Development of Conservation Focus Area Models
for EPA Region 7

Regional Geographic Initiative (RGI) Report
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Executive Summary

We used current scientific techniques and uniform, transparent methods to identify conservation focus areas as an aid to identification of critical ecosystems, to provide a basis for permit and project review, to aid in funds allocation, and for other uses by EPA Region 7 and its partners. We designed an approach to ensure locally and ecologically relevant results. Key elements include:

1. Separate terrestrial and aquatic assessments.
2. Assessments completed within ecologically-based planning regions (ecoregions for terrestrial ecosystems and evolutionarily significant watersheds for aquatic ecosystems).
3. Use of relatively uniform, region-wide data sets to ensure consistent regional coverage to the maximum extent possible.
4. Evaluation of both biological and abiotic (representation) targets in determining ecological significance whenever possible.
5. Evaluation of both significance/importance and threat/stressors to assign final priorities whenever possible.
6. Assignment of spatially specific results at as fine of resolution as allowed by the data sets.

Terrestrial and aquatic assessments were conducted separately because different stressors operate on aquatic versus terrestrial ecosystems differently, and because watershed boundaries need to be used as aquatic planning regions, since they circumscribe evolutionarily significant sub-divisions of riverine ecosystems. Ecologically-based planning regions were used in order to make results both more locally and ecologically relevant.

Terrestrial conservation focus areas were defined based on an algorithm combining a risk data layer (defined by a combination of ecological significance and threat) and an Irreplaceability data layer (based on the ranking of 40 sq km hexagons using abiotic and biotic targets; see Figure 1). Since assessments were specific to ecological planning units, conservation focus areas are identified in all parts of EPA Region 7, with an average of 8.3% of all planning regions identified as conservation focus areas. More natural planning regions such as the Ozark Highlands, Nebraska Sand Hills, Flint Hills, and Cross Timbers and Prairies had more focus areas, whereas areas that are heavily agricultural had fewer (see Appendix 4). Because of inherent differences in land use practices and some input data, notably roads, results are most valid on a planning region by planning region (usually section by section) basis.

Aquatic conservation focus areas were defined at two resolutions based on the availability of data. Watersheds were ranked using human stressors and the distribution of public lands for the region (see Figures 17, 33, 34), and groups of connected stream valley segments were identified as conservation focus areas within Missouri. The 358 aquatic focus areas that were identified and mapped across the EPA Region 7 provide a blueprint for holistic conservation of the freshwater ecosystems within the region, as opposed to the largely random and patchwork approach used in the past. These areas can be, and in Missouri are already, used to guide protection efforts such as land acquisitions, restoration efforts, and regulatory activities like the permit review process administered under the Clean Water Act. These areas also provide an ideal template for research designed to elucidate fundamental ecological processes within riverine ecosystems.

Data development, especially the modeling of aquatic species distribution by stream valley segment type, and efforts of partners, particularly the Missouri Department of Conservation, made a finer resolution assessment possible in Missouri. Hence, 158 conservation focus areas are identified by targeting representation of distinct watershed (aquatic ecological system) types, distinct stream valley segment types, and aquatic species within aquatic planning regions (ecological drainage units, which are evolutionarily significant larger watersheds). In every instance, this initial strategy of ensuring the representation of abiotic targets successfully represented 95-100% of the biotic targets (species) within the initially-selected set of conservation focus areas. This is especially surprising in the Ozark Aquatic Subregion, which contains numerous local endemics with restricted and patchy distributions. These results suggest that our classification units do a good job of capturing the range of variation in stream and watershed characteristics that are partly responsible for the patchy distribution of these species. These results also illustrate the utility of abiotic targets for freshwater conservation planning, which can prove critical for regions lacking sufficient biological data. This is especially encouraging in terms of the regional results considering the fact that we were unable to include biological targets in the regional assessment.

Results of this project are meant to be used, along with other data and considerations, to help EPA R7 and state and local partners define priorities at multiple scales. The example of how these data were refined in Missouri to define conservation focus areas should be repeated across the region for both terrestrial and aquatic assessments. Whereas information provided can be combined with existing analyses to suggest the top few regional conservation focus areas, we also provide several uniform, continuous, relatively fine-resolution data layers ranking ecological significance, risk, and threat that can be used for refined priority setting and individual project and permit review throughout the region.

I. Introduction

EPA Region 7 set the identification of critical ecosystems as one of three strategic priorities (see http://www.epa.gov/region7/priorities/index.htm). According to the web site, "The mission of the Critical Ecosystems Team is to facilitate the protection and/or restoration of the ecosystems in EPA Region 7 which are critical to biodiversity, human quality of life, and/or landscape functions." The guiding principles include the definition of critical ecosystems and development of criteria for selection, integration of protection into EPA programs, and enhancement of ecosystem protection via better communication about Region 7 ecosystem protection strategies and initiatives.

The conservation focus area results provide spatially-specific, scientifically based input data toward identification and selection of critical ecosystems. The idea was to build on, and to move past, previous efforts. Past work continues to provide valuable insights, but was based largely on methods that were not uniformly applied across the region, were not transparent, relied too heavily on professional judgment, and failed to adequately consider aquatic resources. What sets the current effort apart from past effort is (1) the rigorous application of current scientific methods, (2) the more careful documentation of logic and methodology, (3) the application of newly available, digital data sets, (4) the uniform use of ecologically based planning regions, (5) the assignment of ecological value at a relatively fine level of resolution to the entire region, and (6) the increased attention paid to aquatic resource assessment.

A. Goal and Objectives

Our overall goal is to effectively conserve ecosystem structure and function and protect human health and quality of life in EPA R7. The objectives are to (1) assign terrestrial ecological risk scores to the entire region at relatively fine resolution based on significance and threat, (2) assign terrestrial irreplaceability scores to 40 sq km hexagons based on the distribution and abundance of abiotic and biotic conservation targets, (3) combine terrestrial irreplaceability and risk scores to identify terrestrial conservation focus areas, (4) rank watersheds throughout the region based on stressor variables important to aquatic ecosystem function and the distribution of public lands by watershed, and (5) identify and rank aquatic conservation focus areas for Missouri by building on work already completed at the state level. We followed guidelines for conservation assessments and planning outlined in Noss and Cooperrider (1994), Margules and Pressey (2000), Noss et al. 2002, and Groves (2003).

To ensure better buy-in from key partners, we formed an interagency expert group to help formulate basic methods. EPA Region 7 staff, MoRAP staff, and key state partners formed this group, and we started with basic, accepted principles of conservation planning (see Margules and Pressey 2000, Groves 2003). This group settled on the following principles: (1) assessments need to be based on rigorous, transparent methodologies so that planners and managers can understand, and embrace, results, (2) assessments must be based on the best available data, (3) insofar as possible, a uniform, region-wide assessment should be provided, but given that data are not uniform across

R7, we should provide examples of better assessments using better data where appropriate, (4) assessments need to be conducted within ecologically defined subunits, so as to be representative of the biogeographic conditions across the region and therefore both scientifically sound (assessments compare apples to apples) and locally applicable (the subunits are small enough to make results locally relevant), (5) since assessments identify conservation focus areas within ecologically based planning regions, whole planning regions, extending beyond state borders, must be analyzed whenever appropriate data are available (e.g. we did not conduct the assessment only with state boundaries), and (6) assessments need to be as fine-resolution as possible to ensure maximum practical utility at the regional, state, and local level.

Separate terrestrial and aquatic natural resource assessment are warranted because different stressors impact terrestrial and aquatic resources in different ways, and because we can identify watershed divides across which the biotic composition (e.g. ecosystems) of similar stream types change dramatically due to the impact of isolation (e.g. evolutionary history), even within a single terrestrial ecoregion (Sowa et al. 2005). Therefore, our aquatic assessment used a hierarchical, watershed-based classification system to define planning regions (Sowa et al. 2005), whereas our terrestrial planning regions were based on a hierarchical ecoregion classification (see Bailey 1996, Cleland et al. 2005).

In fiscal year 2004, we analyzed the Ozark Highlands and Chariton River Hills as pilots for conservation focus area identification. The current effort builds on those results. The following text is divided into major sections detailing the separate terrestrial and aquatic assessments. For clarity, we organized the presentation such that methods and results are grouped together within a single section for each of the several data layers developed.

II. Terrestrial Assessment

We developed a series of data layers and combined them in ecologically meaningful ways to produce the final conservation focus area result (Figure 1). Ecological significance and threat were combined to define risk, and then risk was combined with irreplaceability to define conservation focus areas. Significance and threat are, in turn, each developed from intermediate data layers. To ensure that results were locally relevant and ecologically based, all analyses were conducted within ecological planning regions based on ecological sections (Cleland et al. 2005) on a planning region by planning region basis (Figure 2; see Margules and Pressey 2000, Noss et al. 2002). Each data layer developed, and the variables and methods used to create the layers, are described in the following sections.

For large ecoregions at the edge of EPA Region 7 states, we did not choose full ecological sections as planning regions, but rather combinations of subsections. These modifications were as follows: the inclusion of only the Cross Timbers-Cherokee Prairies and Central Tall Grass Prairie subsections within the Cross Timbers and Prairies section (255A, Figure 2), only the Red Prairie within the Canadian-Cimarron Breaks within the Northern Texas High Plains (315F), only the Sand Hill-Ogolla Plateau, Sandy-Smooth

High Plains, and Western Arkansas River Lowlands within the Southern High Plains (331B), and only the Oak Savannah Till and Loess Plains within the Minnesota and Northeast Iowa Morainal-Oak Savannah section (222M). In addition, we excluded the Hartsville Uplift subsection and subsections west and north of the Shale Scablands, Pine Ridge Escarpment, and Keya Paha Tablelands within the Western Great Plains section (331F). To gain complete coverage of western Kansas, we included the Lower Arkansas-Big Sandy Valley subsection (part of the Arkansas Tablelands section) together with the Central High Tablelands section (331C). Finally, the Boston Mountains section was added as a southern extension of the Ozark Highlands section (223A).

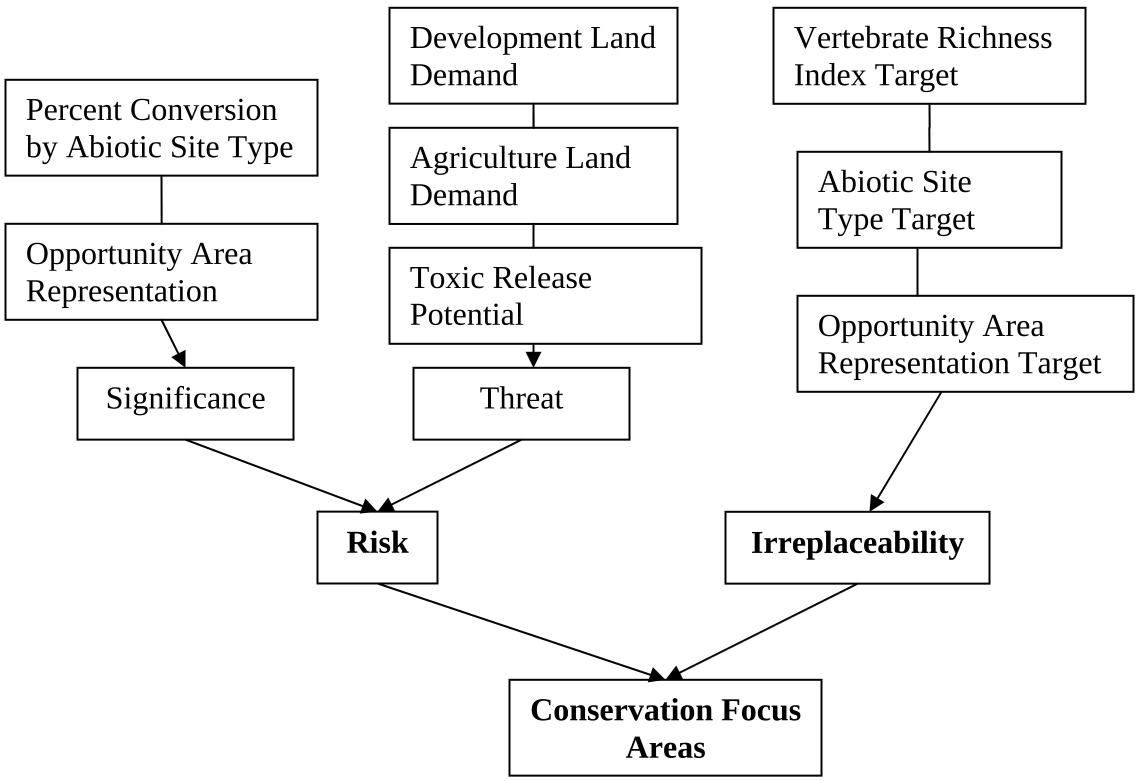
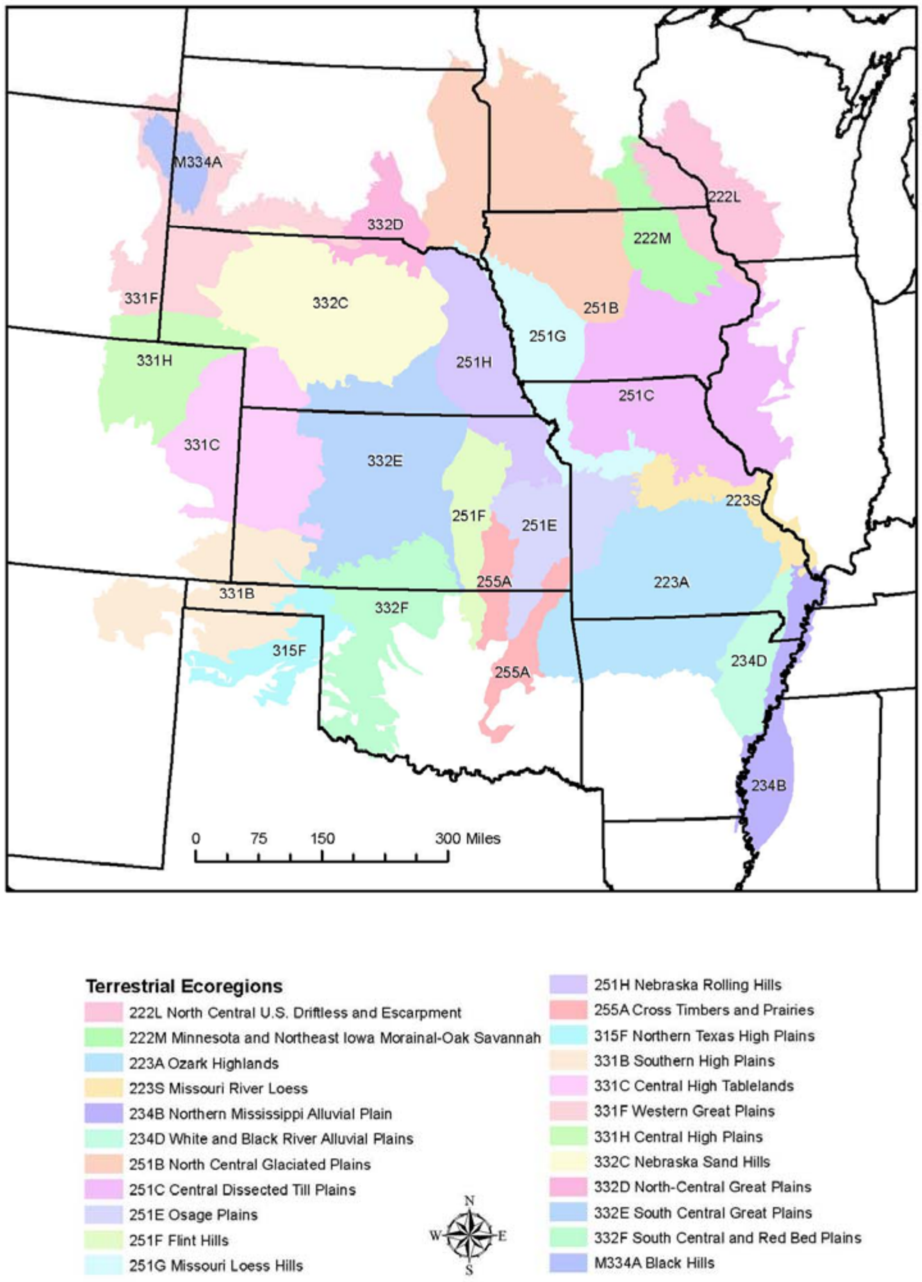


Figure 1. Flow chart showing variables used to reach the final Conservation Focus Area data layer. Please note that intermediate layers, such as ecological risk, significance, and development land demand may prove as useful for planning and management as the final conservation focus area layer.

Figure 2. Terrestrial ecoregions intersecting the boundary of EPA Region 7 states that were used as planning regions for the terrestrial conservation focus area assessment.



A. Assessment of Ecological Risk

The ecological risk data layer is derived from significance and threats data layers. Those data, in turn, were developed from other layers. The following sections describe the creation of the significance and threats data, and how those were combined to define an ecological risk layer.

1. Creation of Significance Surface

Ecological significance is an indicator of the relative importance of an area to conservation of the biota and maintenance of ecological processes based on evaluation of relevant, surrogate characteristics (Margules and Pressey 2000, Noss et al. 2002). Significance values were attached to each 30m pixel based on two separate variables: (1) values representing percent conversion of a given abiotic site type from natural or semi-natural land cover to non-natural land cover, which is a surrogate for importance based on the loss of major habitat types in the landscape, and (2) values representing terrestrial opportunity areas representation, which is a surrogate for viability and functionality of existing extant vegetation patches across all landscape types (see section d., Final Ecological Significance Data Layer, below). Opportunity areas are also places on the landscape where development land demand is relatively low, so the opportunity to pursue conservation management extends farther into the future. These two variables were in turn combined into a single value and pixels were ranked from one (high significance) to five (low ecological significance), with areas of non-natural vegetation ranked six.

a. Abiotic Site Type Modeling

To model abiotic site types, we used neighborhood analyses of 30-m resolution digital elevation models (DEMs). The key variables assigned to each pixel included solar insolation, which integrates slope percent, shading, and exposure, and relative land position. We used a program called Shortwave to calculate solar insolation, and a program developed initially by Frank Biasi of The Nature Conservancy to calculate relative land position within a 9-cell neighborhood. Finally, we placed the pixels into classes (one to four) for solar insolation and land position, and then combined these to identify seven different abiotic site types (Table 1, Figure 3a, Figure 3b, Appendix 1). Flat uplands were modeled as an eighth site type when local relief within a 9-cell neighborhood was less than 15m, and the pixel was not identified as a floodplain or well-defined river valley bottom, which is the ninth abiotic site type. Finally, we identified all sandy soil types from the digital version of the state soil geographic (STATSGO) soils data layer from the National Resource Conservation Service (NRCS; download available at http://www.ncgc.nrcs.usda.gov/products/datasets/statsgo/fact-sheet.html) and, within the Ozark Highlands planning region, sedimentary rocks versus granitic parent materials based on a digital version of the 1979 geologic map of Missouri (down load available at http://msdisweb.missouri.edu/metadata/sgeol.html).

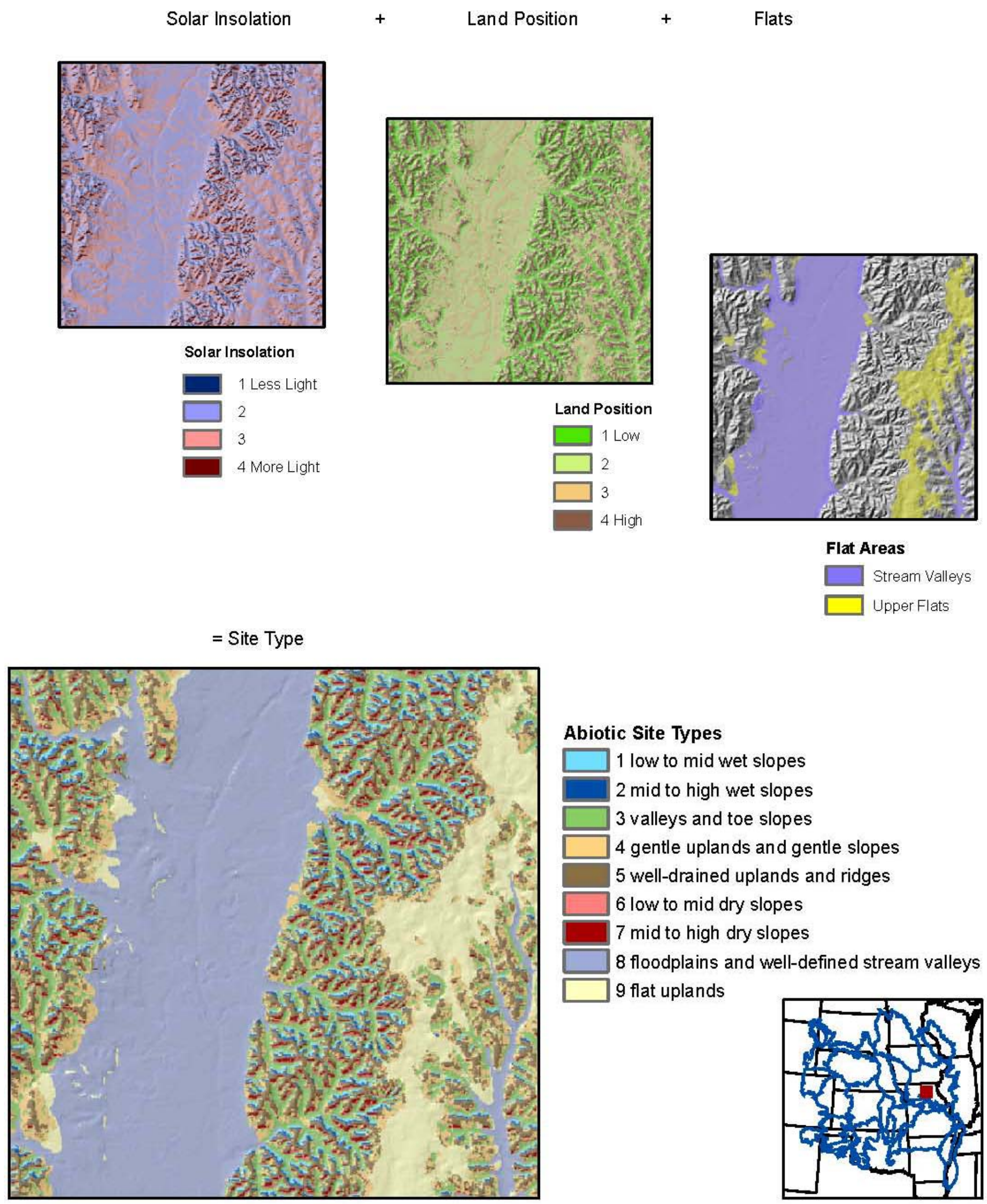


Figure 3a. Abiotic site type modeling procedures. Site types were modeled using values for solar insolation and landposition, as well as modeled river floodplains and well-defined stream valleys.

Figure 3b. Abiotic site types for EPA Region 7.

