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THE MISUSE OF HYDROLOGIC UNIT MAPS FOR EXTRAPOLATION, REPORTING, AND ECOSYSTEM MANAGEMENT[1]

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ABSTRACT: The use of watersheds to conduct research on land/water relationships has expanded recently to include both extrapolation and reporting of water resource information and ecosystem management. More often than not, hydrologic units (HUs) are used for these purposes, with the implication that hydrologic units are synonymous with watersheds. Whereas true topographic watersheds are areas within which apparent surface water drains to a particular point, generally only 45 percent of all hydrologic units, regardless of their hierarchical level, meet this definition. Because the area contributing to the downstream point in many hydrologic units extends far beyond the unit boundaries, use of the hydrologic unit framework to show regional and national patterns of water quality and other environmental resources can result in incorrect and misleading illustrations. In this paper, the implications of this misuse are demonstrated using four adjacent HUs in central Texas. A more effective way of showing regional patterns in environmental resources is by using data from true watersheds representative of different ecological regions containing particular mosaics of geographical characteristics affecting differences in ecosystems and water quality.
(KEY TERMS: watersheds; hydrologic units; watershed management; ecoregions; ecosystem management.)

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INTRODUCTION

"It does not occur to most Americans that a good map *raises* more questions than it answers – that the question of why things are located where they are raises important intellectual issues, with immediate serious implications" (Peirce Lewis, 1985, pg. 471).

For many decades, watersheds have been used appropriately in the study of characteristics related to natural and anthropogenic activities and their associations with the quality and quantity of water at specific points on a stream and on particular water bodies. This use has expanded recently to include extrapolation and reporting by means of hydrologic units, particularly since the development of a U.S. Geological Survey (USGS) digital framework and a paper, "Hydrologic Unit Maps" (Seaber *et al.,* 1987). Magnusson (2001) stressed the importance of catchments (watersheds) as the basic unit of management in terrestrial biomes and urged their use in conservation biology courses. Although one cannot dispute the value of watersheds as the basic unit of study for land/water relationships, use of the watershed as an ideal unit for ecosystem management is not well understood and can be inappropriate. As with any geographic unit used to study and extrapolate scientific information, the strengths and limitations of watersheds must be clarified, and the limitations of surrogates such as hydrologic units need careful examination.

According to Seaber *et al.* (1987, pg. 1), "The Hydrologic Unit Maps show drainage, hydrography, culture, and political and hydrologic unit codes (HUCs), thus providing a standard geographic and hydrologic framework for detailed water-resource and related land-resource planning." The hydrologic units shown on these maps are commonly referred to as HUCs, even though the codes are merely identifiers for the units at their particular hierarchical level. In this paper, these hydrologic units will be referred to as HUs. The HU framework is hierarchical in which

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units of roughly similar size have been mapped at several levels. For the conterminous United States 21 units have been defined at the first level, 222 have been mapped at the second level, 352 at the third level, and 2,150 at the fourth level. Although examination of the publication by Seaber *et al.* (1987) reveals that not all of these HUs shown on the maps are true watersheds, most proponents or users of the framework believe watersheds and HUs to be synonymous, or at least so similar that the HU framework could be termed a watershed framework (e.g., USFWS, 1995; Jones *et al.,* 1997; Ruhl, 1999; Alexander *et al.,* 2000; Graf, 2001; USEPA, 2001). Moreover, because hydrologic units and watersheds seldom correspond to areas containing similar mosaics of geographic phenomena associated with differences in water quality and quantity, the logic of using these units for most "water-resource and related land-resource planning" is questionable (Omernik and Bailey, 1997; Griffith *et al.,* 1999). This is not to say that hydrologic units have no use in the management of water resources. For some specific subjects or issues, such as flood control and fish management, they can be helpful. They are also useful for research on tracking water quality characteristics as they move downstream (Smith *et al.,* 1997; Alexander *et al.,* 2000).

The fact that most (about 55 percent) HUs are not true watersheds has been stated in the literature (e.g., Omernik and Griffith, 1991; Omernik, 1995; Omernik and Bailey, 1997; Bryce *et al.,* 1999; Griffith *et al.,* 1999). However, authors have not explicitly defined the serious implications of considering them synonymous, and of extrapolating and reporting data gathered from HUs to show patterns in the status or trends of environmental resources (particularly water quality) on regional or national scales. This paper describes these implications, and suggests a way in which information gathered from true watersheds and other reference areas could be used effectively to show national and regional patterns in environmental resources.

DISTINGUISHING BETWEEN WATERSHEDS AND HYDROLOGIC UNITS

Watersheds are defined as topographic areas within which apparent surface water and subsurface water drain to a specific point on a stream or to a water body such as a lake (Omernik and Bailey, 1997; Griffith *et al.,* 1999). Although mapped confluences are commonly used to define watersheds, there are literally an infinite number of points along streams from which watersheds can be defined. Whereas there is little disagreement over this definition, the definition of hydrologic units is not as clear, and certainly not as well understood. The hydrologic units identified on the U.S. Geological Survey framework (Seaber *et al.,* 1987) can be defined as watersheds, and downstream segments of watersheds, many of which include adjacent intersticies, or areas that lie in between topographic watersheds (Omernik and Bailey, 1997). The downstream points of over half of these hydrologic units drain areas that are greater than the areas defined by their hydrologic unit boundaries. Hence, the hydrologic unit maps are not maps of watersheds.

