Development of Critical Ecosystem Models
for EPA Region 7

Regional Geographic Initiative (RGI) Report
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I. Introduction

EPA Region 7 set Critical Ecosystems as one of three major areas of emphasis in 2001. According to the Region 7 web page, "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 enabling ecosystem protection by providing better communication about Region 7 ecosystem protection strategies and initiatives.

EPA R7 staff, MoRAP, and key state partners have worked together to provide guidelines for identification of critical ecosystems. These include the notion that separate assessments are needed for aquatic and terrestrial ecosystems (e.g. there is no 'one size fits all' assessment), assessments need to be as fine-resolution as possible to ensure practical utility, and assessments need to be based on rigorous, transparent methodologies so that planners and managers can understand, and embrace, results.

Based on discussions with partners, the project outlined that emerged included (1) selection of the Ozark Highlands and Chariton River Hills (Figure 1) ecoregions as pilots for Terrestrial Critical Ecosystem modeling, since data were available immediately and they represent different ecoregions, one primarily agricultural and the other primarily forested ecoregion, (2) development of a terrestrial ecological risk surface at fine resolution (30m pixel, 900 square meters) (3) development of an aquatic conservation opportunity area data layer, in collaboration with state partners, (4) development of a coarser resolution irreplaceability assessment, since this uses a proven, rigorous technique, and (5) development of an algorithm to define terrestrial critical ecosystems based on overlay of the ecological risk surface, aquatic conservation opportunity area, and irreplaceability assessment.

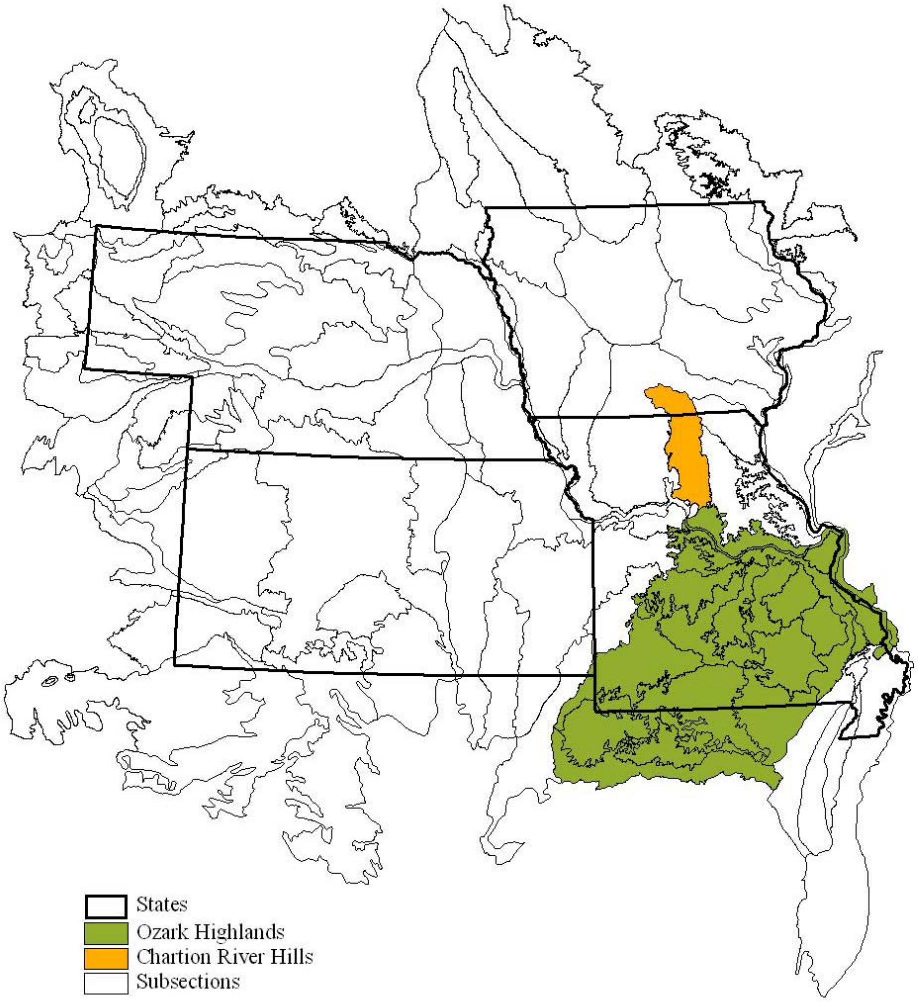

Figure 1. Map of the Chariton River Hills subsection and Ozark Highlands section. These ecoregions were the pilot areas used for this study.

Development of an ecological risk surface (objective 2) and a coarse resolution irreplaceability layer (objective 4) were combined for defining critical ecosystems (objective 5). In the following document each layer, along with the variables and methods used to create the layers, are described. Based on the results of this pilot study, we will move forward, as data are available, and apply these methods to define critical ecoregions across EPA Region 7. Figure 2, below, demonstrates the flow of inputs used to create the final terrestrial critical ecosystems assessment.

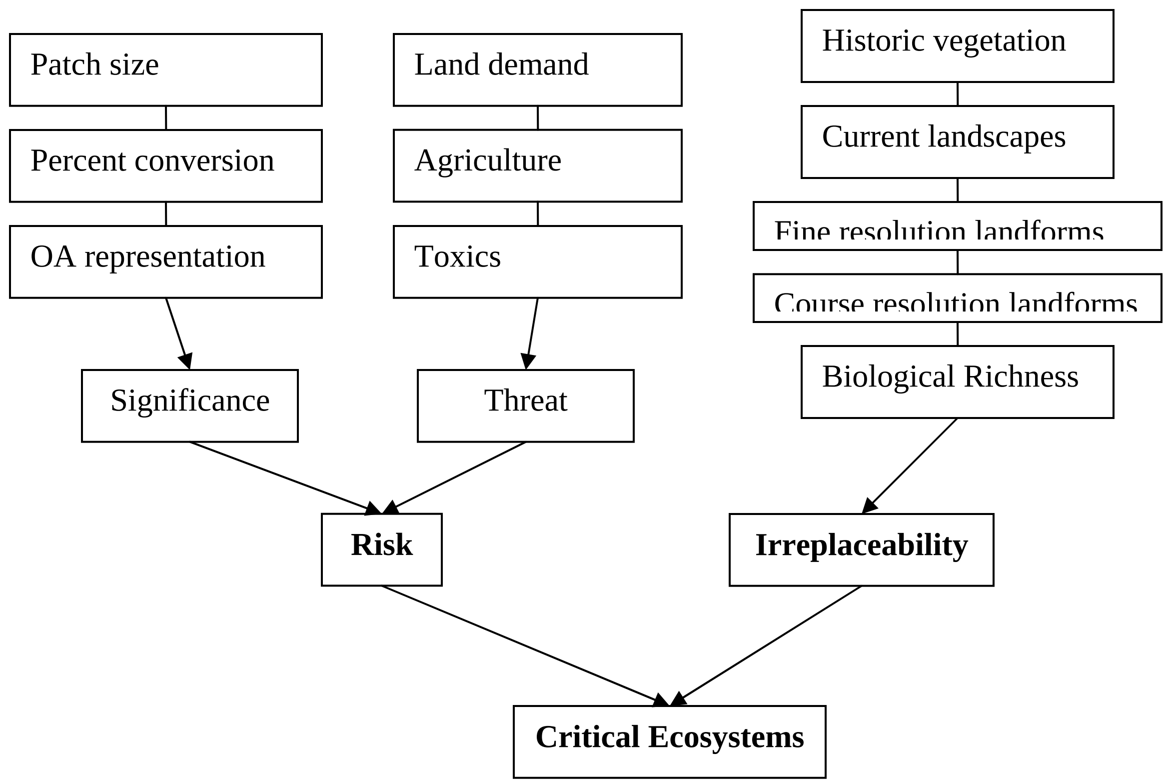

Figure 2. Flow chart showing variables used to reach final layer of Terrestrial Critical Ecosystems.

II. Terrestrial Ecological Risk Surface

We created an ecological risk surface at 30m pixel resolution by overlaying ecological significance and threat layers. The significance and threat layers were in turn defined based on overlays of three individual layers. Pixels that had a high value for both significance and threat were considered most at risk.

A. Ecological Significance: Patch Size, Percent Conversion, and Conservation Opportunity Area Representation

Ecological significance is an indicator of the relative importance or value of an area to conservation of the biota and maintenance of ecological processes based on evaluation of relevant, surrogate characteristics. Significance values were attached to each 30m pixel based on three separate variables, including (1) scores for patch size of current vegetation where these are similar to modeled historic vegetation, (2) scores for geolandforms based on the percent of each geolandform that remains in a vegetation type similar to the historic vegetation, and (3) scores for pixels that represent terrestrial conservation opportunity areas. The three variables are ranked from one to five where lower values indicate areas of lower ecological significance. The final ecological significance layer could have values from 1 to 15 with 15 representing the highest ecological significance. The methods used to derive the three input variables are described below.

Patch size of current 'no conversion' vegetation

The patch size of 'no conversion' vegetation is based on a comparison of current land-use/land-cover to modeled historic vegetation. Areas where current land-cover is similar to modeled historic vegetation are identified as 'no conversion' patches. Patches are ranked from lowest to highest size classes.

The National Land Cover Database (NLCD) provided current vegetation information. The 18 vegetation classes were reclassified to 8 main land-cover types as follows (Table 1).

Table 1. NLCD reclassification scheme from 18 to 8 land-cover types.

Reclassified NLCD Name / *Original NLCD Name*	**Reclassified NLCD code** / *Original NLCD code*
Grass	**10**
Grassland/herbaceous	*71*
Pasture/hay	*81*
Forest	**30**
Deciduous forest	*41*
Evergreen forest	*42*
Mixed forest	*43*
Wetland	**50**

Woody wetland		*91*
Herbaceous wetlands		*92*
Water	**60**	
Water		*11*
Shrubland	**70**	
Shrubland		*51*
Urban	**80**	
Low intensity residential		*21*
High intensity residential		*22*
Commerical/industrial/transportation		*23*
Urban/recreational grasses		*85*
Barren	**90**	
Bare/transitional		*31*
Quarries/strip mines/gravel pits		*32*
Bare rock/sand		*33*
Cropland	**100**	
Row crops		*82*
Small grains		*83*

Historic vegetation was modeled using a combination of environmental and physical characteristics. Input data for historic vegetation was based on assigning general vegetation types to fine-resolution landforms within landscapes by precipitation zone and solar insolation value. Differences in landform, geology, fine-resolution landforms, precipitation, and solar insolation were used to model vegetation (see Appendix A for the Chariton River Hills and Ozark Highlands historic vegetation models). The modeled vegetation was used as a surrogate for historic land-cover conditions. MoRAP developed landforms based on Hammond's landform classification (see Diamond et al. 2003 for more detail on the creation of this dataset). For the purposes of modeling the historic vegetation these landforms were grouped into three main categories: flats (flat plains, smooth plains, and irregular plains), hills and breaks (hills, breaks, and low mountains), and floodplains. The geology dataset represents major compositions of bedrock geology. This dataset was gathered from various state agencies and is grouped into three major geologic types: sandstone, igneous, and dolomite/limestone/shale (see Appendix B for a list of geologic citations and descriptions).

Fine-resolution landforms were created by combining physical landscape characteristics of slope and landscape position (Figure 3). The percent of slope and landscape position were calculated for each 30m pixel in the study area. The percent slope values were examined within each major landform type: flats, hills, and breaks. Slope was divided into three classes: flat, sideslope, and steep slope. Definitions of these three classes varied by major landform type. For example, in the flat landforms, areas defined as steep slopes had lower thresholds than in the hills landforms where thresholds for steep slopes were higher. This method of classification was also performed for landscape position which had four categories: highest, high, mid, and lowest. Slope and landscape position were combined to create 12 possible site types. For example, we separated low flats versus high flats, and high slopes versus mid slopes. These site descriptions were collapsed into six fine-resolution landform types: upper slopes, steep slopes, gentle slopes, lower slopes, upland flats, and lowland flats.

A floodplain layer was then added to the landform layer. For the creation of the floodplain layer we selected all 30m pixels with less than 8% slope (e.g. flats), and placed each pixel into one of nine classes corresponding to different elevations within each 12-digit hydrologic unit. These classes included 10% of the highest elevation within the watershed, 20%, 30%, and so on to 90%. Each class was color coded for on-screen analysis. Hence, all 30m pixels in flats with an elevation equal to or less than 10% of the highest elevation within a watershed were one color, pixels with an elevation between 10% and 20% of the maximum for the watershed were a second color, and so on. Finally, we selected and zoomed to each 12-digit hydrologic unit on screen against a backdrop of a topographic hill shade and stream network, and separated high flats from floodplains and low flats by selecting a cut-off point for pixel elevation (e.g. 10% of the highest elevation within the watershed represents floodplains and low flats, or 20%, and so on). For the purposes of historic vegetation modeling the classes were also combined into four major site types: upland flat/upper slope, lower slope/lowland flat, gentle slope/steep slope, and floodplain.

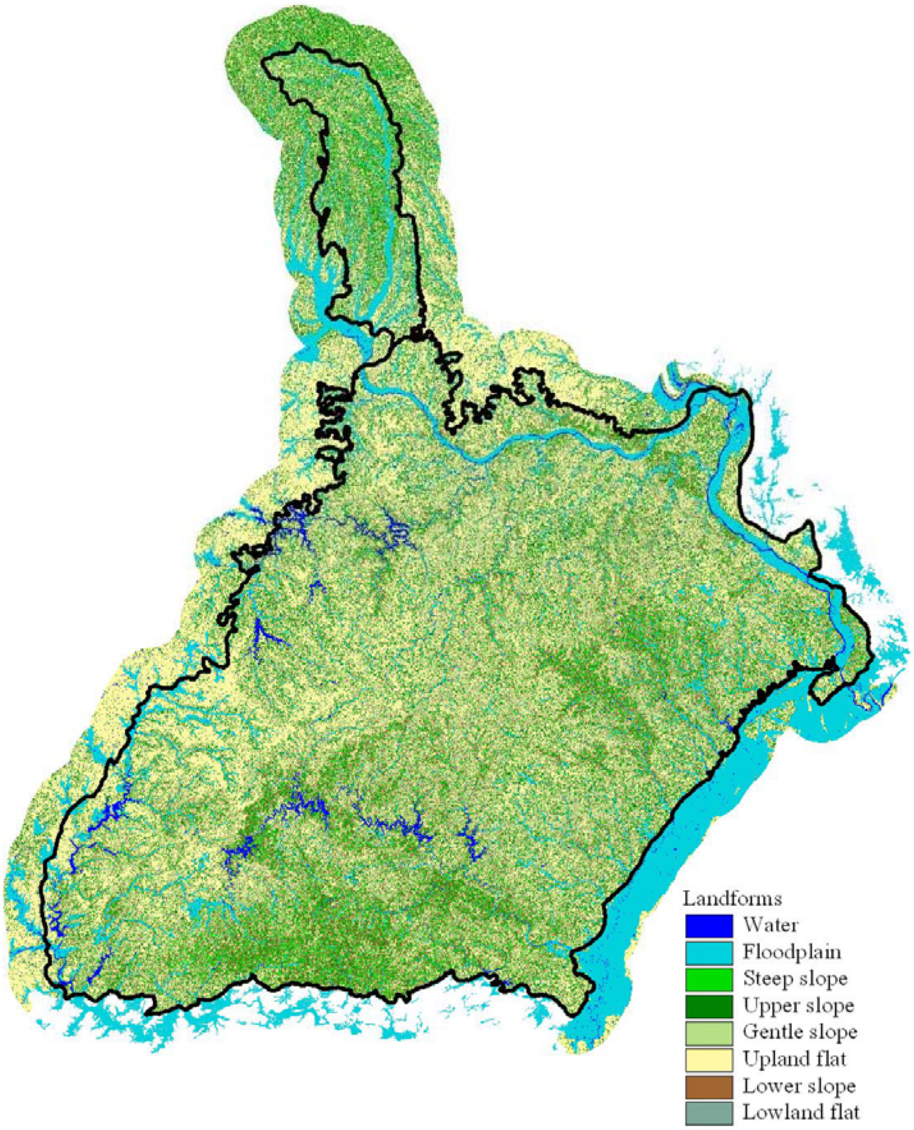

Figure 3. Map of fine-resolution landforms in the Chariton River Hills and the Ozark Highlands.

