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DISTINGUISHING BETWEEN WATERSHEDS AND ECOREGIONS[1]

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ABSTRACT: In an effort to adopt more holistic ecosystem approaches to resource assessment and management, many state and federal agencies have begun using watershed or ecoregion frameworks. Although few would question the need to make this move from dealing with problems and issues on a case by case or point-type basis to broader regional contexts, misunderstanding of each of the frameworks has resulted in inconsistency in their use and ultimate effectiveness. The focus of this paper is on the clarification of both frameworks. We stress that the issue is not whether to use watersheds (or basins or hydrologic units) or ecoregions for needs such as developing ecosystem management and non-point source pollution strategies or structuring water quality regulatory programs, but how to correctly use the frameworks together. Definitions, uses, and misuses of each of the frameworks are discussed as well as ways watersheds and ecoregions can be and have been used together effectively to meet resource management needs.
(KEY TERMS: ecoregions; basins; watersheds; hydrologic units; ecosystem management.)

BACKGROUND

Much of the recent popularity with the terms "watershed" and "ecoregion" has come about because of the attempt by government agencies at regional, state, national, and international levels to adopt more holistic approaches to research, assess, monitor, inventory, and manage their resources. The intent appears to be to shift from dealing with single issues, point-source problems, and micro scales, to a broader approach that considers spatial patterns of the aggregate of natural and anthropogenic interrelationships involving ecosystems and their components. This no doubt stems from a growing realization of the insidious nature of increased human population and modification of environmental resources (Holling, 1994).

To accomplish this redirection, the need for a spatial framework is obvious. The problem is which one. Do we use existing frameworks, or do we need to develop one to fit this particular purpose? Many have felt that watersheds provide the spatial tool necessary for effective research, assessment, and management of ecosystems (Water Environment Federation, 1992; Armitage, 1995; Montgomery *et al.*, 1995; Parsons, 1985; USFWS, 1995; Cannon, 1994; Lotspeich, 1980; FEMAT, 1993; Maxwell *et al.*, 1995; Coastal America, 1994; USEPA, 1996a). However, publications recommending use of the watershed framework do not all agree on how and at what scales this use should be undertaken. For example, Montgomery *et al.* (1995) and the report by the Forest Ecosystem Management Assessment Team (FEMAT, 1993) suggest the watershed (or basin) framework is applicable at two middle hierarchical levels, with physiographic regions or ecological regions (also known as ecoregions), such as we have developed (Omernik, 1995; Bailey, 1995a, 1995b), being appropriate at the broadest level, and project or site delineations being most useful at the more detailed levels (largest scales). Others, such as the U.S. Fish and Wildlife Service (USFWS), recommend use of watersheds, basins, or hydrologic units at all hierarchical levels (USFWS, 1995).

There have been warnings regarding the potential misuse and misunderstanding of watersheds for structuring ecological research and management (Omernik and Griffith, 1991; Hughes and Omernik, 1981; Hughes *et al.*, 1994), but unfortunately such caveats are often veiled (Cannon, 1994; Born and Sonzogni, 1995; Water Environment Federation, 1992). At the Watershed '93 Conference, John Cairns (1994)

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gave a plenary presentation titled "The Current State of Watersheds in the United States: Ecological and Institutional Concerns." Except for its appearance in the title, the word "watershed" can be found only once in the proceedings manuscript. The bulk of the paper was aptly focused on the complexities of ecosystems, what we do not know about them, and ecosystem management and restoration scenarios. Cairns stressed that although lip service is given to it, little understanding exists of ecosystems and ecosystem management in a holistic sense. He stated that current efforts to emphasize watershed management remain focused on components such as water quality. When discussing the spatial extrapolation of ecosystem level restoration activities, Cairns referred to ecoregions rather than watersheds. Repeatedly, Cairns made the point that there has been a reluctance to deal with that in which few have experience and understanding, i.e., ecosystem-level decisions.

Jonathan Cannon (1994), in another paper in the proceedings of the Watershed '93 Conference, strongly endorsed the U.S. Environmental Protection Agency (EPA) watershed approach and cited the "Water Quality 2000" report which stated that watersheds provide the appropriate spatial framework for total environmental and economic planning (Water Environment Federation 1992). He acknowledged the caveat buried in "Water Quality 2000" stating: "In some watersheds, planning and management activities may be more effective in attaining water quality goals if they are organized by ecological regions (sub-watersheds). This is because the natural differences in climate, geology, soil, land form, and vegetation may not conform strictly to hydrologic regions. These features can determine the ecological character of surface water and near-surface groundwater." Notice, however, that in this statement ecoregions are considered "sub-watersheds," indicating at least an imprecise use of terms, if not a lack of understanding of the difference between ecoregions and watersheds and their hierarchical nature.

The purpose of this paper is to clarify the difference between watersheds and ecological regions and to explain some appropriate and inappropriate uses of these spatial frameworks. We will not present a discussion of the different techniques for defining ecoregions. Although we are not in complete agreement regarding the delineation of ecoregions, we share the concern that a spatial framework of watersheds, basins, or hydrologic units has very different purposes than one of ecological regions, and that there is an urgent need to clarify the differences to reduce the misuse of each framework. We also wish to address some common misconceptions about watersheds, ecoregions, and hydrologic units that are germane to their utility for the regionalization of ecosystem management strategies. We stress that it is not an "either/or" argument. Both frameworks have important purposes and are complementary when used together correctly.

DEFINITIONS

Ecoregions

The most glaring difference between the definitions of watersheds and ecoregions concerns the degree of agreement on the definitions. Whereas the definition of the term watershed is fairly widely accepted, there are marked differences of opinion regarding ecoregions and how they can or should be delineated. Much of the difference in approaches to define ecoregions stems from a lack of agreement on a definition of that which we are attempting to regionalize – ecosystems in aggregate (Born and Sonzogni, 1995). Allen *et al.* (1993) claimed that the concept of ecosystem is both widely understood and diffuse and ambiguous. Some question the concept itself (Callicott, 1995; Fitzsimmons, 1996). In discussing the complexities of this problem, Kay and Schneider (1994) stated that most North American ecological journals (particularly U.S. journals) do not consider holistic ecosystem research a fit topic because it does not follow traditional scientific methods in that there are not observer-independent ways of defining ecosystems. The definition of "ecosystem" as it relates to regionalization and ecosystem management (versus individual lakes, streams, wetlands, forests, etc., comprising ecosystems) appears to be evolving (Haeuber and Franklin, 1996; Grumbine, 1994; Barnes, 1993). Originally the definition was centered on the biota and then became thought of as subsuming biotic and abiotic characteristics but in the absence of humans. More recently the term has taken on a more holistic meaning that considers humans as part of the biota (McDonnell and Pickett, 1993; Barnes, 1993; Rowe, 1990, 1992). The definition has also evolved somewhat regarding scale. It is now common to consider ecosystems in a multi-scale sense, from specific sites to global regions, as opposed to mostly relatively homogeneous small areas. Some of the difference in definition is the result of our different educational backgrounds and experiences and differences in the missions of the agencies we work within.