Characteristics of spatial geographic phenomena such as soils, geology, vegetation, land use, physiography, and climate can be mapped to show regions within which there is less variability compared to other regions. Similarly, these maps can show a particular variability of a characteristic that makes a region different from other regions. It is also possible to compile a map of hydrologic characteristics, such as karst, or differences in lake density patterns, lake types, and stream drainage networks. However, since streams are *linear* units rather than spatial ones, it is not possible to map the watersheds of streams and attain a final map completely covered with watersheds of similar size. A national map of HUs (6-digit, 8-digit, or any other hierarchical level) contains roughly 45 percent true watersheds. At the coarsest 2-digit level (Water Resource Regions), the percentage is only 33 percent. The remaining HUs comprise downstream segments of watersheds, or groups of adjacent watersheds, along a sea coast, lake, estuary, or major river.

How does this understanding of watersheds and HUs affect use of the HU framework to extrapolate water quality data gathered from downstream segments, or any other part of an HU, to illustrate national or regional patterns in status or trends? To grasp the problem, first consider the ecological regions (ecoregions) and 8-digit HUs that cover Texas and parts of adjacent states (Figure 1). The ecoregions on this figure comprise regions within which there is similarity in the mosaic of biotic, abiotic, aquatic, and terrestrial ecosystem components, with humans considered part of the biota (Omernik, 1995; Omernik *et al.,* 2000). Considering the 8-digit HUs that are completely or partly in Texas, Figure 2 illustrates those that are true watersheds and those that are not. Only 48 percent of the HUs in this region are true watersheds.

Next, let us examine four contiguous 8-digit HUs that occupy similar ecoregions (Figure 3). All four HUs are centered on the East Central Texas Plains (33), called the "Claypan Area," which once was largely covered by a post oak savanna and is now a region