The 103-Year High-Resolution Precipitation Climate Data Set for the Conterminous United States dataset was used as a source for climate information. This dataset was obtained from the Spatial Climate Analysis Service at Oregon State University, Corvallis, Oregon and displays mean annual precipitation from 1895 to 1997. This dataset was divided into two main climate categories: dry (less than 44 inches/year of rainfall) and wet (greater than or equal to 44 inches of rainfall per year). Solar insolation provided the amount of incoming solar radiation to each pixel. The SOLARFLUX program (Rich and Hetrick 1994) which models radiation based on surface orientation, solar angle, shadows from topographic features, and atmospheric conditions calculated this variable.

The final historic vegetation classes for the Chariton River Hills and Ozark Highlands were tallgrass prairie, woodland/savanna, forest, mesic forest, bottomland forest, and glade/woodland. In areas where water is currently present the digital elevation layer cannot accurately report pre-lake elevation values. Since these areas were not historically present as ponds or lakes, the level of accuracy when modeling these areas was considered low. Further investigation is needed for a relatively accurate method of modeling these areas. For the purposes of this pilot project these areas remained classified as water.

The historic vegetation and current land-use/land-cover were compared to evaluate the change in land-cover conditions over time (Figures 4 and 5).

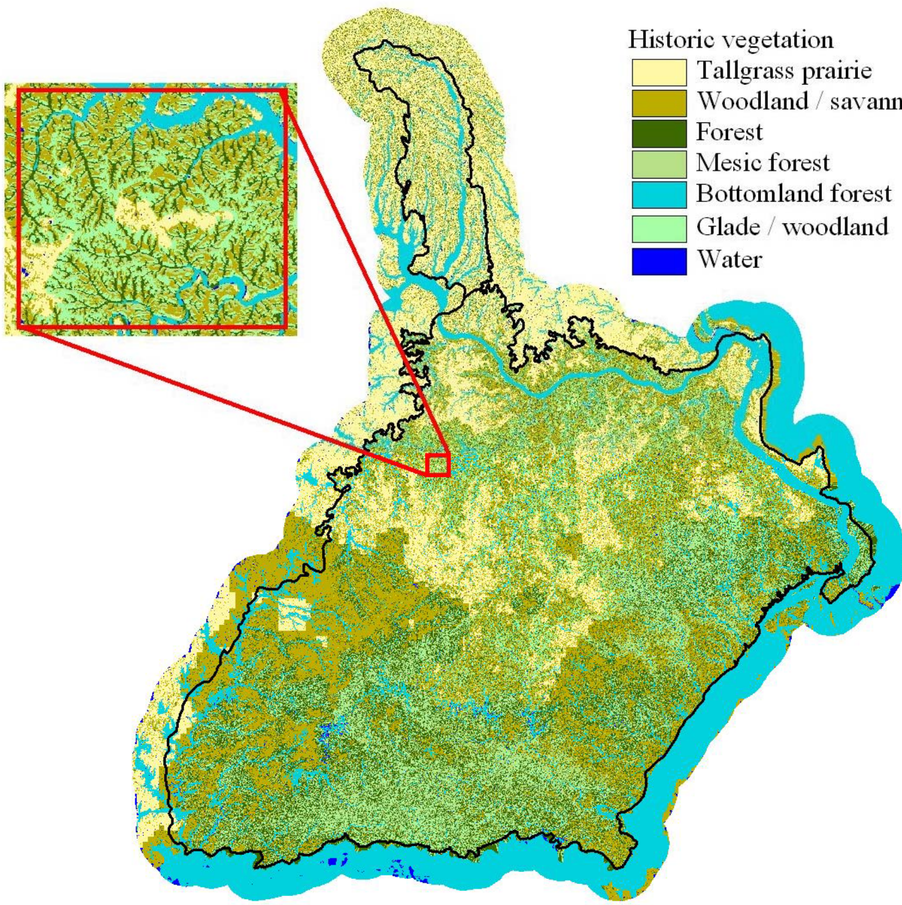

Figure 4. Map of modeled historic vegetation in the pilot areas.

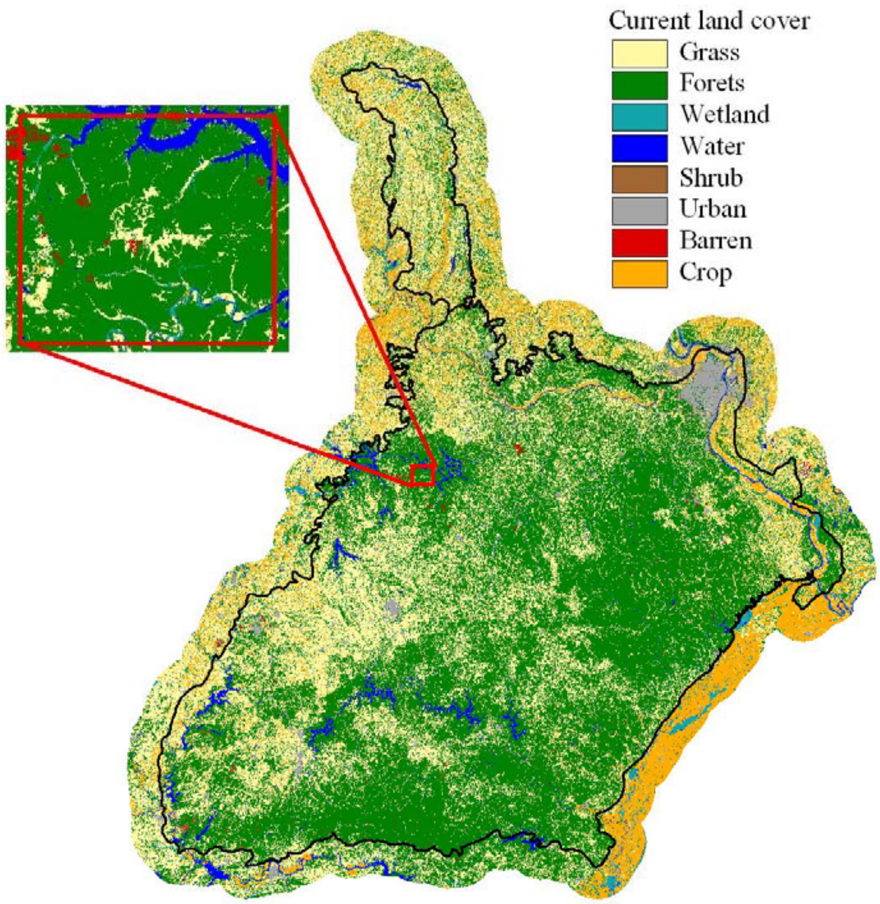

Figure 5. Map of current land use / land cover. National Land Cover Database 1992-1993.

Areas converted to urban or cropland were not considered in further analysis. Likewise, areas that were converted to a different but natural or semi-natural land use/land cover (e.g. current forest on patches modeled as historic grassland) were not considered. Land cover patches where current vegetation was similar to historic modeled vegetation were labeled as 'no conversion' and analyzed for patch size. These 'no conversion' classes included the following historic and current land cover classes (Table 2):

Table 2. Current and modeled historic land-cover that indicate no conversion.

Current land-cover	Historic vegetation
Grass	Prairie
Forest	Woodland/savanna, forest, or mesic forest
Wetland	Bottomland forest
Water	Water
Shrubland	Prairie, woodland/savanna, or bottomland forest

Once the areas of 'no conversion' were identified the patches were ranked by size. The size of each 'no conversion' patch was ranked by using Jenks' natural breaks into 5 classes. Values range from one (smallest size classes) to five (largest size classes) (Figure 6). Values of zero indicate areas where significant land cover conversion had occurred.

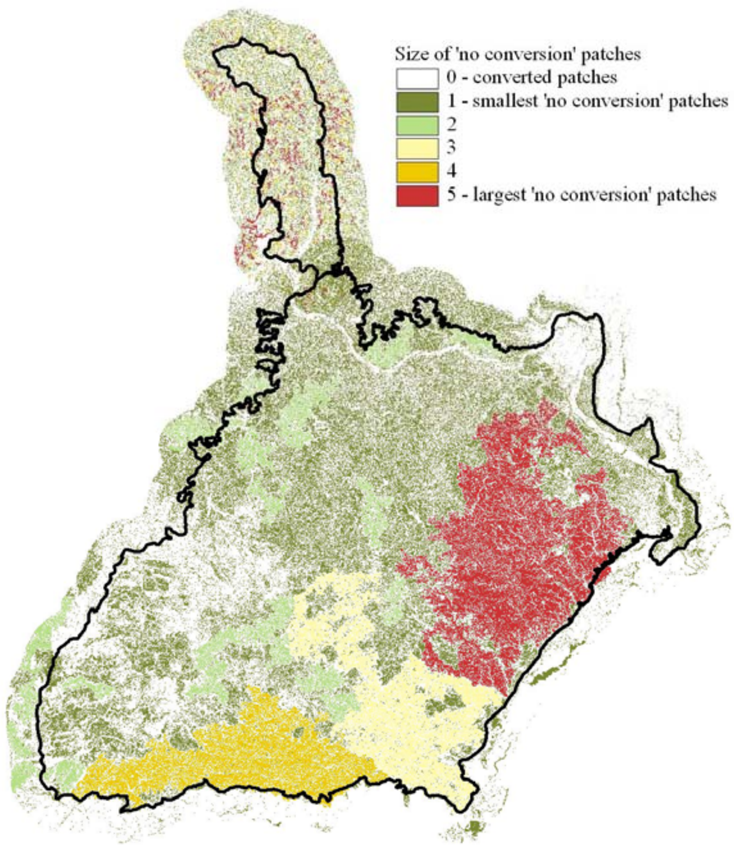

Figure 6. Map showing areas of 'no conversion' from historic to current land-cover ranked from smallest (one) to largest (five) by ecoregion.

Percent of 'no conversion' by geolandform

Hammond's landforms were ranked by the percent of 'no conversion' pixels in each landform. This variable is a useful indicator to identify those landforms with the least amount of remaining historic vegetation. The area of 'no conversion' patches was calculated by Hammond's landforms. A ranking from one to five was applied to each landform where areas with the least amount of remaining historic vegetation were assigned the highest value (Table 3 and Figure 7).

Table 3. Final ranking of landforms by percent of 'no conversion' pixels.

Rank	Percent of 'no conversion' pixels in geolandform
1	80 - 100 (most remaining historic vegetation)
2	60 - 80
3	40 - 60
4	20 - 40
5	0 - 20 (least remaining historic vegetation)

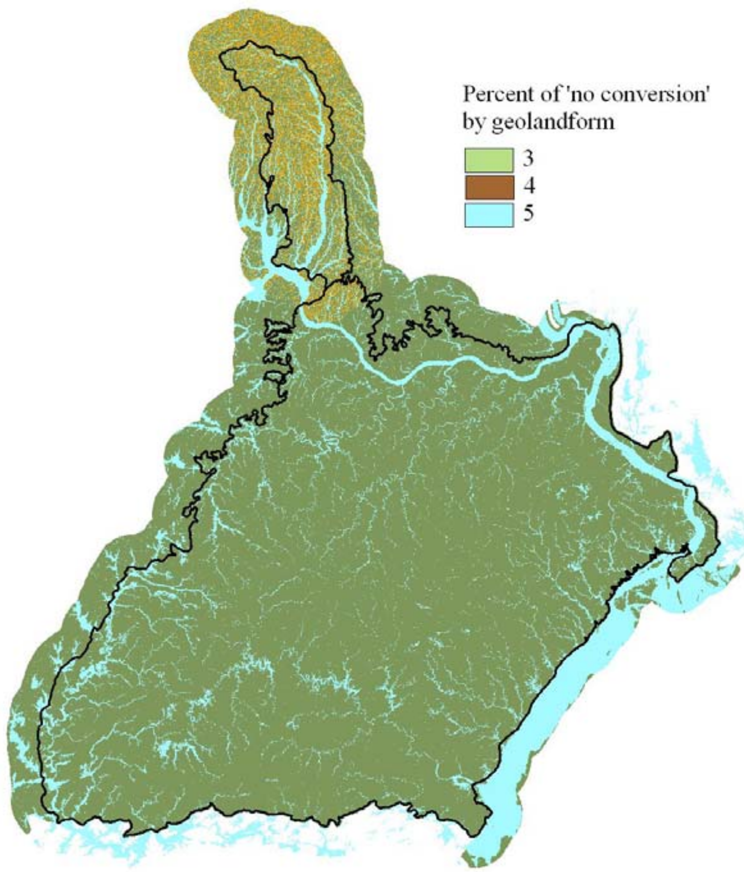

Figure 7. Map showing the percent of 'no conversion' patches by geolandform. Higher values indicate more conversion from historic conditions.

<u>Conservation opportunity area representation</u>

Conservation opportunity areas (OAs) are defined as natural and semi-natural land cover patches away from roads and habitat patch edges (Diamond et al. 2001). Ranks for landform representation were assigned to each opportunity area polygon by subsection by (1) intersecting Hammond's landforms with the opportunity area polygons to form a new opportunity area/landform polygon data layer, (2) assigning each opportunity area/landform polygon a score from one (largest size for that type) to *n*, where *n* is the total number of polygons for that type, and (3) assigning each opportunity area the lowest number (highest significance score) from among the landform type ranks it circumscribed. Step three was necessary in order to resolve the issue of what score to assign an opportunity area that was made up of more than one landform type. The smallest OAs by landform representation received a rank of one. The size classes of the OAs were determined using Equal Area breaks with values ranging from one (smallest OAs) to five (largest OAs). Values with a zero indicate areas where OAs were not present (Figure 8).