Although the authors of this paper have employed dissimilar approaches in developing ecological regions (Bailey, 1995a; Omernik, 1995), our objectives have been similar, and as we revise our understandings of the meaning of the term "ecosystems" the products of our efforts to refine the ecoregion frameworks are tending to look more alike. In broad terms, ecological regions, at any scale, can be defined as areas with relative homogeneity in ecosystems. Our intent has been to depict regions within which the mosaic of ecosystem components (biotic and abiotic as well as terrestrial and aquatic) is different than that of adjacent regions.

Watersheds

Unlike ecoregions, there is little disagreement regarding the definition of watersheds. Quite simply, they are topographic areas within which apparent surface water runoff drains to a specific point on a stream or to a waterbody such as a lake. There is an infinite number of points from which topographic watersheds can be delineated, although regarding streams, confluences are normally used. Large watersheds are commonly termed basins (e.g., the Colorado River Basin or the Susquehanna River Basin). The hierarchical classification of hydrologic units as mapped by the U.S. Geological Survey (Seaber *et al.*, 1987) is made up of watersheds or segments of watersheds often with adjacent interstices (areas in between). However, at each level of classification, the majority of these hydrologic units are not true topographic watersheds.

Much of the apparent usefulness of watersheds as study units arises from the general understanding that the quantity and quality of water at a point on a stream reflects the aggregate of the characteristics of the topographic area upgradient from that point. However, the conclusion that because of this a framework of watersheds, basins, or hydrologic units is ideally suited for spatially organizing ecosystem management, or even water quality management, is flawed for at least three major reasons. First, and most important, the areas within which there is similarity in the aggregate of geographic characteristics related to the quality and quantity of environmental resources seldom if ever correspond to patterns in topographic watersheds. Second, in many xeric regions of the country where watersheds can be defined and "influent" streams predominate (where streams feed the groundwater, as compared to "effluent," where the groundwater feeds the streams), topographic watersheds do not encompass the same integrating processes as in mesic and hydric areas. Third, in many areas watersheds are difficult or impossible to define (Hughes and Omernik, 1981). These types of areas comprise roughly a third of the conterminous United States (Figure 1). Regions of continental glaciation, deep sand, karst topography, flat plains, and xeric climates all fall into this category. More than one of these conditions occur in many areas making the problem more complex.

Many parts of the country that have been affected by continental glaciation are pocked with lakes, potholes, swamps, and marshes where surface water does not drain directly into streams. Although most of the Midwest, much of the Northeast, and the northern fringe of the western United States contain these characteristics, they are most common in North Dakota, Minnesota, Wisconsin, and Michigan (Figure 2). Delimiting the watershed boundaries of large rivers can be approximated fairly accurately in much of this region, but that is not the case with many of the smaller streams. Other parts of the country where watershed delimitation is particularly problematic include the nearly level, karst and sand dominated state of Florida, the Sand Hills of Nebraska, the semiarid karst and playa lands of west Texas and Oklahoma and eastern New Mexico, and the deserts of western and southwestern United States.

USE AND MISUSE OF ECOREGIONS

Ecoregions are intended to provide a spatial framework for ecosystem assessment, research, inventory, monitoring, and management. These regions delimit large areas within which local ecosystems reoccur more or less throughout the region in a predictable pattern. By observing the behavior of the different kinds of systems within a region it is possible to predict the behavior of an unvisited one. This affords the extrapolation mechanism for identifying areas from which site specific knowledge on ecosystem behavior can be applied. As such, they also suggest areas within which similar responses and management strategies are applicable (Bailey, 1987). Ecoregions should be thought of as multi-purpose regions, designed to show areas within which the aggregate of all terrestrial and aquatic ecosystem components is different from or less variant than that in other areas. They provide a common spatial framework for the various resource management agencies responsible for different aspects of the environment (e.g., forests, fish and wildlife, wetlands, water quality, and agriculture) to organize their activities as they move toward a more holistic ecosystem approach that requires consideration of all aspects of the environment.

Applications of ecoregions are appropriate at various scales. International applications include the analysis of types and distributions of protected areas across North America, the evaluation of the representativeness of these areas, and the assessment of cross-boundary environmental impacts related to the North American Free Trade Agreement(NAFTA) (Wiken and