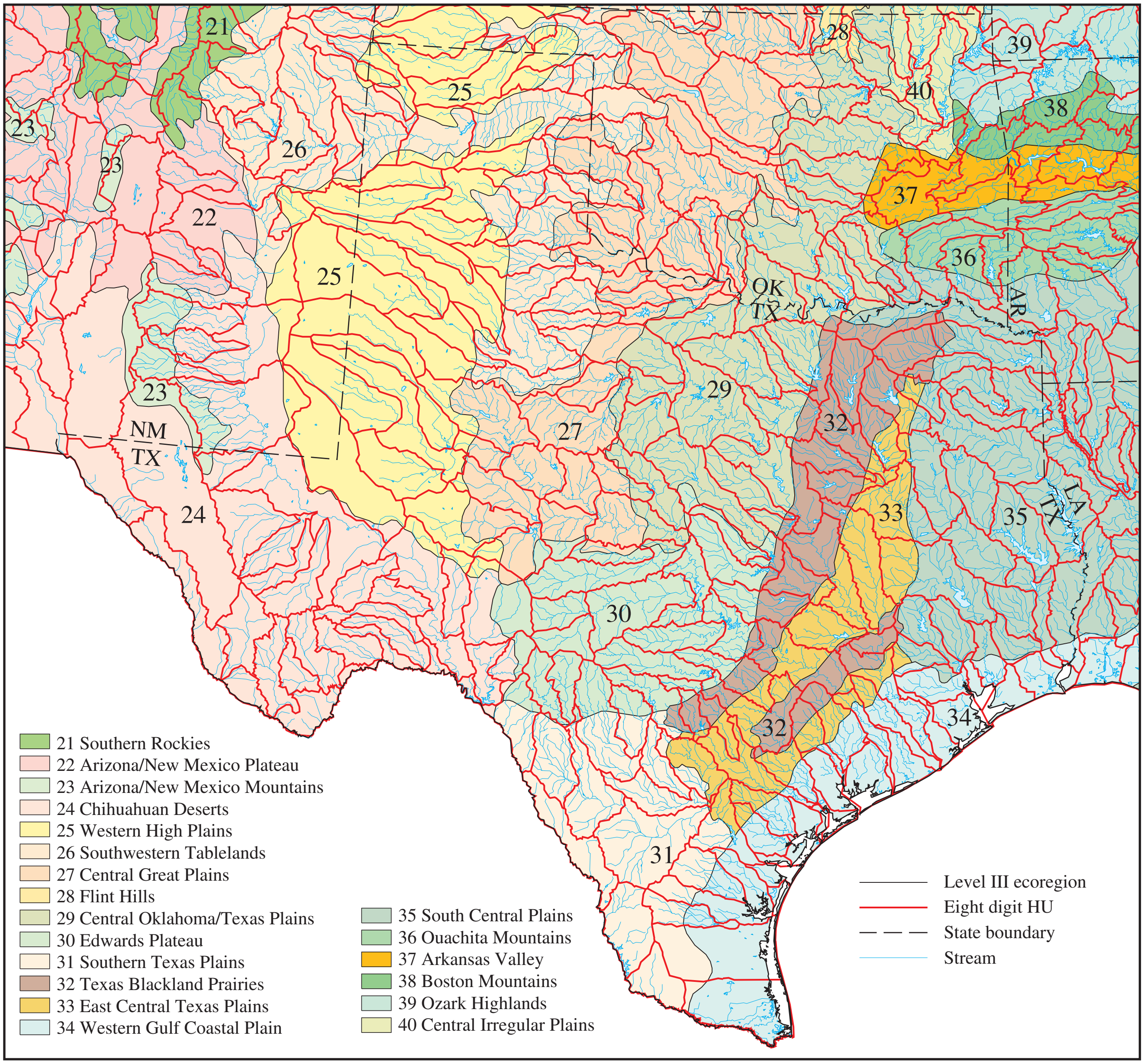

Figure 1. Level III Ecoregions and Eight-Digit Hydrologic Unit Codes (HUs) in Texas and Parts of Adjacent States.

of pasture and range. The HUs also occupy, albeit each to a different extent, parts of the Texas Blackland Prairie (32), a region that once was prairie and now contains a much higher percent of cropland agriculture than surrounding ecoregions. If these HUs were true watersheds, because they occupy the same ecoregions, one would expect them to have similar characteristics regarding water quality and quantity at their downstream points, compared to watersheds of surrounding ecoregions. However, as Figure 4 shows, only two of these HUs (B and D) are true watersheds. The downstream points on the other two (A and C) drain areas 15 to 22 times larger than the areas defined by the 8-digit HUs. Also, HUs A and C drain ecoregions having characteristics far different from those covered by the HUs. Thus, the quality and quantity of water at the downstream sites for A and C are quite different from those of B and D (Figure 5).

Most aspects of water quality and quantity are similar for HUs A and C, and for B and D, as well (Figure 5). There are, however, fairly sharp differences between the values for A and C and those for B and D. Even though the headwaters of the true watersheds for A and C are much drier than the points

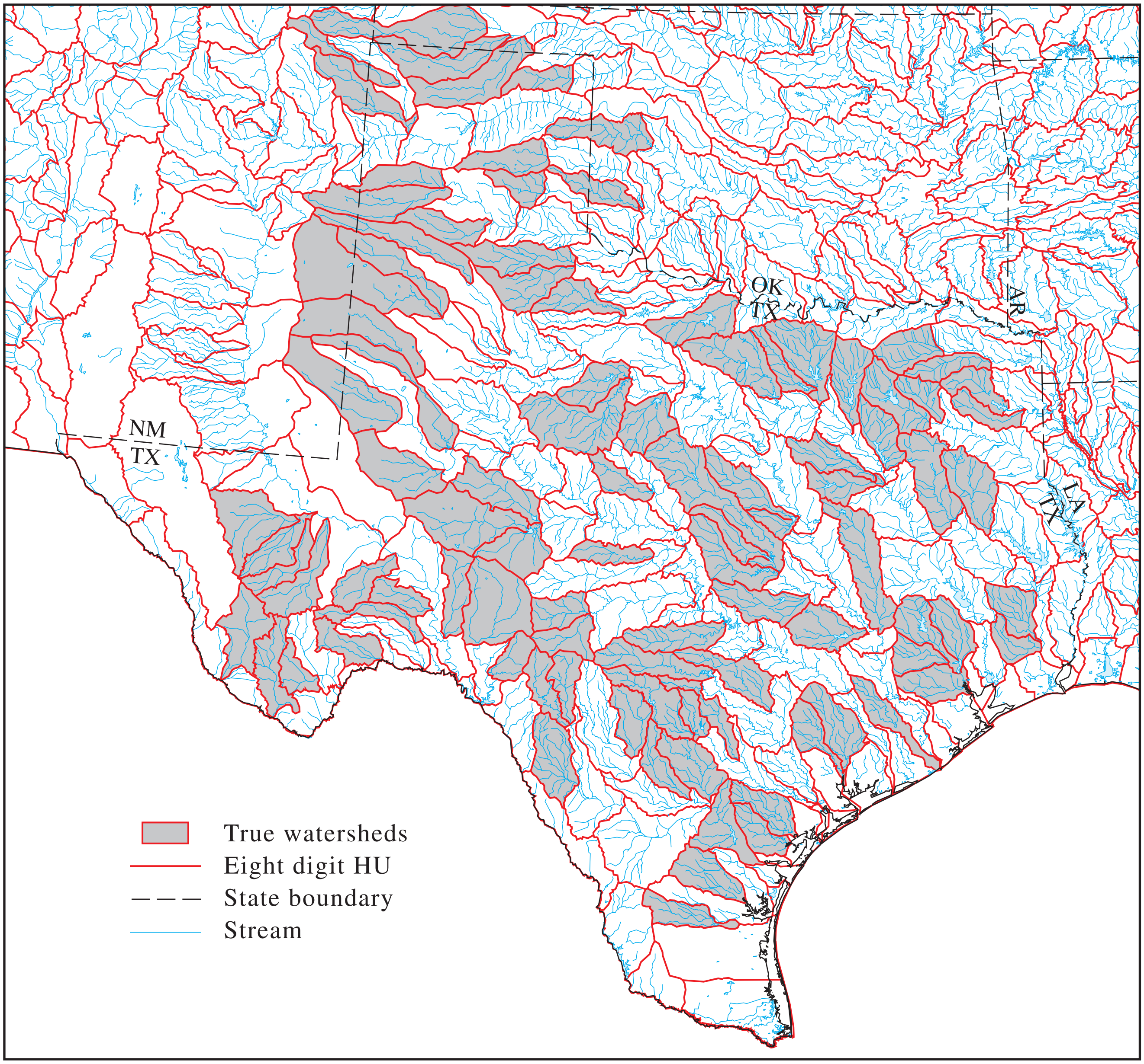

Figure 2. Eight-Digit HUs That Are True Watersheds and Are Completely or Partially in Texas.