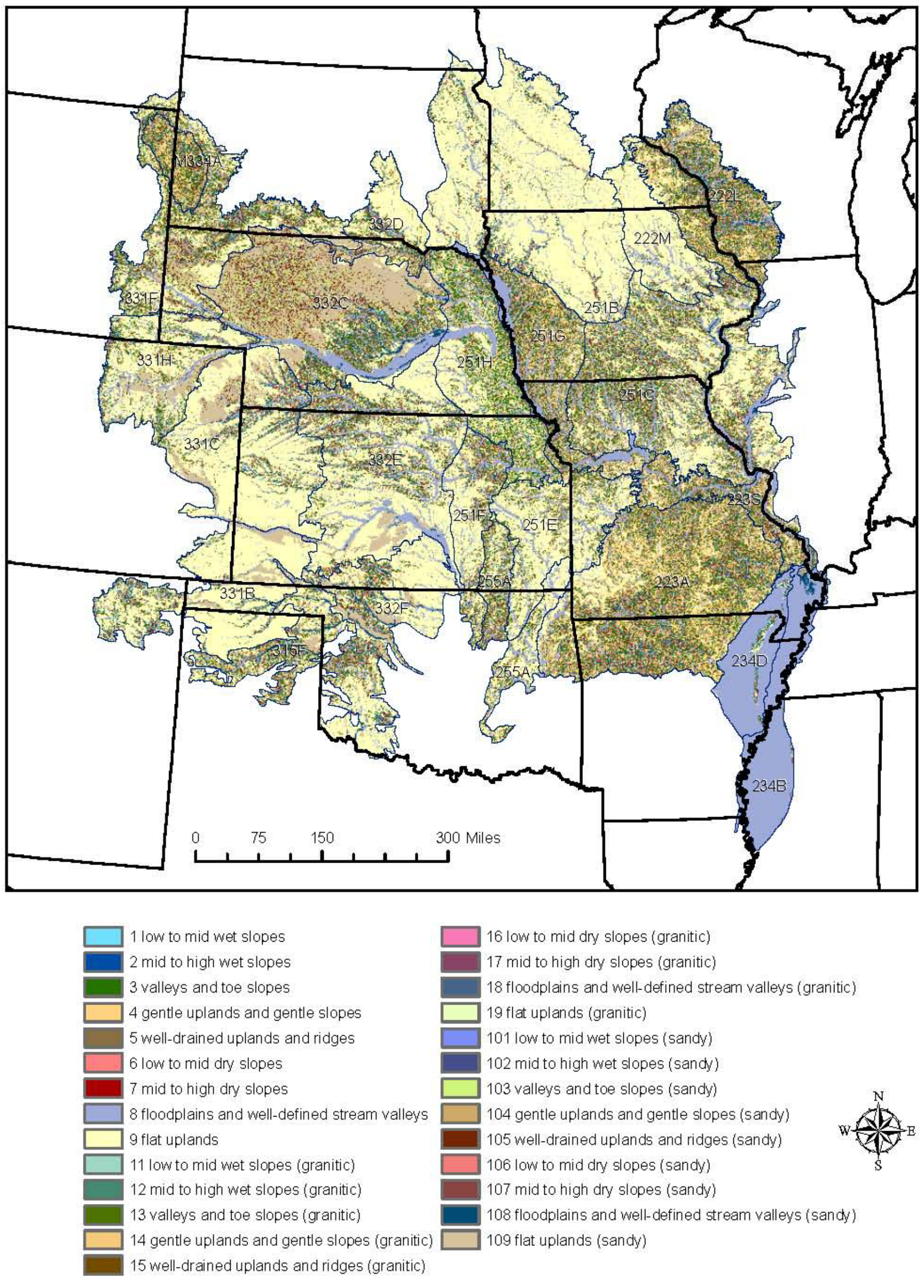


Table 1. Abiotic Site Types for EPA Region 7 (based on Solar Insolation and Land Position)*

Solar Insolation[1]	Land Position[2]	Site Description/ Examples of Site Types	Abiotic Site Type	Site Type Code
1	1	moderately to poorly drained with low light (mainly toe slopes and low slopes)	low to mid wet slopes	1
1	2	moderately drained with low light (mainly low and mid slopes)	low to mid wet slopes	1
1	3	well drained with low light (mid and high slopes)	mid to high wet slopes	2
1	4	very well drained with low light (high slopes and slope crests)	mid to high wet slopes	2
2	1	poorly drained with moderately low light (relatively moist valleys)	valleys and toe slopes	3
2	2	moderately drained with moderate light (gentle uplands and lower gentle slopes)	gentle uplands and gentle slopes	4
2	3	moderately drained with moderate light (gentle uplands and higher gentle slopes)	gentle uplands and gentle slopes	4
2	4	very well drained with moderate light (high uplands and ridges)	well-drained uplands and ridges	5
3	1	poorly drained with moderately low light (relatively moist valleys)	valleys and toe slopes	3
3	2	moderately drained with moderate light (gentle uplands and higher gentle slopes)	gentle uplands and gentle slopes	4
3	3	well drained with moderately high light (typical uplands, high gentle slopes)	gentle uplands and gentle slopes	4
3	4	very well drained with moderate light (high uplands and ridges)	well-drained uplands and ridges	5
4	1	moderately to poorly drained with high light (toe slopes and low slopes)	low to mid dry slopes	6
4	2	moderately drained with low light (low slopes to mid slopes)	low to mid dry slopes	6
4	3	well drained with low light (mid slopes to high slopes)	mid to high dry slopes	7
4	4	very well drained with high light (high slopes and slope crests)	mid to high dry slopes	7
Other Modeled Site Types **				
Modeled floodplains and well-defined stream valleys			floodplains and well-defined stream valleys	8
Modeled flat and gentle uplands with local relief less than 15 meters			flat uplands	9

[1] Solar Insolation
1 to 4 = wet to dry

[2] Land position
1 to 4 = low to high

* Modeled site types were intersected with soils and geologic data to define geolandforms for some sections
** See text for description of other modeled site types

Floodplain and well-defined river valley modeling required a separate and time-consuming procedure. Modeled floodplains were a combination of five different datasets: 1) Missouri Alluvium, 2) Missouri River valley bottom, 3) floodplains created using digital elevation models, 4) FEMA floodplains data, and 5) buffered streams.

Missouri Alluvium

This dataset was acquired from the Missouri Department of Natural Resources. It represents areas within the state that have an alluvium surficial geology. This dataset was used as a surrogate for floodplains within the state of Missouri.

Missouri River Valley Bottom

This dataset was acquired from the River Studies Unit at USGS's Columbia Environmental Research Center. The dataset represents the valley bottom of the Missouri River.

Floodplains delineated by MoRAP using Digital Elevation Models

For the creation of this dataset we used NED elevation data and selected all 30m pixels with less than 8% slope. The study area was then divided into 40 square kilometer hexagons. Flat areas within each hexagon were placed into one of nine classes corresponding to different elevations. These classes included 10% of the highest elevation within the hexagon, 20%, 30%, and so on to 90%. We then color-coded each hexagon by these percent values for on-screen analysis using a backdrop of a topographic hillshade and a 1:100,000 stream network. This procedure included zooming to each hexagon within a section and making a decision as to the best cut-off value (10%, 20%, etc) for floodplain representation. These cut-off values were used to create grids of potential floodplains for each section. As a general rule, floodplains were only delineated for streams with Strahler stream order of two or greater. These grids were then converted into shapefiles for on-screen digitizing of any necessary corrections. Once again using a backdrop of a topographic hillshade and a 1:100,000 stream network, we edited these shapefiles to better represent the potential floodplain. These shapefiles were then converted into grids for final representation of floodplains and flat stream valleys.

FEMA Floodplains

Of the 769 counties within or partially within the study area, 115 had floodplain data delineated by the Federal Emergency Management Agency (FEMA). We ordered these data and in places where FEMA floodplains existed, we used those delineations instead of modeling them from DEMs. Most counties had complete coverage, however some had only partial coverage around large cities and towns. Because of this intermittent coverage, the FEMA data were used in these counties to augment the floodplains created from DEMS.

Buffered Streams

In an effort to ensure that all primary waterways were included in the floodplains data layer, all 1:100,000 streams with a Strahler stream order of 3 or higher were incorporated into the final floodplains for each section. Streams were converted into 30m grids and then buffered by one 30m grid cell on either side.

For the final floodplains data layer for each section, these five datasets were merged together in the order they are listed above (Figure 4). In this way, datasets at the beginning of the list were treated as the most important.

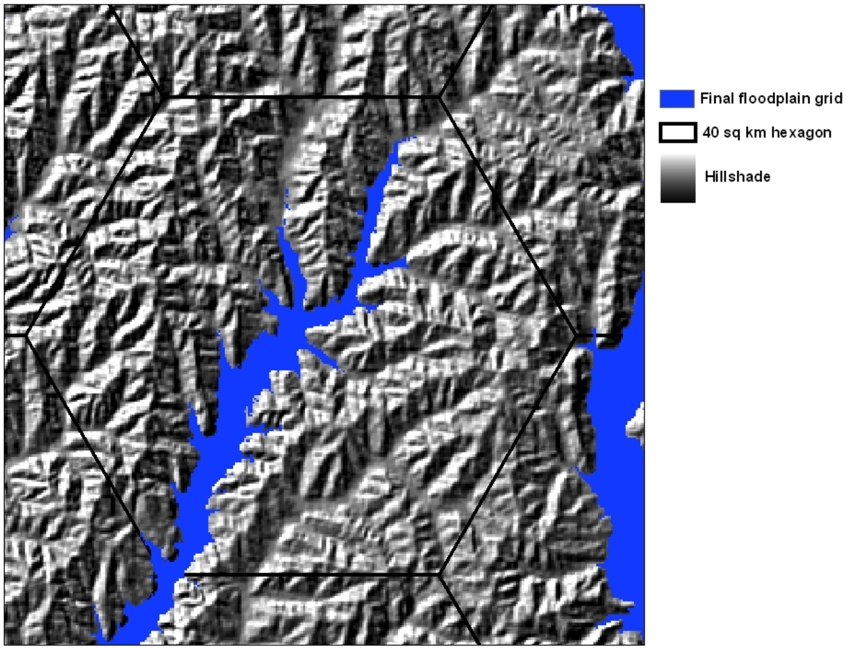


Figure 4. Example of the final river floodplain and well-defined stream valley data layer, which was incorporated into the modeled site types for EPA Region 7.

b. Percent Conversion by Abiotic Site Type

Percent conversion is based on the amount of natural or semi-natural land cover (from the National Land Cover Dataset, NLCD, see Vogelmann et al. 2001) remaining within each abiotic site type, and was calculated by ecological section. Hence, for each section, each site type or geolandform was summarized by the amount of non-natural land cover it supported. Land cover types considered non-natural were urban, cropland, water, and bare ground. The area of non-natural land cover was divided by the total area of the site type within that section and the result was multiplied by 100 to represent percent conversion.

c. Opportunity Area Data Layer

Opportunity areas are natural and semi-natural land cover patches that are away from roads and away from habitat patch edges. They are ranked based on size by landscape, from one (most important) to five (least important) within each ecological subsection. Following are brief methods; a complete outline of methods is found in (Diamond et al. 2003).

Base Data Creation

Land Cover. We used the NLCD, derived from 30-meter resolution classified Landsat 7 Thematic Mapper satellite data, to calculate land cover metrics (Vogelmann et al. 2001). We reclassified the NLCD from 21 land cover classes for the study area to seven major classes: forest, shrubland, grassland, cropland, urban, barren or sparsely vegetated, and water.

Creation of Distance Grids for Land Cover Patches and Roads. Each 30-m pixel in a grid was assigned a value from zero to nine for distance into the interior of a forest, grassland, shrubland, or 'mosaic' (see below) land cover patch, and distance away from a road. Many studies have shown that the impacts of edge and habitat fragmentation vary among species and land cover types (see Noss and Csuti 1997, Villard et al. 1999). Likewise, the impacts of roads, and of different road types, vary by species and habitat (see Trombulak and Frissell 2000). Therefore, we selected a mathematical rule for assigning cell values to create the distance grids for land cover and roads. The interval between high and low values for each category, is 1.5 times the distance between high and low for the category below it. A cell value of one corresponds with all cells zero to 30 meters from the edge of a land cover patch or a road right-of-way, and a two is assigned to cells 30 to 75 meters from the edge, and so on. Interstate highways with limited access (see TIGER roads data files at http:/www.census.gov/geo.maps/) were assigned zeros for three pixels that represent the road and right-of-way, whereas a zero was assigned to the single centerline pixel for all others.

We created a 'mosaic' land cover class to recognize areas of natural and semi-natural vegetation with high interspersion but no large patches of any one land cover type. Ninety-meter edges between forest, grassland, and shrubland were collectively defined and modeled as 'mosaic' land cover. Ninety-meter edges were selected after iterative modeling trials were run with wider and narrower edges; wider edges had more and more overlap with large patches of a single land cover type, whereas results using narrower edges did not capture significant mosaics of interspersion of different classes of natural and semi-natural vegetation.

Creation of Landscape Type Coverage. We modeled landscape types by calculating neighborhood statistics from original 30-meter DEM input data. Model results were initially classified following Hammond (1954, 1964), who used slope, relief, and profile to define landforms for the United States based on examination of 1:250,000 USGS quadrangles. We modified his definitions in an iterative way using more than 20 modeling trials. For the models, we grouped all pixels into landscape type classes based on analysis of slope and relief within circular neighborhoods ranging from 0.25-square kilometers to five-square kilometers. We selected a model in which slope was broken into two categories: more than 50% of the neighborhood on >8% slope or less than 50%, and relief was broken into seven categories; < 15 meters, 15 to 30 meters, 30 to 90 meters, 90 to 150 meters, 150 to 300 meters, 300 to 900 meters, and >900 meters. Results fit the recognizable landforms of the study area. Hence, 14 landscape types are possible (two slope categories multiplied by seven relief categories). We selected a one-kilometer neighborhood size base on visual examination of on-screen overlays of the DEMs with results using smaller and larger neighborhood windows, and overlays of the results from different trials themselves. Smaller neighborhoods did not identify important, larger-resolution landform variations such as gently sloping hills, whereas larger neighborhoods failed to accurately define the spatial location of features such as break-points where plateaus and hills come together on the landscape. Nigh and Schroeder (2002) also selected a one-square kilometer neighborhood roughness grid to delineate ecological subsection lines for Missouri.

Defining and Ranking Opportunity Areas

We intersected each land cover distance grid with the road distance grid to identify opportunity areas. We selected all distance grid cell values of three or more for any land cover class and for roads. The result is a coverage that represents areas more than 75m into the interior of a land cover patch and 75m away from any road. We then ranked all conservation opportunity areas based on size by landscape type within each ecological subsection. Each opportunity area was assigned a single, ordinal value from one (highest value) to N (lowest value; where N is the total number of conservation opportunity areas within the subsection). The value was equal to the highest value (lowest ordinal rank) for any landscape type patch comprising a portion of the opportunity area. The largest opportunity area polygons for each landscape type were considered the most important, and the smallest patches were considered least important.

d. Final Ecological Significance Data Layer: Percent Conversion and Opportunity Area Representation

We combined scores for percent conversion and opportunity area representation to create final ecological significance scores (Table 2, Figure 5). Natural and semi-natural land cover on abiotic site types that have been largely converted to cultural uses were considered more significant, because they represent habitats that were once more common but have become relatively rare in the modern landscape. For example, extant forests on large river floodplains, which have largely been converted to cropland, were considered more important than forest on slopes, since the present-day forests on slopes are relatively intact. Opportunity areas are relatively large patches of natural and semi-natural vegetation that are away from roads and habitat patch edges, and therefore are relatively more likely to be viable and functional, and less likely to be lost to urban development, in the near future (Fahrig 1997, Noss and Csuti 1997, Villard et al. 1999, Trombulak and Frissell 2000). They are ranked based on size by landscape representation. Therefore, they capture the most viable land cover patches across all representative landscape types within each subsection.

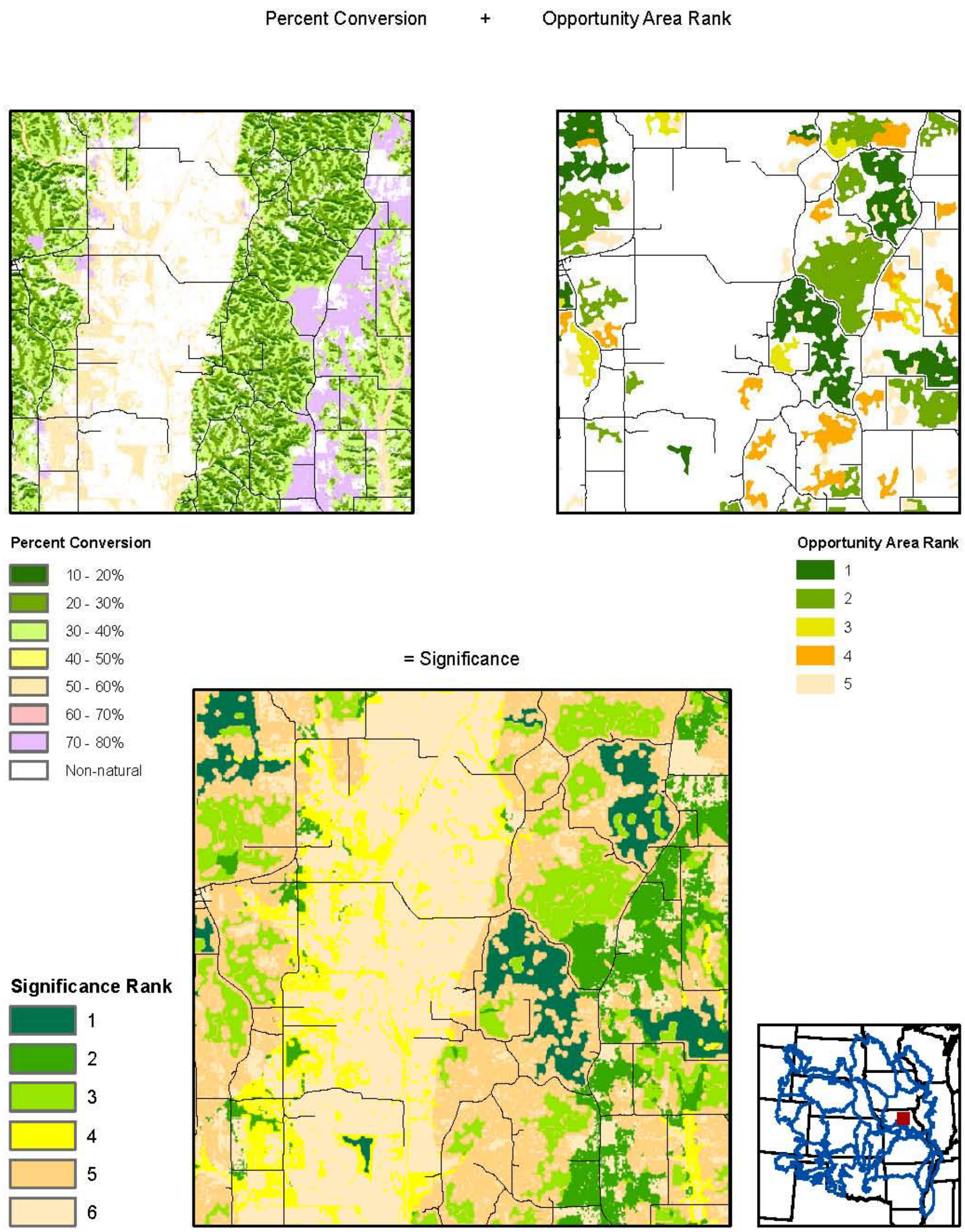


Figure 5. Ecological significance modeling procedures. Significance was determined from evalution of percent conversion of site sipes and opportunity area representation (see Table 2).

Table 2. Ecological Significance Ranking Scheme Combining Percent Conversion and Opportunity Area Representation

		Opportunity Area Rank			
		1	2,3,4,5	none	non-natural
Percent	High (70-100)	1	2	2	6
Conversion	Medium (40-60)	1	2	4	6
	Low (10-30)	1	3	5	6

We set out to combine individual pixel scores for percent conversion and opportunity area representation uniformly across all ecological sections in an ecologically meaningful and logical way. Thus, we did not use the product or sum of ranked values for percent conversion and opportunity area representation. Some assumptions included (1) all natural and semi-natural land cover has some ecological significance in terms of ecosystem function, biological conservation, and human health, and non-natural land cover is generally much less important, especially to biological conservation, (2) natural and semi-natural land cover on abiotic site types that have largely been converted to non-natural uses is more significant versus that on site types that are relatively intact, (3) all opportunity areas have at least a medium level of significance, since they represent areas that are away from roads and away from habitat patch edges, and are assumed to be both more functional and less subject to immediate future disturbance, and (4) high ranked opportunity areas have the most significance, since they are the largest, representative land cover patches of all landscape types (Table 2).

We considered a number of different ranking schemes that corresponded to our assumptions, and also looked at the additive and multiplicative models. Each resulted in a different percent of the ecological sections being identified as highly significant or significant (a rank of one or two on a scale of one to six, as outlined in Table 2). We settled on the first ranking scheme, since it corresponded most closely with our assumptions and logic, and no alternate scheme was meaningful across all sections. The top two ranks pulled out a mean of 14.04% of the area of each planning region with a standard deviation of 6.27% (Appendix 2).

The results of this assessment should be viewed as having most meaning on a planning region by planning region basis, and comparisons across the entire region should be avoided. Our algorithms for assigning significance were uniform across the region, but inherent differences among planning regions in terms of land use, land cover, internal landscape variability, and road density influence the results. The total area identified in the top two ranks for three planning regions was more than one standard deviation higher than the mean, whereas this value was more than one standard deviation less than the mean for three planning regions (Appendix 1). These latter two planning regions, the North Central U.S. Driftless and Escarpment section (222L), the Cross Timbers and

Prairies (225A) and the Osage Plains (251E, Figure 2), each had more than 70% natural and semi-natural vegetation and a relatively high density of roads. Therefore, the opportunity areas were small due to road density and the percent conversion values were low, which combined resulted in a low area represented in significance scores one and two. In the case of the three sections where relatively more area was identified in significance class one and two, the values for percent conversion were high, and thus much of the remaining natural and semi-natural vegetation in these largely agricultural regions fell within significance class two (see the North Missouri Alluvial Plain section, 234B; Southern High Plains 331B; Central High Plains 331H; Figure 2).

2. Creation of Threats Surface

The primary threats to ecological integrity in EPA Region 7 result from habitat alteration or destruction due to development of urban infrastructure or conversion of natural vegetation to row crops. For terrestrial ecosystems, there is a lesser threat from toxic releases. The threat index was constructed to reflect these three sources of stress by combining indices constructed from widely available medium to large scale data sets.

a. Development Land Demand

Development land demand is a surface of 30-meter pixels that represents the base desire for land (Wickman et al., 2000) based on proximity to urban areas (cities greater than 10,000 people) and population density change from 1990 to 2000. Previous work completed by Wickman et al. (2000) modeled land demand by splining quotients of population over distance and tested several weighted results using an inverse distance weighted surface. We adapted the analysis through expanded roles for the two primary variables, urban area and population density.

The proximity portion of the development land demand index weighted combinations of buffers around urban areas, roads, and metropolitan statistical areas (MSAs). We made the basic assumption that growth is more likely to occur within urban areas and we filtered the weights along roads (1 km buffer) and within MSA boundaries (25 km). Pixels are weighted from one (not within a buffer) to five (within an urban area > 10,000 people) and are summarized below:

1 - not within 1 km of any road and not near a city or metropolitan statistical area (MSA)
2 - within 1km of a road but not within 25km of a metropolitan MSA or 10km of city
3 - within 1 km of a road and within 25km of an (MSA) but not within 10km of a city
4 - within 1km of a road and within 10km of a city
5 - within the boundary of a city limit

Proximity data sources are summarized as follows:

Cities larger than 10,000	National Atlas of the United	ESRI Data & Maps, 2003

	States and the United States Geological Survey, ESRI	
Roads	U.S. Census Tiger/Line	U.S. Census, 2004
Metropolitan Statistical Areas (MSAs)	U.S. Office of Management and Budget	ESRI Data & Maps, 2003

Weighted change in population density from 1990 to 2000 reflects the population demand portion of the Development Land Demand index. We reasoned that areas where the human population expanded would be subjected to a higher development land demand versus those that were stable or declined in population. Population density change was calculated using U.S. Census Blocks. Geolytics software rectified spatial changes in block boundaries by weighting data across the 1990 or 2000 block and than re-apportioned the data to the "corresponding" block (A complete technical description of the area weighting methodology can be found online at: http://www.geolytics.com/USCensus,Census-1990-Long-Form-2000-Boundaries,Data,Methodology,Products.asp). The density change equals the 1990 population per km^2 subtracted from the 2000 population per km^2 and then normalized by the 2000 population per km^2. The resulting percentages received a weight from one to five.

1 = large population loss (less than -1.0)
2 = population loss (-1 to -0.25)
3 = stable population (-0.25 to 0.25)
4 = population growth (0.25 to 0.50)
5 = large positive growth (0.50 to 1.0)

Proximity and population density change analyses occurred within vector polygon shapefiles and then were converted into 30-meter grid datasets. The proximity weight grid summed with the population change weight grid resulted in the Development Land Demand (D_D) index with a value range from one (low demand) to ten (high demand).

b. Agricultural Threat

An agricultural threat index was created from the USGS GIRAS land cover data and NLCD data. Both data sets were reclassified to reflect only agricultural and non-agricultural land uses. The historic data used was the USGS GIRAS landcover data with dates ranging from the mid 1970s to the early 1980s (Environmental Protection Agency's Office of Information Resources Management (OIRM). The data set was re-classified to reflect agricultural land coded as 1 and all other classes coded to zero as follows:

21 Cropland and pasture
22 Orchards, groves, vineyards, nurseries, and ornamental horticultural
23 Confined feeding operations

24 Other agricultural land
31 Herbaceous rangeland
33 Mixed rangeland

The existing 100 m grid was re-sampled to a 30m grid to conform to the NLCD grid structure. Agricultural density was then calculated using ArcGIS 9.1 rectangular neighborhood analysis with a 33x33 cell local window. The "current" data used was the NLCD land cover classification product based primarily on 1992 Landsat Thematic Mapper (TM) data. This data set was also re-classified to reflect agricultural land coded as 1 and all other classes coded to zero as follows:

61 Orchards/Vineyards/Other
71 Grasslands/Herbaceous
81 Pasture/Hay
82 Row Crops
83 Small Grains
84 Fallow

Agricultural density was calculated as for the GIRAS grid. The change in density was then calculated by subtracting the GIRAS density grid from the NLCD density grid and the result was reclassified into five classes using Jenk's natural breaks.
The NLCD density grid was then multiplied by the change weighting factor and the results reclassified into a final five class agricultural threat index, where one is the lowest threat and five the highest. Natural breaks were again used to derive the classes.

c. Toxics Index

The toxics index was derived from the EPA Toxic Release Inventory (TRI) of 2002 and the location of Missouri lead mines and smelters. Only air releases in the TRI were considered to have a potentially significant impact on terrestrial systems. Lead is a significant ecological problem in the historic and current lead mining areas of Missouri, not all of which are represented in the TRI, hence the addition of these data into the index calculations. Buffers were created for the TRI facilities based on the amount of the annual release. Total air releases were categorized into a five tier classification and buffers were created from 1-5000 m based on the class for each facility. Lead mines and smelters were also buffered, 1000 m for mine sites and 3000 m for smelters. Only those sites not included in the TRI were used. The three shapefiles were then combined and the combined shapefile converted to a 30m grid with each grid cell having a value equal to the total number of buffers that overlay it. This grid was then reclassified from 0-5 for the final toxics index.

d. Creation of Final Threats Surface

The final threats surface was calculated as the sum of development land demand, agriculture land demand, and potential toxic release impacts. The final grid was ranked from 1-6 based on standard deviations, where one is the lowest threat and six the highest.