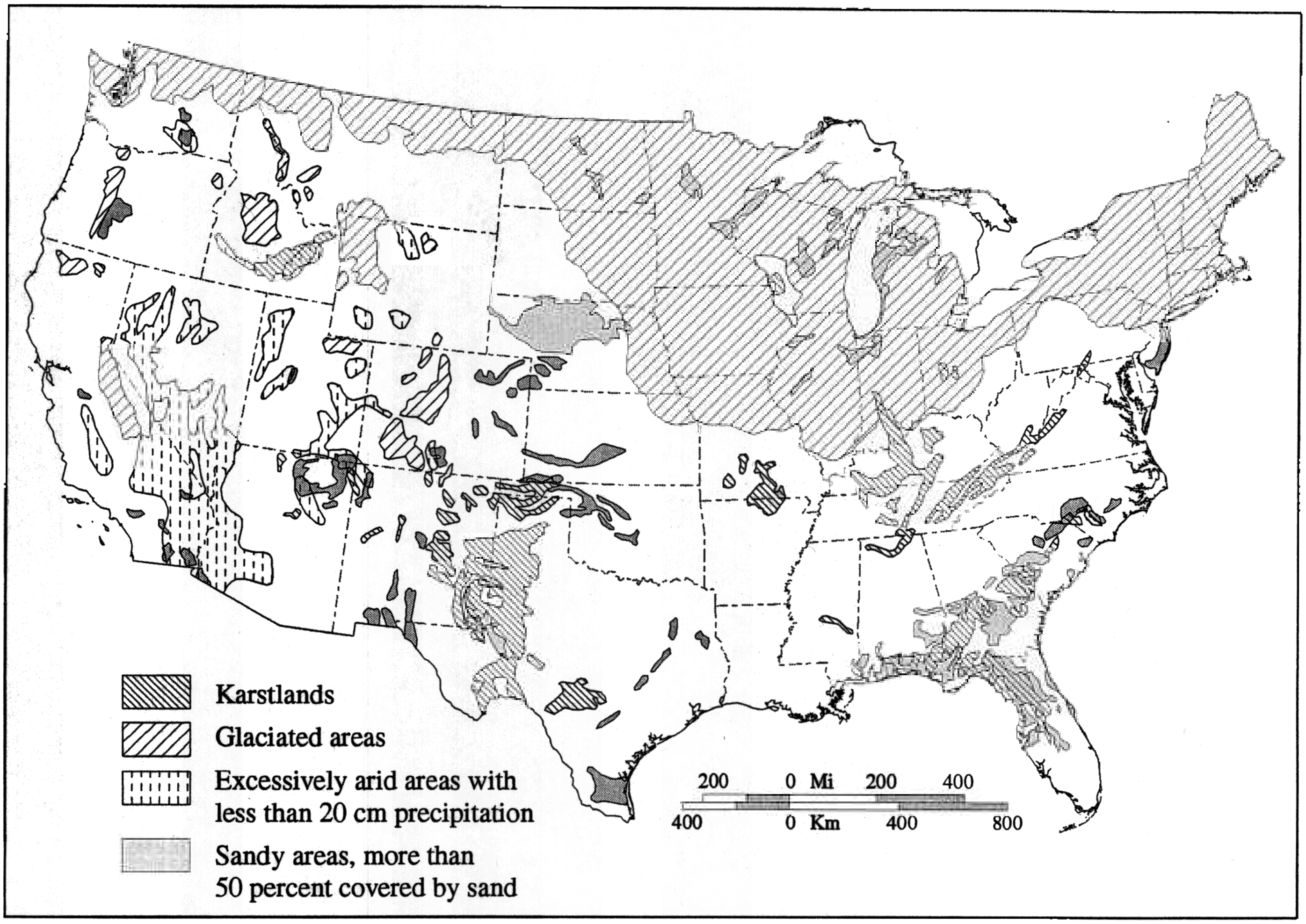

Figure 1. Characteristics That Hinder or Preclude Watershed Delineation. (Adapted from Hughes and Omernik, 1981.)

Lawton, 1995; Commission for Environmental Cooperation Working Group, 1996). At national levels, existing monitoring networks of research sites, such as those of the Long Term Ecological Research (LTER) network, can be compared to ecoregion maps to determine where representation is inadequate and additional sites are needed (Bailey, 1995a). In recommending a national aquatic ecosystem restoration strategy for the United States, the National Research Council stated that restoration goals and assessment strategies should be established for each ecoregion (National Research Council, 1992). Canada's uses of ecoregions include reporting on the state of the environment in that country, developing protected area strategies, and developing regional indicators of forest disturbance and biodiversity (Government of Canada, 1991; Ecological Stratification Working Group, 1995).

The most common usage of ecoregions within the United States has been at the state level where the framework has been central to structuring environmental resource regulatory programs and management strategies. The effectiveness of ecoregions for stratifying stream water quality information has been demonstrated in many states including Arkansas (Rohm *et al.*, 1987), Iowa (Wilton, 1996), Nebraska (Bazata, 1991), Ohio (Larsen *et al.* 1986, 1988), Oregon (Hughes *et al.*, 1987; Whittier *et al.*, 1988), Texas (Hornig *et al.*, 1995), and Washington (Plotnikoff, 1992). State resource management agencies in these states have used ecoregions primarily to set water quality standards and to develop biological criteria and nonpoint source pollution management goals. Davis *et al.* (1996) reported that as of 1995, 15 states were using ecoregional reference conditions in their biological assessment programs and another 24 states were in the process of developing similar programs.

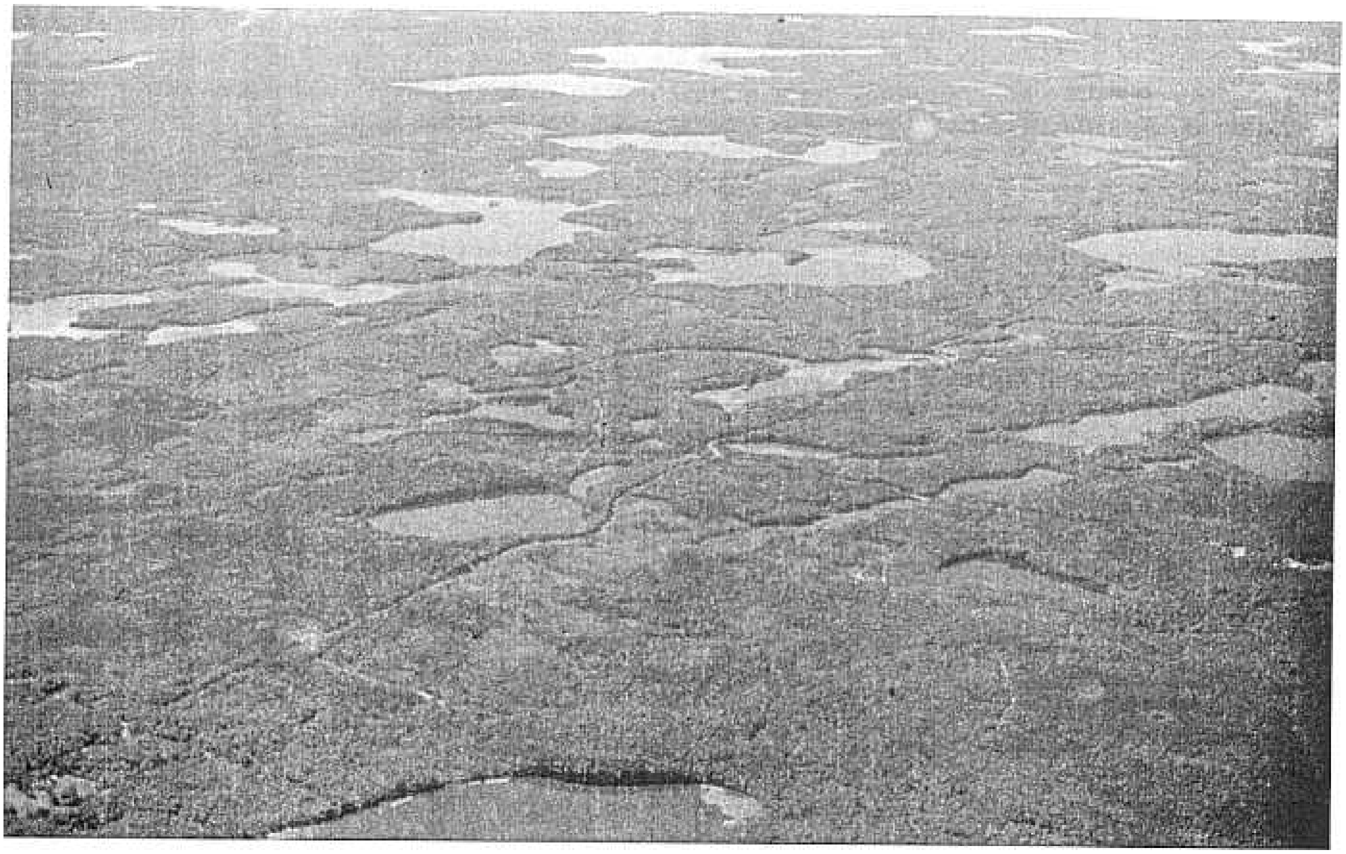

Figure 2. In Many Regions Affected by Continental Glaciation, Such as This Area in Northwestern Wisconsin, Streams are Lacking, Many Lakes Have No Inlets or Outlets, and the Topographic Watersheds of Rivers Can Only be Approximated.

