact that ecoregions might not correspond to the distribution of any one particular feature, in this case stream macroinvertebrates. Ecoregions should be thought of as multipurpose regions intended to organize activities for a holistic approach that considers the spatial patterns in the mosaic of all ecosystem components.

Florida is also serving as a test state for developing lake bioassessment procedures. The FL DEP tried to use the ecoregion framework to pair reference lakes and test lakes in their initial lake bioassessment work, but for statewide lake assessments in Florida, the ecoregion framework was too general and the FL DEP had to go beyond the ecoregion map for the specific purpose of lake management. Although the level III ecoregions have been useful for lake assessment and management in Minnesota (Heiskary et al. 1987; Heiskary and Wilson 1989), neither the level III nor level IV ecoregions were sufficiently helpful in distinguishing different lake areas in Florida. To meet this more specific need for lake management and lake biocriteria development, a lake region spatial framework was developed (Griffith et al. 1997). Regions were defined where there was homogeneity in the physical, chemical, and biological types and characteristics of lakes, or where there was a particular mosaic of lake types and quality associated with landscape features (Figure 10).

In the Florida Panhandle, there is a distinct lake region called the New Hope Ridge/Greenhead Slope. It is a sandy

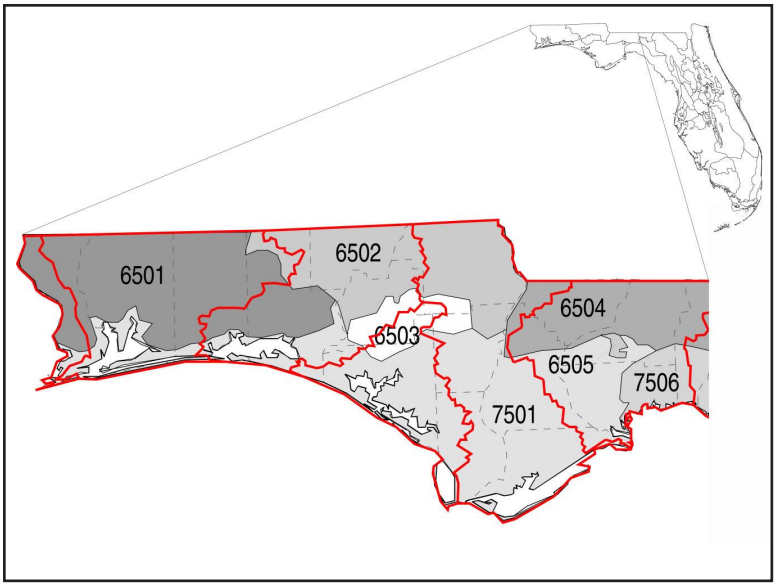

Figure 11. A homogeneous lake region (6503) was split by a basin-based ecosystem management framework (red lines) in the Florida Panhandle.

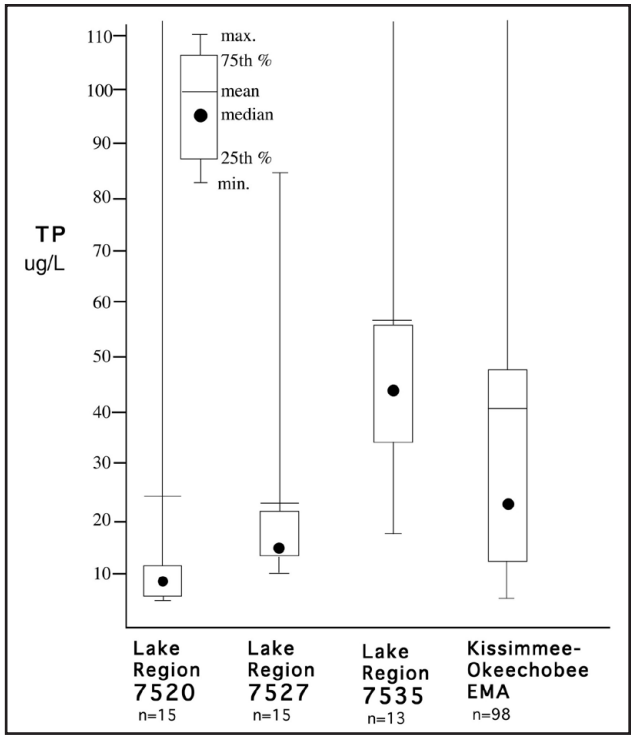

Figure 12. Boxplots of lake phosphorus value distributions in three lake regions within the Kissimmee-Okeechobee ecosystem management area.

upland region with clear, acidic soft water lakes. These are some of the most oligotrophic lakes in the United States. But if one overlays the ecosystem management framework, watersheds, or hydrologic units on this lake region, it breaks the New Hope Ridge (6503) into three different units, based only on rather meaningless surface topography (Figure 11). A homogeneous area of very similar clear, oligotrophic lakes is then broken up into hydrologic units that include a mix of darker water mesotrophic lakes and different ecological characteristics.

