

**USING GIS AND AN AQUATIC ECOLOGICAL CLASSIFICATION SYSTEM TO  
CLASSIFY AND MAP DISTINCT RIVERINE ECOSYSTEMS  
THROUGHOUT EPA REGION 7**

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## **INTRODUCTION**

Several prominent scientists have stated that linking biomonitoring and biodiversity conservation efforts is critical to conserving our nation's natural resources and without integrating such programs we may not achieve the goals of either (Hughes and Noss 1993; Moyle 1994; Davis and Simon 1995; Karr 1995). Having a common set of conservation units and biomonitoring reporting units would be a first critical step towards such formal integration. A common geographic framework would facilitate information exchange and the more effective use of results generated from biomonitoring programs for on-the-ground biodiversity conservation efforts. Unfortunately, a common obstacle to both efforts is the lack of a widely accepted protocol for classifying our nation's tremendous diversity of aquatic ecosystems into relatively homogeneous units amenable to mapping, monitoring and conservation (Orians 1993; Angermeier and Schlosser 1995).

There are an endless number of ways in which the landscape can be tessellated into relatively homogenous units and the specific approach is largely dictated by the specific purpose or need for the classification. From a biodiversity conservation standpoint, the purpose must be to delineate and map ecological units or ecosystems that account for genetic, species, community, landscape and ecosystem diversity (Noss 1990). This involves trying to account for all natural selection forces operating at multiple spatiotemporal scales. From a biomonitoring standpoint the purpose has largely been to delineate and map ecological units that account for natural variation in the metrics or indices used to assess impairment (Larsen et al. 1986; Hughes et al. 1987; Rohm et al. 1987; Whittier et al. 1988; Jackson and Harvey 1989; Lyons 1989; Hughes et al. 1994; Harding et al. 1997). Accounting for natural variation in biological indices is essential for minimizing false positives and false negatives. And, if the objective of biomonitoring is to identify impairment then existing classifications, like EPA's level 3 or 4 ecoregions, are well suited because they have been shown to consistently account for natural variation in the most common metrics or indices used to assess stream health. However, if the purpose of biomonitoring is to assist with the conservation of biodiversity or biological integrity as outlined in the Clean Water Act, then existing classifications do not serve as suitable strata or reporting units, because they do not account for biogeographical constraints and therefore do not account for genetic, species or in some instances family-level variation in aquatic assemblages across the landscape (Matthews 1998; Angermeier et al. 2000).

We should definitely strive for metrics or indices, like the Index of Biological Integrity (IBI), that are sensitive to a wide array of anthropogenic stressors and broadly applicable across the landscape—metrics that are immune to the gross differences in species composition. This makes the scientists life simpler from a logistical standpoint, but more importantly it simplifies the results so that legislators and the public can readily interpret and understand what they really mean. This broad applicability is why indices like the IBI are so popular.

However, we often fail to recognize the reason why most biological indices are so broadly applicable is that they focus on family-level composition and trophic status. Family-level variation is significantly lower than species-level variation across the landscape and trophic-level variation is often less than family-level variation. Yet, even if we can develop indices that are immune to gross differences in species composition we should still try to identify, monitor, and conserve ecological units that are taxonomically or phylogenetically distinct as separate ecosystems. That is, we can't let biological indices alone determine our conservation or reporting units. We must first identify ecological units suitable for conserving biodiversity and then use these units as the spatial framework for monitoring—regardless of whether the same biological criteria may be suitable for multiple units.

It is now widely recognized that both watersheds and ecoregions account for important variation in aquatic assemblages across the landscape (Pflieger 1971; Lotspeich and Platts 1982; Hawkes et al. 1986; Lyons 1989; Maxwell et al. 1995; Lyons 1996; Maret et al. 1997; Omernik and Bailey 1997; Matthews 1998; Angermeier and Winston 1999; Angermeier et al. 2000; Rabeni and Doisy 2000; Jensen et al. 2001; Wilton 2004). Watershed boundaries, or all isolation mechanisms for that matter, largely account for differences in evolutionary history and thus account for geographic variations in taxonomic (family or species-level) or phylogenetic composition. Ecoregions, on the other hand, largely account for differences in the structural components and functional processes of ecosystems and thus account for geographic variations in the ecological character (e.g., physiological tolerances, foraging and reproductive strategies, or specific life history requirements) of aquatic assemblages. Since it is the ecological character of organisms that determines their susceptibility to anthropogenic disturbances we should not be surprised that efforts to account for natural variation in aquatic assemblages, for the purpose of improving biomonitoring, have largely focused on this single aspect, which just so happens to be largely accounted for by ecoregional classifications. However, all three forms of ecosystem distinctiveness (structure, function, and biological or genetic composition) are important for effective biodiversity conservation, which is why neither ecoregions nor watersheds by themselves are appropriate geographic strata for identifying distinctive aquatic ecosystem units. What is needed is a classification framework that accounts for all three forms of distinctiveness that could then serve as the common geographic framework for both biomonitoring and biodiversity conservation.

So, if watersheds and ecoregions, or more correctly, isolation mechanisms, climate, geology, soils, and landform are all important to defining distinct ecosystems the question becomes, "how do we integrate these factors to define relatively distinct aquatic ecosystem units at multiple spatial scales?" As part of the Missouri Aquatic GAP Pilot Project, MoRAP has developed a broadly applicable hierarchical classification framework incorporating both physical and biological delineation criteria into a methodology for defining and mapping distinct

riverine ecosystems within a GIS. We believe the ecological classification system developed by MoRAP is ideally suited to provide a common geographic framework for biomonitoring and biodiversity conservation throughout the United States (Sowa et al. 2005). In fact, the Missouri Department of Natural Resources (MDNR) and the Missouri Department of Conservation (MDC) are already using our classification system as part of their biomonitoring programs and the MDNR is proposing that our classification system provide the foundation for the development and enforcement of Missouri's biological criteria (Sarver et al. 2002). Furthermore, the MDC is using this classification framework as the foundation for developing a comprehensive strategy for conserving freshwater biodiversity throughout Missouri.

### **General Description of the Classification Hierarchy**

Our classification framework integrates the theory and classification methods of several existing classification frameworks (Warren 1979; Lotspeich and Platts 1982; Frissell et al. 1986; Pflieger 1989; Angermeier and Schlosser 1995; Bailey 1995; Maxwell et al. 1995; Omernik 1995; Seelbach et al. 1997; and Higgins et al. 1999). Eight geographically dependent and hierarchically-nested levels describe riverine ecosystems according to factors that exert primary control over ecological and evolutionary processes operating at, and biophysical patterns observed at, each spatial scale (Table 1). The first six levels of the framework follow an ecologically-based and hierarchically-nested classification that integrates the role that isolation mechanisms, climate, geology, soils, and landform play in shaping local aquatic assemblages. Specifically, Levels 1, 2, 3, and 5 account for compositional differences in local aquatic assemblages resulting from distinct evolutionary histories, while Levels 4 and 6 account for differences in local aquatic assemblages resulting from geographic variation in ecosystem structure and function. In Level 7 of the hierarchy distinct Valley Segment Types (VSTs) are delineated and mapped, which account for linear variations (e.g., stream size, gradient) in ecosystem structure and function. The final level of the hierarchy, Habitat Units (e.g., high-gradient riffle, lateral scour pool), are simply too small and temporally dynamic to map within a GIS, yet 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; Petersen and Rabeni 2001).

Table 1. Hierarchical framework with defining physical and biological features used for classifying and mapping riverine ecosystems in EPA Region 7. Hierarchy is adapted after the classification hierarchies of Frissell et al. 1986, Pflieger et al. 1989, and primarily Maxwell et al. 1995, Seelbach et al. 1997 and Higgins et al. 1999. *Note: Levels in red account for differences in local stream assemblages resulting from distinct evolutionary histories, while levels in black account for differences resulting from geographic variation in ecosystem structure and function.*

Level	Description	Defining Physical Features	Defining Biological Features
Zones	Six major zoogeographic zones of the world that resulted from distinct evolutionary histories associated with plate tectonics	Continental boundaries Global climate	Family level patterns Endemism
Subzones	Subcontinental zoogeographic strata with relatively unique aquatic assemblages created in large part by plate tectonics, glaciation, and mountain building	Major river networks and basin boundaries Regional climate	Family level patterns Endemism
Regions	Subzone zoogeographic strata created in large part by drainage network patterns that determine dispersal routes and isolation mechanisms that have resulted in different responses to longterm changes in climate	Major river networks and basin boundaries Regional climate	Family and species level patterns Endemism Phylogenetics
Subregions	Region stratification units. Large areas of similar climate and physiography that often correspond to broad scale patterns in dominant vegetation	Regional climate Physiography General physiognomy of vegetation	Family and species level patterns Endemism Distinct foraging, reproductive and habitat-use guilds Differences in physiological tolerances
Ecological Drainage Units	Subregion zoogeographic strata. Aggregates of drainages within a distinct physiographic setting that share a common evolutionary history	Drainage boundaries Physiography	Family and species level patterns Endemism Phylogenetics
Aquatic Ecological System Types	Hydrogeomorphic subunits of Ecological Drainage Units. Hydrologic units with similar physiographic character, basin morphometry and position within the larger drainage (e.g., located in the headwaters versus near the drainage outlet).	Watershed boundaries Position within larger drainage Local and watershed physiography Local climate (in montane regions) Basin morphometry	Species level patterns Distinct foraging, reproductive and habitat-use guilds Differences in physiological tolerances
Valley Segment Types	Hydrogeomorphic subunits of Aquatic Ecological Systems. Aggregates of stream reaches with broad similarities in fluvial processes, sediment transport, riparian vegetation, and thermal regime.	Temperature Stream size Permanence of flow Position within drainage network Valley geomorphology	Species level patterns Distinct foraging, reproductive and habitat-use guilds Differences in physiological tolerances
Habitat Unit Types	Hydrogeomorphic subunits of Valley Segment Types (e.g., riffle, pool, run).	Depth Velocity Substrate Position within the channel Physical forming features	Species level patterns Distinct foraging, reproductive and habitat-use guilds Differences in physiological tolerances

### ***Zones, Subzones, and Regions***

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).

### ***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 (e.g., depth, velocity, substrate) and function (e.g., hydrologic regime, nutrient cycling, energy dynamics) (Figure 1). 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.

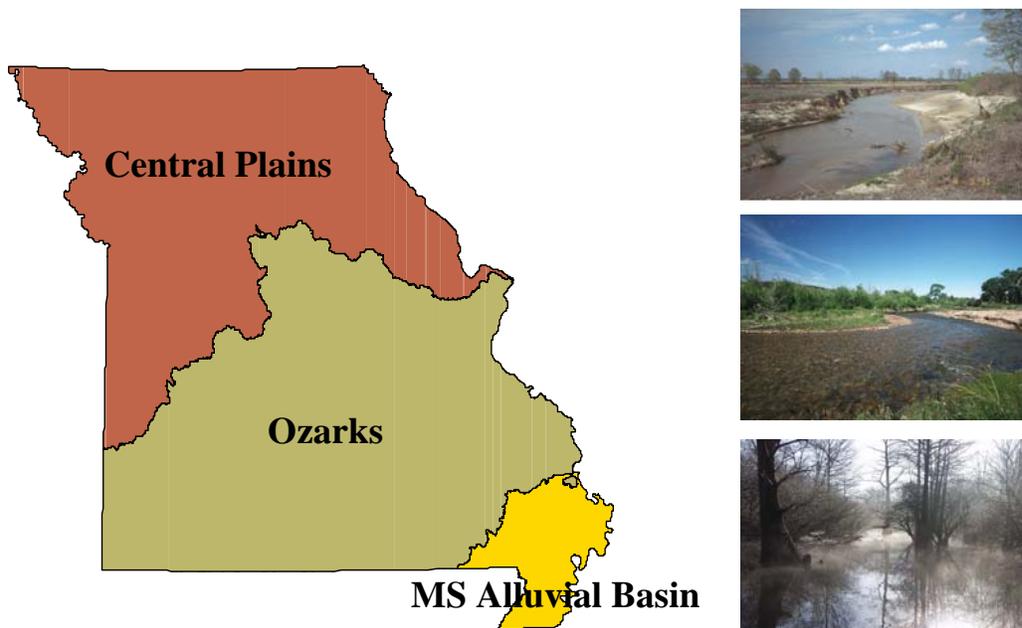


Figure 1. Map showing the three Aquatic Subregions of Missouri. These Subregions account for geographic variation in the structure (e.g., depths, gradients, velocities, substrate) and function (e.g., hydrologic regimes, nutrient cycling, energy sources/dynamics) of riverine ecosystems across the state and generally correspond to widely accepted ecoregional boundaries. Differences in ecosystem structure are quite evident in the images on the right, which show typical habitat conditions for streams in these three different Subregions. The top to bottom order of these images follows the top to bottom order of the Subregions on the map.

### ***Ecological Drainage Units***

Embedded within Aquatic Subregions are geographic variations in local aquatic assemblage composition (species and genetic level) resulting from the geographically distinct evolutionary histories of the major drainages. For instance, The Huzzah Creek and West Fork of the Black River watersheds are two watersheds that are structurally and functionally similar within the Ozark Aquatic Subregion and have similar historic and present-day land uses. However, the aquatic assemblages of these two watersheds are very different. Even though they share a common drainage divide, the outlets of these two watersheds are separated by over a thousand miles of stream, much of this being the Mississippi River and the Mississippi Alluvial Plain Aquatic Subregion, both of which are unsuitable habitat for most of the species that inhabit these two watersheds (Pflieger 1989). Comparing the assemblages of these two watersheds reveals the dramatic influence that millions of years of isolation can have on generating differences in species composition. Collectively, a total of 110 fish, crayfish, mussel, and snail species have been collected in these intensively sampled watersheds. Only 29 of these 110 species have been collected in both watersheds. Level 5 of our hierarchy (Ecological Drainage Units) accounts for these compositional differences (Figure 2).

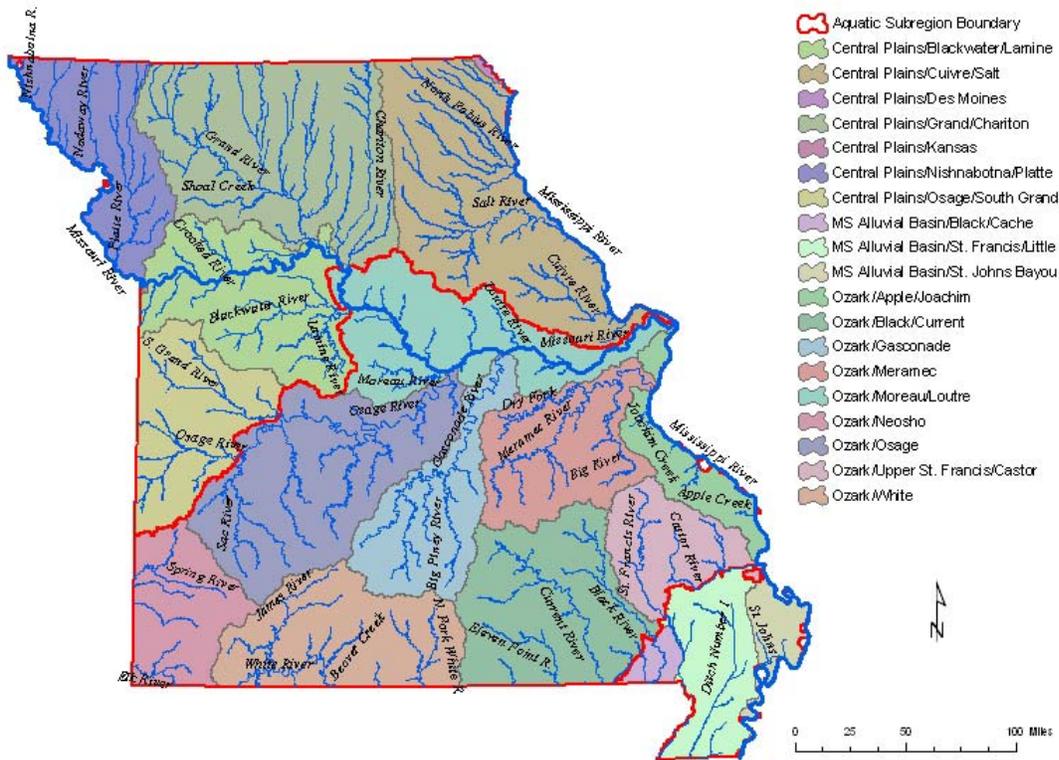


Figure 2. Map of Ecological Drainage Units (EDUs) for Missouri.

EDU's 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 "islands" reside. In fact, our multivariate analyses show that the relative similarity of assemblages among EDU's, within an Aquatic Subregion, is negatively related to the distance separating their respective outlets, just as the similarity of the flora and fauna of islands is negatively related to the distance between any two islands. Consequently, within a given Aquatic Subregion, all of the EDU's have assemblages with relatively similar ecological characteristics (physiological tolerances, reproductive traits, feeding habits), however, the actual species that make up the assemblage in any given EDU is relatively distinct. Such ecological or functional redundancy in assemblage composition across the landscape is quite common for all major taxonomic groups of plants and animals (Noss and Cooperrider 1994).

### ***Aquatic Ecological System Types***

While Aquatic Subregions are relatively distinct in terms of their climatic, geologic, soil, and landform character, they are by no means homogenous and these finer-resolution variations in physiography also influence the ecological composition of local assemblages (Figure 3). Examining species distributions and replacements that occur throughout the Meremec River watershed provides an example of these finer-scale physiographic controls on local aquatic assemblages. The Bourbeuse and Dry Fork River watersheds are covered with a thin mantle of younger Pennsylvanian (PN) sandstones and shales, while the rest of the Meremec watershed is underlain by much older Ordovician limestones and dolomites (Figure 4). Because these PN geologic

strata are poor aquifers there are significantly fewer springs in these watersheds and the water is significantly warmer in summer, streams have significantly lower gradients, water is more turbid and substrates are composed of a higher percentage of fine sediments. These last few differences are due to the fact that PN sandstones and shales are more easily eroded and the erosional breakdown products of these geologic strata are fine textured sands, silts and clays compared to the coarse textured breakdown products, largely chert fragments, that result from the breakdown of the limestone/dolomite found in the remainder of the Meramec watershed (Pflieger 1971). These differences in ecosystem structure and function result in dramatic differences in the aquatic assemblages throughout the Meramec, most notably the absence of ten characteristic Ozarkian fish, mussel and crayfish species from the Bourbuese and Dry Fork drainages. In addition, several species, which are much more characteristic of streams draining the Central Plains Aquatic Subregion of northern Missouri, actually show dramatic increases in abundance within these two Ozark watersheds (Pflieger 1971). The increased abundance of these “Central Plains-species” makes sense when you consider the fact that environmental conditions of the streams within these two watersheds are more typical of the streams draining the Central Plains (Pflieger 1971).

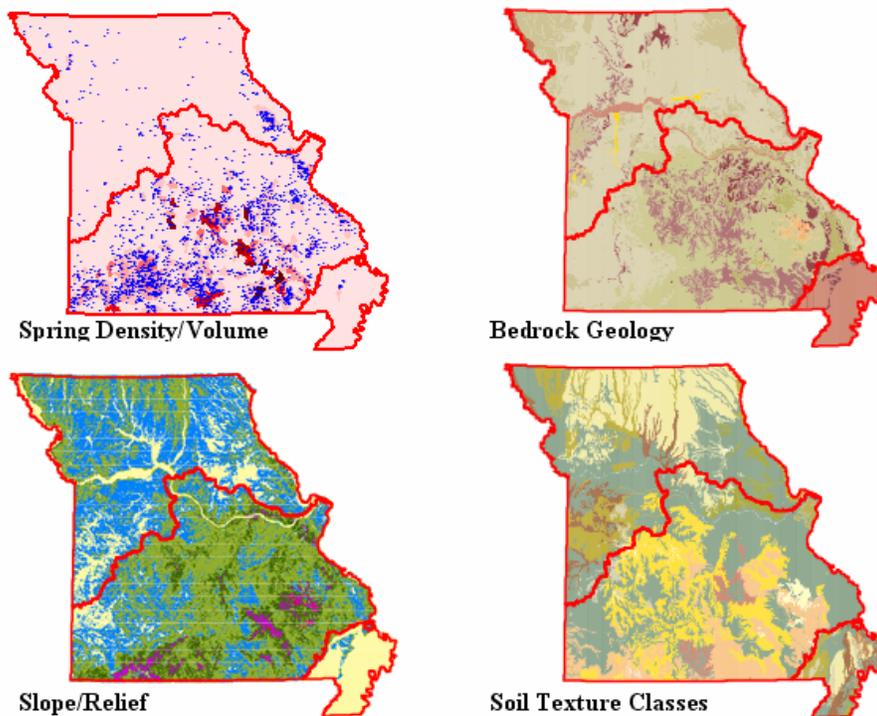


Figure 3. Maps showing the geographic variation in physiographic and groundwater features throughout each of Missouri’s Aquatic Subregions. These finer-scale variations in landscape features result in finer-scale geographic variation in ecosystem structure and function, which ultimately lead to geographic variations in the ecological character of local aquatic assemblages (i.e., physiological tolerances, reproductive and foraging guilds).

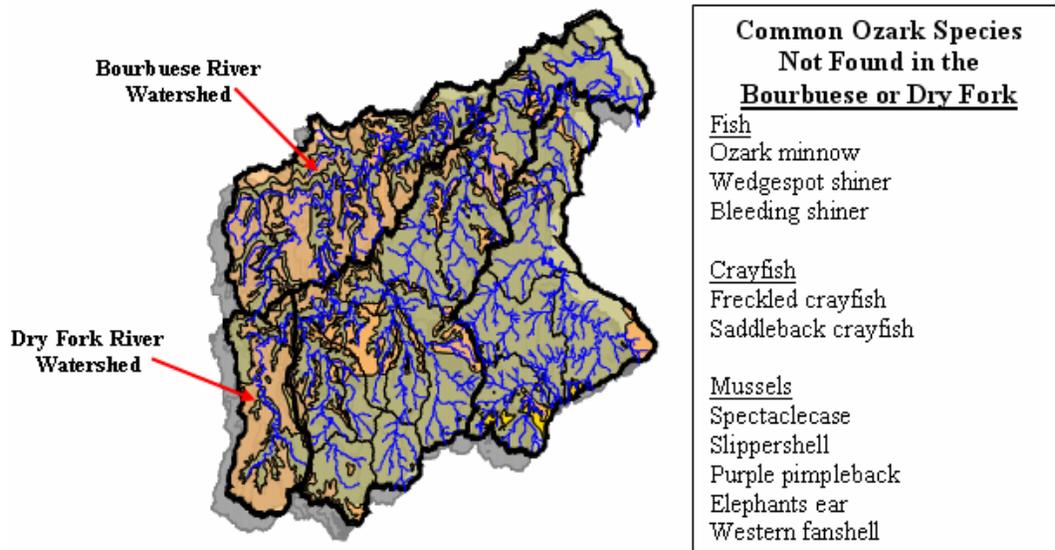
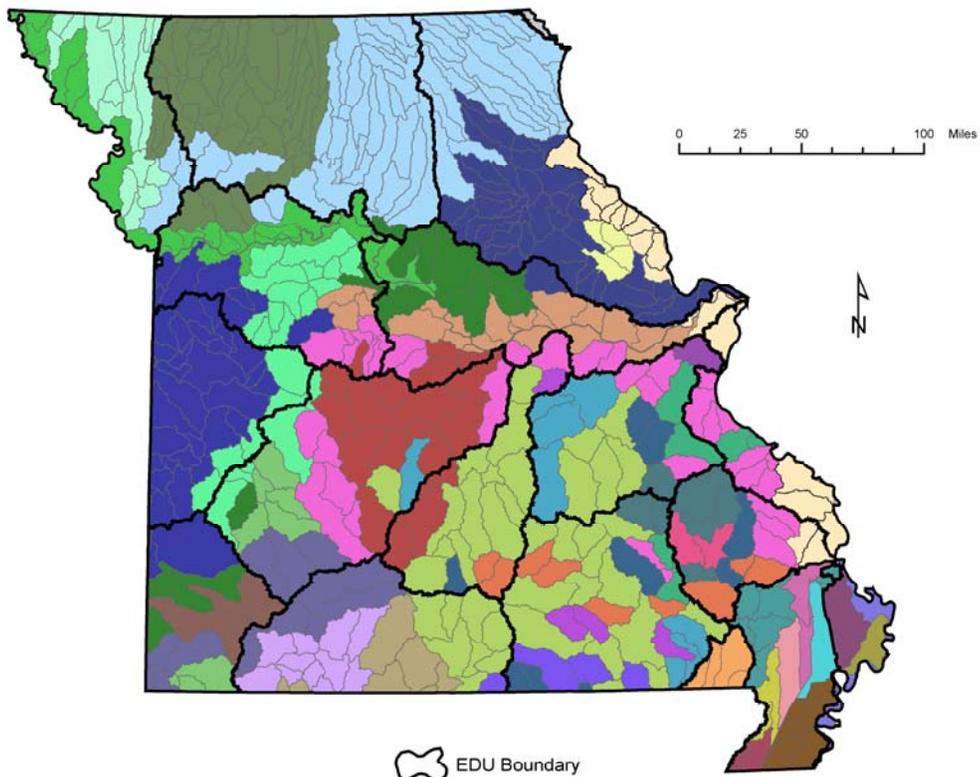


Figure 4. Map of the Meramec River watershed in the Ozark Aquatic Subregion showing geographic variation in bedrock geology. Most of the Meramec watershed is underlain by Ordovician Limestones and Dolomites (tan color), whereas, the Bourbuese and Dry Fork subwatersheds are underlain by Pennsylvanian Sandstone (beige color), which creates differences in ecosystem structure and function. These differences cause the streams within the Bourbuese and Dry Fork watersheds to be quite similar to streams found in the Central Plains Aquatic Subregion. As a result, several common Ozark species are actually absent from these two subwatersheds while species that are generally considered more characteristic of streams in the Central Plains increase in abundance.

To account for this finer-resolution variation in ecosystem structure and function we use data on soil texture, soil depth, infiltration, bedrock geology, relief, and groundwater contributions to identify and map groups of hydrologic units that are relatively similar with regards to these landscape properties that ultimately control instream habitat conditions and functional processes (Figure 5). We call these ecological units Aquatic Ecological System Types (AES-Types). These AES-Types, often generate confusion initially 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 and AES-Types are no different except that they apply specifically to riverine ecosystems. And, just like any habitat classification you can have multiple examples of the same habitat type. For instance, a riffle is an example of a habitat type and 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. This is the same with our AES-Types. Each individual AES is a spatially distinct macrohabitat, however, all individual AES's that are structurally and functionally similar fall under the same AES-Type.



**AES Type Names**

- |                              |                          |                                  |
|------------------------------|--------------------------|----------------------------------|
| Beaver Creek                 | East Locust Creek        | Ramsey Creek                     |
| Big Creek of the St. Francis | Finley Creek             | Rock Creek                       |
| Boeuf Creek                  | Honey Creek              | Sampson Creek                    |
| Bull Creek                   | Indian Creek             | South Deepwater Creek            |
| Cane Creek                   | Jacks Fork               | Spring Creek of the Eleven Point |
| Crowley's Ridge              | Lick Creek               | Spring River of the Eleven Point |
| City of Chaffee              | Little River             | St. Johns Diversion Ditch        |
| City of Charleston           | Little St. Francis River | Tavern Creek                     |
| City of Gideon               | Lower Meramec            | Upper Big Piney                  |
| City of Hayti                | Middle River             | Upper Cuivre River               |
| City of Senath               | Middle Upper Big River   | Upper Spring River of the Neosho |
| Clear Creek                  | Middle Upper Little Sac  | West Ditch                       |
| Dry Fork of the Meramec      | Moniteau Creek           | Wilkerson Ditch                  |

Figure 5. Map of the thirty-nine distinct Aquatic Ecological System Types (AES-Types) for Missouri.

### **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 (Figures 6 & 7). 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.

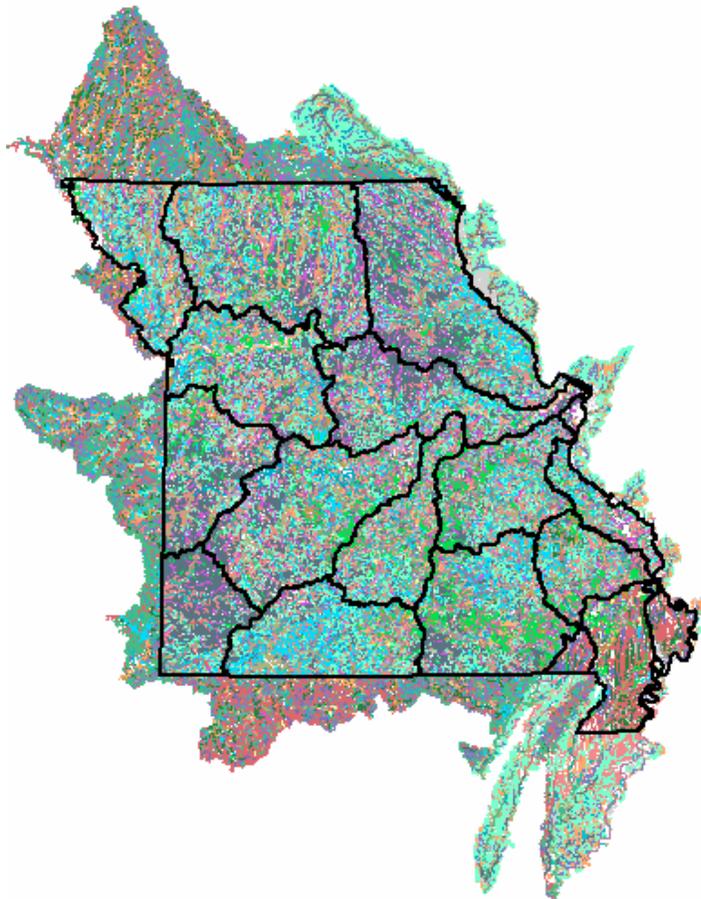


Figure 6. Map showing streams classified in to distinct stream valley segment types for Missouri.

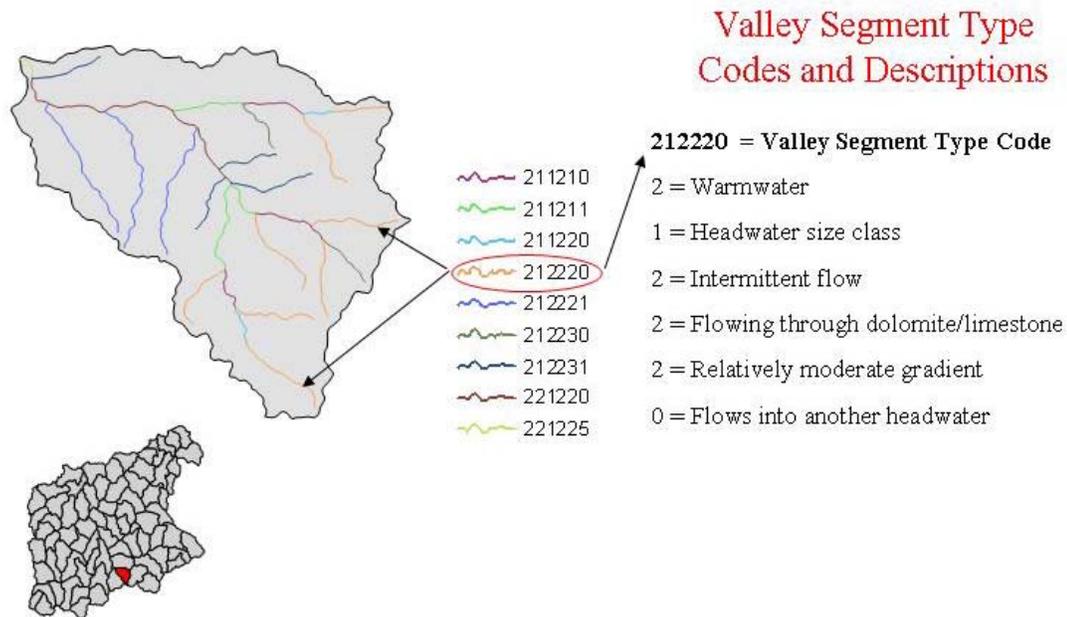


Figure 7. An example of Valley Segment Types (VSTs) for a single 12-digit hydrologic unit. The placement and value of each number in the VST code has meaning and can be deciphered to make informed decisions on the spatial arrangement and relative abundance of stream types across any geographic area of interest.

### ***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 and is often used to stratify sampling, including sampling done for the purpose of biomonitoring (Bisson et al. 1982; Frissell et al. 1986; Peterson 1996; Peterson and Rabeni 2001).

### **PROJECT OBJECTIVE AND DELIVERABLES**

The overall objective of this project was to use the GIS-based methods developed by Sowa et al. (2005) to classify and map levels 4 through 7 of the MoRAP riverine classification hierarchy for Iowa, Kansas, and Nebraska—which would complete the classification of these ecological units for EPA Region 7.

The specific set of deliverables established for this project include:

1. 1:100,000 ArcView coverage of Aquatic Subregions for Region 7
2. 1:100,000 ArcView coverage of EDUs for Region 7
3. 1:100,000 ArcView coverage of AES-Types for Region 7
4. 1:100,000 ArcView coverage of Valley Segment Types for Region 7
5. Metadata for each coverage
6. Written descriptions for each Aquatic Subregion, EDU, and AES-Type
7. Written report of classification methods for each level of the hierarchy

In addition, MoRAP agreed to provide training to personnel from EPA Region 7 and from monitoring programs in Nebraska on how to use the resulting geospatial datalayers and the associated attribute tables to assist with research, management, and biomonitoring efforts. This training will be take place once the final report and other deliverables are approved by EPA.

## **METHODS and RESULTS**

### ***Classifying and Mapping Aquatic Subregions***

#### *Methods*

Our objective for this level of the classification hierarchy was to identify groups of major drainages that drain regions with similar physiographic character and contain riverine assemblages that are relatively similar in terms of their functional composition (e.g. life history strategies and physiological tolerances). To accomplish this objective we followed the methods of Pflieger (1971; 1989). These methods involve conducting a distributional limit analysis to identify correspondence between the range limits of fish species and major physiographic discontinuities across the landscape. Ideally, these analyses should be based on multiple taxonomic groups, however, our analyses were based solely on fishes because this is the only taxonomic group for which sufficient collection records have been compiled and georeferenced at a resolution suited to detailed mapping of contemporary range limits.

To conduct the distributional limit analysis we first compiled 15,807 existing community fish sampling records from state resource agencies and academic institutions in Kansas, Iowa and Nebraska (Figure 8). These collection records contain 121,702 species occurrence records for 189 fish species. We spatially linked these collection records to individual stream segments within the 1:100,000 National Hydrography Dataset (NHD) using a unique identifier given to each stream segment. We then extracted the sampled stream segments to create an ArcView shapefile containing only sampled segments. We then used this shapefile to create separate shapefiles containing the collection records for each of the 189 fish species.

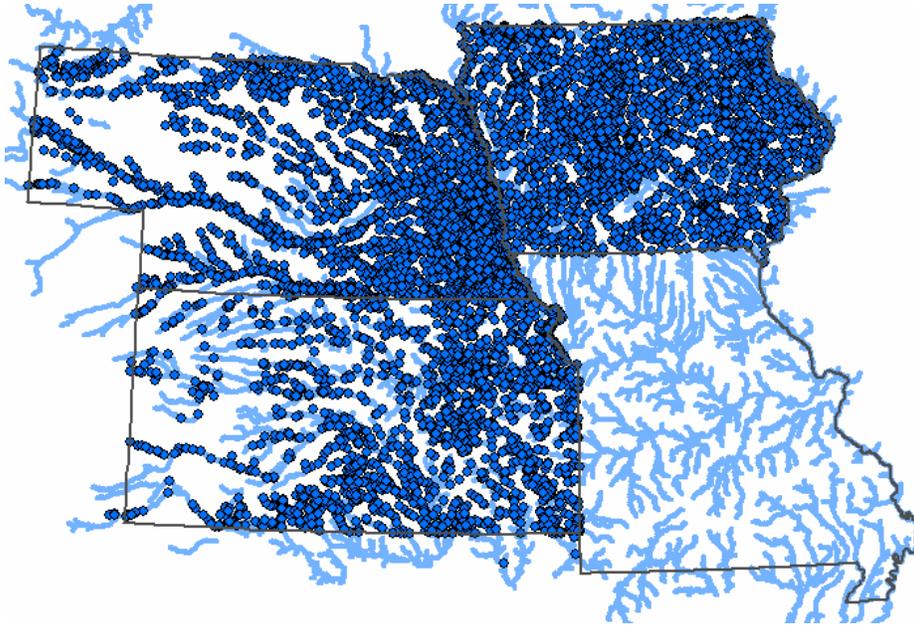


Figure 8. Map showing the 15,807 fish community collection records obtained from the states of Iowa, Kansas, and Nebraska for the range-limit analyses.

Next we created a 1500 km<sup>2</sup> hexagon grid for EPA Region 7 (Figure 9). This grid size was selected because preliminary efforts found that 8-digit HUs were too big for generating precise range limits and 10-digit HUs were too small for identifying areas of overlapping range limits. The 1500 km<sup>2</sup> hexagons represented an intermediate size between these two, and based upon the final results appear to be an appropriate size for the objective at hand. In the attribute table for the hexagon grid we added fields for each of the native fish species that occur in Iowa, Kansas, and Nebraska. Using ArcMap we overlaid the distribution shapefile of each species on the hexagon grid (Figure 10). We then selected all hexagons that marked the geographic range limit of each species (Figure 10). During this process we ignored areas where a species was known to be introduced. We also consulted other sources of information during this process, including the Fishes of Missouri (Pflieger 1997), Fishes of Arkansas (Robison and Buchanan 1988) and the NatureServe Explorer website (<http://www.natureserve.org/explorer/>).

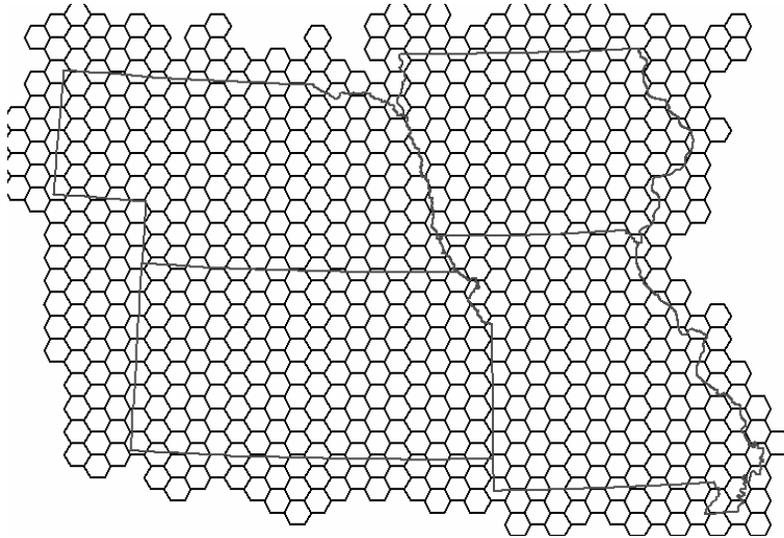


Figure 9. Map showing the 1500 km<sup>2</sup> hexagon grid that was made for defining the range limits of native fish species across EPA Region 7.

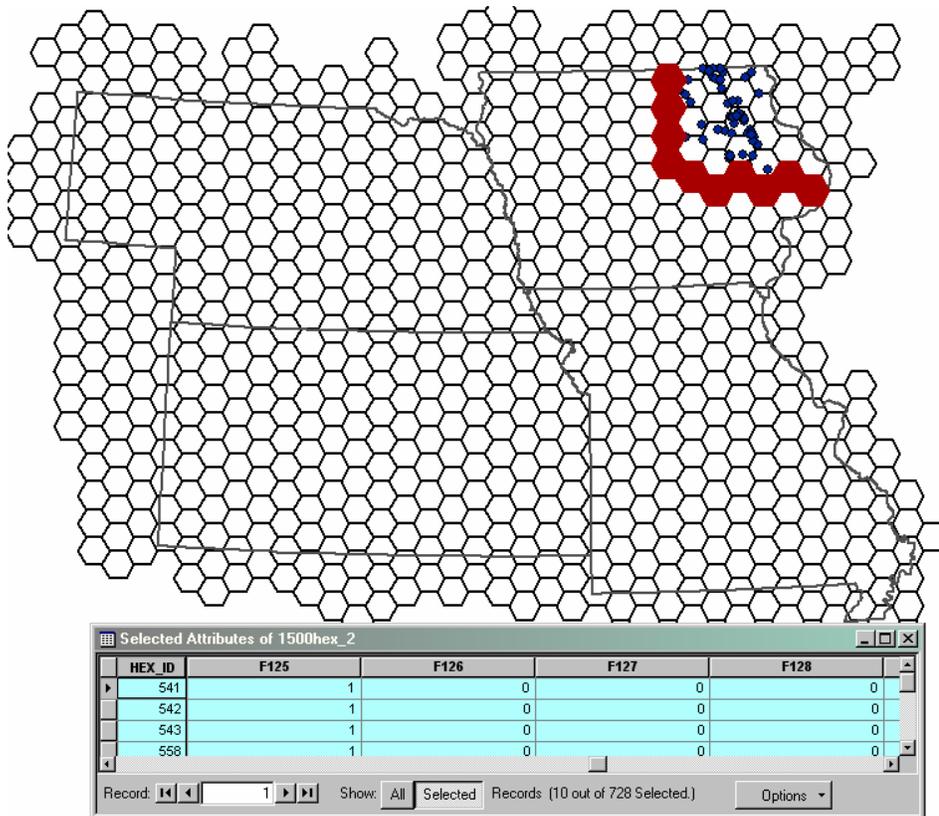


Figure 10. Example of how the hexagons were used to define the range limit of native fish species. In this example, the blue dots represent collections containing the rainbow darter, with the hexagons in red selected to represent the range limit. In the attribute table at the bottom, the column labeled “F125” represents this species and those highlighted hexagons were attributed with a value of 1 to designate that these hexes contain the range limit of the rainbow darter.

Once selected, all of the hexagons representing the range limit of a given species were given a value of one in the column representing that species. After completing this for all species, we then summed the values for each hexagon so each hexagon had a value equal to the number of species that have a range limit falling within that hexagon. Using the hexagon grid, we created a graduated color map for the region that showed the number of range limits within each hexagon (Figure 11). There is essentially a continuum of numbers from 0 to 33 that represent the number of range limits falling within any given hexagon.

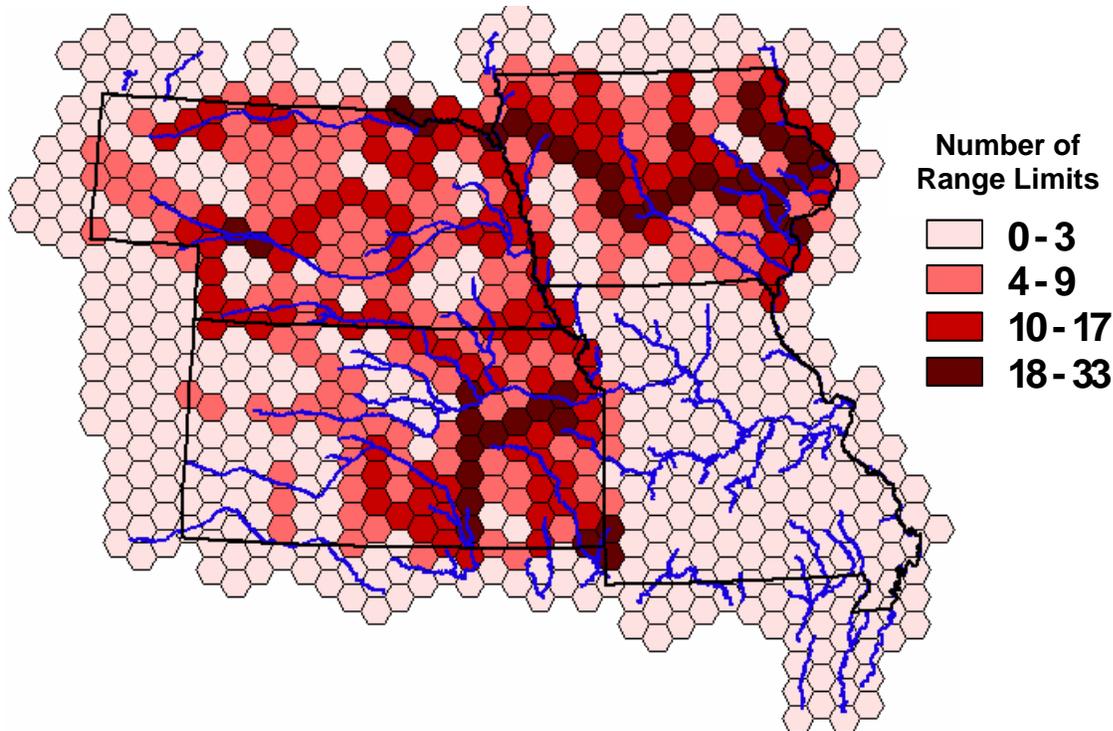


Figure 11. Graduated color map of the 1,500 Km<sup>2</sup> hexagons displaying the number of native fish species that have a range limit falling within each hexagon.

Several other geospatial data layers were also used to help decide where to draw the initial boundary lines for the Aquatic Subregions. The bottom layer was the graduated color hexagon range limit map. We overlaid the range limit map with various ecoregion and physiographic maps (e.g., Omernik 1987; Bailey 1995; Chapman et al. 2001) to identify spatial correlations between the range limits of fish species and major physiographic discontinuities across the landscape. It should be noted that we were not looking for a correspondence between range limits and drainage boundaries since these patterns are accounted for in the next level of the hierarchy (EDUs).

### *Results*

Four distinct boundaries, which corresponded with major physiographic boundaries, were identified with the range limit analysis (Figure 11). The first of these runs in an east-west belt across central Iowa, which corresponds with the southern most extent of

the Wisconsin glacial advance. Most of the hexagons in this east-west belt correspond with the range limit of 20 or more fish species. The second distinct boundary occurs in northeastern Iowa and separates the rugged and karst region known as the Paleozoic Plateau from the rolling terrain and deep soils of the North Central Glaciated Plains to the west and the Central Plains to the south (Figure 11). The third distinct boundary is only represented by three hexagons and occurs in extreme southeastern Kansas (Figure 11). This boundary corresponds with the abrupt boundary that separates the rugged and karst Ozark region from the Osage Plains/Flint Hills, which is a boundary that had already been established in the previous work done for Missouri. The last readily apparent boundary corresponds with the northern and western edge of the Osage Plains and Flint Hills, respectively (Figure 11). This latter boundary resulted in a change in the Aquatic Subregions previously delineated for Missouri. Our prior range-limit analyses, which were restricted only to Missouri, did not reveal any discrete boundary between the Central Dissected Till Plains and the Osage Plains. However, the broader analyses performed for this project revealed a very distinct boundary between these two physiographic regions. These different results illustrate how the geographic extent of your analyses can influence the resulting patterns that are observed. Ideally, these range-limit analyses should be done in a top-down fashion from a national or continental perspective, however, assembling such national datasets was beyond the scope of this project.

Based on the range limit analysis we generated a draft map of Aquatic Subregions for EPA Region 7, which contained six Subregions (Figure 12). This map was sent out for professional review to a regional committee of aquatic resource professionals. We also sent them the range-limit map so they would have the raw data to aid them in evaluating the Subregion map. The reviewers suggested two major revisions. First, they stated that the data suggest the need to separate the Central Plains into the drier western short and midgrass prairies and the moister tallgrass prairies to the east. Furthermore, they believed that the drier western short and midgrass prairies needed to be further stratified to mark the southern most boundary of the glaciation. Based on this input we used the results of the range-limit analyses, in conjunction with major drainages and physiographic boundaries to break the Central Plains into three distinct Aquatic Subregions; the North Central Great Plains, the South Central Great Plains and the Central Dissected Till Plains. With the revisions the total number of Aquatic Subregions was increased to eight (Figure 13). Biophysical descriptions for each of Aquatic Subregion are provided in Appendix A.