As with any framework, ecoregions can be and have been misused and misunderstood. Ecoregions have not been designed for regionalization of a particular characteristic. A number of studies have attempted to evaluate the usefulness of ecoregions by comparing them to patterns of specific factors such as fish assemblages, wildlife communities, particular hydrologic characteristics, and macroinvertebrate distributions (e.g., Lyons, 1989; Inkley and Anderson, 1982; Poff and Allan, 1995; Poff and Ward, 1989; Spindler, 1996). Although in nearly every case the ecoregions and subject of study were determined to be generally correlated, it is not surprising that other spatial characteristics were often found to be more helpful. For example, elevation and watershed size were found to be more useful than a coarse level of ecoregions in explaining differences in macroinvertebrate community structure in Arizona streams (Spindler, 1996). Had a lower, more detailed hierarchical level of ecoregions been available for Arizona that would have reflected zonal (without the effects of landform) differences in vegetation, precipitation, soils, and hydrologic characteristics, ecoregions would have shown a stronger correlation. Hence, part of the issue here is recognition of the most appropriate hierarchical level of ecological regionalization. However, in this case and others, the bulk of the misuse and misunderstanding of ecoregions centers on recognition of their purpose and appropriate methods of evaluating them. Ecoregions are generally useful for structuring the research, assessment, and management of all environmental resources, but may not be the best framework for any one particular resource. Most important, however, ecoregions provide the spatial tool necessary to address the health, integrity, and quality of the aggregate of environmental resources.

USE AND MISUSE OF WATERSHEDS

Watersheds have been and will continue to be a critical spatial framework for scientific study of the effects of natural and anthropogenic phenomena on water quality and quantity. Hundreds, or perhaps thousands, of studies on the effects of agricultural and silvicultural practices have been based on data generated in small (between a hectare or two to tens of square kilometers in size) watersheds. Much of the LTER work has been conducted in watersheds at places such as Coweeta, Hubbard Brook, and H. J. Andrews (Franklin *et al.*, 1990; Risser *et al.*, 1993). The authors have depended on watershed data for evaluating the effectiveness of ecological regions (e.g., Bailey, 1984; Hughes *et al.*, 1986) and stream buffer strips (Omernik *et al.*, 1981), for clarifying nonpoint source – stream nutrient level relationships (Omernik, 1977), and for mapping sensitivity of surface waters to acidification (Omernik and Powers, 1983; Omernik and Griffith, 1986) and lake phosphorus regions (Rohm *et al.*, 1995; Omernik *et al.*, 1988). However, for the effective extrapolation of these watershed data one must know the larger regions within which similar characteristics exist. These larger regions seldom correspond to watersheds or basins. Whereas the watersheds serve as the study units, ecological regions, rather than watersheds, provide the extrapolation mechanism.

Much of the use of a watershed as a spatial unit stems from our basic understanding of watershed functions (Black, 1997) and how they relate to flood forecasting and prevention or water supply for agricultural, urban, and industrial use. However, even though the purpose of watersheds for tracking water supply is clear, use of the framework in a social-science context is not self evident (Ciriacy-Wantrup, 1961). The physical and economic conditions relative to watershed functions have little correlation with patterns of consumption (Ciriacy-Wantrup, 1961) or with the distributions of most geographic phenomena that affect or reflect spatial differences in ecosystem health, integrity, and quality (Omernik, 1995).

Watershed-type frameworks are widely used by resource management agencies. Although a few are changing, or considering changing, to ecoregions, most state environmental resource management agencies presently use basins or hydrologic units (Seaber *et al.*, 1987) to organize their semi-annual 305b reports to Congress [in response to Section 305 (b) of the Federal Water Pollution Control Act of 1972 (Public Law 92-500)] on the status of water quality in their state. Following guidance from the USEPA Office of Water, a number of states have recently adopted river basin or watershed approaches to address their resource assessment and management needs (USEPA, 1995, 1996a, 1996b). We believe it is inappropriate to promote the use of watersheds as an extrapolation tool for these purposes. State, regional, and national level management strategies, particularly those involving ecosystem management, require a spatial framework that considers the regional tolerances and capacities of the landscape. Ecoregions were designed to fill that need and identify areas with similarity in the combination of geographic phenomena that cause and reflect regional differences in the quality of ecosystems and ecosystem components (Omernik, 1995; Bailey, 1995a). Watersheds and basins do not correspond to these patterns.

However, we stress that basins and watersheds *are* the appropriate spatial unit for resource management agencies to assess the relative contribution of human activities to the quality and quantity of water at specific points on streams and on particular water bodies. Because they integrate the surface and subsurface flow of water upgradient from the point at which measurements are made, watersheds allow drainage basin-specific accountings to be made of factors such as point and nonpoint source pollutants, whose transport is associated with the movement of water. Watersheds are essential for these purposes.

In developing a spatial framework for implementing an ecosystem approach to fish and wildlife conservation, the USDI Fish and Wildlife Service adapted the U.S. Geological Survey's hydrologic unit map (USFWS, 1995). One cannot argue the importance of drainage divides in helping to explain spatial differences in fish assemblages and abundance, although ecoregions have also been shown to be important (Hughes *et al.*, 1994; Hughes *et al.*, 1987; Lyons, 1989; Whittier *et al.*, 1988; Pflieger, 1971). On the other hand, the watershed framework does not seem appropriate if the intent of the USFWS was to adopt a holistic approach to assessment and management. Such an approach would recognize patterns in the quality, quantity, and similarity in interactions of all ecosystem components. Most of these components have little or no association with drainage divides.

A recent publication by the U.S. Forest Service titled "A hierarchical framework of aquatic ecological units in North America (Nearctic Zone)," (Maxwell *et al.*, 1995) outlines a classification scheme for what they term "aquatic ecological units." It describes a rather complex hierarchical framework of aquatic units under an umbrella of "zoogeographic" zones, subzones, regions, and subregions (which are different hierarchical levels of watersheds and hydrologic units). Although the publication attempts to establish a linkage with ecoregions (which they term "geoclimatic settings"), we believe it errs by inferring that watersheds, groups of watersheds, or hydrologic units form the primary framework for dividing ecosystems. Moreover, the reader could easily draw a second erroneous inference that aquatic and terrestrial ecosystems need to be considered separately. An "ecosystem approach" recognizes that ecosystem components do not function as independent systems, rather they exist only in association with one another (Bailey 1995a).