3. Creation of Ecological Risk Surface: A Combination of Significance and Threat

By our definition, ecological risk is high when there is a high risk of loosing a highly significant patch of natural or semi-natural vegetation. Our approach to combining ecological significance and threat data to create a risk surface was based on the assumption that ecological significance should be weighted more than threat. We also assumed that areas of non-natural vegetation are of low risk, because they are of low functional ecological value. Areas of high significance are important regardless of the threat level, and areas of low significance are low risk regardless of threat. Areas of intermediate significance are more important if the threat is higher (Figure 6, Appendix 3)

The mean percent of area within the highest two risk categories by planning region was 32.4%, with a standard deviation of 16.7%. These results are most relevant at on a planning region by planning region basis.

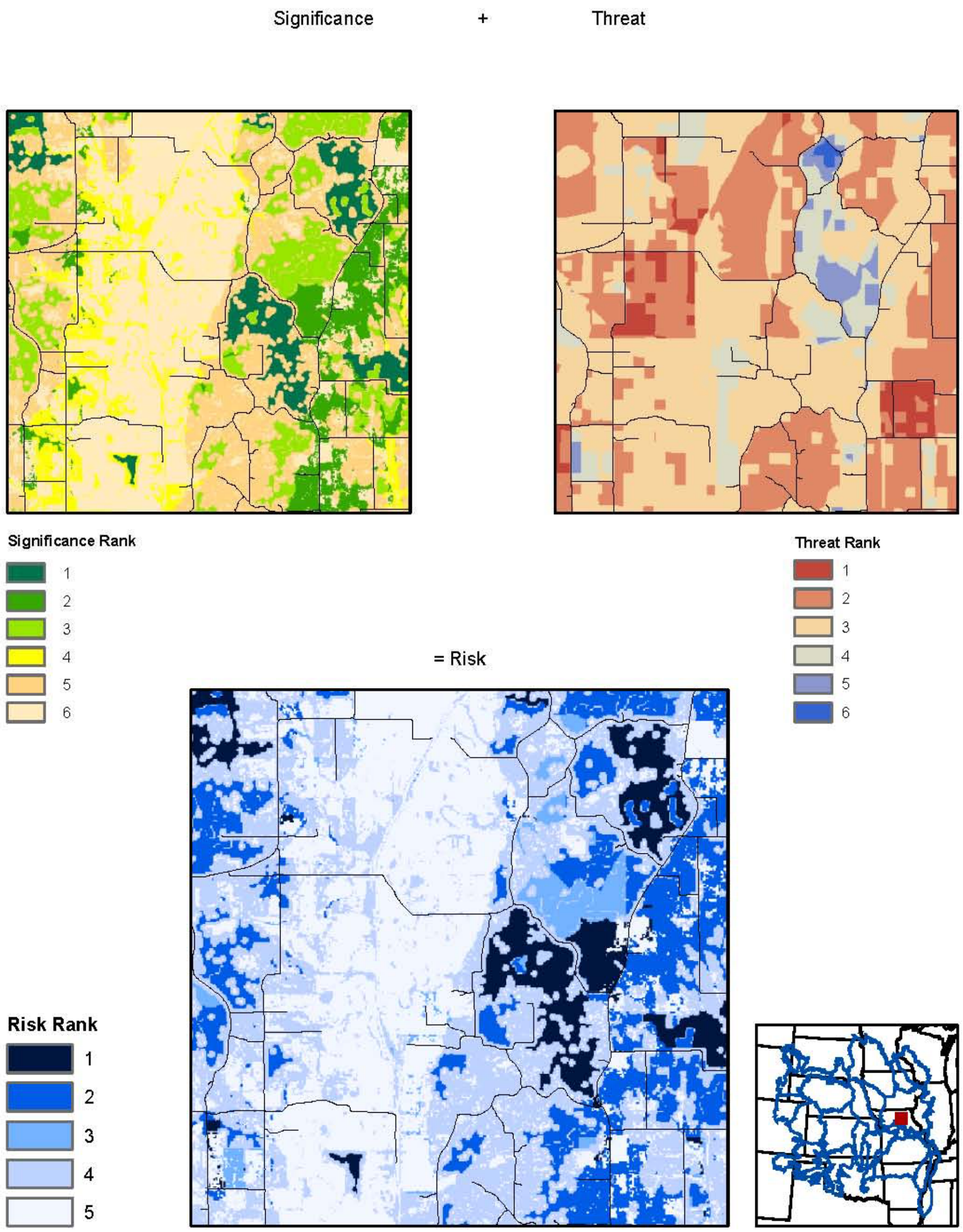


Figure 6. Ecological risk modeling procedures. Risk was determined by evaluating significance and threat (see Table 3).

Table 3. Risk Assessment Methods

Significance

			high 1	2	3	4	*low* 5	*non-natural* 6
	low	10	11	12	13	14	15	16
		20	21	22	23	24	25	26
Threats		30	31	32	33	34	35	36
		40	41	42	43	44	45	46
		50	51	52	53	54	55	56
	high	60	61	62	63	64	65	66

Risk		
	1	*high*
	2	
	3	
	4	*low*
	5	*non-natural*

B. Irreplaceability Analysis

Several algorithms and software programs have been recently designed to attach values to assessment units, such as hexagons, parcels, or a regular grid, within assessment regions, such as ecoregions or states (see Ferrier et al. 200, Noss 2004). Such assessments require a combination of biotic and abiotic conservation targets that represent ecological structure, function, and processes (Margules and Pressey 2000). Planners and managers must also set quantitative goals for representing the targets, such as hectares or percent representation within the planning region (see Noss et al. 2002). Noss (2004) points out that appropriate, even coverage of digital data is required for all targets, and that different assessments and assessment regions may require a different set of surrogate targets.

1. Overall methodology

We selected the software package C-Plan to attach irreplaceability values to 40 square kilometer hexagons, our assessment units, within each planning region. The definition of irreplaceability is "the likelihood that a given site will need to be protected to achieve a specified set of targets or, conversely, the extent to which options for achieving these targets are reduced if the site is not protected" (Pressey et al. 1994). A highly irreplaceable hexagon has few or no replacements in the scheme of selected sets of hexagons that achieve the conservation goals within the section.

The irreplaceability of hexagon X is based on the proportion of sets of hexagons that meet the quantitative target goals ("representative sets," R) that must include hexagon X versus those that meet the target goals without hexagon X:

$$\text{Irreplaceability} = \frac{R(\text{x included}) - R(\text{x removed})}{R(\text{x included}) + R(\text{x removed})}$$

When multiple targets are assessed, the site irreplaceability is equal to the highest irreplaceability value for a given hexagon across all targets, whereas the summed irreplaceability is the sum of all irreplaceability values for all targets for a given hexagon. We were interested in site irreplaceability, so each 40 sq km hexagon was assigned a value between 0 and 1.

2. EPA Region 7 Results

For EPA Region 7, we selected targets and set thresholds for capture of targets in EPA R7 as follows:

Abiotic Site Types: 25% of each within the section
Opportunity Areas Ranked #1: 40%
Areas of High Vertebrate Richness: 25% of the top 20% richest areas

Abiotic site type targets ensure representation of habitats, whereas high vertebrate richness is a biotic target. Opportunity areas are both a biotic and abiotic target, since they are the largest, most functional patches of extant semi-natural vegetation of each landscape type by section.

Vertebrate richness was assigned to 30 m grid cells based on state by state results of Gap Analysis projects. Since different states used different methods to model species distribution, we first clipped each state grid with the section boundaries, and then selected the top 20% richest grid cells for each state. We then merged the section pieces together and selected the top 25% richest cells in each section. This process served to smooth differences among results across state lines. No results were available for the states of Minnesota and Wisconsin, so we ran separate Irreplaceability analyses for sections that intersected those states excluding vertebrate richness as a target (sections 251B, the North Central Glaciated Plains; 222M, the Minnesota and Northeast Iowa Morainal-Oak Savanna; and section 222L, the North Central U. S. Driftless and Escarpment section).

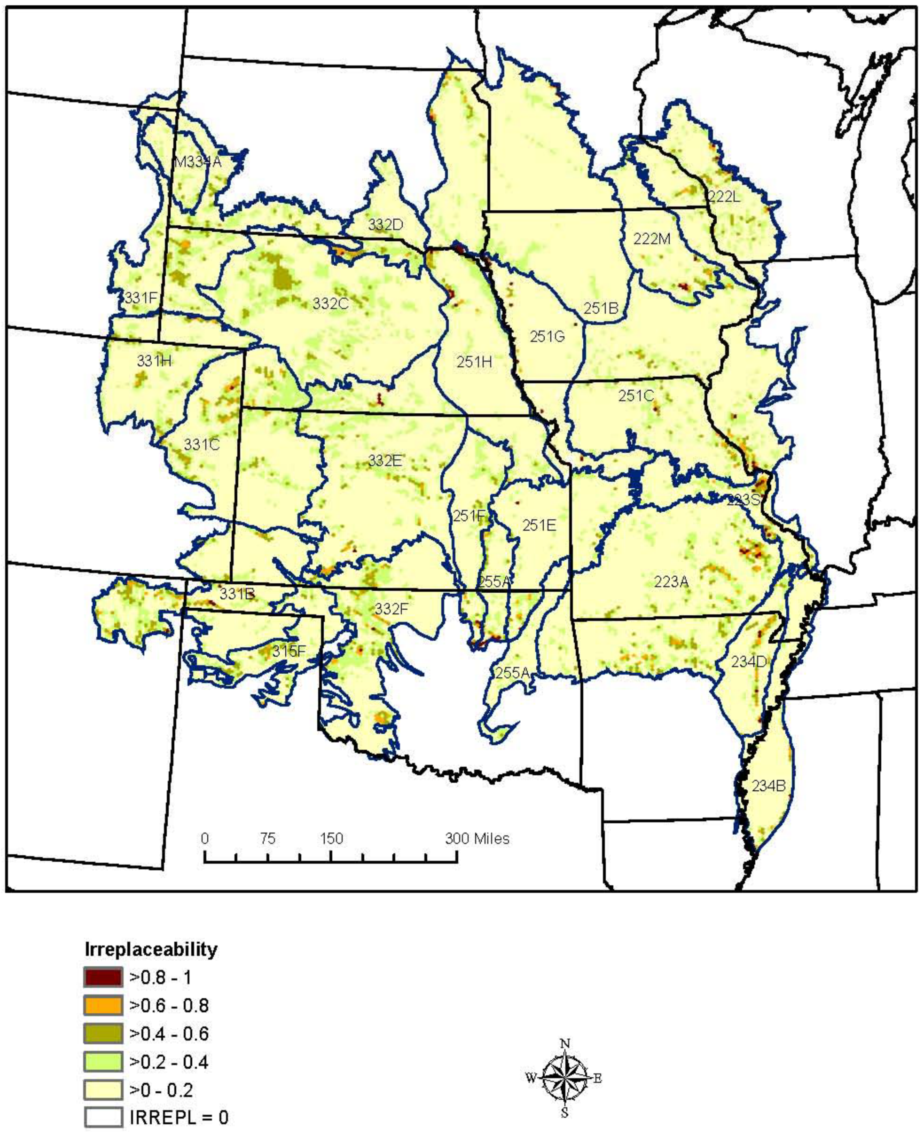
We assigned each 40 square kilometer hexagon into one of five Irreplaceability classes based on the raw scores. Raw scores ranged from 0 (most replaceable) to 1 (highly irreplaceable) and were assigned to classes one to five as follows:

Raw Irreplaceability Score:	Irreplaceability Class
0 - 0.2	5
0.2 - 0.4	4

0.4 - 0.6	3
0.6 - 0.8	2
0.8 - 1.0	1

The mean area by section within Irreplaceability categories one was 4.3% with a standard deviation of 5.9% (see Figure 7, Appendix 3). The mean area within categories one plus two combined was 8.7% with a standard deviation of 9.2%. Again, results are most relevant on a planning region by region (section by section) basis.

Figure 7. Irreplaceability values attached to 40 square kilometer hexagons (assessment units) for EPA Region 7. Irreplaceability scores for each hexagon were determined by evaluation of biotic (opportunity area representation, vertebrate species diversity) and abiotic (site type representation) targets.



C. Identification of Conservation Focus Areas: A Combination of Risk and Irreplaceability

We used the ecological risk and irreplaceability results to identify conservation focus areas (Figure 8). We used logic similar to that used to combine significance and threat to define risk. Areas of highest risk or high irreplaceability and high risk or at least moderate risk and highest irreplaceability were identified as conservation focus areas:

Conservation Focus Area Identification:

Case 1: highest risk (ranked 1) and any irreplaceability
Case 2: high risk (>=2) and high irreplaceability (>=2)
Case 3: at least moderate risk (>=3) and moderate irreplaceability (>=3)

We eliminated all conservation focus area patches that were less than two hectares. An average of 8.3% of each planning region was within conservation focus areas, with a standard deviation of 4.3% (Table 4, Figure 8). Planning regions that are relatively natural had higher percentages of conservation focus areas. These planning regions included the Nebraska Sand Hills (332C), Flint Hills (251E) and adjacent Cross Timbers and Prairies, and Ozark Highlands (223A) had relatively large patches of natural and semi-natural vegetation that are away from roads and habitat patch edges, which are considered conservation focus areas (Figure 8, Appendix 5). Planning regions that are largely cultural such as the North Central Glaciated Plains (251C) and the Central Dissected Till Plains (251B) had relatively small percentages of conservation focus areas. However, due to the scale at which the figures are produced herein, they appear to have more conservation focus areas than they do, because many of the conservation focus areas are small patches of semi-natural vegetation within a sea of row crop agriculture.

Figure 8. Conservation focus areas for EPA Region 7.

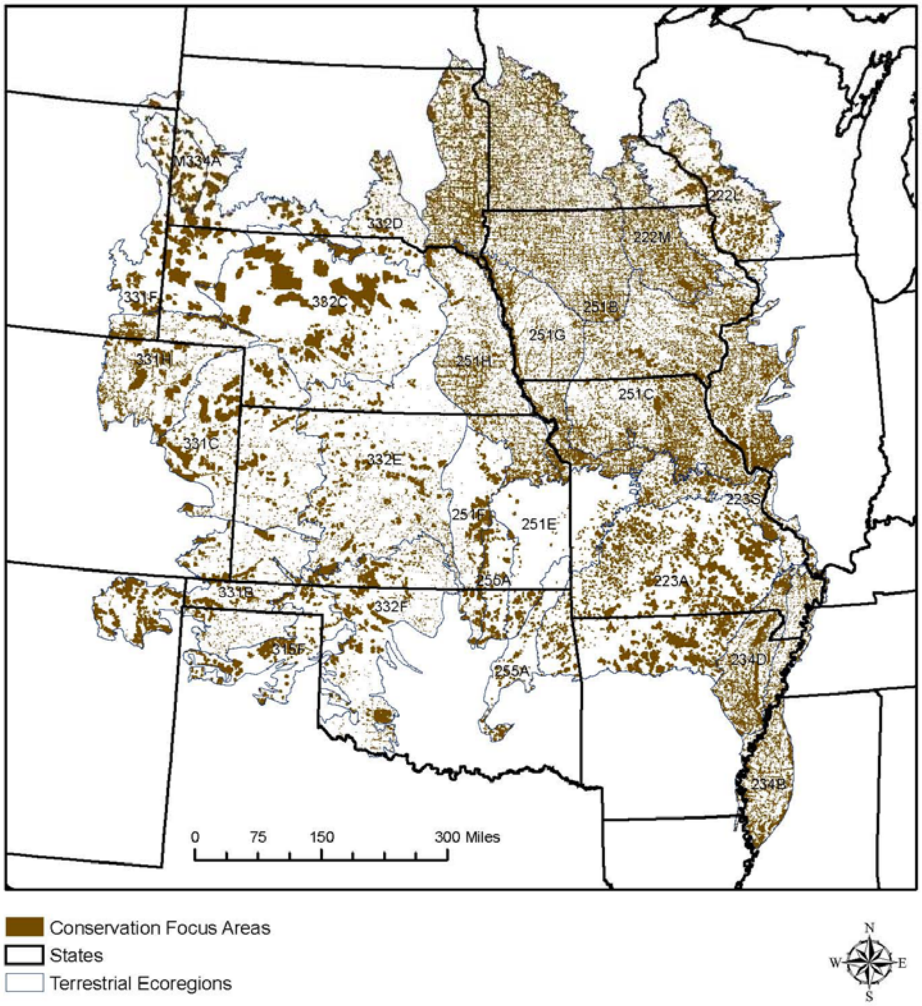


Table 4. Summary of Conservation Focus Areas by Area and Percent for Ecological Planning Regions in EPA Region 7 *

Section Number	Section Name	Focus Areas Area (ha)	Percent
222L	North Central U. S. Driftless and Escarpment	275,130	5.5%
222M	Minnesota and Northeast Iowa Morainal-Oak Savanna	90,730	3.2%
223A	Ozark Highlands	1,567,500	13.5%
223S	Missouri River Loess	209,920	8.7%
234B	North Mississippi Alluvial Plain	165,940	4.8%
234D	White and Black River Alluvial Plains	162,210	6.9%
251B	North Central Glaciated Plains	383,980	3.0%
251C	Central Dissected Till Plains	528,020	4.3%
251E	Osage Plains	121,440	2.8%
251F	Flint Hills	226,850	8.6%
251G	Missouri Loess Hills	195,290	4.2%
251H	Nebraska Rolling Hills	151,690	2.9%
255A	Cross Timbers and Prairies	229,540	8.5%
315F	Northern Texas High Plains	333,340	12.9%
331B	Southern High Plains	690,790	11.4%
331C	Central High Tablelands	701,820	9.1%
331F	Western Great Plains	978,720	15.1%
331H	Central High Plains	501,710	11.4%
332C	Nebraska Sand Hills	1,441,900	15.4%
332D	North-Central Great Plains	223,810	10.5%
332E	South Central Great Plains	419,810	4.4%
332F	South Central and Red Bed Plains	429,320	7.5%
M334A	Black Hills	195,170	15.1%

* Only areas >= 2 hectares were selected

III. Aquatic Assessment

The methods used to identify aquatic conservation focus areas throughout EPA Region 7 were developed by a EPA staff, MoRAP staff, and a team of aquatic resource professional from around Missouri. At a series of meetings this team was instructed on the general goal of the project and was provided detailed overviews on the geospatial and tabular data available for the assessment process. The first task set before the team was to develop a narrative goal for the aquatic assessment that would provide a common baseline for all those involved. The team formulated the following goal; *"Ensure the long-term persistence of native aquatic plant and animal communities, by conserving the conditions and processes that sustain them, so people may benefit from their values in the future."* The team then identified a list of principles, theories, and assumptions they believed had to be considered or adhered to in order to achieve this goal. These mainly related to basic principles of stream ecology, landscape ecology, and conservation biology (Appendix 6). However, some reflected the personal experiences of team members and the challenges they face when conserving natural resources in regions with limited public land holdings. For instance, one of the assumptions identified by the team was: "Success will often hinge upon the participation of local stakeholders, which will often be private landowners." In fact, the importance of private lands management for aquatic biodiversity conservation was a topic that permeated throughout the initial meetings of the team. Next, the team drafted a more specific tactical objective for meeting the overall goal; "*Identify and map a set of aquatic conservation focus areas that holistically represent the full breadth of distinct riverine ecosystems and multiple populations of all native aquatic species.*"

Once the goal, fundamental principals and assumptions, and tactical objective were established, we worked to develop a customized GIS-based decision support system for the Meramec Ecological Drainage Unit, which served as the pilot area for the assessment. The team developed a specific assessment strategy that identified/adopted the, a) geographic framework for the assessment, b) abiotic and biotic targets, and c) quantitative and qualitative assessment criteria for selecting priority locations for conservation. The pilot decision support system and assessment strategy were slightly modified based on the collective input of all individuals participating in the assessment. Decision support systems were then developed for all of the other EDUs across Missouri. Regional teams of experts were established and conservation assessments were then conducted for each EDU. Based on these assessments, a total of 158 conservation focus areas were identified across Missouri. We then used a conservation planning software (C-Plan) to assess the complimentarity of species capture across all of the focus areas and provide one means of prioritizing all 158 areas.

Only a subset of the data used to identify aquatic conservation focus areas in Missouri were available for the other three states within EPA Region 7. Consequently, we developed a more general and coarser-scale conservation assessment strategy to identify conservation focus areas throughout Iowa, Kansas, and Nebraska. Yet, the resulting focus areas across these three states still provide a very useful blueprint for conserving the diversity of freshwater ecosystems that occur within this part of EPA Region 7.

A. Aquatic Conservation Assessment for Missouri

The decision support systems that were used to conduct the aquatic conservation assessments across Missouri included all of the data compiled or created for the Missouri Aquatic GAP Project, as well as other pertinent geospatial data developed for this project. In particular, four geospatial datasets served as the core information sources used to identify conservation focus areas across the state. In the next four sections we provide overviews of these primary geospatial datasets in order to provide the reader an understanding of the utility and limitations of these data. Following these overviews are sections outlining the conservation assessment strategy developed by the team of aquatic resource professionals and the results of the assessment for the pilot area and the state.

1. Aquatic Classification

Conservation planning and assessment are geographical exercises and thus require the selection of a suitable geographic framework. More specifically, this involves selecting, defining, and mapping *planning regions* and *assessment units*. A planning region refers to the area for which the conservation assessment is conducted. It defines the spatial extent of the assessment or conservation plan. Assessment units are geographic subunits of the planning region. These units define the spatial grain of analysis and represent those units among which relative quantitative or qualitative comparisons will be made in order to select specific geographic locations as priorities for conservation. Planning regions and assessment units can be variously defined and should be hierarchical in nature to allow for multiscale assessment and planning (Wiens 1989). Boundaries could be based on sociopolitical boundaries (e.g., nations, states, counties, townships), regular grids (e.g., UTM zones or EPA EMAP hexagons), or ecologically defined units (e.g., watersheds or ecoregions).

Since ecosystems or patterns of biodiversity do not follow sociopolitical boundaries or regular grids, whenever possible, planning regions and assessment units should be based on ecologically defined boundaries since these boundaries provide a more informative ecological context (Bailey 1995; Omernik 1995; Leslie et al. 1996; Higgins 2003). Agreeing with this premise, the team of aquatic resource professionals selected the MoRAP aquatic ecological classification hierarchy as the geographic framework for the conservation assessment. This classification hierarchy is briefly described below.

It is widely accepted that to conserve biodiversity we must conserve ecosystems (Franklin 1993; Grumbine 1994). It is also widely accepted that ecosystems can be defined at multiple spatial scales (Noss 1990; Orians 1993). Consequently, a key objective was to define and map distinct riverine ecosystems (often termed ecological units) at multiple levels. Yet, before distinct riverine ecosystems could be classified and mapped, the question "What factors make an ecosystem distinct?" needed to be answered. Ecosystems can be distinct with regard to their structure, function, or composition (Noss 1990).

Structural features in riverine ecosystems include factors such as depth, velocity, substrate, or the presence and relative abundance of habitat types. Functional properties include factors such as flow regime, thermal regime, sediment budgets, energy sources, and energy budgets. Composition can refer to either abiotic (e.g., habitat types) or biotic factors (e.g., species). While both are important, our focus here will be on biological composition, which can be further subdivided into ecological composition (e.g., physiological tolerances, reproductive strategies, foraging strategies, etc...) or taxonomic composition (e.g., distinct species or phylogenies) (Angermeier and Schlosser 1995). Geographic variation in ecological composition is generally closely associated with geographic variation in ecosystem structure and function. For instance, fish species found in streams draining the Central Plains of northern Missouri generally have higher physiological tolerances for low dissolved oxygen and high temperatures than species restricted to the Ozarks, which corresponds to the prevalence of such conditions within the Central Plains (Pflieger 1971; Matthews 1987; Smale and Rabeni 1995a, 1995b). Differences in taxonomic composition, not related to differences in ecological composition, are typically the result of differences in evolutionary history between locations (Mayr 1963). For instance, differences among biological assemblages found on islands despite the physiographic similarity of the islands.