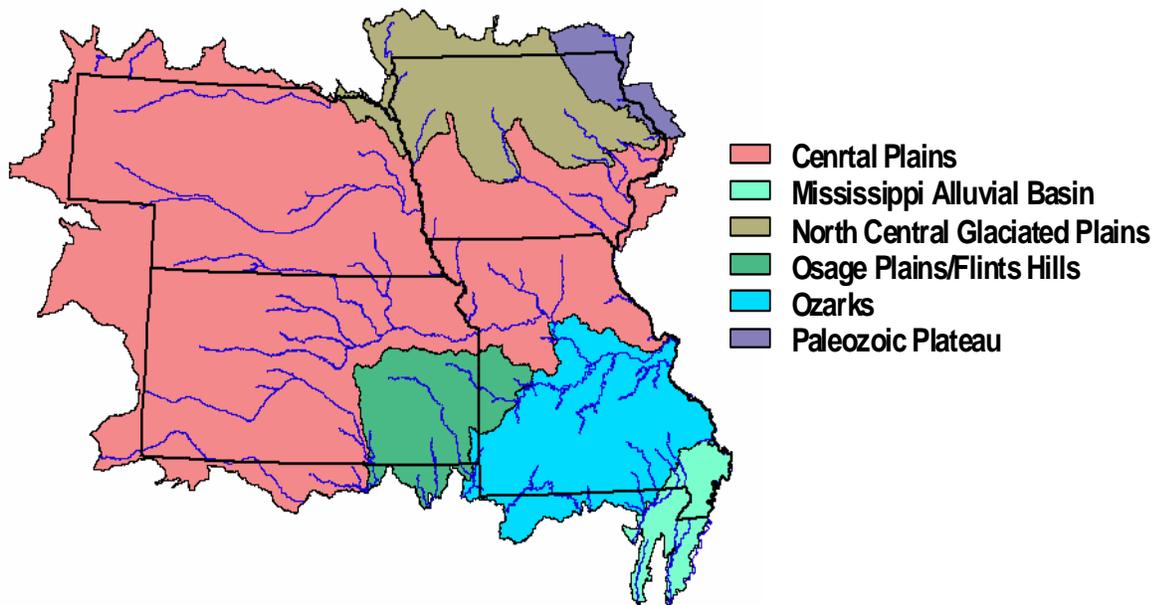


Figure 12. Map showing the draft version of the initial six Aquatic Subregions delineated for EPA Region 7 based on the range-limit analysis.

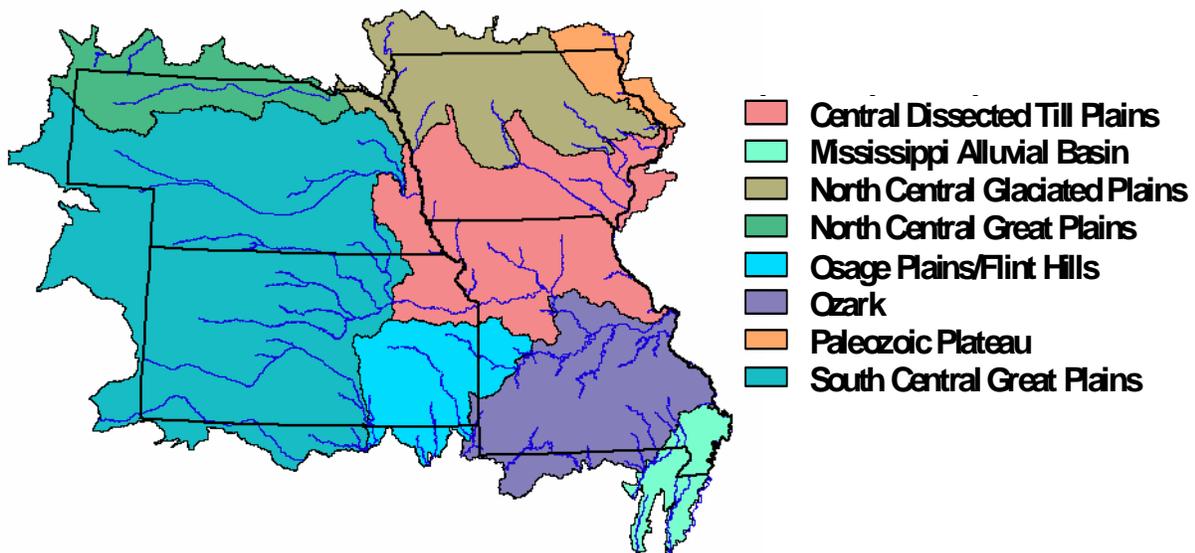


Figure 13. Final version of the Aquatic Subregions for EPA Region 7. This map was based on the results on the native fish species range-limit analysis and expert opinion.

## Classifying and Mapping Ecological Drainage Units

### Methods

Our objective for this level of the classification hierarchy was to identify groups of major drainages within each Aquatic Subregion that have relatively distinct evolutionary histories as evidenced by the relative similarity of their native fish assemblages. To accomplish this objective we followed the methods used by Sowa et al. (2005), which provides a detailed description of the specific methods. Here we provide a more general review of the process.

The baselayer for delineating EDUs was created by intersecting our Aquatic Subregion coverage with USGS 8-digit Hydrologic Units (HUs) to create a new set of HU polygons that were fully contained within only one of the four Aquatic Subregions that were included in the analyses (Figure 14). Many of the original 8-digit HUs remained unchanged after this procedure since they were already fully contained within one of the Subregions. However, those HUs that straddled the boundaries between any of the Aquatic Subregions were split into two separate HUs. A mandatory criteria for these HUs is that they must contain a stream that is classified as either large or great river (i.e.,  $\geq 6^{\text{th}}$  order).

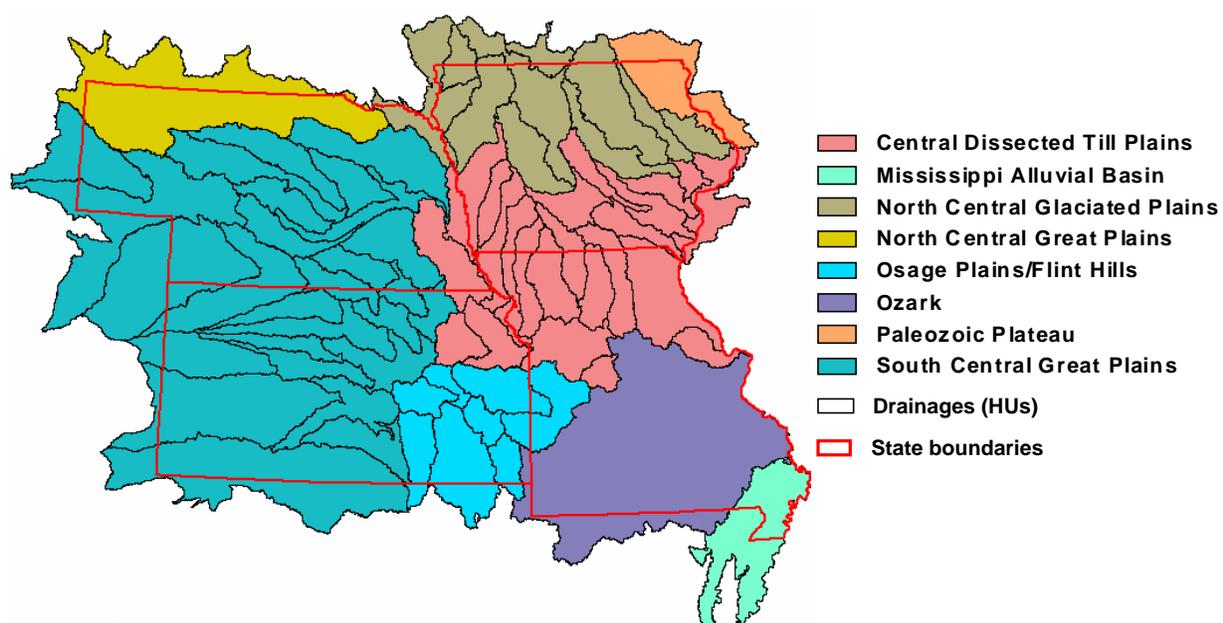


Figure 14. Map showing the individual drainages or hydrologic units that were used as the baselayer for delineating Ecological Drainage Units for the Central Dissected Till Plains, Osage Plains/Flint Hills, North Central Glaciated Plains, and South Central Great Plains Aquatic Subregions.

Next, we spatially linked 15,807 existing community fish samples (presence data) to the 1:100,000 USGS/EPA National Hydrography Dataset and the newly created HU polygons. The number of samples within an HU was not evenly distributed among all of the HUs, which could have significantly distorted any assessments of faunal similarity among HUs. For instance, (dis)similarities among an HU with 50 samples to one with 250 samples may be more related to differences in sampling effort rather than actual

differences in fish assemblage composition. Consequently, following the recommendations of Sowa et al. (2005) we standardized the number of samples used in the analysis for each HU at 40.

Fish assemblages can vary tremendously with stream size (Matthews 1998) and the fish community samples contained within the final set of HUs were by no means evenly distributed with regard to this parameter. Consequently, we also had to account for these sampling “biases” since they could severely affect the results of our analyses. For instance, it is possible that a randomly selected, 40-sample, subset from one HU could be comprised of mostly small and large river samples, while the subset from another HU contained mostly headwater and creek samples. In such a scenario, these two HUs, no matter how similar their overall fish assemblages really were, would almost certainly appear to be quite different based on species prevalence statistics. To account for this potential problem, we randomly selected 20 headwater/creek samples and 20 small river/large river samples from each HU in order to generate our overall random selection of 40 samples for each HU. We then created separate data matrices, for each of Aquatic Subregions that occur in Iowa, Kansas, and Nebraska. These matrices had a column for each native species known to occur within the given Aquatic Subregion and a row for each HU. For each HU we then calculated the percentage of the 40 randomly selected samples in which each species occurred. These matrices illustrate the prevalence of each species throughout each HU, within a given Subregion. For instance, a species found in 20 of the 40 randomly selected samples within a given HU would be given a value of 50 for that HU because it was found in 50% of the samples, while a species found in only 5 of the samples would be given a value of 12.5. This random selection process and matrix construction was done three times for each Subregion, with each of the matrices analyzed separately in order to examine consistency in results.

Datasets were analyzed using a two-dimensional analysis with Nonmetric Multidimensional Scaling (NMS in PC-ORD ver. 4.0)(Kruskal 1964). In addition, hierarchical, agglomerative, polythetic cluster analysis was used to examine the data. We used the resulting ordination plots and clustering dendograms to group HUs with relatively similar fish assemblages into a draft set of EDUs. Ordinations shown in this report were chosen on the basis of clarity (i.e., we selected relatively square ordinations that visually demonstrated the conclusions arrived at through both ordination and cluster analysis). Once delineated, each EDU was given a name based on one or two of the major streams draining that particular EDU.

The low number of HUs and limited fish sampling data in the Paleozoic Plateau and North Central Great Plains Aquatic Subregions eliminated the possibility of using multivariate analyses to stratify them into EDUs. Also, only a small fraction of these Aquatic Subregions occur in EPA Region 7 and ideally we should include all or most of each Subregion in the analyses in order to fully assess spatial variation in community composition across the entire Subregion. In lieu of the multivariate analyses, we used professional judgment, by examining the drainage patterns of large and great rivers, to break the North Central Great Plains into three EDUs and decided not to further stratify the Paleozoic Plateau since this Aquatic Subregion is largely comprised of smaller

tributaries with outlets that are in close proximity to one another and are readily connected via the Mississippi River. However, we emphasize the need for analyses of faunal similarity to be completed for these two Subregions and until that time the EDUs for these two Subregions should only be considered draft approximations. We also need to point out that all of the drainages that comprise the EDUs already defined for the Central Dissected Till Plains within Missouri were also included in the analyses in order to reexamine these HUs in a broader context across the entire Subregion. For these drainages we used the community fish sampling data that had already been compiled for the Missouri Aquatic GAP Project (Sowa et al. 2005). Drainages within the Ozarks and Mississippi Alluvial Basin were not reexamined for this project since they fall almost entirely within Missouri and EDUs had been previously delineated for these Subregions (Sowa et al. 2005). The remainder of this section of the report therefore presents the results of the multivariate analyses used to stratify four Aquatic Subregions that cover most of EPA Region 7; North Central Glaciated Plains, Central Dissected Till Plains, South Central Great Plains, and Osage Plains/Flint Hills.

## *Results and Discussion*

### North Central Glaciated Plains

Only a small fraction of the Minnesota River watershed falls within EPA Region 7 and the lack of fish sampling data for the various subwatersheds of this river precluded its inclusion in the analyses conducted for the North Central Glaciated Plains. Based on the size and isolated nature of this watershed, relative to the other major drainages in this Subregion, we decided to define the Minnesota drainage as a distinct EDU. However, this ecological unit should be considered to be in draft form until future analyses either confirm or refute the distinctiveness of the fauna that occurs in the Minnesota River watershed.

Based on the collective results of the analyses we identified four distinct EDUs for the North Central Glaciated Plains (Figure 15). Adding the subjectively defined Minnesota EDU increases the total number of EDUs to five. The ordinations were all consistent except for rotation. Axis 1 mainly separates the HUs draining to the Mississippi River, while Axis 2 separates these HUs from those draining to the Missouri River. The HUs containing the Big Sioux, Little Sioux, and Floyd Rivers consistently clustered together as did the HUs containing the Maquaketa and Wapsipinicon Rivers, and those containing the upper Des Moines and Raccoon Rivers. Each of these sets of HUs were thus grouped together to form three distinct EDUs (Figure 15). The only difference among the three separate analyses pertained to the inconsistent clustering of the HU containing the upper Iowa River. This HU plotted near the Maquaketa and Wapsipinicon HUs for one of the analyses, then plotted near the upper Des Moines and Raccoon River HUs for another set of analyses, and on the third set of analyses the upper Iowa HU plotted in between these two sets of HUs. These results suggest that the upper Iowa River represents a faunal transition between the Maquaketa and Wapsipinicon HUs and the upper Des Moines and Raccoon River HUs. This makes sense from a physiographic standpoint since the upper Iowa River runs along the

boundary between two widely recognized ecoregions in Iowa, the Des Moines Lobe and the lowan Surface (Chapman et al. 2002). Based on these collective findings we determined that the HU containing the upper Iowa River should be a distinct EDU since it represents an evolutionary transitional unit. Descriptions of these five EDUs are provided in Appendix B.

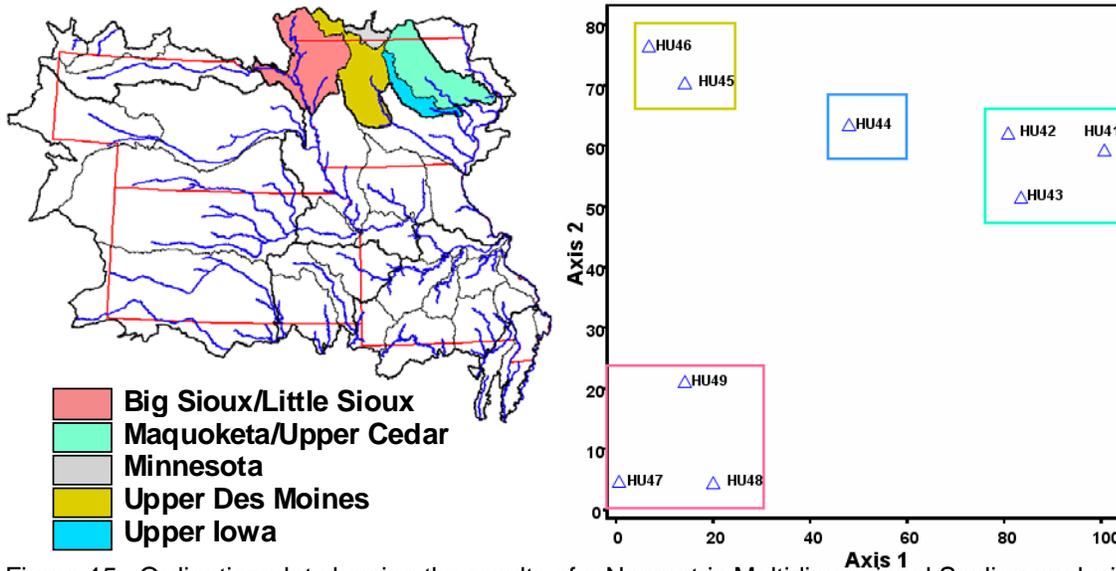


Figure 15. Ordination plot showing the results of a Nonmetric Multidimensional Scaling analysis performed on fish prevalence statistics for Hydrologic Units (HU## in plot) within the North Central Glaciated Plains Aquatic Subregion. The color of the boxes enveloping HUs on the plot correspond with the colors of the EDUs that were generated by grouping each respective set of HUs. Note: The Minnesota River watershed was not included in the analyses due to a lack of data and the limited amount of area that occurs within EPA Region 7.

### South Central Great Plains

Based on the collective results of the analyses we identified four distinct EDUs for the South Central Glaciated Plains (Figure 16). Descriptions of these EDUs are provided in Appendix B. The ordinations were all relatively consistent except for rotation. The HUs containing the North and South Platte Rivers consistently clustered together and were grouped to form one of the four EDUs. All of the HUs within the a) lower Platte River watershed, b) Kansas River watershed, and c) Arkansas River watershed also consistently clustered together and were therefore respectively grouped to form the other three EDUs (Figure 16). The surprising result of these analyses is the size of the resulting EDUs relative to the rest of EPA Region 7. However, our results are relatively consistent with the results of Hawkes et al. (1986) who defined fish ecoregions for Kansas. Our results in conjunction with Hawkes et al. (1986) suggest that the relatively harsh environments of the South Central Great Plains promote a high degree of homogeneity in the fish assemblages across vast geographic areas.

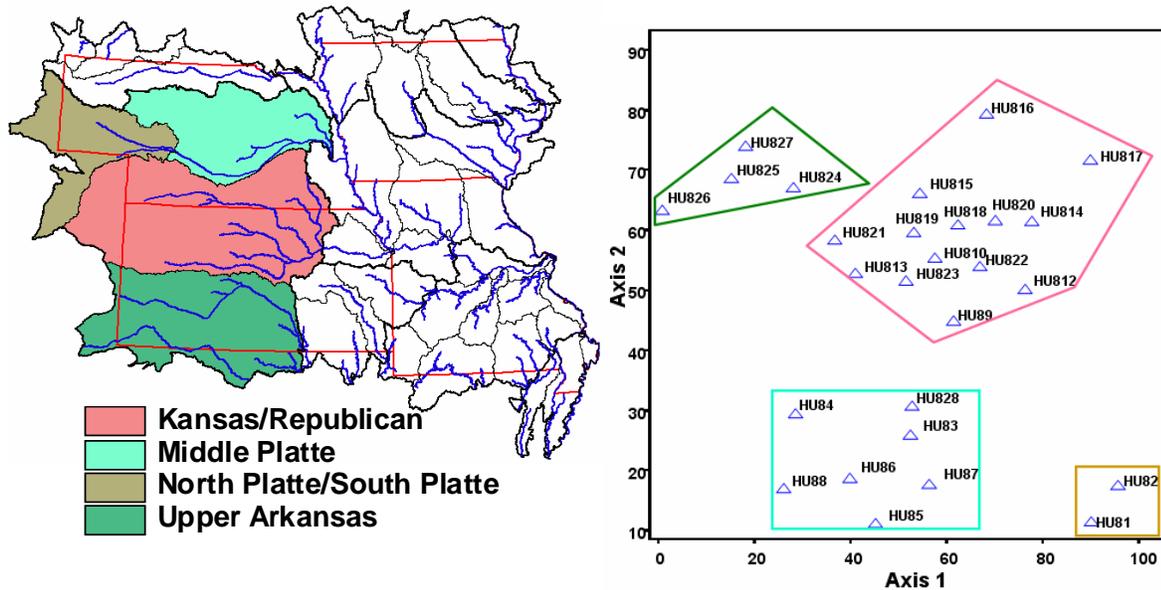


Figure 16. Ordination plot showing the results of a Nonmetric Multidimensional Scaling analysis performed on fish prevalence statistics for Hydrologic Units (HU## in plot) within the South Central Great Plains Aquatic Subregion. The color of the boxes enveloping HUs on the plot correspond with the colors of the EDUs that were generated by grouping each respective set of HUs.

### Osage Plains/Flint Hills

Based on the collective results of the analyses we identified three distinct EDUs for the Osage Plains/Flint Hills (Figure 17). The ordinations were all relatively consistent except for rotation. The HUs containing the Verdigris River and Turkey Creek watersheds consistently clustered together and were grouped to form one of the three EDUs. The HUs within the upper Neosho River watershed and those within the Osage River watershed also consistently clustered together and were therefore respectively grouped to form the other two EDUs for the Osage Plains/Flint Hills Subregion (Figure 17). The ordination plot provided in Figure 17 reveals an inverted east/west gradient in faunal composition along Axis 1, which is described in Appendix B.

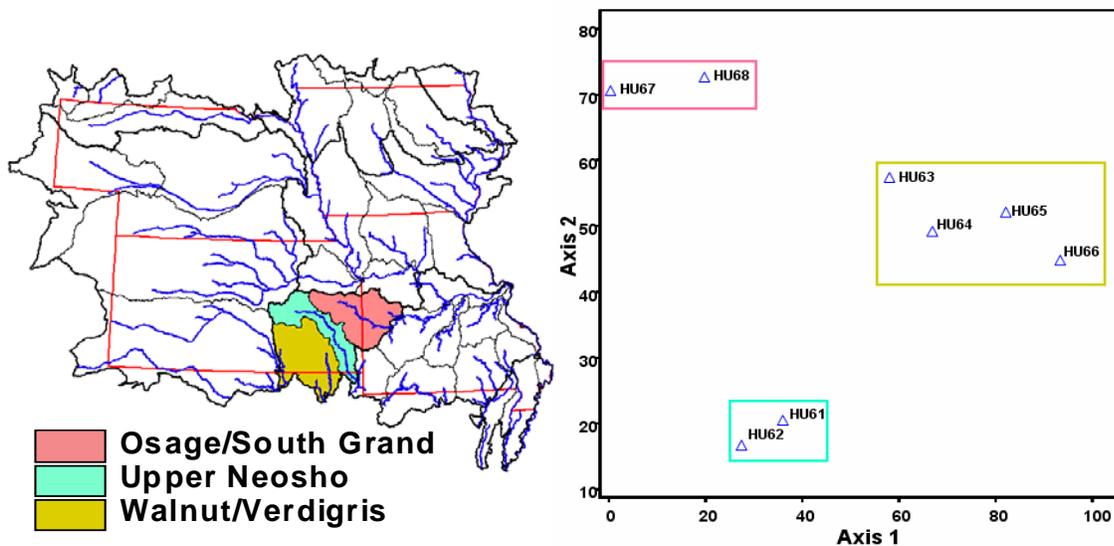


Figure 17. Ordination plot showing the results of a Nonmetric Multidimensional Scaling analysis performed on fish prevalence statistics for Hydrologic Units (HU## in plot) within the Osage Plains/Flint Hills Aquatic Subregion. The color of the boxes enveloping HUs on the plot correspond with the colors of the EDUs that were generated by grouping each respective set of HUs.

### Central Dissected Till Plains

Based on the collective results of the analyses we identified six distinct EDUs for the Central Dissected Till Plains (Figure 18). Descriptions of these six EDUs are provided in Appendix B. The ordinations were all relatively consistent except for rotation. Generally, results of these analyses are consistent with the previous analyses conducted for the Missouri Aquatic GAP project, which had identified four of these six EDUs based only on fish community data from Missouri (Sowa et al. 2005). The only difference is that the boundary of the Platte/Nishnabotna EDU was extended northward to include the lower Platte and Boyer River watersheds, which were not included in the analyses previously done only for Missouri. The only pattern on the ordination plot was that the HUs draining to the Mississippi River generally fall within the northwest quadrant of the plot, while those draining to the Missouri generally fall within the southeast quadrant. However, the HUs comprising those EDUs draining to the Mississippi River actually plot closer to some of the HUs draining to the Missouri River. For instance, the HUs within the Cuivre/Salt EDU plot closer to HUs in both the Blackwater/Lamine and the Grand Chariton EDUs than to the HUs in the Wapsipinicon/DesMoine EDU.

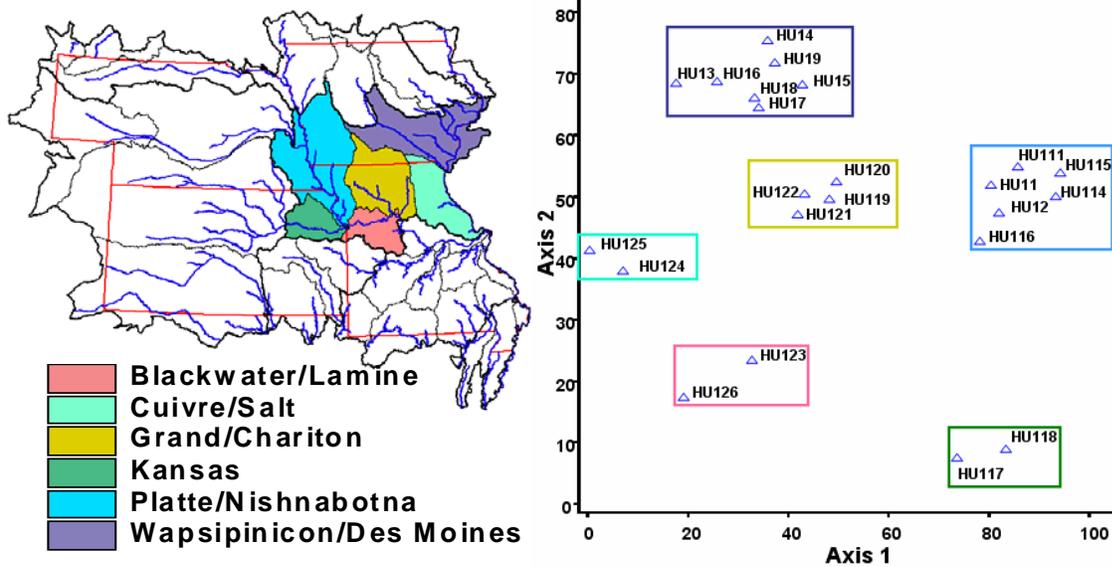


Figure 18. Ordination plot showing the results of a Nonmetric Multidimensional Scaling analysis performed on fish prevalence statistics for Hydrologic Units (HU## in plot) within the Central Dissected Till Plains Aquatic Subregion. The color of the boxes enveloping HUs on the plot correspond with the colors of the EDUs that were generated by grouping each respective set of HUs.

Based on the multivariate analyses of fish community data and professional judgment, a total of thirty four EDUs were delineated throughout EPA Region 7 (Figure 19). Nebraska contains all or portions of the fewest number of EDUs, at 8, followed by Kansas with 9, and Iowa with 10. Missouri contains a significantly higher number of EDUs than these other states with 17, mainly because of the relatively high number of EDUs that occur within the Ozark Aquatic Subregion, which contains nine. As previously mentioned, the most surprising results of these analyses and those done for Missouri pertain to the tremendous variation in the size of the EDUs across EPA Region 7. The smallest EDUs occur in the Ozark Aquatic Subregion, while EDUs in the South Central Great Plains are five to ten times larger than the EDUs in the other Subregions.



Figure 19. Map of the thirty four Ecological Drainage Units delineated throughout EPA Region 7. Note: This map does not show the full, unknown, extent of those EDUs that cross state boundaries along the periphery of EPA Region 7.

It is hard to say if the disparities in the size of the EDUs across EPA Region 7 and the patterns reflected in the ordination plots reflect differences in habitat diversity, harshness of environmental conditions, geographic isolation, or relate to distances from original post-glaciation colonizing source populations in the lower Mississippi River, since all four possible explanations would fit the observed patterns. It is most likely a combination of all these factors and additional, more detailed, analyses into the phylogenetics, physiological tolerances, and life history strategies of many of these species/populations would be required to discern the relative influence of each factor.

### ***Classifying and Mapping Aquatic Ecological System Types***

#### ***Methods***

Our objective for this level of the classification was to identify and map hydrologic units that are relatively similar with regard to nutrient and energy sources and dynamics, physical habitat, water chemistry, hydrologic regimes, and biological assemblages. Lacking sufficient field data for this broad range of factors and processes, we had to rely on a more indirect “top-down” approach that utilized surrogate landscape variables to classify distinct ecological units at this level of the classification. Generally, for each AES polygon we quantified percentages or densities for a suite of variables (soils,

landform, and spring/groundwater inputs) that ultimately determine hydrologic and physicochemical conditions within stream ecosystems (Hynes 1970; Hynes 1975; Dunne and Leopold 1978; Frissell et al. 1986; Allan 1995; Richards et al. 1996; Matthews 1998).

Our first step in classifying Aquatic Ecological System (AES) Types involved preparing a coverage of distinct drainage polygons between all Small River and larger stream confluences. This was accomplished by taking a subset of the full drainage network contained within the 1:100,000 Valley Segment Coverage. Specifically, we removed all stream segments classified as headwater or creek from the Valley Segment Coverage and then removed all pseudo nodes to create a digital stream network that contained only streams classified as small, large, or great river. Each resulting stream segment was given a unique identifier. An AML developed by The Nature Conservancy (TNC) was used in conjunction with this reduced stream network and a 30-meter digital elevation model (DEM) to generate drainage polygons for each of the resulting stream segments (Figure 20). The resulting coverage served as the polygonal baselayer for calculating landscape statistics and classifying distinct AES-Types, which is discussed below. For data management purposes, each of the resulting AES polygons was given a unique identifier. The only polygons that are true watersheds are those that correspond to the uppermost segments of Small Rivers, which is why we use the term hydrologic unit to describe the AES polygons.

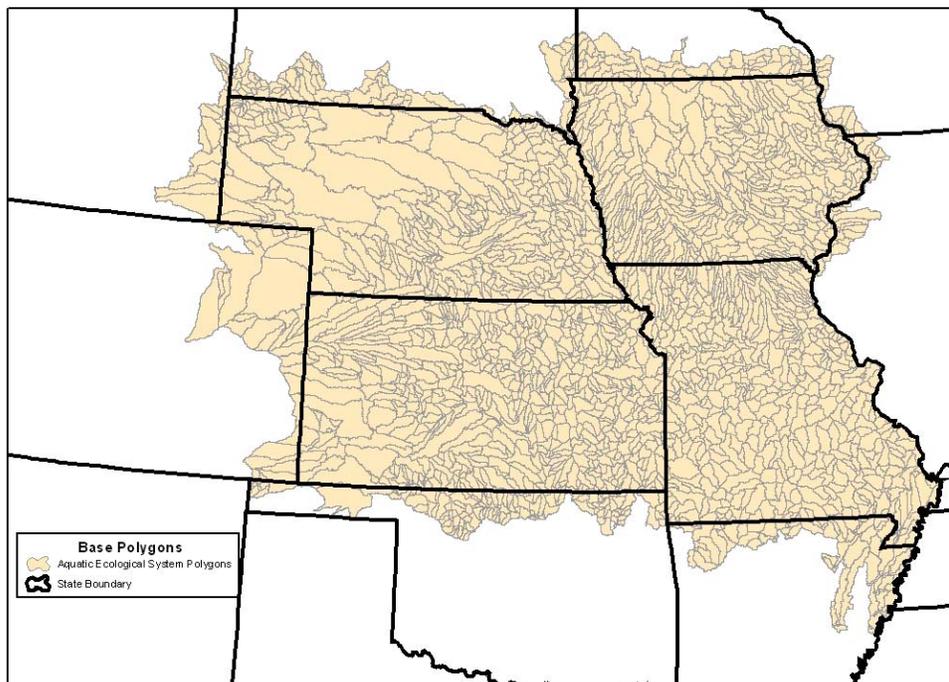


Figure 20. Map showing the baselayer of AES polygons used to classify distinct AES-Types throughout EPA Region 7. The size of these polygons is determined by the apriori criteria that each AES must contain a stream classified as small, large, or great river.

Unfortunately state-level geologic data were not consistently mapped across the three state area and national coverages exhibit obvious errors and were were at too coarse of

scale for the resolution of our calculations. Consequently, our landscape statistics relied heavily on soil attributes and relief. Specifically, percent area statistics were generated for 43 variables; 8 hydrologic soil group classes, 14 soil surface texture classes, 6 rock fragment classes, 7 rock depth classes, and 8 relief classes (Table 2). These statistics were based on the data provided in the 1:250,000 STATSGO soil data and a 30-meter DEM. Relief statistics were generated with the DEM by first creating a relief grid for the study area by using the grid command FOCALRANGE. For each cell in the input grid, this command finds the range of the values (maximum and minimum) within a specified neighborhood and sends it to the corresponding cell location on the output grid. We used a 1-Km<sup>2</sup> circle to define the neighborhood.

Percent area statistics, for each of the 43 variables, were calculated for the both local (individual AES polygon) and the overall watershed draining to each AES polygon (Figure 21). Consequently, for each AES polygon we generated percent area statistics for a total of 86 parameters (43 local and 43 watershed). These 86 parameters were then used as the input data for the cluster analysis in order to identify relatively distinct groupings of AES polygons. For the uppermost AES polygons, the values for the 43 local parameters were identical with the 43 watershed factors. However, for all other units the values for these two sets of parameters were different. The reason we generated both local and overall watershed statistics for each AES polygon is that significant changes in stream conditions can occur as a result of changes in local character, the issuance of a major tributary draining an entirely different landscape, or both.

Table 2. Classes for each of the variable groups used to generate the local and overall watershed percent area statistics for each AES polygon and subsequently used to define the initial AES-Types based on cluster analysis.

<b>Local Relief (range in m)</b>	<b>Soil Texture</b>	<b>Hydrologic Soil Group</b>	<b>Soil Rock Fragment Volume (%)</b>	<b>Depth to Bedrock (cm)</b>
0 – 15	Sand	A	0	0
16 - 30	Loamy sand	B	0.1 – 10	1 – 30
31 - 61	Sandy loam	BC	10.1 – 20	31 – 61
62 - 91	Silt loam	BD	20.1 – 40	62 – 91
92 - 152	Silt	C	40.1 – 60	92 – 122
153 - 213	Loam	D	> 60	123 - 152
214 - 274	Sandy clay loam	CD		> 152
>= 275	Silty clay loam			
	Clay loam			
	Sandy clay			
	Silty clay			
	Clay			
	Organic materials			
	Water			
	Bedrock			

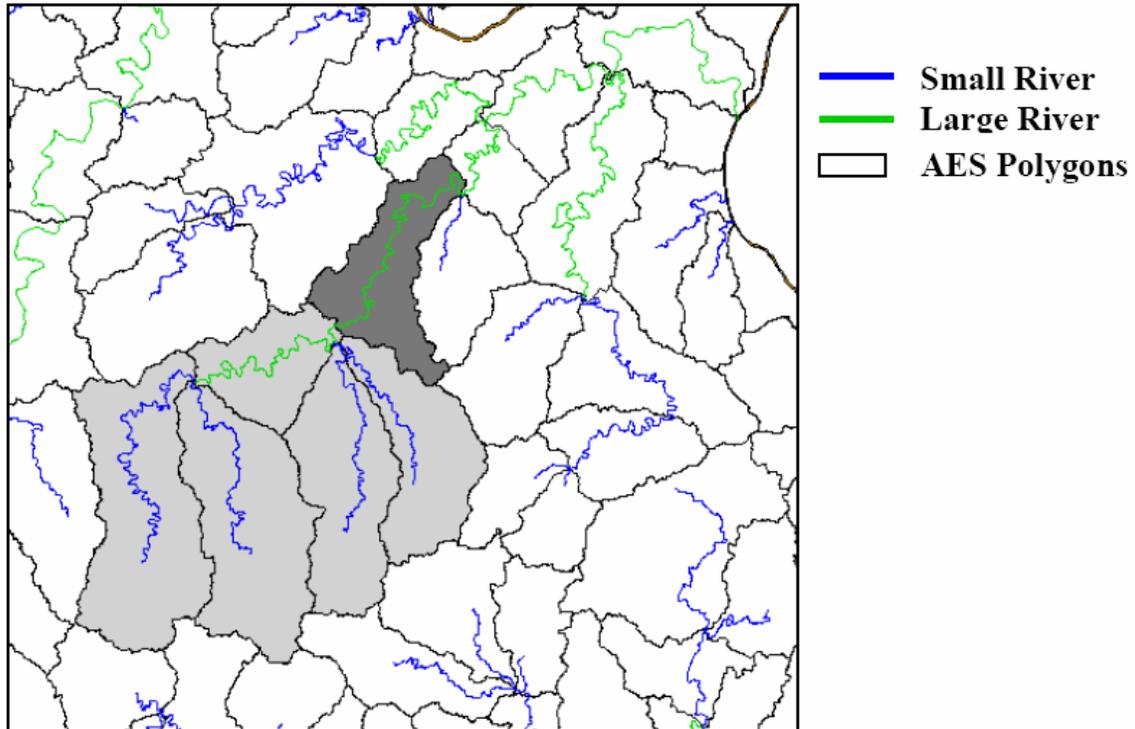


Figure 21. Map showing an example of the two spatial scales (local and overall watershed) at which landscape statistics were generated for each AES polygon. The dark grey polygon shows the local drainage for an individual AES polygon, while the entire shaded area represents the overall watershed for that same AES polygon. Percent area statistics were generated for both of these geographic areas for all 43 landscape variables, which resulted in a total of 86 variables used in the classification of AES-Types.

To calculate percent area statistics for the overall watershed of each AES polygon we joined the polygonal attributes to the corresponding stream network (small rivers and larger streams) via the common identifier and subsequently traced the stream network to accumulate the total watershed area for each of the 43 variables and these values were applied to each individual AES polygon. This was accomplished using the TRACE ACCUMULATE command in ArcPlot by accumulating the area of each individual AES polygon progressively and then converting this to a percent of the entire area above the outlet of every AES polygon for each variable.

Multivariate clustering was performed with the FASTCLUS procedure in SAS 8.0.2. Cluster analysis is a multivariate analysis technique that seeks to organize information about variables so that relatively homogeneous groups, or "clusters", can be formed. The resulting clusters should be internally homogenous (members are similar to one another) and externally heterogeneous (members within one cluster are dissimilar from members of other clusters). Consequently, our objective for this analysis was to identifying AES polygons that are relatively similar with regard to the 88 parameters used as input for the cluster analysis.

Cluster analysis methods will always produce groupings, which may or may not prove useful for classifying objects of interest. If the groupings discriminate between variables

not used to do the grouping (e.g., instream habitat) and those discriminations are useful, then cluster analysis is useful. Consequently, an assumption of our project is that the variables used to identify clusters (geology, soils, and landform) are significantly related to the structure and function of the stream ecosystems. With this assumption we expect streams of similar size and also both local and overall watershed geology, soils, and landform to be relatively similar with regards to water chemistry, energy dynamics, instream habitat, flow regimes, and resident biota.

There are no completely satisfactory methods for determining the true number of clusters for any type of cluster analysis (Everitt 1979; Bock 1985; Hartigan 1985). Ordinary significance tests, such as analysis-of-variance F-tests, are not valid for testing differences between clusters. Since clustering methods attempt to maximize the separation between clusters, the assumptions of the usual significance tests, parametric or nonparametric, are drastically violated. For example, if you take a sample of 100 or 1000 observations from a single univariate normal distribution, have PROC FASTCLUS divide it into two clusters, and perform a t-test to compare the cluster means, you usually obtain a significant P-value (SAS 2001). There are, however, various external or internal criteria that can be used to help determine the appropriate number of clusters within a particular multivariate dataset (Jongman et al. 1995). External criteria are not dependent upon the method of clustering since independent data are used to test whether or not the clustering results are meaningful. However, in our case, external data, such as species composition or abundance, water chemistry, flow regimes, or instream habitat, were not available and therefore could not be used to assess the proper number of clusters. Internal criteria are dependent upon the data used for obtaining the clusters and also the specific clustering method. Most often, two types of internal criteria are used to determine the optimum solution (Jongman et al. 1995). The first is the homogeneity of the clusters, which requires some measure of the (dis)similarity of the members of each cluster. The second is the degree of separation of the clusters, which requires some measure of the (dis)similarity of each cluster to its nearest neighbor. Typically, plots of these internal criteria against the number of clusters are used to guide the decision of how many clusters are optimal (Jongman et al. 1995; Salvador and Chan 2003).

In addition, PROC FASTCLUS provides estimates of the overall r-square, a pseudo F-statistic, and the cubic clustering criterion (Calinski and Harabasz 1974; Sarle 1983). Plotting these statistics against the number of clusters and then determining where all three are simultaneously maximized, also provides a good indication of the proper number of clusters within the overall dataset (Milligan and Cooper 1985; SAS 2001). However, caution must be used with these statistics when the discriminatory variables are correlated, which does occur in our case. It must also be emphasized that these criteria are appropriate only for compact or slightly elongated clusters, preferably clusters that are roughly multivariate normal.

We used all three of the internal criteria described above to provide insight into the proper number of clusters for each dataset. Specifically, we generated three separate diagnostic plots for the dataset.

1. Plots of the mean root-mean-square distance between observations within clusters versus the number of clusters (Figure 22). (Provides a means of assessing the relative homogeneity of observations within clusters as the number of clusters changes).
2. Plots of the mean distance among cluster centroids versus the number of clusters (Figure 23). (Provides a means of assessing the degree of separation among clusters as the total number of clusters changes).
3. Overlay plots of the overall r-square, cubic clustering criterion (CCC), and pseudo F-statistic values versus the number of clusters (Figure 24). (Provides a means of collectively assessing how much of the overall variance in the dataset is explained by the clusters (overall r-square), the significance/validity of the clusters against the null hypothesis of a multivariate uniform distribution (CCC), and relative significance of the differences among the cluster means (pseudo F-statistic) as the number of clusters changes).

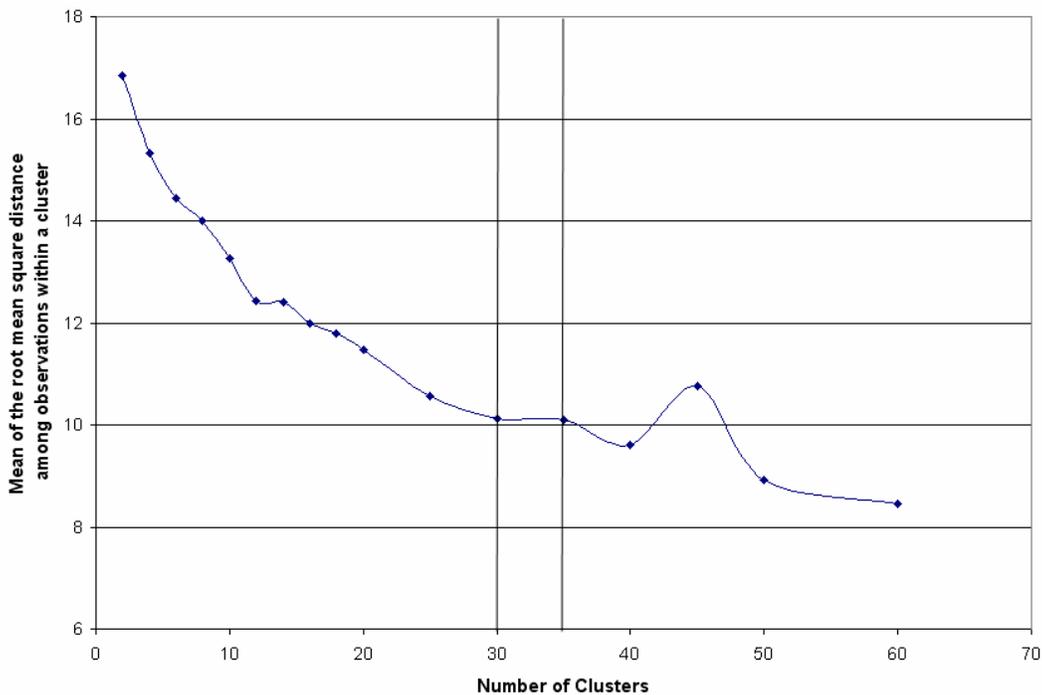


Figure 22. Scatter plot of the mean of the root-mean-square distance among observations within all clusters versus the number of clusters. This plot suggests that somewhere above 30 to 35 clusters (see vertical lines) only minimal additional variation within the set of classification variables is accounted for.

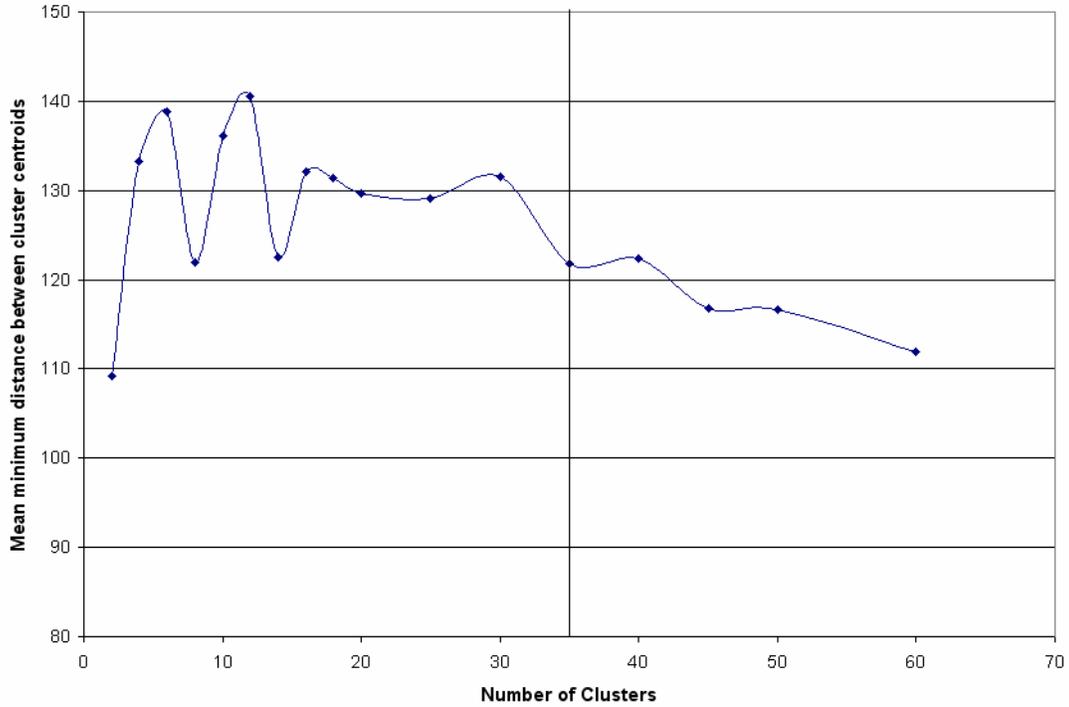


Figure 23. Scatter plot of the mean distance between cluster centroids versus the number of clusters. This plot suggests that above 35 clusters (see vertical line) only minimal additional variation within the set of classification variables is accounted for.

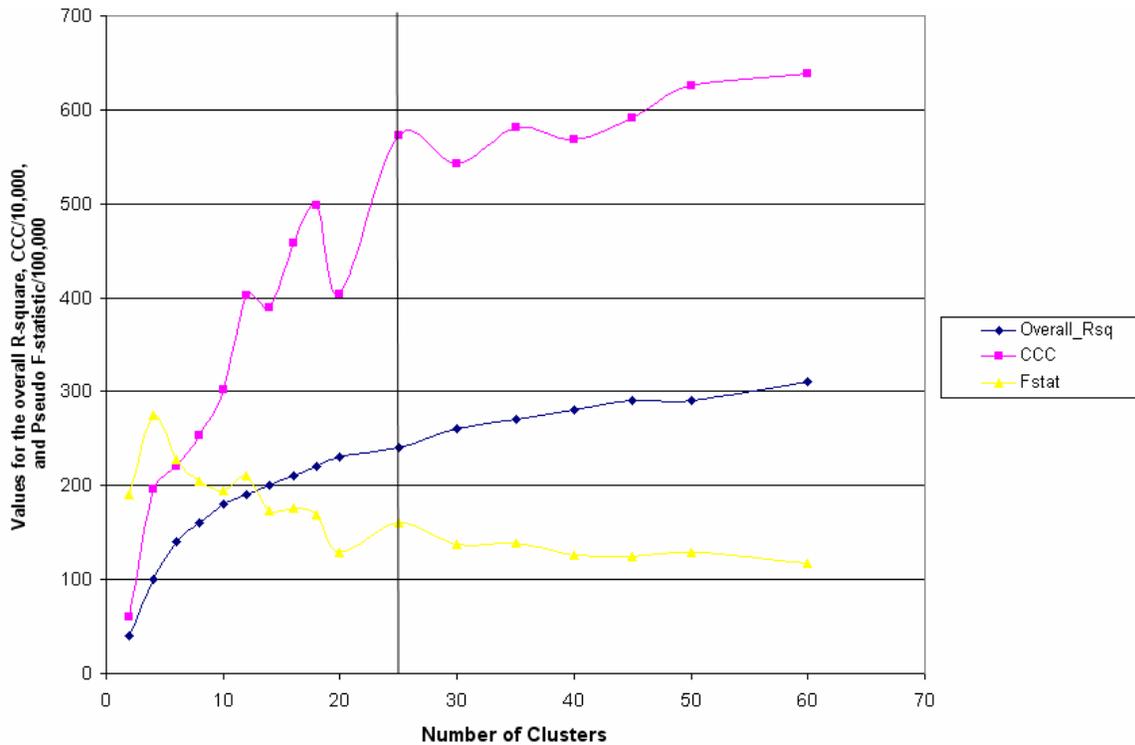


Figure 24. Plot of the overall r-square (Overall\_Rsq), cubic clustering criterion (CCC), and pseudo F-statistic (Fstat) values versus the number of clusters. This plot suggests that are 25 distinct clusters (see vertical line) within the dataset. Note: for presentation purposes, the CCC and Pseudo F-statistic values were divided by 10,000 and 100,000, respectively.

Agreement among these various diagnostic plots generally provides a good indication of the number of distinct clusters (Cooper and Milligan 1984; Milligan and Cooper 1985).