Boundaries of ecological significance emerge from studies that reveal corresponding change in ecosystem components. This is different from attempting to synthesize ecosystem units by addition of components initially defined as things in themselves, with no whole unit in mind. If we follow the rationale for separate but equal systems, one could argue that we need separate maps for soils, timber, range, water, fisheries, etc. Analyzing resource interactions is difficult because each discipline selects its own unit of land for analysis (e.g., stands of trees for foresters and watersheds for water-quantity analysts). Decades of research and field operations by a host of practitioners have produced spatial classifications that deal with resources as singular and independent items. What is needed now is a new approach that provides a basis for a firm understanding of the relationships and interactions of resources on the same unit of land. An ecosystem approach to resource evaluation stresses the interrelationships among components rather than treating each as separate characteristics of the landscape. It provides a basis for making decisions about resource interaction. To accomplish this, we believe that the terrestrial and aquatic components must be considered together at the same time, rather than after separate classifications have been developed.

Like the USFWS (1995) framework, the alignments of the ecological regions suggested by Maxwell *et al.* (1995) follow drainage divides. Three hierarchical levels of these regions, termed zoogeographic settings, were proposed. In providing a rationale for using watersheds and drainage divides, Maxwell and his colleagues claimed that watersheds provide a natural nested hierarchy for ecological stratification over a wide range of scales, and that watersheds integrate many physical, chemical, and biological processes affecting the form and function of both aquatic and terrestrial ecosystems. However, spatial patterns of most of the principal factors that determine the integrity of surface water resources (Karr, 1991; Yoder, 1995) generally do not correspond well to patterns of watersheds, but they do correspond to ecoregions (Hughes *et al.*, 1994; Larsen *et al.*, 1988; Brown and Brown, 1994). Factors such as physical habitat, water chemistry, energy sources, and biota are directly associated with the aggregate of factors (climate, geology, physiography, soils, and land cover characteristics including vegetation) that are used to define ecoregions.

CLARIFYING HYDROLOGIC UNITS

There is also a common misunderstanding that hydrologic units do in fact comprise watersheds. For example, in a well meaning effort to implement a spatial and more integrated approach to environmental resource management, particularly regarding water quality programs, the EPA has recently advocated a "watershed approach" (USEPA, 1995, 1997). This approach emphasizes "managing by watersheds" and recommends use of U.S. Geological Survey hydrologic units (Seaber *et al.*, 1987) which are claimed to "provide a common national framework for delineating watersheds and their boundaries at a number of different geographic scales" (USEPA, 1995). Another EPA Office of Water publication, accompanied by a set of maps, is directed toward characterizing "the aquatic condition and vulnerability of each of the 2,150 watersheds in the continental United States" (USEPA, 1997). Watersheds in this publication are defined as the eight digit cataloging units of the U.S. Geological Survey hydrologic unit system. Aside from providing additional examples of misuses of watersheds, the problem here is that it is not possible to divide the country, any state, or as far as we know, any county, into a finite number of topographic watersheds. For instance, in Tennessee only four of the eleven "accounting level" hydrologic units covering the state are true topographic watersheds (Seaber *et al.*, 1987)(Figure 3). Most are segments of watersheds with adjacent interstices. Less than half (26 of 54) of the "cataloging units," the next more detailed hierarchical level of hydrologic units, that are partly or completely in Tennessee, are true topographic watersheds (U.S. Department of the Interior, Geological Survey, 1974).

One reason given by the USFWS for their decision to use what they term "watershed based units," was that "watersheds are discrete physical units that provide widely recognized and generally well-defined boundaries" (USFWS 1995). Another reason given was "watersheds provide a vehicle to consider the critical linkages between upstream and downstream effects." The implication here is that the hydrologic units they adapted and the "watershed based units" are at least similar to true topographic regions where the limits of apparent surface water runoff can be clearly defined, and that the stream system within these spatial units provides the pathways for interactions of the ecosystem components. However, of the 41 USFWS "watershed based units" defined for the conterminous United States, only 17 percent are actually topographic watersheds. One of these units, the Mississippi Headwaters/Tallgrass Prairie straddles a continental divide; the northwestern portion drains north

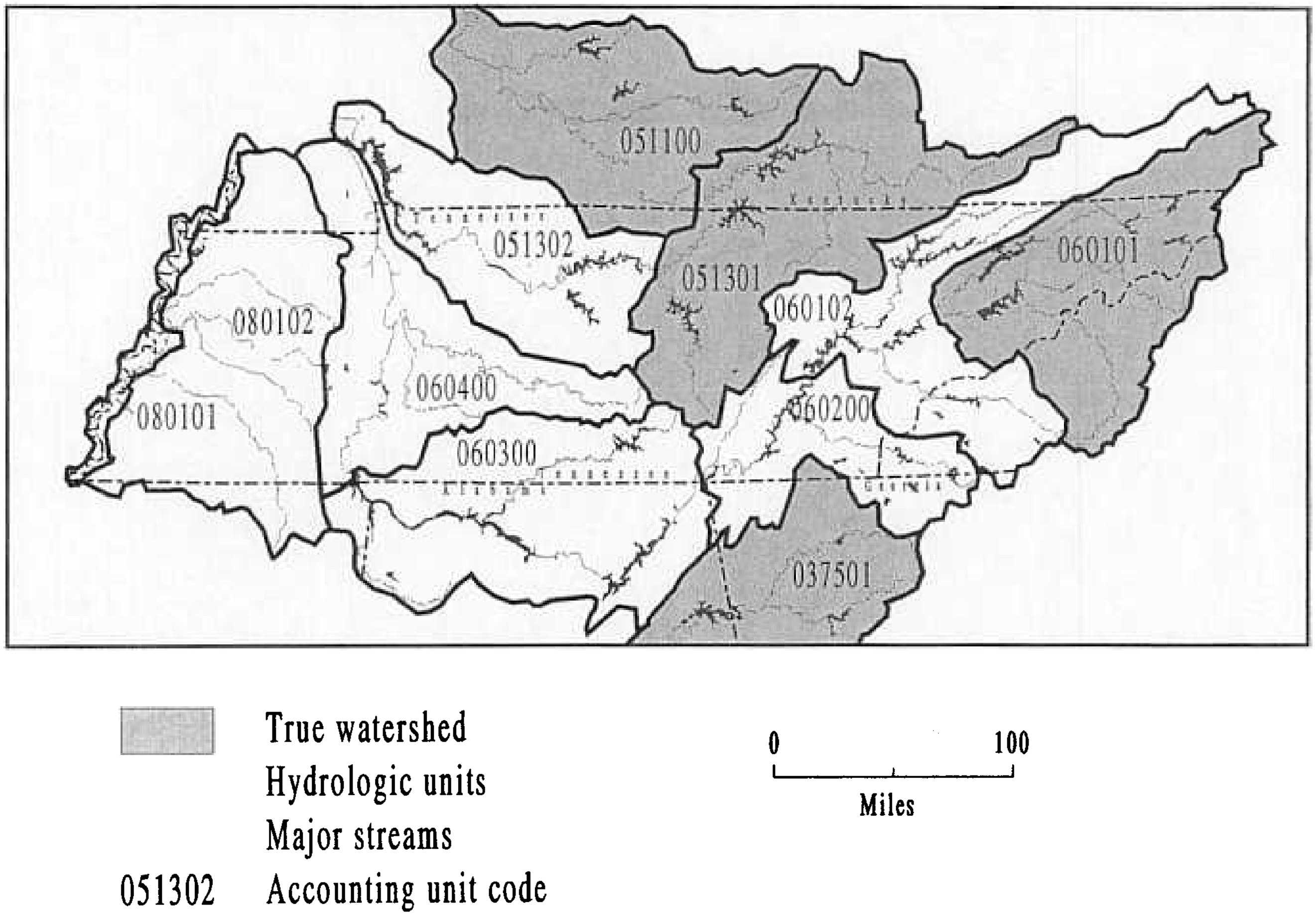

Figure 3. Accounting Level Hydrologic Units of Tennessee That Are True Watersheds. (Adapted from Seaber *et al.*, 1987.)