Considering the above, a more specific objective was to identify and map riverine ecosystems that are relatively distinct with regard to ecosystem structure, function, and evolutionary history at multiple levels. To accomplish this, an eight-level classification hierarchy was developed in conjunction with The Nature Conservancy's Freshwater Initiative (Higgins 2003, Figure 9). These eight geographically-dependent and hierarchically-nested levels (described next) were either empirically delineated using biological data or delineated in a top-down fashion. For the top-down approach we used landscape and stream features (e.g., drainage boundaries, geology, soils, landform, stream size, gradient, etc.) that have consistently been shown to be associated with or ultimately control structural, functional, and compositional variation in riverine ecosystems (Hynes 1975; Dunne and Leopold 1978; Matthews 1998). More specifically, levels 1-3 and 5 account for geographic variation in *taxonomic or genetic-level composition* resulting from distinct evolutionary histories, while levels 4 and 6-8 account for geographic variation in ecosystem structure, function, and *ecological composition* of riverine assemblages. The most succinct way to think about the hierarchy is that it represents a merger between the different approaches taken by biogeographers and physical scientists for tesselating the landscape into distinct geographic units.

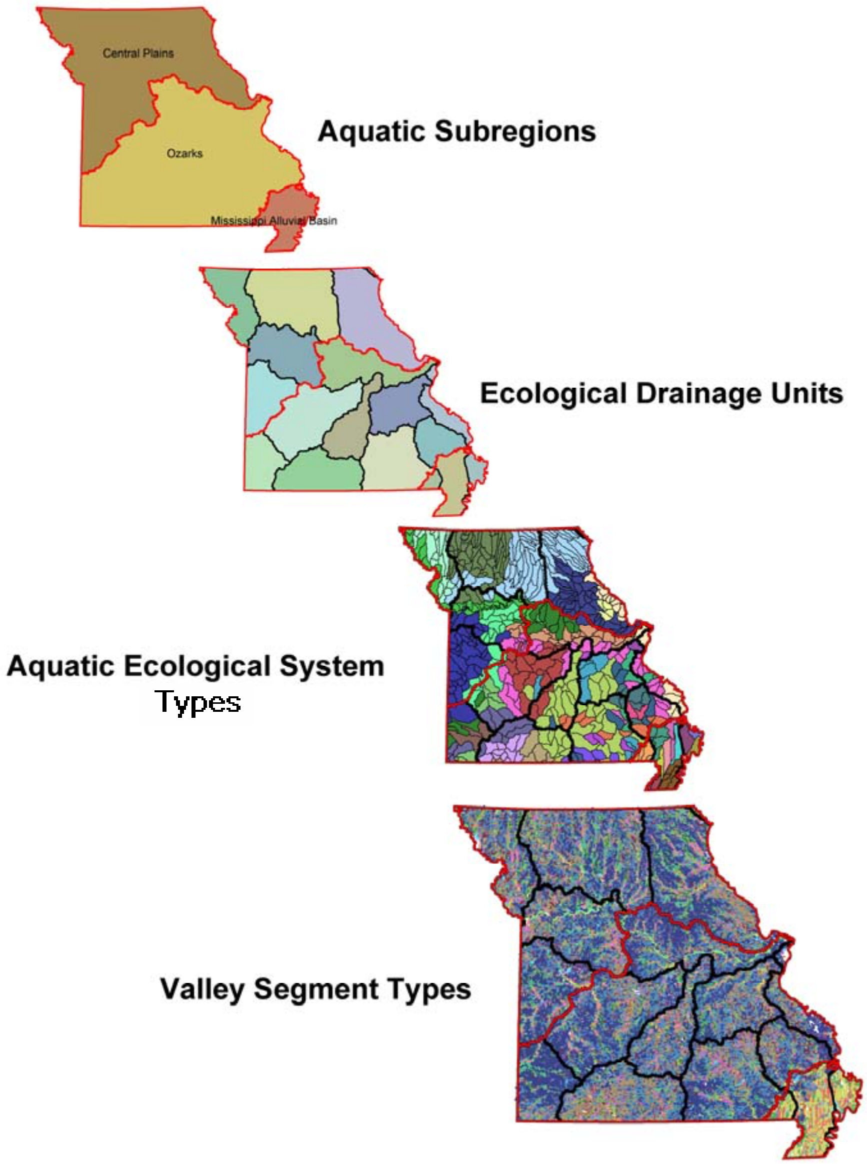


Figure 9. Maps showing Levels 4-7 of the MoRAP Aquatic Ecological Classification hierarchy.

a. Levels 1 – 3: Zone, Subzone, and Region

The upper three levels of the hierarchy are largely zoogeographic strata representing geographic variation in taxonomic (family and species-level) composition of aquatic assemblages across the landscape resulting from distinct evolutionary histories (e.g., Pacific versus Atlantic drainages). For these three levels we adopted the ecological units delineated by Maxwell et al. (1995) who used existing literature and data, expert opinion, and maps of North American aquatic zoogeography (primarily broad family-level patterns for fish and also unique aquatic communities) to delineate each of the geographic units in their hierarchy. More recent quantitative analyses of family-level faunal similarities for fishes conducted by Matthews (1998) provide additional empirical support for the upper levels of the Maxwell et al. (1995) hierarchy. The ecological context provided by these first three levels may seem of little value; however, such global or subcontinental perspectives are critically important for research and conservation (see pp. 261-262 in Matthews 1998). For instance, the physiographic similarities along the boundary of the Mississippi and Atlantic drainages often produce ecologically similar (i.e., functional composition) riverine assemblages within the smaller streams draining either side of this boundary, as Angermeier and Winston (1998) and Angermeier et al. (2000) found in Virginia. However, from a species composition or phylogenetic standpoint, these ecologically similar assemblages are quite different as a result of their distinct evolutionary histories (Angermeier and Winston 1998; Angermeier et al. 2000). Such information is especially important for those states that straddle these two drainages, such as Georgia, Maryland, New York, North Carolina, Pennsylvania, Tennessee, Virginia, and West Virginia, since simple richness or diversity measures not placed within this broad ecological context would fail to identify, separate, and thus conserve distinctive components of biodiversity. The importance of this broader context also holds for those states that straddle the continental divide or any of the major drainage systems of the United States (e.g., Mississippi Drainage vs. Great Lakes or Rio Grande Drainage).

b. Level 4: Aquatic Subregions

Aquatic Subregions are physiographic or ecoregional substrata of Regions and thus account for differences in the ecological composition of riverine assemblages resulting from geographic variation in ecosystem structure and function (Figure 10). However, the boundaries between Subregions follow major drainage divides to account for drainage-specific evolutionary histories in subsequent levels of the hierarchy. The three Aquatic Subregions that cover Missouri (i.e., Central Plains, Ozarks, and Mississippi Alluvial Basin) largely correspond with the three major aquatic faunal regions of Missouri described by Pflieger (1989). Pflieger used a species distributional limit analysis and multivariate analyses of fish community data to empirically define these three major faunal regions. Subsequent studies examining macroinvertebrate assemblages have provided additional empirical evidence that these Subregions are necessary strata to account for biophysical variation in Missouri's riverine ecosystems (Pflieger 1996; Rabeni et al. 1997; Rabeni and Doisy 2000). Each Subregion contains streams with relatively distinct structural features, functional processes, and aquatic assemblages in terms of both taxonomic and ecological composition.

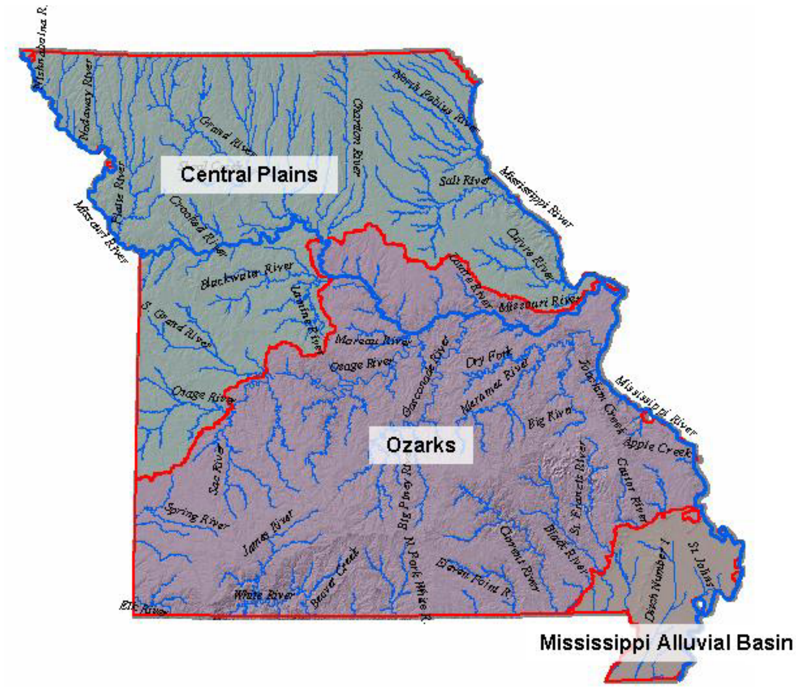


Figure 10. Map showing the boundaries of the three Aquatic Subregions of Missouri.

c. Level 5: Ecological Drainage Units

Embedded within Aquatic Subregions are geographic variations in taxonomic composition (species- and genetic-level) resulting from the geographically distinct evolutionary histories of the major drainages within each Subregion (Pflieger 1971; Mayden 1987; Mayden 1988; Crandall 1998; Matthews and Robison 1998). Level 5 of the hierarchy, Ecological Drainage Units (EDUs), account for these differences (Figure 11). An initial set of EDUs was empirically defined by grouping USGS 8-digit hydrologic units (HUs) with relatively similar fish assemblages based on the results of multivariate analyses of fish community data (Nonmetric Multidimensional Scaling, Principal Components Analysis, and Cluster Analysis). We then used collection records for three other taxa (crayfish, mussels, and snails) to further examine faunal similarities among the major drainages within each Subregion and refined the boundaries of this draft set of EDUs when necessary. Spatial biases and other problems with the data prohibited including these taxa in the multivariate analyses. In only one instance were the draft boundaries altered. Within the Ozark Aquatic Subregion the subdrainages of the Osage and Gasconade basins consistently grouped together using the methods described above. However, a more general assessment using Jacaard similarity coefficients suggested the need to separate these two drainages. Using just fish community data, the Jacaard similarity coefficient among these two drainages is 86, while when using combined data for crayfish, mussels, and snails the similarity coefficient drops to only 56.

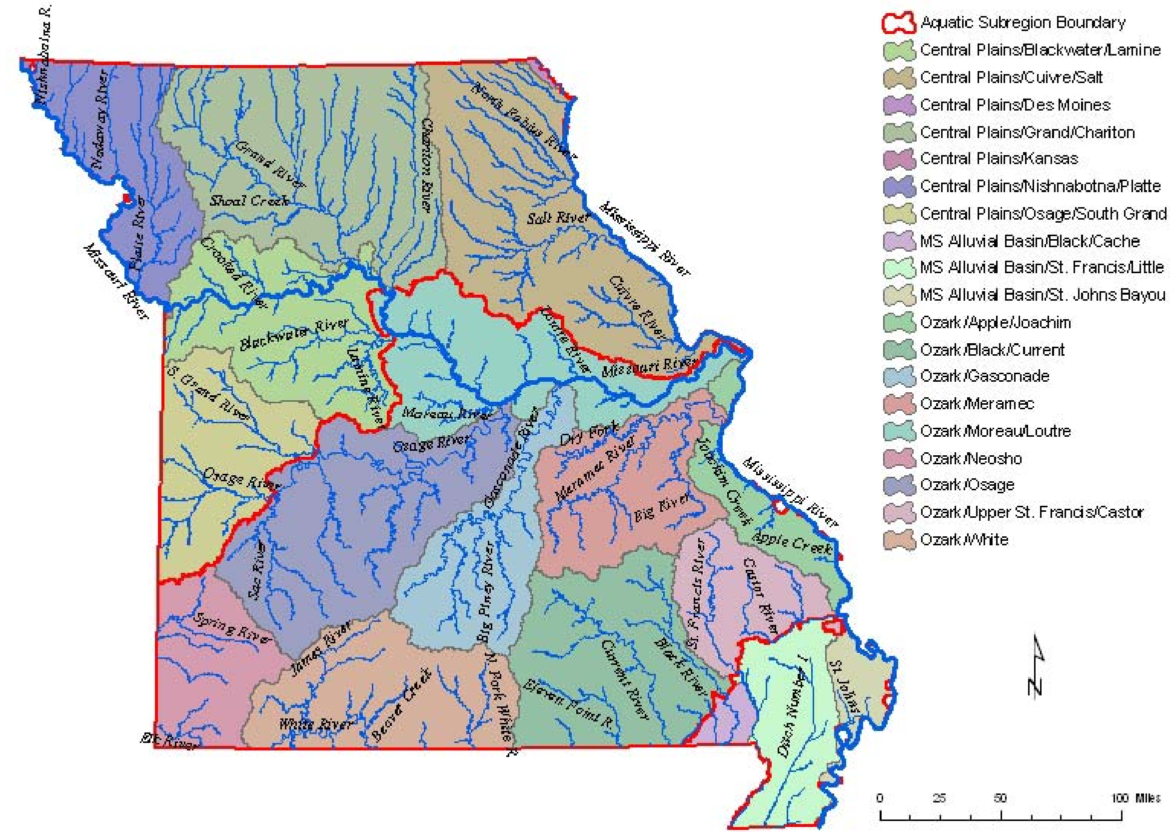


Figure 11. Map of Ecological Drainage Units (EDUs) for Missouri.

EDUs are very much analogous to "islands" when viewed within the context of the surrounding Aquatic Subregion, which is analogous to the "sea" in which the EDUs reside. Our analyses show that the relative similarity (based on centroid distance) of EDUs, within an Aquatic Subregion, is negatively related to the number of river miles separating their respective outlets. Matthews and Robison (1998) found this same relationship for a similar analysis conducted in Arkansas. These results also directly correspond with the relative similarity of assemblages on two or more islands, which is generally negatively related to the distance between the islands (Mayr 1963). Consequently, within a given Aquatic Subregion, all of the EDUs have assemblages with relatively similar ecological composition (e.g., physiological tolerances, reproductive and foraging strategies). However, the taxonomic composition (species and genetic level) of the assemblage of any given EDU is relatively distinct due to evolutionary processes such as adaptive radiation, differences in colonization history, random genetic mutation, etc.

d. Level 6: Aquatic Ecological System Types

While Aquatic Subregions are relatively distinct in terms of their climatic, geologic, soil, landform, and stream character, they are by no means homogeneous. These finer-resolution variations in physiography also influence the ecological composition of local assemblages (Pflieger 1971; Hynes 1975; Richards et al. 1996; Panfil and Jacobson 2001;

Wang et al. 2003). To account for this finer-resolution variation in ecological composition we used multivariate cluster analysis of quantitative landscape data to group small- and large-river watersheds into distinct Aquatic Ecological System Types (AES-Types). AES-Types represent watersheds or subdrainages (that are approximately 100 to 600 mi^2 with relatively distinct (local and overall watershed) combinations of geology, soils, landform, and groundwater influence (Figure 12). We determined the number of distinct types by examining relativized overlay plots of the cubic clustering criterion, pseudo F-statistic, and the overall R-square as the number of clusters was increased (Calinski and Harabasz 1974; Sarle 1983). Plotting these criteria against the number of clusters and then determining where these three criteria are simultaneously maximized provides a good indication of the number of distinct clusters within the overall data set (Calinski and Harabasz 1974; Sarle 1983; Milligan and Cooper 1985; SAS 1990; Salvador and Chan 2003). Thirty-eight AES-Types were identified for Missouri with this method.

AES-Types often initially generate confusion simply because the words or acronym used to name them are unfamiliar. In reality, AES-Types are just “habitat types” at a much broader scale than most aquatic ecologists are familiar with. We have no problem recognizing lake types or wetland types; AES-Types are no different except that they apply specifically to riverine ecosystems. And, just like any habitat classification, there can be multiple instances of the same habitat type. For example, a riffle is a habitat type, yet there are literally millions of individual riffles that occupy the landscape. Each riffle is a spatially distinct habitat, however, they all fall under the same habitat type with relatively similar structural features, functional processes, and ecologically-defined assemblages. The same holds true for AES-Types. Each individual AES is a spatially distinct macrohabitat, however, all individual AESs that are structurally and functionally similar fall under the same AES-Type.

One assumption for this level of the hierarchy is that under natural conditions individual AESs of the same Type will contain streams having relatively similar hydrologic regimes, physical habitat, water chemistries, energy sources, energy and sediment budgets, and ultimately aquatic assemblages. Another assumption is that each AES-Type has a relatively distinct land use potential and vulnerability to a given land use. The reason biological data were not used to empirically define and map AES-Types is that the available data was not suited to the task at hand. At this level of the hierarchy we are interested in differences in the relative abundance of various physiological and functional guilds, not the mere presence or absence of species and existing data are not suited to this more detailed quantification. We are also interested in defining assemblages in a pluralistic context at this level, meaning we are trying to identify relatively distinct complexes of multiple local assemblages (e.g., distinct interacting complexes of headwater, creek, small, and/or large river assemblages).

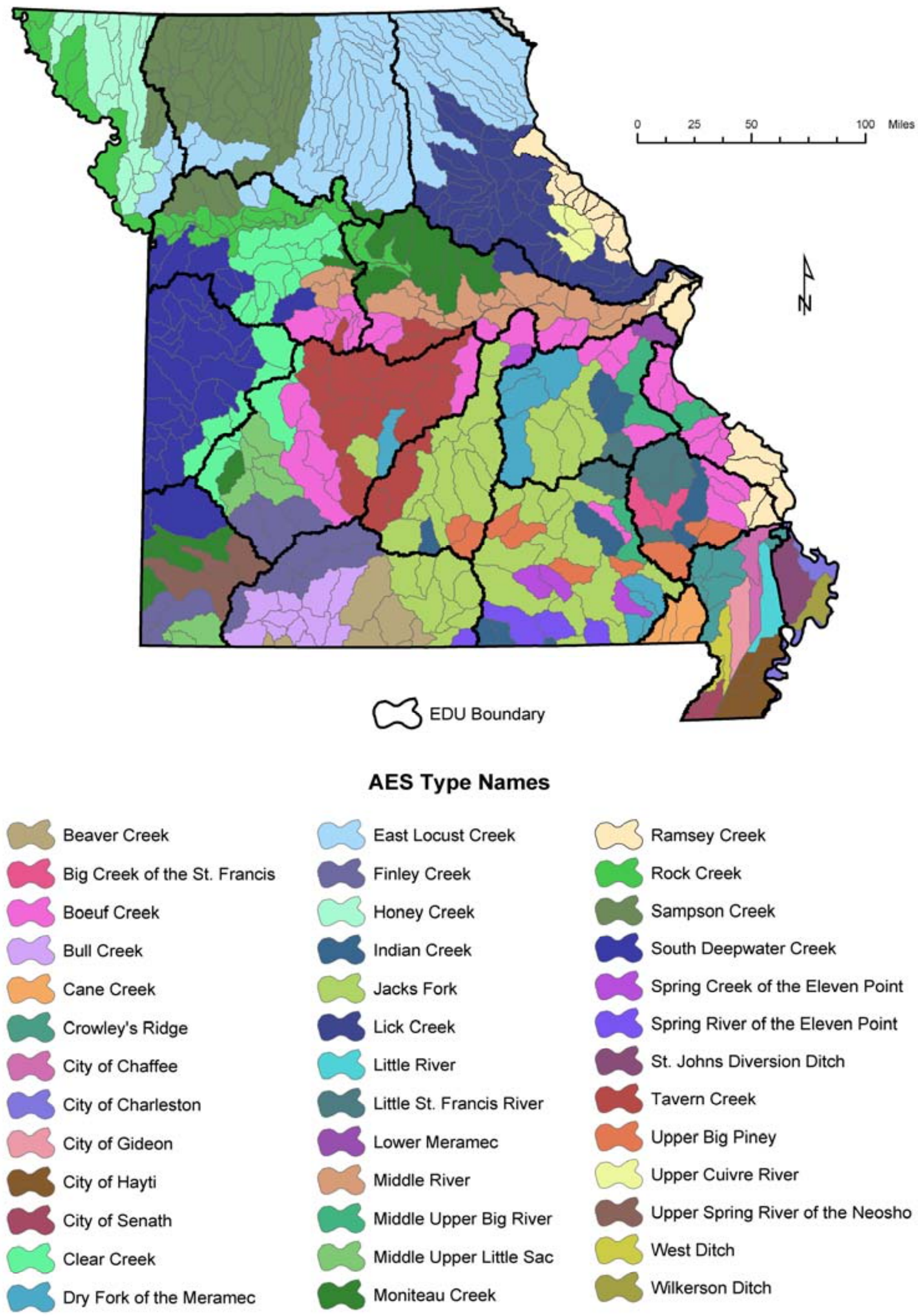


Figure 12. Map of the thirty-nine distinct Aquatic Ecological System Types (AES-Types) for Missouri.

e. Level 7: Valley Segment Types

In Level 7 of the hierarchy Valley Segment Types (VSTs) are defined and mapped to account for longitudinal and other linear variation in ecosystem structure and function that is so prevalent in lotic environments (Figure 13). Stream segments within the

1:100,000 USGS/EPA National Hydrography Dataset were attributed according to various categories of stream size, flow, gradient, temperature, and geology through which they flow, and also the position of the segment within the larger drainage network. These variables have been consistently shown to be associated with geographic variation in assemblage composition (Moyle and Cech 1988; Pflieger 1989, Osborne and Wiley 1992; Allan 1995; Seelbach et al. 1997; Matthews 1998). Each distinct combination of variable attributes represents a distinct VST. Stream size classes (i.e., headwater, creek, small river, large river, and great river) are based on those of Pflieger (1989), which were empirically derived with multivariate analyses and prevalence indices. As in the level 6 AESs, VSTs may seem foreign to some, yet if they are simply viewed as habitat types the confusion is removed. Each individual valley segment is a spatially distinct habitat, but valley segments of the same size, temperature, flow, gradient, etc. all fall under the same VST.

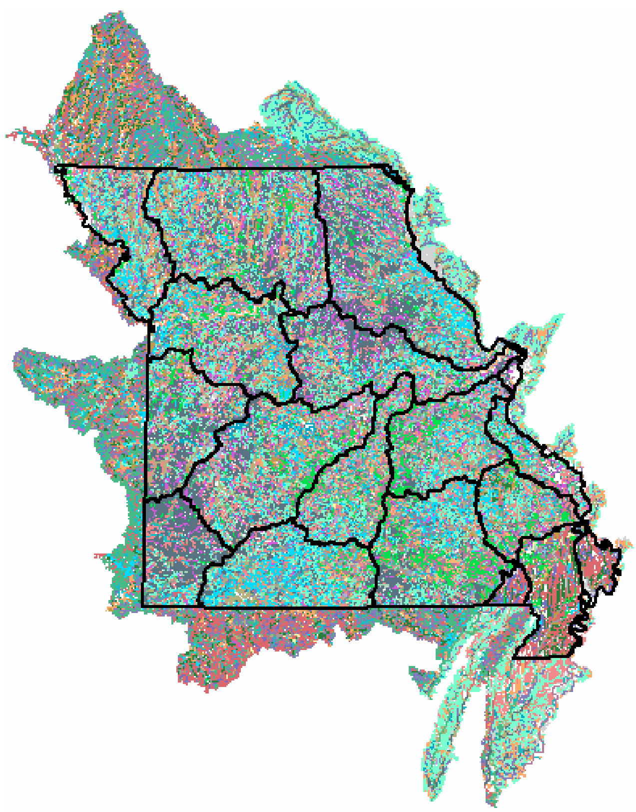


Figure 13. Map showing streams classified in to distinct stream Valley Segment Types for Missouri.

f. Level 8: Habitat Types

Units of the final level of the hierarchy, Habitat Types (e.g., high-gradient riffle, lateral scour pool), are simply too small and temporally dynamic to map within a GIS across broad regions or at a scale of 1:100,000. However, we believe it is important to recognize this level of the hierarchy since it is a widely recognized component of natural variation in riverine assemblages (Bisson et al. 1982; Frissell et al. 1986; Peterson 1996; Peterson and Rabeni 2001).

2. Biological Data

For the Missouri Aquatic GAP Project, MoRAP compiled nearly 7,000 collection records for fish, mussels, and crayfish. Despite this relatively high number of samples, these data reveal that 99.7% of the stream miles in Missouri have never been sampled. In addition, several of the USGS/NRCS 10 and 12-digit Hydrologic Units have either no samples or only a handful of samples for any of these three taxa. Analyses, performed by MoRAP also showed that approximately 30 to 40 samples are required to accurately document fish species composition within a 10-digit HU alone. These analyses reveal that conservation assessments that utilize existing collection records to calculate various biological metrics (e.g., species richness) to identify geographic priorities will, in all likelihood, generate priorities that are more a reflection of sampling effort than true patterns of biodiversity. Consequently, to overcome this problem MoRAP developed predicted distribution models for 315 fish, mussel, and crayfish species that occur within Missouri. The team of aquatic resource professionals agreed that the biological metrics used to identify conservation focus areas should be primarily based on the data provided by these predicted models. However, they also agreed that, when necessary and appropriate, actual collection records should be used as a supplemental information source in the decision making process. The following paragraphs provide a brief description of the methods used to generate predicted distribution models and maps for riverine biota in Missouri. More detailed methods can be found in Sowa et al. (2005).