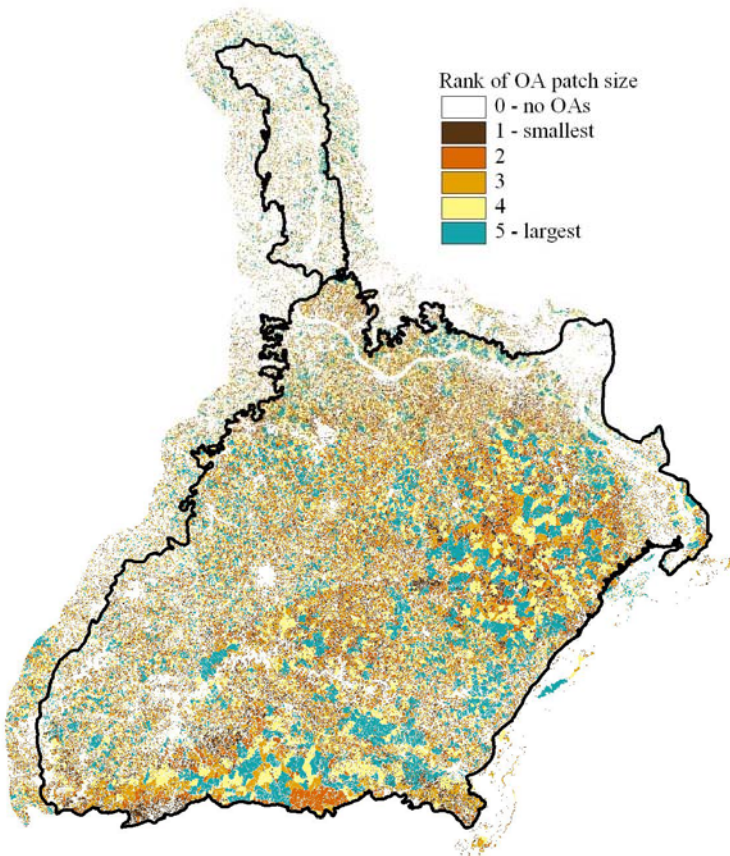

Figure 8. Map showing the ranking of conservation opportunity areas based on size and landform representation within the Chariton River Hills and the Ozark Highlands.

The final ecological significance scores ranged from 3 to 15 for the Chariton River Hills and the Ozark Highlands (Figure 9). High significance values indicate areas with large patches of 'no conversion' land cover, a low percentage of 'no conversion' in a geolandform, and large opportunity areas.   In the Ozark Highlands the eastern and southern portions of the section have some of the greatest significance scores. The lowest significance scores exist around metropolitan areas.

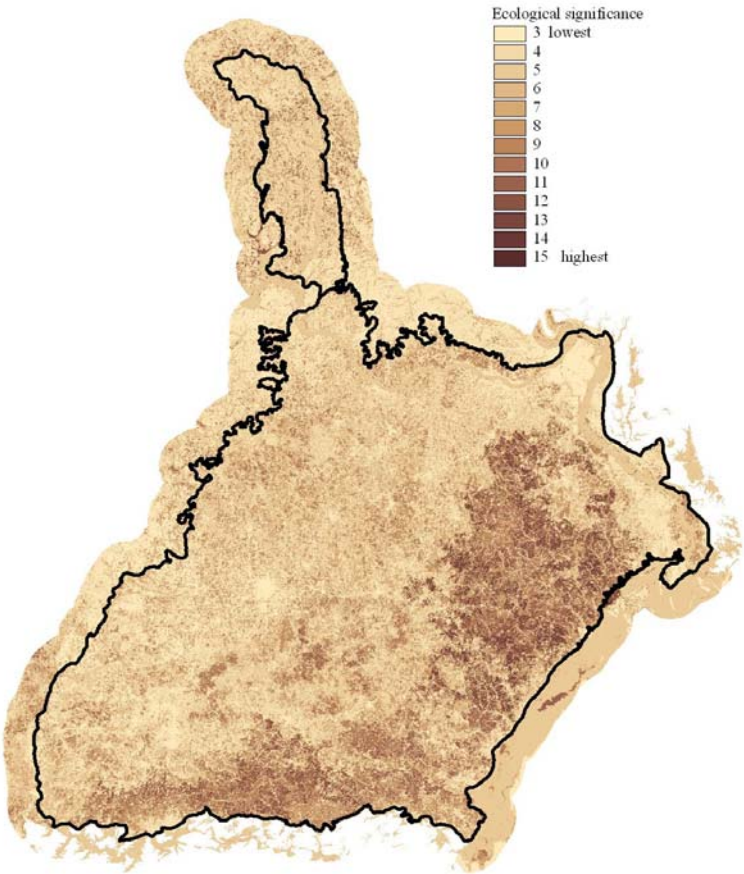

Figure 9. Map of final ecological significance for the pilot ecoregions.

B. Ecological Threat: Land Demand, Agriculture, and Toxic Releases

Ecological threat was defined using an overlay of three different, spatially explicit data layers. These included agriculture threat, urban land demand, and toxic releases. Following we provide an outline of the methods used to define these threats surfaces.

Agriculture Threat

Threat for agriculture was defined as the threat of conversion of semi-natural vegetation to rowcrop agriculture. Data came from the 1992 and 1997 county agriculture census (US Department of Agriculture, National Agricultural Statistics Service). Threat of conversion was calculated as the area of cropland in 1997 minus area of cropland in 1992. In order to smooth the county-by-county data, we found the centroid of each county and created a surface by attaching countywide data to the centroid points and interpolating between centroids using the Inverse Distance Weighted (IDW) method in ArcMap GIS. Cell size for the interpolation was 1000m (1 square kilometer). IDW was selected for interpolation because this method used centroid points to weight cell values, whereas all other methods were focused on creating a smooth surface. Values were assigned to county centroid points as outlined (Figure 10).

Cropland Acres Lost or Gained	Assigned Cell Value
-41696 - -38904	-5
-38903 - -29178	-4
-29177 - -19452	-3
-19451 - -9726	-2
-9725 – 0	-1
1 – 9726	1
9727 – 19452	2
19453 – 29178	3
29179 – 38904	4
38905 – 48630	5

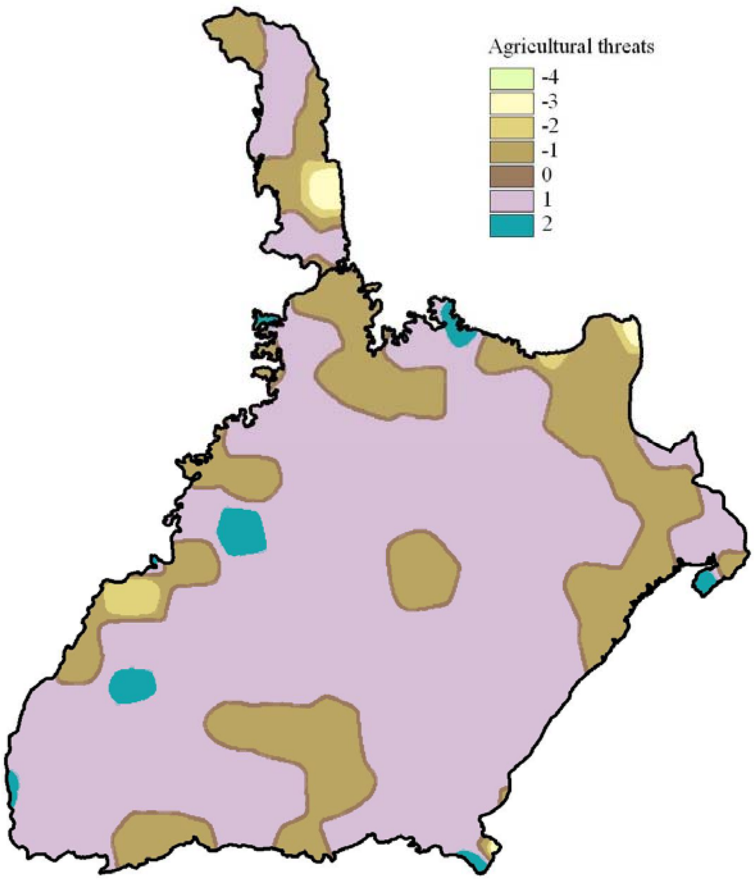

Figure 10. Map of agricultural threats in the Chariton River Hills and Ozark Highlands.

Land Demand

Human infrastructure land demand was defined for 30m grid cells and was calculated as the sum of two scores, one assigned based on human population change and one for proximity to roads and urban areas. Population change was defined using data from Geolytics CensusCD2000. Population density (people/square kilometer) by census block in 2000 was compared with population density in 1990. The following formula was used: (population density 2000 - population density 1990)/population density 2000. Scores for population density were assigned as follows:

1 - large negative change (less than -1.0)
2 - negative change (-1 to -0.25)
3 - relatively no change (-0.25 to 0.25)
4 - positive change (0.25 to 0.50)
5 - large positive change (0.50 to 1.0)

Proximity to roads and urban centers was scored using the Census Bureau's TIGER files to identify roads, cities, and metropolitan statistical areas (MSAs, see http://www.census.gov/population/www/estimates/metrodef.html).

1 - not within 1 km of a road
2 - within 1 km of a road but not within 25km of an msa or 10km of a city
3 - within 1 km of a road and within 25km of an msa but not within 10km of a city
4 - within 1 km of a road and within 10km of a city
5 - within the boundary of a city limit

Thus, each 30m cell had a value from 2 to 10 for land demand (Figure 11).

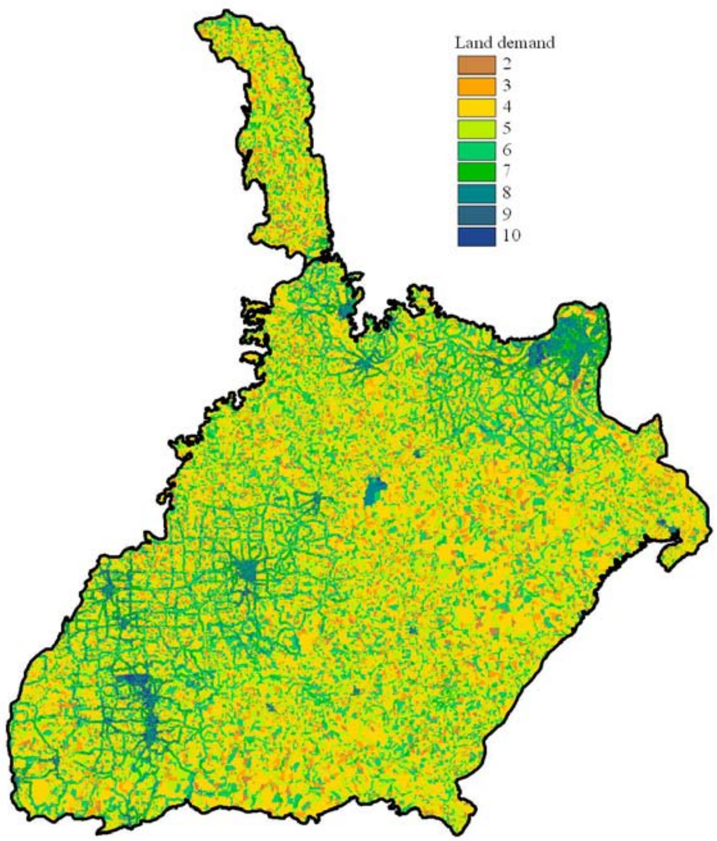

Figure 11. Map of land demand for the Chariton River Hills and Ozark Highlands. Higher values indicate more human land demand.

Toxic Release

A toxic release threat value was assigned to 30m pixels based on their proximity to known toxic release sites. Known release sites were given a score from one to ten, and each pixel was assigned a value equal to the total score within a neighborhood of 137 pixels, or 1.233 square kilometers. Values for toxic release sites were assigned a value as follows (Figure 12):

Release Site Type	Score
TRI (Toxics Release Inventory)	10
TSD (Treatment Storage and Disposal)	10
AIR Major (Large air permitted facilities)	10
All Superfund	8
LQG (Large Quantity Generator)	8
AIR minor (Smaller air permitted facilities)	5
NPDES major (National Pollutant Discharge Elimination System permitted pipes)	3
CAFOs (Confined Animal Feeding Operations)	3
SQG (Small Quantity Generator)	3
NPDES minor	1
CEG (Conditionally Exempt)	1

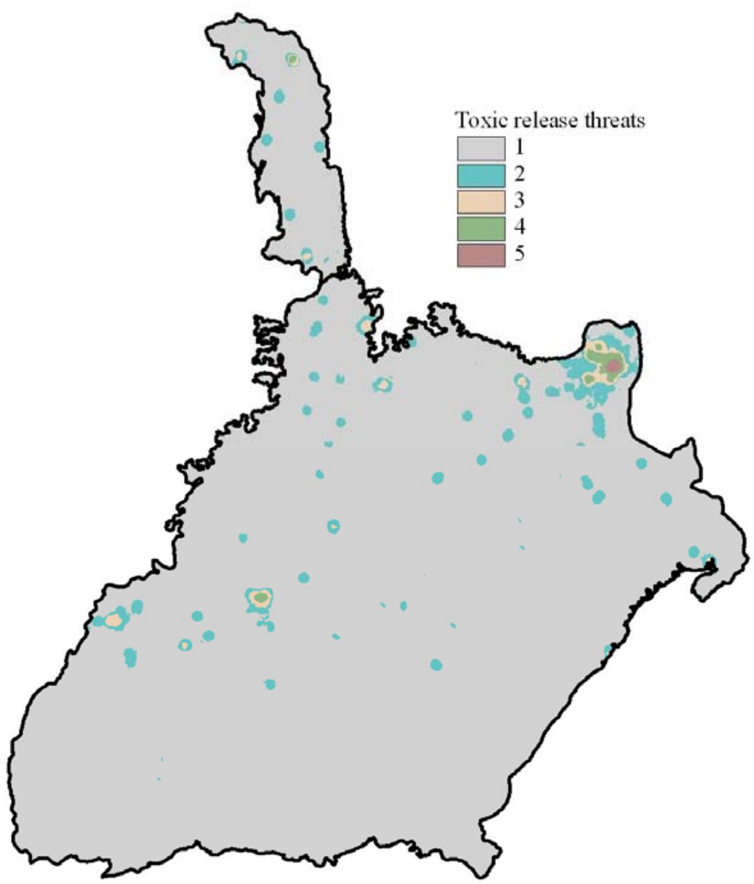

Figure 12. Map of toxic release for Chariton River Hills and Ozark Highlands.