to the Hudson Bay, whereas the southeastern part is in the Mississippi drainage system. More important, from a standpoint of suitability for framing ecosystem or water quality assessment and management, this "watershed based unit" covers distinctly different ecological regions, which are based on entirely different criteria. The unit encompasses a large part of a region of nutrient poor soils and high quality lakes and forests in northwestern Wisconsin and northeastern and central Minnesota, as well as sections of several formerly prairie but now largely agricultural regions – the Corn Belt in southern Minnesota, the flat Lake Agassiz Plain (Red River Valley), and the semi-arid prairie pothole country of North Dakota. Hence, not only do hydrologic units lack spatial correspondence to areas within which there is similarity in the quality and quantity of surface waters and the factors associated with spatial differences in quality and quantity, most are not true topographic watersheds.

THE NATIONAL NETWORK OF HYDROLOGIC BENCH MARKS

The U.S. Geological Survey's Network of Hydrologic Bench Marks, as envisioned by Luna Leopold, and Leopold's proposal for an international "Vigil Network," reflect the need to couple watersheds with ecological regions (Leopold, 1962a). Although Leopold did not use the terms ecosystems and ecoregions specifically (those terms were not as commonly used in the late "50s" and early "60s" as they are now), the implication is clear. Leopold recognized the need for a system of regionally representative, *small* watersheds for which "field observations of the same kind in many places would improve our understanding of the hydrologic and biologic aspects" of ecosystems (Leopold, 1962a). These measurements he stated would "enhance our opportunity to distinguish between the effects of man and nature on the environment" (Leopold, 1962b). The key element of Leopold's vision was that each of these small watersheds "would be chosen to represent a typical area in a general region – that is typical in its general geology, vegetation, slopes, topography, and land use" (Leopold, 1962a).

Regrettably, the eventual design of the National Network of Hydrologic Bench Marks did not adequately result in a system of regionally representative watersheds. Leopold's vision regarding regional representativeness differed from that of Langbein and Hoyt (1959), who originally proposed the network, and that vision was not reflected in the subsequent design (Biesecker and Leifeste, 1975; Briggs, 1978). Whereas Leopold stressed that the bench marks be typical of the regions they represent, yet relatively undisturbed, Langbein and Hoyt were mainly concerned that the bench marks be located in places where anthropogenic impacts and future modification would be minimal. "National and state parks or public lands purposely withdrawn from entry" were to be considered first for selection of stations (Langbein and Hoyt, 1959). Because many of our parks contain anomalous landscapes and were selected for preservation due to these characteristics rather than that they typified the larger ecological regions they occupy, many of the bench mark stations are also anomalous. Crater Lake in the Cascade Mountains is probably the best example of a bench mark which is unique and not at all representative of the larger region it occupies. The North Fork of the Quinault River in Washington is another example. The headwaters of the Quinault are in the Olympic Mountains where glaciers produce milky colored streams atypical of streams in the lower elevation Coast Range where there are generally mild winter conditions and no glaciers. Streams draining the high Olympic Mountains, although situated in the Coast Range, tend to be more like those in the North Cascade Range of Washington and British Columbia.

The National Network of Hydrologic Bench Marks also missed its intended goal regarding coverage of sites and maximum watershed size. The eventual network contained considerably less than the 100 watersheds thought necessary by Langbein and Hoyt (1959), and the size criteria that each watershed be less than 100 square miles was not followed. Biesecker and Leifeste (1975) reported the network to contain 57 stations and Briggs (1978) reported 51, of which only 39 drained watersheds less than 100 square miles.

USING WATERSHEDS AND ECOREGIONS TOGETHER

Discussions of the appropriateness of watershed and ecoregion frameworks for environmental resource management are unfortunately often divisive, arguing for one structure over the other. However, although the two frameworks have very different purposes, they can be used together to effectively help assess and manage environmental resources. In areas where watersheds are relevant and can be defined, both ecoregions and watersheds are necessary for developing a system of regional reference sites enabling an understanding of the attainable quality, integrity, and health of ecosystems and their components. A true ecosystem approach for reaching these objectives requires consideration of the mosaic of biotic and abiotic components in both the aquatic and terrestrial environment. Watersheds, in part, facilitate this meshing. For those areas where watersheds cannot be defined, where they are of little relevance (e.g., in xeric areas), and where there are few if any streams (e.g., parts of the Prairie Pothole region and the western part of the Nebraska Sand Hills), relevant representative "areas" rather than watersheds must be chosen. For the bulk of the country, however, ecoregional reference sites will comprise watersheds. We therefore define these reference sites as watersheds or areas that are representative of the ecoregions they occupy, but that are relatively unimpacted (Hughes, 1995; Omernik, 1995; Hughes *et al.*, 1986).

Watersheds and ecoregions can be complementary tools. The characteristics of the portions of large watersheds that cover more than one ecoregion will be different in each of the ecoregions they cover (Bailey, 1995a). For example, the portions of the Platte River watershed that are in the largely forested Rocky Mountains contribute differently to the quality and quantity of the Platte River than portions in the much drier Great Plains. Depending on the ecoregion their watersheds are within, streams flowing into the Platte have very different thermal characteristics, gradients, aeration, and resultant biota (Figure 4). Watersheds that are within similar ecoregions tend to be similar to one another and different from those of other ecoregions (Omernik and Griffith, 1991). Although no two watersheds are alike, regarding their quality and quantity of water and mosaic of ecosystem components, the variation in characteristics between watersheds within the same ecoregion will tend to be less, or of a similar nature, as compared to other ecoregions. For example, within the United States, all watersheds that are completely within the Great Plains are similar to one another, as compared to those of the eastern temperate forests, as compared to those of the xeric basin and range country in the west, and so on. Each of these broad ecoregions contains a particular mosaic of geographic phenomena (including climate, physiography, geology, soils, and land cover) that cause or reflect differences in capacities and potentials of ecosystems. These