To construct our predictive distribution models we compiled nearly 7,000 collection records for fish, mussels, and crayfish and spatially linked these records to the 12-digit USGS/NRCS Hydrologic Unit coverage for Missouri and also to the Valley Segment GIS coverage, described above. Range maps were produced for each of the 315 species, sent out for professional review, and modified as needed. Then we used Decision Tree Analyses to construct predictive distribution models for each species. Ultimately, a total of 571 models were developed to construct reach-specific predictive distribution maps for the 315 species. The resulting maps were merged into a single hyperdistribution (Figure 14), which is related to a database containing information on the conservation status, ecological character, and endemism level of each species.

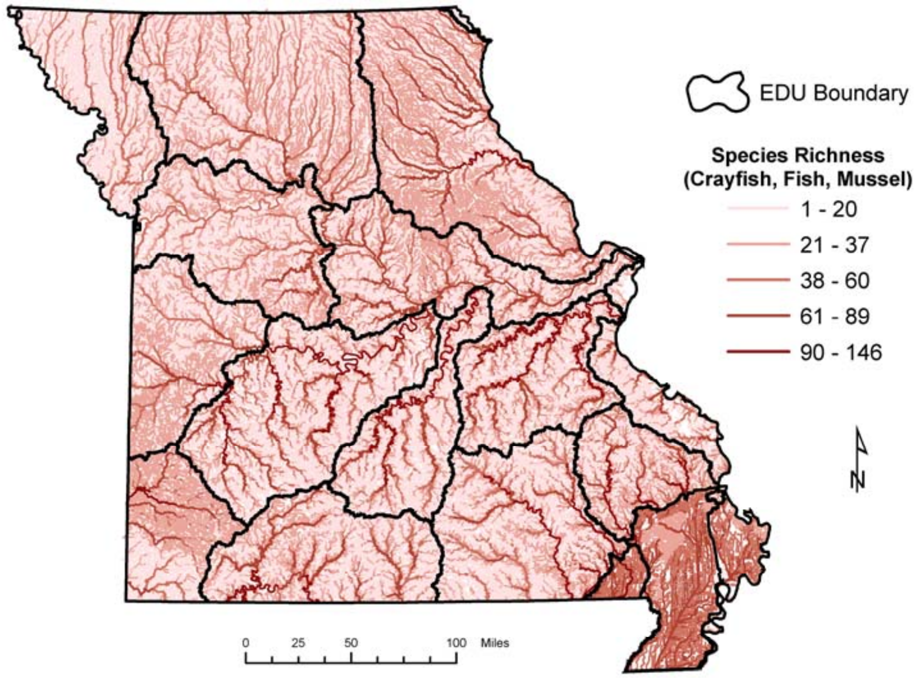


Figure 14. Map of species richness for Missouri, which is based upon predicted distribution models for 315 fish, mussel, and crayfish species. Users can also individually select stream segments within a GIS to obtain a list of the species predicted to occur within each segment of interest.

Users can select an individual stream segment within the Valley Segment coverage and generate a list of those species (and associated information) predicted to occur in that segment under relatively undisturbed conditions (anthropogenic stressors were not or could not be accounted for). In addition, the data from these predictive models were spatially linked to the upper levels of the MoRAP aquatic classification hierarchy so that species lists can be generated for any or all of the spatial units at any given level of the hierarchy. An accuracy assessment was conducted for each taxonomic group using independent data. Commission errors, averaged across all three taxa, were relatively high (55%), while omission errors were relatively low (9%). We believe these accuracy statistics can be improved by incorporating watershed variables as predictors as well as by getting more detailed temperature data for valley segments. However, it must be pointed out that this accuracy assessment is fraught with problems mainly related to the inadequacy of the independent data used to evaluate the accuracy of our models (e.g., insufficient length of stream sampled, only a single sample at a single point in time, inefficient gear, and many of the sampling sites were degraded to some degree while our models predict composition under relatively undisturbed conditions). An assessment of a handful of relatively high-quality, intensively-sampled, streams revealed a much lower commission error rate (35%), but also a higher omission error rate (18%).

3. Human Stressors

Another fundamental principal or assumption identified by the team of aquatic resource professionals was that, proactive protective measures are less costly and more likely to succeed than intensive restoration measures with regard to the conservation of freshwater ecosystems. Based on this assumption the team agreed that the conservation assessment should take account for human stressors affecting the ecological integrity of freshwater ecosystems. When all other elements being assessed were equal, then the geographic location (i.e., AES polygon or VST complex) determined to have the lowest degree of human disturbance was selected. To make these determinations the team agreed to use the Human Stressor Index developed by MoRAP to account for human stressors at the AES-level of assessment and to use a more subjective visual assessment of human stressors and professional knowledge for the VST-level of assessment. The methods we used to quantify human stressors at the AES and VST level of the aquatic classification hierarchy are briefly described in the following paragraphs. More detailed descriptions of the methods can be found in Sowa et al. (2005).

Working in consultation with a team of aquatic resource professionals, we generated a list of the principal human activities known to negatively affect the ecological integrity of Missouri streams. We then assembled the best available (i.e., highest resolution and most recent) geospatial data that could be found for each of these stressors. Next, we generated statistics on 65 individual human stressors (e.g., percent urban, lead mine density, degree of fragmentation) for each of the 542 Aquatic Ecological System (AES) polygons in Missouri (Table 5). We then used correlation analysis to reduce this overall set of metrics into a final set of 11, relatively uncorrelated, measures of human disturbance (Table 6). Relativized rankings (range 1 to 4) were then developed for each of these 11 metrics. A rank of 1 is indicative of relatively low disturbance for that particular metric, while a rank of 4 indicates a relatively high level of disturbance. The relativized rankings for each of these 11 metrics were then combined into a three number Human Stressor Index (HSI) (Figure 15). The first number reflects the highest ranking across all 11 metrics (range 1 to 4). The last two numbers reflect the sum of the 11 metrics (range 11 to 44). This index allows you to evaluate both individual and cumulative effects of the various human stressors. For instance, a value of 418, indicates relatively low cumulative impacts (i.e., last two digits = 18 out of a possible 44), however, the first number is a 4, which indicates that one of the stressors is relatively high and potentially acting as a major human disturbance within that particular ecological unit.

Table 5. List of the GIS coverages, and their sources, that were obtained or created in order to account for existing and potential future threats to freshwater biodiversity in Missouri.

Data layer	Source
303d Listed Streams	Missouri Department of Natural Resources (MoDNR)
Confined Animal Feeding Operations	MoDNR
Dam Locations	U.S. Army Corps of Engineers (1996)
Drinking Water Supply (DWS) Sites	U.S. Environmental Protection Agency (USEPA)
High Pool Reservoir Boundaries	Elevations from U.S. Army Corps of Engineers
Industrial Facilities Discharge (IFD) Sites	USEPA
Land Cover	1992-93 MoRAP Landcover Classification
Landfills	Missouri Department of Natural Resources, Air and Land Protection Division, Solid Waste Management Program
Mines - Coal	U.S. Bureau of Mines
Mines - Instream Gravel	Missouri Department of Conservation (MDC)
Mines - Lead	U.S. Bureau of Mines
Mines – All other	U.S. Bureau of Mines
Nonnative Species	Missouri Aquatic Gap Project - Predicted Species Distributions; Missouri Resource Assessment Partnership (MoRAP)
Permit Compliance System (PCS) Sites	USEPA; Ref: http://www/epa.gov/enviro
Resource Conservation and Recovery Information System (RCRIS) Sites	USEPA; Ref: http://www.epa.gov/enviro
Riparian Land Cover	MDC
Superfund National Priority List Sites	USEPA; Ref: http://www.epa.gov/enviro
TIGER Road Files	United States Department of Commerce, Bureau of the Census
Toxic Release Inventory (TRI) Sites	USEPA; Ref: http://www.epa.gov/enviro

Table 6. The 11 stressor metrics included in the Human Stressor Index (HSI) and the specific criteria used to define the four relative ranking categories for each metric that were used to calculate the HSI for each Aquatic Ecological System.

	Relative Ranks			
Metric	**1**	**2**	**3**	**4**
Number of Introduced Species	1	2	3	4-5
Percent Urban	0-5	5-10	11-20	>20
Percent Agriculture	0-25	26-50	51-75	>75
Density of Road-Stream Crossings (#/mi^2)	0-0.24	0.25-0.49	0.5-0.9	≥1
Population Change 1990-2000 (#/mi^2)	-42-0	0.1-14	15-45	>45
Degree of Hydrologic Modification and/or Fragmentation by Major Impoundments	1	2 or 3	4 or 5	6
Number of Federally Licensed Dams	0	1-9	10-20	>20
Density of Coal Mines (#/mi^2)	0	1-5	6-20	>20
Density of Lead Mines (#/mi^2)	0	1-5	6-20	>20
Density of Permitted Discharges (#/mi^2)	0	1-5	6-20	>20
Density of Confined Animal Feeding Operations (#/mi^2)	0	1-5	5-10	>10

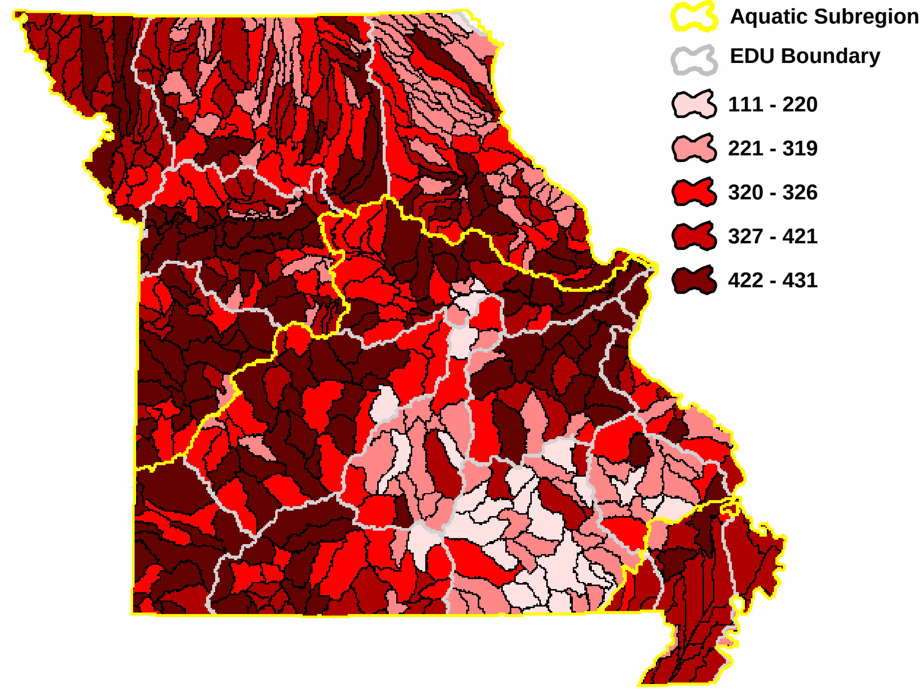


Figure 15. Map showing the composite Human Stressor Index (HSI) values for each Aquatic Ecological System in Missouri. The first number represents the highest value received across all 11 metrics included in the HSI, while the last two digits represent the sum of the scores received for each of the 11 metrics.

4. Public Ownership and Stewardship Statistics

Two of the fundamental principals or assumptions identified by the team of aquatic resource professionals were; a) public lands or protected areas are critical to ecosystem conservation and the long-term maintenance of biodiversity and b) it is easier to implement on-the-ground conservation measures on public lands. Based on these assumptions the team agreed that the conservation assessment should take into consideration the amount of public land when decisions between two or more locations were being made. More specifically, when all other elements being assessed were equal, then the geographic location (i.e., AES polygon or VST complex) containing the highest percentage of public land would be selected. The methods we used to quantify public ownership at the AES and VST level of the aquatic classification hierarchy are briefly described in the following paragraphs. Again, more detailed descriptions of the methods can be found in Sowa et al. (2005).

To quantify public ownership for each AES polygon we simply quantified the percentage of public lands within each polygon based on the Missouri GAP Stewardship coverage. During the assessment process each AES polygon was labeled with this percentage so that the assessment team could easily compare the ownership percentages among two or more AES polygons.

The GAP stewardship coverage for Missouri was used in conjunction with the Valley Segment coverage to identify stream segments flowing through public lands. A customized ArcView tool was used to first identify and attribute stream segments that had the majority of their length (> 51%) within public lands. These segments were then further attributed with the agency responsible for the management of the surrounding tract of land. Another Arc Marco Language algorithm was then used to calculate the percentage of each stream segment's watershed and upstream drainage network that is within public lands. Since the watersheds of many of the stream segments within Missouri extend beyond the state boundary, the GAP stewardship coverages for the neighboring states of Arkansas, Iowa, and Kansas were merged with that of Missouri. This collection of attributes allowed the assessment teams to select any, of the approximately 154,000 individual, stream segments within Missouri and see which segments are flowing through public lands and also the percentage of the overall watershed and upstream drainage network that is within public lands.

5. Conservation Strategy

Once all of the data were assembled into GIS-based decision support systems the team crafted a general conservation strategy that would be used to identify and map a statewide portfolio of Conservation Focus Areas (COAs) that collectively and holistically represent all of the distinct riverine ecosystems within Missouri and multiple populations of all fish, mussel, and crayfish species. The reasoning behind each component of this strategy is best illustrated by discussing what conservation objectives the team hoped to achieve with each component. These reasons are provided in Box 1, below.

Basic Elements of the Conservation Strategy:

- Separate conservation plans must be developed for each EDU,
- whenever possible, represent two distinct spatial occurrences/populations of each target species within each EDU;
- AES-Types should be further stratified according to the size of mainstem stream flowing within its boundary (i.e., small, large, or great river)
- represent one example of each AES-Type within each EDU;
- within each selected AES, represent at least 1 km of the dominant VSTs for each size class (headwater, creek, small river, and large river) as an interconnected complex; and
- represent a least three separate headwater VSTs within each of the Conservation Focus Areas.

Box 1. Explanation of what we were attempting to achieve with each component of the general conservation strategy that was used to select aquatic conservation focus areas.

By attempting to conserve every EDU

- Provide a holistic ecosystem approach to conservation, since each EDU represents an interacting biophysical system
- Represent all of the characteristic species and species of concern within the broader Aquatic Subregion and the entire state, since no single EDU contains the full range of species found within the upper levels of the classification hierarchy
- Represent multiple distinct spatial occurrences ("populations") or phylogenies for large-river or wide-ranging species (e.g., sturgeon, catfish, paddlefish), which, from a population standpoint, can only be captured once in any given EDU

By attempting to conserve two distinct occurrences of each Target Species within each EDU

- Provide redundancy in the representation of those species that collectively determine the distinctive biological composition of each EDU in order to provide a safeguard for the long term persistence of these species

By attempting to conserve an individual example of each AES-Type within each EDU

- Represent a wide spectrum of the diversity of macrohabitats (distinct watershed types) within each EDU
- Account for successional pathways and safeguard against long-term changes in environmental conditions caused by factors like Global Climate Change.
    - For instance, gross climatic or land use changes may make conditions in one AES-Type unsuitable for a certain species, but at the same time make conditions in another AES-Type more favorable for that species
- Represent multiple distinct spatial occurrences ("populations") for species with moderate (e.g., bass or sucker species) and limited dispersal capabilities (e.g., darters, sculpins, certain minnow species, most crayfish and mussels)
- Account for metapopulation dynamics (source/sink dynamics)

By attempting to conserve the dominant VSTs for each size class within a single AES

- Represent the dominant physicochemical conditions within each AES, which we assume represent the environmental conditions to which most species in the assemblage have evolved adaptations for maximizing growth, reproduction and survival (*sensu* Southwood 1977)
- Represent a wide spectrum of the diversity of mesohabitats (i.e., stream types) within each EDU since the dominant stream types vary among AES-Types
- Promote an ecosystem approach to conservation by representing VSTs within a single watershed
- Account for metapopulation dynamics (source/sink dynamics)

Box 1. Continued.

By attempting to conserve an interconnected complex of dominant VSTs

- Account for seasonal and ontogenetic changes in habitat use or changes in habitat use brought about by disturbance (floods and droughts)
    - For instance, during periods of severe drought many headwater species may have to seek refuge in larger streams in order to find any form of suitable habitat due to the lack of water or flow in the headwaters
- Account for metapopulation dynamics (source/sink dynamics)
- Further promote an ecosystem approach to conservation by conserving an interconnected/interacting system

By attempting to conserve at least 3 headwater VSTs within each COA

- Represent multiple distinct spatial occurrences ("populations") for headwater species with limited dispersal capabilities (e.g., darters, sculpins, certain minnow species, most crayfish and mussels)
- Represent multiple high-quality examples of key reproductive or nursery habitats for many species

By attempting to conserve at least a 1 km of each priority VST

- Represent a wide spectrum of the diversity of Habitat Types (e.g., riffles, pools, runs, backwaters, etc.) within each VST and ensure connectivity of these habitats
- Account for seasonal and ontogenetic changes in local habitat use or changes in habitat use brought about by disturbance (e.g., floods and droughts)
    - For instance, many species require different habitats for foraging (deep habitats with high amounts of cover), reproduction (high gradient riffles), over-wintering (extremely deep habitats with flow refugia or thermally stable habitats like spring branches), or disturbance avoidance (deep or shallow habitats with flow refugia).
- Account for metapopulation dynamics (source/sink dynamics)
- Again, further promote an ecosystem approach to conservation by representing an interacting system of Habitat Types

The team then established quantitative and qualitative assessment criteria for making relative comparisons among the assessment units. Since the assessment was conducted at two spatial grains (AES and VST), there exist two different assessment units with assessment criteria developed separately for each.

AES level criteria (listed in order of importance)

- Highest target species richness (based on predicted models)
- Lowest Human Stressor Index value, further supported by a qualitative examination of threats posed by the individual human stressors
- Highest percentage of public ownership
- Degree of overlap with existing conservation initiatives
- Ability to achieve connectivity among dominant VSTs across size classes

- When necessary, incorporate professional knowledge of opportunities, constraints, or human stressors not captured within the GIS projects to guide the above decisions.

VST level criteria (listed in order of importance)

- If possible, select a complex of valley segments that contains known viable populations of species of special concern.
- If possible, select the highest quality complex of valley segments by qualitatively evaluating the relative local and watershed conditions using the full breadth of available human stressor data.
- If possible, select a complex of valley segments that is already within the existing matrix of public lands.
- If possible, select a complex valley segments that overlaps with existing conservation initiatives or where local support for conservation is high.
- When necessary, incorporate professional knowledge of opportunities, constraints, or human stressors not captured within the GIS projects to guide above decisions.

The conservation strategy and assessment boils down to a five-step process:

- Use the AES selection criteria to identify one priority AES for each AES-Type within the EDU.
- Within each priority AES, use the VST selection criteria, to identify a priority complex of the dominant VSTs.
- For each complex of VSTs create a map of the localized subdrainage, termed "Conservation Focus Area", that specifically contains the entire interconnected complex.
- Evaluate the capture of target species.
- If necessary, select additional focus areas to capture underrepresented target species.

Since conservation efforts cannot be initiated immediately within all of the Focus Areas, priorities must be established among the Focus Areas in order to develop a schedule of conservation action (Margules and Pressey 2000). For Missouri, we generated statewide priorities by calculating irreplaceability values for each Focus Area using all of the native fish, mussel, and crayfish species as conservation targets. We used a target capture threshold of three for each species in order to represent three distinct populations of each species across the state. Due to data management limitations of C-Plan, the irreplaceability analyses had to be performed separately for each taxonomic group. To get an overall picture of irreplaceability we simply summed that resulting values across all three taxa.

6. Results for the Pilot Area

The team then used the conservation strategy and assessment process to develop a conservation plan for the Meramec EDU, which served as the initial pilot area for the statewide conservation plan. By using the above process all elements of the conservation strategy were met with 11 conservation focus areas (Focus Areas) (Figure 16). With the initial assessment process and selection criteria, which focus on abiotic targets (AESs and VSTs), 10 separate focus areas were selected. These 10 areas represent the broad diversity of watershed and stream types that occur throughout the Meramec EDU. Within this initial set of 10 focus areas, all but five of the 103 target species were captured. The distribution of all five of these species overlapped within the same general area of the EDU, near the confluence of the Meramec and Dry Fork Rivers. Consequently, all five of these species were captured by adding a single focus area (Dry Fork/Upper Meramec) (see Figure 16).

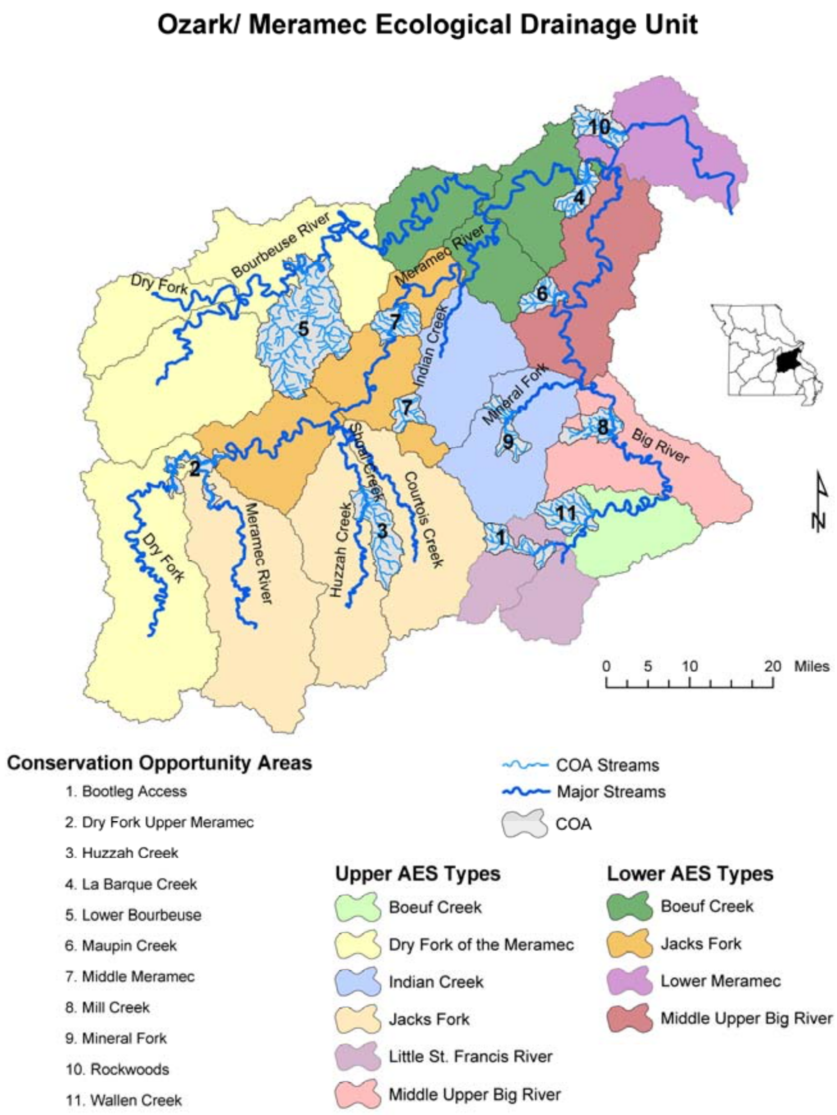


Figure 16. Map of 11 Conservation Focus Areas, within the Ozark/Meramec EDU, that were selected to meet all elements of the basic conservation strategy developed for the freshwater biodiversity conservation planning process in Missouri. The figure also shows the Aquatic Ecological System Types for context. Lower and Upper types differ in terms

of their position within the larger drainage network. Specifically, a “Lower AES Type” contains streams classified as Large River and associated headwater and creek tributaries, while Upper types contain streams classified as Small River and these smaller tributaries.

The final set of priority valley segments, within the 11 Focus Areas, constitutes 299 km of stream. This represents 2.8% of the total length of stream within the Meramec EDU. The Focus Areas themselves represent an overall area of 552 km^2, which is just 5% of the nearly 10,360 km^2 contained within the EDU. Obviously, efforts to conserve the overall ecological integrity of the Meramec EDU cannot be strictly limited to the land area and stream segments within these Focus Areas. In some instances, the most important initial conservation action will have to occur outside of a given Focus Area, yet the intent of those actions will be to conserve the integrity of the streams within that particular Focus Area. All of the team members agreed that specific attention to, and more intensive conservation efforts within, these 11 Focus Areas will provide an efficient and effective strategy for the long-term maintenance of relatively high quality examples of the various ecosystem and community types that exist within the Meramec River watershed.