Actual scores for ecological threat ranged from 0 to 16 in the Chariton River Hills and from -2 to 15 in the Ozark Highlands (Figure 13). Higher values indicate areas where the greatest ecological threats exist. In the Ozark Highlands those areas around cities have the highest threats. The Chariton River Hills has a zone of low threats in the south-central portion of the subsection. This area is primarily in the forested hills and breaks and reflects the relatively low proportion of threats in that area.

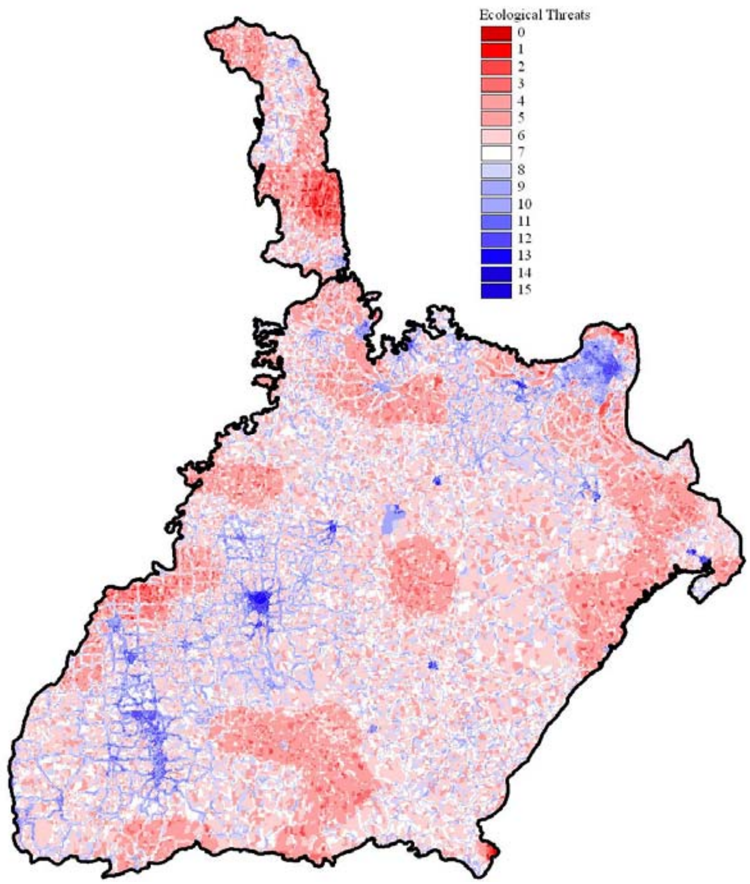

Figure 13. Map of final ecological threats in pilot areas.

C. Ecological Risk: Significance + Threat

Ecological risk was defined as the sum of significance and threat for each 30m pixel. Areas that have a high ecological significance score and a high threat score are considered at greater risk than areas that also have a high threat but are not considered ecologically significant. Pixel scores for significance ranged from three to 15 and values for threat ranged from -2 to 16. Therefore, values for ecological risk could range from 1 to 31. The actual scores for the Chariton River Hills were from 3 to 27 and for the Ozark Highlands were from 3 to 25.

We assigned each pixel to a ranked class, from one to five, using the Jenks' natural breaks classification available in ESRI's ArcView software (Figure 14). The natural breaks algorithm assigns breaks to continuous data by minimizing the sum of the variance within each class (Jenks 1967). In the Chariton River Hills, a region of 963,176 hectares, 1.5 % (14,191 hectares) of the region was within the highest class (score >=17), and 13.8 % was within the second class (score <=14). A total of 46.5 % of the area was within the lowest class (score >=11). The areas identified as highest risk are relatively low compared to those areas that are identified as the lowest risk. This is due to the fact that as a whole the subsection has very few areas of ecological significance. Much of this subsection has been converted to cropland, particularly along the broad floodplains that were historically bottomland forest.

In the Ozark Highlands, a region of 14,015,612 hectares, 6.6 % of the region was within the highest class (score >=18), and 25.1 % was within the second class (score >=15). A total of 58.8 % of the area was within the lowest class (score <=12). The areas with the highest risk occur in the eastern and southern portions of the section. This is due to the high ecological significance of these regions. Even with mid-range threats, these regions are identified as having some of the highest significance values of the section.

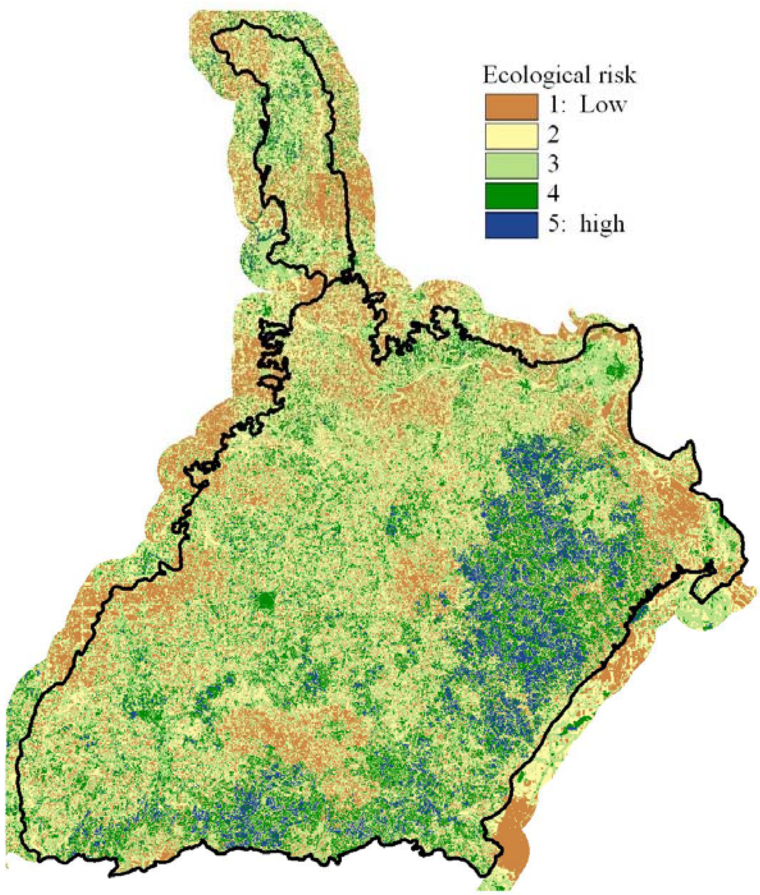

Figure 14. Map of ecological Risk in Chariton River Hills and the Ozark Highlands.

III. 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.

We selected the software package C-Plan to attach irreplaceability values to 40 square kilometer hexagons, our assessment units, within the Chariton River Hills and Ozark Highlands, our two assessment regions. The definition of irreplaceability in C-Plan 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 assessment unit has few or no replacements in the scheme of selected sets of assessment units that achieve the conservation goals over the assessment region.

The irreplaceability of assessment unit X is based on the proportion of sets of assessment units that meet the quantitative target goals ("representative sets," R) that must include assessment unit X versus those that meet the target goals without assessment unit 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 assessment unit across all targets, whereas the summed irreplaceaility is the sum of all irreplaceability values for all targets for a given assessment unit. C-Plan is linked to ArcView 3.x for its graphical interface (Pressey et al. 1995).

We selected multiple targets and set thresholds for capture of all targets. The following table summarizes targets for each of the pilot ecoregions analyzed (Table 4).

Table 4. Targets used for irreplaceability analysis.

Chariton River Hills Ecoregion			
Target Category	**Target Name**	**% Area**	**Target Goal (% of ecoregion)**
Historic Vegetation - Abiotic Habitats	Tallgrass prairie	55.5%	40%
	Woodland/savanna	14.6%	
	Forest	09.3%	
	Mesic forest	05.6%	
	Bottomland forest	14.4%	
Current Landscapes	Conservation Opportunity areas ranked 1	03.8%	40%
Historic Vegetation - Fine Resolution Abiotic Habitats	Floodplain	14.5%	25%
	Steep Slope	16.0%	
	Slope Crest	02.5%	
	Upper Slope	14.3%	
	Flat summit	13.6%	
	Sideslope	13.7%	
	Lower sideslope	09.3%	
	High flat	08.4%	
	Low flat	07.3%	
Course Landforms - Abiotic Landscapes	Flat Plains	01.1%	25%
	Smooth Plains	42.3%	
	Irregular Plains	33.5%	
	Plains w/Low Hills	<0.1%	
	Rugged Plains	<0.1%	
	Breaks	08.4%	
Biological Richness	Reptiles	<0.1%	25%
	Mammals	0.2 %	
	Birds	<0.1%	
	Amphibians	3.6%	

Table 4, cont'd.

Ozark Highland Ecoregion

Target Category	Target Name	% Area	Target Goal
Historic Vegetation - Abiotic Site Types	Tallgrass prairie	11.9%	40%
	Woodland/savanna	29.6%	
	Forest	21.8%	
	Mesic forest	15.2%	
	Bottomland forest	08.7%	
	Glade or woodland	12.1%	
Current Landscapes	Conservation Opportunity areas ranked 1	01.8%	40%
Historic Vegetation - Fine Resolution Abiotic Site Types	Floodplain	07.3%	25%
	Steep slope	09.2%	
	Upper slope	12.8%	
	Gentle slope	17.1%	
	Upland flat	33.4%	
	Lower slope	11.2%	
	Lowland flat	06.9%	
Course Landforms - Abiotic Landscapes	Flat Plains	02.4%	25%
	Smooth Plains	15.0%	
	Irregular Plains	33.2%	
	Plains w/Low Hills	00.2%	
	Plains with Hills	<0.1%	
	Rugged Plains	<0.1%	
	Breaks	34.8%	
	Low Hills	09.1%	
	Hills	03.4%	
	Low Mountains	<0.1%	
Biological Richness	Reptiles	02.1%	25%
	Mammals	04.7 %	
	Birds	32.7%	
	Amphibians	04.5%	

Targets that made up less than 10% of an ecoregion were excluded from analysis, except for conservation opportunity areas and biological species richness. Data on species richness was from Gap Analysis results. Since modeled species richness results varied from state to state, we identified high richness pixels relative to each state and then merged coverages.

We calculated both site and summed irreplaceability values for all assessment units within the two assessment regions, the Chariton River Hills and Ozark Highlands. We then used the natural breaks algorithm in ArcView to group assessment units into five classes (Jenks 1967) (Figure 15). In the Chariton River Hills, 1.2 % of the region is within the highest ranked class (score >= 0.245), and 8.1 % is within the second highest class (score >= 0.187). A total of 68.7 % of the region is within the two lowest ranked classes (score <= 0.158). In the Ozark Highlands, 21.6 % of the region is within the highest ranked class (score >= 0.302), and 54.7 % is within the second highest class (score >= 0.248). A total of 20.6 % of the region is within the two lowest ranked classes (score <= 0.183).

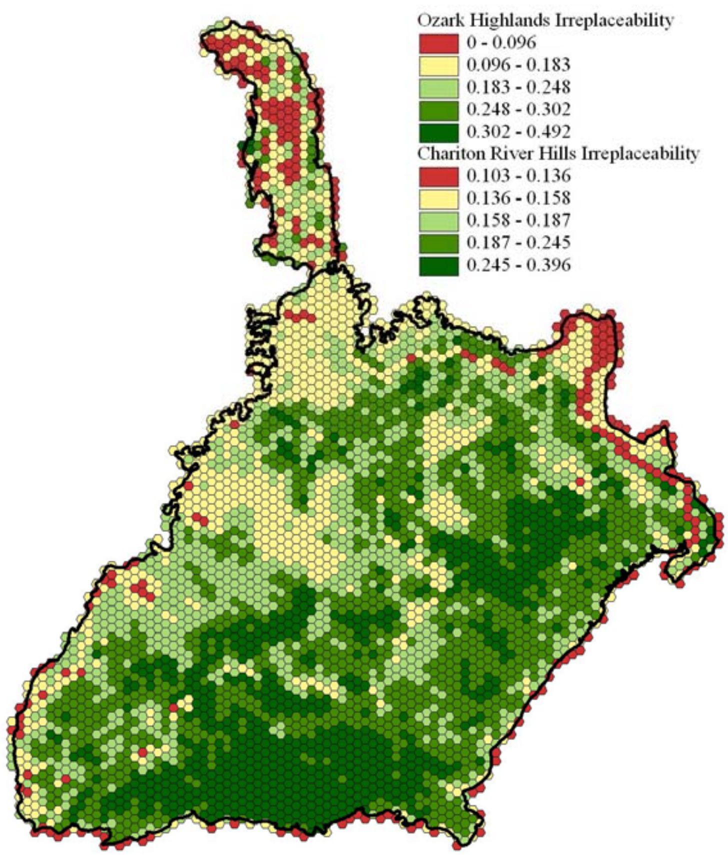

Figure 15. Map of irreplaceability within Chariton River Hills and Ozark Highlands.

IV. Defining Critical Terrestrial Ecosystems

Critical terrestrial ecosystems were defined by overlaying results from the ecological risk assessment and the irreplaceability assessment. Both ecological risk and summed irreplaceability values were placed into five classes using Jenk's natural breaks algorithm, and scores formed the basis for identification of critical ecoregions. The following algorithm was applied.

	30m Pixel-based Ecological Risk Ranked Class	**Assessment Unit Irreplaceability Ranked Class**
Case 1	5 (highest ranked)	any
Case 2	>= 4	>= 3
Case 3	>= 3	5 (highest ranked)

In other words, areas of very high ecological risk represent critical ecosystems wherever they occur, areas of high to very high ecological risk within medium, high, or very high ranked irreplaceability assessment units are critical ecosystems, and areas of medium, high, or very high risk within very highly ranked irreplaceability assessment units are critical ecosystems (Figure 16). Following is a summary of the extent and type of critical ecoregions for our pilot study areas (Table 5).

Table 5. Summary of the area and percent of Chariton River Hills and Ozark Highlands identified as critical ecoregions.