farthest downstream, with mean annual precipitation ranging from less than 40.6 cm (16 in) in the headwaters to greater than 101.6 cm (40 in) at the mouth of each watershed (USDA, 2001), the mean annual discharges for A and C are still 8 to 11 times greater than those for B and D. Mean annual water temperatures are about 5ºC less for A and C than for B and D. Similar examples, many with far greater implications, can be found throughout the United States. The problem obviously has important ramifications for using HUs as spatial units within which to extrapolate data taken from downstream points. Examples of this type of use can be seen in products of the U.S. Environmental Agency's Office of Water Index of Watershed Indicators project (USEPA, 2001) the goal of which was to characterize regional patterns in water quality conditions and "show existing water quality across the country" (USEPA 1997, pg. 4). Smith *et al.* (1997) also used the approach to characterize water quality in the conterminous United States. Because half or more of the contributing areas to the HUs are often incorrectly represented using this approach, misleading illustrations are presented. As can be seen in Figures 3 through 5, an HU that has a drainage area

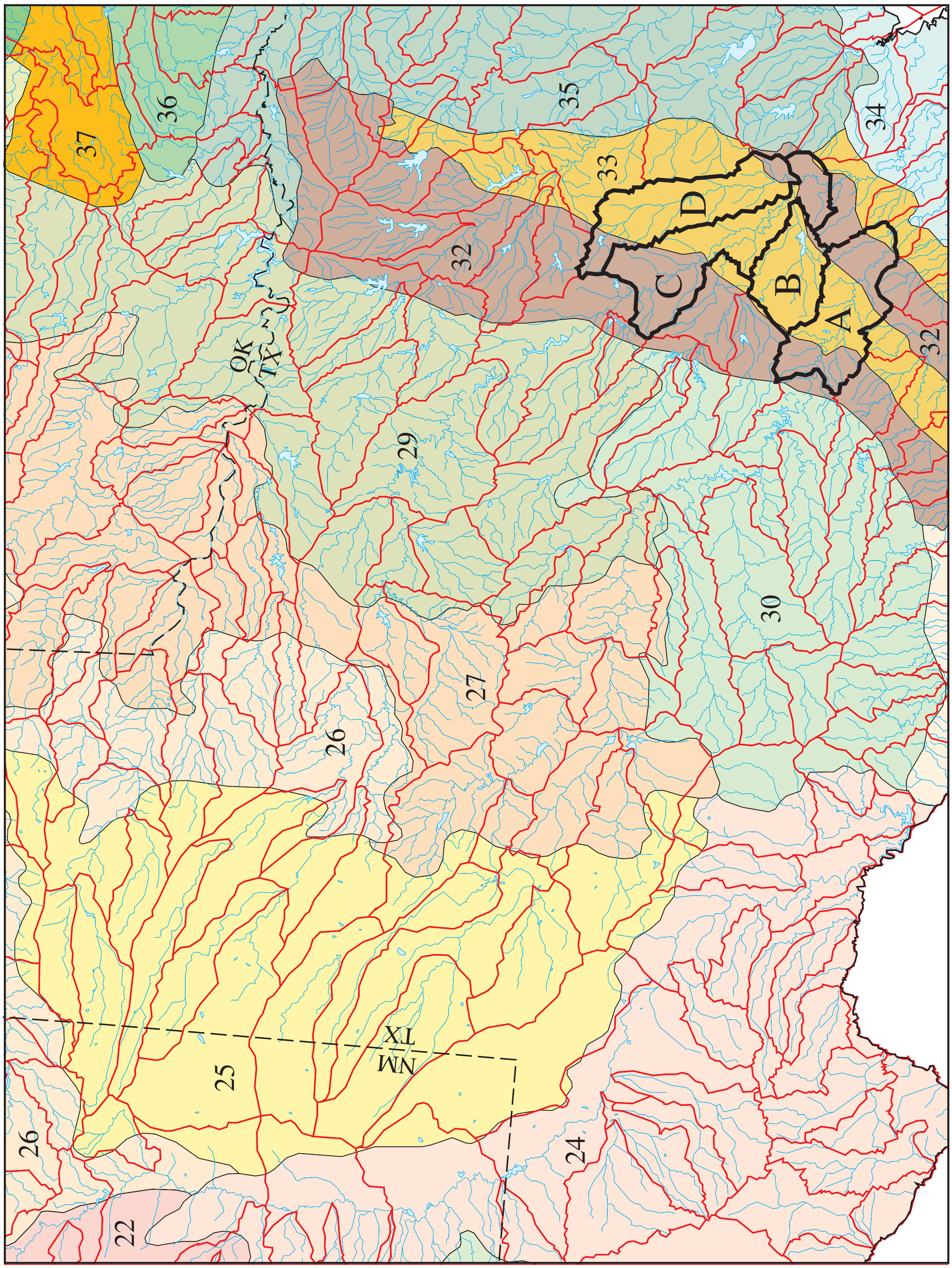

Figure 3. Four Eight-Digit HUs Covering Ecoregions 32 (the Texas Blackland Prairie) and 33 (the East Central Texas Plain). The hydrologic unit codes for A,B, C, and D are 12090301, 12070102, 12080101, and 12070103, respectively