In addition to devising the conservation strategy for identifying and mapping Focus Areas, the team also identified other information that needed to be documented during the conservation planning process. This information was captured within a database that can be spatially related to the resulting GIS coverage of the Focus Areas. Specifically, each Focus Area was given a name that generally corresponds with the name of the largest tributary stream, and then each of the following items was documented:

- all of the agencies or organizations that own stream segments within the Focus Area and own portions of the overall watershed or upstream riparian area,
- the specific details of why each AES and VST complex was selected,
- any uncertainties pertaining to the selection of the AES or VST complex and if there are any alternative selections that should be further investigated,
- how these uncertainties might be overcome, such as conducting field sampling to evaluate the accuracy of the predictive models or doing site visits to determine the relative influence of a particular human stressor,
- all of the management concerns within each Focus and the overall watershed,
- any critical structural features, functional processes, or natural disturbances,
- what fish, mussel, and crayfish species exist within the Focus Area for each stream size class, and
- any potential opportunities for cooperative management or working in conjunction with existing conservation efforts

All of this information is critical to the remaining logistical aspects of conservation planning that must be addressed once geographic priorities have been established.

7. Statewide Results for Missouri

Once the core team finalized the conservation strategy and had completed the conservation plan for the pilot area, the state was partitioned into four “regions” with each of these regions containing four EDUs. Regional teams of aquatic resource professionals were then established for each region. Each team consisted of six or more resource managers/biologists with detailed and extensive knowledge of the stream resources within the region they were assigned. Three-day conservation planning sessions were held in each region during summer and early fall of 2004. During these three-day sessions, the regional team used the overall conservation strategy to develop conservation plans for each of the EDUs within their region.

Conservation plans were completed for all 17 EDUs in Missouri. Statewide, a total of 158 Focus Areas were identified through the above assessment and planning process (Figure 17). These Focus Areas represent the broad diversity of stream ecosystems and riverine assemblages within Missouri and cover a relatively small percentage of the landscape. Specifically, the Focus Areas contain 10,915 km of stream, which represents 6.3% of the 174,059 km of stream within Missouri. In terms of land area, the Focus Areas cover 11,331 km² (2.8 million acres), or just 6.6% of the state. Collectively, these 158 Focus Areas represent multiple distinct occurrences of all native fish, mussel, and crayfish species in the state. They also represent the best opportunity for successful conservation since they represent the highest quality examples of each ecosystem unit and in many instances those having the highest percentage of public land within the immediate drainage and overall watershed. This relatively high percentage of public ground with facilitate on the ground conservation action and provide flexibility in long-term strategies for conservation.

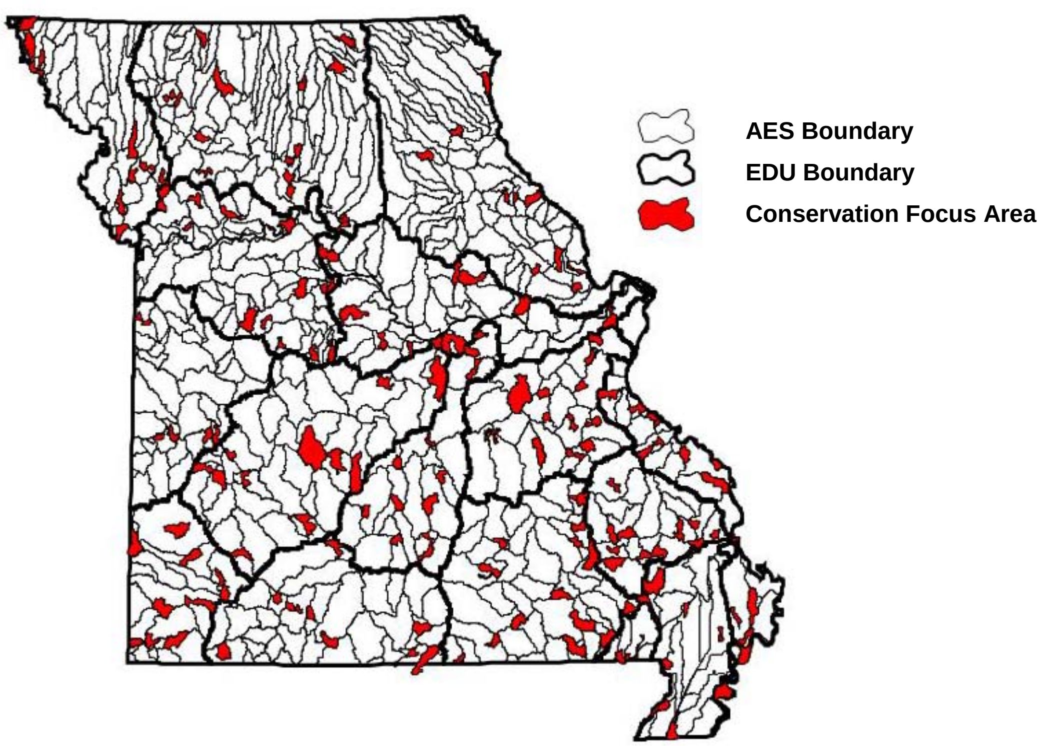


Figure 17. Map showing all 158 freshwater Conservation Focus Areas that were selected for Missouri. Taking measures to conserve all of these locations represents an efficient

approach to representing multiple examples of all the distinct species, stream types, and watershed types that exist within the state.

Results of the statewide irreplaceability analyses identified mainly four regions of the state as critical initial priorities for the long-term maintenance of freshwater biodiversity and ecosystem conservation (Appendix 7 and Figure 18). These regions included virtually all of the Mississippi Alluvial Basin, the southern Ozarks (particularly the Neosho and White River EDUs), the Meramec River watershed, and to a lesser extent the Focus Areas containing the mainstems of both the Missouri and Mississippi Rivers. The relatively high irreplaceability values for the Focus Areas in the MAB are likely a reflection of the fact that Missouri is situated at the northern edge of this ecoregion which contains many unique species that are otherwise more extensively distributed throughout this region to the south. The high values along the southern Ozarks and the Meramec EDU are a reflection of the many local endemic fish, mussel, and crayfish species that occur within these two regions. Finally, the moderately high values for those focus areas that contain the Missouri and Mississippi Rivers mainly reflect the distinctive great river fish species that occur exclusively within these rivers within the state; many of which are wide-ranging species with distinctive life-history strategies.

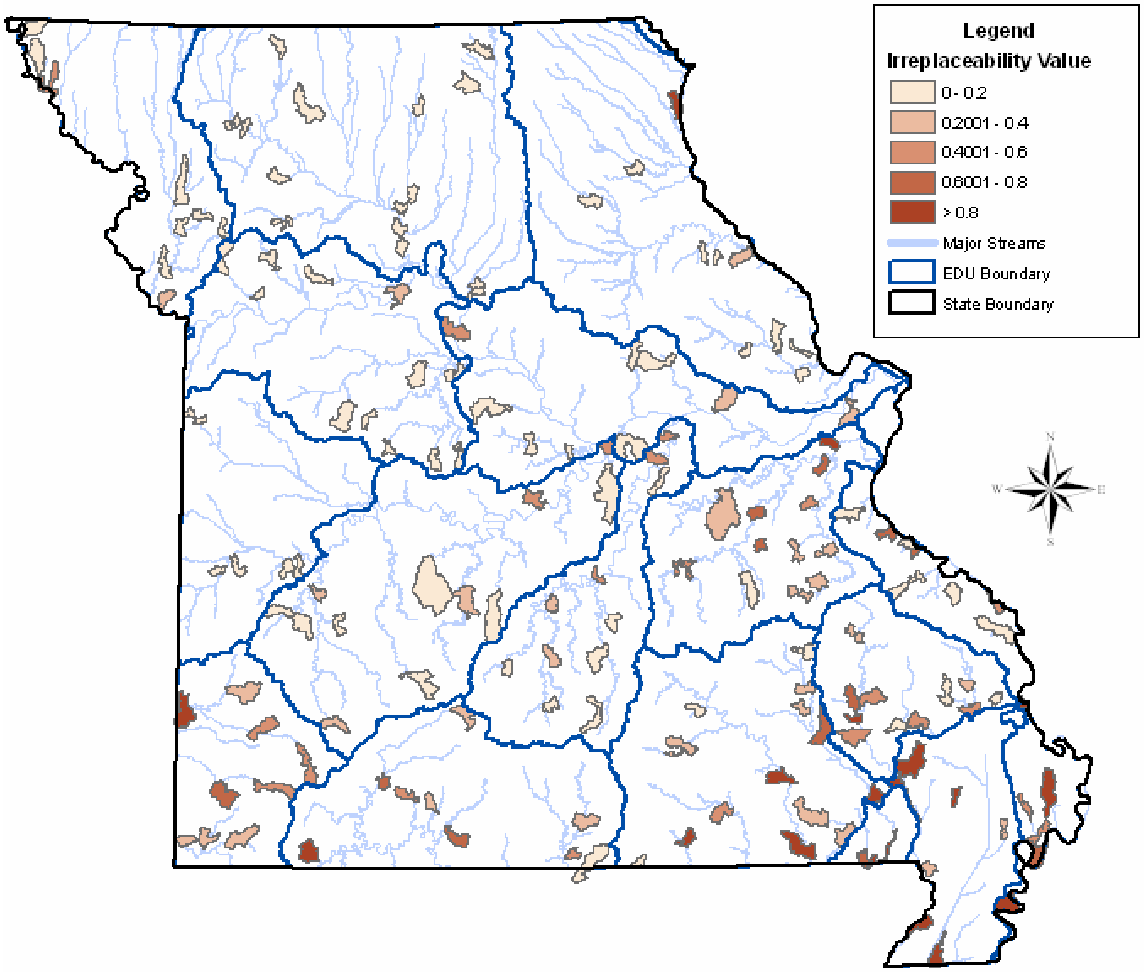


Figure 18. Map showing the overall irreplaceability values for each of the 158 focus areas identified in Missouri. These values generated by summing the individual values obtained from separate analyses performed for fish, mussels, and crayfish.

B. Regional Conservation Assessment

The tactical objective for the regional aquatic assessment was the same as the one used for Missouri; "*Identify and map a set of aquatic conservation focus areas that holistically represent the full breadth of distinct riverine ecosystems and multiple populations of all native aquatic species.*" However, there were two fundamental differences between the assessments conducted in Missouri and those carried out for Iowa, Kansas, and Nebraska. First, while state and regional Aquatic GAP projects are currently underway throughout EPA Region 7, the full spectrum of data currently available for Missouri were not available for Iowa, Kansas, or Nebraska at the time of this project. Consequently, we had to develop/assemble a separate, reduced, set of data in order to conduct a more general regional assessment of conservation opportunities and priorities for aquatic ecosystems. Second, professional judgment played an important role in the conservation assessment for Missouri. Time and financial limitations prevented us from incorporating local expert opinion into the assessment process for the other three states. This lack of expert opinion influenced both the resolution at which the regional assessment could be conducted and the finality of the resulting focus areas.

1. Aquatic Classification

Through funding provided by EPA Region 7 and the USGS National Gap Analysis Program, MoRAP is currently classifying and mapping distinct aquatic ecosystem units throughout Iowa, Kansas, and Nebraska, following the same methods that were developed and used in Missouri (Sowa et al. 2005). The classification units are not finalized and may change based on professional review or further analyses. Based on our experience with generating classification units for Missouri, however, it is likely that only minor revisions will be made to these draft units, which would have only a minor influence on the final results. Consequently, since we believe that the existing draft units for the classification hierarchy provide a more appropriate ecological context than either ecoregions or USGS Hydrologic Units, we elected to use the draft classification units as the geographic framework for our regional aquatic assessment.

a. Level 4: Aquatic Subregions

Following the methods of Pflieger (1971), a range-limit analysis for fishes was conducted throughout Iowa, Kansas, and Nebraska in order to identify and map relatively distinct Aquatic Subregions. Based on these analyses a total of four Aquatic Subregions were identified, which, when added to those already identified for Missouri results in a total of seven distinct Subregions throughout EPA Region 7 (Figure 19). As we described above, Aquatic Subregions are physiographic or ecoregional substrata of regions and thus account for differences in the ecological composition of riverine assemblages resulting from geographic variation in ecosystem structure and function. However, the boundaries between Subregions follow major drainage divides to account for drainage-specific evolutionary histories in subsequent levels of the hierarchy.

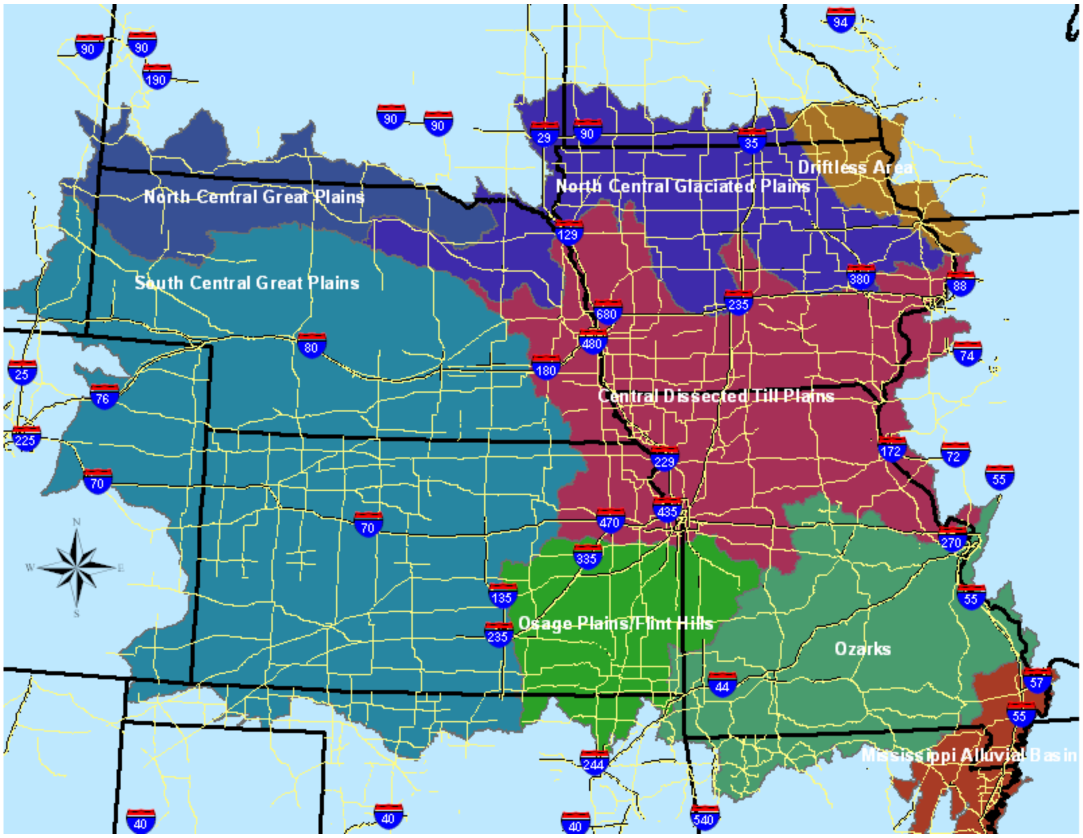


Figure 19. Aquatic Subregions within EPA Region 7.

b. Level 5: Ecological Drainage Units

A total of 38 Ecological Drainage Units were identified and mapped throughout EPA Region 7 (Figure 20). EDUs represent islands in the landscape. Each EDU has a relatively distinct aquatic assemblage with a relatively distinct evolutionary history. These ecological units served as our primary planning units for both the Missouri and regional aquatic assessments since each EDU circumscribes a functionally distinct ecosystem unit that plays an important role in defining the overall ecological character of upper levels of the classification hierarchy.

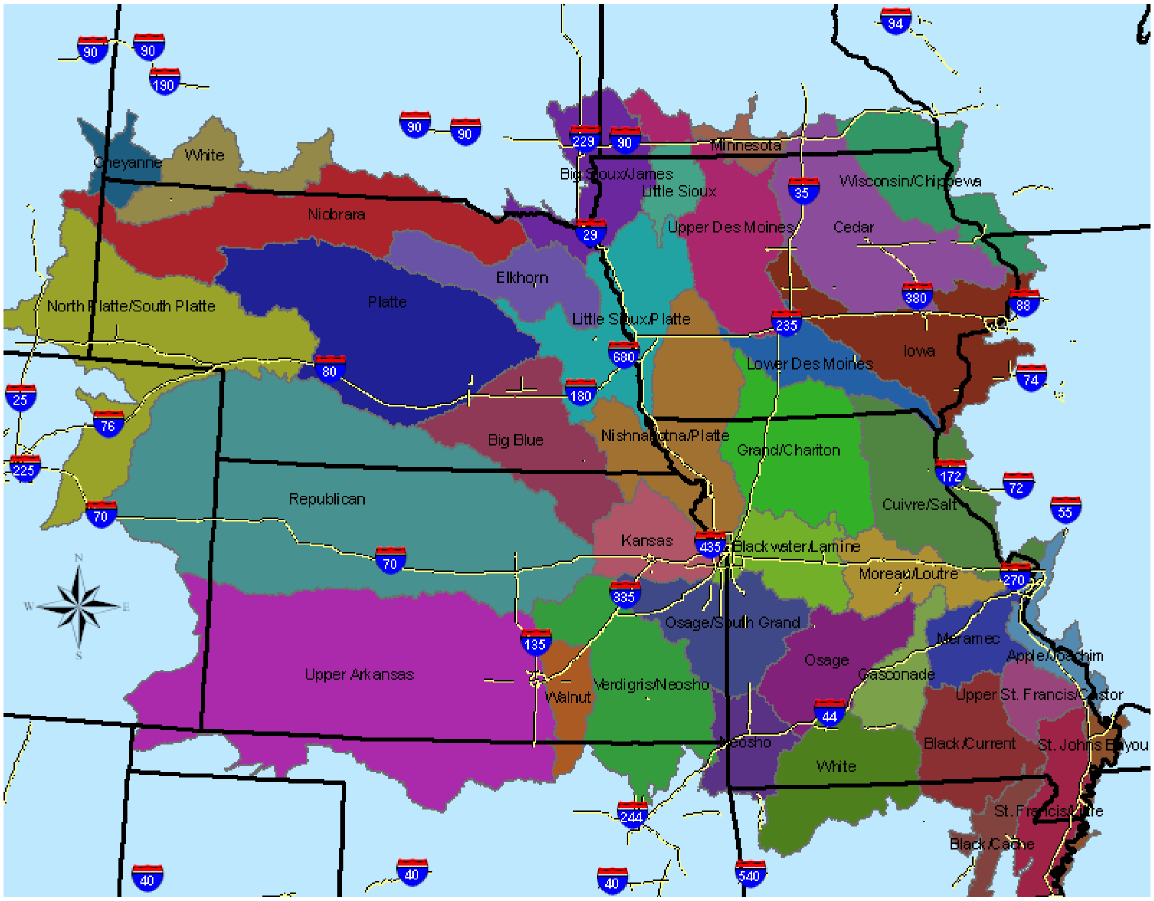


Figure 20. Ecological Drainage Units within EPA Region 7.

c. Level 6: Aquatic Ecological System Types

Thirty nine Aquatic Ecological System Types (AES-Types) were identified in Missouri. Seven of these overlap with the 63 AES-Types that were identified throughout Iowa, Kansas, and Nebraska. Consequently, based on our multivariate analyses of watershed landscape data there are a total of 95 distinct AES-Types throughout EPA Region 7 (Figure 21). These distinct watershed types served as our principal conservation target in the regional aquatic assessment.

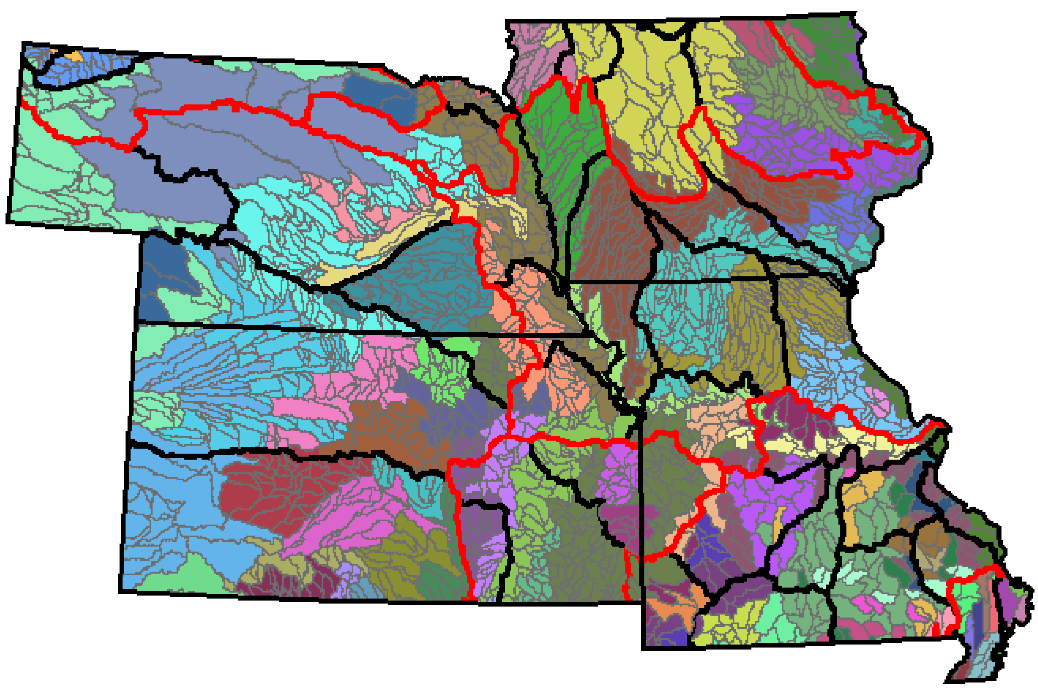


Figure 21. Map showing the 95 distinct Aquatic Ecological System Types that occur throughout EPA Region 7. Red lines show Aquatic Subregion boundaries and thick black lines show Ecological Drainage Unit boundaries.

d. Level 7: Valley Segment Types

Valley Segment Types (VSTs) have been mapped throughout EPA Region 7 (Figure 22). However, the lack of biological and human stressor data for these geographic units, coupled with our inability to incorporate professional judgment into the assessment process, precluded the use of these finer-grained spatial units in our regional aquatic assessment. These VST data should be incorporated into future assessments that seek to identify more spatially-explicit conservation priorities within the each of the AES polygons that were identified as conservation focus areas throughout Iowa, Kansas, and Nebraska.

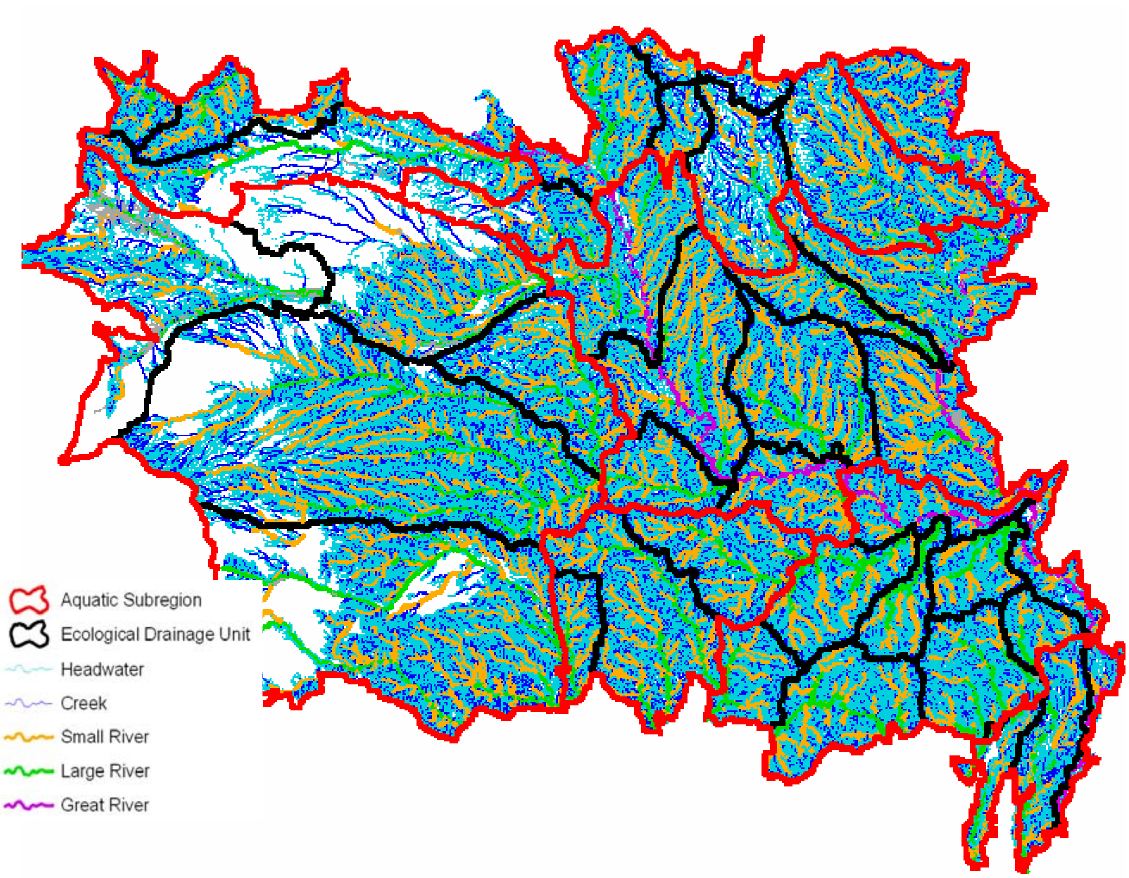


Figure 22. Map of the 1:100,000 Valley Segment Coverage for EPA Region 7 displayed according to the five general stream size classes.