	Extent of Critical Ecoregions (total area for each ecoregion is not the sum of the columns; see text for explanation)			
	Chartion River Hills		**Ozark Highlands**	
Critical Ecoregion Definition	Area (ha)	% of Ecoregion	Area (ha)	% of Ecoregion
Case 1:High Risk and any Rank for Irreplaceability	14,191	1.5%	497,698	3.6%
Case 2: Moderately High and High Risk and Medium, High or Very High Irreplaceability	29,040	3.0%	2,248,002	16.0%
Case 3: Medium, High, or Very High Risk and High Irreplacebality	6,094	0.6%	4,266,005	30.4%

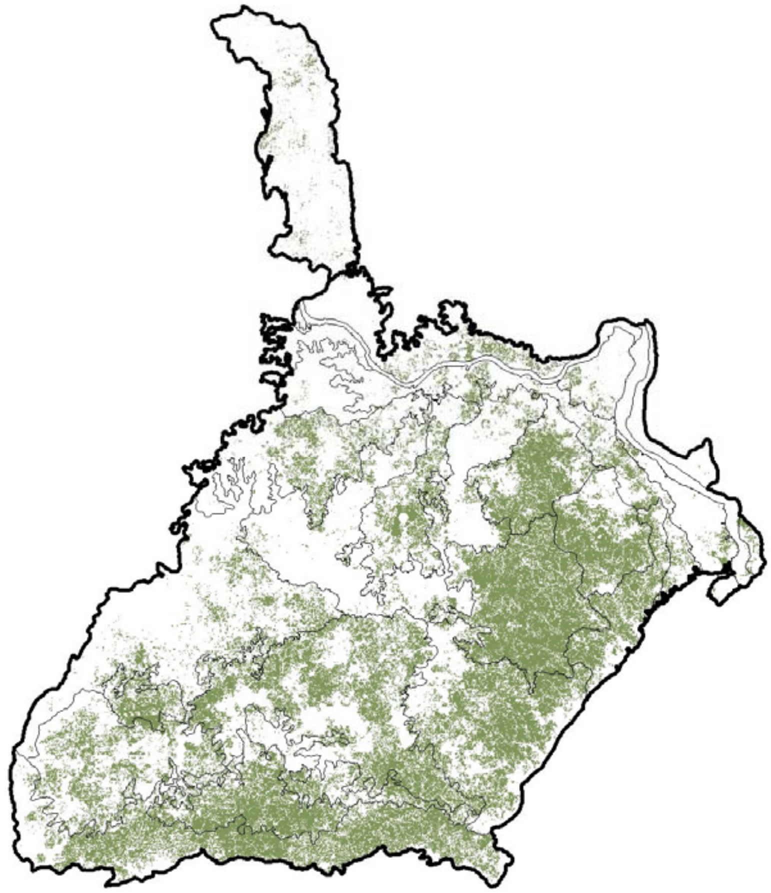

Figure 16. Map of critical ecosystems of Chariton River Hills and Ozark Highlands shown with subsection boundaries.

A total of 4.4% (418,982 hectares) of the Chariton River Hills and 32.9 % (4,614,686 hectares) of the Ozark Highlands were identified as critical ecosystems. Please note that some areas fit the definition for critical ecoregions under more than one of the three scenarios, so the total area given under each scenario cannot be simply added to find the total area of critical ecosystems within an ecoregion. For example, within the Chariton River Hills, a total of 0.77% of the ecoregion was identified as a critical ecosystem under more than one scenario.

V. Aquatic Conservation Opportunity Areas

A. Classification of Watersheds and Stream Valley Segments

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 17). 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.

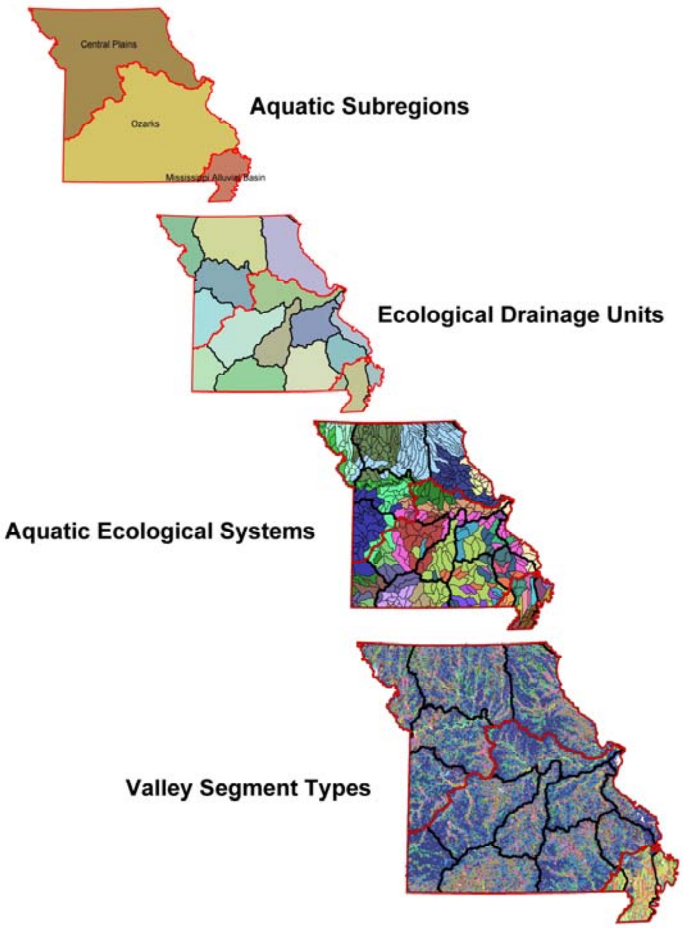

Figure 17. Maps of Missouri showing four of the eight levels of the MoRAP aquatic ecological classification hierarchy. Maps of the upper three levels (Zone, Subzone, and Region) of the hierarchy are provided in Maxwell et al. (1995). Level 8 of the hierarchy is also not shown since the distinct units within this level (e.g., riffles, pools, glides) cannot be mapped within a GIS at a scale of 1:100,000.

<u>Levels 1 – 3: Zone, Subzone, and Region</u>

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).

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 18). 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.

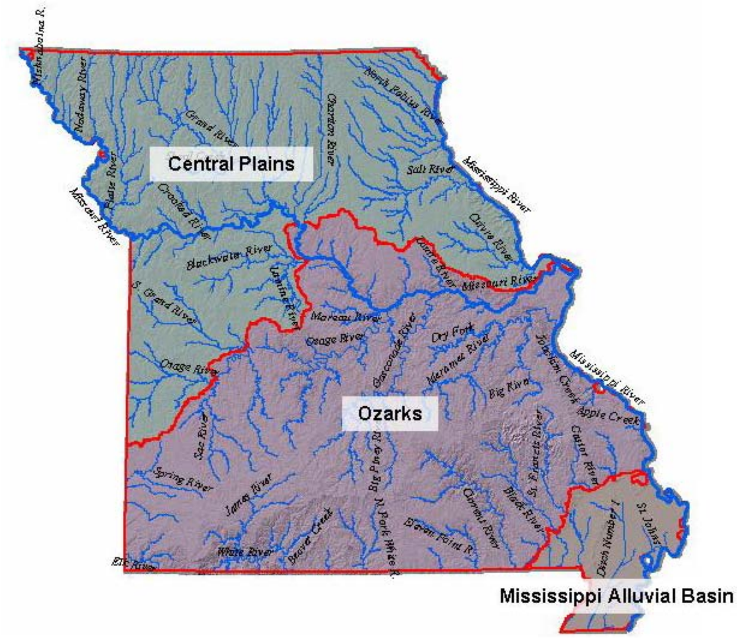

Figure 18. Map showing the Aquatic Subregions in Missouri.

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 19). 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.

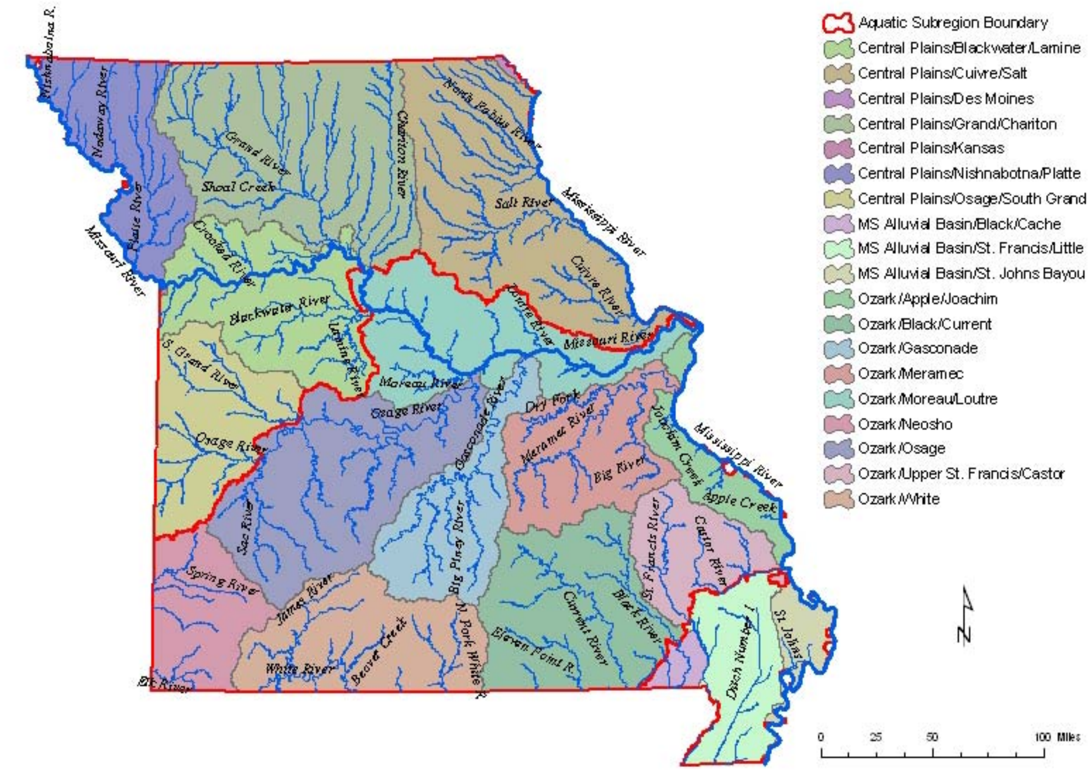

Figure 19. Map of the Ecological Drainage Units (EDUs) in Missouri.

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.

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. 1997; 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 mi² with relatively distinct (local and overall watershed) combinations of geology, soils, landform, and groundwater influence (Figure 20). 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.

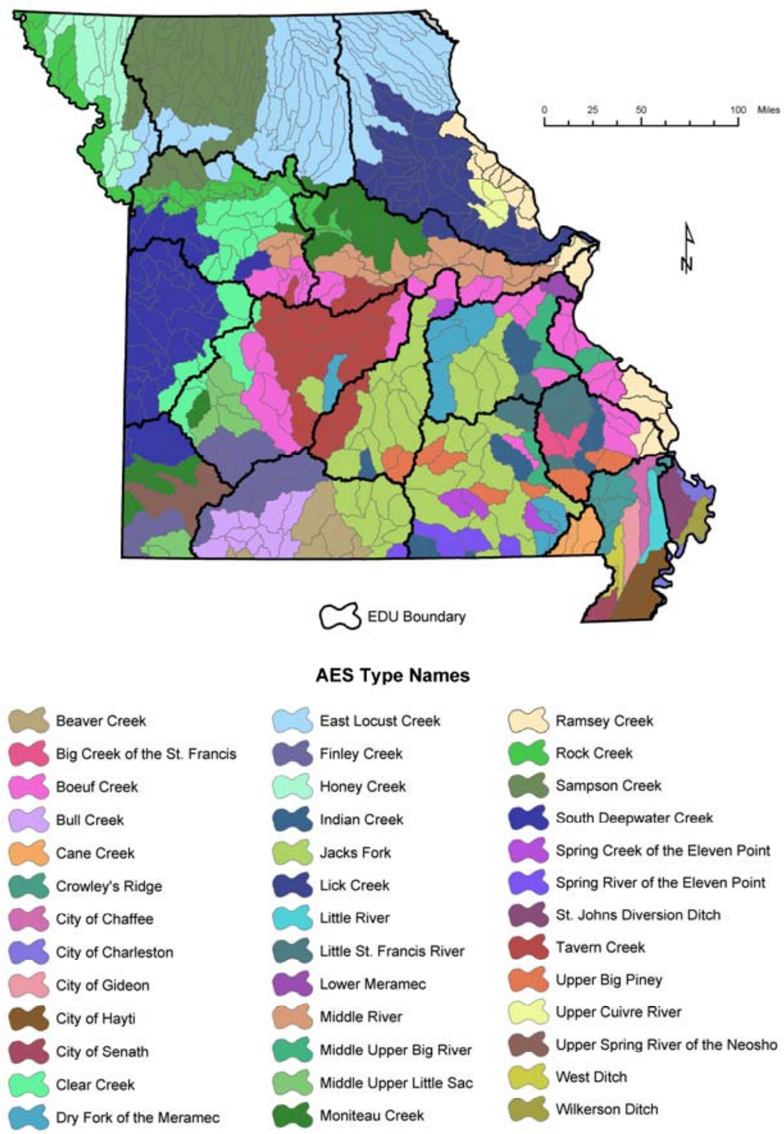

Figure 20. Map of the Aquatic Ecological Systems (AESs) and Types (AES-Types) for Missouri.

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).

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 21). 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.

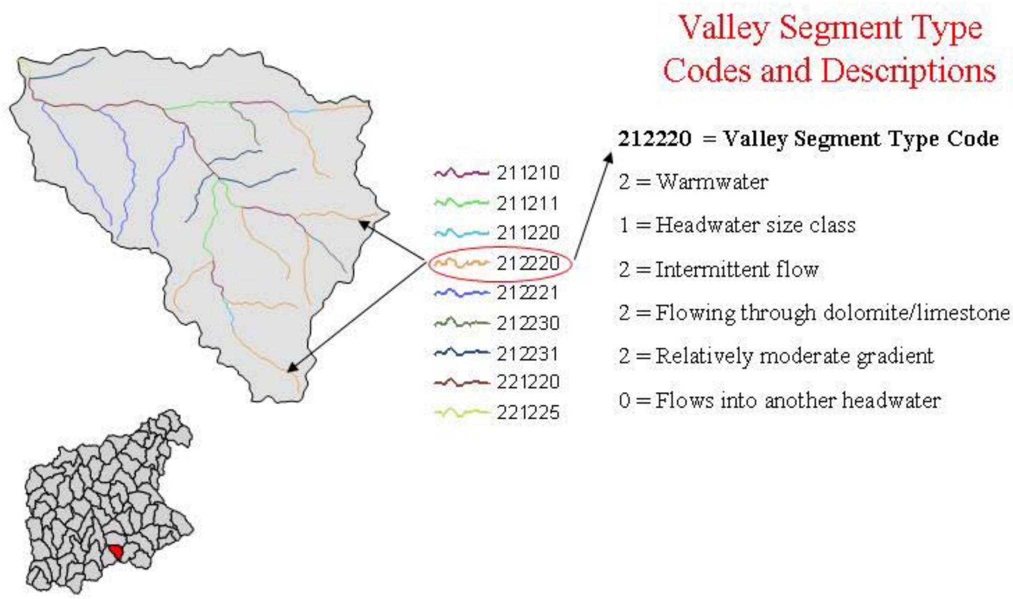

Figure 21. Map showing examples of several different Valley Segment Types (VSTs) within a small watershed of the Meramec EDU.

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).