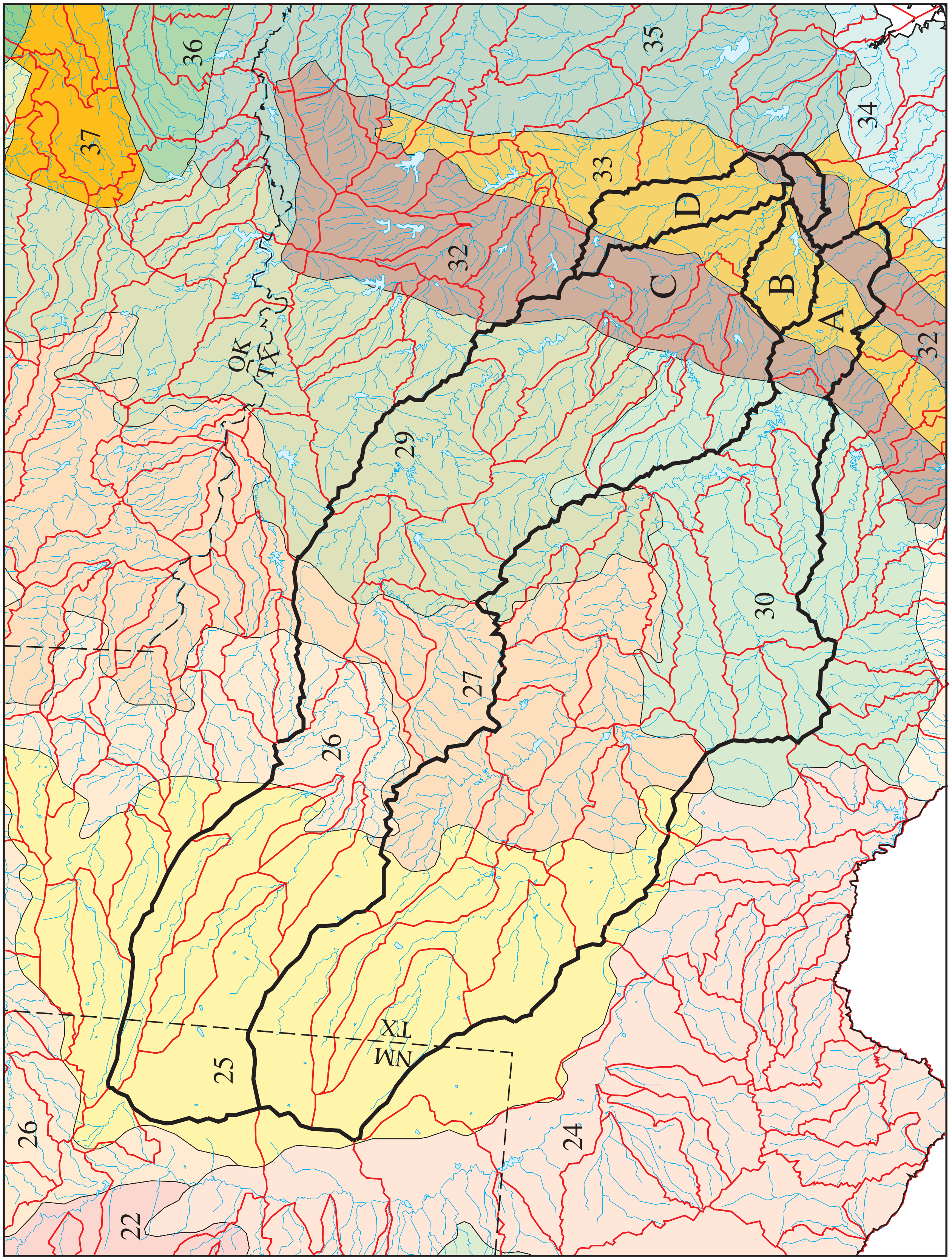

Figure 4. True Watersheds Associated With Downstream Points in HUs A, B, C, and D.