2. Biological Data

Biological data played an important role in the identification of aquatic focus areas throughout Missouri. Specifically, richness statistics, based on the predictive distribution models for 315 fish, mussel, and crayfish species, were used to rank AES polygons within each EDU, while actual collection records and professional knowledge were used to aid the selection of specific VST complexes. Predicted distribution data were used to avoid the many biases and limitations of the existing collection data (Sowa et al. 2005). Unfortunately, these same biases and limitations exist within Iowa, Kansas, and Nebraska despite the fact that 16,529 distinct fish collection records have been compiled for these three states (Figure 23).

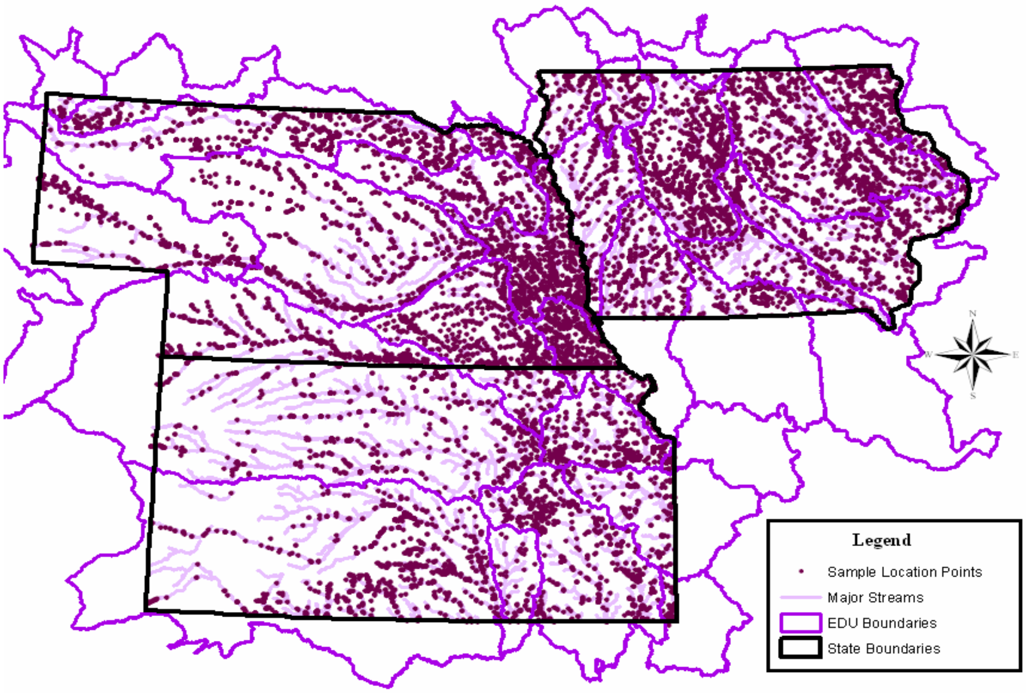


Figure 23. Fish collection records compiled for Aquatic GAP projects throughout Iowa, Kansas, and Nebraska.

While 16,529 collection records may seem more than adequate for accurately characterizing the fish assemblages occurring within the watersheds or hydrologic units across these states, a closer examination of these data reveals that this is not the case. A simple plot of native species richness versus the number of samples occurring within each AES polygon reveals that a staggering 100 or more samples are needed in order to accurately characterize the fish assemblage of these geographic units (Figure 24). When you consider that only 22 (1.4%) of the 1,603 individual AES polygons within Iowa, Kansas, and Nebraska have more than 100 samples and many have only a handful or no samples at all (Figure 25), it becomes readily apparent that any priorities based on these existing collection records would be more a reflection of disparities in sampling effort rather than true biogeographic patterns (Figure 26). Although predictive distribution models are being developed for the fish species across these three states, these data were not available at the time of this project. As a result, we decided not to use any biological data for the regional aquatic assessment and to rather focus on abiotic conservation targets based on the aquatic classification hierarchy.

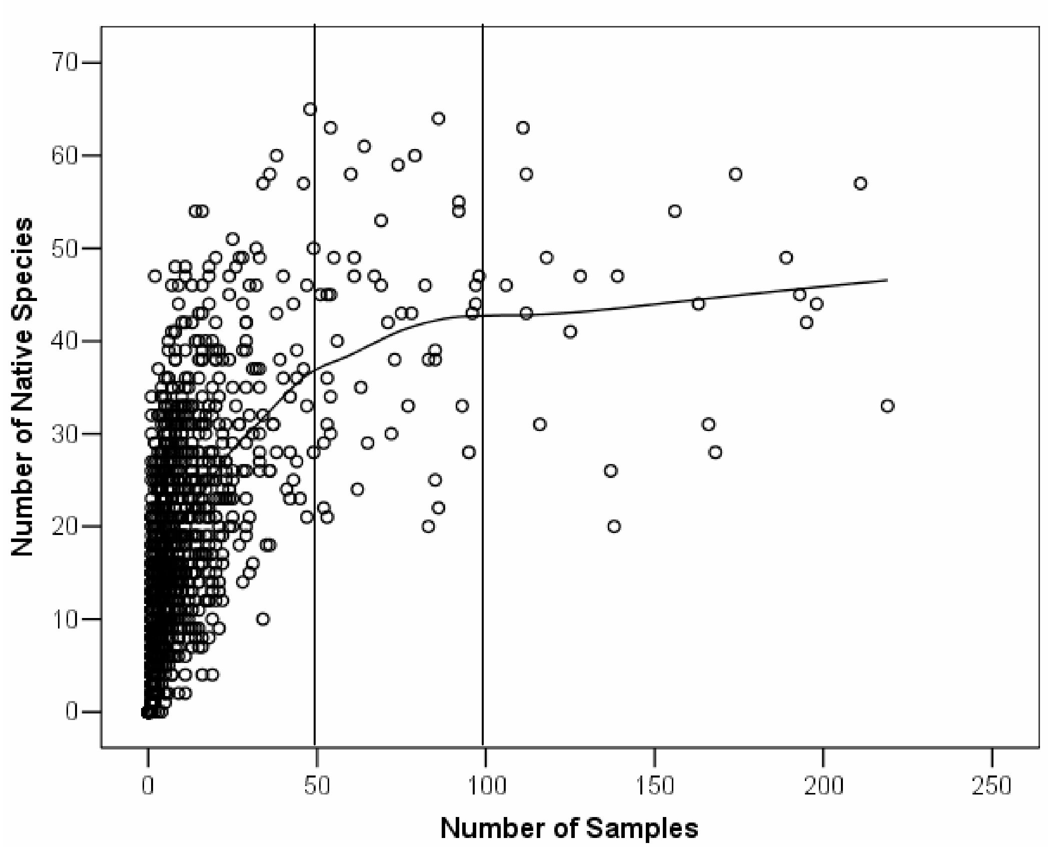


Figure 24. Scatter plot showing the number of native fish species documented to occur within each AES polygon versus the number of fish collections within AES polygon throughout Iowa, Kansas, and Nebraska. This plot shows that anywhere from 50 to 100 collections are needed to accurately document the species composition of a given AES throughout this region.

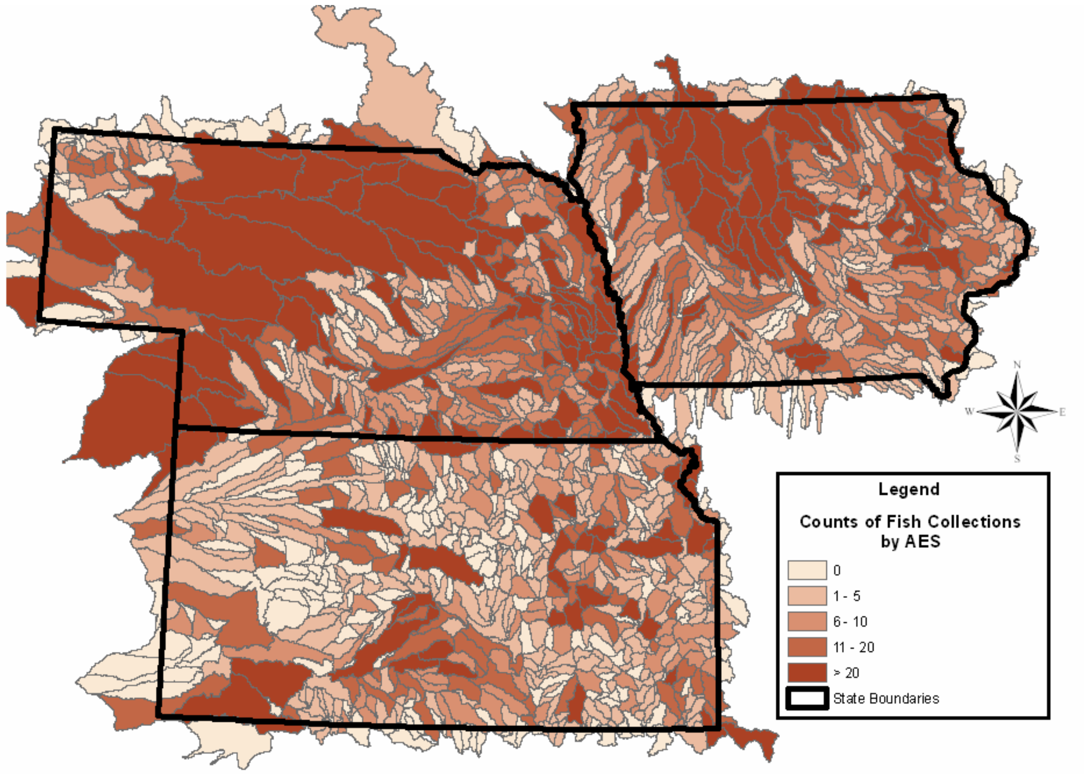


Figure 25. Number of fish collection records for each AES polygon in Iowa, Kansas, and Nebraska.

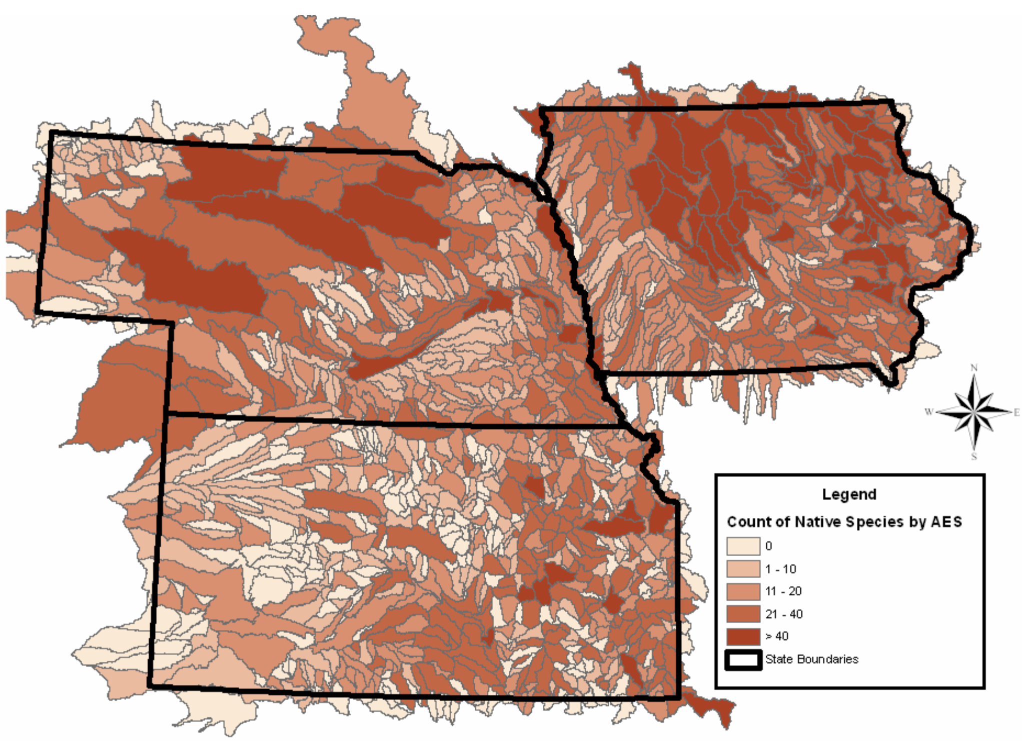


Figure 26. Native fish species richness by AES polygon. The patterns displayed on this map reflect both real and perceived patterns of biodiversity due to geographic variations in sampling effort.

3. Human Stressors

Most of the geospatial data used to account for human stressors in the statewide aquatic assessment for Missouri were also available for Iowa, Kansas, and Nebraska (Figures 27 and 28). Lacking were spatial data on confined animal feeding operations and predictive distributions for nonnative aquatic species. Using the available data we generated statistics for nine human stressors for each of the 2,244 AES polygons that occur in EPA Region 7 (Table 7).

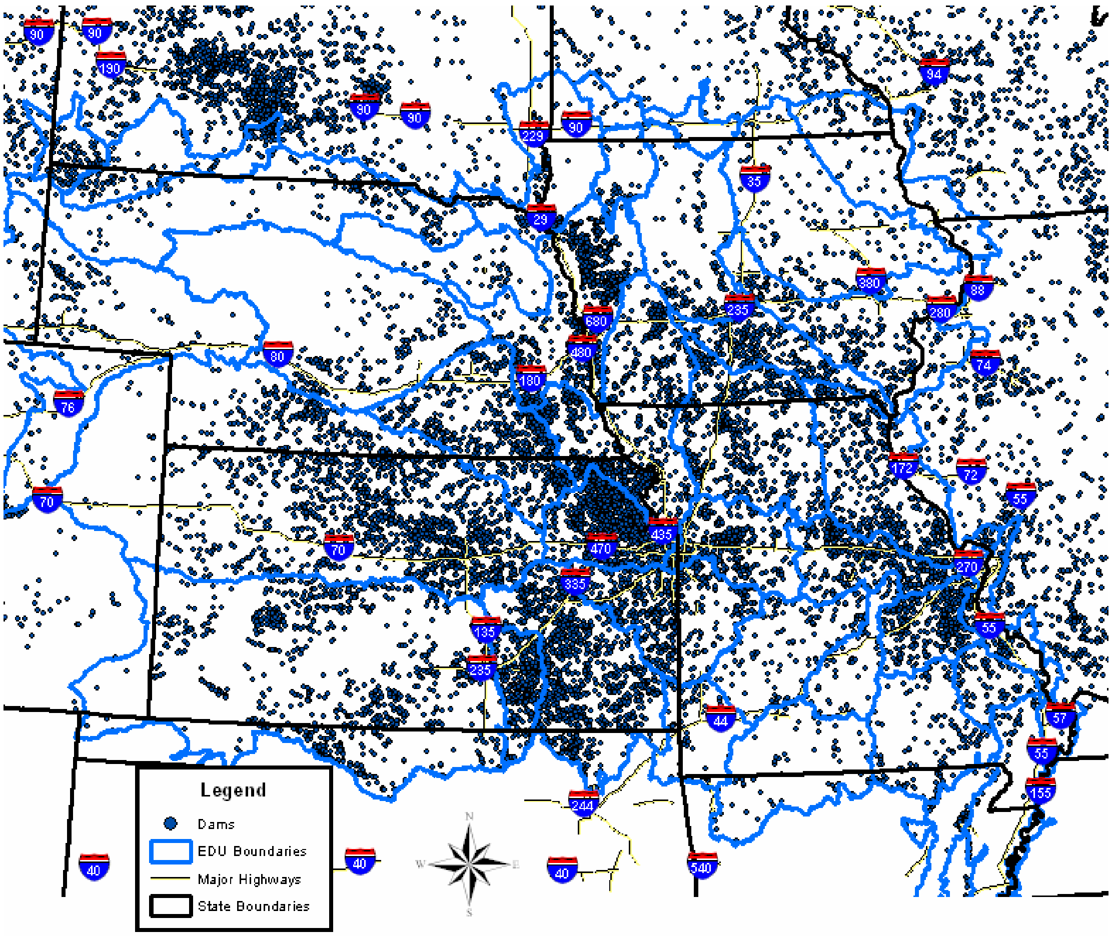


Figure 27. Map of federally licensed dams throughout EPA Region 7.

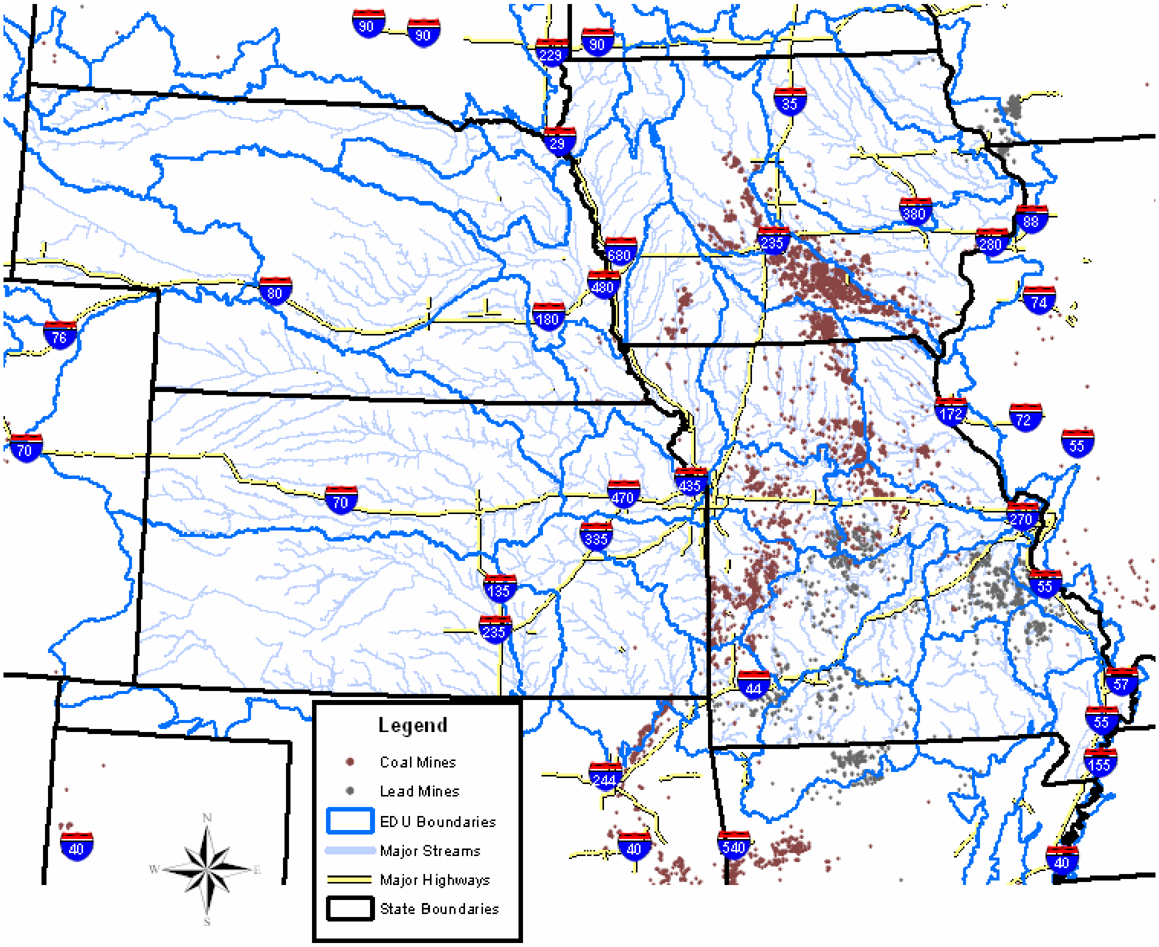


Figure 28. Map of lead and coal mines within EPA Region 7.

Table 7. Individual human stressor statistics that were generated for each AES polygon across EPA Region 7.

Human Stressor Statistic
Percent Urban
Percent Agriculture
Density of Road-Stream Crossings (#/mi²)
Population Change 1990-2000 (#/mi²)
Degree of Hydrologic Modification and/or Fragmentation by Major Impoundments
Density of Federally Licensed Dams
Density of Coal Mines (#/mi²)
Density of Lead Mines (#/mi²)
Density of Permitted Discharges (#/mi²)

In an effort to more accurately quantify the degree of human disturbance within a given AES, we elected to use slightly different methods for ranking both within and among these nine human stressors throughout the region. Each of the 2,244 AES polygons within EPA Region 7 were ranked from 1 to N for each of the human stressors, where N equals the total number of AES polygons in Region 7. The lowest values were given a rank of 1 and the highest values were given a rank of 2,244. Ties were all given the next lowest value in the ranking sequence. Figure 29 provides an example of the resulting rankings for the percentage of urban area within each AES across EPA Region 7.

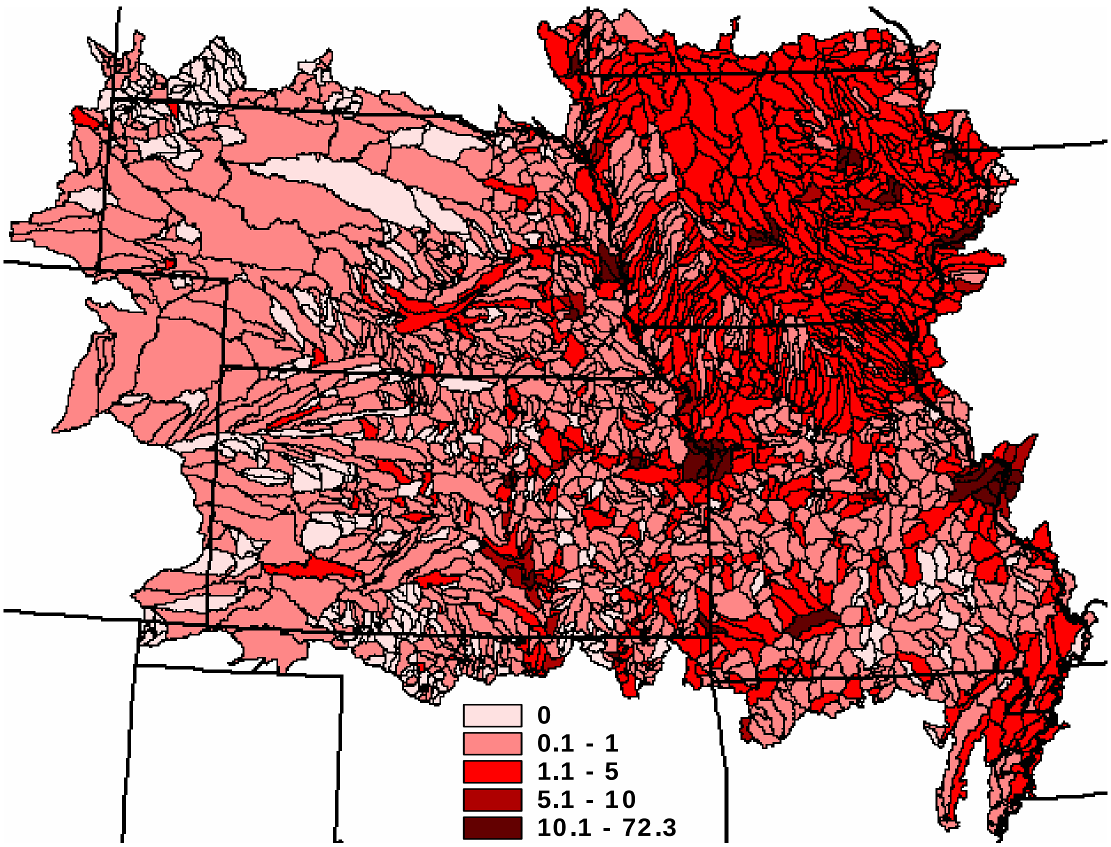


Figure 29. Map showing the percentage of urban area occurring within each AES polygons throughout EPA Region 7.

After the rankings were completed for each of the human stressors we generated a cumulative stressor index by summing the ranks across all nine stressors for each AES polygon. During this summing process the ranks for the percentage of urban area were weighted by a factor of three to account for the fact that urbanization of a watershed generally results in severe and irreparable disturbance to freshwater ecosystems (Klein 1979; Osborne and Wiley 1988; Limburg et al. 1990; Booth 1991; Weaver and Garmen 1994; Booth and Jackson 1997; Wang et al. 2000). The resulting index provides a relative measure of the degree of cumulative human disturbance within each individual AES throughout EPA Region 7 (Figure 30).