### Results

Based on the diagnostic statistics and a visual examination of resulting classification units, we elected to use the groupings produced by the thirty clusters (Figure 25). The initial thirty groups were further stratified by accounting for groundwater influences. AES polygons were given binary code that discriminated between those AES polygons with limited spring/groundwater influence and those with “significant” spring or groundwater influence. A “significant” spring/groundwater influence was based on three criteria;

1. Contains a stream classified as coldwater
2. Contains a spring with a discharge greater than or equal to 10 cfs
3. Has a spring density greater than or equal to 1 spring per 10 mi<sup>2</sup>

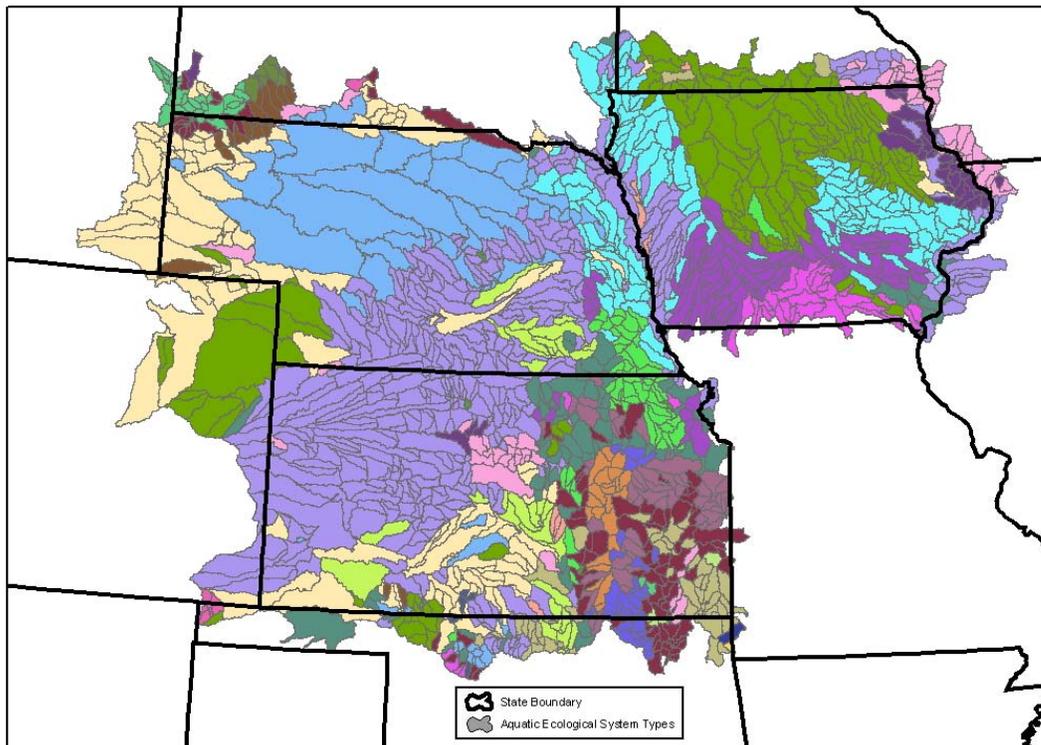


Figure 25. Map showing the spatial patterns of the initial thirty AES-Types delineated for Iowa, Kansas, and Nebraska based on the results of the cluster analyses using the 86 soil and relief variables.

Any AES polygon that met one or more of these three criteria was given a binary code to denote a significant spring/groundwater influence. Using the above criteria, an additional 33 groups were added to the initial 30 groups within the Central Plains and Ozarks (Figure 26). The resulting 63 groups for Iowa, Kansas, and Nebraska, combined with the 39 delineated for the Missouri, resulted in a total of 102 distinct AES-Types for throughout EPA Region 7 (Figure 27). Maps and descriptions for each of the AES-Types can be found in Appendix C.

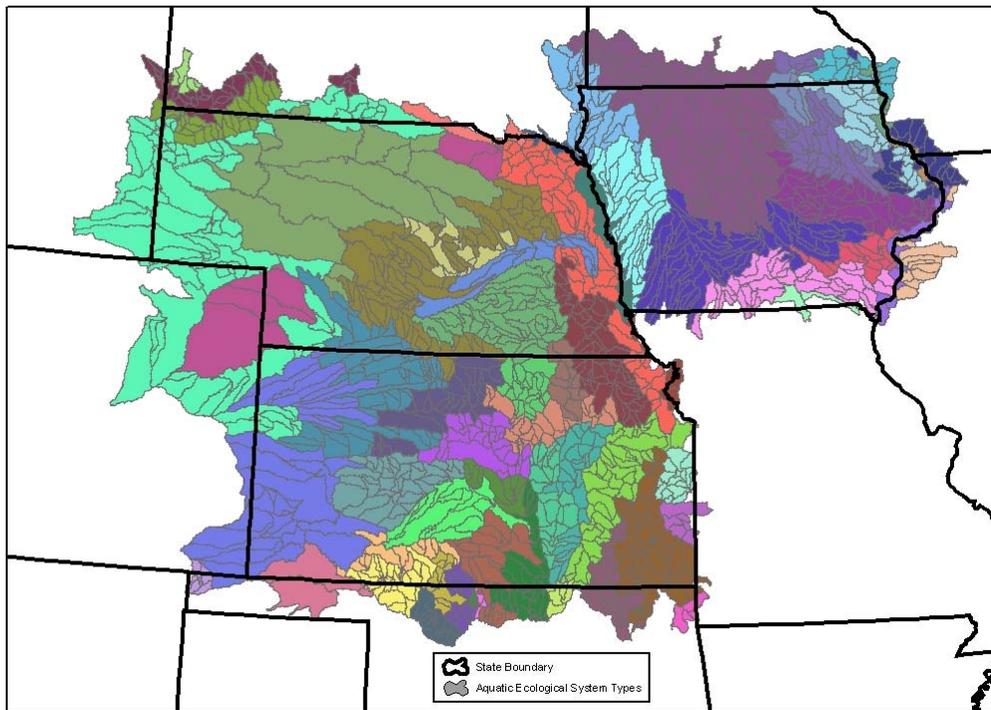


Figure 26. Map of the final set of 63 distinct AES-Types delineated for Iowa, Kansas, and Nebraska.

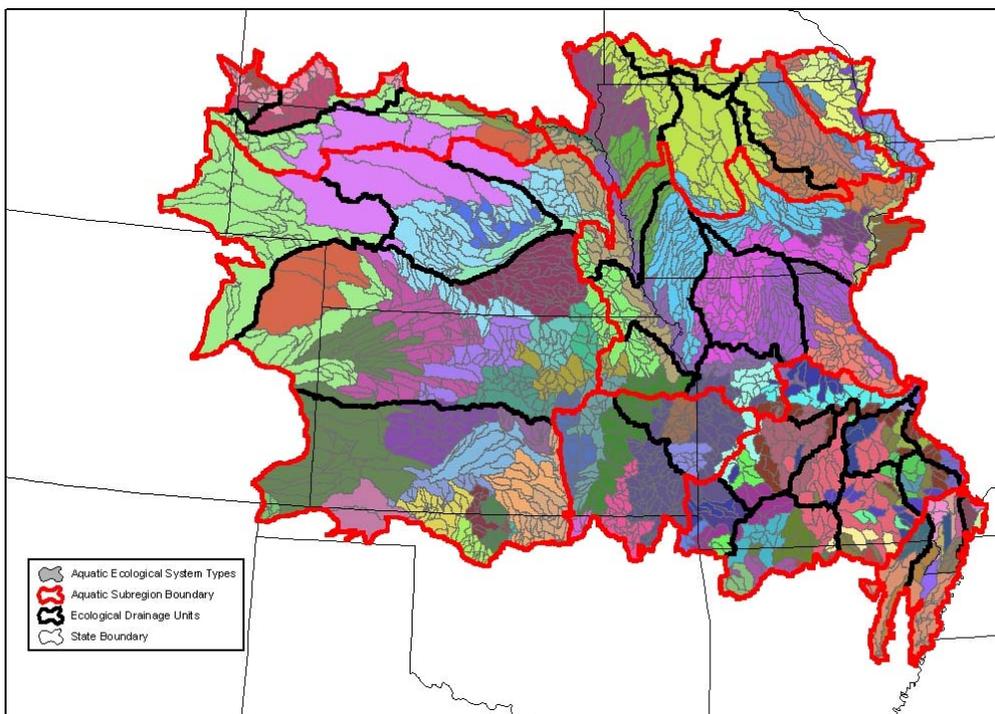


Figure 27. Map of the final set of 102 distinct AES-Types delineated throughout EPA Region 7.

Each AES-Type was assigned a unique identifier called the AES-Type Code. AES-Types are defined according to the input variable metrics and don't necessarily have to

be in geographic proximity. AES-Types were assigned names based on the name of a major stream contained within the most representative or typical AES of a given AES-Type. Representative AESs were selected based on the distance from the cluster centroid. The individual AES that plotted closest to the cluster centroid, for each cluster, was selected as the most typical AES for a given Type. In cases where no stream name could be identified, the name of a municipality or a major landform, contained in the representative unit, was assigned as the AES-Type name.

The spatial patterns of the AES-Types correspond quite well with existing ecoregion classifications, such as EPA Level III ecoregions or the ecological sections of the USFS ECOMAP hierarchy. However, there are also many exceptions. These exceptions are largely the result of the fact that the methods we use to classify AES-Types accounts for groundwater influences and also overall watershed conditions, which ecoregion classifications do not account for. Consequently, in those areas where groundwater influences are prevalent, such as the Ozarks, Paleozoic Plateau, and North Central Great Plains Aquatic Subregions, you find the greatest discrepancies between our AES-Type boundaries and existing ecoregional classifications. You also find major discrepancies from ecoregional classifications along the mainstems of large rivers, particularly at the junction of two large rivers since watershed conditions in the mainstem tend to change abruptly at these junctions and the ecoregional classifications do not account for influence of watershed conditions on stream habitat. Consequently, ecoregional boundaries tend to change abruptly where the landscape changes abruptly whereas our classification units change when there is an abrupt change in watershed conditions, local conditions, or both.

### ***Classifying and Mapping Valley Segment Types***

#### ***Methods***

Our objective for this level of the classification hierarchy was to classify stream segments contained within the 1:100,000 National Hydrography Dataset into distinct valley segment types according to distinct combinations of factors known to individually and collectively influence local biophysical conditions.

To accomplish this objective we followed the methods of Sowa et al. (2005), which provides a detailed description of this complex process. Readers should consult Sowa et al. (2005) or the corresponding metadata for a full description of the methods used to generate the attributes contained in the 1:100,000 VST coverage. Here we provide a more general overview.

Generally speaking, stream segments within the 1:100,000 USGS/EPA National Hydrography Dataset (NHD) were attributed according to various categories of stream size, flow, gradient, temperature, and the surficial 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.

More specifically, we began by using the 1:100,000 scale National Hydrography Dataset (NHD) as our base stream layer. After acquiring the NHD files for the three state area (Iowa, Kansas, and Nebraska) we first ran the Fixnhd.aml program that was developed by the Missouri Department of Conservation. The AML preprocesses each NHD file (an individual 8-digit hydrologic unit) by attaching a number of attributes from related tables to the arc attribute table (.aat). This facilitates the use of the NHD streams by eliminating the need for the numerous and complex related tables inherent to the NHD. The AML also removes polygonal water body features resulting in a centerlined stream network.

Some areas in the 1:100,000 scale NHD were mapped with lower stream densities than most of the nation. These areas correspond to specific 1:100,000 scale topographic maps with the same problem and can be identified by viewing the stream networks across fairly large regions as evidenced by the rectangular nature of these low density area boundaries. These areas present problems when attempting to get an accurate stream order because much of the contributing network is missing. We fixed these areas of lower stream density by generating the “missing streams” using a DEM (Figure 28).

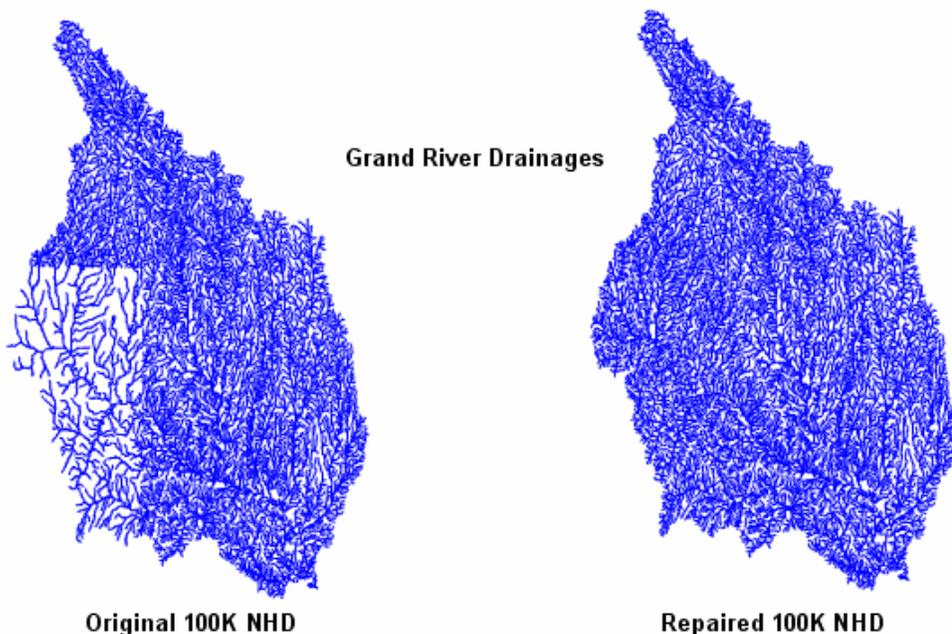


Figure 28. Example of a low-density area within the original National Hydrography Dataset (NHD) and the same area after repairing the networks using streams generated from a 30-meter DEM.

In addition to fixing areas of low stream density in the NHD we also occasionally fixed disconnected stream networks when they were determined to be errors. This was accomplished by using digital representations of topographic maps for reference. In instances where a clear connection could not be determined or it was just a first order stream, we did not attempt to make a connection. Fixing these connections also helped improve the accuracy of stream ordering.

## Unique Identifier

To facilitate linking data to our stream networks we added a unique stream segment identifier called the Seg\_ID. The Seg\_ID was created by concatenating the 8-digit hydrologic unit code with a unique value within all segments contained in a given 8-digit unit. For ease of reading we placed a space between the 8-digit hydrologic unit code prefix and the unique value portion of the Seg\_ID. Every stream segment classified as part of the Missouri project has a unique Seg\_ID.

## Coding Primary and Secondary Channels

To run stream ordering programs on the networks it was necessary to code and temporarily remove the secondary channels (loops and braids) from the primary channels (Figure 29). Coding primary and secondary channels can be a difficult task without doing extensive field verification. Several NHD table attributes that helped in determining the primary from the secondary channels were the flow attributes (permanent flow takes precedence over intermittent flow), stream name (a named channel takes precedence over an unnamed channel) and stream Level (the lowest level takes precedence). Another means of identifying the primary channel is to look at the angle created where two channels converge. The main path is generally the one that creates the least angle when looking upstream. Many instances arose where a judgment call had to be made. Areas presenting particular difficulty are those that have had their drainage patterns altered through channelization and ditching. It is often difficult to determine whether the majority of flow remains in the natural channel or has been diverted into a ditched portion; some ditches may even have a flow control gate. Without field verification places with multiple channels may not always be coded “correctly”. These conditions should be recognized as a limitation in the data.

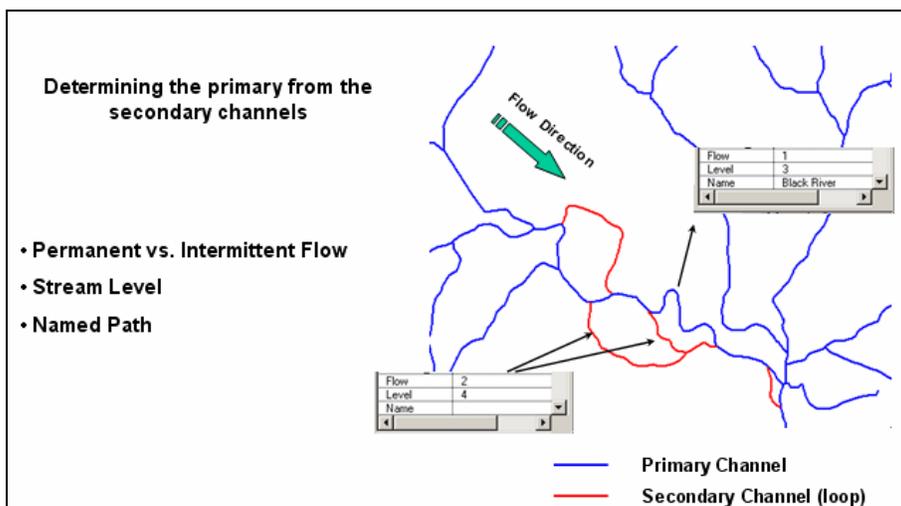


Figure 29. Example of mapping primary and secondary channels.

In addition to a primary channel network the stream ordering programs required that pseudo-nodes also be removed from the network. Once this initial preprocessing was complete and a clean primary channel network was available we were then able to commence with the stream ordering.

## Stream Size

It has long been recognized that a wide array of structural features and functional processes, occurring within and along stream ecosystems, tend to change in a longitudinal continuum from the smallest headwaters to the largest rivers (Vannote et al. 1980). Consequently, studies designed to examine the potential influence of a given factor (other than drainage area) on the ecological character of streams, must somehow account for differences in stream size among sites.

Instead of using the more precise measures of drainage area or discharge most investigators have utilized discrete stream size classes (Sensu Horton 1945 and Strahler 1957) in order to more tractably account for longitudinal changes in the abiotic and biotic character of streams. The Strahler ordering system is certainly the most widely recognized and the one most often used by stream ecologists for research and management (Hansen 2001). However, Strahler order often underestimates stream size due to vagaries in drainage network structure (Hynes 1970). With the Strahler ordering system it is common to have lower order streams (e.g., 3<sup>rd</sup>) with substantially larger drainage areas than higher order streams (e.g., 5<sup>th</sup>). Recognizing this problem Shreve (1966) devised another measure of stream size, termed link magnitude, which overcomes this problem since it is much more precisely related to drainage area (Hansen 2001). Link magnitude simply reflects the number of first order stream channels above a given stream segment.

Stream ordering consisted of running Arc Macro Language (AML) programs on the primary channel stream network to generate Strahler stream order, Shreve link magnitude, and downstream Shreve link magnitude. We used the Stream\_o.aml program, developed by the US Forest Services Redwood Sciences Laboratory (Lamphear and Lewis 1994), to compute the Strahler Order for each arc in the network. We then used the Shreve.aml program, which was originally developed by the Missouri Department of Conservation and subsequently modified to work with this project, for computing Shreve link magnitude for each arc. This AML utilizes the Arcplot command TRACEACCUMULATE to accumulate the number of streams with a Strahler stream order of 1 above each segment.

The ordered networks were then classified into more general stream size classes. These size classes were based on Pflieger (1989), following his *Aquatic Community Classification System for Missouri*. Pflieger's size classes were based on fish community composition computed for over 1,600 sample locations. He defined his size categories using Strahler stream order. We modified this approach slightly and based our size class breaks on Pflieger's categories, but used Shreve link number when describing our intervals because link gives a more precise category than does Strahler order. Like Pflieger, our size classes were made relative to the surrounding Aquatic Subregion. Table 3.6 shows the stream size classes used for each of the Aquatic Subregions and Figure 3.31 shows a map of the resulting size classes for Missouri.

Table 3. Shreve link ranges used to designate the five stream size classes.

Stream Size	Size Code	All Other Subregions (Shreve link range)	Ozark (Shreve link range)	MS Alluvial Basin (Shreve link range)
Headwater	1	1-2	1-4	1-4
Creek	2	3-30	5-50	5-50
Small River	3	31-700	51-450	51-450
Large River	4	Greater than 700	Greater than 450	Greater than 450
Great River	5	Missouri and Mississippi Rivers	Missouri and Mississippi Rivers	Missouri and Mississippi Rivers

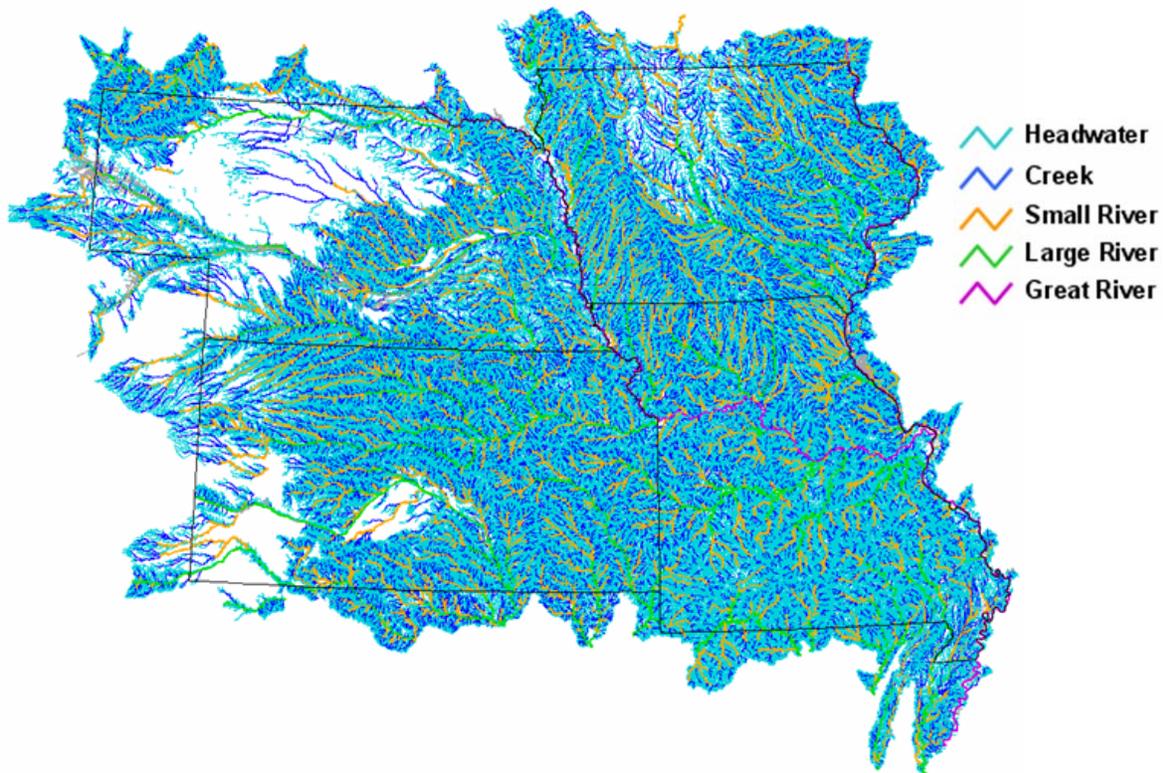


Figure 30. Map showing the five stream size classes used in the classification of valley segment types for EPA Region 7.

The size of the downstream confluence can have a significant influence on the aquatic assemblages of the influent stream (Osborne and Wiley 1992). To account for this phenomena we also attributed stream segments within the NHD according to stream size discrepancy. This was accomplished by running the Dlink.aml program that was developed by the Missouri Department of Conservation and modified for use in this project. The Dlink program finds the Shreve link number of the next downstream segment for all segments in a network and attaches the value to each segment in a field called Dlink. We applied our stream size classes to the Dlink field to create a new field for downstream stream size called Dsize. We created distinct attribute categories for the different available combinations (i.e. headwater connecting to a creek or a headwater connecting to a small river, etc) (Table 4). These eleven classes (0-10) were

also condensed into just two classes, which identifies stream segments that flow into a segment falling into a larger size class.

Table 4. Size discrepancy classes and codes.

<b>Size Discrepancy</b>	<b>Size Discrepancy Code (11 Class)</b>	<b>Size Discrepancy Code (2 Class)</b>
None	0	0
Headwater – Creek	1	0
Headwater – Sm. River	2	1
Headwater – Lg. River	3	1
Headwater – Great River	4	1
Creek – Sm. River	5	1
Creek – Lg. River	6	1
Creek – Great River	7	1
Sm. River – Lg. River	8	0
Sm. River – Great River	9	1
Lg. River – Great River	10	0
Disconnected streams	-1	-1

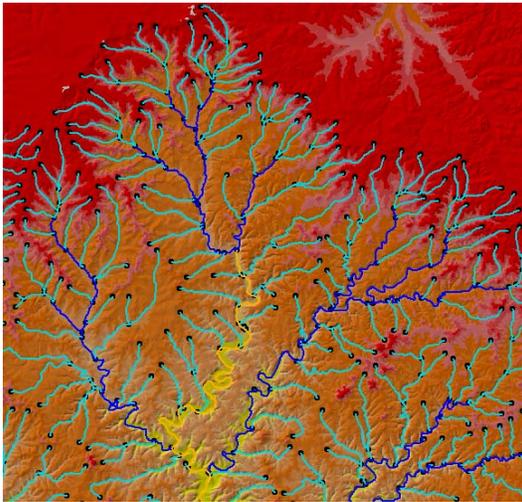
### Stream Gradient and Relative Gradient

Stream gradient is another important variable to consider when devising any experimental design since it has long been recognized as a principle adjustable property of rivers that is often found to be associated with numerous abiotic and biotic factors within streams (Hack 1957; Knighton 1998; Nino 2002).

A 30-meter resolution DEM was processed using the Fill Sinks algorithm that is part of the Hydrologic Modeling tool set in ArcView. Sinks are locations in a DEM that cannot be assigned a flow direction. Sinks in digital elevation data are generally the result of errors in the data. The resulting depressionless DEM was subsequently used to gradients for each arc within the modified 1:100,000 NHD.

Stream gradient was calculated and applied in two different ways. The first and most straightforward method involved calculating gradient for every confluence-to-confluence segment and is represented in meters per kilometer (Figure 31). This was accomplished by draping the stream network over a 30-meter resolution digital elevation model (DEM) and getting the elevation for the node of each stream confluence. Once the upstream and downstream elevations for every stream segment were acquired the difference between them was divided by the segment length (in meters) and multiplied by 1000 to get a gradient in meters per kilometer.

**Method 1**



**Method 2**

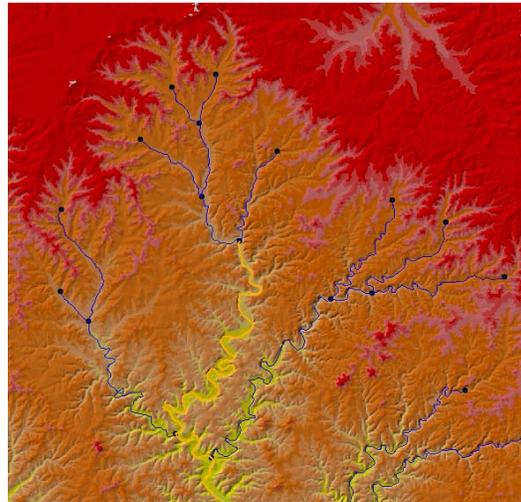


Figure 31. The map on the left shows all streams and confluence nodes on top of a DEM. The map on the right shows the same area with the headwaters removed and the subsequent pseudo nodes also removed. The maps illustrate the different segments for which gradients were generated for streams classified as Creek or larger.

There were instances where the 1:100,000 stream network and the DEM did not correspond perfectly. In some of these instances a portion of the stream fell on valley wall instead of the stream bed, as depicted in the DEM, which produced an elevation on the downstream node that was higher than the upstream node. This resulted in a negative stream gradient. When this occurred we looked at the stream segment in question and the DEM and manually corrected the erroneous elevation and recomputed gradient. In certain instances an appropriate elevation correction could not be determined manually. In these cases we calculated the gradient equal to zero and flagged these segments. These problems were most prevalent in relatively low relief areas.

The second method of calculating stream gradient involved computing gradient over longer distances for streams classified as a Creek. This was necessary because the drop in elevation between two closely spaced confluences on these larger streams was often less than 1 meter, which is the vertical precision of the DEM. By computing gradient over a longer distance the drop is more likely to be at least a meter allowing a gradient other than zero to be determined. To accomplish this we removed all headwater segments from the stream network and then removed all of the pseudonodes (see Figure 31). Gradients were then obtained for these much longer segments and these gradients were then applied back to all of the arcs that had initially made up that segment prior to removing headwater streams. The raw stream gradients of this second method were also placed into relative-gradient categories of low, medium or high (Figure 32). These gradients are relative to both stream size and Aquatic Subregion.

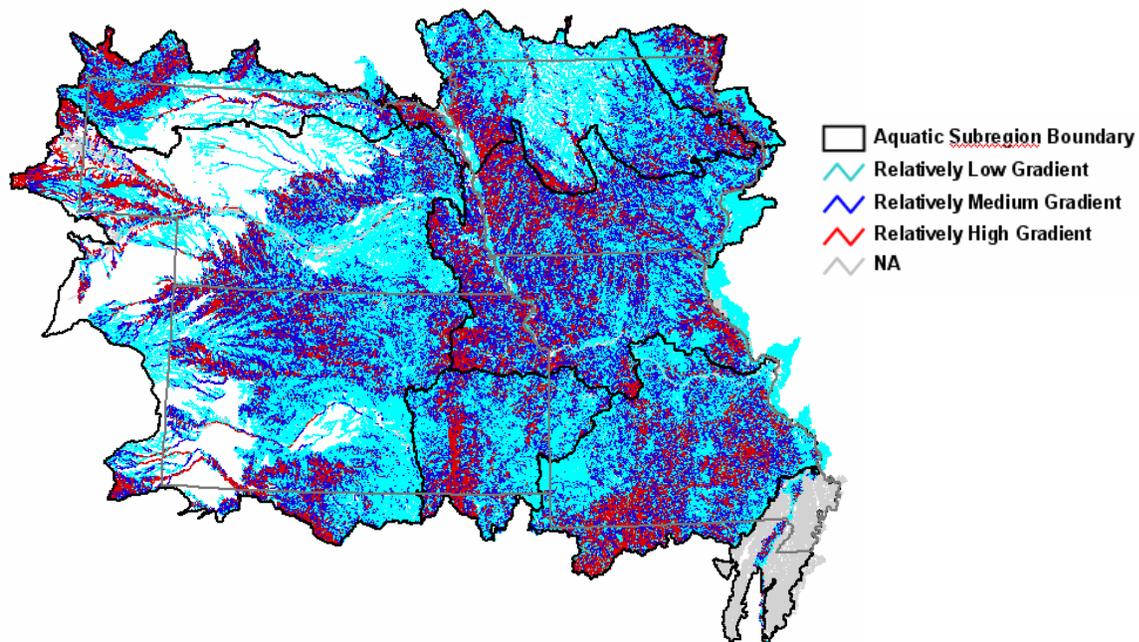


Figure 32. Relative stream gradients for streams in EPA Region 7. Gradients are relative to both stream size and Aquatic Subregion.

### Stream Flow

Stream flow (intermittent or perennial) was an attribute that was already contained within the NHD. For our purposes this attribute was translated into a binary code. In areas of low stream density where we “repaired” the NHD (described earlier) the resulting stream reaches we added were assigned an estimated flow. To accomplish this we found the “average” Shreve link number at which flow transitioned from intermittent to perennial within the same Ecological Drainage Unit. This Shreve link value was used to assign flow to all added reaches. Segments having Shreve link values smaller than this “average transition to perennial flow” were assigned a code for intermittent flow and all link values equal to or larger were assigned a code for permanent flow.

Inundated stream segments in the NHD are typically coded as having permanent flow. We made an effort to code streams that are now inundated by lakes or reservoirs according to the flow that they would have if inundation had not occurred. This was accomplished by looking immediately upstream of the inundated segments and applying the upstream flow codes to the inundated segments.

### Temperature

A temperature code was assigned to every stream segment based on a coverages of known coldwater stream reaches developed by the Missouri Department of Conservation, Nebraska Department of Environmental Quality, and Iowa Department of Natural Resources. Stream segments were coded as being either “cold” or “warm”. Specific temperature ranges were not available.

### Surficial Geology

Surficial geology codes were assigned to each stream segment by assigning the general surficial geology that the majority of the segment is flowing through. This approach is used to avoid having to break a stream segment into numerous small segments every time it crosses a geologic boundary. A good example of a stream segment that would otherwise have to be broken is a segment that flows along a geologic boundary and frequently crosses back and forth from one surficial geology to another. The source data for the surficial geology codes comes from the 1:7,500,000 scale surficial geology of the conterminous United States (Clawges and Price 1999). Within this coverage there are nineteen distinct surficial geology classes that fall within EPA Region 7.

### Generating Valley Segment Types

Once the primary channel network was completely classified, we joined the attributes back to the full stream network, which includes all primary as well as secondary channels (Figure 33). Finally, the individual codes for each of the attributes were concatenated to create the Valley Segment Type (VST) code. Each distinct combination of codes represents a distinct VST. The boundaries between different VSTs can be determined by a single attribute (e.g., change in stream size category) or a combination of attributes (e.g., change in surficial geology and gradient). Each individual valley segment is a spatially distinct habitat, however, all valley segments of the same size, temperature, flow, gradient, etc... fall under the same VST. Different combinations or subsets of variables can be used to create different VSTs.

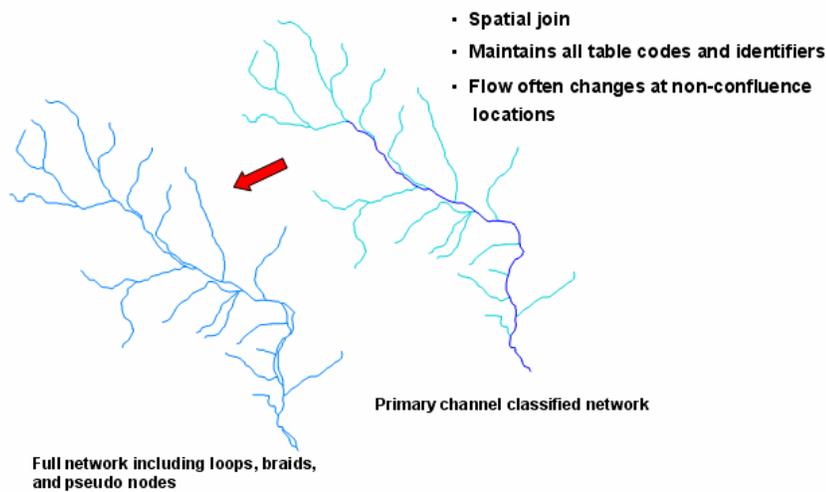


Figure 33. An example of how the classified primary channel network was joined back to the full network, which contained all of the secondary channels.

### *Results*

Through the above process over 400,000 individual stream segments were classified into distinct VSTs across EPA Region 7. The number of distinct VSTs throughout the four state area is dependent upon which suite of attributes are used to define the VSTs.

Using the full suite of attributes there are 599 distinct VSTs, however, this extremely high number is due to the 19 surficial geology attributes. Removing this attribute the number of distinct VSTs drops to 32. This coverage more than any other provides resource professionals with a valuable tool for developing field sampling schemes to meet a variety of research, monitoring and management needs.

## **DISCUSSION**

From a biomonitoring standpoint, the classification system presented in this report has many qualities that offer advantages over other existing classification systems that are currently used for biomonitoring. Currently most states use EPA Level 3 or sometimes Level 4 ecoregions as the principle strata for developing and enforcing biological criteria. In addition to accounting for the structural and functional variation in stream ecosystems as the ecoregions do, our classification also accounts for longitudinal variation along stream ecosystems and incorporates biogeographic and distributional patterns of riverine biota. In their review of the draft document “Biological Criteria: Technical Guidance for Streams and Small Rivers”, the EPA Science Advisory Board noted these two factors as major limitations of existing classification systems used by EMAP to stratify stream ecosystems (EPA 1994). Furthermore, our classification units, at all levels of the hierarchy, fit the definition of an ecosystem for obligate aquatic biota, by incorporating the prominent role isolation mechanisms (e.g., watershed boundaries) play in shaping aquatic assemblages (Pflieger 1989). As a result, our classification system more closely relates to the goal of EMAP which is to monitor and assess “ecological condition” or “ecosystem integrity” by more formally agreeing with EPA’s definition of an ecosystem: “The interacting system of a biological community and its non-living environmental surroundings” (EPA 1992). From a freshwater perspective, ecoregions do not meet this definition of an interacting system. Therefore, we believe that our units provide more meaningful units for reporting the results of biomonitoring programs. This point is directly analogous to reporting scientific results of monitoring or assessment efforts for island chains. The biomonitoring community has overlooked the fact that major river basins are islands embedded in the landscape. Our classification provides this island context so that those interested in biodiversity conservation are not left with questions like; “Which of the major drainages that include this or that ecoregion are experiencing the most dramatic decline resource health?”, when results of biomonitoring programs are published. From a holistic management perspective, *which* watershed or major basin truly matters. The utility of this classification has been illustrated in Missouri. The Missouri Departments of Natural Resources and Conservation are using our classification as the geographic framework for defining reference conditions, developing stratified random sampling designs, reporting results, and the MDNR has proposed using the classification as geographic framework for the development and enforcement of biological criteria (Sarver et al. 2002).

Because of the qualities listed above we believe the resulting geospatial datalayers can be used by EMAP as an efficient tool for developing stratified sampling designs for biomonitoring stream resources across the United States and enable the establishment of more precise biological criteria. Equally important is the fact that this classification

can be used as a common spatial framework for biomonitoring programs and biodiversity conservation efforts as it accounts for structural, functional, and compositional differences among ecosystem units across the landscape.

Another important issue is that this classification hierarchy and associated GIS coverages can be used by individuals with very little GIS experience to help develop a stratified random sampling design for extremely large or small areas in a matter of minutes. More importantly, using the full suite or even a modest subset of the attributes will account for considerably more natural variation in local ecosystem structure, function and composition than will the ecoregion/stream size strata currently used by most states.

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## Appendix A. Biophysical Descriptions of Aquatic Subregions in EPA Region 7

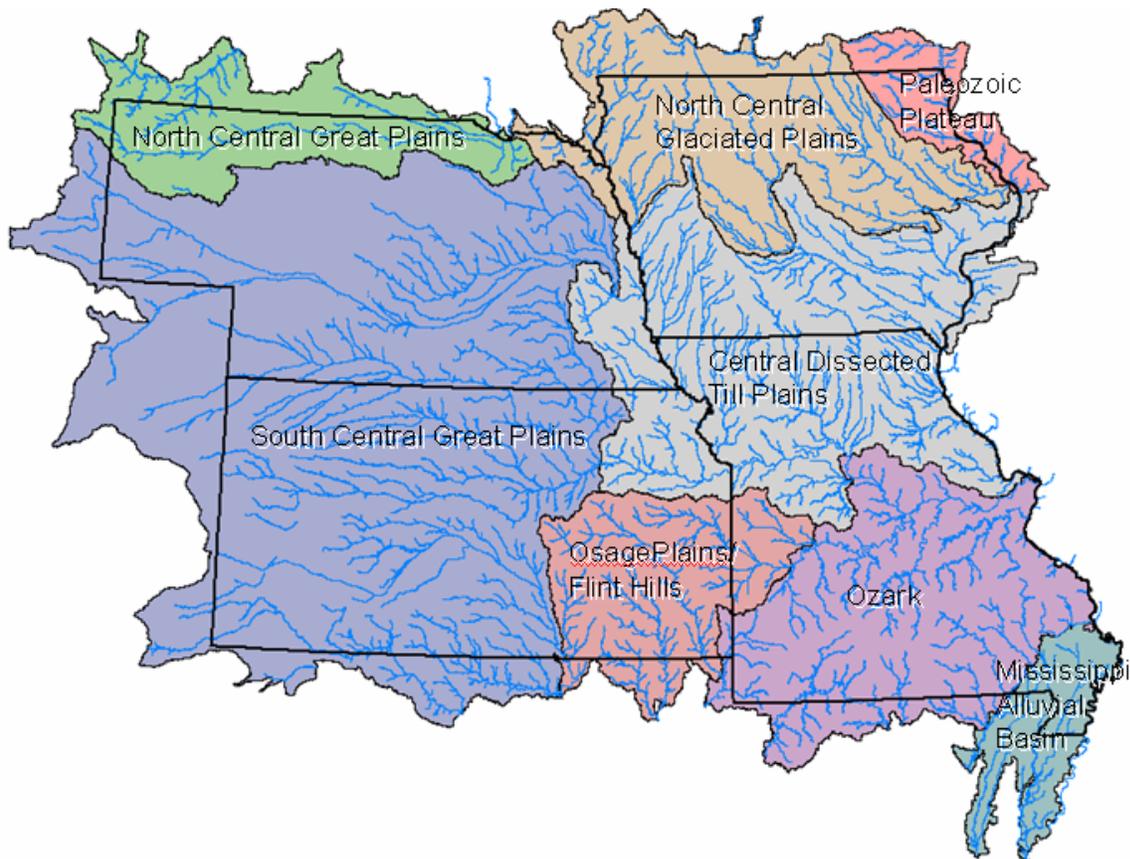


Figure A1. Map of the eight Aquatic Subregions within EPA Region 7.

### **North Central Great Plains**

#### *Boundary*

The boundary of the North Central Great Plains includes all of the Niobrara and White River watersheds (Figure A1).

#### *Climate*

The North Central Great Plains has a continental climate with modest precipitation and temperature gradients that generally follow an east-west trend. Average annual precipitation increases from 18 inches in the west to 24 inches in the east while average annual snowfall decreases from 55 inches in the west to approximately 32 inches in the east. Average annual temperatures range from 45 °F in the west to 48 °F in the east. Average daily January minimum temperatures range from 10 °F in the west to 9 °F in the east, while average daily July maximum temperatures range from 86 °F in the west to 88 °F in the east.

#### *Physiography and Historic Vegetation*

This Subregion largely corresponds with the region known as the Missouri Plateau which covers a diverse landscape that includes gently sloping to rolling plains that are heavily dissected by the tributaries of the upper Missouri River.

Elevation ranges from 1,500 to 3,900 feet while relief averages 100 feet and generally ranges from 20 to 170 feet. The geology of the Subregion is dominated by soft Cretaceous and lower Tertiary shales, siltstones, and sandstones. A unique feature of this Subregion is the prevalence of waterfalls within the Niobrara River watershed west of Valentine Nebraska. These waterfalls primarily occur at the contact between the Valentine and the more resistant Rosebud geologic formations. Bedrock formations are overlain by highly variable soils largely of windblown and stream deposit origin. Mollisols are dominant, however, Alfisols, Entisols, and Vertisols are also locally prevalent in the central and western portions of the Subregion. Soils range from shallow to deep, but generally have a clayey texture, and very slow infiltration. A major exception occurs along the southern boundary of the Subregion, which includes the northern edge of the Sand Hills; here the windblown sand deposits have high infiltration rates. Much of the Subregion is still covered in natural prairie vegetation, which includes western wheatgrass, green needlegrass, blue grama, and buffalograss. On the shallower soils bluebunch wheatgrass, little bluestem, and sideoats grama are the characteristic native grasses. Buffaloberry, chokecherry, snowberry, and sagebrush are common shrubs found in draws and along streams. Ponderosa pine or woodland also occurs on many of the more rugged breaks. Mid and tallgrass prairies cover the Sandhills portion of the Subregion, while valley bottoms are primarily covered in northern flood plain forest.

#### *Stream Habitat and Biota*

Stream habitats vary greatly across the North Central Great Plains and are arguably some of the most variable of any of the Aquatic Subregions in EPA Region 7. Like all prairie/plains regions most small streams in the North Central Great Plains can be generally characterized as having harsh environmental conditions, with an unpredictable and high frequency of flooding and drying. Intermittent and ephemeral channels are very prevalent due to the limited precipitation and high evapotranspiration. However, in this Subregion there are also numerous cold, spring-fed, high gradient streams thanks to the high groundwater potential of the Sand Hills. These latter stream types are mainly concentrated in the upper White and Niobrara River watersheds along the periphery of the Sand Hills. Many of these streams support cool or coldwater fisheries. Coarse substrates and riffle habitats are not nearly as prevalent as that of the Ozarks or the Paleozoic Plateau, however, they are more prevalent than in the other Subregions. Local fish assemblages often reflect the degree of flow stability with habitat generalists and species with rapid colonization capabilities dominating at sites with highly variable flow. The dichotomy of flow conditions found in this Subregion creates a mosaic of habitat conditions that supports a relatively diverse assemblage of riverine species when compared to other geographic regions within the broader Central Plains. Larger streams of the Subregion have more predictable flow regimes since the convective thunderstorms that generally produce the rapid runoff found in smaller channels typically only cover a small fraction of the watershed of these larger rivers.

Larger streams like the White River are extremely turbid and carry high silt/sand loads, however, the Niobrara River has much lower turbidity and more stable hydrology than most other prairie rivers due to the relatively high contributions of groundwater to this river. Smaller streams generally lack a forested riparian corridor and instream cover is often limited. As a consequence most of these streams are dominated by autotrophic processes. Larger rivers are generally bordered by a mixture of grassland and riparian forest and due to downcutting are often bordered by cliffs and fed by groundwater seeps. On average, the smaller streams within the North Central Great Plains have stream gradients only slightly lower than those of the Ozarks and Paleozoic Plateau Subregions. Headwater streams have an average gradient of 13 m/km while creeks have an average gradient of 4 m/km (Figure A2). Streams classified as small and large river actually have the highest gradients for streams of this size in all of EPA Region 7. Average gradients for small rivers are 1.5 m/km and 1 m/km for large rivers (Figure A2).

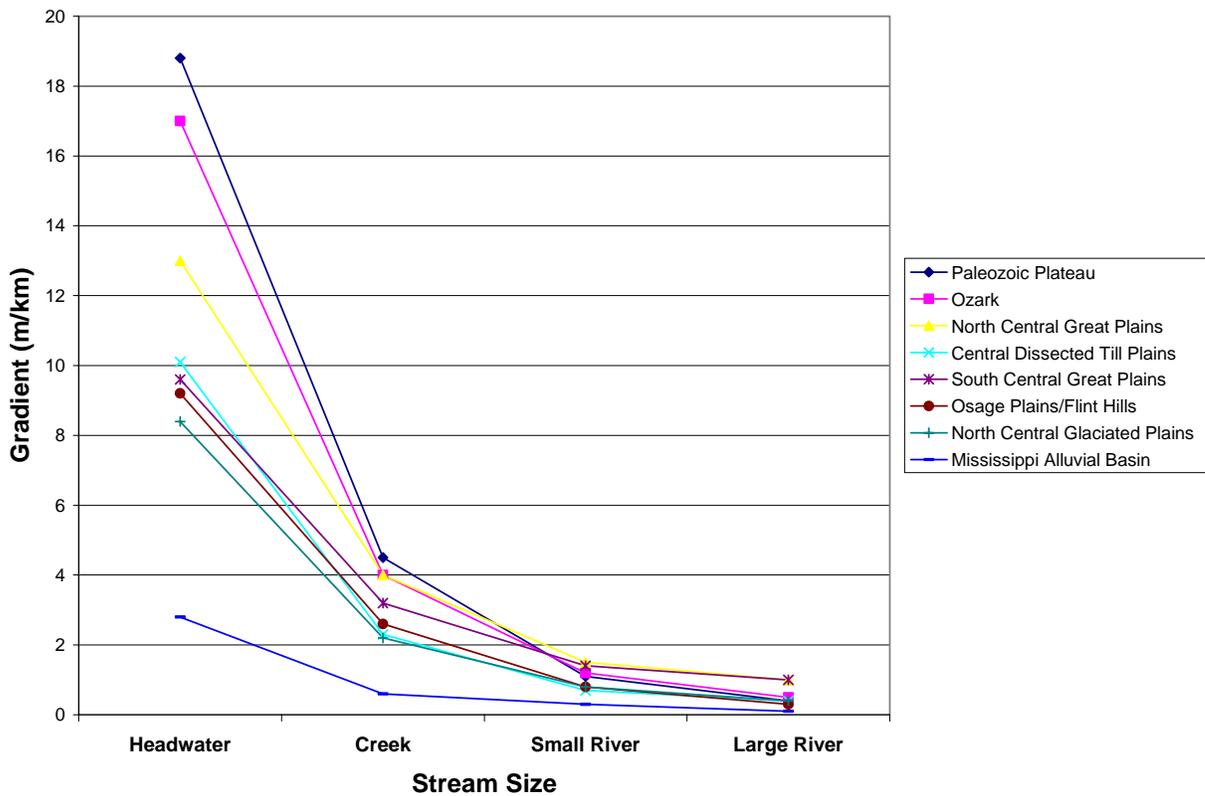


Figure A2. Average gradients for four stream size classes in each of the Aquatic Subregions.

Like the Paleozoic Plateau, the North Central Great Plains Subregion contains many riverine species that are considered glacial relicts that are much more common in the northern, western, or eastern United States. In the most general sense there are two distinct riverine assemblages found in this Subregion. In the spring-fed and stable flowing headwaters of the White and Niobrara River exist most of the glacial relict species that are adapted to clear, cool, headwater

stream habitats. These include the mountain sucker, pearl dace, finescale dace, blacknose dace, northern redbelly dace, and central stoneroller. Many of these streams also support populations of introduced trout species. The lower White and Niobrara River contain a large number of great river species such as flathead catfish and paddlefish and species like the sturgeon chub and flathead chub that have special adaptations to fine substrates and turbid conditions.