B. Indicators for Ranking the Relative Health of Aquatic Ecological Systems

There are a multitude of stressors that negatively affect the ecological integrity of riverine ecosystems (Allan and Flecker 1993; Richter et al. 1997; U.S. EPA 2000). The first step in any effort to account for anthropogenic stressors is developing a list of candidate causes. Aquatic resource professionals generated a list of the principal human activities known to affect the ecological integrity of streams in Missouri. Then the best available (i.e., highest resolution and most recent) geospatial data that could be found for each of these stressors was assembled (Table 6). Fortunately, and somewhat surprisingly, data were available for most stressors. However, for some, such as channelized stream segments, there were no available geospatial data, and efforts to develop a coverage of such segments using a sinuosity index proved ineffective. Most of the geospatial data were acquired from the U.S. EPA and the Missouri Departments of Conservation and Natural Resources.

Table 6. List of the GIS coverages, and their sources, that are used to assess the current conservation status and threats during the conservation planning process for the Missouri CWCS.

Data layer	Source
303d Listed Streams	Missouri Department of Natural Resources (MoDNR)
Cafos	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
Landcover	1992 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 (other/all)	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

We initially generated statistics for nearly 50 individual human stressors (e.g., percent urban, lead mine density, degree of fragmentation) for each Aquatic Ecological System in Missouri (see above description). We then used correlation analyses to reduce this overall set of metrics into a final set of 11, relatively uncorrelated, measures of human disturbance (Table 7). Relativized rankings (range 1 to 4) were then developed for each of these 11 metrics (see Table 7). 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. These rankings were based on information contained within the literature or simply quartiles when no empirical evidence on thresholds was available. For instance, rankings for percent urban were; 1: 0-5%, 2: 6-10%, 3: 11-20%, and 4: >20%, were based on the results of various studies that have examined the effects of urban land cover on the ecological integrity of stream 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). However, existing research for percent agriculture has not identified clear thresholds, suggesting that there is a more or less continual decline in ecological integrity with each added percentage of agriculture in the watershed. For this measure of human stress we simply used quartiles, 1: 0-25%, 2: 26-50%, 3: 51-75%, and 4: >75%.

Table 7. 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 are 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 (#/mi²)	0-0.24	0.25-0.49	0.5-0.9	$\geq$1
Population Change 1990-2000 (#/mi²)	-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 (#/mi²)	0	1-5	6-20	>20
Density of Lead Mines (#/mi²)	0	1-5	6-20	>20
Density of Permitted Discharges (#/mi²)	0	1-5	6-20	>20
Density of Confined Animal Feeding Operations (#/mi²)	0	1-5	5-10	>10

Note: A major impoundment was defined as those that occur on streams classified as small river or larger. The 3-digit qualitative codes used to categorize the degree of hydrologic modification and/or fragmentation can be interpreted as follows.

1: No hydrologic alteration or fragmentation

2: Externally fragmented: obligate aquatic biota could reach adjacent watersheds, but not the MO or MS Rivers without passing through a major impoundment

3: Hydrologically modified: included all innundated subwatersheds and any area downstream of the dam known to have a significantly modified hydrologic regime

4: Both externally fragmented and hydrologically modified: includes those stream segments situated in the interceding area between two major impoundments on the same stream

5: Isolated: obligate aquatic biota could not reach any adjacent watershed without passing through a major impoundment

6: Both Isolated and Hydrologically modified

The relativized rankings for each of these 11 metrics were then combined into a three number Human Stressor Index (HSI). The first number reflects the highest ranking across all 11 metrics (range 1 to 4) (Figures 22 and 23). The last two numbers reflect the sum of the 11 metrics (range 11 to 44) (Figure 24). This index allows you to evaluate both individual and cumulative impacts. 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 the ecosystem. Figure 25 provides a map of the resulting HSI scores for each AES in Missouri.

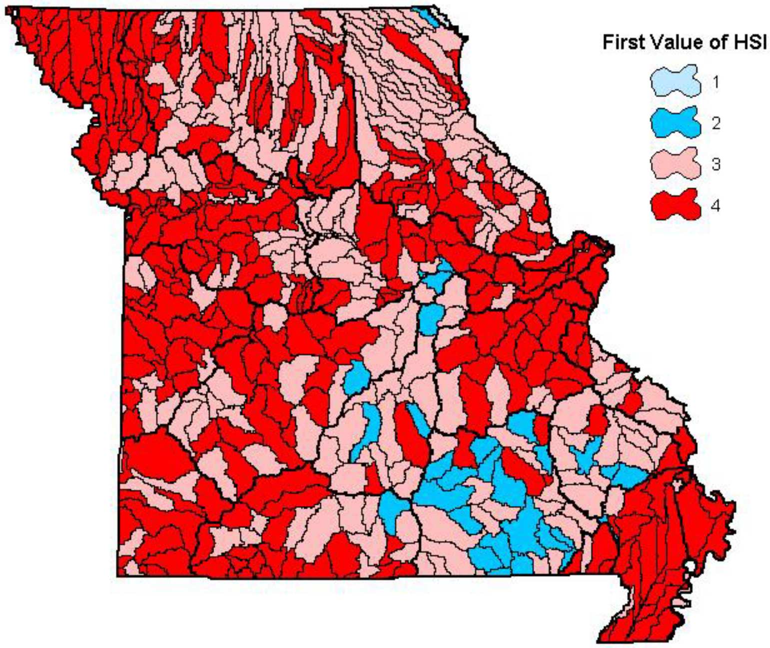

Figure 22. Map showing the first value in the Human Stressor Index (HSI) for each of the Aquatic Ecological Systems in Missouri. A value of 1 indicates a relatively low level of human disturbance, while a value of 4 indicates a relatively high level of disturbance. None of the AESs polygons received a value of 1.

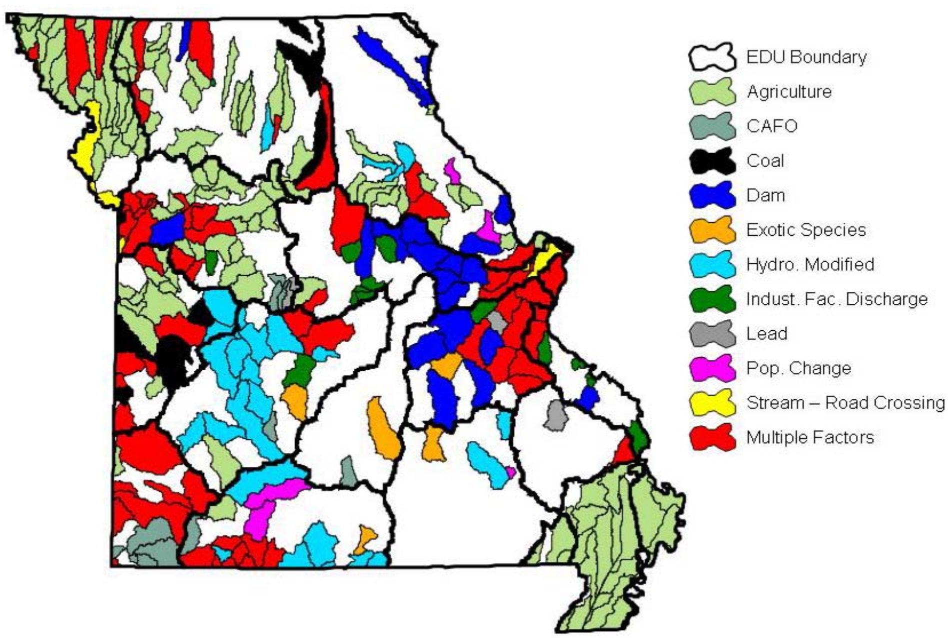

Figure 23. Map showing which Aquatic Ecological Systems received a value of 4 for the first value in the Human Stressor Index, further broken down according to which specific human stressor was responsible for this high value.

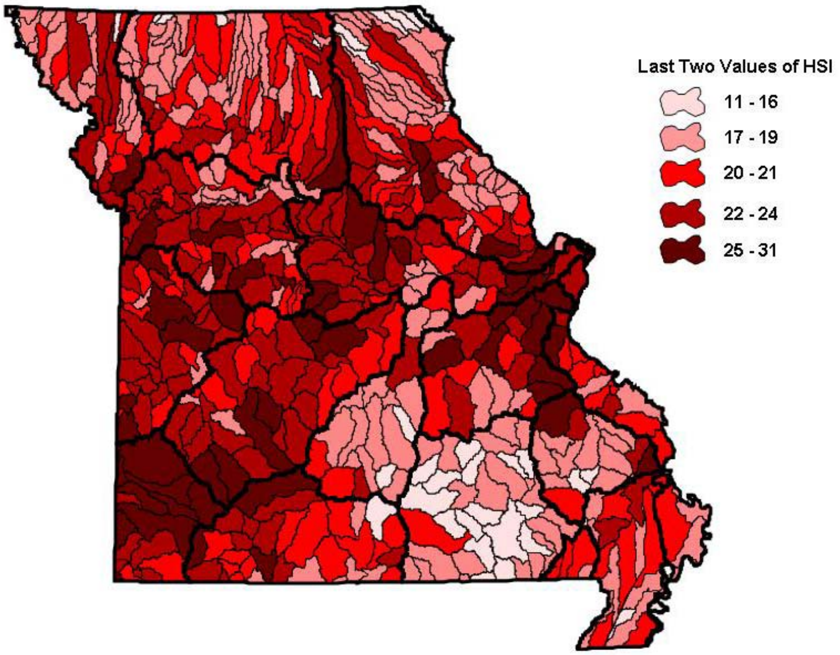

Figure 24. Map showing the last two values in the Human Stressor Index for each of the Aquatic Ecological Systems in Missouri. A value of 11 indicates an extremely low level of cumulative impact.

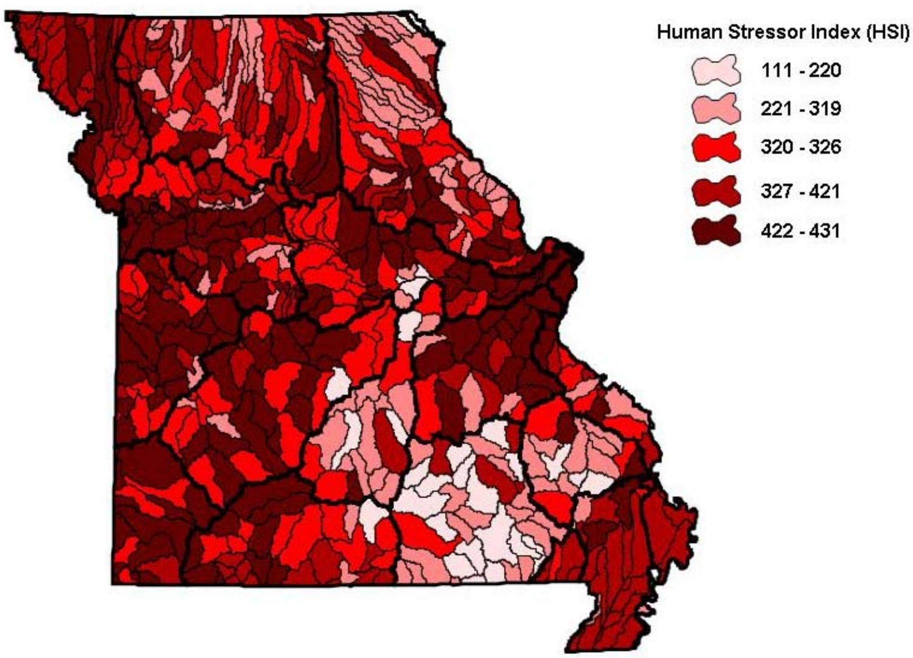

Figure 25. Map showing the composite Human Stressor Index (HSI) values for each Aquatic Ecological System in Missouri. The first number represents the highest value received across all 11 metrics included in the HSI, while the last two digits represent the sum of the scores received for each of the 11 metrics.

C. First-cut Critical Riverine Ecosystems for the Meremac EDU

MoRAP developed customized GIS projects to assist in the development of a statewide plan for conserving aquatic biodiversity. These customized GIS projects include all of the data compiled or created for the Missouri Aquatic GAP Project, as well as other pertinent geospatial data developed for this project. After the customized GIS projects were developed, a team of aquatic resource professionals from around Missouri was assembled. The objective of this team was to address each of the basic components of conservation planning and devise a strategy for identifying critical freshwater ecosystems.

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 that must be considered in order to achieve this goal. These mainly related to basic principles of stream ecology, landscape ecology, and conservation biology (Appendix C). 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.

The MoRAP aquatic ecological classification hierarchy was adopted as the geographic framework (i.e., Planning Regions and Asssessment Units) for developing the conservation plan. From this classification hierarchy they selected AES-Types and VSTs as abiotic conservation targets. They also agreed that, in order to fully address biotic targets, a list of target species (fish, mussel, and crayfish) should be developed for each EDU. These lists were developed and they represent species of conservation concern (i.e, global ranks: G1-G3 and state ranks: S1-S3), endemic species, and focal or characteristic species (e.g., top predators, dominant prey species, unique ecological role, etc.).

Next the team crafted a general conservation strategy. 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 Appendix D.

General Conservation Strategy

- must develop separate conservation plans for each EDU (Primary Planning Regions);
- whenever possible, represent two distinct spatial occurrences/populations of each target species;
- represent at least 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.

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.

<u>AES level criteria (listed in order of importance)</u>

- Highest predicted richness of target species
- Lowest Human Stressor Index value (also qualitatively examine individual stressors)
- Highest percentage of public ownership
- Overlaps 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.

<u>VST level (listed in order of importance)</u>

- If possible, select a complex that contains known viable populations of species of special concern.
- If possible, select the highest quality VST complex by qualitatively evaluating the relative local and watershed condition using the full breadth of available human stressor data.
- If possible, select a VST complex that is already within the existing matrix of public lands.
- If possible, select a VST complex 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:

1) Use the AES selection criteria to identify one priority AES for each AES-Type within the EDU;
2) Within each priority AES, use the VST selection criteria, to identify a priority complex of the dominant VSTs;
3) For each complex of VSTs create a map of the localized subdrainage (i.e., Conservation Opportunity Areas) that specifically contains the entire interconnected complex;
4) Evaluate the capture of target species; and

5) If necessary, select additional conservation opportunity areas to capture underrepresented target species.

The team then used the conservation strategy and assessment process to develop a conservation plan for the Meramec EDU. By using the above process all of the objectives of the conservation strategy were met with 11 conservation opportunity areas (Table 8, Figure 26). With the initial assessment process and selection criteria, which focus on abiotic targets (AESs and VSTs), 10 separate conservation opportunity 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 conservation opportunity 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 conservation opportunity area (the Dry Fork/Upper Meramec, see Figure 26).

Table 8. Target species list for the Ozark/Meramec EDU showing global and state conservation ranks (from Missouri Natural Heritage Program), endemism level (corresponds to the MoRAP classification hierarchy), and the number of conservation opportunity areas in which each species is predicted to occur.