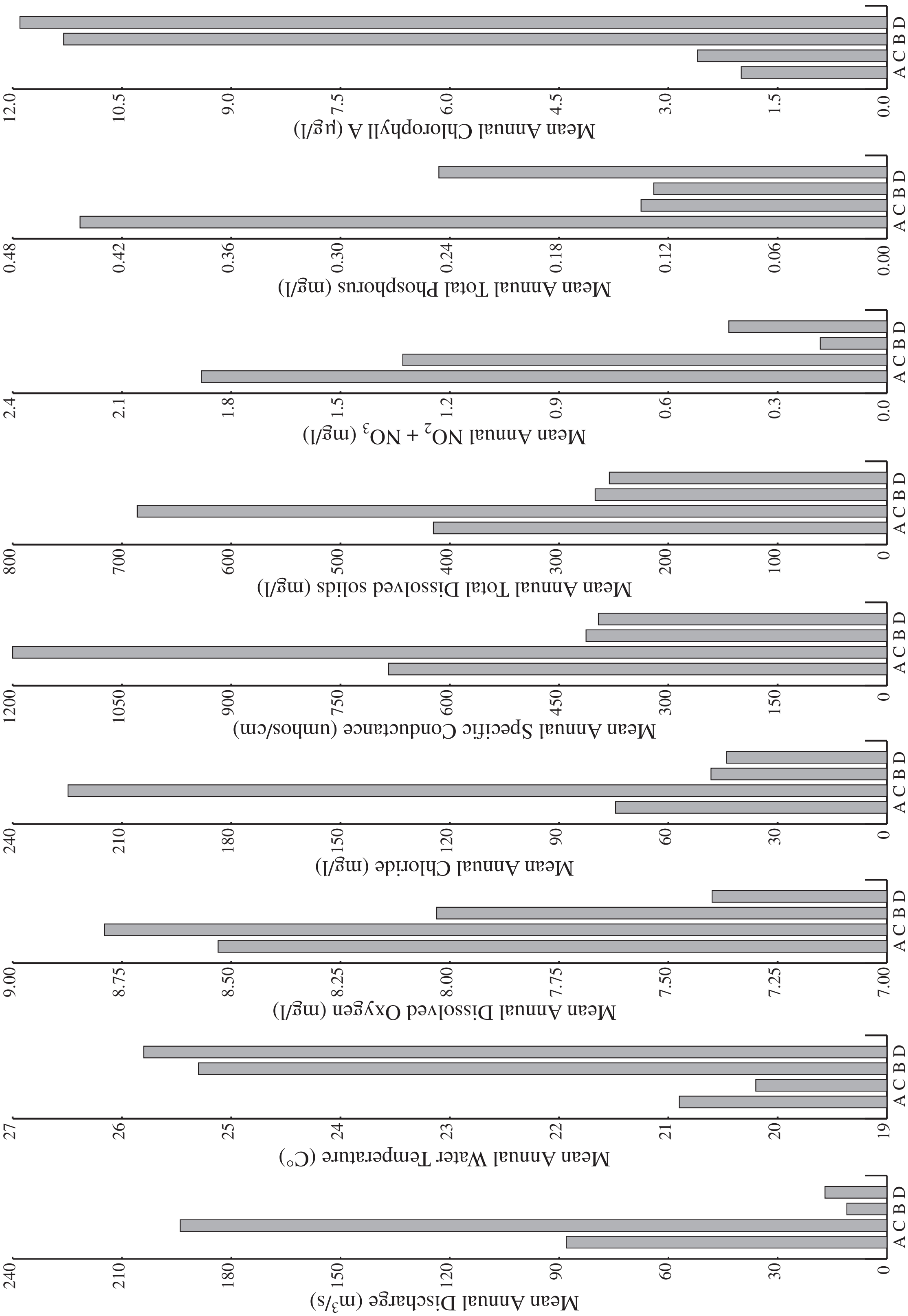

Figure 5. Discharge and Water Quality Characteristics for HUs A, C, B, and D. (Sources: Gandara *et al.*, 1995; Gandara *et al.*, 2001a,b; and the Texas Natural Resources Commission, 1996.)

quite different and many times larger than the area it occupies is unlikely to have water characteristics similar to that of an adjacent HU that is a true watershed. If, for example, the values for downstream points in HUs A, B, C, and D (HUCs 12090301, 12070102, 12080101, and 12070103) are used to produce maps of nitrate and nitrite, HUs A and C would be represented by values that are three to six times less than that of adjacent HUs B and D. The area contributing to HU A includes 24 additional HUs and that contributing to HU C includes 21 additional HUs.

Only data representative of the region from which the data were collected should be used to develop maps illustrating patterns in stream quality. Of the four HUs highlighted on Figures 3 and 4, only data from HUs B and D are representative of the region they occupy. By including data from A and C and assigning the values taken from their downstream points to their respective HUs, a misleading picture is presented of the quality one might expect in the region. For maps of water quality, or any environmental resource, the information used to portray the values must be consistent with the spatial variation of factors associated with differences in the quality of the resource of interest.

This example helps clarify the fact that topographic watersheds are infinite in number. Unlike characteristics such as soils, geology, vegetation, and physiography, which are amenable to classification, watersheds are spaces associated with points on streams. There are an infinite number of these points on streams. To those who suggest managing water resources and terrestrial biomes by watersheds (catchments), one can ask the question, "For watersheds of what size?" If the answer is, for instance, roughly 1,000 km^2 (386 mi^2), what is to be done with the remainder of the country after the headwaters of stream systems that are true topographic watersheds of that size have been mapped? If one chooses to break these areas into downstream segments of drainage basins, such as HUs, these "other" units are not "watersheds." They might have been defined by different segments of topographic divides, but they do not enclose the entire drainage areas for the HU's points farthest downstream.