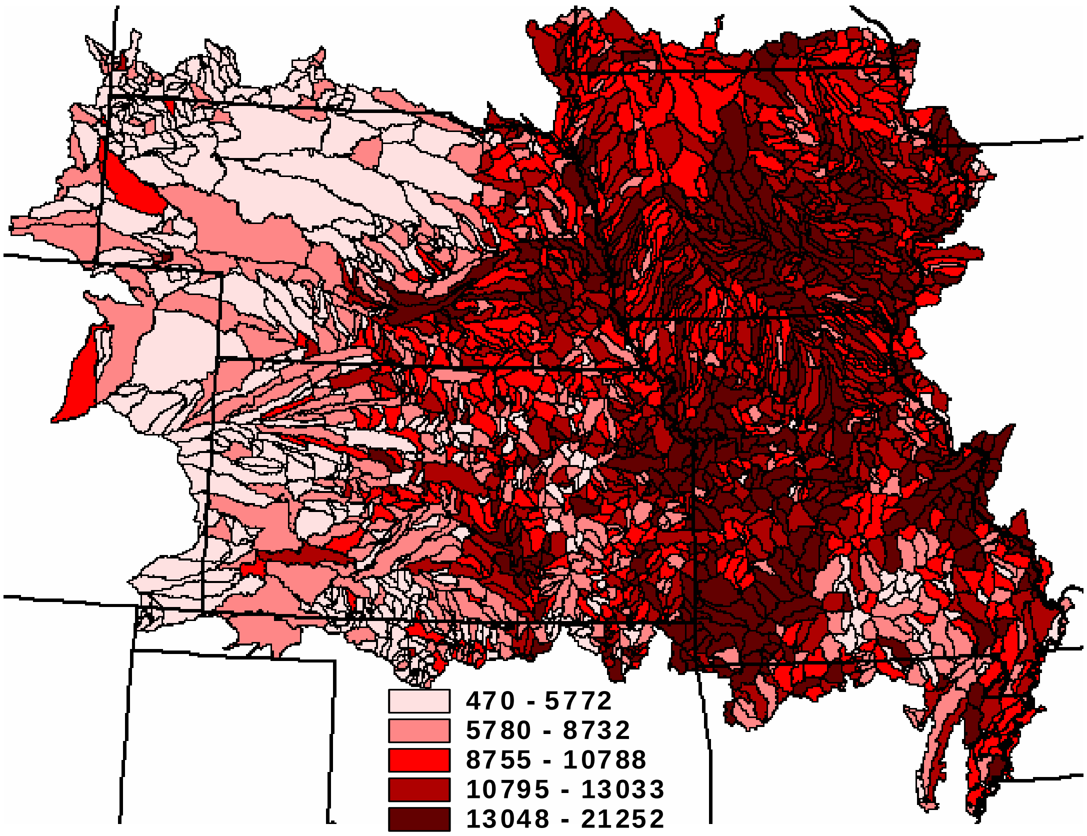


Figure 30. Graduated color map of the cumulative stressor index that was used to rank AESs across EPA Region 7.

The lowest value for the cumulative stressor index was 470 and occurred within the AES containing the upper reaches of the White River between Willow and Grass Creeks, just north of the Nebraska state line. The highest value was 21,252 and occurred within the AES containing the Missouri River between Cedar Creek and the Moreau River, which falls mainly within the boundaries of Jefferson City, Missouri.

4. Public Ownership

We assembled the GAP Stewardship coverages from each the four states in EPA Region 7 (Figure 31). Reservoirs coded as public land were removed from these coverages. We used these coverages to calculate the percent of public ownership within each AES polygon. No distinctions were made among owners or the gap stewardship codes. The percentage of public ownership was used as another means of ranking AESs across EPA

Region 7. Figure 32 shows the AES polygons within EPA Region 7 displayed according to the percentage of public lands within their boundaries.

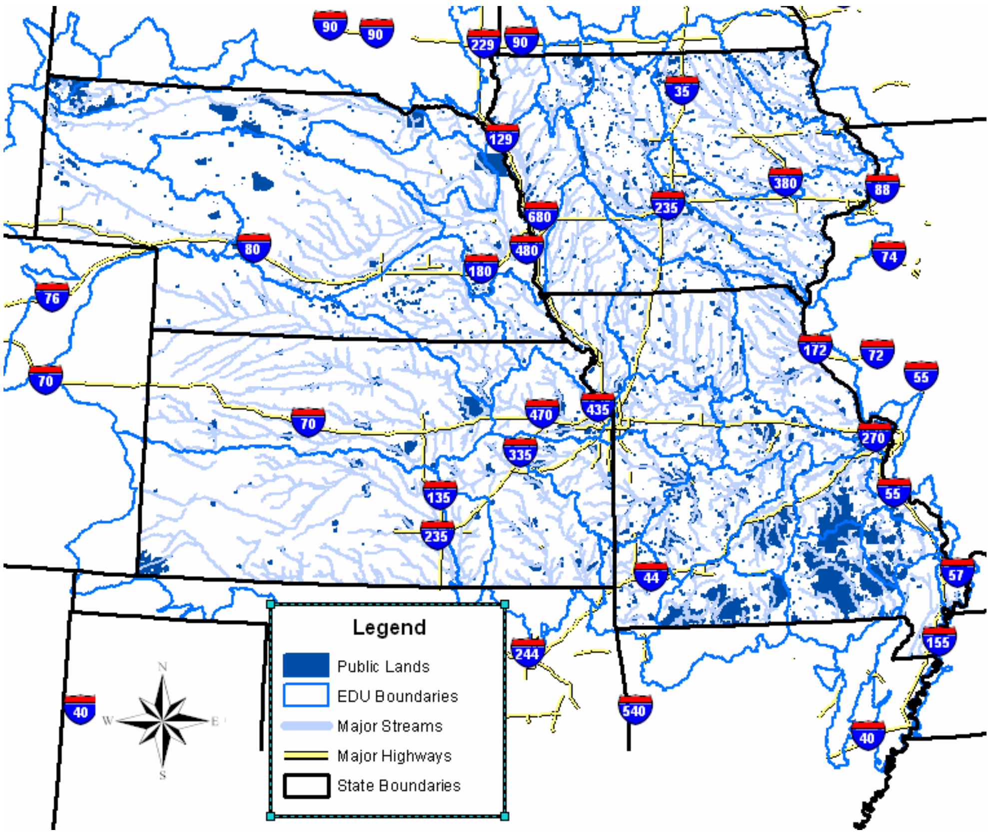


Figure 31. Map showing the distribution of the public lands within EPA Region 7.

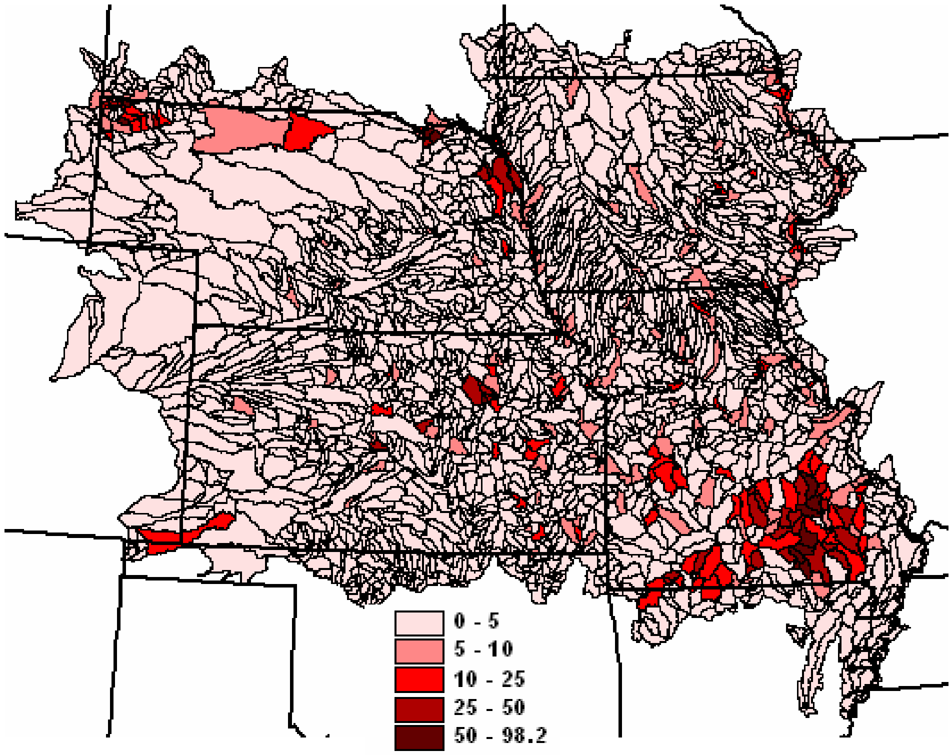


Figure 32. Graduated color map showing the percentage of public lands within each AES polygon.

5. Conservation Assessment Strategy

We wanted to ensure that the conservation strategy used to select aquatic conservation focus areas for Iowa, Kansas, and Nebraska was consistent with the more detailed assessment carried out for Missouri. However, the lack of biological data (predicted distribution data) and expert input for these three states dictated that a coarser-grained and more general conservation strategy be used.

Basic elements of the regional conservation strategy:
Separate conservation plans must be developed for each EDU,
Select one example of each AES-Type within each EDU,
Prior to the ranking process all AES-Types should be further stratified according to the size of the largest stream flowing within its boundary (i.e., small, large, or great river)

Like the assessment for Missouri, EDUs served as the primary planning unit and AES-Types were a principal conservation target. However, again due to the lack of biological data, we were unable to use biological targets, and the lack of expert review prevented us from using VSTs as targets. Yet, if the results of the Missouri assessment hold for these other three states, then this more general strategy should still provide a set of focus areas that represent the full breadth of freshwater ecosystems and multiple populations of 95% or more of the native aquatic species that occur in these three states (Sowa et al. 2005). The reason we further stratified AES-Types according to the size of the largest stream was to account for the fact that drainage area plays such a critical role in the structural and functional character of riverine ecosystems and associated wetland complexes and their biotic communities (Vannote et al. 1980). All AES polygons contain streams classified as headwater and creek, but in addition only contain segments falling into one of the three larger size classes (small, large, or great river). Therefore, those AESs that contain **small river** were differentiated from those containing **large river** and these were further differentiated from those containing **great river** stream segments. AESs that contain complexes of headwater, creek, and small river are termed “upper” units since they are generally situated in the uppermost positions of the larger drainage network. By extension, those containing headwater, creek, and large river complexes are termed “middle” units and those containing headwater, creek, and great river are termed “lower” units.

Another major difference between the assessment conducted in Missouri and what could be achieved in the other three states pertains to the integration of multiple assessment criteria. In Missouri, the human stressor index, percentage of public ownership, and target species richness were the three principle assessment criteria that were used to collectively identify and rank AESs and VST complexes. The integration of these criteria was subjectively carried out by the team of aquatic resource professionals since there is no clear way to automate the integration of such criteria in the computer based on simple ranking criteria. Lacking this professional input we decided to generate separate rankings based on the cumulative stressor index and the percentage of public ownership. Due to the limited amount of public land in these three states we determined that the cumulative stressor index should serve as the primary ranking criteria for selecting aquatic focus areas. Separate rankings were also done based on the percentage of public land, however, these rankings were not used in the selection of focus areas, but were integrated with the rankings based on the cumulative stressor index in order to provide information that could be used to possibly refine the initial selection. **Consequently, the focus areas that we identified across Iowa, Kansas, and Nebraska represent the AES polygons of a given Type with the lowest rank for the cumulative stressor index value within a given EDU.** Specifically, within each EDU we ranked each AES polygon from 1 to N based on the cumulative stressor index, where N equals the number of AES polygons of a given Type within that EDU. The AES polygon with the lowest cumulative stressor index rank was given a value of 1. We also separately ranked each AES polygon from 1 to N, using the same stratification, based on the percentage of public ownership within the AES. The AES polygon with the highest percentage of public land was given a value of 1. These two rankings were then integrated in order to identify those AESs that had both the lowest relative cumulative stressor index and the highest relative percentage of public land.

6. Results of the Regional Aquatic Assessment

A total of 200 aquatic focus areas were identified throughout Iowa, Kansas, and Nebraska (Figure 33). The highest concentration of focus areas occurs in those regions with the greatest variability of watershed conditions, which tend to correspond with the areas of highest species diversity. When combined with the 158 focus areas identified for Missouri. a total of 358 focus areas were identified throughout EPA Region 7 (Figure 34). The relatively high number of AESs selected within the Ozarks is again reflective of the relatively high abiotic and biotic diversity that occurs within this Aquatic Subregion. However, since the assessment for Missouri also focused on target species capture there were several instances in which additional AES polygons were selected in order to capture underrepresented species. This finer-filter assessment was not done for Iowa, Kansas, and Nebraska. It is likely that a similar, more-detailed, assessment for these three states would add more AESs to the existing portfolio of aquatic focus areas. When we integrated the rankings based on the cumulative stressor index with those based on the percentage of public land, an amazing 139 (70%) of the 200 focus areas within Kansas, Iowa, and Nebraska had both the lowest relative stressor index and highest relative percentage of public land (Figure 35).

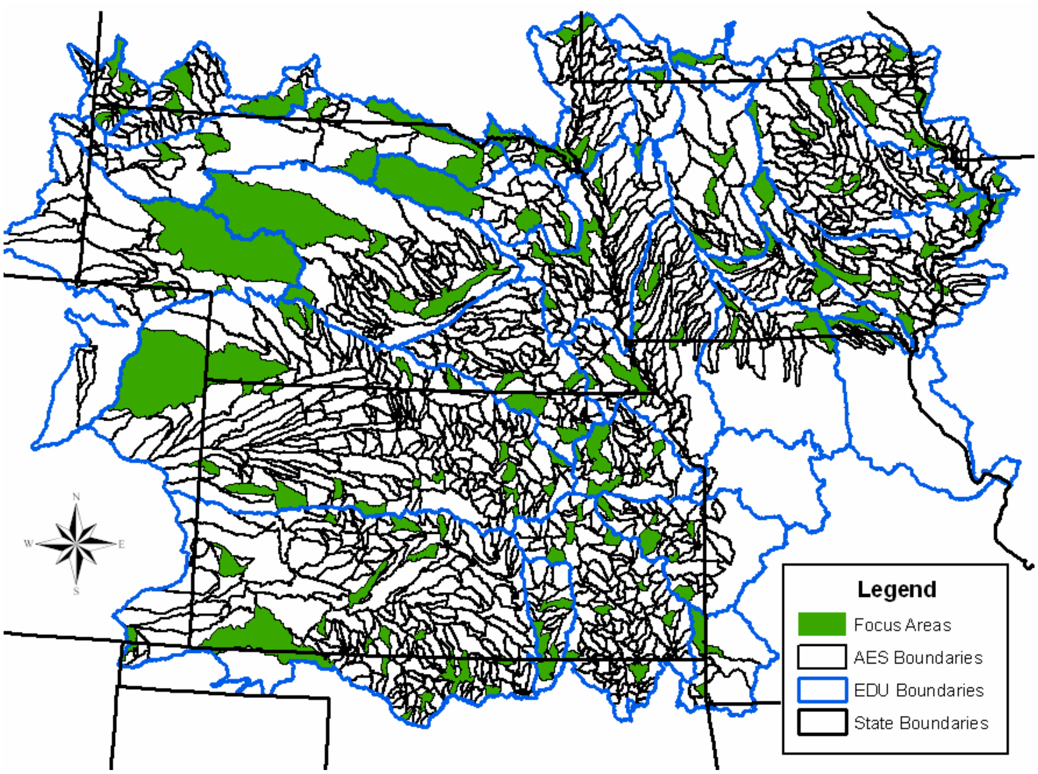


Figure 33. Map of the 200 aquatic focus areas identified throughout Iowa, Kansas, and Nebraska.

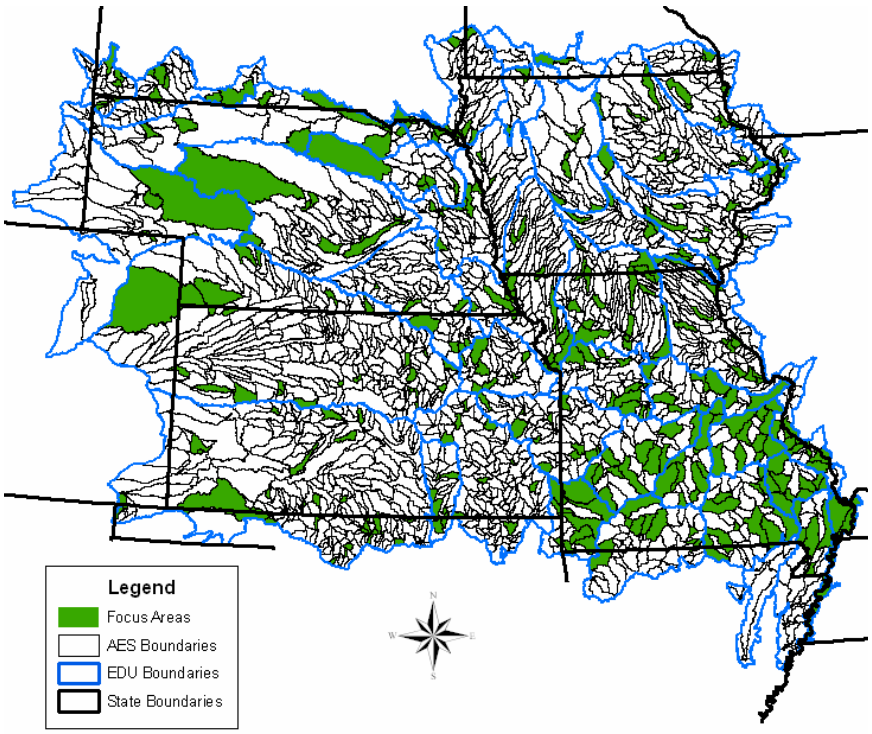


Figure 34. Map of the 358 aquatic focus areas identified throughout EPA Region 7.

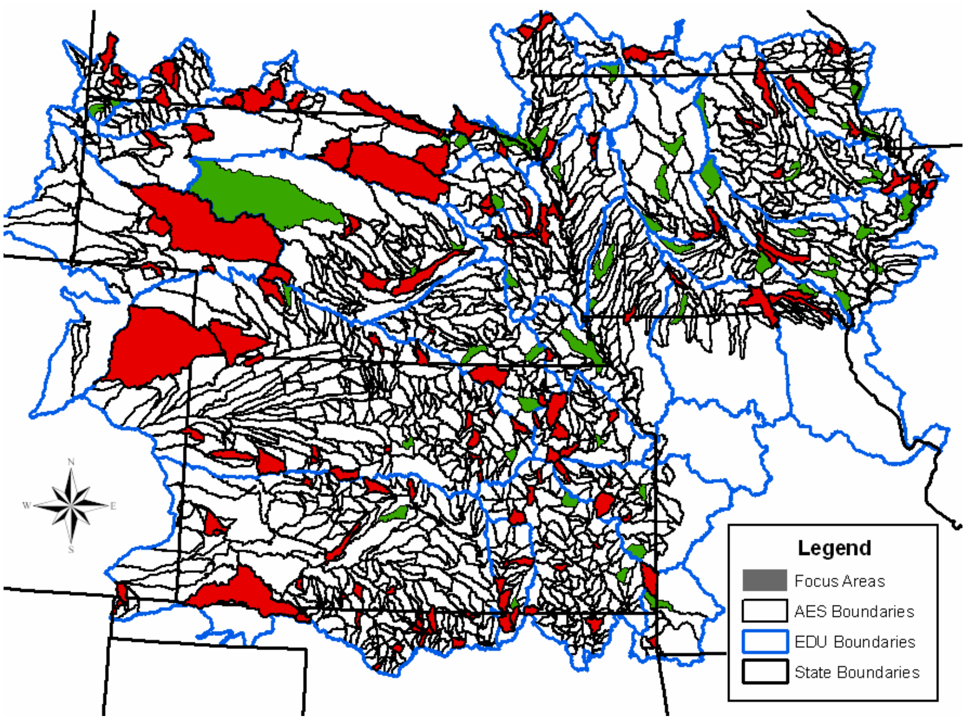


Figure 35. Map showing the 200 aquatic focus areas for Iowa, Kansas, and Nebraska (highlighted in both red and green). The focus areas highlighted in red were those that had both the lowest relative cumulative stressor index and highest relative percentage of public land (70% of the total).

IV. Discussion and Future Needs

A. Terrestrial Assessment

Terrestrial conservation focus areas were identified on a planning region by planning region basis across EPA Region 7 using relatively uniform methods and data sets. Even though we used regionally available data sets, inconsistencies in input data and in land use among the regions do exist. For example, roads are developed and mapped differently across EPA Region 7, even in rural areas, and differences in road density have profound impacts on the significance, threats, and risk results. Because of inherent differences among regions, we believe that it is most appropriate to view results on a planning region by planning region (essentially section by section) basis, rather than comparing results across sections. Results within a planning region are both locally relevant and ecologically most meaningful.

The terrestrial conservation focus areas we identified are not ranked within section, so local priorities cannot be discerned. Likewise, they are only polygons of various sizes without names, so local managers and planners will have trouble relating to the results in that regard. Local, finer-resolution input needs to be used to rank conservation focus areas for conservation action, the polygon boundaries will need to be re-drafted based on finer resolution data, and the most important areas will need to be provided with locally-identifiable names. These actions need to take place at the state and local level.

B. Aquatic Assessment

During the conservation assessment process for Missouri we found that the local experts are often humbled by the GIS data. Often, what appear to be the best places to conserve are those places that the local managers know little or nothing about. This exemplifies that the world is a big place, and we cannot expect a handful of experts to know every square inch of an Ecological Drainage Unite (i.e., 10,000+ km^2). At the same time we found that the GIS data are often insufficient and, if solely relied upon, may lead to poor decisions. In several cases, GIS data identified a particular location, while the local experts quickly pointed out problems. For example, in one case the sewage treatment facility just upstream from one potential focus area had one of the worst spill records in the state, and fish kills occur almost on an annual basis. While the GIS data show the location of the sewage treatment facility, they do not contain this more detailed information. Capturing this type of information within a GIS must become a priority.

In Missouri, we were pleasantly surprised to find that even in the most highly altered and severely degraded landscapes we were able to identify “hidden jewels” that have somehow escaped the massive landscape transformations and other insults in neighboring watersheds. Yet, in many instances these relatively high quality locations were quite small and therefore highly susceptible to any future changes in local or watershed conditions. Those locations facing any potential immediate threats must be identified and the necessary conservation actions must be put into action quickly, otherwise these "hidden jewels" could be lost forever.

Another surprising result was that we were able to represent all of the abiotic and biotic targets within a relatively small fraction of the overall resource base in Missouri (~6%). Unfortunately, the area that must be managed in order to protect/restore the ecological integrity of any given focus area is often substantially larger and much more daunting than the boundaries we delineated. However, the spatially-explicit nature of the focal point areas provides a focal point for resource managers, because even when on-the-ground management is far removed from one of these priority locations, the streams and assemblages within each focus area are the ultimate focus of conservation action.

When we began our project we recognized the fact that, whenever possible, priorities should be established at a scale that managers can understand and use (e.g., individual stream segments) in order to apply spatially-explicit conservation actions. Each team of local experts found the conservation planning process much more useful than previous planning efforts they were involved in, which identified relatively large areas as priorities for conservation. The managers stated that, because we selected localized complexes of specific stream segments, much of the guesswork on where conservation action should be focused has been taken "out of the equation," which will expedite conservation action. This same level of geographic precision is not provided with the focus areas identified for Iowa, Kansas, and Nebraska. Identifying more spatially-explicit conservation priorities within the focus areas of these three states must become a priority.

Since conservation efforts cannot be initiated immediately within all of the focus areas, priorities must be established among these areas in order to develop a schedule of conservation action (Margules and Pressey 2000). For Missouri, this was accomplished by conducting an irreplaceability analysis based on the representation of native fish, mussel, and crayfish species. While all of the focus areas are important to the long-term conservation of freshwater ecosystems in Missouri, the results of these analyses identified several critical locations in the state where conservation action will provide the greatest initial return for the effort expended. Once predictive distribution models are completed for the fish species in Iowa, Kansas, and Nebraska, the regional focus areas should be reexamined and an irreplaceability analysis should be performed in order to rank the priority AES polygons across the entire region.

A surprisingly high percentage (70%) of the aquatic focus areas had both the lowest relative stressor rank and the highest percentage of public land. These results illustrate two important points. First, public lands are critical to minimizing human disturbance to freshwater ecosystems as well as in terrestrial ecosystems. Second, state and federal resource management agencies have a critical role to play in the long-term conservation of many of these focus areas, even in states with a relatively low percentage of public land. One of the more difficult tasks will be getting these many agencies to work together in order to develop holistic management strategies for each of these focus areas.

Data development and analysis needs beyond species modeling and the incorporation of local knowledge in the priority-setting process also exist. These include the development of data on critical stress such as water withdrawals and channelization. We also need to and evaluate the accuracy of the inputs that have already been used. We need to generate quantitative date for the inputs (e.g. ranking one mine versus others or one point source versus another. We need to calculate each human stressor for each individual stream segment, rather than simply for larger watersheds. Finally, we need to provide for validation of GIS-based human stressor metrics with field data.

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