## **North Central Glaciated Plains**

### *Boundary*

The western boundary of the North Central Glaciated Plains Aquatic Subregion includes all of the smaller tributaries of the Missouri River north of, and including, the outlet of the Little Sioux River up to and including the Big Sioux River (Figure A1). The eastern boundary with Paleozoic Plateau Subregion is represented by the watershed boundary that divides the Turkey River watershed from the Wapsipinicon River watershed. The southern boundary closely approximates the southernmost extent of the Wisconsin glacial advance; however, the exact boundaries follow major drainage divides in order that subsequent levels of the classification hierarchy meet the definition of an ecosystem. More specifically, the southern boundary includes all of the Des Moines River watershed including and above the confluence of the Raccoon River, the Iowa River watershed above Clear Creek, the Wapsipinicon River watershed including and above Walnut Creek, and the entire Maquoketa River watershed. The southern boundary of this Subregion corresponds with the northern or southern range limit of an amazing 85 fish species, which illustrates both the relatively young nature of this Subregion (glaciated 12-14,000 years ago) and the abrupt transition in stream conditions on either side of this boundary.

### *Climate*

The North Central Glaciated Plains has a continental climate with only minimal spatial variation in temperature and precipitation throughout the Subregion. Average annual precipitation is approximately 34 inches while average annual snowfall is generally 30 inches. Average annual temperatures range from 46 °F in the northwest to 48 °F in the southeast. Average daily January minimum temperatures range from 5 °F in the northwest to 10 °F in the southeast, while average daily July maximum temperatures are approximately 86 °F throughout the Subregion.

### *Physiography and Historic Vegetation*

The landforms of the North Central Glaciated Plains Aquatic Subregion have been strongly influenced by glacial forces, however, erosional and depositional processes associated with wind, rivers, and marine environments operating over the geologic timeframe have also played a significant role. This Subregion can be generally characterized as a flat to smooth or irregular plain with elevations ranging from 900 to 1600 feet. Percent slope is mostly below 5% with relief averaging 60 feet, but typically ranging from 15 to 105 feet. Geology of the North

Central Glaciated Plains includes materials left by rivers, wind, glaciers, and marine environments. Because of the generally thick deposits of windblown and glacial deposits found throughout this Subregion, bedrock geology tends to have limited influence on the structural and functional properties of the freshwater ecosystems. However, there is a general trend to these deposits, with younger Cretaceous limestone and shale materials dominating the western half of the Subregion, which grade into older Mississippian limestones and dolomites and Devonian limestone and shales materials toward the east. Some of the larger streams throughout the Subregion have cut down into the even older Silurian and Ordovician limestones, siltstones, and shales.

Soils in the Subregion are dominated by Mollisols, which developed under the tallgrass prairie that once dominated this geographic region. These soils were derived from highly fertile glacial till, however, in the western and eastern third of this Subregion these glacial tills are also capped with windblown loess deposits. Soil textures range from loam to silty- or clayey loam and primarily have moderate infiltration rates, except for the DesMoines lobe where the soils typically have very slow infiltration rates. The bulk of this Subregion was historically covered in tallgrass prairie, with the prairies of the DesMoines lobe often referred to as black soil prairies due to the deep, dark, and highly fertile glacial soils of this region. The western two-thirds of this Subregion was almost entirely bluestem prairie with narrow corridors of northern floodplain forest or oak-hickory forest bordering many of the streams. The morainal plain in the eastern one third of the Subregion was also covered in bluestem prairie with extensive maple-basswood forest and lesser amounts of oak savannah, oak-hickory forest, and northern flood plain forest. Over 75 percent of this Subregion has been converted to row-crop agriculture, primarily corn and soybeans, and much of the remainder is in forage for livestock. Also, wet meadows and natural lakes were historically scattered throughout the DesMoines Lobe, however, most of these have been drained and filled for agricultural purposes.

#### *Stream Habitat and Biota*

It is generally believed that prior to European settlement the marshy headwaters, coupled with the deep prairie sod, absorbed rainfall like a sponge and released it slowly to the stream channels providing continuous perennial flow throughout much of the system—except during the driest years. Headwater streams were believed to be narrow and deep with relatively cool and clear water compared with the conditions that prevail today. Prairies are now largely gone, replaced by crop fields and intensively grazed fescue pastures that facilitate runoff, soil erosion, and sedimentation. These and many other land use changes have substantially altered hydrologic regimes—particularly high and low flow conditions. Streams in this Subregion are surface water dominated with widely fluctuating flow conditions, including relatively high elevated and peak discharges and extremely low base-flow discharges. Even the very large streams in this Subregion can become a mere trickle during extended dry periods.

Historically, within these relatively open upland prairie stream systems, autotrophic processes dominated and the energy to drive the system was supplied principally by algal production and secondarily by riparian grasses. However, larger, perennial, streams were sometimes bordered by forest. Presently, many streams are no longer nutrient limited, as both point and nonpoint pollution sources have significantly increased nitrate, phosphate, ammonia concentrations, particularly during elevated discharges. Stream gradients in this Subregion are among the lowest in all of EPA Region 7. Headwater streams have an average gradient of 8.4 m/km while creeks have an average gradient of 2.2 m/km (Figure A2). These smaller streams are often intermittent or ephemeral, but are fairly sinuous and deeply downcut into the deep glacial soils. Riffle habitat is scarce as substrates are dominated by silts, sands and clays. However, coarse substrates do occur at locations where streams cut through glacial outwash. Water is generally turbid and woody cover provides important structural habitat and increases in streams from west to east. Small and large rivers have average stream gradients of 0.8 and 0.4 m/km, respectively (Figure A2). These gradients are similar to those of the Osage Plains/Flint Hills Aquatic Subregion.

Assemblages found in most streams of the North Central Glaciated Plains contain species able to withstand harsh environments with widely fluctuating environmental conditions, particularly low dissolved oxygen, high turbidity, high temperatures and intermittent water or complete drying of the stream. Most fish species are either omnivorous or insectivorous. The dominant fish families include Cyprinids, Catastomids, and Percids. Ictalurids are the dominant piscivores in many streams, while Centrarchids such as largemouth bass and green sunfish are also prevalent. Mussel populations, once abundant in this Subregion, are severely declining and research suggests that these declines are associated with the agricultural practices that dominate the region.

## **Paleozoic Plateau**

### *Boundary*

The boundary of the Paleozoic Plateau Aquatic Subregion includes all of the smaller tributaries of the Mississippi River north of the outlet of the Wapsipinicon River in Iowa and south of the outlet of the St. Croix River along the boundary of Minnesota and Wisconsin (Figure A1). This Subregion also includes the lower mainstems and tributaries of the Wisconsin River below Portage, WI, the Black River below Nellville, WI, and Chippewa River below Chippewa Falls, WI. The western boundary with the North Central Glaciated Plains Subregion is represented by the watershed boundary that divides the Turkey River watershed from the Wapsipinicon River.

### *Climate*

This Paleozoic Plateau Aquatic Subregion has a continental climate with modest precipitation and temperature gradients. Average annual precipitation ranges

from 29 inches in the west to 34 inches in the southeast. Average annual snowfall ranges from 32 inches in the south to approximately 50 inches in the north. Average annual temperatures range from 45 °F in the north to 46 °F in the south. Average daily January minimum temperatures range from 3 °F in the north to 8 °F in the south, while average daily July maximum temperatures are fairly homogenous throughout the Subregion only ranging from 83-84 °F. Length of the growing season ranges from 129 to 170 days.

### *Physiography and Historic Vegetation*

The Paleozoic Plateau Subregion is characterized by an abundance of bedrock exposures, deep and narrow river valleys, and limited glacial deposits. The steep slopes, bluffs, abundant rock outcrops, waterfalls and rapids, sinkholes, springs, and entrenched stream valleys provide a physiographic character that within EPA Region 7 is most similar to that of the Ozarks. Along the western edge of the Subregion, where glacial drift is several feet thick, topography is controlled by the underlying glacial till, while further east, where glacial drift is thin, topography is largely bedrock controlled. This boundary between glacial and bedrock controls corresponds with the geographic range limit of 48 fish species. The Subregion is moderately sloping and highly dissected with an overall average land slope of 10% and an average local relief of 157 feet, however local relief of 300 feet or more is common and even ranges to over 600 feet in those areas bordering the Mississippi River. The Paleozoic rock units that characterize this Subregion range in age from 350 to 600 million years old and include formations from the Devonian, Silurian, Ordovician, and Cambrian. The more resistant sandstones and carbonate rocks form cliffs and escarpments high on the landscape whereas the more easily weatherable shales have gentler slopes. A thin cap of glacial loess or drift covers most of the Subregion. Soils are primarily classified as Alfisols with silty-loam texture and moderate infiltration rates. Major vegetation types included tallgrass prairie and bur oak savanna on ridge tops and dry upper slopes. Sugar maple-basswood-oak forest occurred on moister slopes while sugar maple-basswood forests occupied protected valleys and north-facing slopes. River valleys contained northern floodplain forests, wet prairies, marshes, and even mesic prairies at sites more distant from the rivers.

### *Stream Habitat and Biota*

On average, the smaller streams within the Paleozoic Plateau have the highest stream gradients found in any of the Aquatic Subregions in EPA Region 7. Headwater streams have an average gradient of 18.8 m/km while creeks have an average gradient of 4.5 m/km (Figure A2). These smaller streams are often springfed, with cool, clear, water and an abundance of coarse substrates and riffle habitats. These smaller streams have moderately entrenched valleys with average sinuosity. Most of these smaller streams were historically bordered by riparian forest, however, some small streams cutting through flatter terrain were also bordered by prairie, which created a highly diverse mosaic of autotrophy and heterotrophy. Woody cover is present, but not excessively abundant. The more

deeply entrenched small and large rivers have average stream gradients of 1.1 and 0.4 m/km, respectively (Figure 2). These gradients are similar to those of the Ozarks and slightly less than the aggrading, highly braided, rivers of the North and South Central Great Plains. These larger streams were historically bordered by riparian forest. They are cool, clear, and also have substrates dominated by coarse particle sizes and riffle habitats are still present, but not nearly as abundant as the smaller stream sizes. Woody debris is slightly more abundant than in the headwaters. Dissolved oxygen levels are high throughout the year in all stream size classes and pH levels are slightly basic due to the influence of groundwater and its interaction with the calcareous bedrock found throughout the Subregion. Stream assemblages contain a fairly rich diversity of fish, mussel, crayfish, and macroinvertebrates. Many of these species are stenothermic and are intolerant of high temperatures, low dissolved oxygen, turbidity, or fine substrates. In contrast, the North Central Glaciated Plains Subregion to the west is dominated by tolerant species with broad physiological tolerances that can persist in streams with high turbidity, temperatures, low dissolved oxygen, and fine substrates. Fish communities are dominated, in terms of species and total number of organisms, by Cyprinids and Catostomids, but Percids and Centrarchids are also prevalent.

### **South Central Great Plains**

#### *Boundary*

The northern boundary of this Subregion includes the entire Platte River watershed above, but including, the Loup and Elkhorn River watersheds (Figure A1). The eastern boundary of the Subregion includes the entire Kansas River watershed above, but including, the Big Blue River watershed, the Arkansas River watershed above the Walnut River, and the Salt Fork of the Arkansas River above where it empties into the Arkansas River. The western and southern boundaries of the South Central Great Plains were not specifically defined for this project but the western boundary should generally correspond with the physiographic boundary separating the foothills of the Rocky Mountains from the Western High Plains and the southern boundary should generally correspond with the southern boundary of the Edwards Plateau.

#### *Climate*

The South Central Great Plains has a continental climate with fairly strong precipitation and temperature gradients that follow a northwest to southeast trend. Average annual precipitation ranges from 17 inches in the northwest to 35 inches in the southeast. Average annual snowfall ranges from 48 inches in the northwest to approximately 9 inches in the southeast. Average annual temperatures range from 47 °F in the northwest to 58 °F in the southeast. Average daily January minimum temperatures range from 14 °F in the northwest to 20 °F in the southeast, while average daily July maximum temperatures range from 87 °F in the northwest to 94 °F in the southeast.

### *Physiography and Historic Vegetation*

The South Central Great Plains is a large and highly variable Subregion, ranging from very flat areas to rugged hills within the Sand Hills and bordering some of the tributaries to the lower Platte River. However, the Subregion can generally be described as gently rolling and sloping plains where broad ridgetops are separated by moderately steep valleys. Some of the larger rivers that cut through this Subregion, like the Platte River, are highly braided and have very wide flood plains and terraces while the smaller streams have narrow valleys. Elevation ranges from 1,310 to 2,950 ft while relief averages 70 feet and generally ranges from 15 to 120 feet. However, topography is highly variable and there are many areas with near zero relief. The Subregion is underlain by a variety of Quaternary, Tertiary, and Cretaceous sedimentary deposits. These are predominantly shales, but also include siltstones, sandstones, and limestones that originated as erosional materials of the Rocky Mountains. In most places these geologic strata have a deep mantle of windblown sand and loess. These sandy and silty loams are primarily Mollisols and Alfisols that have high to moderate infiltration rates. Most of this Subregion, except the Sand Hills, has been converted to cropland, but historically was covered in prairie. The Subregion ranged from shortgrass prairie in the west to tallgrass prairie in the east with intervening midgrass prairies. The western shortgrass prairies were largely covered in grama-buffalo grass prairie, bluestem-grama prairie, sandsage-bluestem prairie, and wheatgrass-bluestem-needlegrass prairie. Mid and tallgrass prairies cover the Sandhills portion of the Subregion, with wheatgrass-bluestem-needlegrass prairie communities. The eastern edge of the Subregion was covered in tallgrass bluestem prairie and the larger perennial streams were often bordered by northern floodplain forest.

### *Stream Habitat and Biota*

Most small streams in the South Central Great Plains can be generally characterized as having harsh environmental conditions, with unpredictable and high frequency of flooding and drying. Intermittent and ephemeral channels are very prevalent due to the limited precipitation and high evapotranspiration. However, in this Subregion there are also numerous cold, spring-fed, high gradient streams thanks to the high groundwater potential of the Sand Hills. These latter stream types are mainly concentrated in the North Platte and upper Republican River watersheds along the periphery of the Sand Hills. Many of these streams support cool or coldwater fisheries. In addition, the high groundwater contributions to the rivers such as the Loup and Elkhorn, which emanate from the Sand Hills have some of the most stable flow regimes found anywhere in the world. Stream substrates are primarily dominated by sand and silt and most of the larger rivers are wide, shallow, and highly braided. Local fish assemblages often reflect the degree of flow stability with habitat generalists and species with rapid colonization capabilities dominating at sites with highly variable flow. Riparian forest cover varies across the Subregion, being essentially absent in the west and central sections where the drier shortgrass and midgrass prairies dominate and gradually increasing as you enter the

tallgrass prairies. As a consequence most of the western and central streams of this subregion are dominated by autotrophic processes, while streams in the eastern portions exhibit a mixture of autotrophy and heterotrophy. On average, the smaller streams within the South Central Great Plains have stream gradients similar to those in the Osage Plains/Flint Hills. Headwater streams have an average gradient of 9.6 m/km while creeks have an average gradient of 3.2 m/km (Figure A2). Streams classified as small and large river have stream gradients comparable to those in the North Central Great Plains, which are the highest gradients for streams of this size in all of EPA Region 7. Average gradients for small rivers are 1.4 m/km and 1 m/km for large rivers (Figure A2).

## **Osage Plains/Flint Hills**

### *Boundary*

The northern boundary of the Osage Plains/Flint Hills Aquatic Subregion follows the watershed boundaries of the South Grand, Osage, and Neosho Rivers (Figure A1). The western boundary follows the western watershed divide of Turkey Creek and the Verdigris River, which generally separate the Flint Hills to the east from the South Central Great Plains to the west. The eastern boundary generally follows the edge of the Ozark Highlands and more specifically the southern edge of Mississippian geologic deposits. It includes portions of the Osage River watershed above the confluence with the Sac River and the entire South Grand River watershed. The southern boundary is generally unknown since it falls outside of EPA Region 7, however, it should be coextensive with the Osage Plains and Flint Hills ecoregions which would include all of the Verdigris River watershed and the Neosho River watershed, exclusive of those streams draining the Ozarks.

### *Climate*

The Osage Plains/Flint Hills Subregion has a continental climate with modest precipitation and temperature gradients that generally follow a west to east trend. Average annual precipitation ranges from 27 inches in the west to 40 inches in the east. Average annual snowfall ranges from 21 inches in the west to approximately 15 inches in the east. Average annual temperatures are approximately 55 °F throughout the Subregion. Average daily January minimum temperatures range from 17° F in the west to 19 °F in the east, while average daily July maximum temperatures range from 94 °F in the west to 90 °F in the east.

### *Physiography and Historic Vegetation*

The Osage Plains/Flint Hills Subregion is mainly underlain by Permian and Pennsylvanian deposits that are overlain by up to 6 feet of loess. The lithology consists of alternating beds of limestone, sandstone, shale and coal. The limestones are most resistant to erosion and have created northeast to southwest trending escarpments with minor rock outcroppings. Topography is gently rolling, with relief generally in the range of 100-150 feet within the

northwest trending limestone escarpments, and 50 feet in the interceding regions, which are dominated by shale. The Subregion is covered primarily by silty-clays and silty-clayey-loams with slow infiltration rates. Soils were formed in loess or residuum from Permian or Pennsylvanian shale, sandstone, or limestone with or without a thin veneer of loess. Depth of soil is variable, with deep soils along the ridgetops and valley bottoms and relatively thin soils on the adjacent side slopes and bedrock exposures are often visible throughout the Subregion. Flatter areas were nearly continuous tallgrass prairie (bluestem variety), while the more rugged and dissected scarped limestone areas were covered in a mixture of prairie and oak savanna or woodland. Bottomlands were covered in extensive wetlands and bottomland forest. This forest included silver maple, green ash, cottonwood, pecan, pin oak, and bur oak. However, streams in the Flint Hills were and are mainly covered in a mixture of grassland and very narrow and patchy riparian forest. Today this Subregion is primarily an agricultural landscape consisting of a mixture of grassland and row-crop agriculture.

#### *Stream Habitat and Biota*

The sandstone and shales that underlie this Osage Plains impeded downward water movement, making for poor aquifers, which results in these streams being largely surface water dominated. As a result, most of the smaller streams in the Osage Plains are ephemeral or intermittent. Even the largest streams in this part of the Subregion have extremely low discharges during extended dry periods. Springs are extremely rare and those that do exist have minimal discharge and many are saline. Streams occupy broad, shallow valleys that slope gradually into the flat to gently rolling uplands. Stream channels are highly meandering, entrenched, with extremely low gradients (although channels running off the escarpments have relatively high gradients). Waters are generally turbid and substrates mainly sand and silt, with riffles poorly defined or often completely absent, but when present contain slate-like pieces of shale and sandstone embedded in fines. Bedrock is intermittently exposed in some of the smaller streams. Oxbow lakes, sloughs and marshes were once common along the largest streams.

The higher groundwater potential in the Flint Hills results in higher groundwater contributions to stream channels and thus a higher relative percentage of perennial streams and springs in this portion of the Subregion. These streams also tend to have higher gradients, clearer and cooler water, and coarser substrates than streams in the Osage Plains. However, flash flooding is still prevalent in the Flint Hills due to the relatively impermeable bedrock and moderately sloping terrain.

Across the entire Subregion the average gradient across all stream size classes is 6.3 m/Km. Average gradients (m/Km) by size class are: headwater 9.2, creek, 2.6, small river 0.8, and large river 0.3 (Figure A2). The fauna within those streams draining the Osage Plains is characterized by highly tolerant, wide-ranging, species. Within the streams draining the Flint Hills, intolerant species

become more common and abundant (e.g., Topeka shiner, rosyface shiner, orangethroat darter, southern redbelly dace, and central stoneroller). Common crayfish species include the grassland and papershell crayfish. Common mussels include the ellipse and black sandshell.

## **Central Dissected Till Plains**

### *Boundary*

The eastern boundary of the Central Plains Aquatic Subregion (CP) includes all of the drainages entering the Mississippi Rivers between the Wapsipinicon River and the Missouri River (Figure A1). The western boundary of this Subregion includes the outlet of the Platte River watershed below the Elkhorn River and also the lower Kansas River watershed below the outlet of the Big Blue River. The northern boundary closely approximates the southernmost extent of the Wisconsin glacial advance; however, the exact boundaries follow major drainage divides in order that subsequent levels of the classification hierarchy meet the definition of an ecosystem. More specifically, the northern boundary includes the Des Moines River watershed below the confluence of the Raccoon River, the Iowa River watershed below Clear Creek, and the Wapsipinicon River watershed below Walnut Creek. The southern boundary follows the northern edge of the Ozark Highlands and the Osage Plains and includes all of the smaller drainages of the Missouri River west of the outlet of the Chariton River, including the Blackwater-Lamine drainage.

### *Climate*

The CP has a mean annual temperature of 53 ° F that ranges from 52 in the northwest to 54 in the southwestern and southeastern corners of the Subregion. Mean July maximum temperatures vary only slightly (88 to 90° F) and follow a northeast to southwest gradient. Mean January minimum temperatures range from 12 ° F in the northwest to 18 ° F in the southeastern part of the Subregion.

Mean annual precipitation ranges from 34 inches in the extreme northwest section of the Subregion to 41 inches in the southwest. Precipitation is lowest in the winter with monthly averages typically less than 2 inches during this period, which is notably less than the other two Subregions. Mean annual snowfall is highest in this Subregion with an overall average of 20 inches. Precipitation is generally highest from late spring to early fall with monthly averages of around 4 to 5 inches. Like the rest of the state, however, most parts of this Subregion experience a noticeable dip in precipitation during hottest part of the summer—late July and August, which can prove to be a very stressful period for riverine biota.

Intense rainfall, drought, and both heat and cold waves occur throughout Missouri and can all serve as potential disturbances affecting community composition over short and long temporal scales and also local and broad spatial scales. Once every two years 24-hour rainfall totals of 3 to 4 inches are

expected to occur in any given part of the state and in north Missouri temperatures above 90° F are recorded on an average of 40-50 days each year.

### *Physiography and Historic Vegetation*

Topography of this Subregion can be generally described as low or gently rolling plains. Streams occupy broad flat valleys that almost imperceptibly grade into the surrounding uplands. Surface elevations range from approximately 300 feet in the floodplains of the larger streams draining to the Mississippi River to 1,600 feet in the northwest corner of the Subregion. Elevations along the divides separating the larger rivers range from ~ 800 to 1,000 feet. The CP is gently sloping and moderately dissected, even within those areas affected by glaciation, with an overall average land slope of 5% and local relief of 80 feet, but relief typically ranges from 50 to 200 feet.

Bedrock within the CP consists mainly of Pennsylvanian-age (3.2 million ybp) shales, coal, sandstones, and limestones with shales accounting for the greatest surface area. Along the Mississippi River, particularly in the North River and Salt River watersheds, there is a region known as the Lincoln Anticline or Fold, which brings older Mississippian and Ordovician-age formations to the surface. The CP is dominated by mollisols in the west/southwest and alfisols in the east/northeast. Although alfisols are generally thought to develop under forested conditions it is believed that both the mollisols and alfisols of this Subregion developed under prairie.

The original landscape of the Glaciated Plains subdivision was leveled by continental glaciation during the Pleistocene Epoch (2,000,000 ybp) and subsequently buried under layers of till and loess of varying thickness. Today this area north of the Missouri River consists of tills (sand, silt, and clays) that were largely derived from the disintegration of sandstones, limestones, and shales originating in Minnesota, Wisconsin, Iowa, Illinois, and northern Missouri. Loams and silty-loams with high to moderate infiltration rates are the dominant surface materials in much of this area. Highest infiltration rates occur along the loess bluffs bordering the Missouri and Mississippi Rivers. However, these relatively high infiltration rates are somewhat offset by the significantly steeper slopes of the loess bluffs, which promote runoff. The Audrain Plain in the southeastern part of the Subregion also has very slow infiltration rates and high runoff due to the presence of an extensive claypan in the subsoil, which is why this area is also sometimes referred to as the "Claypan" region. Prairies dominated the CP prior to extensive Euro-American settlement. Prairies occurred as both upland prairies and wet prairies on the wide alluvial plains along the major rivers. Headwaters were likely marshy and dominated by wetland grass complexes while the immediate riparian area of many, but not all, of the larger streams was forested. In addition, oak forests occurred in the hills and blufflands along the Missouri and Mississippi Rivers, except in northwestern Missouri where midgrass prairies occupied the deep-loess blufflands. Upland

deciduous forests also dominated the more rugged Lincoln Hills.

### *Stream Habitat and Biota*

The shales and heavy clay subsoils that underlie most of this Subregion are poor aquifers. As a result, there are relatively few springs and those that do exist have very minimal discharge and most are highly mineralized. Despite this lack of springs, it is generally believed that prior to European settlement the marshy headwaters, coupled with the deep prairie sod, absorbed rainfall like a sponge and released it slowly to the stream channels providing continuous perennial flow throughout much of the system—except during the driest years. Prairies are now largely gone, replaced by crop fields and intensively grazed fescue pastures that facilitate runoff, soil erosion, and sedimentation. These and many other land use changes have substantially altered hydrologic regimes—particularly high and low flow conditions. Streams in the CP are surface water dominated with widely fluctuating flow conditions, including relatively high elevated and peak discharges and extremely low base-flow discharges. Even the very large streams in this Subregion can become a mere trickle during extended dry periods.

Water is normally a calcium-magnesium-bicarbonate type and total dissolved solids are generally less than 500 mg/l. Historically, within these relatively open upland prairie stream systems, autotrophic processes dominated and the energy to drive the system was supplied principally by algal production and secondarily by riparian grasses. Farther downstream, forested bottomlands were more prevalent, and riparian shrubs and trees provided the dominant organic energy source. Presently, many streams are no longer nutrient limited, as both point and nonpoint pollution sources have significantly increased nitrate, phosphate, ammonia concentrations, particularly during elevated discharges.

Low dissolved oxygen concentrations are quite common throughout this Subregion, especially during summer and winter. Considering that many of the characteristic fish species of this Subregion are tolerant of hypoxic conditions suggests that such conditions occurred naturally and played a strong selective role in the evolution of this Subregions riverine fauna.

Average channel gradients, in meters per kilometer, are 10.1 for headwaters, 2.3 for creeks, 0.7 for small rivers, and 0.4 for large rivers (Figure A2). Historically, headwater streams had well defined pools and riffles and further downstream pools would become quite long and riffles were short, poorly developed, or often completely absent. Larger streams use to be extremely sinuous, which maintained high habitat diversity (diversity of depths, velocities and substrates). Silt, sand and fine gravel are the predominant bottom types. Bedrock is exposed only in some upland tributaries that have cut completely through the thick mantle of glacial till, and in some larger streams that transgress divides of the preglacial drainage. Streams within most of this Subregion are believed to have at one time carried much clearer and cooler water than they do today. Row-crop agriculture, grazing, channelization, roads, and removal of riparian vegetation

have collectively led to substantially elevated sediment loads and temperatures in these streams. Even slight elevations in discharge will render these streams turbid due to resuspension of the abundant fine sediments that dominate the stream bottoms and banks. Only during extended base-flow conditions will most streams achieve any sort of clarity.

Historically, the larger streams in this Subregion would freely meander across their broad-valleys and in the process create numerous backwater sloughs and oxbows. These lentic floodplain habitats served as important accumulators and transformers of both autotrophic and heterotrophic energy sources, which the adjacent river and biota would access during overbank flows. They also served as important reproductive and nursery habitats for many fish species, as well as, the principle habitat for many crayfish, mussel, and amphibian species.

Presently there are very few channels, of any size, that have not been channelized or straightened to some degree. Almost all of the sloughs and oxbows have been drained and filled. These once diverse stream ecosystems have subsequently become remarkably homogenous in character; often straight as an arrow with uniform depths and velocities, and substrates dominated by sands and silts. Riffle habitats are not nearly as common as they historically were and woody structure has been, and continues to be, removed from most of the larger streams to further expedite the downstream transmission of water.

Assemblages found in most streams of the CP contain a species able to withstand harsh environments with widely fluctuating environmental conditions, particularly low dissolved oxygen, high turbidity, high temperatures and intermittent water or complete drying of the stream. Because the species that occur in the CP can live in a variety of environmental conditions they generally have broad geographic ranges. Only two species, one fish (Topeka shiner: *Notropis topeka*) and one crayfish (grassland crayfish: *Procambarus gracilis*), are endemic to the CP.

## **Ozarks**

### *Boundary*

The Ozark Subregion includes all of the smaller direct tributaries to the Missouri River downstream from the outlet of the Little Chariton River, excluding the Blackwater/Lamine drainage (Figure A1). It includes the eastern third of the Osage River watershed, downstream from, and including, the Sac River watershed, but excluding the South Grand River watershed. It also includes the entire Gasconade and Meramec River watersheds and those portions of the Neosho and White River watersheds that fall within Missouri. The southeast boundary with the MAB is marked by an abrupt change in elevation, relief, and surficial materials. This boundary affects streams like the Eleven Point, Current, Black, and St. Francis River that drain some of the most rugged and characteristic Ozark landscapes, but eventually flow into the MAB with a

corresponding abrupt change in physicochemical conditions. The mainstems of these large rivers were clipped at this abrupt change in physiographic conditions and all of the tributaries (and their watersheds) that flowed into these mainstems while they were cutting through the Ozarks were included as part of the Ozark Subregion. Lastly, it includes all of the small direct tributaries to the Mississippi River between the outlet of the Headwater Diversion Channel near Cape Girardeau, Missouri and the outlet of the St. Francis River near Helena, Arkansas.

Three physiographic subdivisions of the Ozarks are widely recognized in Missouri: the St. Francois Mountains, the Salem Plateau, and the Springfield Plateau. The St. Francois Mountains is a small area of igneous knobs and peaks located in southeast Missouri, which covers much of the St. Francis River watershed and minor portions of the Black and Meramec River watersheds. The Salem Plateau is the largest subdivision and is coextensive with those areas of the Ozarks underlain by Ordovician age and older sedimentary rocks. The Springfield Plateau lies west of the Salem Plateau and is coextensive with those areas underlain by Mississippian age rocks. Our discussion of variations in physiographic character and stream conditions will often be framed within these three subdivisions.

#### *Climate*

The Ozark Subregion has a mean annual temperature of 55 ° F and ranges from 54 in the north to 56 in the southeastern corners of the Subregion. Mean July maximum temperatures are a fairly uniform 90° F, however, slightly lower maximums occur in the central Ozarks. Mean January minimum temperatures range from 16 ° F in the northeast to 22° F in the southeastern part of the Subregion.

Mean annual precipitation ranges from 40 inches in the north to 48 inches in the southeast. Precipitation is lowest in the winter with monthly averages around 2 to 3 inches during this period. Estimated mean annual evapotranspiration is 30 to 35 inches/year. Precipitation is generally acidic with a low dissolved solids concentration (Adamski et al. 1995). There is a wide range of mean annual snowfall across the Subregion, but it is still a hydrologically insignificant form of precipitation. In the northeast snowfall averages 20 inches, but only half this amount generally falls in the southeast corner. Precipitation is generally highest from late spring to early fall with monthly averages of around 3 to 5 inches but, like the Central Plains Subregion, there is a noticeable dip in precipitation during hottest part of the summer; late July and August.

#### *Physiography and Historic Vegetation*

Topography of the Ozark Subregion is highly variable ranging from very steep in those areas bordering the major streams to nearly level along many of the

drainage divides. Valleys in the upper parts of basins are generally wide with gradual slopes extending from the stream channel to the valley wall. Larger streams occupy narrow, steep-sided, valleys that are frequently bordered by high bluffs. Surface elevations range from approximately 400 feet in the floodplains of the larger streams draining to the Mississippi River to almost 1,800 feet at Tom Sauk Mountain—the highest elevation in Missouri. Elevations along the divides separating the major drainages typically range from 1200 to 1,600 feet in the central Ozarks. The Subregion is moderately sloping and highly dissected with an overall average land slope of 9% and local relief of 148 feet, however local relief of 300 feet or more is common. Slopes greater than 20% are most common in the St. Francois Mountains and the Salem Plateau, particularly in those lands bordering the major rivers. The Springfield Plateau has much lower slopes and local relief.

Geologically, the Ozarks is one of the oldest regions of the world, having been an exposed, unglaciated, land surface since the end of the Paleozoic Era. The Subregion is characterized by a core of Precambrian igneous rocks that underlie the St. Francois Mountains surrounded by nearly flat-lying Paleozoic sedimentary rocks of Cambrian, Ordovician, and Mississippian age. Ordovician age rocks are the dominant underlying structure within the Salem Plateau. The Springfield Plateau is primarily underlain with Mississippian and Pennsylvanian age rocks, which also underlie the northern edge of the Ozarks along the Missouri River. As previously stated, the distributional limit of many species characteristic of the Ozarks correspond with the Mississippian-age geologic formations that separate the younger Pennsylvanian formations that dominate the Central Plains from the older Ordovician formations that dominate the central Ozarks. The sedimentary rocks of this Subregion are dominated by cherty limestone and dolomite, with smaller contributions of sandstone and shale.

The alfisols and ultisols that dominate the Ozarks are generally considered “poor” and are unsuited for row-crop agriculture except within the alluvial floodplains along the larger rivers and some of the broad flat ridgetops. Weathering of the carbonate rocks has produced a variable thickness of residuum. Most soils have moderate to slow infiltration rates) and have high potential to leech nutrients to groundwater and a high potential for runoff during periods of intense rainfall that bypass the karst drainage system. In areas of high relief and steep slopes the surface texture of soils range from coarse-loam to very coarse-silty-loam. Gradual sloping areas are dominated by silty-loams. Extremely stony soils occur in the St. Francois Mountains and also in those lands just north of the Missouri River between the outlet of the Osage River and the city of St. Louis.

Presettlement vegetation included forests, woodland, savanna, and significant prairie tracts. Forests covered most of the Salem Plateau and St. Francois Mountains. Oaks dominated most of the forests, however, pine was codominant and sometimes occurred as nearly pure stands in the southern and southeastern sections of the Subregion. Bottomlands were typically covered in deciduous

forest. These lowland forests generally contained a larger variety of species including sycamore, cottonwood, maple, black walnut, butternut, hackberry, poplar, and bur oaks. Prairies occurred in small to moderately sized tracts along the outer belts of the Ozarks and were most abundant within the Springfield Plateau. These prairies generally occurred on the smooth uplands while the bottomlands were forested. These scattered upland prairies along the northern and western border of the Ozarks represented a transitional vegetative cover between the forested interior of the Ozark Subregion and the more extensive prairie tracts of the Central Plains Subregion.

#### *Stream Habitat and Biota*

Within the soluble carbonate rocks (i.e., limestone and dolomite) that dominate the Ozarks a karst drainage system has developed with abundant caves, sinkholes, springs, and underground streams. Losing streams, which are streams that lose a portion or all of the surface flow to the underlying groundwater system, are scattered throughout the Subregion. Most Ozark streams are high gradient, cool, and clear with coarse substrates and bedrock exposures. Riffles are abundant and channels are generally moderately sinuous with minimal braiding. Streams that receive water from a large spring may maintain water temperatures suitable for supporting coldwater fisheries for a considerable distance below the spring. Sections of several Ozark streams are classified as coldwater and all but a few contain naturalized populations of rainbow trout or put and take fisheries of brown and rainbow trout. Despite the relatively high baseflow discharge of Ozark streams, surface runoff from intense storms that bypass the karst drainage system can produce extremely high unit discharges. Waters are typically calcium or calcium-magnesium bicarbonate.

Low dissolved oxygen concentrations are generally not a problem in Ozark streams. However, low concentrations can and do occur within the intermittent pools of headwater streams from late summer through winter due to high temperatures and high biological oxygen demand resulting from the decay of organic matter trapped within these pools.

Headwaters generally have shallow valleys and steep gradients averaging 17 m/Km but range as high as 40 or 50 m/Km (Figure A2). Stream reaches are characterized by short pools and well-defined riffles with substrates comprised of gravel, cobble, boulder and bedrock. Small springs and seeps are common especially within the south and southeastern Ozarks. Many headwater streams have intermittent flow, meaning they may be dry with the exception of the deepest pools during the summer. Creeks have deeper valleys and significantly lower gradients than the headwaters—averaging 4 m/Km (Figure A2). Riffle substrates are generally gravel and cobble while the substrate in pools will include detritus, sand, and silt in addition to coarser substrates. Gravel bars on convex banks are common as are extensive stretches of exposed bedrock, especially when the channel is near the valley wall. As with headwater streams all except the largest and deepest pools may be dry during the summer. Small

rivers exhibit deep pools with sand and silt bottoms, but riffles still contain mainly gravel and cobble substrates. Large springs are fairly common along these streams, which typically have permanent flow. Average gradients for small rivers is 1.2 m/Km while large rivers have an average gradient of 0.5 m/Km (Figure A2). Broad deep valleys with channels containing long pools and deep chutes along with backwaters and cut-offs typify the largest Ozark rivers. Pools have sand and silt bottoms, while swifter areas maintain gravel and cobble substrates.

Under natural conditions, the energy dynamics of Ozark streams nearly typify the synthesis put forth in the River Continuum Concept. Headwaters and creeks are generally well shaded with little primary production and are heterotrophic—deriving most of their energy from allochthonous inputs from the surrounding riparian vegetation. The invertebrate community within these headwaters is dominated by shredders which breakdown the abundant coarse particulate organic matter. In small rivers the channels become wider and primary production increases such that photosynthesis is greater than respiration resulting in an autotrophic community. In these reaches there is a codominance of collector-filterers and scrapers, which feed on the attached algae. In large rivers (orders >6), the surrounding vegetation does not shade the stream, however, turbidity of the water inhibits primary production and even though the vegetation contributes little to the energy budget of the system, these reaches are also characterized as heterotrophic. However, some large rivers in the Ozarks (e.g., Current, Black, Meramec) maintain relatively clear waters and therefore maintain relatively high autotrophic production.

The Ozark Aquatic Subregion supports a highly diverse and distinctive aquatic fauna. A total of 296 species (202 fish, 65 mussels, and 29 crayfish) can be found in the flowing waters of this Subregion. Fifty-six of these species (25 fish, 9 mussels, and 18 crayfish), or 19%, have geographic ranges that are either entirely or nearly restricted to the Subregion. This high number of endemic species is a result of both the age of the Ozarks and the isolation of the principal drainage systems by the Great Rivers (e.g., Missouri and Mississippi Rivers) into which they drain.

The 202 fish species represent 27 different families with the most dominant small fishes being minnows (Cyprinidae) and darters (Percidae) while suckers (Catastomidae) and sunfishes (Centrarchidae) are the dominant large species. Twenty six of these fish species are considered endemic to the Ozark Aquatic Subregion. There are 63 native and two introduced mussel species in the Ozark Aquatic Subregion. All but one of the native species falls within the family Unionidae and one of three subfamilies, Ambleminae, Lampsilinae, and Anodontinae. The most common and widespread species are the giant floater (*Pyganodon grandis*), pondmussel (*Ligumia subrostrata*), fatmucket (*Lampsilis siliquoidea*), and paper pondshell (*Utterbackia imbecillis*). Nine mussel species have geographic ranges that are either entirely or nearly restricted to the Ozarks. Like all species of crayfish east of the Rocky Mountains, all of 29 crayfish species that inhabit Ozark

streams fall within the family Cambaridae (Pflieger 1996). The most common and widespread species are the spothanded (*Orconectes punctimanus*), golden (*Orconectes luteus*), devil (*Cambarus diogenes*), and virile (*Orconectes virilis*) crayfish. Nearly three quarters (21 species, 72%) of the crayfish species found in Ozark streams are endemic to the Ozark Aquatic Subregion.

## **Mississippi Alluvial Basin (MAB)**

### *Boundary*

The MAB includes the lower portions of the Current, Black, and St. Francis River watersheds (Figure A1). It also includes the Little River drainage, St. Johns Ditch and the New Madrid Floodway of the Mississippi River. The Benton Hills and Crowley's Ridge, which are essentially topographic "islands" of Ozark character surrounded by a "sea" of nearly flat alluvial plain are also included within the MAB Subregion. The features defining the boundary between the MAB and the Ozarks is described above within the discussion of the boundary of the Ozark Subregion.

### *Climate*

The MAB has the highest mean annual temperature and precipitation within the state. The mean annual temperature is 58 ° F and ranges from 57 in the north to nearly 59 in the south. Mean July maximum temperature is 90° F, which is essentially the same as the Ozarks, however, mean January minimum temperature is 24° F, which is slightly higher than the Ozarks and substantially higher than the Central Plains.

Mean annual precipitation is 50 inches. Unlike the other two Subregions, which generally receive the lowest amounts of precipitation during winter, precipitation in the MAB is lowest in late summer and early fall. There are generally two peaks in precipitation, one throughout the spring and again in late fall and early winter with monthly averages of around 5 inches during these two periods. Like the rest of the state, rainwater is generally acidic with a low dissolved solids concentration. On average this Subregion only receives 6 to 8 inches of snowfall each year.

### *Physiography and Historic Vegetation*

The Mississippi River and its tributaries originally sculpted the MAB landscape producing a surface geomorphology consisting of natural levees, meander scar lakes, point bars, ridges, and swales. More generally this Subregion is characterized as a broad plain that averages 300 feet above sea level with a gentle slope to the south. The overall average slope is less than 1% and overall average relief is approximately 10 feet. Crowley's Ridge, which rises anywhere from 50 to 250 feet above the surrounding plain, is the most prominent topographic feature of the Subregion. This topographic island has much higher

slopes of approximately 5% and local relief ranging to 150 feet or slightly more in some places.

Bedrock is an unimportant feature of MAB landscape except within Crowley's Ridge, which is underlain mainly by Cretaceous and Tertiary sandstones, siltstones and shales with some minor inclusions of Ordovician sandstones and dolomites. Crowley's Ridge is capped by a relatively thick mantle of windblown loess deposits similar to those found along the bluffs of the Missouri and Mississippi Rivers in other parts of the state. The remainder of the MAB is underlain by Cretaceous and Tertiary deposits of clay, sand, and gravel that range from a few feet to more than 2,700 feet in thickness. These older sediments are buried under a layer of alluvium deposited by the St. Francis, Mississippi, and Ohio rivers during Pleistocene and recent times. Inceptisols and entisols with relatively low infiltration capacities dominate the alluvial bottoms of the larger rivers and ditches while higher ground is covered primarily by alfisols with moderate to high infiltration capacities.

In its original condition the MAB was one of the most heavily timbered regions of Missouri. Also, despite the nearly level landscape of this Subregion, a relatively high water table combined with varied soils provided a diverse landscape for plant communities to form. Site conditions within the MAB ranged from permanently flooded areas supporting only emergent or floating aquatic vegetation, to high elevation sites supporting complex hardwood forests. The dominant historic natural communities included various types of bottomland hardwood forests, but major areas consisted of upland deciduous forests dominated by oaks and smaller areas associated with sandy ridges supported prairie and oak savanna. The distribution of community types and successional stages of the bottomland hardwood forests was partly determined by the timing, frequency, and duration of flooding. Elevational differences of only a few inches resulted in great differences in soil saturation characteristics and plant distribution. As a result, components of this bottomland hardwood ecosystem ranged from bald cypress/tupelo swamp communities in saturated or inundated situations, to a cherrybark oak/pecan community where inundation is infrequent and temporary. Between these distinct types are transitional overcup oak/water hickory, elm/ash/hackberry, and sweetgum/red oak communities.

Of all the regions of Missouri, the MAB has lost the greatest part of its historic vegetation with only a few small remnants of the nineteenth century forest cover remaining. Almost 95% (excluding Crowley's Ridge) of this Subregion has been drained and converted to farmland with the vast majority being cropland; particularly soybeans, wheat, corn, cotton, and rice. The only extensive areas of standing timber and swamps that remain are Duck Creek Conservation Area and Mingo National Wildlife Refuge. Other smaller remnants include Otter Slough, Alldred Lake, Wolf Bayou, Big Oak Tree State Park, and Cash Swamp.

### *Stream Habitat and Biota*

The MAB is now a region of few natural alluvial rivers as a result of one of the world's most ambitious land clearing and drainage efforts that took place during the first half of the twentieth century. This once swamp- and wetland-dominated landscape is now covered with thousands of miles of an amazingly complex network of drainage ditches. Channelization efforts typically lead to a reduction in overall stream miles, however, in the MAB ditching and draining efforts have led to a dramatic increase in the mileage of stream channels. The actual increase in miles of channel is unknown, however, historic maps of the Subregion show very few stream channels—certainly nothing close to what exists today.

Average annual runoff ranges from 18 to 20 inches, which is the highest in the state. However, the nearly flat topography of the MAB results in low runoff rates and the sand and gravel alluvial deposits that overlay the relatively impermeable clayey subsoils make excellent shallow aquifers. These two factors are collectively responsible for the relatively stable hydrographs and high baseflow potential of streams and ditches within the MAB where even the smallest channels tend to carry water during the driest periods of the year.

Despite the seemingly homogenous character of the MAB landscape, the ditches and few remaining natural streams in the Subregion vary substantially in terms of discharge, turbidity, current, substrates, aquatic vegetation and shading by riparian vegetation. Smaller ditches are most variable in character, but generally have higher water clarity than larger ditches. Some have no perceptible current during base flow with bottoms comprised mainly of silt while others are fairly swift and have bottoms mostly comprised of sand and small gravel. Channels with clear water and little riparian shading are generally choked with submergent vegetation. Some of the major ditches are large enough to be classified as either small or large rivers. These ditches are extremely wide and shallow with considerable current throughout. Channels classified as headwaters have an overall average gradient of 2.6 m/Km, while the average gradient of channels falling within all other sizes classes are less, and often substantially less, than 1 m/Km (Figure A2). Despite these low stream gradients headcutting and rill and gully erosion are substantial problems upstream from channelized sections. Cover is generally sparse and is often confined to undercut banks and associated vegetation or woody debris. Woody cover is typically much more abundant in unchannelized stream sections.

The small streams draining Crowley's Ridge have hydrologic and instream habitat conditions similar to those found in some streams within the Ozarks. Streams are relatively clear with sand and gravel substrates and occasional bedrock exposures. Seeps and springs are common and many of the smallest channels are either intermittent or completely dry during base flow periods.

The aquatic fauna of the MAB Subregion is not nearly as diverse as the Ozarks, but no less distinctive. A total of 172 species (128 fish, 34 mussels, and 10

crayfish) inhabit the streams and ditches of this Subregion. While only five of these species are endemic to the MAB, thirty species of fish and crayfish are either confined or occur only occasionally elsewhere in Missouri. Many of these species are characteristic of the Gulf Coastal Plain of the southern United States and reach the northern limit of their range in MAB Subregion of southeast Missouri.

The 128 fish species represent 23 different families with the most dominant small fishes being minnows (Cyprinidae) and darters (Percidae). There is really no single group of large fishes that are dominant in the MAB. Only two of these fish species, the bantam sunfish (*Lepomis symmetricus*) and the sabine shiner (*Notropis sabinae*), are endemic to the MAB. All of the 34 mussel species of the MAB fall within the family Unionidae and one of three subfamilies, Ambleminae, Lampsilinae, and Anodontinae. No mussel species are endemic to the MAB.

The MAB supports a small but distinctive crayfish fauna of 10 species. The most common and widespread species are the devil (*Cambarus diogenes*), gray-speckled (*Orconectes palmeri*), red swamp (*Procambarus clarkii*), and Shufeldt's dwarf (*Cambarellus shufeldtii*) crayfish. Only the shrimp (*Orconectes lancifer*) and vernal (*Procambarus viaeviridis*) crayfish are endemic to the MAB.

## Appendix B. Biophysical Descriptions of Ecological Drainage Units (EDUs) in EPA Region 7.

### Central Dissected Till Plains Aquatic Subregion

#### *Blackwater/Lamine EDU*

The Blackwater/Lamine EDU lies in westcentral Missouri. Overall there are 13,841 km of primary stream channel within this EDU, of which 3,819 km are classified as perennial in the 1:100,000 National Hydrography Dataset (Figure B1).

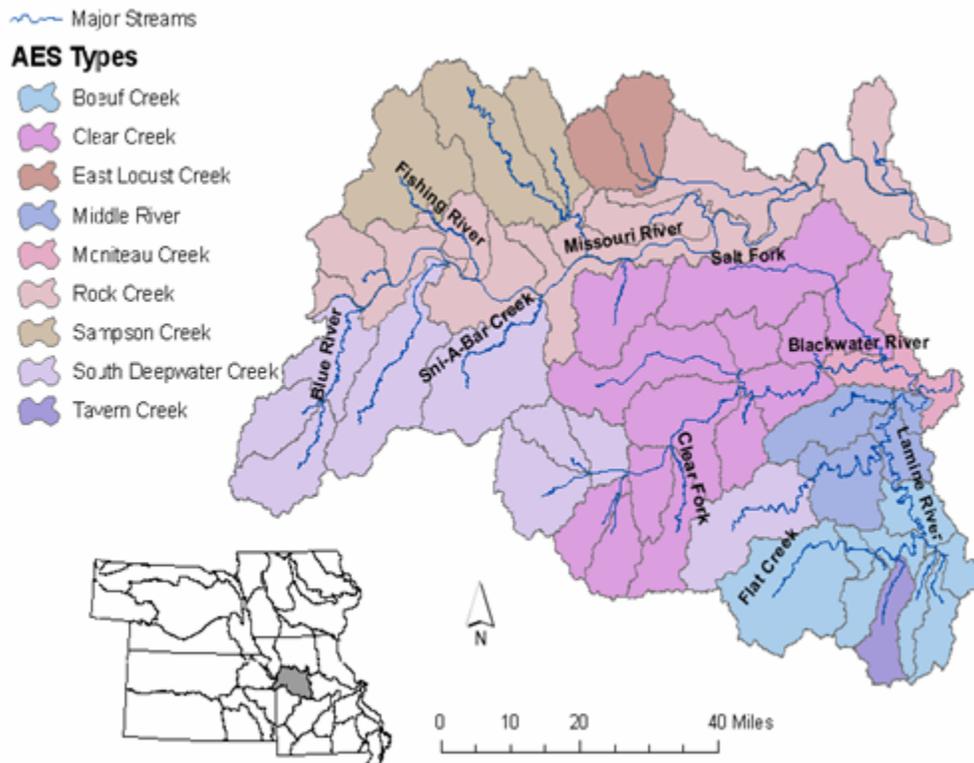


Figure B1. Map showing the boundaries and various Aquatic Ecological System Types for the Blackwater/Lamine Ecological Drainage Unit.