As important as it is to distinguish between watersheds and HUs, it is even more important to recognize that watersheds and HUs seldom depict areas of similar combinations of characteristics associated with water quality and patterns in the mosaic of ecosystem components (Omernik and Bailey, 1997; Bryce *et al.,* 1999; Griffith *et al.,* 1999). Although topographic watersheds always will provide a critical spatial framework for assessing the relative contributions of natural and anthropogenic characteristics to the quantity and quality of water at specific points, they tend to cross regions of similarity in characteristics such as soils, geology, physiography, vegetation, climate, and land use – the characteristics associated with spatial differences in water quality. This fact has been corroborated in several scientific papers. Cooke and Doornkamp (1974), for example, noted that a *land systems* approach to environmental management and planning "is based on the identification of regional boundaries that are frequently independent of watersheds (catchment divides)." Hornbeck and Swank (1992), recognizing the difference between, as well as the complementary nature of, watersheds and ecoregions (which they called "regional landscapes"), pointed out that watersheds used for ecosystem analysis should be representative of regional landscapes. In writing on the limitations of the watershed framework for natural resource management, Hatch *et al.* (2001) recognized that the geographic characteristics that affect soil erosion and water quality often vary greatly within watersheds. They suggested using ecoregions that incorporate these characteristics (e.g., precipitation, physiography, certain soil properties, and cropping systems).

USING WATERSHED INFORMATION TO SHOW SPATIAL PATTERNS IN ENVIRONMENTAL CONDITIONS

The quality and quantity of water at any point on a stream reflect the aggregate of the characteristics upgradient from that point (McMahon *et al.,* 2001). The quality and quantity of water in streams whose associated watersheds are completely within a particular ecoregion tend to be comparable, yet different from those in streams of adjacent regions. It follows then that if regional, state, and national maps depict the central tendencies and ranges of water quality and other environmental conditions from representative watersheds within different ecoregions, meaningful pictures of the status and trends of water quality and other ecosystem conditions could result. The key here is to ensure the representativeness of watershed data used to compile these maps. Figure 6 illustrates sets of 8-digit HUs that are true watersheds completely, or nearly completely, within specific ecoregions in Texas. Data from these types of HUs are appropriate for use in compiling maps of water quality for Texas, as well as the United States, if the interest is in spatial differences at the level III ecoregion (USEPA, 2002) or Common Ecological Region (CER) (McMahon *et al.,* 2001) level of detail.

In selecting watersheds representative of particular ecoregions, one should not be bound by those that