TAXON	COMMON	SCIENTIFIC	GRANK	SRANK	ENDEMISM	COA Count
Fish	Alabama shad	Alosa alabamae	G3	S2	Region	3
Fish	banded darter	Etheostoma zonale	G5	S?	Region	8
Fish	banded sculpin	Cottus carolinae	G5	S?	Region	9
Fish	bigeye chub	Notropis amblops	G5	S?	Region	11
Fish	bigeye shiner	Notropis boops	G5	S?	Region	11
Fish	bigmouth shiner	Notropis dorsalis	G5	S?	Region	3
Fish	black redhorse	Moxostoma duquesnei	G5	S?	Region	11
Fish	blacknose shiner	Notropis heterolepis	G4	S2	Subzone	1
Fish	blackspotted topminnow	Fundulus olivaceus	G5	S?	Region	11
Fish	blackstripe topminnow	Fundulus notatus	G5	S?	Region	8
Fish	bleeding shiner	Luxilus zonatus	G5	S?	Subregion	11
Fish	blue sucker	Cycleptus elongatus	G3G4	S3	Region	1
Fish	bluegill	Lepomis macrochirus	G5	S?	Subzone	11
Fish	bluntnose minnow	Pimephales notatus	G5	S?	Subzone	11
Fish	brook silverside	Labidesthes sicculus	G5	S?	Subzone	10
Fish	chestnut lamprey	Ichthyomyzon castaneus	G4	S?	Region	8
Fish	creek chubsucker	Erimyzon oblongus	G5	S?	Subzone	5
Fish	crystal darter	Crystallaria asprella	G3	S1	Region	4
Fish	fantail darter	Etheostoma flabellare	G5	S?	Subzone	11
Fish	flathead chub	Platygobio gracilis	G5	S1	Subzone	1
Fish	flier	Centrarchus macropterus	G5	S3	Subzone	3
Fish	ghost shiner	Notropis buchanani	G5	S2	Region	1
Fish	gilt darter	Percina evides	G4	S?	Region	7
Fish	golden redhorse	Moxostoma erythrurum	G5	S?	Subzone	10
Fish	grass pickerel	Esox americanus	G5	S?	Subzone	10
Fish	gravel chub	Erimystax x-punctatus	G4	S?	Region	8

Fish	green sunfish	Lepomis cyanellus	G5	S?	Region	11
Fish	greenside darter	Etheostoma blennioides	G5	S?	Region	11
Fish	highfin carpsucker	Carpiodes velifer	G4G5	S2	Region	4
Fish	hornyhead chub	Nocomis biguttatus	G5	S?	Region	11
Fish	lake chubsucker	Erimyzon sucetta	G5	S2	Subzone	1
Fish	largemouth bass	Micropterus salmoides	G5	S?	Subzone	11
Fish	largescale stoneroller	Campostoma oligolepis	G5	S?	Region	11
Fish	least brook lamprey	Lampetra aepyptera	G5	S4	Region	6
Fish	logperch	Percina caprodes	G5	S?	Subzone	10
Fish	longear sunfish	Lepomis megalotis	G5	S?	Subzone	11
Fish	Mississippi silvery minnow	Hybognathus nuchalis	G5	S3S4	Region	3
Fish	Missouri saddled darter	Etheostoma tetrazonum	G5	S?	Subregion	11
Fish	mooneye	Hiodon tergisus	G5	S3	Subzone	5
Fish	mottled sculpin	Cottus bairdi	G5	S4	Subzone	11
Fish	northern brook lamprey	Ichthyomyzon fossor	G4	S4	Subzone	2
Fish	northern hog sucker	Hypentelium nigricans	G5	S?	Subzone	11
Fish	northern studfish	Fundulus catenatus	G5	S?	Region	11
Fish	orangespotted sunfish	Lepomis humilis	G5	S?	Region	9
Fish	orangethroat darter	Etheostoma spectabile	G5	S?	Region	11
Fish	Ozark minnow	Notropis nubilus	G5	S?	Subregion	10
Fish	paddlefish	Polyodon spathula	G4	S3	Region	4
Fish	plains minnow	Hybognathus placitus	G4	S2	Region	1
Fish	plains topminnow	Fundulus sciadicus	G4	S3	Region	1
Fish	rainbow darter	Etheostoma caeruleum	G5	S?	Subzone	11
Fish	redear sunfish	Lepomis microlophus	G5	S?	Subzone	6
Fish	river darter	Percina shumardi	G5	S3	Region	1
Fish	river redhorse	Moxostoma carinatum	G4	S?	Region	8
Fish	rock bass	Ambloplites rupestris	G5	S?	Subzone	11
Fish	rosyface shiner	Notropis rubellus	G5	S?	Subzone	11
Fish	sand shiner	Notropis stramineus	G5	S?	Subzone	9
Fish	silver chub	Macrhybopsis storeriana	G5	S3	Region	1
Fish	silver redhorse	Moxostoma anisurum	G5	S?	Subzone	9
Fish	silverjaw minnow	Notropis buccatus	G5	S4	Region	6
Fish	slender madtom	Noturus exilis	G5	S?	Region	10
Fish	smallmouth bass	Micropterus dolomieu	G5	S?	Subzone	11
Fish	southern cavefish	Typhlichthys subterraneus	G4	S2S3	Subzone	1
Fish	southern redbelly dace	Phoxinus erythrogaster	G5	S?	Region	11
Fish	spotfin shiner	Cyprinella spiloptera	G5	S?	Subzone	11
Fish	spotted gar	Lepisosteus oculatus	G5	S5	Region	1
Fish	steelcolor shiner	Cyprinella whipplei	G5	S?	Region	11
Fish	stippled darter	Etheostoma punctulatum	G4	S?	Subregion	1
Fish	stonecat	Noturus flavus	G5	S?	Subzone	7
Fish	striped shiner	Luxilus chrysocephalus	G5	S?	Region	11
Fish	suckermouth minnow	Phenacobius mirabilis	G5	S?	Region	7
Fish	wedgespot shiner	Notropis greenei	G5	S?	Subregion	11
Fish	western sand darter	Ammocrypta clara	G3	S2S3	Region	3
Fish	western silvery minnow	Hybognathus argyritis	G4	S2	Region	1
Fish	yellow bullhead	Ameiurus natalis	G5	S?	Subzone	11

Mussel	black sandshell	Ligumia recta	G5	S1S2	Subzone	7
Mussel	butterfly	Ellipsaria lineolata	G4	S?	Region	4
Mussel	creeper	Strophitus undulatus	G5	S?	Subzone	11
Mussel	cylindrical papershell	Anodontoides ferussacianus	G5	S1?	Subzone	1
Mussel	ebonyshell	Fusconaia ebena	G4G5	S1?	Region	2
Mussel	elephantear	Elliptio crassidens	G5	S1	Region	4
Mussel	elktoe	Alasmidonta marginata	G4	S2?	Subzone	11
Mussel	ellipse	Venustaconcha ellipsiformis	G3G4	S?	Subzone	11
Mussel	fawnsfoot	Truncilla donaciformis	G5	S?	Region	7
Mussel	flutedshell	Lasmigona costata	G5	S?	Subzone	11
Mussel	monkeyface	Quadrula metanevra	G4	S?	Region	7
Mussel	northern brokenray	Lampsilis reeveiana brittsi	G3T2	S?	Subregion	11
Mussel	Ouachita kidneyshell	Ptychobranchus occidentalis	G3G4	S2S3	Subregion	5
Mussel	pink mucket	Lampsilis abrupta	G2	S2	Region	3
Mussel	purple wartyback	Cyclonaias tuberculata	G5	S?	Region	5
Mussel	rock pocketbook	Arcidens confragosus	G4	S3	Region	3
Mussel	round pigtoe	Pleurobema sintoxia	G4	S?	Region	8
Mussel	salamander mussel	Simpsonaias ambigua	G3	S1?	Region	5
Mussel	scaleshell	Leptodea leptodon	G1	S1S2	Region	4
Mussel	sheepnose	Plethobasus cyphyus	G3	S1	Region	7
Mussel	slippershell mussel	Alasmidonta viridis	G4G5	S?	Subzone	11
Mussel	snuffbox	Epioblasma triquetra	G3	S1	Region	7
Mussel	spectaclecase	Cumberlandia monodonta	G2G3	S3	Region	4
Mussel	threehorn wartyback	Obliquaria reflexa	G5	S?	Region	4
Crayfish	belted crayfish	Orconectes harrisonii	G3	S3	EDU	6
Crayfish	freckled crayfish	Cambarus maculatus	G4	S3	EDU	10
Crayfish	golden crayfish	Orconectes luteus	G5	S?	Subregion	11
Crayfish	saddlebacked crayfish	Orconectes medius	G4	S3?	EDU	10
Crayfish	Salem cave crayfish	Cambarus hubrichti	G2	S3	Subregion	1
Crayfish	spothanded crayfish	Orconectes punctimanus	G4G5	S?	Subregion	11
Crayfish	woodland crayfish	Orconectes hylas	G4	S3?	EDU	4

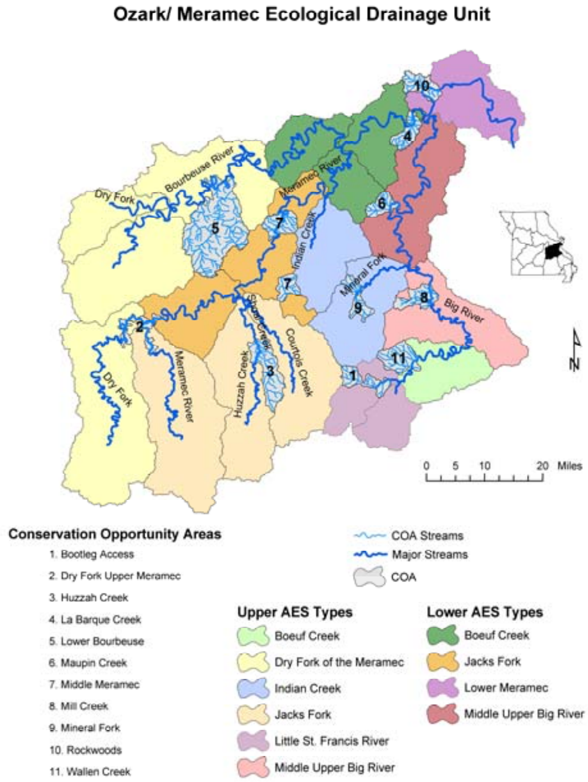

Figure 26. Map showing the 11 Conservation Opportunity Areas (COA) selected for the Meramec EDU as part of the aquatic component of the Missouri Comprehensive Wildlife Conservation Strategy. The stream segments within Focus Area number 2 (Dry Fork Upper Meramec) were selected in order to capture those target species not captured in the 10 Focus Areas selected using the initial assessment and selection criteria, which focus on abiotic targets.

The final set of priority valley segments, within the 11 conservation opportunity areas, constitutes 186 miles of stream. This represents 2.8% of the total stream miles within the Meramec EDU. The conservation opportunity areas themselves represent an overall area of 213 mi², which is 5% of the nearly 4,000 mi² 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 areas. In some instances the most important initial conservation action will have to occur outside of a given conservation opportunity area, yet the intent of those actions will be to conserve the integrity of the particular focus area. Specific attention to, and more intensive conservation efforts within, these 11 areas provides 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 this EDU.

In addition to selecting conservation opportunity areas, the team provided information that can assist with the remaining logistical tasks. This information is captured within a database that can be spatially related to the resulting GIS coverage of the areas. Specifically, each conservation opportunity area is given a name that generally corresponds to the name of the largest tributary stream; then each of the following items are 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 stressor,
- all of the management concerns within each focus area 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.

- The selection of conservation opportunity areas has been completed for all 17 EDUs in Missouri. In all, a total of 158 areas were identified through the above assessment process (Figure 27).

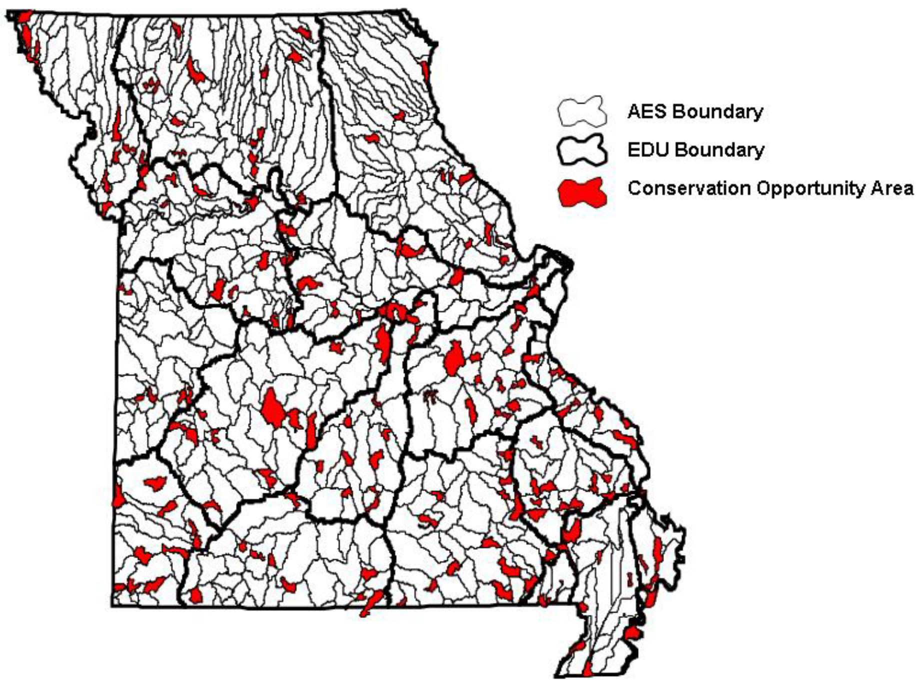

Figure 27. Map showing the 158 Conservation Opportunity Areas developed for Missouri.

VI. Results and Discussion

The largest patches of critical ecosystems in the Chariton River Hills are in the relatively rough, forested eastern and northeastern portions of the ecoregion or in the southwest. Areas in the southwest mainly represent forested bottomlands whereas areas in the east are forested hills and breaks. In the Ozark Highlands the heavily forested southern and eastern portions of the ecoregion were identified as critical ecosystems. These regions have large patches of land cover unchanged from historic conditions and scored high for summed irreplaceability.

This pilot represents a novel approach in several ways. First, we recognized that aquatic ecosystem assessments must be separated from terrestrial assessments, because the biota of riverine ecosystems are influenced by connectivity downstream and drainage divides. Biophysically similar streams within a few kilometers of each other may support different biotas because of the inability of fauna to migrate across stream divides. Thus, ecological drainage units in our classification hierarchy represent biologically disjunct islands in terms of their riverine biota. Second, we created an ecological risk surface using fine-resolution data and sophisticated modeling procedures, and combined those results with traditional C-Plan irreplaceability assessment to identify critical terrestrial ecosystems.