The average gradient across all stream size classes is 7.4 m/km. Average gradients (m/km) by size class are: headwater 10.5, creek, 2.5, small river 0.8, and large river 0.2. There are 9 Aquatic Ecological System Types (AES-Types) found within the Blackwater/Lamine EDU. The predominant AES-Types are Clear Creek, Rock Creek and South Deepwater Creek. Other AES-Types are Boeuf Creek, Middle River, Sampson Creek, East Locust Creek, Moniteau Creek and Tavern Creek.

A total of 85 fish either inhabit or at one time inhabited the Blackwater/Lamine EDU. Of those, 5 have been globally listed with a status of G1, G2 or G3 (rare, threatened, or endangered). They are the blue sucker, pallid sturgeon, sicklefin chub, sturgeon chub and Topeka shiner. The EDU can be generally characterized as a Minnow/Sucker/Sunfish assemblage. The most common species are green sunfish, red shiner, central stoneroller, creek chub, bluntnose minnow, redfin shiner, bluegill, black bullhead, largemouth bass, orangethroat darter, sand shiner, common shiner, orangspotted sunfish and suckermouth minnow.

*Cuivre/Salt EDU*

The Cuivre/Salt EDU lies mainly in northeastern Missouri, but also covers portions of western Illinois and southeastern Iowa (Figure B2). Overall there are 24,617 km of primary stream channel within this EDU, of which 8,148 km are classified as perennial in the 1:100,000 National Hydrography Dataset.

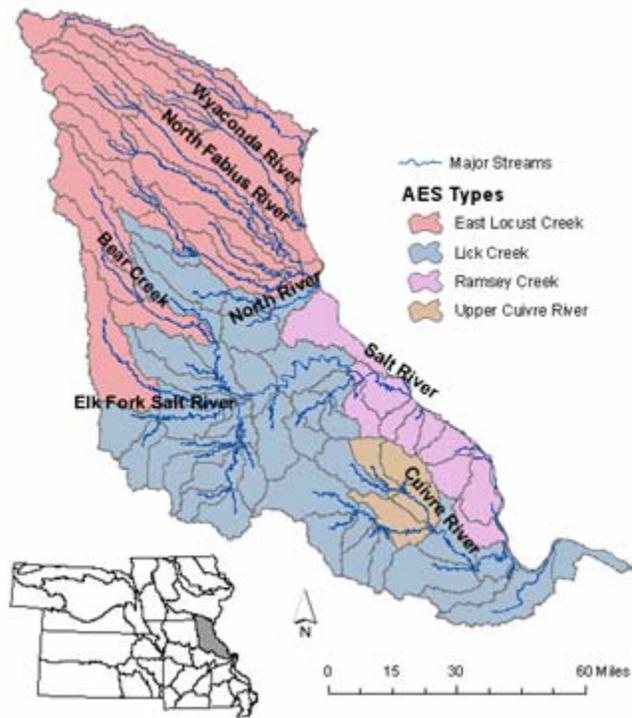


Figure B2. Map showing the boundaries and various Aquatic Ecological System Types for the Cuivre/Salt Ecological Drainage Unit.

The average gradient across all stream size classes is 6.5 m/km. Average gradients (m/km) by size class are: headwater 9.4, creek, 2.6, small river 0.8, and large river 0.3. There are 4 Aquatic Ecological System Types (AES-Types) in the Cuivre/Salt EDU. The predominant types are East Locust Creek in the

north and Lick Creek in the south. Other types are Upper Cuivre River and Ramsey Creek.

A total of 116 fish species inhabit or at one time inhabited the Cuivre/Salt EDU. Of those, 6 have been classified as globally listed with a status of G1, G2 or G3 (rare, threatened or endangered). They are the Alabama shad, alligator gar, blue sucker, lake sturgeon, pallid sturgeon and western sand darter. The EDU can be generally characterized as a Minnow/Sucker/Darter assemblage. The most common species are the green sunfish, bluntnose minnow, red shiner, sand shiner, johnny darter, redfin shiner, central stoneroller, creek chub, bigmouth shiner, orangespotted sunfish, fathead minnow, suckermouth minnow, largemouth bass, orangethroat darter, bluegill, golden shiner, yellow bullhead, golden redhorse, channel catfish, white crappie, white sucker, river carpsucker, bullhead minnow, black bullhead, fantail darter, blackstripe topminnow, slenderhead darter, gizzard shad, emerald shiner, smallmouth bass, quillback and shorthead redhorse.

### *Grand/Chariton EDU*

The Grand/Chariton EDU lies in northcentral Missouri and southcentral Iowa (Figure B3). Overall there are 26,964 km of primary stream channel within this EDU, of which 7,338 km are classified as perennial in the 1:100,000 National Hydrography Dataset.

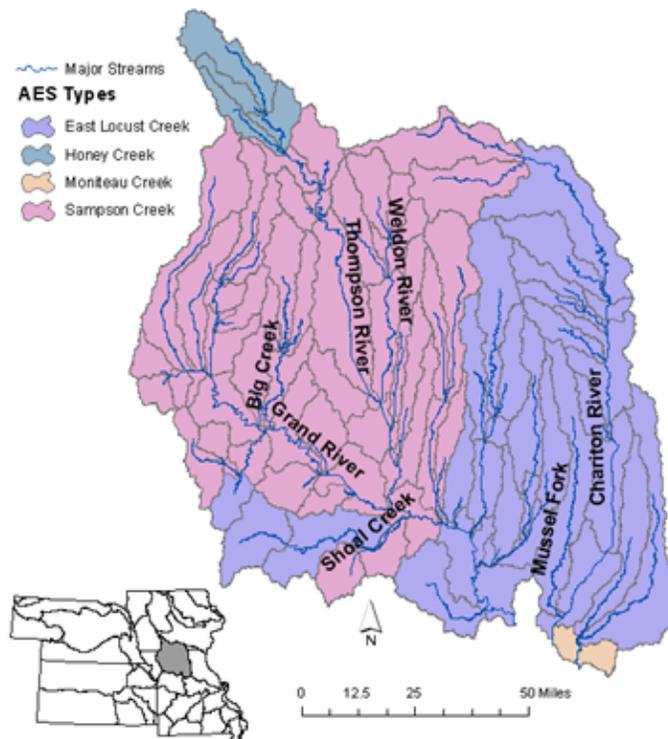


Figure B3. Map showing the boundaries and various Aquatic Ecological System Types for the Grand/Chariton Ecological Drainage Unit.

The average gradient across all stream size classes is 7.0 m/km. Average gradients (m/km) by size class are: headwater 10.5, creek, 2.0, small river 0.7, and large river 0.4. There are 4 Aquatic Ecological System Types (AES-Types) in the Grand/Chariton EDU. The predominant AES-Types are Sampson Creek and East Locust Creek. Other types present in the EDU are Honey Creek and Moniteau Creek.

A total of 67 fish species inhabit or at one time inhabited the Grand/Chariton EDU. Of those, 2 have been classified as globally listed with a status of G1, G2 or G3 (rare, threatened or endangered). They are the blue sucker and Topeka shiner. The EDU can be generally characterized as a Minnow/Sucker/Sunfish assemblage. The most common species are the red shiner, green sunfish, creek chub, fathead minnow, bigmouth shiner, sand shiner, bluntnose minnow, johnny darter, suckermouth minnow, central stoneroller, black bullhead, largemouth bass, bluegill, white sucker, river carpsucker, orangespotted sunfish, channel catfish, yellow bullhead and white crappie.

### *Kansas EDU*

The Kansas EDU lies in the northeastern corner of Kansas (Figure B4). Overall there are 12,889 km of primary stream channel within this EDU, of which 3,856 km are classified as perennial in the 1:100,000 National Hydrography Dataset.

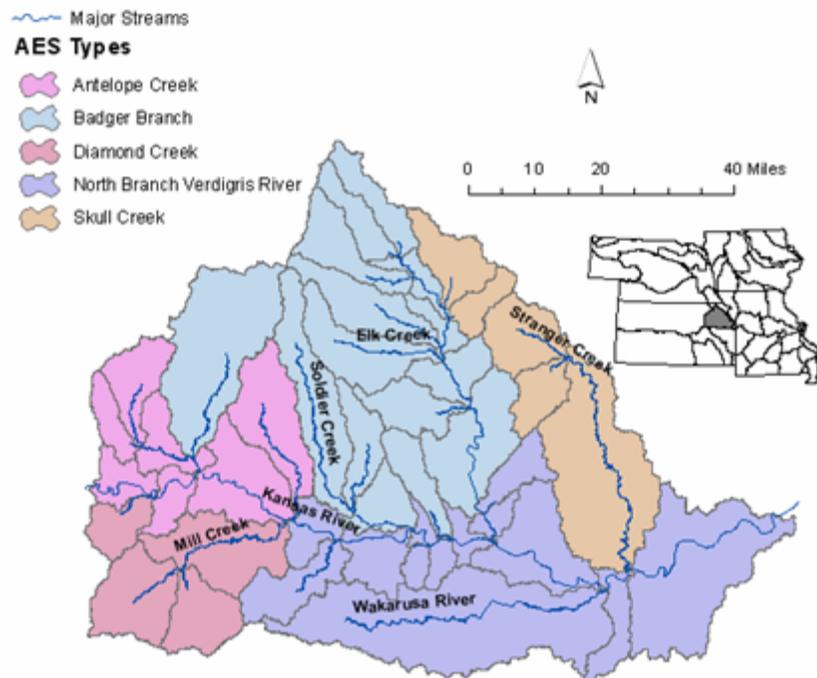


Figure B4. Map showing the boundaries and various Aquatic Ecological System Types for the Kansas Ecological Drainage Unit.

The average gradient across all stream sizes is 8.8 m/km. Average gradients (m/km) by size class are: headwater 12.9, creek 3.2, small river 0.9 and large river 0.3. There are 5 Aquatic Ecological System Types (AES-Types) found within the Kansas EDU. The Badger Branch is the predominant AES-Type in the northern portion of the EDU and the North Branch Verdigris River is the predominant type in the southern portion. Other AES-Types in the EDU are Antelope Creek, Diamond Creek and Skull Creek.

A total of 63 fish species inhabit or at one time inhabited the Kansas EDU. Of those, 3 have been classified as globally listed with a status of G1, G2 or G3 (rare, threatened or endangered). They are the pallid sturgeon, peppered chub and Topeka shiner. The EDU can be generally characterized as a Minnow/Sucker/Sunfish assemblage. The most common species include red shiner, central stoneroller, green sunfish, creek chub, bluntnose minnow, sand shiner, suckermouth minnow, orangethroat darter, fathead minnow, channel catfish, largemouth bass and river carpsucker.

### *Platte/ Nishnabotna EDU*

The Platte/ Nishnabotna EDU straddles four states (Figure B5). It lies in the southwestern corner of Iowa, the southeastern corner of Nebraska, the northeastern corner of Kansas and the northwestern corner of Missouri. Overall there are 41,768 km of primary stream channel within this EDU, of which 14,079 km are classified as perennial in the 1:100,000 National Hydrography Dataset.

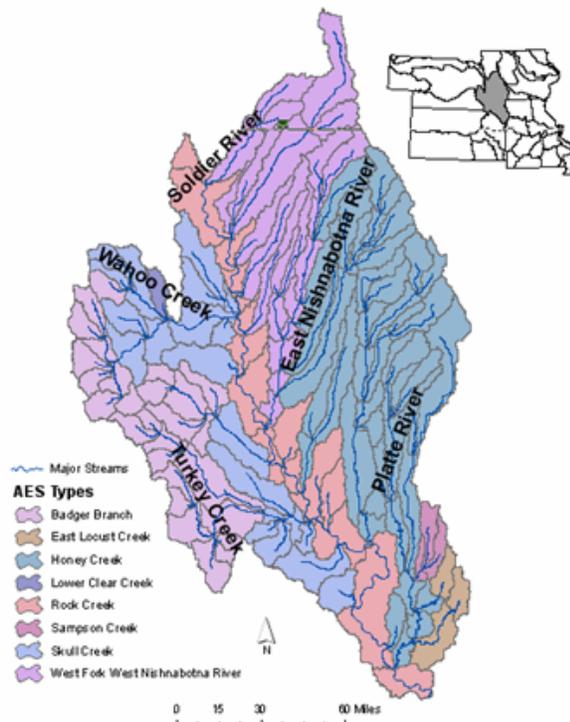


Figure B5. Map showing the boundaries and various Aquatic Ecological System Types for the Platte/Nishnabotna Ecological Drainage Unit.

The average gradient across all stream sizes is 8.2 m/km. Average gradients (m/km) by size class are: headwater 11.8, creek 2.8, small river 0.9 and large river 0.5. There are 8 Aquatic Ecological System Types (AES-Types) found within the Platte/ Nishnabotna EDU. Honey Creek is the predominant AES-Type in the EDU. It runs the length of the EDU's east side. Other AES-Types are Badger Branch, East Locust Creek, Rock Creek, Sampson Creek, Skull Creek, Lower Clear Creek and West Fork West Nishnabotna River.

A total of 77 fish species inhabit or at one time inhabited the Platte/ Nishnabotna EDU. Of those, 6 have been classified as globally listed with a status of G1, G2 or G3 (rare, threatened or endangered). They are the blue sucker, lake sturgeon, pallid sturgeon, sicklefin chub, sturgeon chub and the Topeka shiner. The EDU can be generally characterized as a Minnow/Sucker/Sunfish assemblage. The most common species include sand shiner, fathead minnow, red shiner, creek chub, green sunfish, bigmouth shiner, channel catfish, black bullhead, river carpsucker, suckermouth minnow, bluegill, emerald shiner, flathead chub, largemouth bass, yellow bullhead, gizzard shad, plains minnow, river shiner, western silvery minnow and brassy minnow.

*Wapsipinicon/ Des Moines EDU*

The Wapsipinicon/ Des Moines EDU lies in eastcentral Iowa and a portion of northwestern Illinois (Figure B6). Overall there are 34,998 km of primary stream channel within this EDU, of which 12,226 km are classified as perennial in the 1:100,000 National Hydrography Dataset.

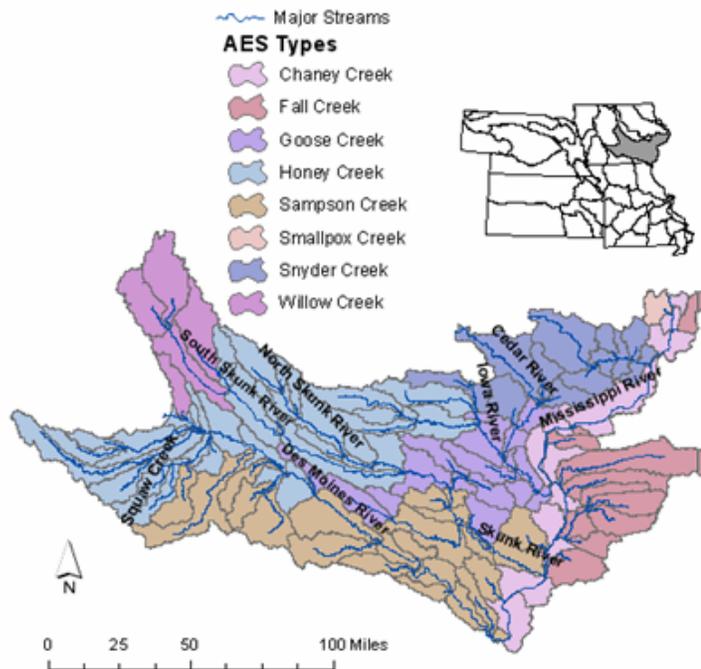


Figure B6. Map showing the boundaries and various Aquatic Ecological System Types for the Wapsipinicon/Des Moines Ecological Drainage Unit.

The average gradient across all stream sizes is 6.0 m/km. Average gradients (m/km) by size class are: headwater 8.8, creek 1.9, small river 0.6 and large river 0.3. There are 8 Aquatic Ecological System Types (AES-Types) in the Wapsipinicon/ Des Moines EDU. Honey Creek is the predominant AES-Type in the northern and western part of the EDU. Other prevalent types are Snyder Creek in the northeast, Fall Creek in the east, Sampson Creek in the south and Goose Creek in the central region. Other AES-Types are Chaney Creek, Smallpox Creek and Willow Creek.

A total of 108 fish species inhabit or at one time inhabited the Wapsipinicon/ Des Moines EDU. Of those, 3 have been classified as globally listed with a status of G1, G2 or G3 (rare, threatened or endangered). They are the blue sucker, Topeka shiner and western sand darter. The EDU can be generally characterized as a Minnow/Darter/Sucker assemblage. The most common species are bluntnose minnow, creek chub, bigmouth shiner, red shiner, green sunfish, central stoneroller, sand shiner, fathead minnow, white sucker, common shiner, johnny darter, suckermouth minnow, channel catfish, bluegill, largemouth bass, yellow bullhead, river carpsucker, black bullhead, gizzard shad, quillback, spotfin shiner, emerald shiner, shorthead redhorse, brassy minnow, smallmouth bass, stonecat, hornyhead chub and freshwater drum.

## **Ozark Aquatic Subregion**

### *Apple/Joachim EDU*

The Apple/Joachim EDU lies in eastcentral Missouri and westcentral Illinois. It includes all of the smaller direct tributaries to the Mississippi River between the outlets of the Missouri and Ohio Rivers (Figure B7). Overall there are 7,166 km of primary stream channel within this EDU, of which 2,791 km are classified as perennial in the 1:100,000 National Hydrography Dataset.

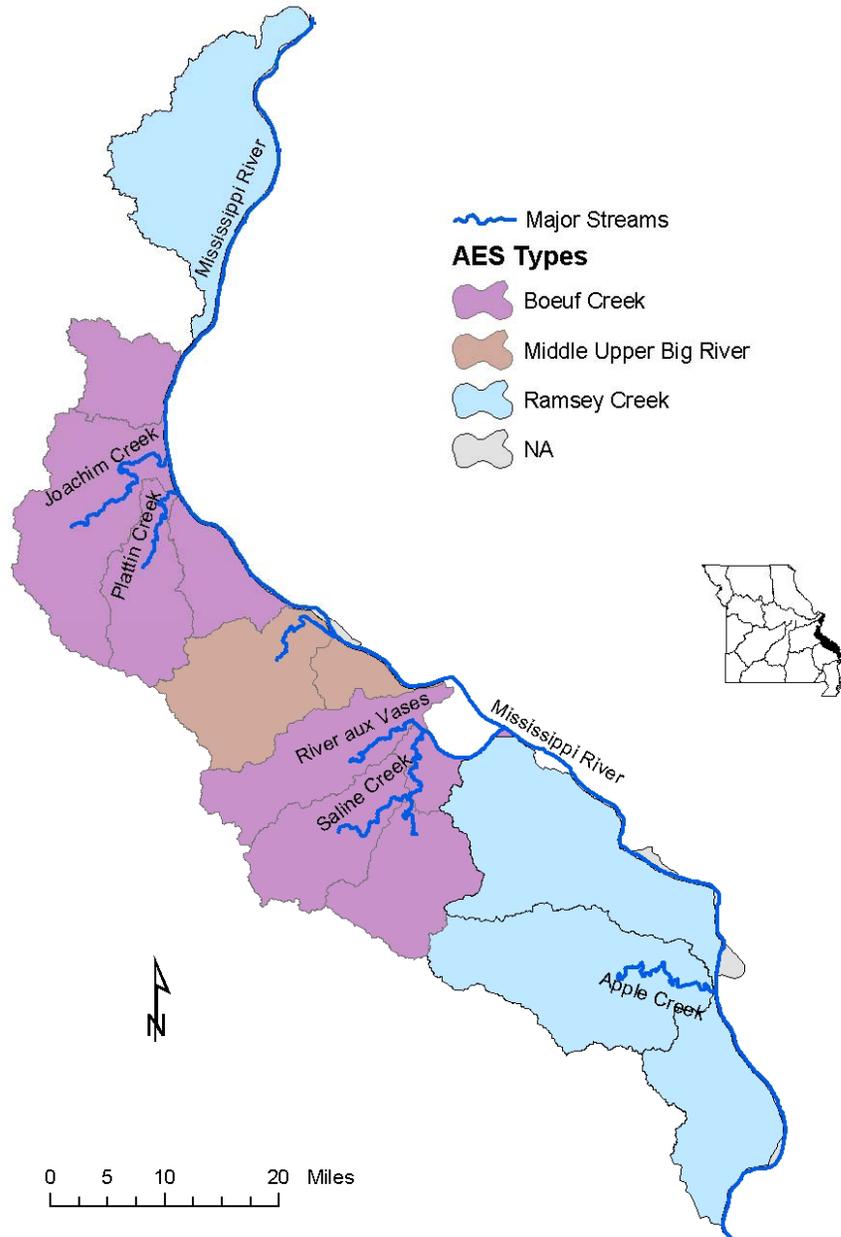


Figure B7. Map showing the boundaries and various Aquatic Ecological System Types for the Apple/Joachim Ecological Drainage Unit.

The average gradient across all stream size classes is 14 m/km. Average gradients (m/km) by size class are: headwater 17.5, creek, 3.8, and small river 0.9. There are no streams classified as large river within this EDU. There are 3 Aquatic Ecological System Types (AES-Types) in the Apple/Joachim EDU. The predominant AES-Types are Ramsey Creek and Boeuf. The other type present in the EDU is Middle Upper Big River.

A total of 115 fish species inhabit or at one time inhabited the Apple/Joachim EDU. Of those, 6 have been classified as globally listed with a status of G1, G2 or G3 (rare, threatened or endangered). They are the Alabama shad, alligator

gar, blue sucker, pallid sturgeon, sicklefin chub and sturgeon chub. The EDU can be generally characterized as a Minnow/Darter/Sucker assemblage. The most common species are the bluegill, longear sunfish, red shiner, bluntnose minnow, central stoneroller, green sunfish, rainbow darter, bleeding shiner, largescale stoneroller, striped shiner, creek chub, orangethroat darter, Ozark minnow, sand shiner, largemouth bass, blackstripe topminnow and northern studfish.

*Black/Current EDU*

The Black/Current EDU lies in southcentral Missouri and northcentral Arkansas (Figure B8). Overall there are 17,899 km of primary stream channel within this EDU, of which 3,642 km are classified as perennial in the 1:100,000 National Hydrography Dataset.

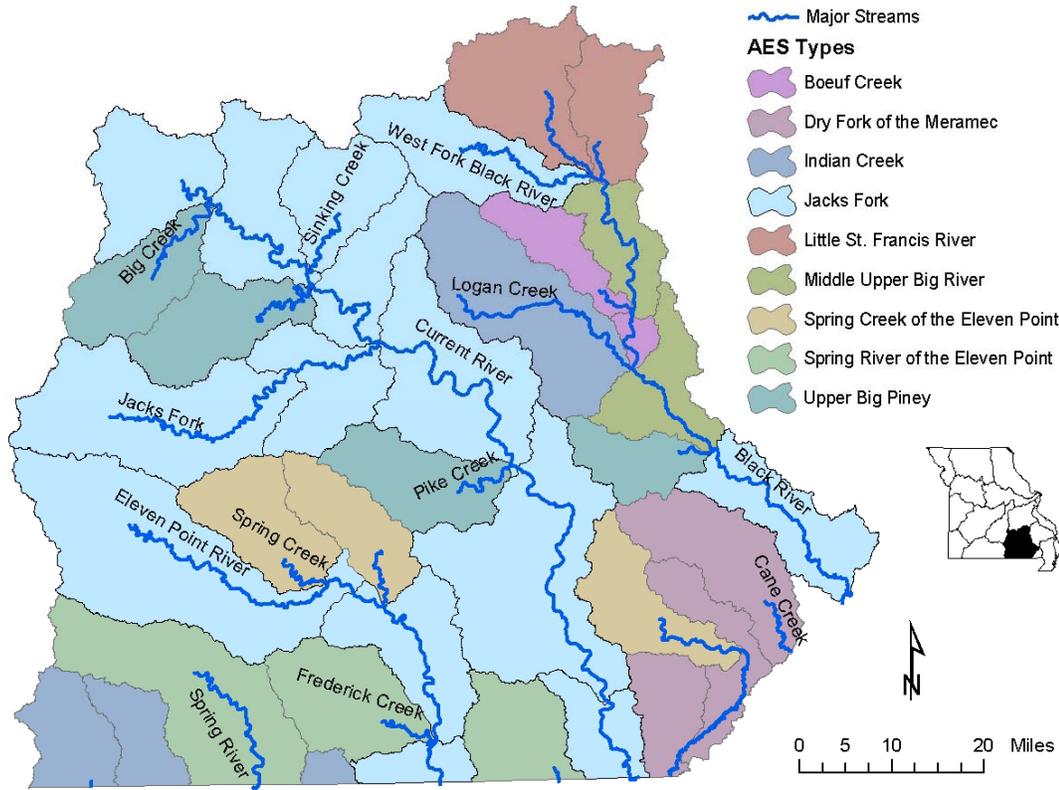


Figure B8. Map showing the boundaries and various Aquatic Ecological System Types for the Black/Current Ecological Drainage Unit.

The average gradient across all stream size classes is 13.6 m/km. Average gradients (m/km) by size class are: headwater 18, creek, 4.4, small river 1.6, and large river 0.8. There are 10 Aquatic Ecological System Types (AES-Types) in the Black/Current EDU. The predominant AES-Type is Jacks Fork. Other types

present in the EDU are Indian Creek, Spring River of the Eleven Point, Upper Big Piney, Little St. Francis River, Dry Fork of the Meramec, Spring Creek of the Eleven Point, Martins Creek, Boeuf Creek and Middle Upper Big River.

A total of 128 fish species inhabit or at one time inhabited the Black/Current EDU. Of those, 9 have been classified as globally listed with a status of G1, G2 or G3 (rare, threatened or endangered). They are the alligator gar, Arkansas saddled darter, blue sucker, checkered madtom, crystal darter, Ozark chub, Ozark shiner, Sabine shiner and stargazing darter. The EDU can be generally characterized as a Minnow/Darter/Sucker assemblage. The most common species are the bleeding shiner, rainbow darter, longear sunfish, largescale stoneroller, northern studfish, Ozark minnow, hornyhead chub, striped shiner, blackspotted topminnow, northern hog sucker, central stoneroller, smallmouth bass, telescope shiner, banded sculpin, green sunfish, bluntnose minnow, rosyface shiner, greenside darter, bluegill, whitetail shiner, bigeye shiner, southern redbelly dace, black redhorse, creek chub, golden redhorse, shadow bass, bigeye chub and Current darter.

#### *Gasconade EDU*

The Gasconade EDU lies southcentral Missouri and comprises the entire watershed of the Gasconade River, which is a tributary to the Missouri River (Figure B9). Overall there are 9,684 km of primary stream channel within this EDU, of which 2,532 km are classified as perennial in the 1:100,000 National Hydrography Dataset.

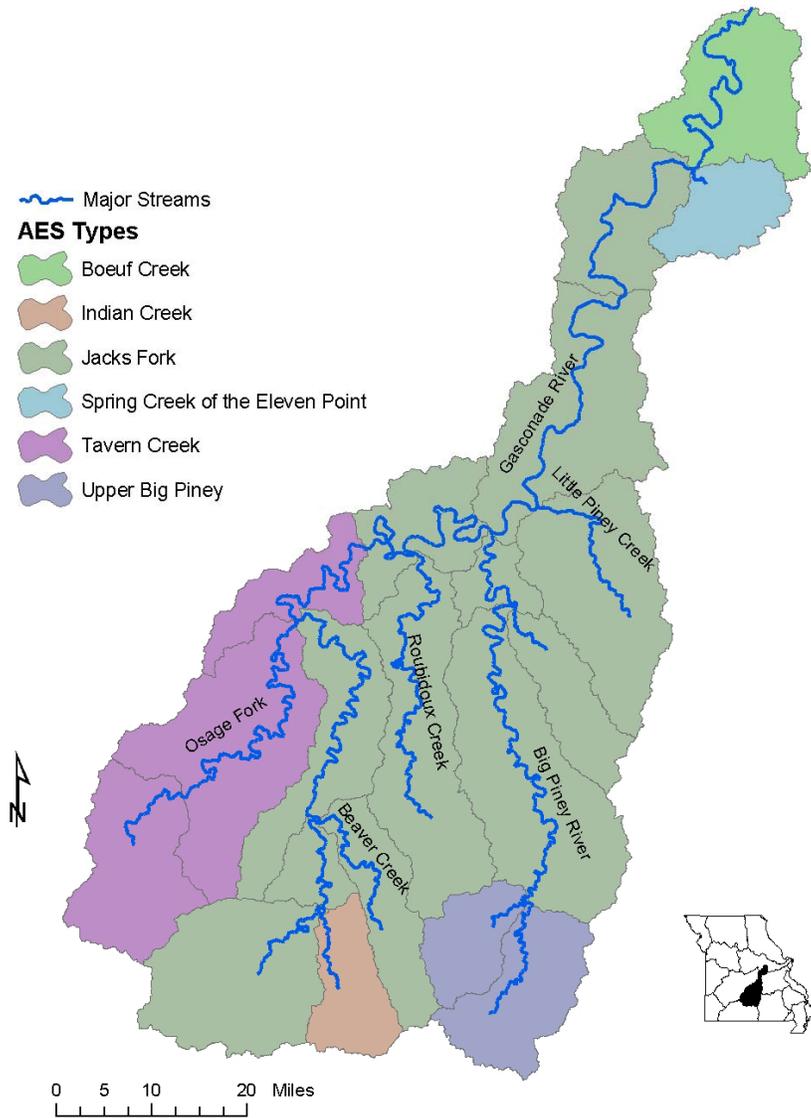


Figure B9. Map showing the boundaries and various Aquatic Ecological System Types for the Gasconade Ecological Drainage Unit.

The average gradient across all stream size classes is 13.4 m/km. Average gradients (m/km) by size class are: headwater 18.5, creek, 4.6, small river 1.2, and large river 0.5. There are 6 Aquatic Ecological System Types (AES-Types) in the Gasconade EDU. The predominant type is Jacks Fork. Other types are Boeuf Creek, Indian Creek, Spring Creek of the Eleven Point, Tavern Creek and Upper Big Piney.

A total of 103 fish species inhabit or at one time inhabited the Gasconade EDU. Of those, 3 have been classified as globally listed with a status of G1, G2 or G3 (rare, threatened or endangered). They are the Alabama shad, bluestripe darter and crystal darter. The EDU can be generally characterized as a Minnow/Darter/Sucker assemblage. The most common species are the bleeding shiner, longear sunfish, hornyhead chub, rainbow darter, central stoneroller,

largescale stoneroller, northern studfish, Ozark minnow, orangethroat darter, greenside darter, smallmouth bass, bluntnose minnow, rock bass, blackspotted topminnow, bluegill, green sunfish, northern hog sucker, largemouth bass and rosyface shiner.

*Meramec EDU*

The Meramec EDU lies in eastcentral Missouri and empties into the Mississippi River just south of the city of St. Louis (Figure B10). There are 10,581 kilometers of primary channel stream within this EDU, of which 2,978 Km are classified as perennial in the National Hydrography Dataset.

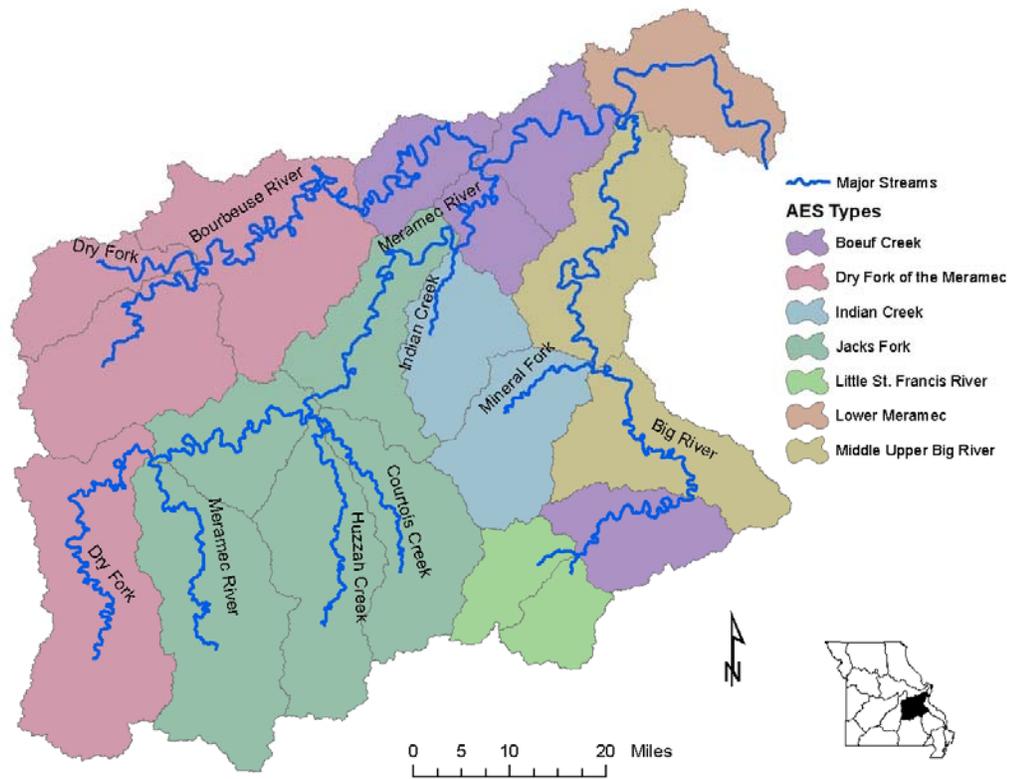


Figure B10. Map showing the boundaries and various Aquatic Ecological System Types for the Meramec Ecological Drainage Unit.

The average gradient across all stream size classes is 13.1 m/Km. Average gradients (m/Km) by size class are: headwater 17.6, creek, 4.0, small river 1.1, and large river 0.5.

There are 7 Aquatic Ecological System Types (AES-Types) in the Meramec EDU. The predominant AES-Type is the Jacks Fork. Other types are Boeuf Creek, Dry Fork of the Meramec, Indian Creek, Little St. Francis River, Lower Meramec and Middle Upper Big River.

A total of 114 fish species inhabit or at one time inhabited the Meramec EDU. Of those, 4 have been classified as globally listed with a status of G1, G2 or G3 (rare, threatened or endangered). They are the Alabama shad, blue sucker, crystal darter and western sand darter. The EDU can be generally characterized as a Minnow/Darter/Sucker assemblage. The most common species are the central stoneroller, striped shiner, northern studfish, longear sunfish, largescale stoneroller, rainfow darter, bleeding shiner, bluntnose minnow, smallmouth bass, orangethroat darter, bigeye shiner, green sunfish, greenside darter, bluegill, hornyhead chub, largemouth bass, blackspotted topminnow and Ozark minnow.

*Moreau/Loutre EDU*

The Moreau/Loutre EDU lies in eastcentral Missouri (Figure B11). Overall there are 13,050 km of primary stream channel within this EDU, of which 3,762 km are classified as perennial in the 1:100,000 National Hydrography Dataset.

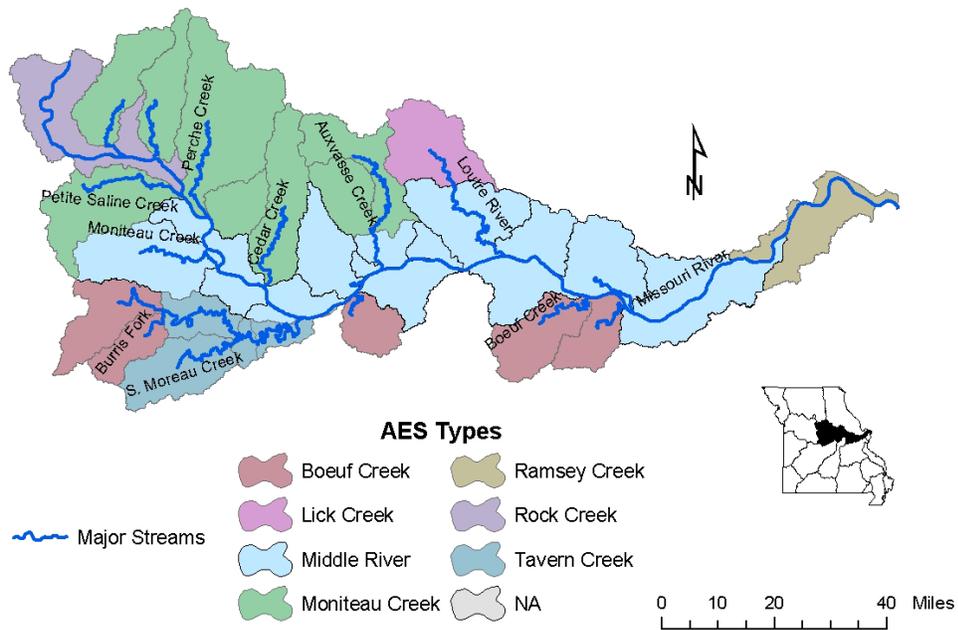


Figure B11. Map showing the boundaries and various Aquatic Ecological System Types for the Moreau/Loutre Ecological Drainage Unit.

The average gradient across all stream size classes is 10.1 m/km. Average gradients (m/km) by size class are: headwater 13.3, creek, 2.6, small river 0.6, and large river 0.4. There are 7 Aquatic Ecological System Types (AES-Types) in the Moreau/Loutre EDU. The predominant AES-Types are Middle River and Moniteau Creek. Other types are Boeuf Creek, Lick Creek, Ramsey Creek, Rock Creek and Tavern Creek.

A total of 112 fish species inhabit or at one time inhabited the Moreau/Loutre EDU. Of those, 7 have been classified as globally listed with a status of G1, G2 or G3 (rare, threatened or endangered). They are the Alabama shad, blue sucker, lake sturgeon, pallid sturgeon, sicklefin chub, sturgeon chub and Topeka shiner. The EDU can be generally characterized as a Minnow/Sunfish/Sucker assemblage. The most common species are the green sunfish, central stoneroller, bluntnose minnow, red shiner, redfin shiner, orangethroat darter, creek chub, sand shiner, bluegill, largemouth bass, johnny darter, white sucker, common shiner, logperch, golden redhorse, orangespotted sunfish, longear sunfish, black bullhead, suckermouth minnow, yellow bullhead, channel catfish, fantail darter, gizzard shad, river carpsucker, slender madtom and fathead minnow.

### Neosho EDU

The Neosho EDU straddles portions of four states, southwestern Missouri, southeastern Kansas, northeastern Oklahoma, and northwestern Arkansas (Figure B12). Overall there are 10,309 Km of primary stream channel within this EDU, of which 2,412 Km are classified as perennial in the National Hydrography Dataset.

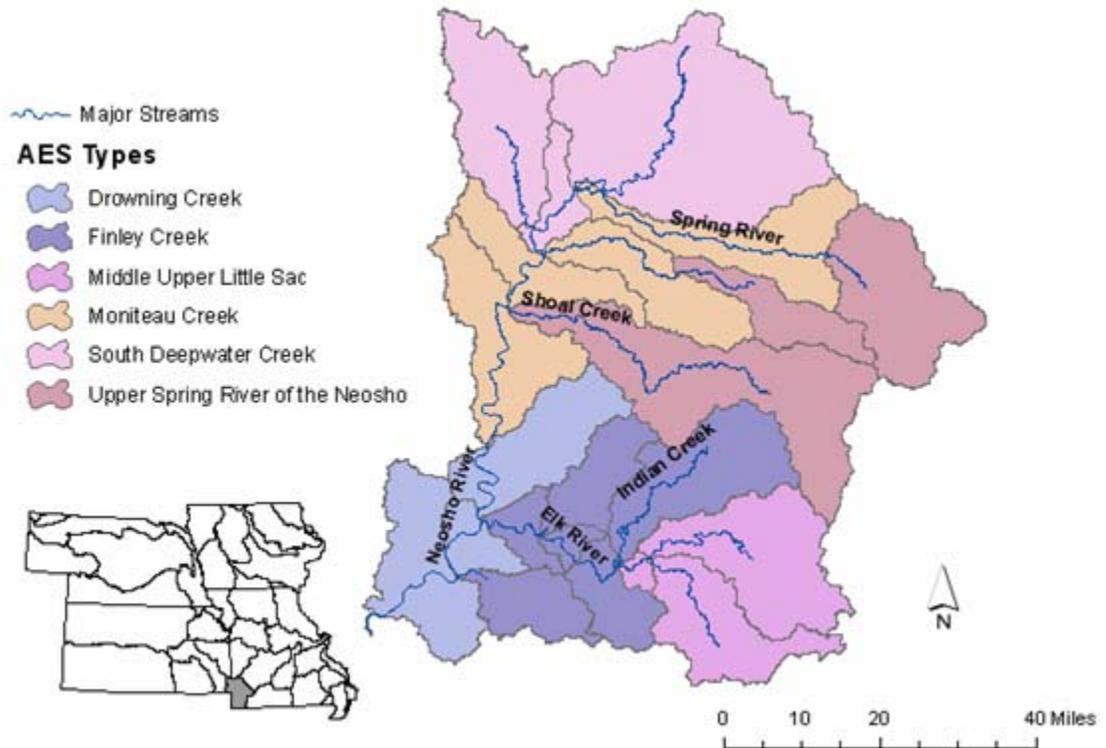


Figure B12. Map showing the boundaries and various Aquatic Ecological System Types for the Neosho Ecological Drainage Unit.

The average gradient across all stream size classes is 7.4 m/Km. Average gradients (m/Km) by size class are: headwater 9.7, creek, 3.0, small river 1.0, and large river 0.5. There are 6 Aquatic Ecological System Types (AES-Types) in the Neosho EDU. The predominant AES-Type is Finley Creek. Other types are Drowning Creek, Middle Upper Little Sac, Moniteau Creek, South Deepwater Creek and Upper Spring River of the Neosho.

A total of 90 fish species inhabit or at one time inhabited the Neosho EDU. Of those, 3 have been classified as globally listed with a status of G1, G2 or G3 (rare, threatened or endangered). They are the Arkansas darter, blue sucker and Neosho madtom. The EDU can be generally characterized as a Minnow/Sunfish/Sucker assemblage. The most common species are the central stoneroller, orangethroat darter, longear sunfish, cardinal shiner, bluntnose minnow, green sunfish, rosyface shiner, slender madtom, bluegill, fantail darter, largemouth bass, Ozark minnow, blackstripe topminnow, redspot chub and banded sculpin.

### Osage EDU

The Osage EDU lies in southcentral Missouri and encompasses the lower portion of the Osage River watershed (Figure B13). Overall there are 16,553 km of primary stream channel within this EDU, of which 4,794 km are classified as perennial in the 1:100,000 National Hydrography Dataset.

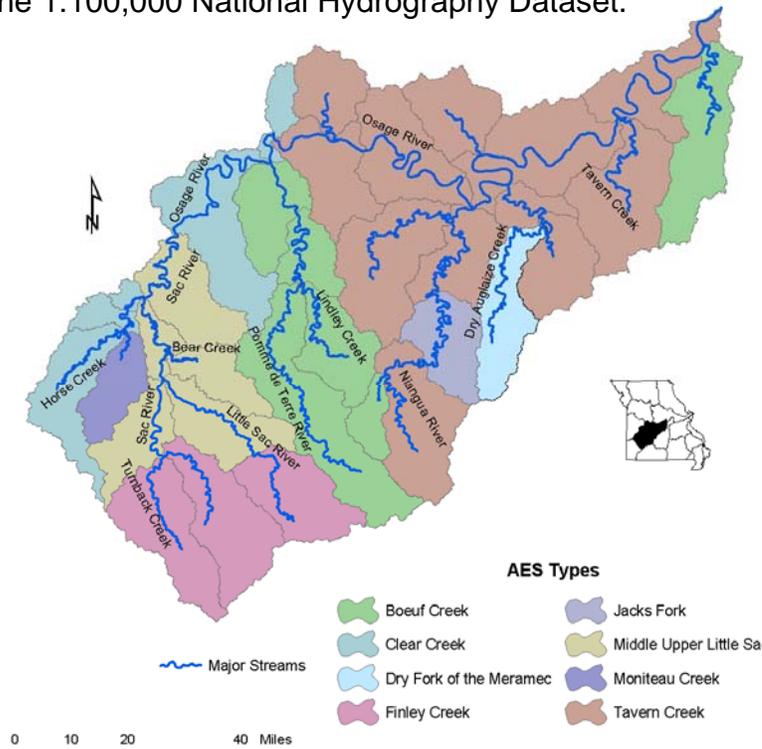


Figure 13. Map showing the boundaries and various Aquatic Ecological System Types for the Osage Ecological Drainage Unit.

The average gradient across all stream size classes is 11.9 m/km. Average gradients (m/km) by size class are: headwater 15.7, creek, 3.6, small river 1.0, and large river 0.3. There are 8 Aquatic Ecological System Types (AES-Types) in the Osage EDU. The predominant AES-Type is Tavern Creek. Other types are Boeuf Creek, Clear Creek, Dry Fork of the Meramec, Finley Creek, Jacks Fork, Middle Upper Little Sac and Moniteau Creek.

A total of 108 fish species inhabit or at one time inhabited the Osage EDU. Of those, 5 have been classified as globally listed with a status of G1, G2 or G3 (rare, threatened or endangered). They are the Alabama shad, blue sucker, bluestripe darter, lake sturgeon and Niangua darter. The EDU can be generally characterized as a Minnow/Darter/Sucker assemblage. The most common species are central stoneroller, orangethroat darter, bleeding shiner, fantail darter, bluntnose minnow, longear sunfish, Ozark minnow, green sunfish, rainbow darter, largescale stoneroller, hornyhead chub, blackspotted topminnow, slender madtom, northern studfish, creek chub, bluegill, brook silverside, northern hog sucker, smallmouth bass, greenside darter, largemouth bass, redbfin shiner, red shiner, black redhorse, golden redhorse, logperch and rosyface shiner.

#### *Upper St. Francis/Castor EDU*

The Upper St. Francis/Castor EDU lies in southeastern Missouri (Figure B14). There are 6,430 km of primary stream channel within this EDU, of which 2,290 km are classified as perennial in the 1:100,000 National Hydrography Dataset.

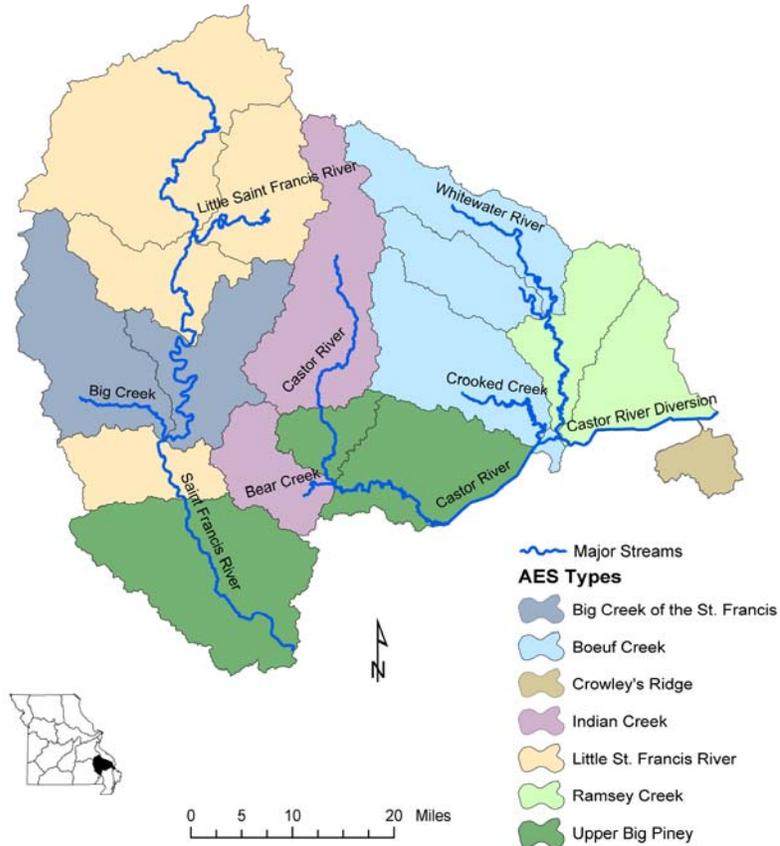


Figure B14. Map showing the boundaries and various Aquatic Ecological System Types for the Upper St. Francis/Castor Ecological Drainage Unit.