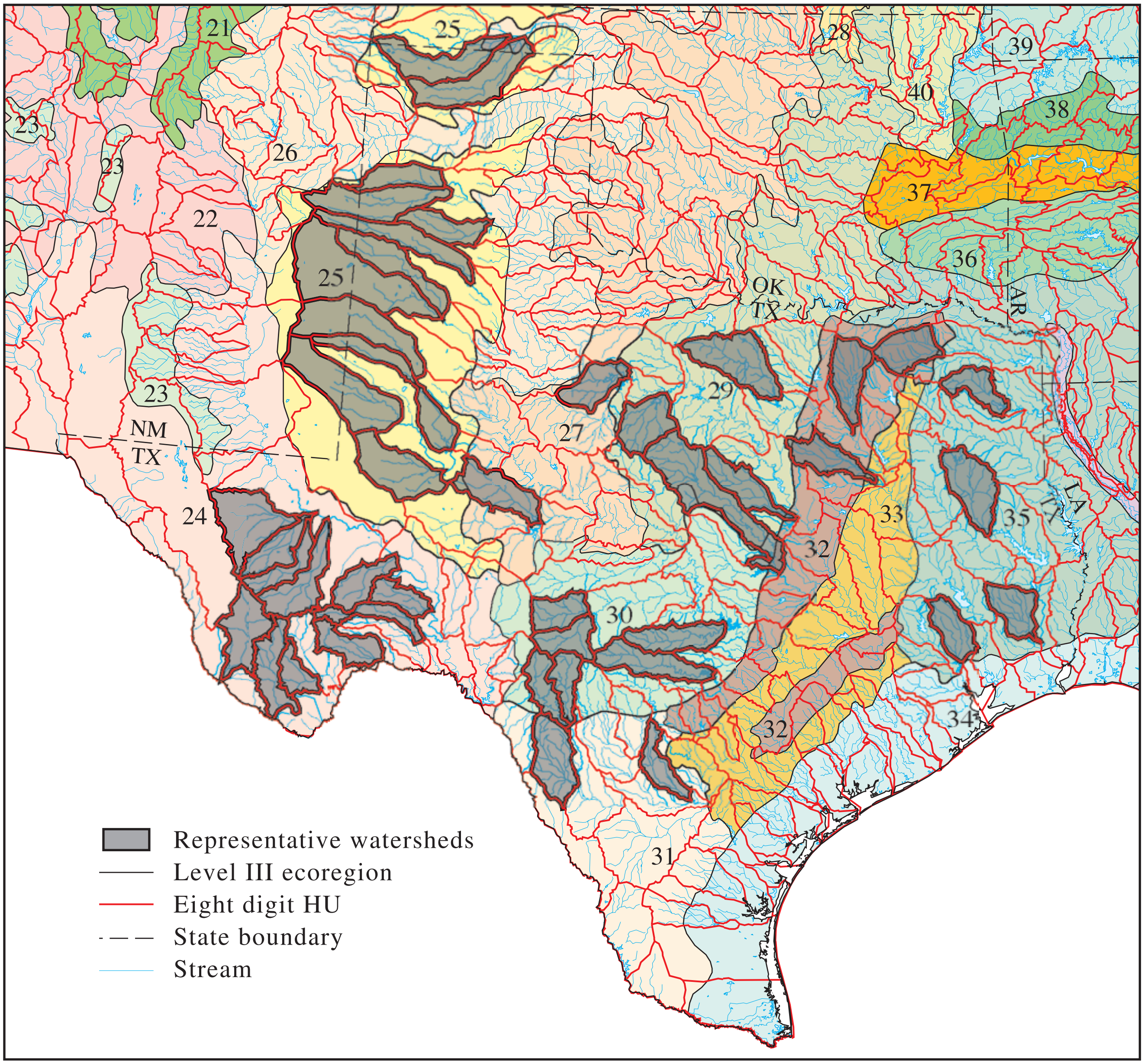

Figure 6. Representative Watersheds Within Level III Ecoregions That Are Completely or Partially in Texas.

happen to be HUs. The watersheds upgradient from a point on a stream should enclose an area that is mostly within the same ecoregion as the stream site. Sets of these sites and their associated watersheds, which can be termed *reference sites* and *reference watersheds*, should be selected for each region to help account for within region variability (Hughes *et al.,* 1986; Omernik, 1995). These sites and watersheds can be selected using a probability based sampling design (Paulsen *et al.,* 1998) or screened to represent least impacted conditions (Omernik, 1995). Reference areas should be identified for some environmental conditions or issues (e.g., soil characteristics, forest condition, land cover change, and wildlife characteristics), and for areas where watersheds are either impossible to define or are irrelevant (Hughes and Omernik, 1981; Omernik and Bailey, 1997). A key criterion for identifying a reference watershed or area is that it be representative of the larger region it occupies.

Different hierarchical levels of ecoregions can be used to paint different types of pictures. For example, Level I ecoregions (CEC, 1997) can be used to show regional differences in the ranking of environmental issues. Forest management and the health of anadromous fish would be high on the list in the Marine

West Coast Forests, salinity would rank high in the North American Deserts, effects of acidification and development on lakes and streams would be of major importance in the Northern Forests (of the north central and northeastern United States), and pesticide use and nitrate contamination of ground water would rank high in the Great Plains. Some of these issues would rank low or would not even make the list in different Level I ecoregions. Data from reference watershed sites and areas representative of Levels I, II, III, and IV ecoregions could be used to show patterns in the status and trends of many characteristics, including water quality, agricultural practice/riparian and water quality associations, and land cover change.

CONCLUSIONS

Much has been said about "the watershed" being the appropriate unit for ecosystem management. Ruhl (1999, pg. 520) wrote, "More so than any other ecosystem management unit that has been proposed in the literature, lay people and politicians can easily understand the concept of a watershed." Although most scientists do understand the concept of a watershed as it relates to their basic research projects and use it correctly for those purposes, it is clear that most people *do not* understand the concept as it relates to extrapolation, reporting, and management. While refining and subdividing ecoregions throughout the country, I learned from my conversations with state and federal resource managers and university scientists that most people are not aware that the USGS maps of hydrologic units are not maps of watersheds. In addition, most are not aware that it is impossible to develop a map of nearly equal sized watersheds. And finally, most people are not aware of the problematic ramifications of using HUs for extrapolation and reporting.

The following points are key to the effective use of geographic units for (1) conducting research on land/water associations and terrestrial ecosystems, (2) mapping patterns in the status and trends of water quality and other environmental conditions, and (3) structuring environmental management and planning strategies.

- The importance of using topographic watersheds (catchments) for research on land/water associations cannot be overstated. Where watersheds can be defined and are relevant, which is over more than two-thirds of the conterminous United States (Hughes and Omernik, 1981; Omernik and Bailey, 1997), they are critical for identifying the characteristics that affect specific water bodies or particular points on streams.

- Most HUs are not true watersheds. It is impossible to develop a map completely covered with hydrologic units comprising watersheds of nearly equal size. Regardless of the hierarchical scale of the HUs being mapped, roughly 55 percent will not define true watersheds. Many HUs drain areas that extend far beyond their boundaries, which has serious implications for the use of HU boundaries to illustrate the spatial patterns of data collected at each HU's downstream point.

- Watersheds rarely correspond to regions of similar characteristics that affect water quality and quantity. Ecoregions, on the other hand, are defined to include areas of coincidence in combinations of characteristics that reflect similarity in ecosystems and ecosystem components.

- Watershed and ecoregion frameworks are complementary. Watersheds provide the framework for determining the land/water associations, and ecoregions provide the framework for extrapolating and reporting this information.

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