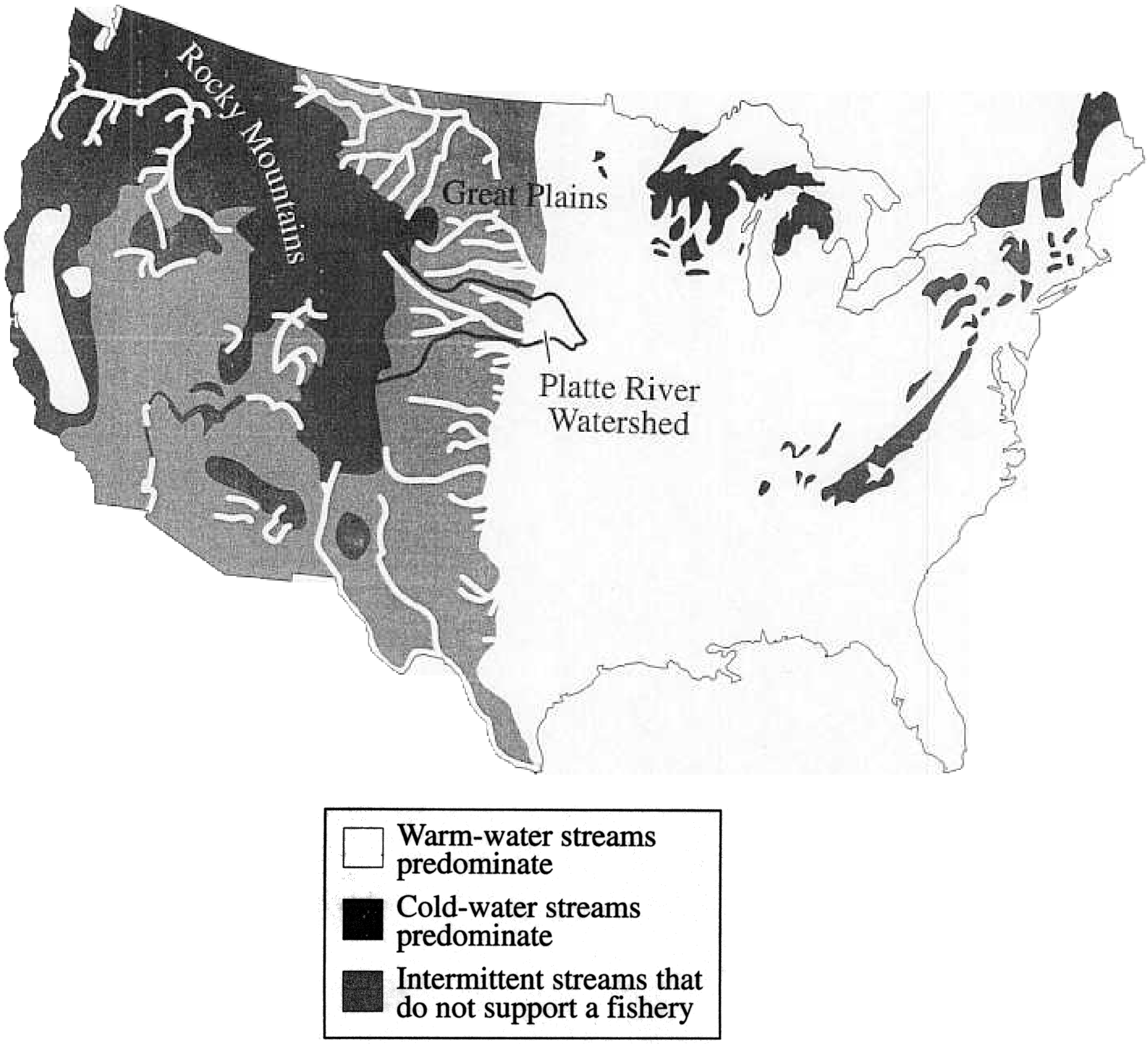

Figure 4. Locations of Streams That Support Warm-Water and Cold-Water Fish and Streams That Do Not Support Fishery (as mapped by Funk, 1970) within the Platte River Watershed (as mapped by the U.S. Geological Survey, 1979).

ecoregions can also be used for the assessment of ecosystem health, quality, and integrity. Lower level, smaller ecoregions that are nested within the larger ecoregions also contain similarities in these phenomena, but they generally contain less variability. Hence watersheds that are completely within each of these smaller ecoregions will be more similar to one another than those of other parts of the larger ecoregions within which they are nested. Watersheds that straddle two different ecoregions will reflect the characteristics of both ecoregions.

Maxwell *et al.* (1995) attempted to address a way watersheds or basins and ecoregions (which they termed geoclimatic units) could be used in a complementary fashion. In our view, there are at least two flaws encompassed in their suggestion: first, they have selected basins or watersheds as the primary meaningful integrating spatial units; and second, they recognized the importance of ecoregions at only one hierarchical level. The example used by Maxwell *et al.* (1995) centered on defining fish distributions and their general habitats, but the overall purpose of the framework they proposed was much broader, encompassing the classification of aquatic systems and ecological analysis of these systems. Although they stated "watersheds can be characterized and assessed on the basis of the geoclimatic setting in which they are found," which could be interpreted as being in agreement with the explanation we presented in the preceding paragraph, the spatial framework they recommended is clearly one of hydrologic units or basins, and not ecoregions. Ecoregions as useful spatial units were only recognized at what they term the "subbasin" level. Here, Maxwell *et al.* (1995) stated that basins "may be divided into subbasins based on physiographic criteria that define different physical-chemical habitat patterns inhabited by distinct species groups." Watershed patterns, they claimed, are defined by similarity in settings and features using information on geoclimatic pattern, zoogeographic pattern, morphology, and disturbance. However, as we have previously noted, areas within which there is similarity in geoclimatic and biologic characteristics, as well as anthropogenic disturbances, seldom correspond to topographic watersheds.

To illustrate the way watersheds and ecoregions can be used together we have adapted a figure from Maxwell *et al.* (1995), and have substituted the term ecoregion for subbasins (Figure 5). In general, the aquatic and terrestrial characteristics of watersheds C, D, and E will be similar to one another and dissimilar to characteristics of watersheds A and B as well as those of F, G, and H. Because the Santee and Savannah basins cover the same ecoregions, the water quality near the mouth of both rivers can be expected to be similar, unless human impacts within the basins are dissimilar. The groups of basins shown on Figure 5 comprise one aquatic ecological unit (the South Atlantic Subregion) of the framework suggested by Maxwell *et al.* (1995). However, from an ecosystem management standpoint, this unit has little meaning. Information for aquatic resource needs, such as water quality standards or biological criteria, that are based on information gathered in reference watersheds/areas in the Coastal Plain will not be applicable in the Piedmont or Blue Ridge portions of this hydrologic unit. However, this information can be extrapolated elsewhere in the same ecoregion, regardless of whether it fits within the South Atlantic Subregion.