In another example, the Kissimmee-Okeechobee ecosystem management area (EMA) in south-central Florida contains several lake regions or portions of regions. By looking at nutrients in the three major lake regions within the basin, it is noted that the first three boxes of phosphorus value distributions (Figure 12) do not have much overlap. Region 7520, Dr. Phillips Ridge, has low nutrient values; region 7527, the Osceola Slope, has low to moderate values, and region 7535, the Kissimmee-Okeechobee Lowland, has higher values. The EMA or basin, lumps these regions together and predictive capabilities are lost.

Although no one spatial framework is likely to be adequate for the variety of resource assessment and management purposes in an ecologically complex state such as Florida, it is apparent that ecoregional areas, rather than hydrological unit areas, are essential for understanding ecological variations. The FL DEP has recently developed a probabilistic sampling scheme to help assess the health of Florida's waters. In explaining this scheme, Bourgeois et al. (1998) gave the warning to "Think before you sample data." One also must think carefully about the framework used to report, extrapolate, and interpret that data.

Lakes and the watershed approach

Lake management strategies regarding protective water quality standards or restoration goals cannot be carried out effectively on a lake-by-lake basis, or by basins or hydrologic units. Management strategies also must consider regional differences in limnological capabilities and potentials. Some state agencies have expressed concern that the emphasis on the watershed approach, or at least its implementation to date, has hurt lake programs and in-lake monitoring (NALMS Government Affairs Committee 1998). Lake assessments can be important for measuring the success of a watershed project as lake quality often reflects longer term watershed conditions.

The Committee for Restoration of Aquatic Ecosystems (National Research Council 1992) recommended that goals for restoration of lakes should be based on the concept of expected conditions for individual ecoregions, and that evaluation techniques based on ecoregion concepts should be encouraged and supported by the U.S. EPA. Recent technical guidance from the U.S. EPA (1998d) gives several examples of how an ecoregion classification is helpful for lake bioassessments and biocriteria development. A continuum of regional frameworks can be useful for assessing lakes, ranging from general purpose to more specific purpose, from ecoregions to lake regions, to themes such as lake phosphorus regions or alkalinity regions (Figure 13).

Conclusions

It is a goal of the U.S. EPA that watersheds and their aquatic ecosystems will be restored and protected to improve human health, enhance water quality, reduce flooding, and provide habitat for wildlife (U.S. EPA 1998b). One objective of this goal is to conserve and enhance the ecological health of the nation's waters and aquatic ecosystems -- rivers and streams, lakes, wetlands, estuaries, coastal areas, oceans, and groundwaters -- so that 75 % of waters will support healthy aquatic communities by the year 2005 (U.S. EPA 1998b). To know if and when we have achieved such an objective, states need adequate resources and proper guidance to conduct better designed and more efficient monitoring and assessments of water quality.

With the recently increased emphasis on watershed indicator and assessment activities, agencies also should recognize