The average gradient across all stream size classes is 12.6 m/km. Average gradients (m/km) by size class are: headwater 16.7, creek, 3.7, small river 1.2, and large river 0.4. There are 7 Aquatic Ecological System Types (AES-Types) in the Upper St. Francis/Castor EDU. The predominant AES-Type is Little St. Francis River, followed by Big Creek of the St. Francis, Boeuf Creek, Indian Creek, Ramsey Creek, Upper Big Piney and Crowleys Ridge.

A total of 124 fish species inhabit or at one time inhabited the Upper St. Francis/Castor EDU. Of those, 5 have been classified as globally listed with a status of G1, G2 or G3 (rare, threatened or endangered). They are the crystal darter, longnose darter, Ozark chub, Ozark shiner and western sand darter. The EDU can be generally characterized as a Minnow/Darter/Sucker assemblage. The most common species are the longear sunfish, blackspotted topminnow, bigeye shiner, striped shiner, bluntnose minnow, bleeding shiner, green sunfish, northern studfish, rainbow darter, northern hog sucker, central stoneroller, Ozark minnow, creek chub. telescope shiner, redbfin shiner, smallmouth bass, orangethroat darter and bluegill.

## Upper White EDU

The Upper White EDU lies in southern Missouri and northern Arkansas (Figure B15). Overall there are 20,880 Km of primary stream channel within this EDU, of which 5,283 Km are classified as perennial in the National Hydrography Dataset.

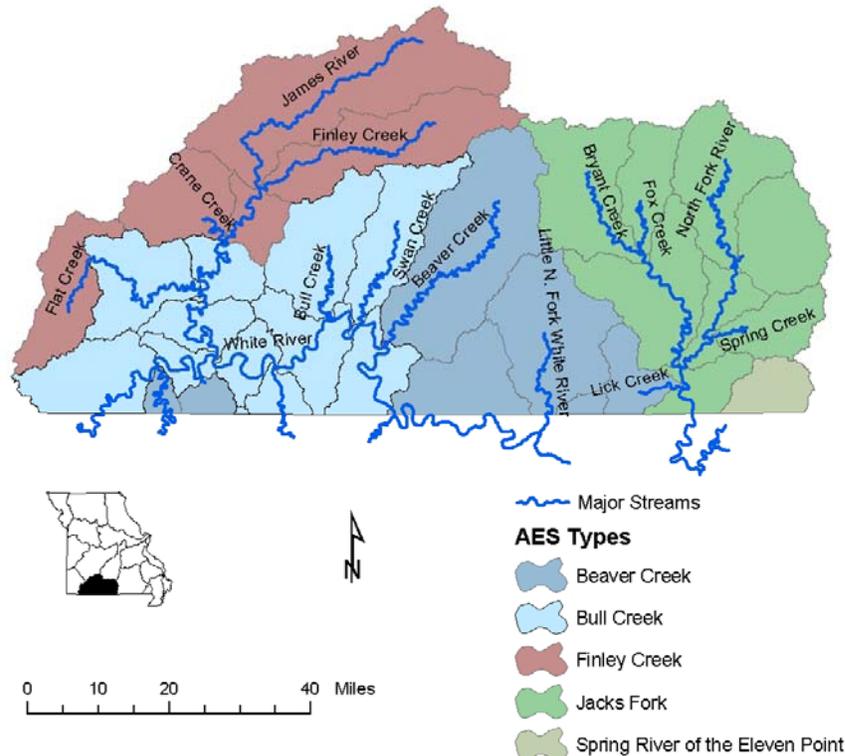


Figure B15. Map showing the boundaries and various Aquatic Ecological System Types for the Upper White Ecological Drainage Unit.

The average gradient across all stream size classes is 18.2 m/km. Average gradients (m/km) by size class are: headwater 24.1, creek, 5.4, small river 1.5, and large river 0.6. There are 9 Aquatic Ecological System Types (AES-Types) in the Upper White EDU. The predominant AES-Types are Bull Creek, Beaver Creek, Jacks Fork and Finley Creek. Other types are Huzzah Creek, Martins Creek, Otter Creek, Spring River of the Eleven Point and Winn Creek.

A total of 69 fish species inhabit or at one time inhabited the Upper White EDU. Of those, 4 have been classified as globally listed with a status of G1, G2 or G3 (rare, threatened or endangered). They are the Arkansas saddled darter, checkered madtom, Ozark chub and Ozark shiner. The EDU can be characterized as having a Minnow/Sunfish/Darter assemblage. The most common species are dusky stripe shiner, rainbow darter, central stoneroller, hornyhead chub, Ozark minnow, banded sculpin, northern studfish, striped shiner, orangethroat darter, blackspotted topminnow, longear sunfish, smallmouth bass, rosyface shiner and largescale stoneroller.

## Mississippi Alluvial Basin Aquatic Subregion

### *Black/Cache EDU*

The Black/Cache EDU lies in southeast Missouri and northeast Arkansas (Figure B16). There are 3 Aquatic Ecological System Types (AES-Types) in the EDU. The predominant AES-Type is City of Osceola. Other types are Cane Creek and Lost Creek. The distinct character of this EDU pertains to its connection with the two most diverse river systems of the Ozarks, the Black and Current Rivers. These rivers export large bedloads of coarse materials into streams otherwise dominated by fine substrates.

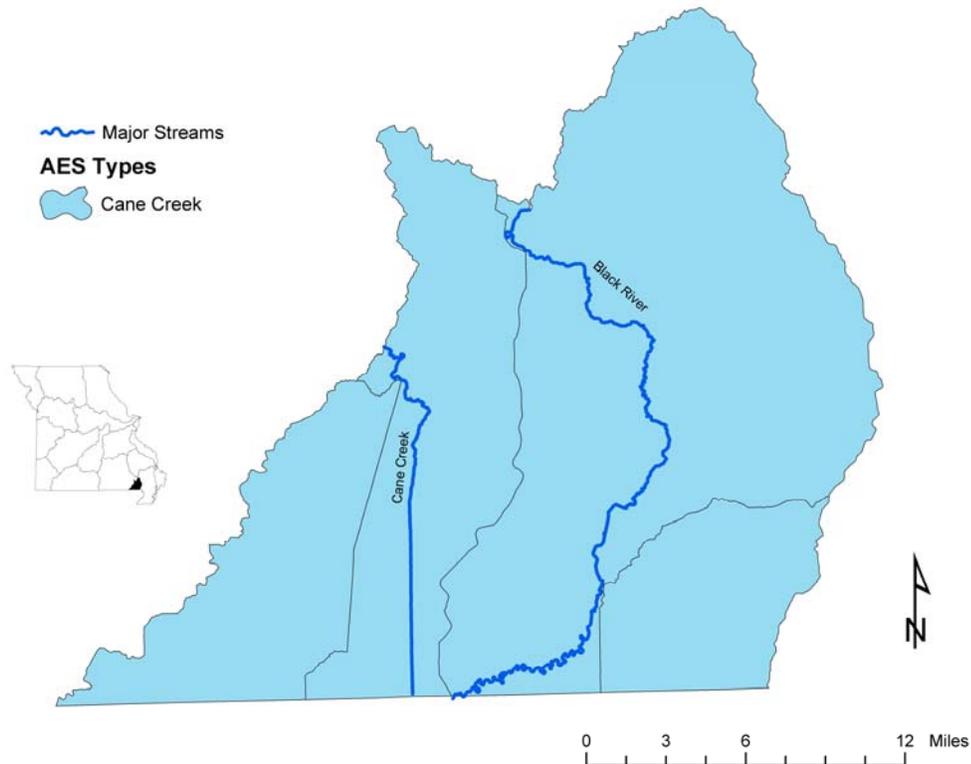


Figure B16. Map showing the boundaries and various Aquatic Ecological System Types for the Black/Cache Ecological Drainage Unit.

A total of 77 fish species inhabit or at one time inhabited the Black/Cache EDU. Of those, 3 have been classified as globally listed with a status of G1, G2 or G3 (rare, threatened or endangered). They are the crystal darter, Sabine shiner and western sand darter. The EDU can be generally characterized as a Minnow/Darter/Sunfish assemblage. Common species are the blackspotted topminnow, bluegill, longear sunfish, weed shiner, western mosquitofish, blacktail shiner, cypress darter, green sunfish, spotted bass, banded pygmy sunfish, bluntnose minnow, bullhead minnow, gizzard shad, pirate perch, ribbon shiner, warmouth, bluntnose darter, logperch and Mississippi silvery minnow.

## St. Francis/Little EDU

The St. Francis/Little EDU lies in southeast Missouri and northeast Arkansas (Figure B17). There are 9 Aquatic Ecological System Types (AES-Types) in the EDU. The predominant AES-Type is City of Osceola. Other types are City of Chaffee, City of Gideon, City of Hayti, City of Senath, Crowleys Ridge, Little River, Lost Creek and West Ditch.

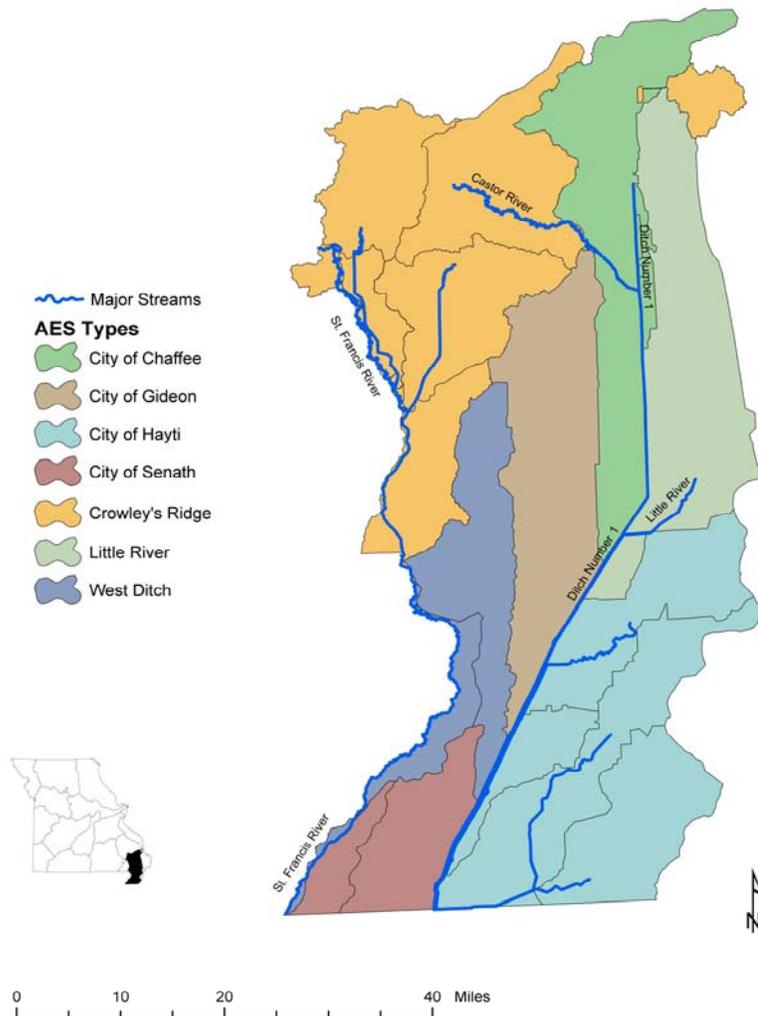


Figure B17. Map showing the boundaries and various Aquatic Ecological System Types for the St. Francis/Little Ecological Drainage Unit.

A total of 98 fish species inhabit or at one time inhabited the St. Francis/Little EDU. Of those, 3 have been classified as globally listed with a status of G1, G2 or G3 (rare, threatened or endangered). They are the blue sucker, crystal darter and western sand darter. The EDU can be generally characterized as a Minnow/Darter/Sunfish assemblage. Common species are the western mosquitofish, blackspotted topminnow, longear sunfish, blacktail shiner, bluegill, spotted bass, bullhead minnow, bluntnose minnow brook silverside, green

sunfish, emerald shiner, tadpole madtom, warmouth, blackstripe topminnow, mimic shiner, cypress darter, largemouth bass, ribbon shiner, dusky darter and gizzard shad.

### *St. John's Bayou EDU*

The St. John's Bayou EDU lies in southeast Missouri and northeast Arkansas (Figure B18). The EDU contains many smaller direct tributaries to the Mississippi River between the outlet of the Headwater Diversion Channel near Cape Girardeau, MO and the outlet of the St. Francis River near Helena, Arkansas. Historically, these channels had an "intimate" relationship with the Mississippi River. These smaller streams were regularly flooded and resculpted by the Mississippi River. Natural levees interspersed with adjacent swamplands and marshes provided a diverse landscape for plant and wetland communities. There are 3 Aquatic Ecological System Types (AES-Types) in the EDU, City of Charleston, St. Johns Diversion Ditch and Wilkerson Ditch.

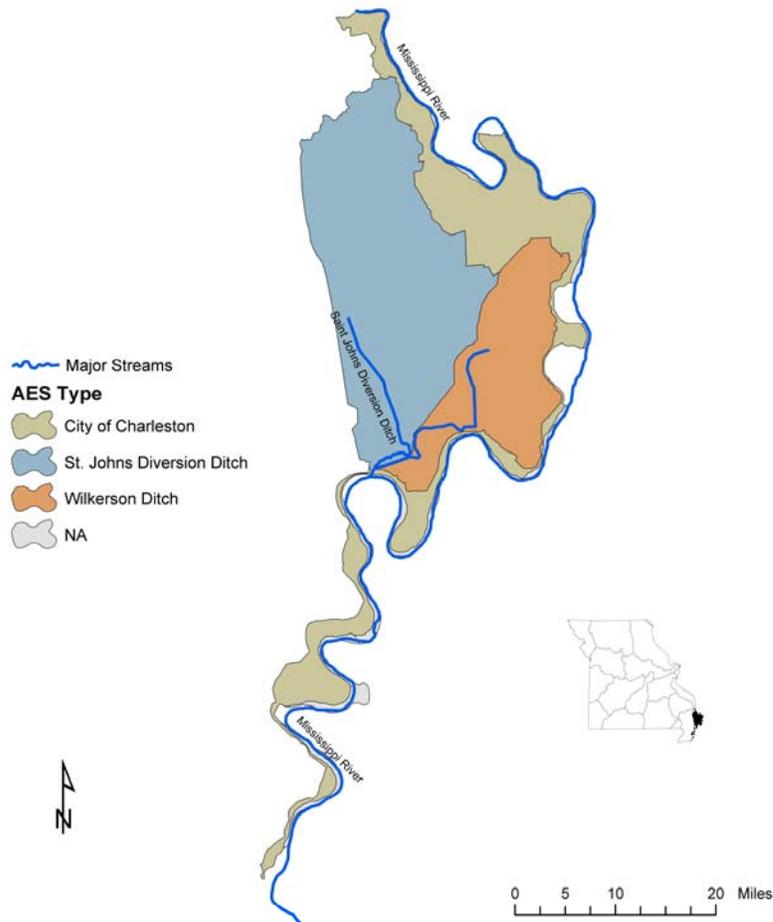


Figure B18. Map showing the boundaries and various Aquatic Ecological System Types for the St. John's Bayou Ecological Drainage Unit.

A total of 108 fish species inhabit or at one time inhabited the St. Johns Bayou EDU. Of those, 4 have been classified as globally listed with a status of G1, G2 or G3 (rare, threatened or endangered). They are the alligator gar, blue sucker, sicklefin chub and sturgeon chub. The EDU can be generally characterized as a Minnow/Darter/Sunfish assemblage. Common species are bluegill, longear sunfish, western mosquitofish, gizzard shad, freshwater drum, channel catfish, green sunfish, largemouth bass, blackspotted topminnow, blacktail shiner, shortnose gar, emerald shiner, brook silverside, white bass, cypress darter, spotted bass, warmouth, black crappie, bullhead minnow and river carpsucker.

## North Central Glaciated Plains Aquatic Subregion

### *Big Sioux/ Little Sioux EDU*

The Big Sioux/ Little Sioux EDU lies in the northwestern corner of Iowa, the northeastern corner of Nebraska and small portions of southeastern South Dakota and southwestern Minnesota (Figure B19). Overall there are 27,384 km of primary stream channel within this EDU, of which 7,314 km are classified as perennial in the 1:100,000 National Hydrography Dataset.

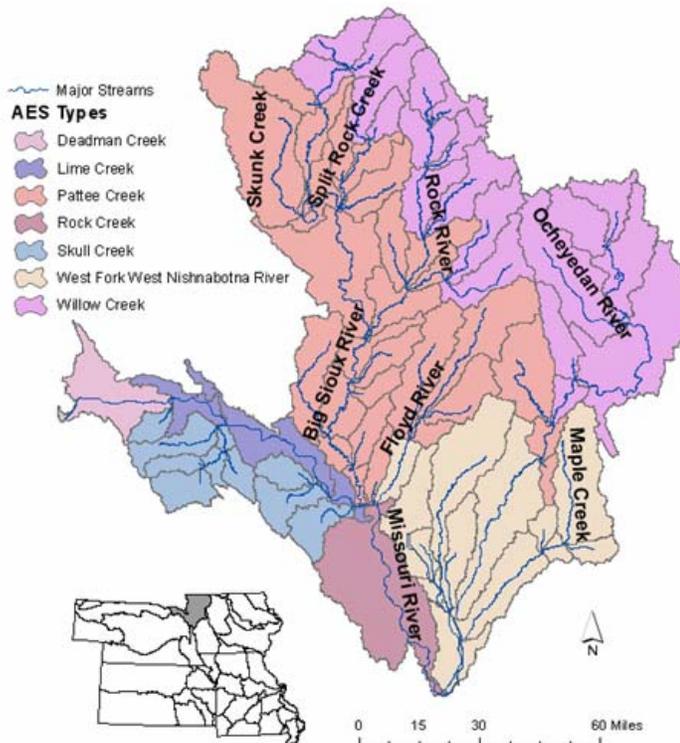


Figure B19. Map showing the boundaries and various Aquatic Ecological System Types for the Big Sioux/Little Sioux Ecological Drainage Unit.

The average gradient across all stream sizes is 6.7 m/km. Average gradients (m/km) by size class are: headwater 9.4, creek 2.8, small river 1.0 and large river 0.4. There are 7 Aquatic Ecological System Types (AES-Types) in the Big Sioux/

Little Sioux EDU. Pattee Creek is the predominant AES-Type in the western portion of the EDU. In the east, Willow Creek is the prevalent type and West Fork West Nishnabotna River is the prevalent type in the south. Other AES-Types are Deadman Creek, Lime Creek, Rock Creek and Skull Creek.

A total of 89 fish species inhabit or at one time inhabited the Big Sioux/ Little Sioux EDU. Of those, 6 have been classified as globally listed with a status of G1, G2 or G3 (rare, threatened or endangered). They are the blue sucker, lake sturgeon, pallid sturgeon, sicklefin chub, sturgeon chub and Topeka shiner. The EDU can be generally characterized as a Minnow/Sucker/Catfish assemblage. The most common species are bigmouth shiner, sand shiner, creek chub, fathead minnow, white sucker, red shiner, common shiner, johnny darter, bluntnose minnow, channel catfish, central stoneroller, green sunfish, black bullhead, blacknose dace, brassy minnow, stonecat, shorthead redhorse, and river carpsucker.

*Maquoketa/ Upper Cedar EDU*

The Maquoketa/ Upper Cedar EDU lies in northeastern Iowa and a small portion of southcentral Minnesota (Figure B20). Overall there are 21,784 km of primary stream channel within this EDU, of which 8,544 km are classified as perennial in the 1:100,000 National Hydrography Dataset.

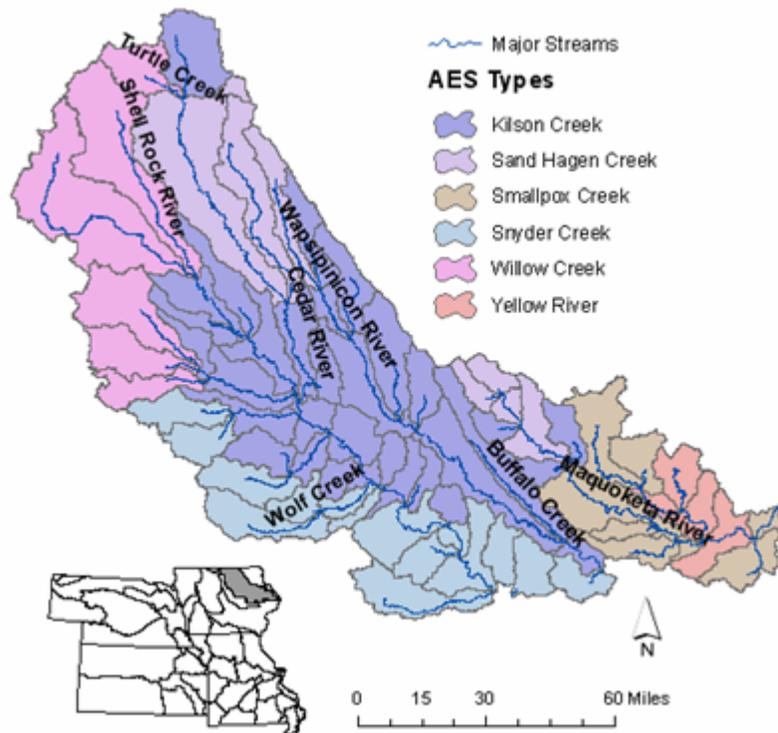


Figure B20. Map showing the boundaries and various Aquatic Ecological System Types for the Maquoketa/Upper Cedar Ecological Drainage Unit.

The average gradient across all stream sizes is 5.3 m/km. Average gradients (m/km) by size class are: headwater 7.7, creek 2.0, small river 0.7 and large river 0.3. There are 6 Aquatic Ecological System Types (AES-Types) in the Maquoketa/ Upper Cedar EDU. Kilson Creek is the predominant AES-Type in the EDU, covering most of the eastern region. Snyder Creek is the prevalent type in the south and Willow Creek is the prevalent type in the west. Other AES-Types are Sand Hagen Creek, Smallpox Creek and Yellow River.

A total of 100 fish species inhabit or at one time inhabited the Maquoketa/ Upper Cedar EDU. Of those, the Topeka shiner has been classified as globally listed with a status of G1, G2 or G3 (rare, threatened or endangered). The EDU can be generally characterized as a Minnow/Darter/Sucker assemblage. The most common species are the creek chub, bigmouth shiner, white sucker, johnny darter, central stoneroller, green sunfish, sand shiner, blacknose dace, fathead minnow, spottfin shiner, smallmouth bass, golden redhorse, hornyhead chub, northern hog sucker, channel catfish, fantail darter, shorthead redhorse, southern redbelly dace, quillback, brassy minnow, black bullhead, river carpsucker, suckermouth minnow, northern pike, orangespotted sunfish, stonecat, rosyface shiner, bluegill, largemouth bass, yellow bullhead, highfin carpsucker, rock bass, white crappie and black crappie.

### *Minnesota EDU*

The Minnesota EDU lies in a small portion of northcentral Iowa and in southcentral Minnesota (Figure B21). Overall there are 1,875 km of primary stream channel within this EDU, of which 886 km are classified as perennial in the 1:100,000 National Hydrography Dataset.



Figure B21. Map showing the boundaries and various Aquatic Ecological System Types for the Minnesota Ecological Drainage Unit.

The average gradient across all stream sizes is 2.0 m/km. Average gradients (m/km) by size class are: headwater 2.8, creek 1.0 and small river 0.5. Willow Creek is the only Aquatic Ecological System Type (AES-Type) in the Minnesota EDU.

A total of 24 fish species inhabit or at one time inhabited the Minnesota EDU. None have been classified as globally listed with a status of G1, G2 or G3 (rare, threatened or endangered). The EDU can be generally characterized as a Minnow/Sucker/Darter assemblage. The most common species are fathead minnow, creek chub, bluntnose minnow, black bullhead, bigmouth shiner, white sucker, tadpole madtom, johnny darter, green sunfish and blacknose dace.

#### *Upper Des Moines EDU*

The Upper Des Moines EDU lies in central and northcentral Iowa and a portion of southwestern Minnesota (Figure B22). Overall there are 14,480 km of primary stream channel within this EDU, of which 6,780 km are classified as perennial in the 1:100,000 National Hydrography Dataset.



Figure B22. Map showing the boundaries and various Aquatic Ecological System Types for the Upper Des Moines Ecological Drainage Unit.

The average gradient across all stream sizes is 5.7 m/km. Average gradients (m/km) by size class are: headwater 8.3, creek 1.8, small river 0.6 and large river 0.4. There are 2 Aquatic Ecological System Types (AES-Types) in the Upper Des Moines EDU. Willow Creek is the predominant AES-Type. Honey Creek AES-Type occurs in the extreme southern portion of the EDU.

A total of 83 fish species inhabit or at one time inhabited the Upper Des Moines EDU. Of those, 3 have been classified as globally listed with a status of G1, G2 or G3 (rare, threatened or endangered). They are the pugnose shiner, Topeka shiner and western sand darter. The EDU can be generally characterized as a Minnow/Sucker/Darter assemblage. The most common species are bluntnose minnow, creek chub, bigmouth shiner, sand shiner, spotfin shiner, common shiner, fathead minnow, white sucker, johnny darter, green sunfish, central stoneroller, brassy minnow, blacknose dace, black bullhead, channel catfish, northern hog sucker, shorthead redhorse, quillback, smallmouth bass, hornyhead chub, suckermouth minnow, blackside darter, stonecat, river carpsucker, golden redhorse, largemouth bass, orangespotted sunfish, bluegill, brook stickleback, emerald shiner and fantail darter.

## Upper Iowa EDU

The Upper Iowa EDU lies generally in central Iowa (Figure B23). Overall there are 6,092 km of primary stream channel within this EDU, of which 2,742 km are classified as perennial in the 1:100,000 National Hydrography Dataset.

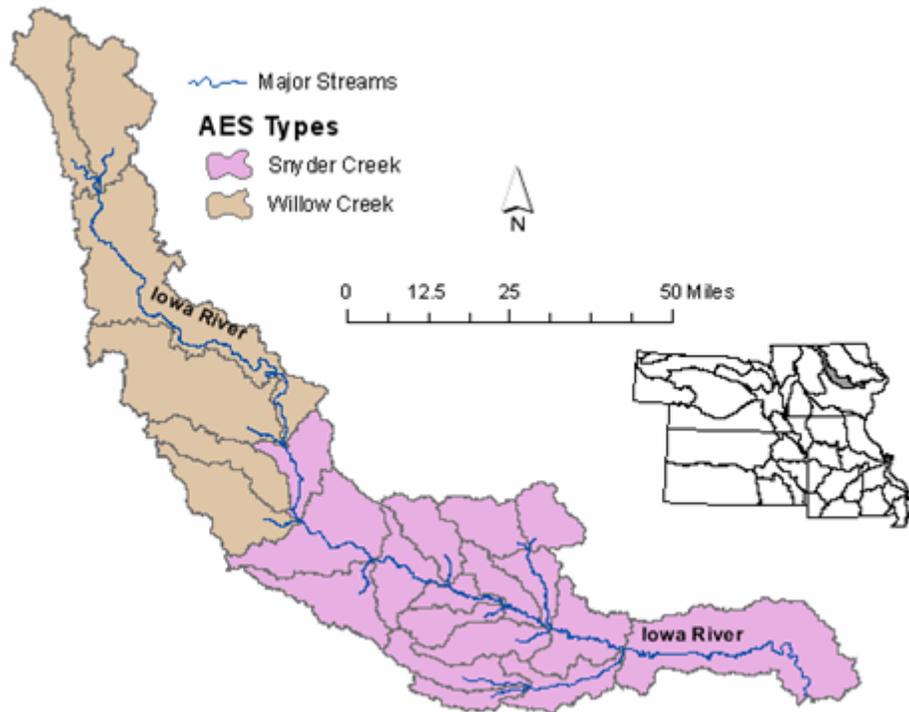


Figure B23. Map showing the boundaries and various Aquatic Ecological System Types for the Upper Iowa Ecological Drainage Unit.

The average gradient across all stream sizes is 5.8 m/km. Average gradients (m/km) by size class are: headwater 8.4, creek 1.9, small river 0.7 and large river 0.4. The EDU is fairly evenly distributed with 2 AES-Types, Willow Creek in the north and Snyder Creek in the south.

A total of 72 fish species inhabit or at one time inhabited the Upper Iowa EDU, one of which, the Topeka shiner, has been classified as globally listed with a status of G1, G2 or G3 (rare, threatened or endangered). The EDU can be generally characterized as a Minnow/Sucker/Darter assemblage. The most common species are the bluntnose minnow, bigmouth shiner, spottin shiner, common shiner, creek chub, white sucker, fathead minnow, green sunfish, sand shiner, blacknose dace, brassy minnow, river carpsucker, johnny darter, shorthead redhorse, central stoneroller, channel catfish, smallmouth bass and golden redhorse.

## Cheyenne EDU

The Cheyenne EDU lies in the northwest corner of Nebraska, the southwest corner of South Dakota and a small portion of eastcentral Wyoming (Figure B24). Overall there are 7,740 km of primary stream channel within this EDU, of which 709 km are classified as perennial in the 1:100,000 National Hydrography Dataset.

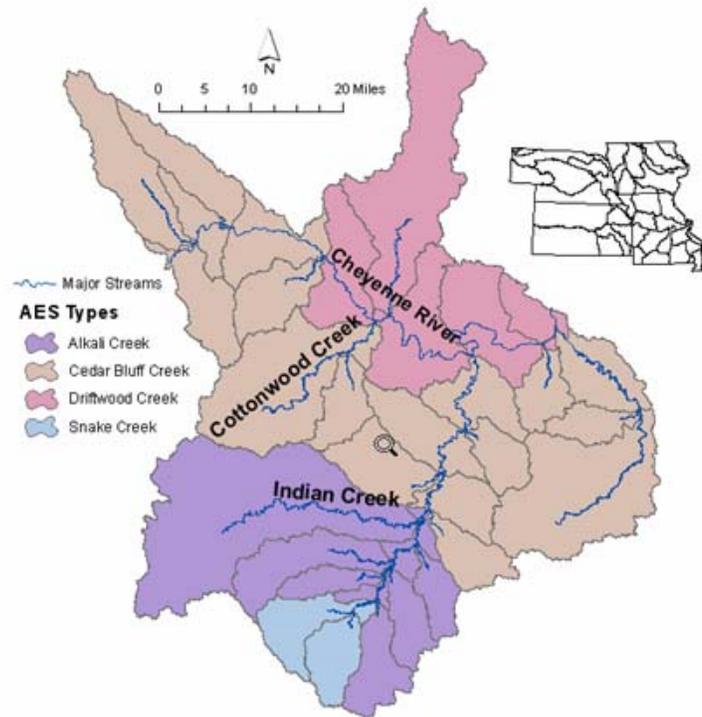


Figure B24. Map showing the boundaries and various Aquatic Ecological System Types for the Cheyenne Ecological Drainage Unit.

The average gradient across all stream sizes is 15.6 m/km. Average gradients (m/km) by size class are: headwater 21.8, creek 6.8, small river 2.2 and large river 1.4. There are 4 Aquatic Ecological System Types (AES-Types) in the Cheyenne EDU. Cedar Bluff Creek is the predominant AES-Type running from northwest to southeast through the EDU. Driftwood Creek and Alkalai Creek AES Types are the prevalent types in the north and south respectively. Snake Creek AES-Type occurs in the extreme southern portion of the EDU.

A total of 10 fish species inhabit or at one time inhabited the Cheyenne EDU, none of which have been classified as globally listed with a status of G1, G2 or G3 (rare, threatened or endangered). Minnow and Sucker are the predominant Families in the EDU. The most common species are fathead minnow and longnose dace.

## Niobrara EDU

The Niobrara EDU lies in northern Nebraska, a portion of southcentral South Dakota and a part of eastcentral Wyoming (Figure B25). Overall there are 20,306 km of primary stream channel within this EDU, of which 5,151 km are classified as perennial in the 1:100,000 National Hydrography Dataset.

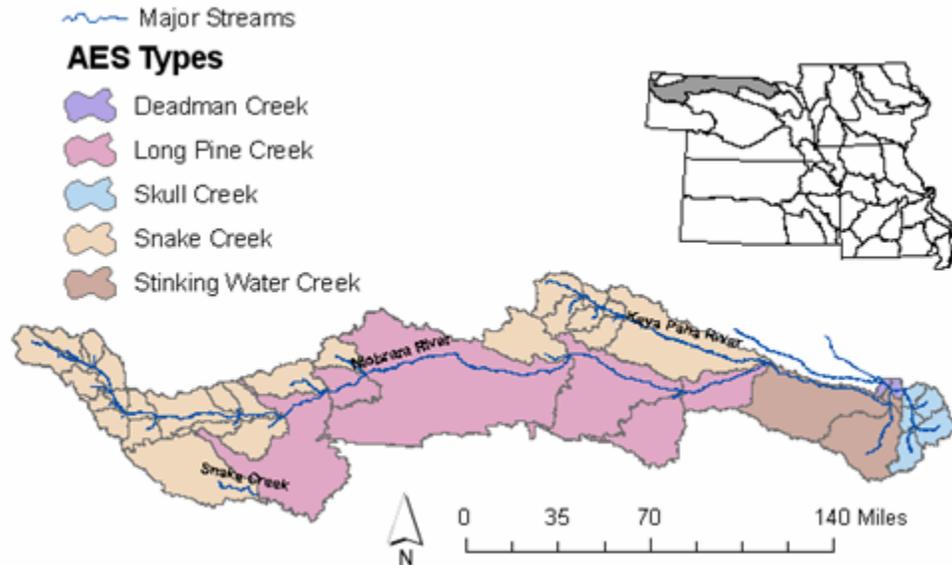


Figure B25. Map showing the boundaries and various Aquatic Ecological System Types for the Niobrara Ecological Drainage Unit.

The average gradient across all stream sizes is 7.5 m/km. Average gradients (m/km) by size class are: headwater 10.7, creek 4.1, small river 1.8 and large river 1.4. There are 5 Aquatic Ecological System Types (AES-Types) in the Niobrara EDU. Snake Creek AES-Type stretches from the western portion of the EDU across the northern section to the east. Long Pine Creek AES-Type is prevalent in the southern portion of the EDU. Other AES-Types are Deadman Creek, Skull Creek and Stinking Water Creek.

A total of 60 fish species inhabit or at one time inhabited the Niobrara EDU. Of those, 2 have been classified as globally listed with a status of G1, G2 or G3 (rare, threatened or endangered). They are the pallid sturgeon and sicklefin chub. The EDU can be generally characterized as a Minnow/Sunfish/Darter assemblage. The most common species are creek chub, longnose dace, white sucker, fathead minnow, bigmouth shiner, sand shiner, green sunfish, plains topminnow, brassy minnow, red shiner, flathead chub, black bullhead, blacknose dace, pearl dace, shorthead redhorse and northern redbelly dace.

## White EDU

The White EDU lies in the northwest corner of Nebraska and in southwestern South Dakota (Figure B26). Overall there are 15,113 km of primary stream channel within this EDU, of which 2,090 km are classified as perennial in the 1:100,000 National Hydrography Dataset.

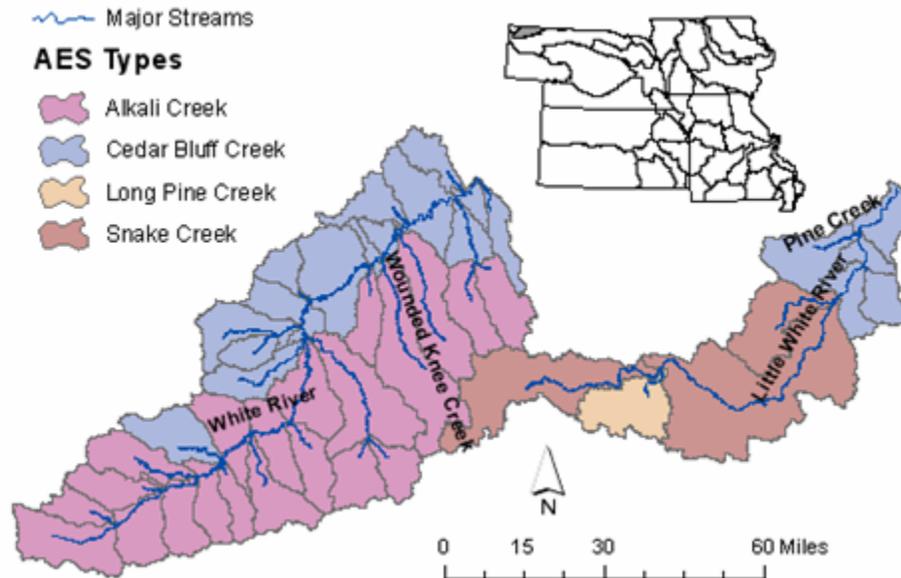


Figure B26. Map showing the boundaries and various Aquatic Ecological System Types for the White Ecological Drainage Unit.

The average gradient across all stream sizes is 13.1 m/km. Average gradients (m/km) by size class are: headwater 17.9, creek 6.0, small river 2.3 and large river 1.0. There are 4 Aquatic Ecological System Types (AES-Types) in the White EDU. Alkalai Creek and Cedar Bluff Creek are the predominant AES-Types in the EDU. Other AES-Types are Long Pine Creek and Snake Creek.

A total of 25 fish species inhabit or at one time inhabited the White EDU, none of which have been classified as globally listed with a status of G1, G2 or G3 (rare, threatened or endangered). The EDU can be generally characterized as a Minnow/Sucker/Catfish assemblage. The most common species are the longnose dace, creek chub, white sucker, fathead minnow, sand shiner and green sunfish.

## Osage Plains/ Flint Hills Aquatic Subregion

### *Osage/ South Grand EDU*

The Osage/ South Grand EDU lies in eastcentral Kansas and westcentral Missouri (Figure B27). Overall there are 21,164 km of primary stream channel within this EDU, of which 5,732 km are classified as perennial in the 1:100,000 National Hydrography Dataset.

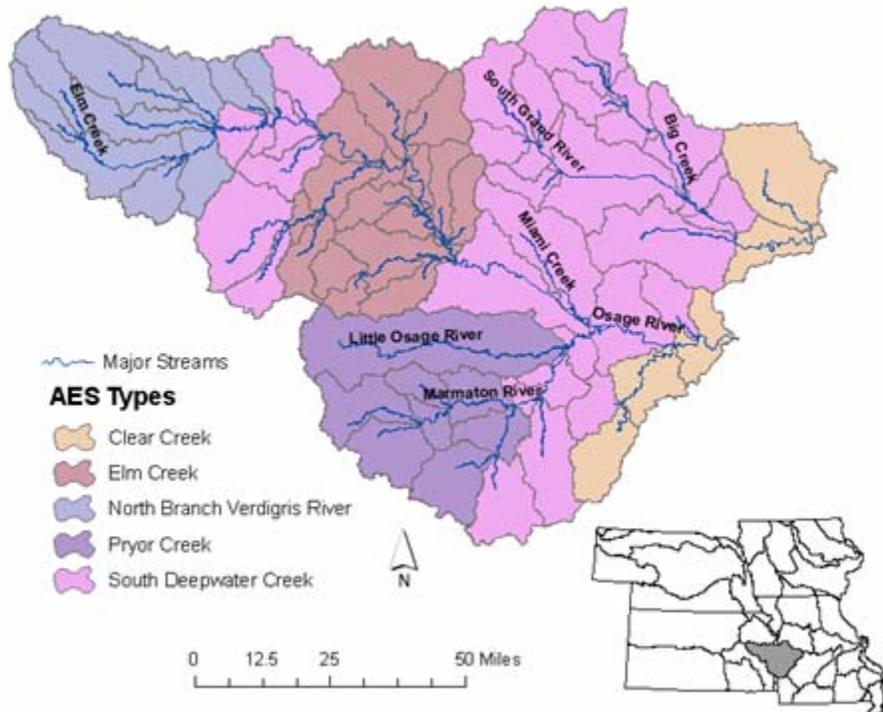


Figure B27. Map showing the boundaries and various Aquatic Ecological System Types for the Osage/South Grand Ecological Drainage Unit.

The average gradient across all stream sizes is 63 m/km. Average gradients (m/km) by size class are: headwater 8.8, creek 2.1, small river 0.6 and large river 0.2. There are 5 Aquatic Ecological System Types (AES-Types) in the Osage/ South Grand EDU. The predominant AES-Type is South Deepwater Creek, which covers much of the area. Other AES-Types are Elm Creek, North Branch Verdigris River, Pryor Creek and Clear Creek.

A total of 71 fish species inhabit or at one time inhabited the Osage/ South Grand EDU. Of those, the Neosho madtom has been classified as globally listed with a status of G1, G2 or G3 (rare, threatened or endangered). The EDU can be generally characterized as a Minnow/Sucker/Sunfish assemblage. The most common species are green sunfish, red shiner, orangethroat darter, central stoneroller, largemouth bass, bluegill, bluntnose minnow and orangspotted sunfish.

## Upper Neosho EDU

The Upper Neosho EDU arcs from eastcentral to southeast Kansas, and takes in a small corner of northeast Oklahoma (Figure B28). Overall there are 17,045 km of primary stream channel within this EDU, of which 4,923 km are classified as perennial in the 1:100,000 National Hydrography Dataset.

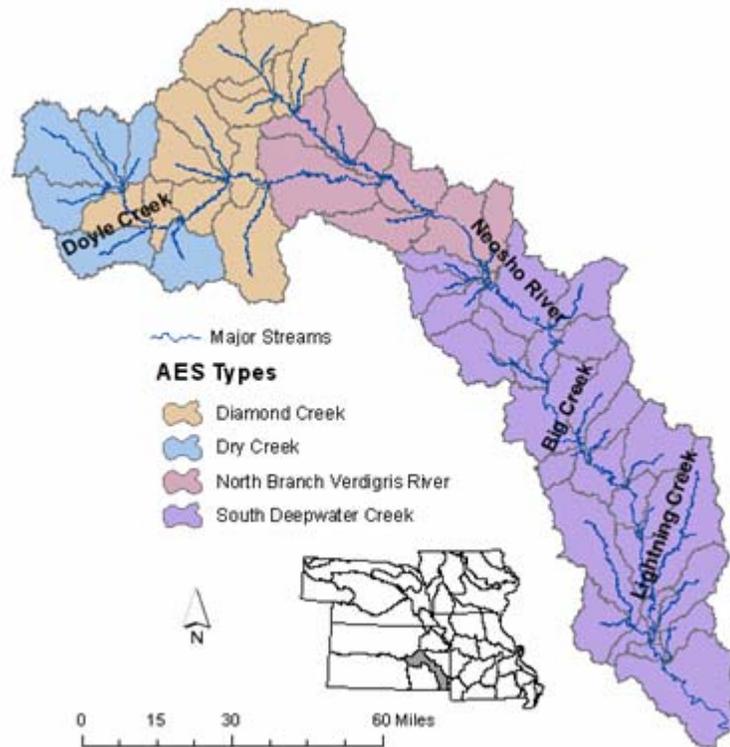


Figure B28. Map showing the boundaries and various Aquatic Ecological System Types for the Upper/Neosho Ecological Drainage Unit.

The average gradient across all stream sizes is 5.0 m/km. Average gradients (m/km) by size class are: headwater 7.1, creek 2.1, small river 0.8 and large river 0.3. There are 4 Aquatic Ecological System Types (AES-Types) in the Upper Neosho EDU. The predominant AES-Type is South Deepwater Creek, which occupies the southern half of the EDU. The other AES-Types are Diamond Creek, Dry Creek and North Branch Verdigris River.

A total of 70 fish species inhabit or at one time inhabited the Upper Neosho EDU. Of those, 3 have been classified as globally listed with a status of G1, G2 or G3 (rare, threatened or endangered). They are the blue sucker, Neosho madtom and Topeka shiner. The EDU can be generally characterized as a Minnow/Darter/Catfish assemblage. The most common species are red shiner, green sunfish, bluntnose minnow, orangespotted sunfish, central stoneroller, orangethroat darter, largemouth bass, longear sunfish, bluegill, blackstripe

topminnow, suckermouth minnow, white crappie, yellow bullhead, golden redhorse, black bullhead, channel catfish, gizzard shad and bullhead minnow.

### *Walnut/Verdigris EDU*

The Walnut/Verdigris EDU lies in southeast Kansas and a portion of northeast Oklahoma (Figure B29). Overall there are 24,632 km of primary stream channel within this EDU, of which 6,430 km are classified as perennial in the 1:100,000 National Hydrography Dataset.

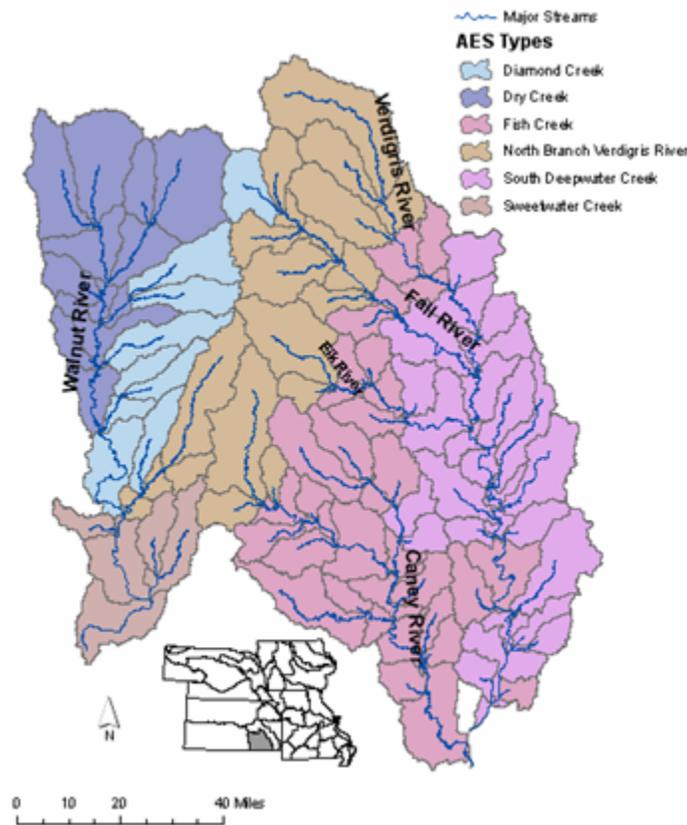


Figure B29. Map showing the boundaries and various Aquatic Ecological System Types for the Walnut/Verdigris Ecological Drainage Unit.

The average gradient across all stream sizes is 7.6 m/km. Average gradients (m/km) by size class are: headwater 10.9, creek 3.3, small river 1.0 and large river 0.4. There are 6 Aquatic Ecological System Types (AES-Types) in the Walnut/Verdigris EDU. Five of the AES-Types are fairly evenly distributed. From east to west they are Dry Creek, Diamond Creek, North Branch Verdigris River, Fish Creek and South Deepwater Creek. Sweetwater Creek AES-Type occupies a small portion in the southern tip of the EDU.

A total of 63 fish species inhabit or at one time inhabited the Walnut/Verdigris EDU, none of which have been classified as globally listed with a status of G1, G2 or G3 (rare, threatened or endangered). The EDU can be generally characterized as a Minnow/Sucker/Sunfish assemblage. The most common species are central stoneroller, red shiner, orangethroat darter, green sunfish, bluntnose minnow, longear sunfish, largemouth bass, channel catfish, bluegill, orangespotted sunfish, golden redhorse, flathead catfish, freckled madtom and suckermouth minnow.

### Paleozoic Plateau Aquatic Subregion

#### *Wisconsin/ Chippewa EDU*

The Wisconsin/ Chippewa EDU lies in the northeastern corner of Iowa, and portions of the southeastern corner of Minnesota, the southwestern corner of Wisconsin and the northeastern corner of Illinois (Figure B30). Overall there are 20,108 km of primary stream channel within this EDU, of which 7,561 km are classified as perennial in the 1:100,000 National Hydrography Dataset.

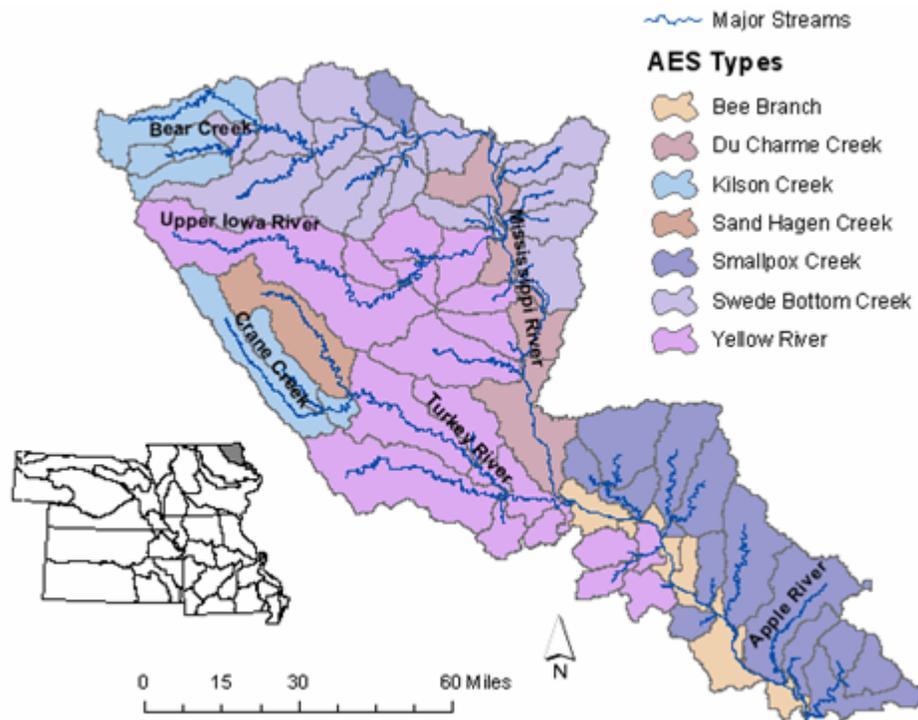


Figure B30. Map showing the boundaries and various Aquatic Ecological System Types for the Wisconsin/Chippewa Ecological Drainage Unit.