Hence, although the watershed framework must often be used to determine regional reference conditions, resource management agencies must first recognize the ecoregions within which ecosystems and the quality and quantity of environmental resources are similar. An ecoregion framework, versus one of basins or watersheds, provides a more effective tool for extrapolating reference conditions, whether they are relative to disturbed, relatively unimpacted, or historic conditions. Basin wide management strategies and planning, while an improvement over dealing with pollution problems on point or site bases, may be misleading in that the plans and strategies often do not fit the regional potentials of the land and water, unless ecoregional differences are determined. Basin or watershed studies, where the interest is on the quality or quantity of water at a specific point, can be conducted relatively quickly if ecoregions and ecoregional reference conditions have been previously determined.

To develop a network (regional, national, or international) of ecoregional reference sites requires building on Leopold's (1962a, 1962b) vision of the National Network of Hydrologic Bench Marks, with the key aspects being regional representativeness and relative lack of disturbance. A third critical element is the number of sites necessary. In order to provide an adequate understanding of the natural variability within and between ecological regions, determine the relative importance of human impacts, and develop scenarios regarding attainable quality of ecosystems and their components, a large number of reference sites will be needed. Sets of watersheds/areas that are, for the most part, completely within ecoregions will be needed for each ecoregion. The number and size of reference watersheds or areas needed will vary from one ecoregion to another and are dependent on the size and heterogeneity of each ecoregion (Hughes, 1995; Omernik, 1995, Bailey, 1991).

CONCLUSION

The current interest in adopting a more holistic ecosystem approach to resource assessment and management has agencies, programs, and individuals scurrying to map shelves for spatial frameworks to help implement the approach. The recent U.S. General Accounting Office (GAO) report on ecosystem management emphasized the need for delineating ecosystem boundaries and noted that management must be along ecological rather than political or administrative boundaries (U.S. GAO, 1994). In commenting on the GAO report, Jack Ward Thomas, then Chief of the U.S. Forest Service, stressed that the process of agreeing on an ecological classification system "should not be one of selecting a watershed approach over an ecoregion approach, but how to best use these tools to assess the condition of the nation's ecosystems." Although ecoregions and watersheds are intended for different purposes, they can be complementary. Ecoregions provide the spatial framework within which the quality and quantity of

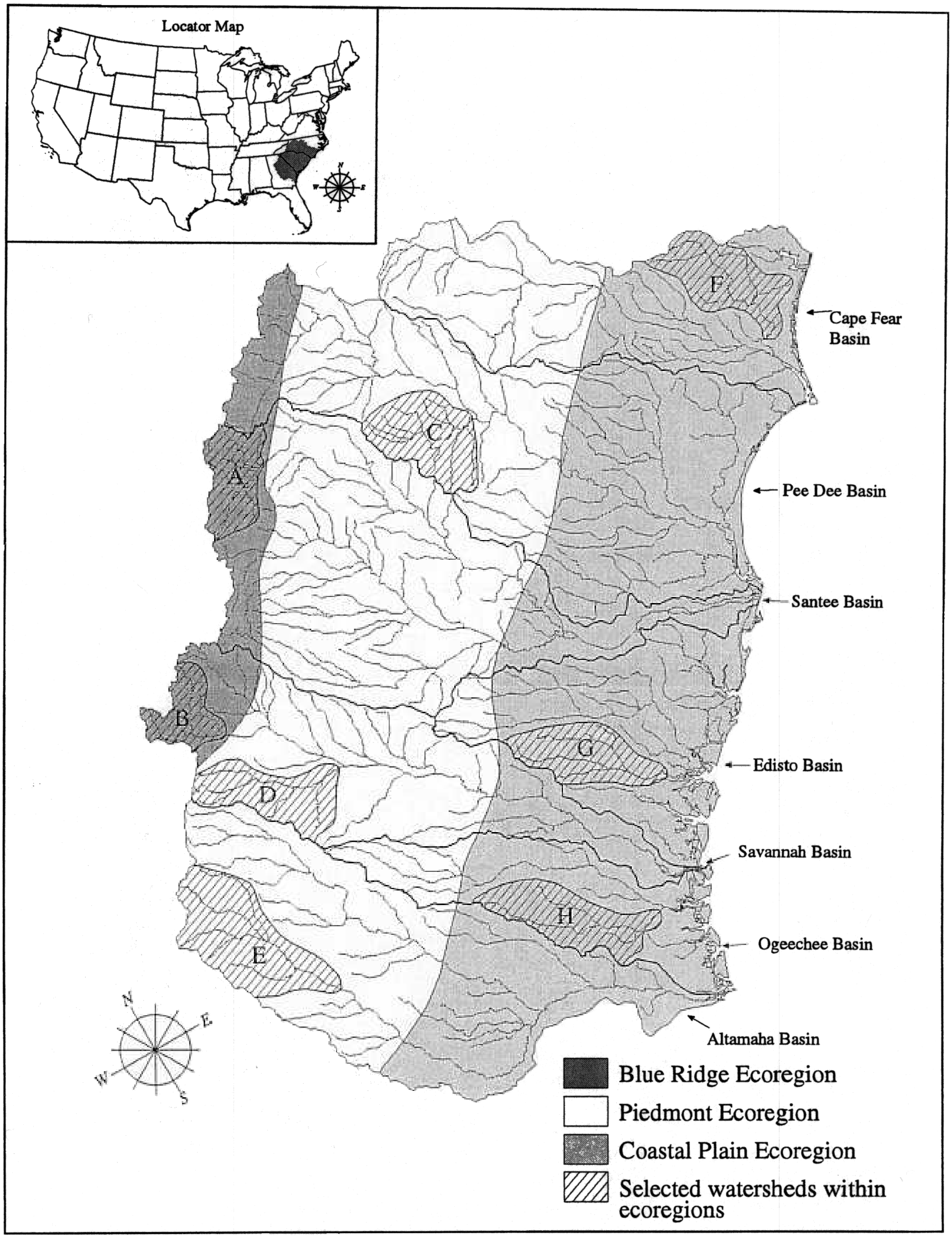

Figure 5. Ecoregions, Basins, and Selected Watersheds Within the South Atlantic Subregion as Defined by Maxwell *et al.* (1995). (Adapted from Maxwell *et al.,* 1995.)

environmental resources, and ecosystems in general, can be expected to exhibit a particular pattern. Where watersheds are relevant and can be defined, they are necessary for studying the relationships of natural and anthropogenic phenomena with water quality, as well as for providing the spatial unit for reference areas within ecoregions at all scales. Where basins (large watersheds) are needed to determine the contributions to the quality and quantity of water at a specific point, ecoregional reference site data can help in making these determinations. When used together correctly, these two frameworks provide a powerful mechanism necessary for meeting the specific resource management goals such as those outlined in the Clean Water Act, as well as the broader ecosystem management objectives currently being sought regionally, nationally, and internationally.

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