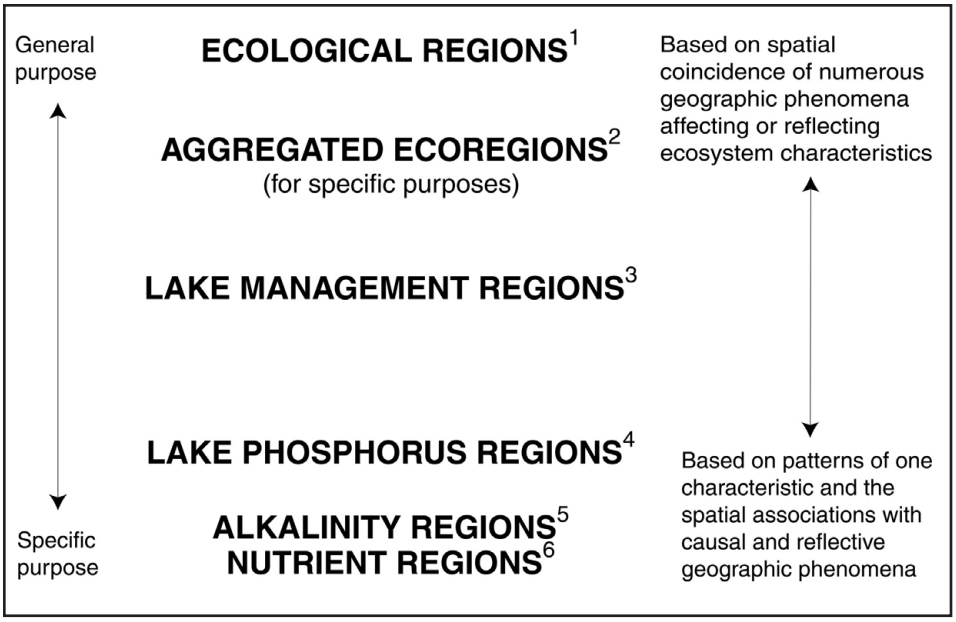

Figure 13. Continuum of regional frameworks for lake assessment and management ([1]Omernik 1987, 1995; [2]U.S. EPA 1998c; [3]Griffith et al. 1997; [4]Omernik et al. 1988, Rohm et al. 1995; [5]Omernik and Powers 1983, Omernik and Griffith 1986; [6]Omernik 1977).

the limitations of state and national assessments of water quality conducted within a hydrologic unit framework. These units usually do not correspond to areas where water quality expectations are relatively similar. Ecological concepts, regional biological criteria, and more effective and statistically-defensible monitoring design need to be incorporated in state water quality programs to help measure environmental results.

Regarding watersheds and ecoregions, it is not an either/or issue; watershed and ecoregional frameworks are both needed, but their purposes and uses differ. Watersheds are necessary for studying land-water relationships, while ecoregions provide prediction and extrapolation capabilities. For depicting areas within which there is similarity in water quality and the mosaic of natural and human related factors that affect water quality and quantity, ecoregions have proven to be effective.

Within both ecoregions and basins, watershed management plans also must account for differences associated with other homogeneous areas or environmental settings that influence water quality (McMahon and Harned 1998). At local levels, links between ecoregional hierarchies and stream habitat classifications also can help scientists and managers better understand aquatic ecosystem patterns and biotic distributions (Bryce and Clarke 1996; Clarke and Bryce 1997). It is becoming evident that a variety of spatial frameworks at different scales might be needed to help integrate landscape data, reference site data, historical and current in-stream data, and expert knowledge to better define attainable conditions for water quality and aquatic life.

Environmental protection programs at all levels of government are evolving, with a transition in several agencies from single-media regulatory programs to more holistic, geographically-based approaches. However, as Cairns (1994) pointed out, the institutional focus and current efforts in watershed management still are centered on components of ecosystems, e.g. lakes, rivers, wetlands, or water quality in general, and not the entire system. Restoration goals and assessment strategies, according to Cairns (1994), should be set by ecoregions. Recently, the U.S. EPA (1998c) has also recognized the importance of an ecoregional framework in the development of nutrient criteria for surface waters.

The growing interest in a more integrated ecological approach to resource management by federal and state agencies, along with recent federal government initiatives to minimize duplication and maximize opportunities for inter-agency cooperation, also has highlighted the need for a common spatial framework of ecological regions. In 1996, a Memorandum of Understanding (MOU) titled "Developing a Spatial Framework of Ecological Units of the United States" was signed by the leaders of nine federal agencies, including the Natural Resources Conservation Service (NRCS), U.S. Forest Service, Bureau of Land Management, USGS, and U.S. EPA. The MOU proposes that the NRCS Major Land Resource Area (MLRA) framework, the U.S. Forest Service National Hierarchy of Ecological Units, and the U.S. EPA Ecoregions framework become a foundation for a common interagency product for classifying and mapping ecological regions at different spatial scales. These existing frameworks differ in important ways regarding their purpose and methods of development, but each framework has evolved, particularly where efforts have been made to include multiple agencies and perspectives in some of the revision projects.

"Common ecological regions" will not necessarily replace the existing frameworks, where these frameworks are found more effective for addressing specific purposes, although it is hoped that when the effort is complete, the boundaries of the individual agency frameworks will have evolved to become more coincident. Some NRCS offices, for example, have used ecoregion mapping products to refine MLRA boundaries and to delineate state-level Common Resource Areas. These Common Resource Areas can be a spatial frame for NRCS Field Office Technical Guide documents used to target the most appropriate conservation practices to a particular ecological area. This work could then be linked to a common interagency ecoregion map to geographically organize and share research, inventory, and monitoring information to help assess soil quality, water quality, rangeland health, forest condition, and watershed health within a region in which natural biotic and abiotic capacities and potentials are similar.

In summary, we believe that water resources can be assessed and managed more effectively by using a framework that reflects the regional differences in their quality, quantity, hydrology, and their sensitivity or resilience to ecological and cultural disturbances. Many of our aquatic ecosystems are resilient, if given half a chance, and are certainly capable of some recovery and restoration. Stewardship can be improved and sustainability can be a goal. Efforts such as multiple-agency collaboration and public and private cooperation to better manage our environmental resources within a regional ecological framework is a step in that direction.

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