The average gradient across all stream sizes is 12.8 m/km. Average gradients (m/km) by size class are: headwater 18.8, creek 4.5, small river 1.1 and large

river 0.4. There are 7 Aquatic Ecological System Types (AES-Types) in the Wisconsin/ Chippewa EDU. Yellow River, in the central portion of the EDU, is the predominant AES-Type. Smallpox Creek is the prevalent type in the eastern part of the EDU. Other AES-Types are Bee Branch, Du Charme Creek, Kilson Creek, Sand Hagen Creek, and Swede Bottom Creek.

A total of 93 fish species inhabit or at one time inhabited the Wisconsin/ Chippewa EDU. Of those, the crystal darter has been classified as globally listed with a status of G1, G2 or G3 (rare, threatened or endangered). The EDU can be generally characterized as a Minnow/Darter/Sucker assemblage. The most common species are white sucker, creek chub, fantail darter, central stoneroller, bluntnose minnow, blacknose dace, longnose dace, johnny darter, common shiner, bigmouth shiner, southern redbelly dace, brook stickleback, hornyhead chub, smallmouth bass, northern hog sucker and fathead minnow.

### **South Central Great Plains Aquatic Subregion**

#### *Kansas/ Republican EDU*

The Kansas/ Republican EDU covers much of southern Nebraska and northern Kansas, and the northeastern section of Colorado (Figure B31). Overall there are 120,966 km of primary stream channel within this EDU, of which 15,332 km are classified as perennial in the 1:100,000 National Hydrography Dataset.

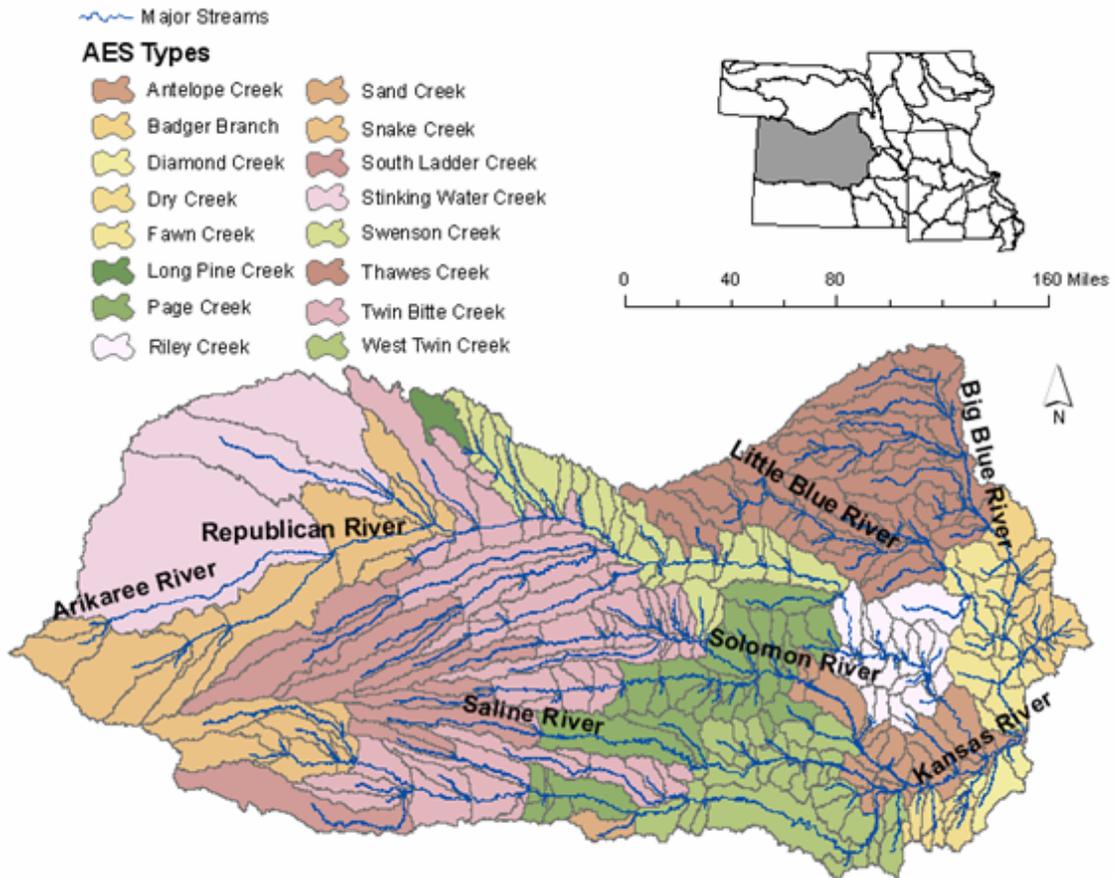


Figure B31. Map showing the boundaries and various Aquatic Ecological System Types for the Kansas/Republican Ecological Drainage Unit.

The average gradient across all stream sizes is 7.0 m/km. Average gradients (m/km) by size class are: headwater 10.0, creek 3.1, small river 1.4 and large river 0.8. There are 16 Aquatic Ecological System Types (AES-Types) in the Kansas/ Republican EDU. Stinking Water Creek in the west, Twin Butte Creek in the center, Page Creek in the center and Thawes Creek in the northeast are the predominant AES-Types in the Kansas/ Republican EDU. Other AES-Types are Antelope Creek, Badger Branch, Diamond Creek, Dry Creek, Fawn Creek, Long Pine Creek, Riley Creek, Sand Creek, Snake Creek, South Ladder Creek, Swenson Creek and West Twin Creek.

A total of 69 fish species inhabit or at one time inhabited the Kansas/ Republican EDU. Of those, 3 have been classified as globally listed with a status of G1, G2 or G3 (rare, threatened or endangered). They are the peppered chub, sturgeon chub and Topeka shiner. The EDU can be generally characterized as a Minnow/Sunfish/Sucker assemblage. The most common species are fathead minnow, red shiner, sand shiner, creek chub, central stoneroller, green sunfish, black bullhead, channel catfish, suckermouth minnow, white sucker, orangethroat darter, bluegill, river carpsucker, orangespotted sunfish, plains killifish,

largemouth bass, stonecat, gizzard shad, yellow bullhead, flathead catfish, freshwater drum, bluntnose minnow, emerald shiner and white crappie.

### *Middle Platte EDU*

The Middle Platte EDU stretches across central to eastcentral Nebraska (Figure B32). Overall there are 45,379 km of primary stream channel within this EDU, of which 8,306 km are classified as perennial in the 1:100,000 National Hydrography Dataset.

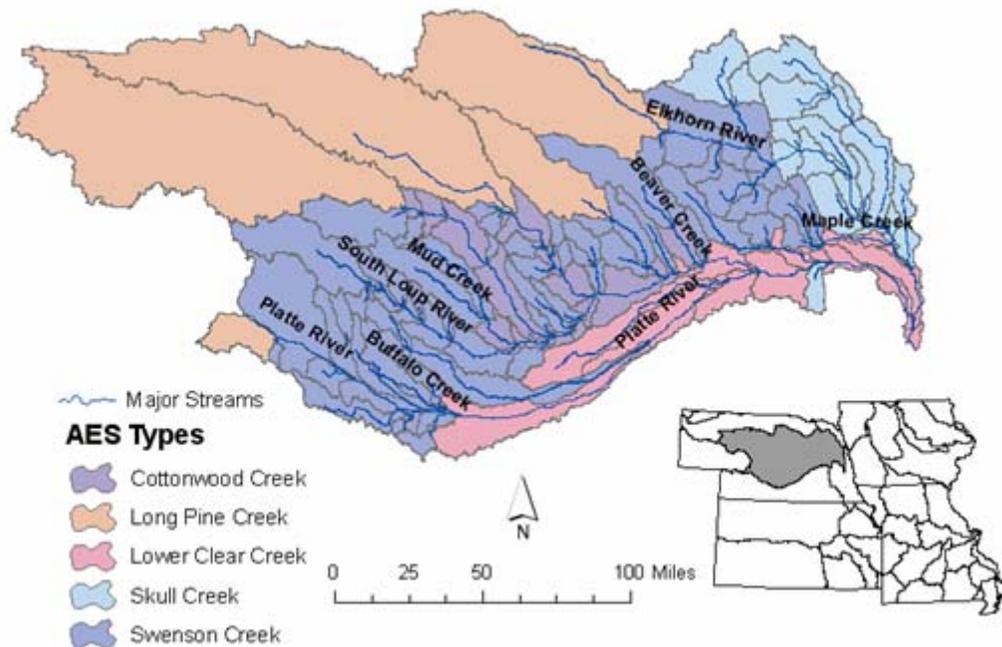


Figure B32. Map showing the boundaries and various Aquatic Ecological System Types for the Middle Platte Ecological Drainage Unit.

The average gradient across all stream sizes is 6.0 m/km. Average gradients (m/km) by size class are: headwater 8.5, creek 2.5, small river 1.1 and large river 1.0. There are 5 Aquatic Ecological System Types (AES-Types) in the Middle Platte EDU. The predominant AES-Types are Long Pine Creek in the west and Swenson Creek in the south and east. Other AES-Types are Skull Creek, Cottonwood Creek and Lower Clear Creek.

A total of 70 fish species inhabit or at one time inhabited the Middle Platte EDU. Of those, 6 have been classified as globally listed with a status of G1, G2 or G3 (rare, threatened or endangered). They are the blue sucker, lake sturgeon, pallid sturgeon, sicklefin chub, sturgeon chub and Topeka shiner. The EDU can be generally characterized as a Minnow/Sunfish/Darter assemblage. The most common species are sand shiner, fathead minnow, red shiner, brassy minnow,

bigmouth shiner, green sunfish, creek chub, white sucker, plains topminnow, river carpsucker, channel catfish, largemouth bass, black bullhead, shorthead redhorse, longnose dace, flathead chub, stonecat, bluegill, quillback, river shiner and plains minnow.

### *North Platte/ South Platte EDU*

The North Platte/ South Platte EDU is in the southwestern corner of Nebraska and portions of the southeastern corner of Wyoming and northeastern Colorado (Figure B33). Overall there are 20,543 km of primary stream channel within this EDU, of which 3,279 km are classified as perennial in the 1:100,000 National Hydrography Dataset.

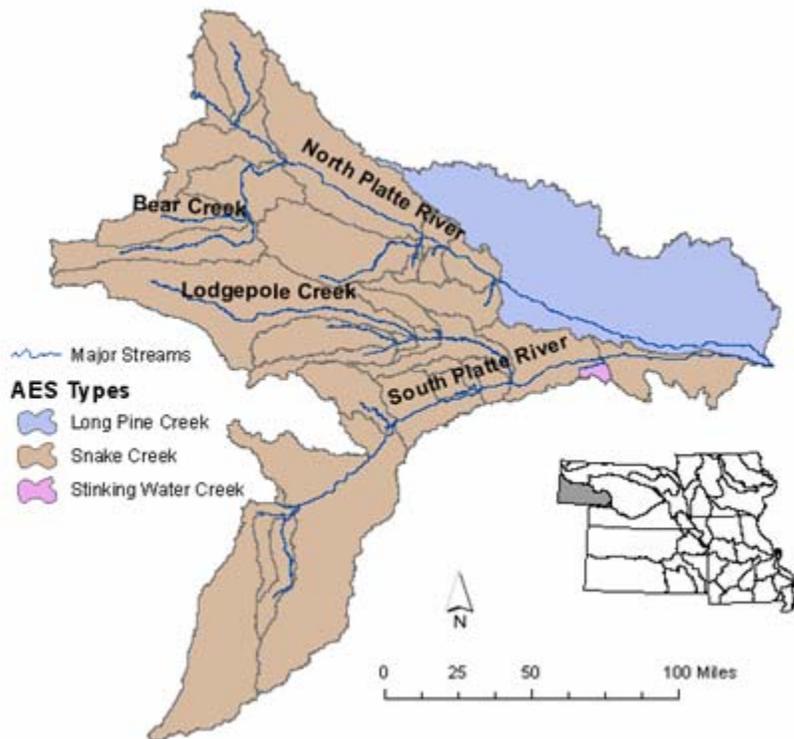


Figure B33. Map showing the boundaries and various Aquatic Ecological System Types for the North Platte/South Platte Ecological Drainage Unit.

The average gradient across all stream sizes is 9.8 m/km. Average gradients (m/km) by size class are: headwater 14.4, creek 5.2, small river 2.6 and large river 1.3. There are 3 Aquatic Ecological System Types (AES-Types) in the North Platte/ South Platte EDU. Most of the EDU is comprised of the Snake Creek AES-Type. Other AES-Types are Long Pine Creek and Stinking Water Creek.

A total of 47 fish species inhabit or at one time inhabited the North Platte/ South Platte EDU, none of which have been classified as globally listed with a status of G1, G2 or G3 (rare, threatened or endangered). The EDU can be generally

characterized as a Minnow/Sunfish/Catfish assemblage. The most common species are creek chub, white sucker, fathead minnow, sand shiner, bigmouth shiner, longnose dace, red shiner, longnose sucker, plains topminnow, plains killifish, central stoneroller and brassy minnow.

### Upper Arkansas EDU

The Upper Arkansas EDU takes in much of the southern half of Kansas, and portions of southeastern Colorado and northern Oklahoma (Figure B34). Overall there are 72,435 km of primary stream channel within this EDU, of which 7,934 km are classified as perennial in the 1:100,000 National Hydrography Dataset.

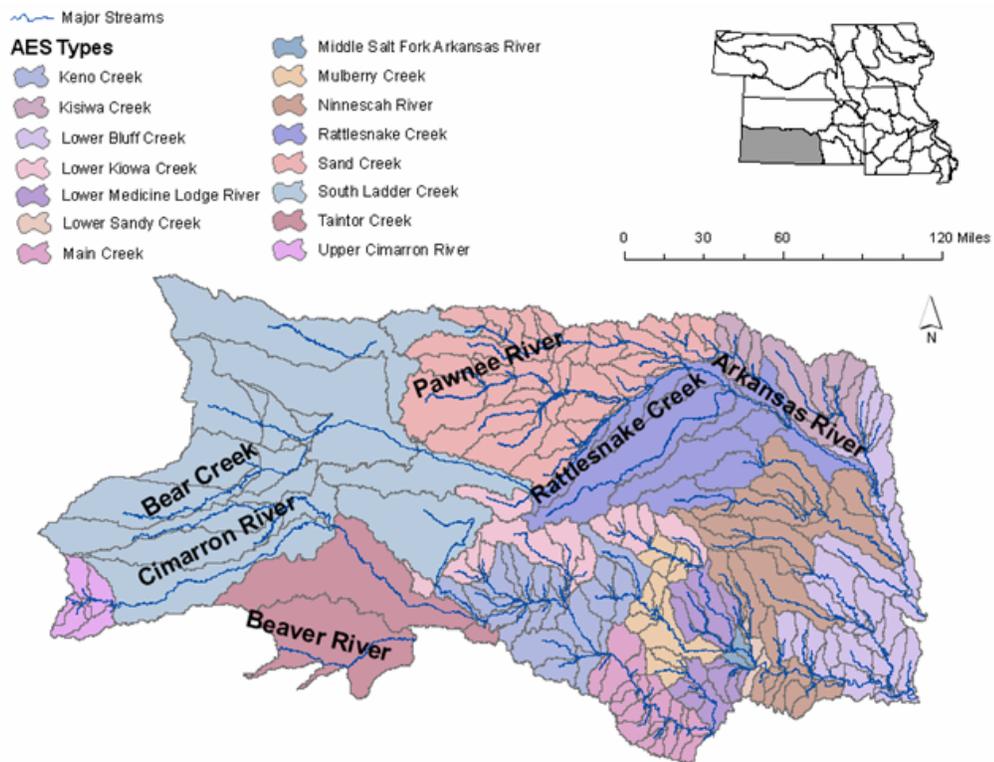


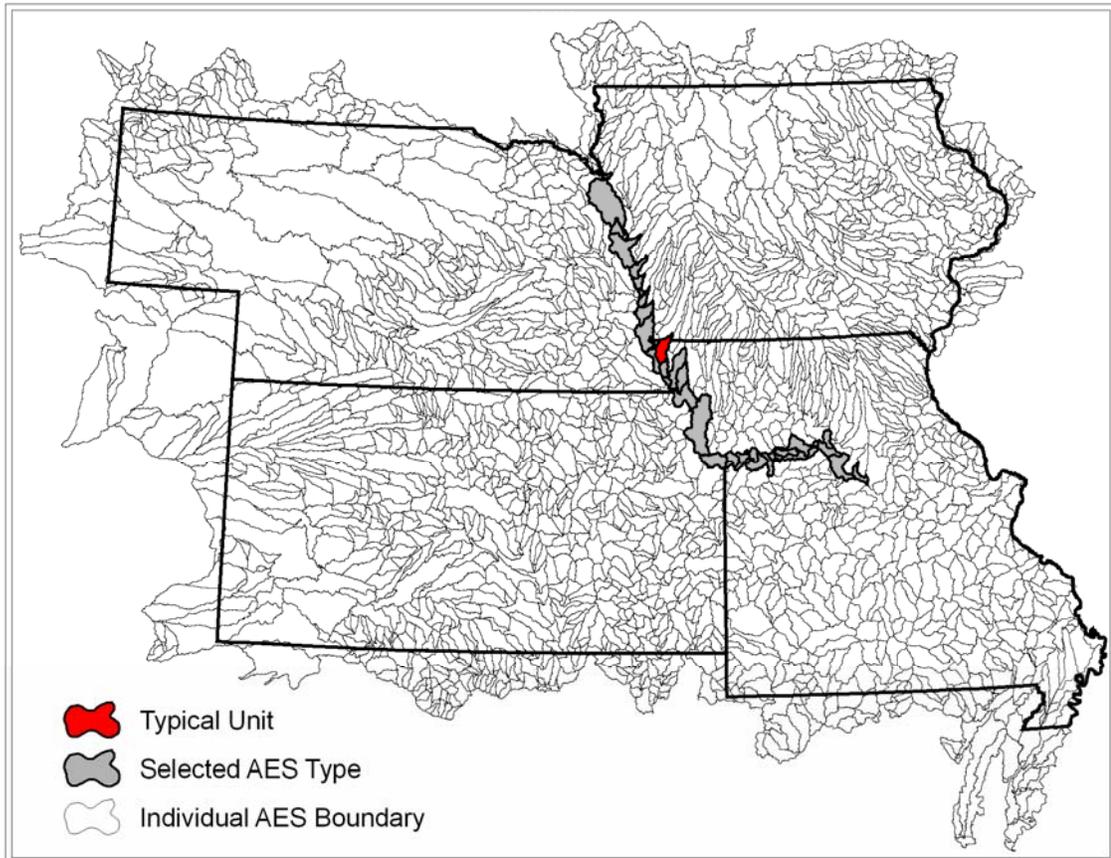
Figure B34. Map showing the boundaries and various Aquatic Ecological System Types for the Upper Arkansas Ecological Drainage Unit.

The average gradient across all stream sizes is 5.9 m/km. Average gradients (m/km) by size class are: headwater 8.1, creek 3.0, small river 1.4 and large river 1.2. There are 15 Aquatic Ecological System Types (AES-Types) in the Upper Arkansas EDU. The predominant AES-Type is South Ladder Creek, which occurs in the western one-third of the EDU. Prevalent AES-Types are Keno Creek, Lower Bluff Creek, Ninnescah River, Rattlesnake Creek and Sand Creek. Other AES-Types are Kisiwa Creek, Lower Kiowa Creek, Lower Medicine Lodge River, Lower Sandy Creek, Main Creek, Middle Salt Fork Arkansas River, Mulberry Creek, Taintor Creek and Upper Cimarron River.

A total of 60 fish species inhabit or at one time inhabited the Upper Arkansas EDU. Of those, 2 have been classified as globally listed with a status of G1, G2 or G3 (rare, threatened or endangered). They are the Arkansas darter and peppered chub. The EDU can be generally characterized as a Minnow/Sunfish/Darter assemblage. The most common species are red shiner, sand shiner, fathead minnow, green sunfish, plains killifish, channel catfish, suckermouth minnow, central stoneroller, Arkansas darter, largemouth bass, gizzard shad, orangespotted sunfish, river carpsucker, bluegill, flathead catfish, yellow bullhead, black bullhead, bullhead minnow and emerald shiner.

## Appendix C. Biophysical Descriptions of Aquatic Ecological System Types (AES-Types) in EPA Region 7.

### AES-Type 1 (Rock Creek)



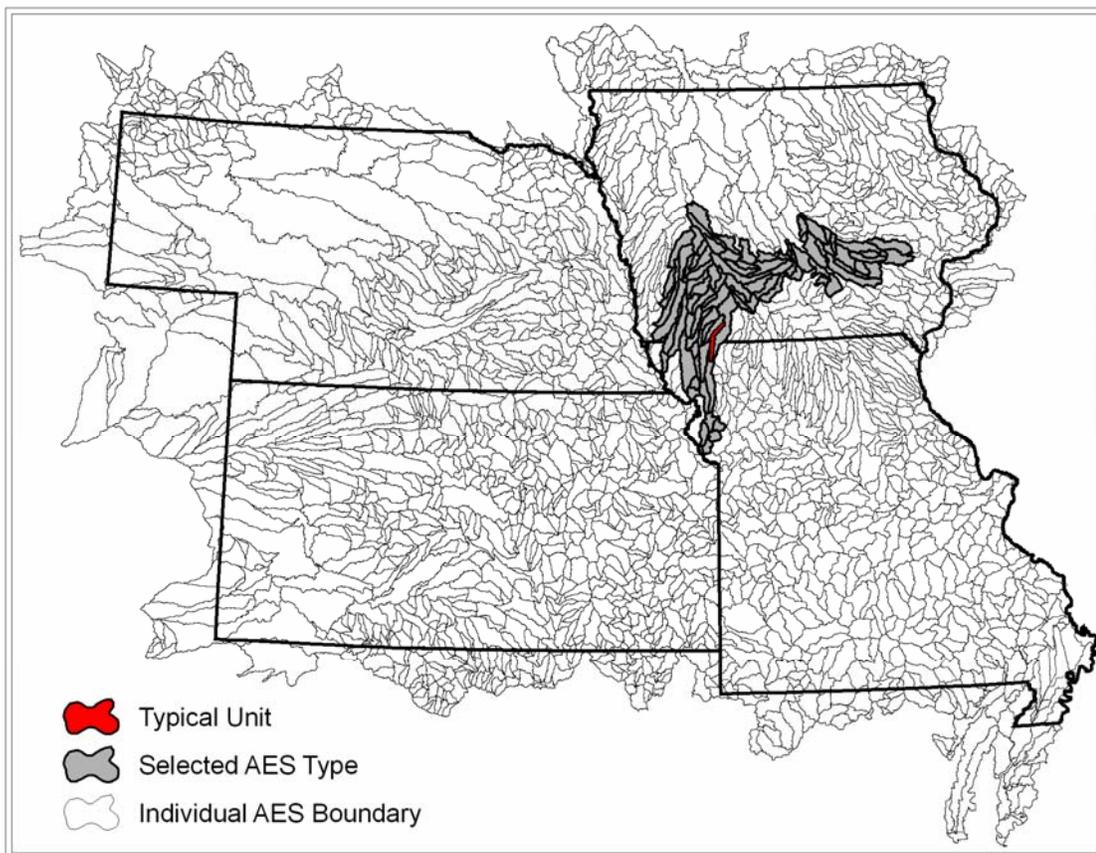
#### ***Description:***

This AES-Type runs in a narrow band along the Missouri River from the northeast corner of Nebraska to just below the outlet of Petite Saline Creek in Missouri and contains much of the Missouri River floodplain and adjacent bluffs. Local relief ranges from nearly zero within the floodplain to about 61 meters in the adjacent uplands and bluffs. The area consists mainly of the alluvial plain along the Missouri River that is composed of Pleistocene and Holocene alluvial materials with Pennsylvanian limestone and occasionally sandstone in the upland portions of this AES-Type. These older alluvial materials consist of gravel, sand, and silts and are overlain by more recent alluvium that is sandy and silty and generally not more than 150 years old. Bedrock is more than 30 feet below the surface. Surface soil textures consist primarily of silt loams and to a lesser extent silty clays. These soils exhibit varied infiltration rates ranging from moderate in the uplands to slow or even very slow in the alluvium of the Missouri River floodplain. Soils may be slightly alkaline. Historically the Missouri River was

very meandering and frequently shifted its channel along with its bars and islands. Wetlands and oxbow lakes were once common here. Headwaters and creeks have a combined mean stream gradient of 8.8 meters per kilometer.

***Typical Unit:*** 82 – Rock Creek

## AES-Type 2 (Honey Creek)

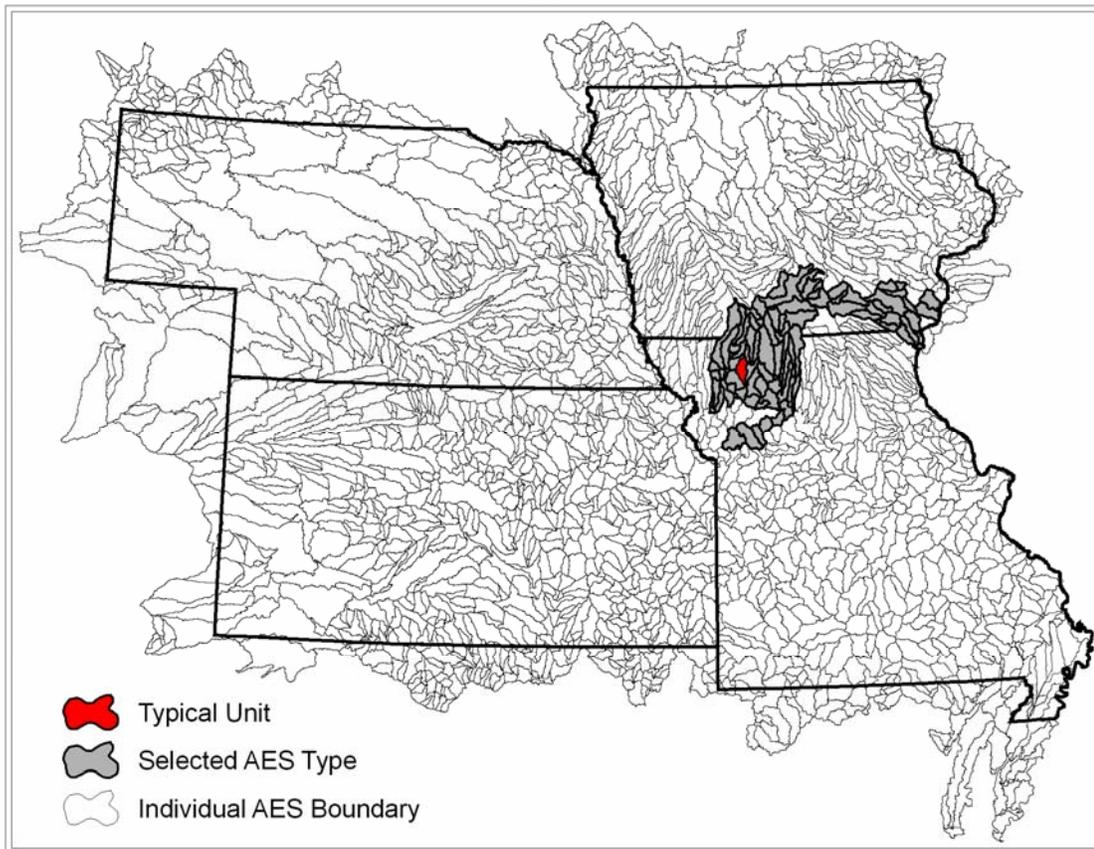


### ***Description:***

This AES-Type is located primarily in central Iowa within the USFS's Central Dissected Till Plains Ecological Section with a band running south into northwestern Missouri. A number of major drainages are partially included in this Type including the Iowa River, Skunk River, Des Moines River, Platte River, and Nodaway River among others. Local relief typically ranges from 15 to nearly 50 meters or more. Surface soil textures consist of silty clay loams and silty loams with moderate infiltration rates. Headwaters and creeks have a combined mean gradient of 9.7 meters per kilometer. Historic vegetation was somewhat varied, but typically consisted of oak-hickory, prairie, and elm-ash-cottonweed forest along the rivers.

***Typical Unit:*** 81 – Honey Creek

### AES-Type 3 (Sampson Creek)

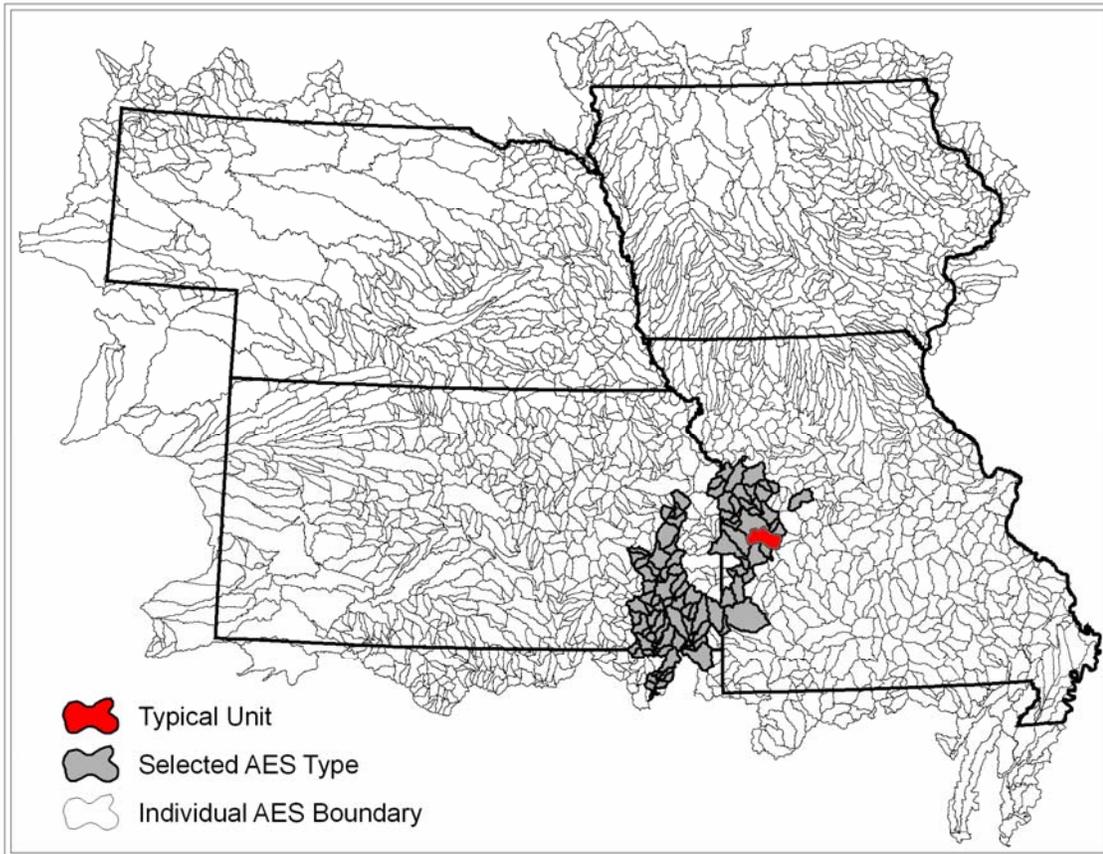


**Description:**

This AES-Type corresponds very closely with the USFS's Central Dissected Till and Loess Plain Ecological Subsection and incorporates much of the Grand, Chariton, and Des Moines River drainages. Most local relief is less than 50 meters. Surface soil textures are varied and consist of loam, clay loam, silt loam, and silty clay loam. These soils exhibit slow to moderate infiltration rates. Headwaters and creeks have a combined mean gradient of 9.0 meters per kilometer. Historical vegetation consisted of mosaics of bluestem prairie and oak-hickory forest.

**Typical Unit:** 2123 – Sampson Creek

## AES-Type 4 (South Deepwater Creek)

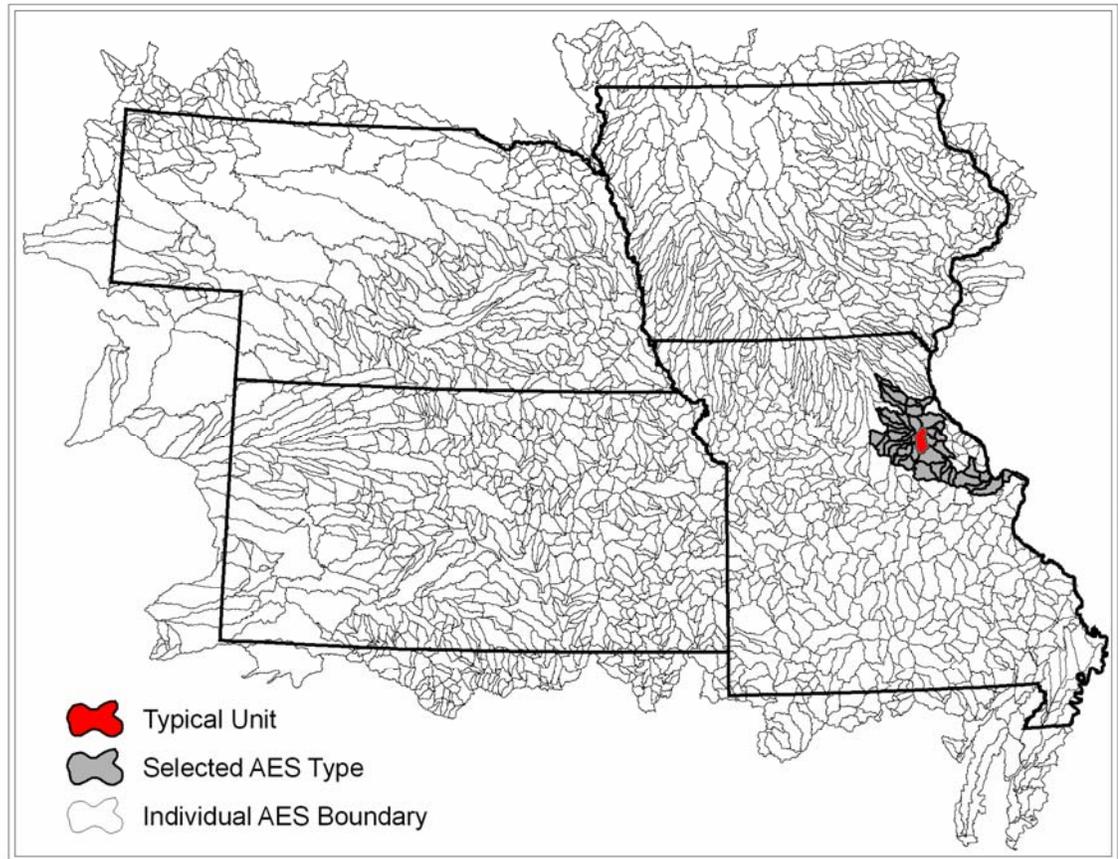


### ***Description:***

This AES-Type is located along the Missouri – Kansas border mostly within the USFS’s Osage Plains Ecological Section and contains portions of the Osage, Neosho, and Verdigris River basins. The area consists of relatively level to rolling plains. Soil surface textures are primarily silt loams with very slow to moderate infiltration rates. Local relief is typically less than 30 meters. Headwaters and creeks have a relatively typical combined mean gradient of 5.9 meters per kilometer. Historically the natural vegetation consisted of oak-hickory forest and prairie.

***Typical Unit:*** 1839 – South Deepwater Creek

## AES-Type 5 (Lick Creek)



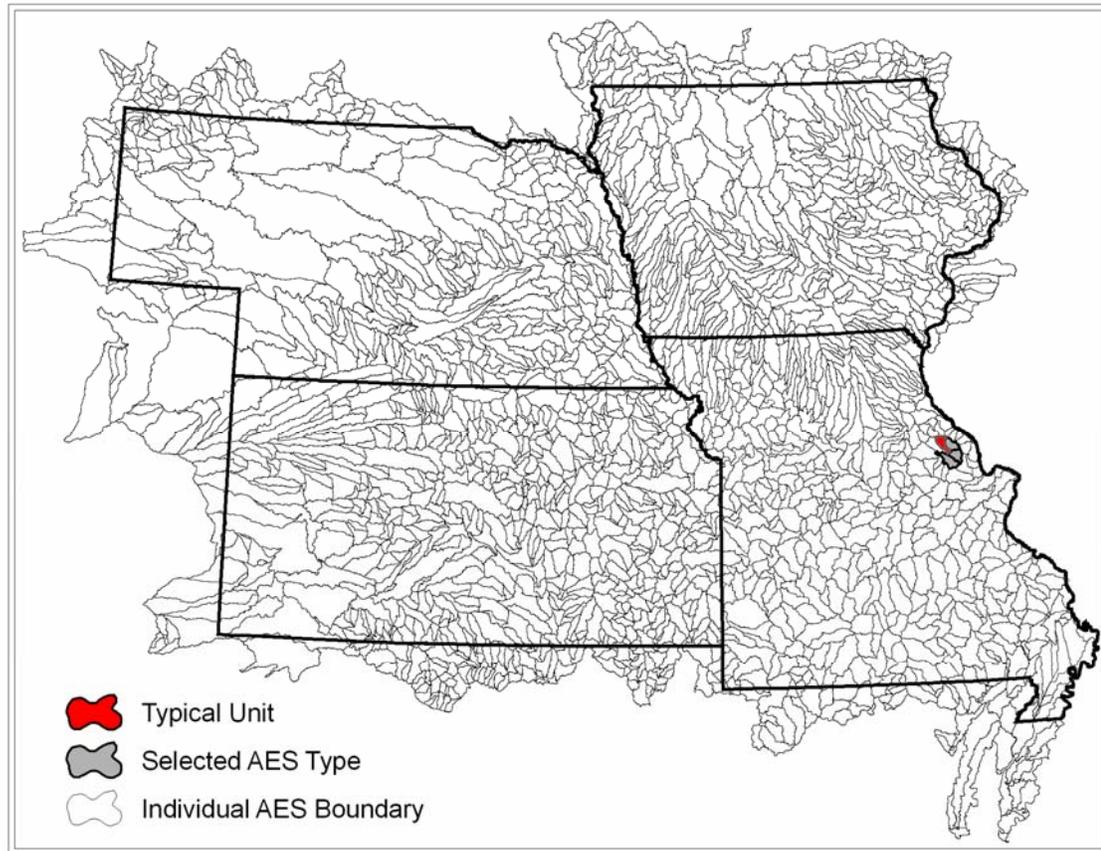
### **Description:**

This AES-Type encompasses portions of the USFS's Claypan Till Plains and West Mississippi River Hills Ecological Subsections. The western, or headwater, portions of this AES-Type consist of Pennsylvanian limestones that transition to Mississippian limestone nearer the Mississippi River. These bedrocks are rarely exposed because of thick overlying deposits of glacial till. The area can be characterized as having well developed claypan soils on a flat to gently rolling plain. Most local relief is less than 30 meters, but occasionally approaches 60 meters. The upland areas of this Type exhibit very low relief while the areas around the main stem rivers are much more rugged. Soils are deep and poorly drained and harbor perched water tables in the winter and spring resulting from the clay subsoils. Surface soil texture consists of silt loams with variable infiltration that ranges from very slow to moderate. Stream channels are typically in silts and clays and are meandering low gradient systems with narrow floodplains. The smaller streams are intermittent or ephemeral while the large streams are perennial, but may have very low flows with disconnected pools during extended dry periods. Springs are small and uncommon while the groundwater is often saline. The eastern, or downstream, portions of this AES-

Type consist of a similar environment as that of the Ozark border areas with Ordovician sandstones and limestones and notable karst features like sinkhole ponds. Topography can range from rolling to rugged. Soils are variable in relation to parent materials. Moderate gradient stream channels may encounter bedrock in some locations. The combined headwater and creek mean gradient is 7.6 meters per kilometer. Historically this area was primarily prairie with timber along stream valleys especially the downstream portions of the larger rivers.

***Typical Unit:*** 1894 - Lick Creek

## AES-Type 6 (Upper Cuivre River)

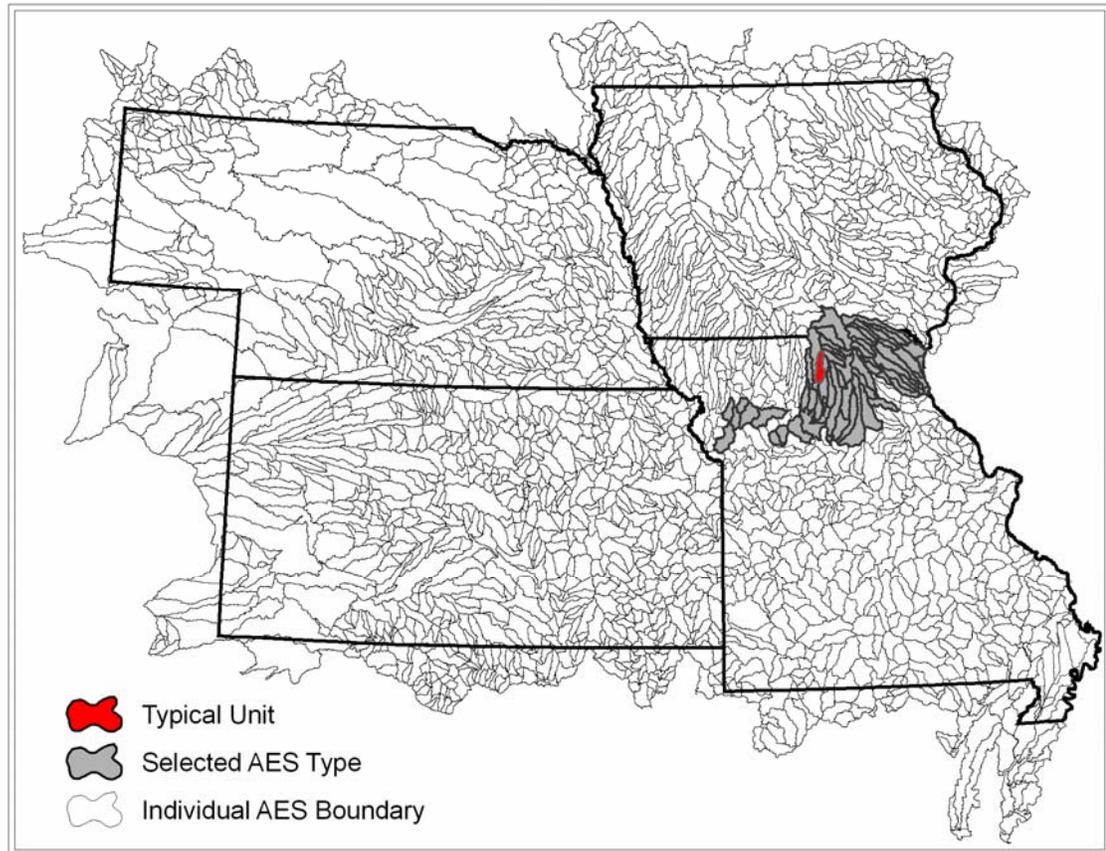


### **Description:**

This AES-Type consists of four relatively small units located in the Cuivre River drainage within a portion of the USFS's West Mississippi River Hill Ecological Subsection. Local relief is less than 60 meters. The surface soil textures are predominantly silt loams with very slow or occasionally moderate infiltration rates. These soils are underlain by Mississippian and Ordovician limestones with small sandstone components. Coldwater is an important ecological feature of this Type. There are 75 headwater/creek springs and 14 main stem springs scattered throughout the four individual units comprising this AES-Type. The median spring count is 20. The combined headwater and creek mean gradient is 11.0 meters per kilometer.

**Typical Unit:** 1877 – Upper Cuivre River

## AES-Type 7 (East Locust Creek)

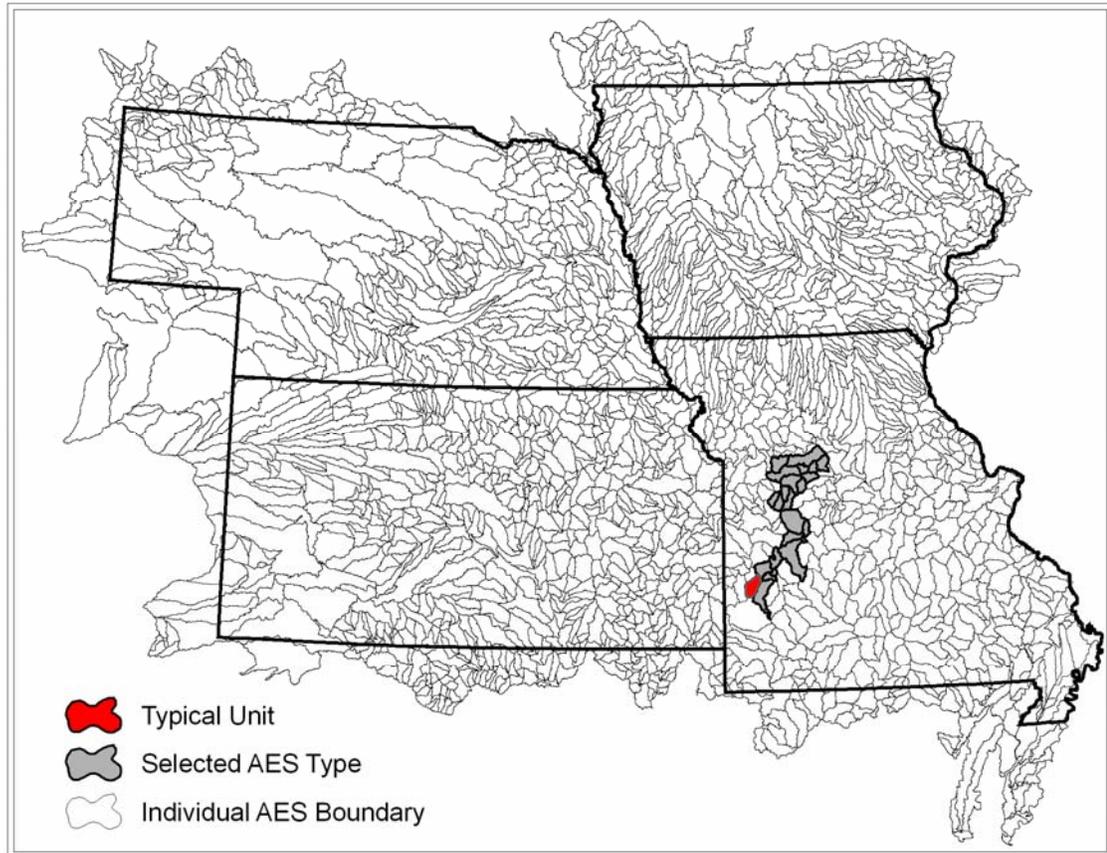


### **Description:**

This is one of the dominant AES-Type of the USFS's Central Dissected Till Plains Aquatic Subregion and encompasses most of the Chariton River Hills and Wyaconda River Dissected Till Plains Ecological Subsections. Local relief is less than 60 meters. Surface soil textures are principally loams and silty loams, or occasionally silty clay loam. Infiltration rates are typically very slow, but variable ranging from moderate to very slow. Bedrock geology consists of limestone and sometimes sandstone. Like most of the Central Dissected Till Plains Aquatic Subregion, springs are relatively uncommon. The combined headwater and creek mean gradient is 7.2 meters per kilometer.