We will move forward using the basic methods outlined here to identify critical terrestrial ecosystems for EPA Region 7, and critical aquatic ecosystems for Missouri. We still need to create data on riverine ecosystems for other states in the regions. We also need to re-visit the targets we used for C-Plan and fine-tune our ecological risk methods. Finally, the algorithm developed to overlay the risk surface with C-Plan results to identify critical ecosystems will need to be re-visited based primarily on modifications to the targets and quantitative goals for C-Plan.

Terrestrial

The overall results represent a proof of concept for identification of critical ecosystems using available digital data. Noss (2004) outlined how all assessments are constrained by available data, and this pilot was no exception. Noss (2004) also suggested that surrogate targets for conservation should be drawn from three general areas, including special elements (including species richness hotspots and rare species locations), representation of environmental variations (including abiotic habitats), and conservation of focal species (including species of high ecological importance). Groves (2003) emphasized the need for both fine-and coarse-filter surrogate conservation targets, including species and communities or landscapes. We agree with Noss (2004) that the choice of targets "is more challenging than it may seem." For this pilot, we selected targets for C-Plan that represent abiotic habitats and areas of high species diversity. We did not have data on keystone, focal, or indicator species.

We do not consider rare species to be appropriate conservation targets in the context of coarse-resolution conservation design for several reasons. First, simple riverine species occurrence records are driven both by local, stream segment conditions as well as watershed conditions, and species are distributed upstream and downstream from known collection sites in an unknown way. The distribution of many riverine species is also constrained by hard boundaries across contiguous watershed divides that can be integrated into plans for their conservation (e.g. some species cannot migrate across watershed boundaries). Therefore conservation targets for riverine biota should be developed from separate analyses. Second, few population locations are known. Therefore these locations would have driven perceived priorities if combined with data layers with more continuous coverage across the study area. Third, the data on rare species are not especially do not represent an inventory and are not especially reliable, considering that (1) the absence of a record does not indicate absence of a rare species, since some areas have been searched for more carefully than others, and (2) the definition of species rarity rankings is based on well-known methodologies, but ultimate decisions of what species to list and more importantly to search for and to track involve many human biases. Finally, the rarity of a given taxa changes over time, and given predictions from global climate change models, these changes are likely to be quite significant over the next few decades (Penuelas and Filella 2001, Root and others 2003). In light of these concerns, we suggest that rare species should be considered separate from, not together with, other targets in conservation planning, if they are considered at all.

Aquatic

The methods developed and used in this project for identifying critical freshwater ecosystems go well beyond anything done to date in any part of the world. This multiscale assessment incorporated both ecological and evolutionary contexts that are so critical to conserving biodiversity, which heretofore have been largely ignored (Scott et al. 1991). Also, the high resolution biological and stewardship data (i.e., individual stream segment) coupled with the tremendous amount of geospatial data on human stressors enabled us to precisely pinpoint specific areas (clusters of stream segments) that are critical to the long term maintenance of biodiversity within Missouri.

Unfortunately, by necessity, our approach to identifying critical freshwater ecosystems is more subjective than the systematic conservation assessment carried out for the terrestrial ecosystems (i.e., we could not use C-Plan or other systematic conservation software). At this time we know of no systematic conservation planning software program that can handle data in a vector format or deal with the issue of connectivity within the complex structure of a stream network. Hopefully, research will eventually lead to conservation software explicitly designed to handle such issues. Nonetheless, we believe the 158 aquatic conservation opportunity areas identified for Missouri represent the best remaining opportunities to conserve relatively high-quality examples of all major stream ecosystem types and freshwater species that exist within the state. These areas provide a blueprint for holistic conservation freshwater ecosystems, as opposed to the patchwork approach used in the past. These areas can be used to guide protection efforts such as land acquisitions, restoration efforts since many of these areas are degraded to some degree, 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. Futhermore, an important aspect of generating such a "comprehensive" plan to conserve biodiversity is that conservation is often driven by opportunity, and by identifying a broad portfolio of priority locations quick action can be taken when opportunities arise (Noss et al. 2002).

Since work cannot be immediately initiated within all of the freshwater conservation opportunity areas, relative priorities must be established across all of these areas in order to develop a schedule of conservation action (Margules and Pressey 2000). This task represents the next phase of the project. Specifically, we anticipate ranking these conservation opportunity areas within each EDU and then again from a statewide perspective.

Some of the most important things learned from this portion of the project include the following:

- Local experts are frequently 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 4,000+ mi^2.
- The GIS data are often insufficient and, if solely relied upon, would often lead to poor decisions. There have been several instances where the GIS data point us to a particular location, while the local experts quickly point out that, for example, the sewage treatment facility just upstream has 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.
- This illustrates the difficulty of accounting for human stressors, particularly cumulative impacts within freshwater ecosystems. The Human Stressor Index we developed is an admittedly crude measure of human disturbance, however, we believe it is well suited for coarse-filter assessments since it does act as a "red flag" for serious degradation.
- Even in the most highly altered and severely degraded landscapes there almost always exist "hidden jewels" that have somehow escaped the massive landscape transformations and other insults in neighboring watersheds. This experience has revealed the social aspects of land use patterns described by Meyer (1995).
- Ninety-five to 100% of the biotic targets are captured by initially only focusing on abiotic targets (AES-Types and VSTs). This is especially surprising in the Ozark Aquatic Subregion, which contains numerous local endemics with very restricted and patchy distributions. This suggests that these classification units do a good job of capturing the range of variation in stream characteristics that are partly responsible for the patchy distribution of these species.
- All of the abiotic and biotic targets can be captured within a relatively small fraction of the overall resource base. Unfortunately, the area of interest for managing these focus areas is often substantially larger and much more daunting. However, managers must remain conscious of the fact that the streams and assemblages within each priority location are the ultimate focus of conservation action. Even when work is being conducted outside of a conservation opportunity

area, it should be directed at maintaining or restoring conditions within a particular area.

If 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 has found the process much more useful than previous planning efforts that have identified relatively large areas as priorities for conservation. The managers have stated that, because we are selecting 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.

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APPENDIX A

HISTORIC VEGETATION BY HABITAT KEY BY ECOREGION

OZARK HIGHLANDS SECTION

Landscape Type	Geolandform/Abiotic Site Type	Climate	Solar Insolation	Historic Vegetation
flat plains, smooth plains,	**dolomite/limestone/shale**			
irregular plains	upland flat, upper slope	wet	neutral	woodland or savanna
			wet	mesic forest
			dry	glade or woodland
		dry	neutral	tallgrass prairie
			wet	mesic forest
			dry	tallgrass prairie
	lower slope, lowland flat	wet	neutral	forest
			wet	mesic forest
			dry	glade or woodland
		dry	neutral	woodland or savanna
			wet	mesic forest
			dry	glade or woodland
	gentle slope, steep slope	wet	neutral	forest
			wet	mesic forest
			dry	glade or woodland
		dry	neutral	woodland or savanna
			wet	mesic forest
			dry	glade or woodland
	igneous			
	upland flat, upper slope	all	neutral	glade or woodland
			wet	mesic forest
			dry	glade or woodland
	lower slope, lowland flat	all	neutral	forest
			wet	mesic foreset
			dry	glade or woodland
	gentle slope, steep slope	all	neutral	forest
			wet	mesic forest
			dry	glade or woodland
	sandstone			
	upland flat, upper slope	wet	neutral	woodland or savanna
			wet	mesic forest
			dry	tallgrass prairie
		dry	neutral	tallgrass prairie
			wet	mesic forest

			dry	tallgrass prairie
	lower slope, lowland flat	wet	neutral	forest
			wet	mesic forest
			dry	glade or woodland
		dry	neutral	woodland or savanna
			wet	mesic forest
			dry	glade or woodland
	gentle slope, steep slope	wet	neutral	forest
			wet	mesic forest
			dry	glade or woodland
		dry	neutral	woodland or savanna
			wet	mesic forest
			dry	glade or woodland
hills, breaks, low mountains	**dolomite/limestone/shale**			
	upland flat, upper slope	wet	neutral	forest
			wet	mesic forest
			dry	glade or woodland
		dry	neutral	woodland or savanna
			wet	mesic forest
			dry	glade or woodland
	lower slope, lowland flat	wet	neutral	mesic forest
			wet	mesic forest
			dry	glade or woodland
		dry	neutral	forest
			wet	mesic forest
			dry	glade or woodland
	gentle slope, steep slope	wet	neutral	forest
			wet	mesic forest
			dry	glade or woodland
		dry	neutral	woodland or savanna
			wet	mesic forest
			dry	glade or woodland
	igneous			
	upland flat, upper slope	all	neutral	glade or woodland
			wet	mesic forest
			dry	glade or woodland
	lower slope, lowland flat	all	neutral	mesic forest
			wet	mesic forest
			dry	glade or woodland
	gentle slope, steep slope	all	neutral	forest
			wet	mesic forest

			dry	glade or woodland
	sandstone			
	upland flat, upper slope	wet	neutral	woodland or savanna
			wet	mesic foreset
			dry	glade or woodland
		dry	neutral	glade or woodland
			wet	mesic foreset
			dry	glade or woodland
	lower slope, lowland flat	wet	neutral	mesic forest
			wet	mesic forest
			dry	glade or woodland
		dry	neutral	forest
			wet	mesic forest
			dry	glade or woodland
	gentle slope, steep slope	wet	neutral	forest
			wet	mesic forest
			dry	glade or woodland
		dry	neutral	woodland or savanna
			wet	mesic forest
			dry	glade or woodland
river floodplains	all types	all		bottomland forest

CENTRAL DISSECTED TILL PLAINS SECTION

flat plains, smooth plains,	high and mid-elevation flats, gentle	all	neutral	tallgrass prairie
irrigular plains	high and mid-elevation slopes		wet	forest
			dry	tallgrass prairie
	gentle lower slopes, low flats	all	neutral	woodland or savanna
			wet	mesic forest
			dry	tallgrass prairie
	steep slopes	all	neutral	forest
			wet	mesic forest
			dry	tallgrass prairie
	riparian zones/floodplains	all		bottomland forest
hills, breaks	high and mid-elevation flats, gentle	all	netural	tallgrass plairie
	high and mid-elevation slopes		wet	mesic forest
			dry	tallgrass prairie
	gentle lower slopes, low flats	all	neutral	mesic forest

			wet	mesic forest
			dry	tallgrass prairie
	steep slopes	all	neutral	forest
			wet	mesic forest
			dry	tallgrass prairie
river floodplains	all	all		bottomland forest

APPENDIX B

List of geologic GIS data layers and sources.

Data	Type	Resolution	Source
Arkansas geology	Arc coverage (polygon)	1:500,000	Arkansas geological survey.
Illinois geology	Arc coverage (polygon)	1:500,000	Illinois natural resources geospatial data clearinghouse. Illinois state geological survey, 1996. Original source paper map 1967, Geologic map of Illinois
Kansas geology	Arc coverage (polygon)	1:500,000	Kansas geological survey. Original source paper map 1964, Geologic Map of Kansas.
Missouri geology	Arc coverage (polygon)	1:500,000	Missouri Department of Natural Resources
Oklahoma geology	Arc coverage (polygon)	1:250,000	U.S. Geological Survey

APPENDIX C

List of the fundamental principles and assumptions developed by the special aquatic task force (with supporting citations) that were used to devise the conservation assessment strategy and select critical freshwater ecosystems throughout Missouri.

1. In order to conserve biodiversity we must conserve ecosystems. Or, in order to conserve or restore the biological assemblage of a particular area of interest we must take measures to conserve or restore the critical structural features, and functional and evolutionary processes that support this assemblage (Franklin 1993; Grumbine 1994; Leslie et al. 1996; DeLeo and Levin 1997).
2. Biodiversity can be described and should be conserved at multiple levels of organization (Whittaker 1962, 1972; Franklin 1993; Noss 1994; Jennings 1996; Leslie et al. 1996).
3. Populations, not species, are the fundamental unit of conservation (Leslie et al. 1996; Meffe and Carroll 1997).
4. Biodiversity conservation efforts should focus on identifying and collectively conserving the variety of distinct genotypes, populations, species, communities, assemblages, and ecosystem types across the landscape (Angermeier and Schlosser 1995; Grossman et al. 1998; Olson and Dinerstein 1998; Abell et al. 2000).
5. Proactive protective measures are less costly and more likely to succeed than restoration actions (Scott et al. 1993).
6. Protected areas are critical to the long-term conservation of biodiversity (Rodrigues et al. 2003).
7. We cannot directly measure, map, or conserve biodiversity, but we can measure, map, and conserve surrogate biotic and abiotic conservation targets (Margules and Pressey 2000; Roux et al. 2002; Noss 2004).
8. Taking measures to conserve a variety of biotic and abiotic targets is the best and most efficient approach to conservation (Belbin 1993; Kirpatrick and Brown 1994; Noss et al. 2002; Diamond et al. *in press*).
9. The structural features and functional processes of a particular location, and how they change through time, provide the habitat template upon which ecological strategies of species develop and evolve through time (Southwood 1977).
10. Connectivity among habitats is often essential for meeting the various life history requirements of certain species, as well as, providing essential dispersal avenues during periods of disturbance (Schlosser 1987; Schlosser 1995; Matthews 1998; Fausch et al. 2002; Benda et al. 2004).
11. Redundancy in representation of populations or ecosystem types is a safeguard against extinction and also promotes the generation of biodiversity through processes like adaptive radiation, random genetic mutations, and genetic drift (Noss and Cooperrider 1994; Meffe and Carroll 1997; Shaffer and Stein 2000; Groves 2003).
12. Priorities should be established and conservation actions taken at multiple spatial scales because different species perceive or utilize the landscape (riverscape) differently and because the critical structural features and functional processes

change with the scale of interest (Frissell et al. 1986, Wiens 1989; Angermeier and Schlosser 1995).

13. Public ownership does not equate to effective biodiversity conservation, especially in riverine ecosystems (Benke 1990; Allan and Flecker 1993).
14. Due to the inherent complexity and dynamic nature of ecosystems, uncertainty is a fundamental component of ecosystem management. This is not an excuse for inaction, but efforts to document and overcome this uncertainty must be a priority (Leslie et al. 1996).
15. Because of competing societal demands and the limited human and financial resources dedicated to biodiversity conservation we must recognize that we cannot conserve everything, in fact, in many instances we can only conserve a relatively small fraction of the resource base (Scott et al. 1993; Rodrigues et al. 2003).
16. We must therefore strive for efficiency in our conservation efforts and one way to accomplish this is to prioritize locations for conservation and try and maximize the complementarities of protected or focus areas (Margules and Pressey 2000).

APPENDIX D

Explanation of what we were attempting to achieve with each component of the general conservation strategy that was used to select critical freshwater ecosystems throughout Missouri

By attempting to conserve every EDU

- Provide a holistic ecosystem approach to biodiversity 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 longterm 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 biodiversity conservation by representing VSTs within a single watershed
- Account for metapopulation dynamics (source/sink dynamics)

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 Focus Area

- Represent multiple distinct spatial occurrences ("populations") for 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 biodiversity conservation by representing an interacting system of Habitat Types.