**Typical Unit:** 1778 – East Locust Creek

## AES-Type 8 (Clear Creek)

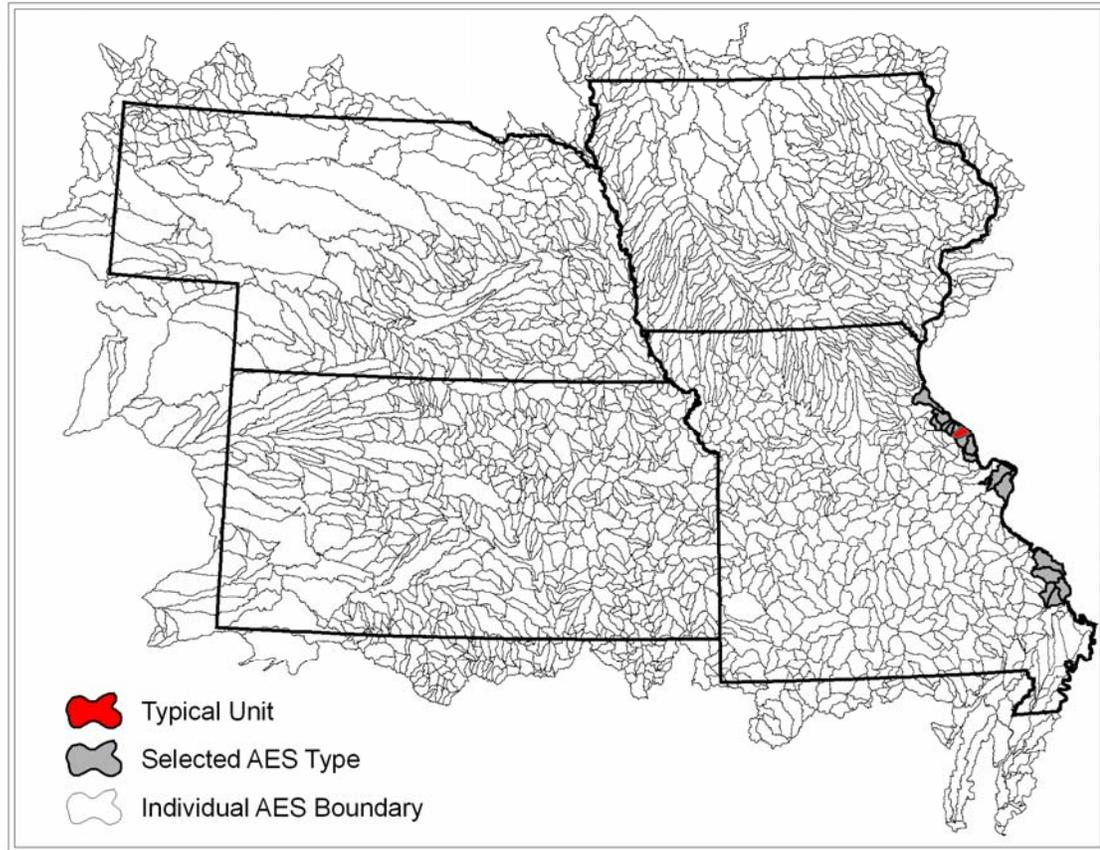


### **Description:**

This AES-Type runs in a belt along the transition areas between the Central Dissected Till Plains, Osage Plains/Flint Hills, and the Ozark Aquatic Subregions beginning in west-central Missouri and continuing in a northeasterly direction to include much of the upper Blackwater River basin. Local relief ranges from nearly zero to almost 60 meters, although most is between 16 and 30 meters. Much of the AES is a very flat plain that, historically, was prairie. Bedrock geology is generally Pennsylvanian limestone. Bedrock outcrops exist, albeit rarely, on some of the valley walls. Surface soil textures consist primarily of silty loams and loams with moderate to sometimes very slow infiltration rates. Streams are generally low gradient meandering systems in broad valleys and have their highest flows in the spring and lowest in the late summer occasionally going nearly dry during dry periods. Springs are not common, but groundwater is abundant and often saline. There are 32 headwater/creek springs and ten main stem springs scattered throughout the 23 individual units comprising this AES-Type. The median spring count is 1. Headwaters and creeks combined have a mean gradient of 7.8 meters per kilometer. Historic vegetation was primarily prairie.

***Typical Unit:*** 1858 – Clear Creek

## AES-Type 9 (Ramsey Creek)



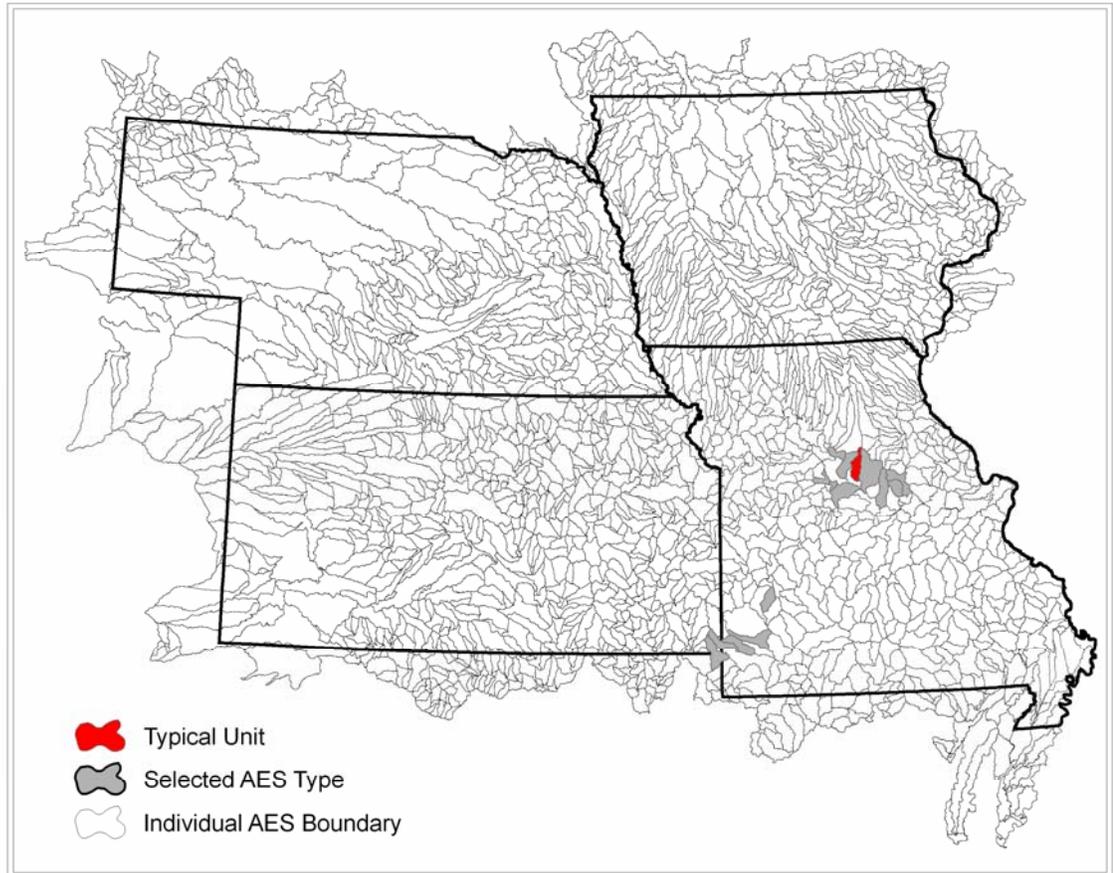
### **Description:**

This AES-Type occurs in three separate patches along the Mississippi River in both the Central Dissected Till Plains and Ozark Aquatic Subregions from the North Fabius River to the Castor River Diversion Channel. This AES-Type consists of an Ozark border type environment and contains many small tributaries to the Mississippi River that begin on the bluffs and flow down across the Mississippi River floodplain. The mouth of the Missouri River is included in this Type. Local relief varies from nearly zero in the floodplain of the Mississippi River to occasionally more than 90 meters in the bluffs further from the river. Rock types are varied, but are mostly cherty dolomites to the south and Ordovician sandstones and limestones to the north. Karst features exist throughout the AES-Type. Soils are diverse and variable depending on the parent material from which they were formed and their position in the landscape. Surface soil textures typically consist of silt loams and silty clays with moderate to slow or very slow infiltration rates. The soils are underlain primarily by limestone in the bluffs with alluvium along the river. Hydrologically this area is relatively diverse. Most streams are headwaters and creeks that are deeply incised with gravel substrates that flow directly to the Mississippi River. Flows are

highest in the spring and lowest in the fall. Backflooding occurs when the Mississippi River is high. Springs are not an important feature here, but groundwater is abundant. There are 64 headwater/creek springs and six main stem springs scattered throughout the 22 individual units comprising this AES-Type. The median spring count is 2. The headwaters and creeks combined have a fairly typical mean gradient of 10.5 meters per kilometer. The historic vegetation consisted largely of oak and mixed-hardwood woodland and forest.

***Typical Unit:*** 1915 – Ramsey Creek

## AES-Type 10 (Moniteau Creek)

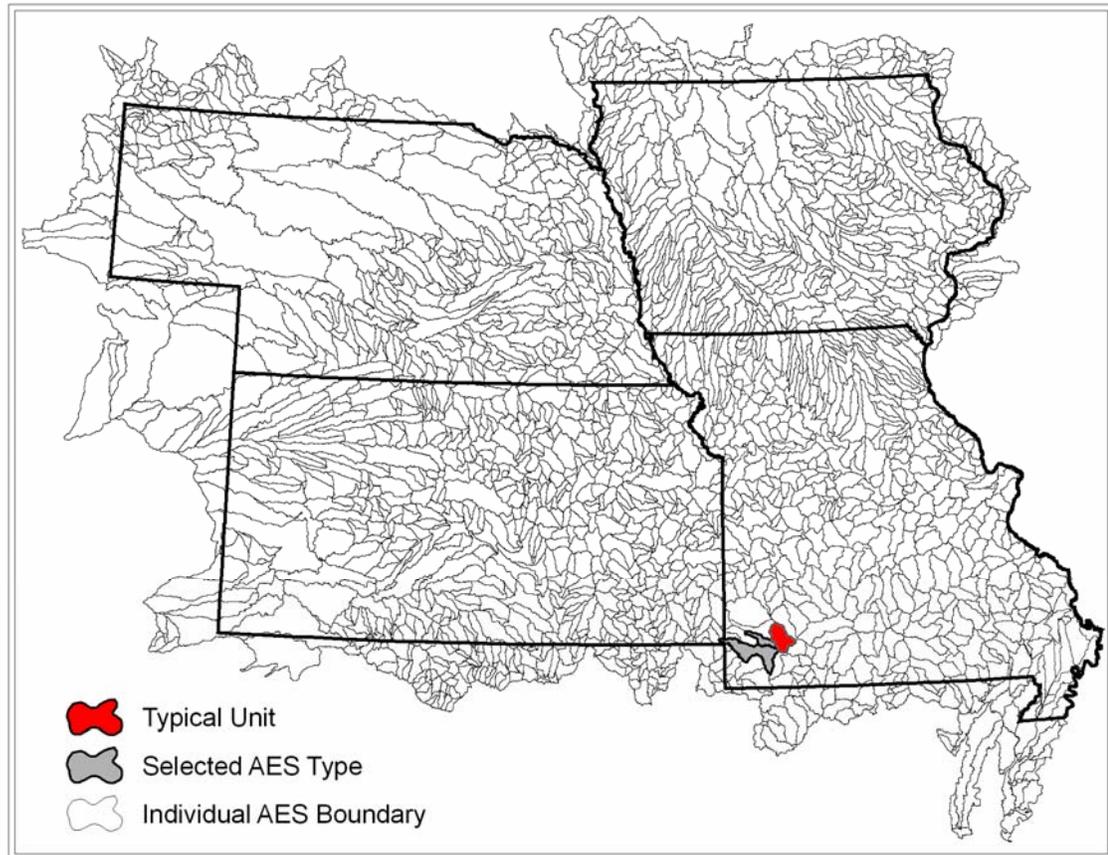


### **Description:**

This AES-Type occurs in two general clusters in the Ozark Aquatic Subregion of Missouri. Local relief varies from nearly zero to almost 60 meters. Bedrock consists primarily of cherty limestones, Pennsylvanian to the north and Mississippian to the south. Karst features are scattered throughout the AES-Type and sinkholes are quite common. Surface soil textures are primarily loams or silt loams with slow to moderate infiltration rates, although very slow infiltration rates are occasionally present. Soils in the north are diverse depending on parent material and formed in deep loess. Silty loess deposits are thickest near the Missouri River and thinner moving away from the river. In the southern cluster of this AES-Type soils formed in weathered cherty limestones with loess surfaces and are moderately to very deep. Throughout the AES-Type stream flows are highest in the spring and lowest in the fall. Stream bed loads are of gravel and sand. Groundwater is abundant. There are 24 headwater/creek springs and two main stem springs scattered throughout the Missouri portion of this AES-Type. The median spring count is 1. The combined headwater and creek mean gradient is fairly low at 9.0 meters per kilometer.

**Typical Unit:** 2028 – Moniteau Creek

## AES-Type 11 (Upper Spring River of the Neosho)



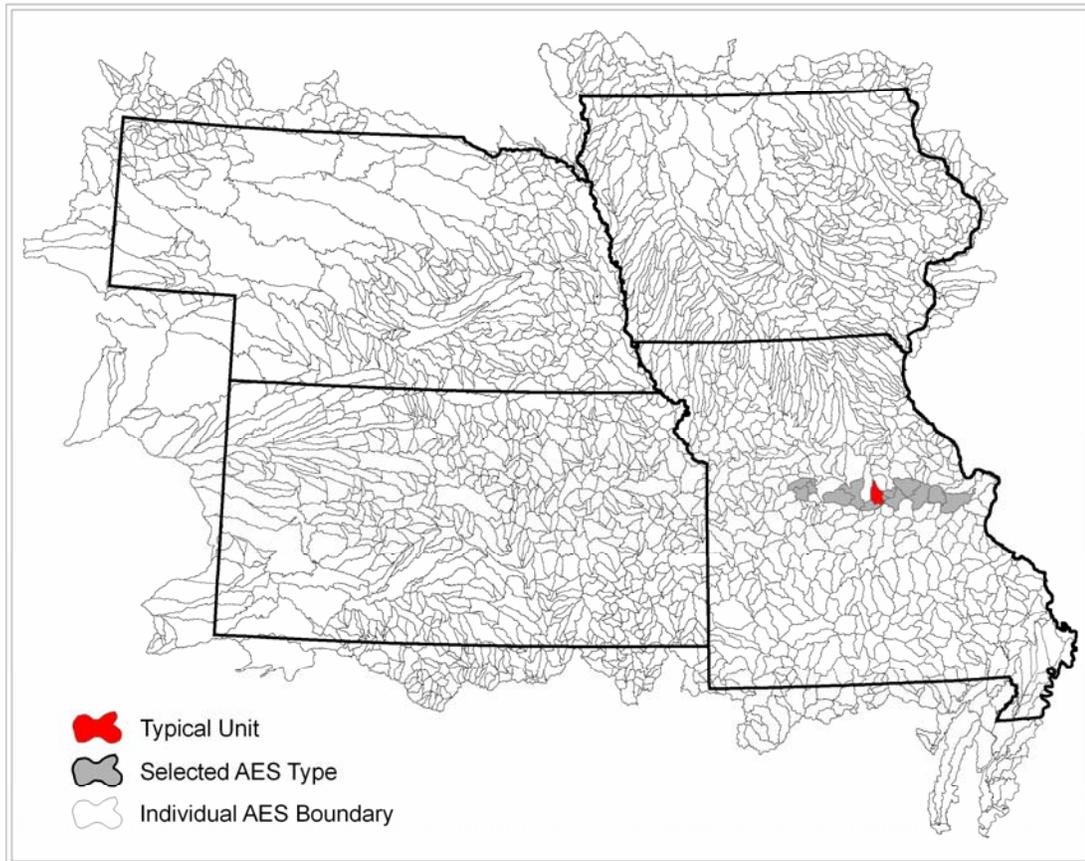
### **Description:**

This AES-Type is located within the Neosho Ecological Drainage Unit in southwestern Missouri and comprises a portion of the USFS's Springfield Plain Ecological Subsection. Local relief is generally less than 30 meters, but will occasionally approach 60 meters. Mississippian period cherty limestones underlie deep soils that formed in this weathered cherty limestone covered with loess. Surface soil textures consist of loams and silty loams with slow to moderate infiltration rates. Karst features are prominent, especially notable are the large number of springs and sinkholes that dot the AES-Type. Stream discharges are highest in the spring and lowest in the fall and flash floods are common after large rain events. Streams generally carry bed loads of cherty gravel and sand. Coldwater is an important ecological feature in this Type. Because springs are abundant and often large they contribute to maintaining stream base flows. Groundwater is usually abundant and of good quality. There are 101 headwater/creek springs and 15 main stem springs scattered throughout the Missouri portion of this AES-Type. This AES-Type contains two springs over 10 cfs. The median spring count is 14. The combined headwater and creek mean

stream gradient is relatively low at 8.6 meters per kilometer. Historic vegetation was principally prairie with timber found along streams.

***Typical Unit:*** 1965 – Upper Spring River of the Neosho

## AES-Type 12 (Middle River)



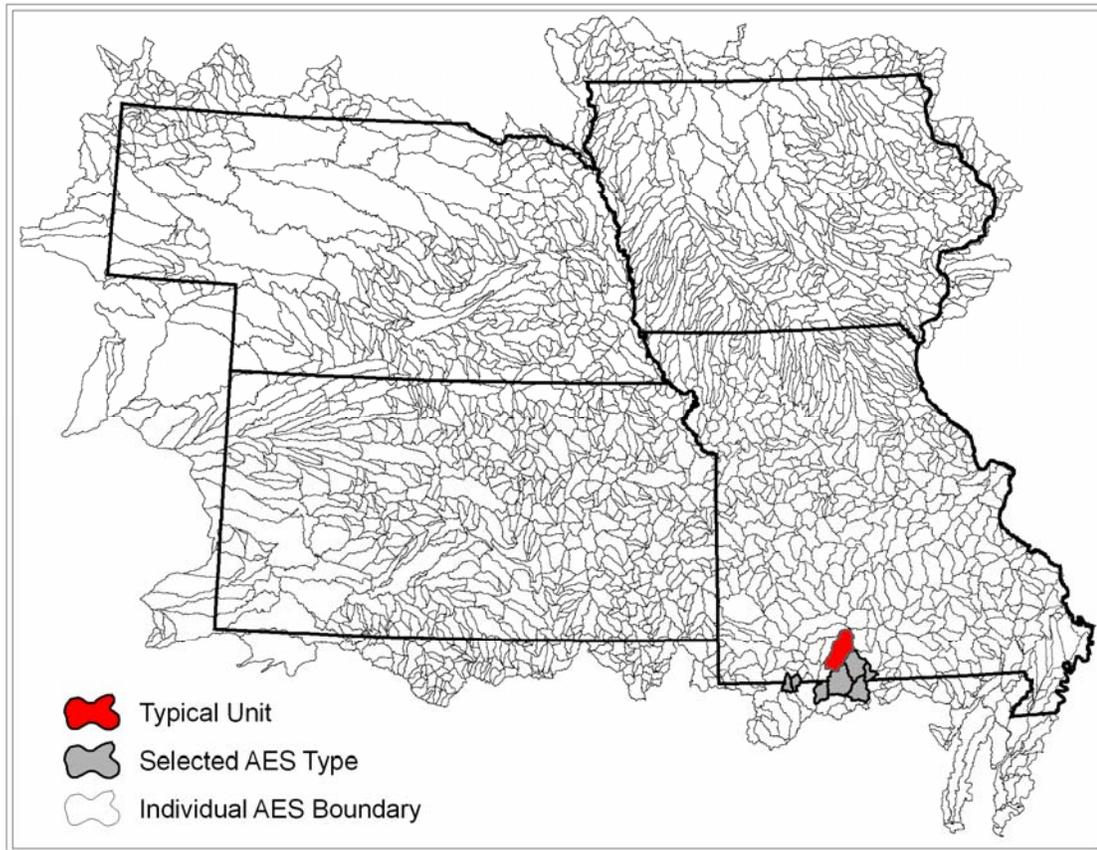
### **Description:**

This AES-Type is located along a portion of the lower Missouri River and much of the lower Lamine River and several of its tributaries including Muddy and Heaths Creeks. This Type falls along the USFS's Inner Ozark Border and Outer Ozark Border Ecological Subsections. Local relief ranges from nearly zero along the Missouri River floodplain to 60 or even 90 meters at the edge of the floodplain. Bedrock is often exposed in this area and consists of varied rock types including Pennsylvanian cherty limestones and cherty dolomites of the Ordovician Jefferson City-Cotter Formation. Karst features occur, but are not abundant. Alluvial areas adjacent to the Missouri River have deep silty loess deposits that become thinner moving away from the river. Soil diversity is high and varies with landscape position and parent material. Surface soil textures consist of loams and stony soils with moderate to very slow infiltration rates. The area is hydrologically diverse with lots of small moderate gradient streams draining directly to the Missouri River. Bed materials are usually in gravel and sand except approaching the Missouri River where bed materials become silty. Stream flows are highest in the spring and lowest in the fall. Flash floods occur after heavy rain events. Springs have minimal impact on stream base flows. Groundwater is abundant. There are 54 headwater/creek springs and three main stem springs scattered throughout the 14 individual units comprising this AES-

Type. The median spring count is 1. The combined headwater and creek mean stream gradient is relatively average at 12.7 meters per kilometer. Historic vegetation was largely oak savanna.

**Typical Unit:** 2033 – Middle River

## AES-Type 13 (Beaver Creek)



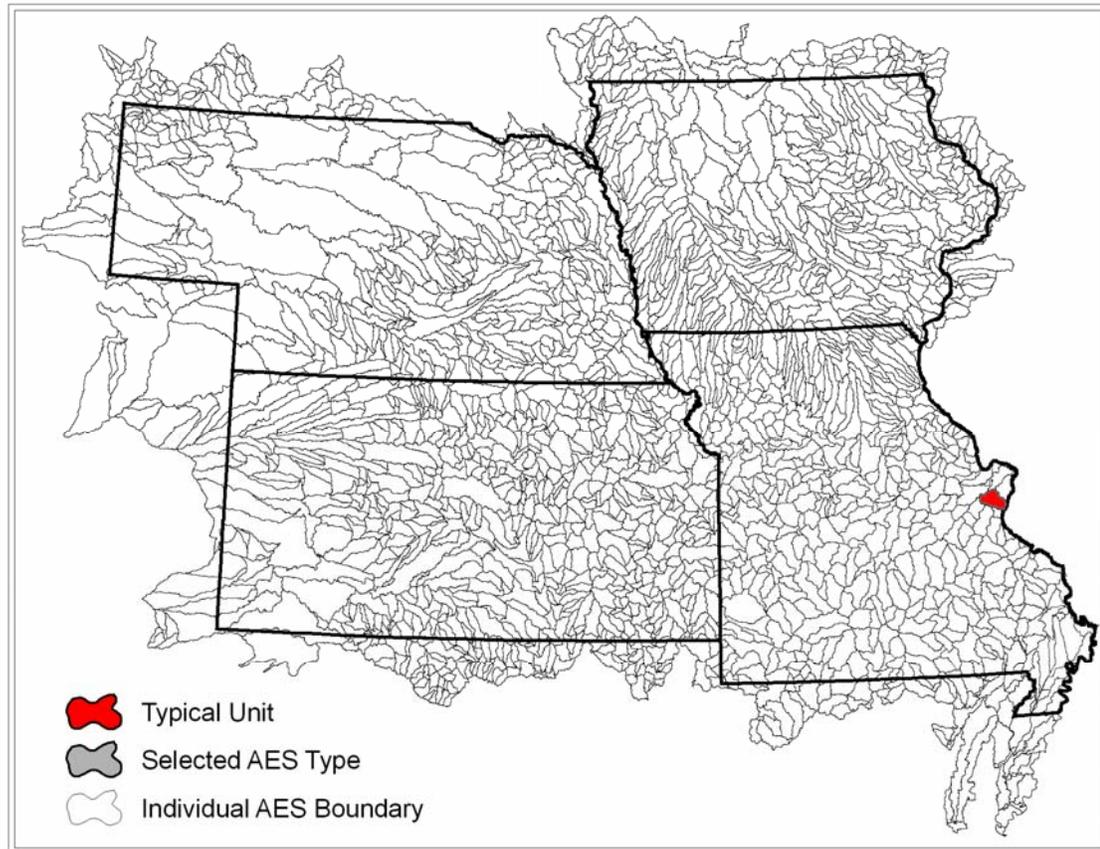
### **Description:**

This AES-Type is located within the White River drainage of the Ozark Aquatic Subregion and encompasses a portion of the USFS's White River Hills Ecological Subsection. Local relief is primarily between 15 and 120 meters. The area is underlain by cherty and shaley dolomites of the Ordovician Jefferson City Cotter Formation. Ridges are more apt to be underlain by limestones of the Mississippian series. Because of the solubility of these rocks karst features are fairly prominent. The surface materials here are clayey and contain lots of chert rock fragments. Soils are the result of weathered dolomites and limestones. Surface soil textures consist of cherty, stony, and silt loam soils. Soil infiltration rates are primarily slow to moderate. Streams exhibit high gradients with bedloads of sand and gravel that form bars and flow through relatively narrow floodplains. Stream flows are highest in late winter and early spring and diminish through the summer to their lowest flows in the fall. Headwater streams may often be dry and lose much of their flow to groundwater as a result of the abundant karst. Flash floods are common after heavy rain events. Stream base flows are maintained to some degree by springs in the area. There are 60 headwater/creek springs and one main stem spring scattered throughout the

Missouri portion of this Type. The median spring count is 1. The combined headwater and creek mean stream gradient is 19.7 meters per kilometer. Historic vegetation was oak woodland and glade woodland complexes.

***Typical Unit:*** 2108 – Beaver Creek

## AES-Type 14 (Lower Meramec)



### **Description:**

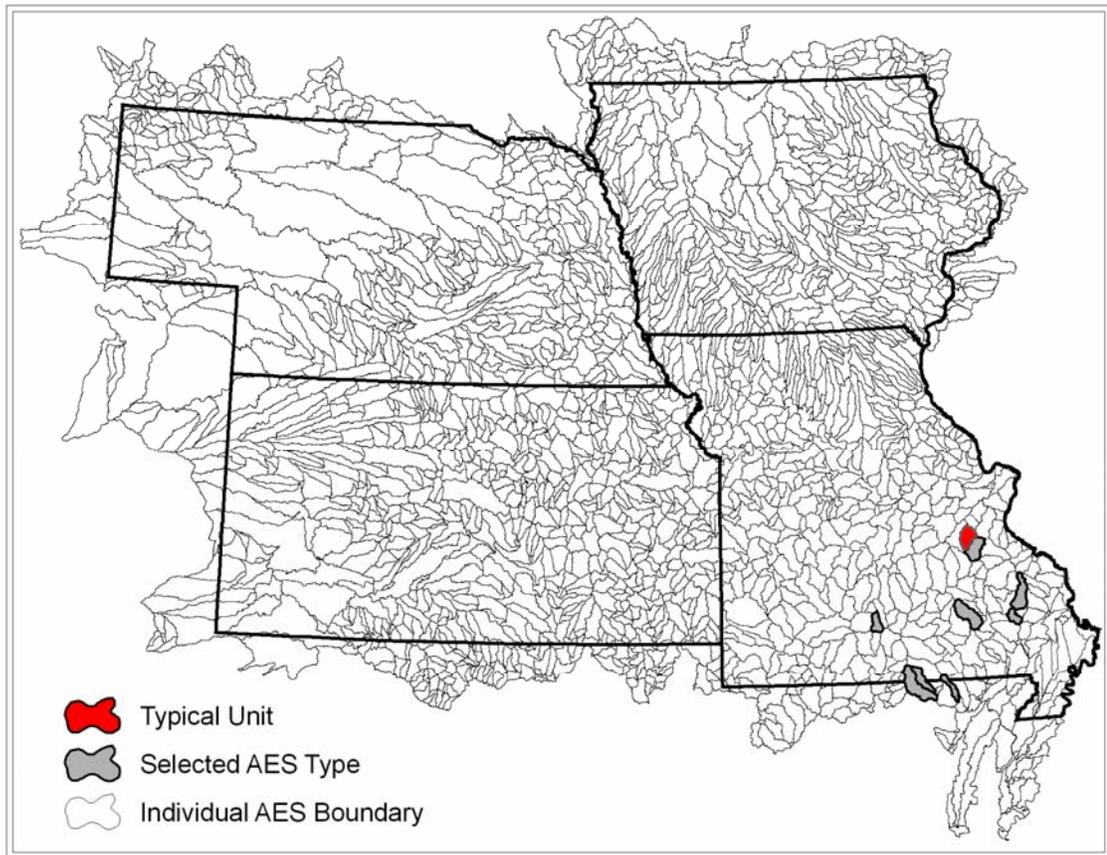
This AES-Type consists of only one small unit in the Ozark Aquatic Subregion at the mouth of the Meramec River. This AES-Type exhibits local relief of less than 90 meters. Surface soils consist primarily of silty loams with moderate to slow infiltration rates. The area is composed of Mississippian limestones and Ordovician dolomite, shale and sandstone. There are significant karstic areas with most springs located in the western portion of the unit and most of the sinkholes located in the north and east. The landscape varies from moderately rugged to rugged. Springs are relatively common making coldwater an important ecological feature of this Type. There are 68 headwater/creek springs and one main stem spring scattered throughout the one individual unit comprising this type. The combined headwater and creek mean stream gradient is 15.0 meters per kilometer. Historically, the area was dominated by oak and mixed hardwood forests.

This unit receives the drainage from the entire Meramec Ecological Drainage Unit. Considering the Meramec Ecological Drainage Unit in its entirety will reveal that local relief is generally between 15 and 90 meters. Surface soil texture

consists chiefly of silty loams, but also of cherty soils. Soil infiltration rates are typically slow. The soils are underlain by varied geology consisting of dolomite and sandstone with much smaller components of limestone and igneous rock.

***Typical Unit:*** 2016 – Lower Meramec

## AES-Type 15 (Indian Creek)

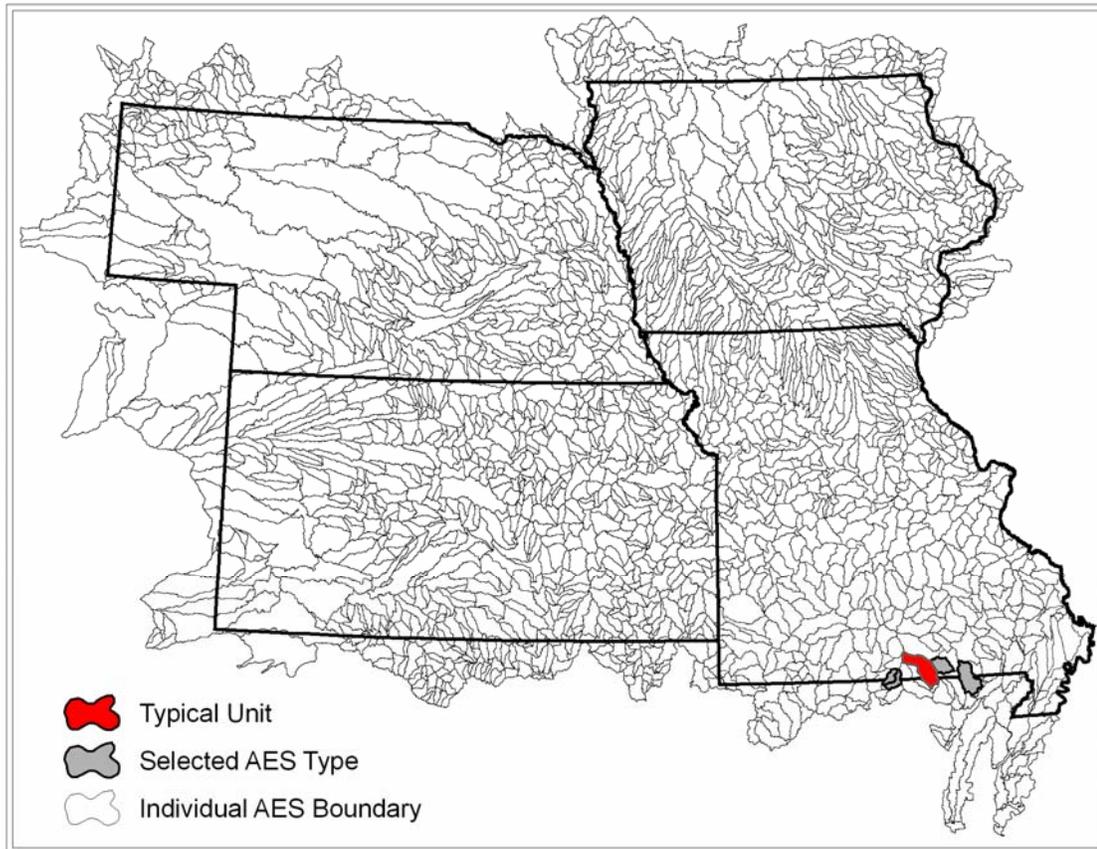


### **Description:**

This AES-Type is scattered in small patches throughout the eastern Ozarks. Local relief ranges from 15 to nearly 90 meters. Surface soil textures are cherty and exhibit moderate infiltration rates. These soils are underlain by dolomite or occasionally sandstone. Springs are relatively common with 65 headwater/creek springs and seven main stem springs scattered throughout the Missouri portion of this AES-Type. The median spring count is 9. The combined headwater and creek mean stream gradient is 14.6 meters per kilometer.

**Typical Unit:** 2003 – Indian Creek

## AES-Type 16 (Spring River of the Eleven Point)



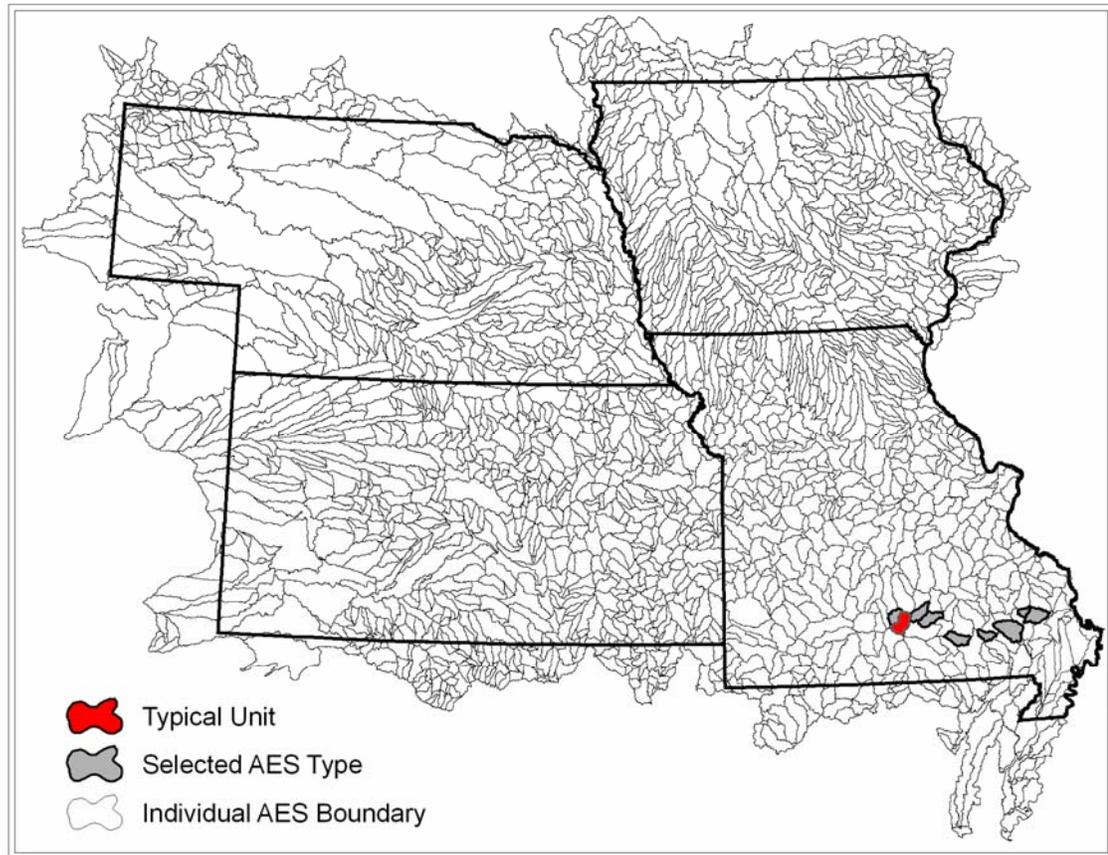
### **Description:**

This AES-Type is located in the southern Ozark Aquatic Subregion along the Missouri-Arkansas border. Local relief is mainly between 15 and 60 meters. The area is underlain by carbonate bedrock consisting primarily of the Jefferson City-Cotter dolomite and contains lots of karstic features. Minor sandstone components are also present along stream valleys. Soils consist largely of deep cherty loams, but are variable in nature with moderate infiltration rates. Stream flows are highest in the late winter and into early spring, but dwindle to a series of disconnected pools during the dry summer months. Although springs are quite common, most of them are small in this AES-Type. Some areas serve as a groundwater source for springs in adjacent valleys. Coldwater may be an important ecological feature of this Type. Springs are very common with 98 headwater/creek springs and 3 main stem springs scattered throughout the Missouri portion of this AES-Type. The median spring count is 20.5. The combined headwater and creek mean gradient is fairly average at 12.5 meters per kilometer. Historically the area was vegetated by mixed oak woodland with some prairie and savanna.

**Typical Unit:** 131 – Spring River of the Eleven Point



## AES-Type 17 (Upper Big Piney)

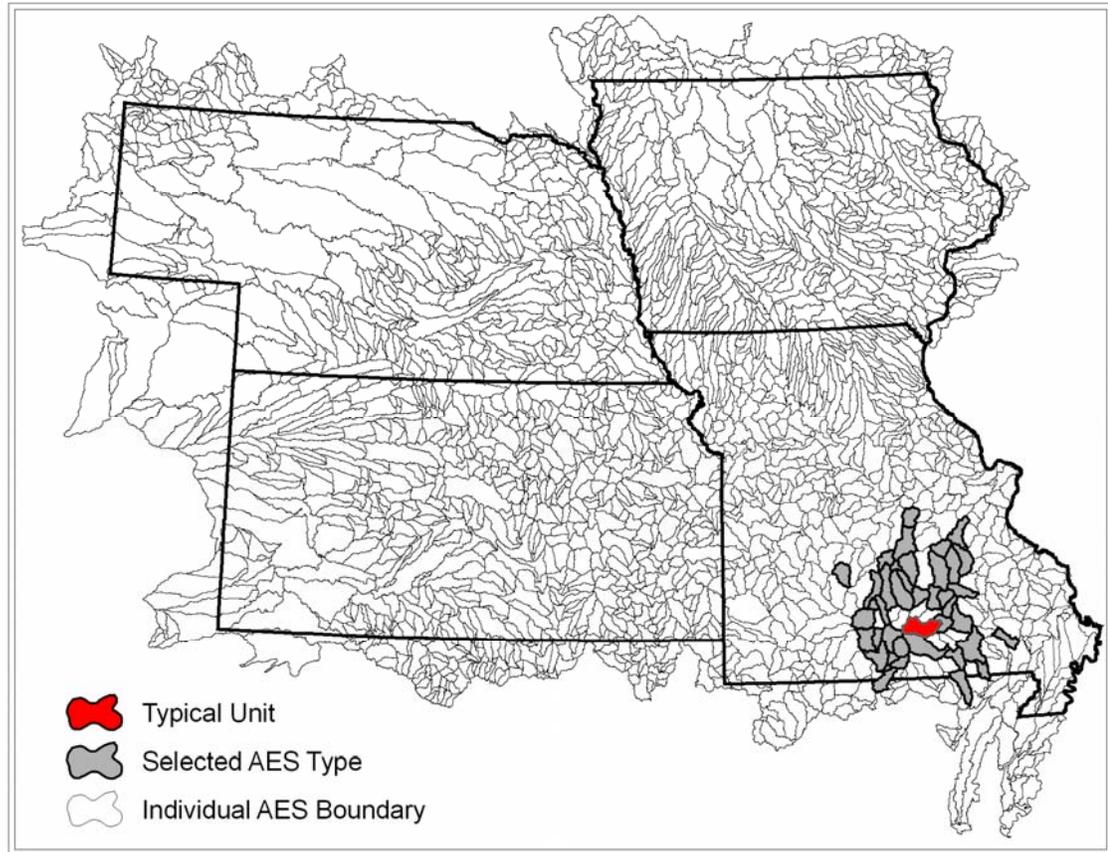


### **Description:**

This AES-Type is found scattered throughout the southeast part of the Missouri Ozark Aquatic Subregion. Local relief is concentrated between 30 and 60 meters, but does range from nearly zero to over 90 meters to a lesser degree. Bedrock geology consists of Ordovician dolomite and sandstone with residuum that contains significant chert fragments. Karst features (sinkholes and springs) are scattered inconsistently across the AES-Type. Surface soil textures are cherty and/or loamy with moderate to slow infiltration rates. Streams carry bed loads of sand and gravel that form bars. Little suspended sediment is carried by these streams. Flash floods may occur after heavy rain events. Springs are relatively common and some contribute notably to the base flow of streams. Groundwater is abundant although often alkaline. There are 32 headwater/creek springs and five main stem springs scattered throughout the nine individual units comprising this AES-Type. This AES-Type contains one spring over 10 cfs. The median spring count is 3. The combined headwater and creek mean stream gradient is 12.7 meters per kilometer.

**Typical Unit:** 1969 – Upper Big Piney

## AES-Type 18 (Jacks Fork)

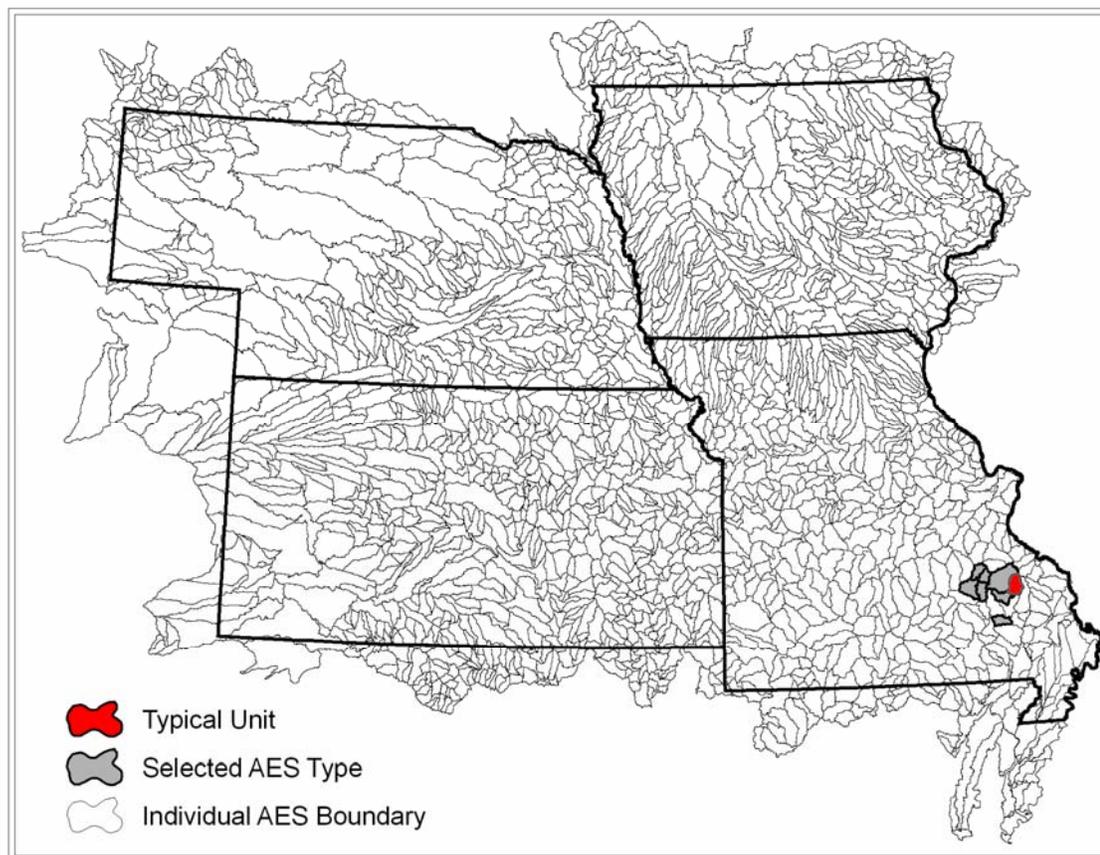


### **Description:**

This AES-Type is represented by much of the heart of the Ozarks in Missouri and covers a wide geographic area. Local relief varies and is concentrated between 30 and 90 meters, but often approaches 150 meters. Bedrock geology consists primarily of cherty dolomites and sandstone from the Gasconade and Roubidoux Formations of the early Ordovician. Karst features are quite common. Soils are formed in weathered bedrock and rock fragments are numerous. Surface soil textures consist of cherty soils and silt loams with moderate to slow infiltration rates. Streams typically have relatively high gradients, low suspended sediment and carry bed loads of sand and gravel that form bars. Flash flood events may occur after heavy rainfall events. Groundwater is abundant, but often alkaline. Springs are numerous making coldwater is an important ecological feature of this AES-Type. There are 968 headwater/creek springs and 126 main stem springs scattered throughout the Missouri portion of this Type. This AES-Type contains 39 of the largest 47 springs (springs over 10 cfs) in Missouri. The median spring count is 25.5. The combined headwater and creek mean stream gradient is relatively high at 17.1 meters per kilometer. Historic vegetation was largely mixed-oak and oak-pine woodland or forest.

***Typical Unit:*** 1948 – Jacks Fork

## AES-Type 19 (Little St. Francis River)



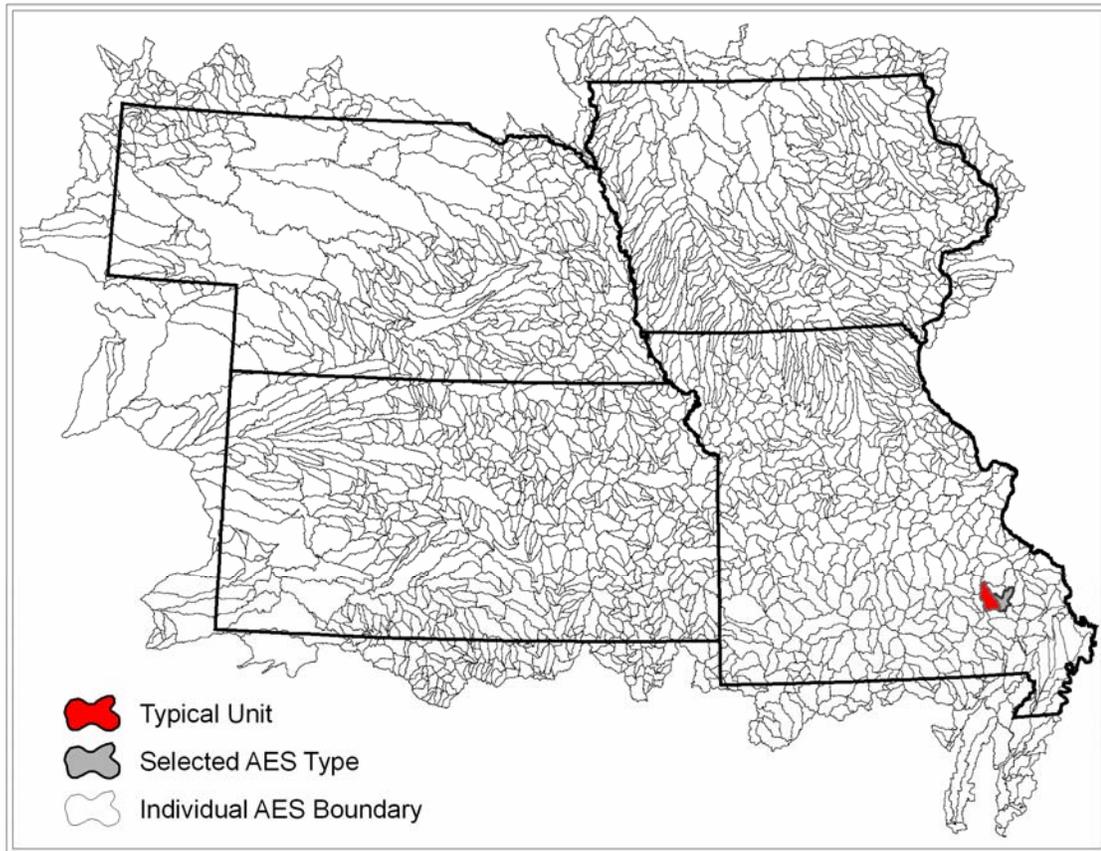
### **Description:**

This AES-Type is located in one general cluster of the Ozark Aquatic Subregion and encompasses much of the USFS's St. Francois Knobs and Basins Ecological Subsection. Local relief is typically high ranging from 15 to about 150 meters. This AES is characterized by resistant Precambrian igneous granite that is intruded by rhyolite and other volcanic rock. Exposed igneous knobs are connected by LaMott sandstone, Bonne Terre dolomite, and Potosi and Eminence cherty dolomites. Soils in this area are moderately deep and acidic with little calcium and magnesium. Surface soil textures consist of cherty, silty loams, and stony soils with moderate to slow infiltration rates. Soils that are found in southern positions are typically very deep with silty clay loam subsoils. This AES-Type has streams with sections that pass over resistant igneous rock forming shut-ins. These streams have little suspended sediment, but carry bed loads of gravel and sand. Springs, although present, are not as common as in other Ozark areas. Groundwater is not abundant due to the igneous rock. When groundwater is present it is often alkaline in nature. There are 34 headwater/creek springs with no main stem springs scattered throughout the 8 individual units comprising this AES-Type. The median spring count is 4. The

mean stream gradient for the headwaters and creeks combined is a relatively high 17.8 meters per kilometer. Historic vegetation was varied and consisted of mixed-oak woodland and glades.

***Typical Unit:*** 2096 – Little St. Francis River

## AES-Type 20 (Big Creek of the St. Francis)



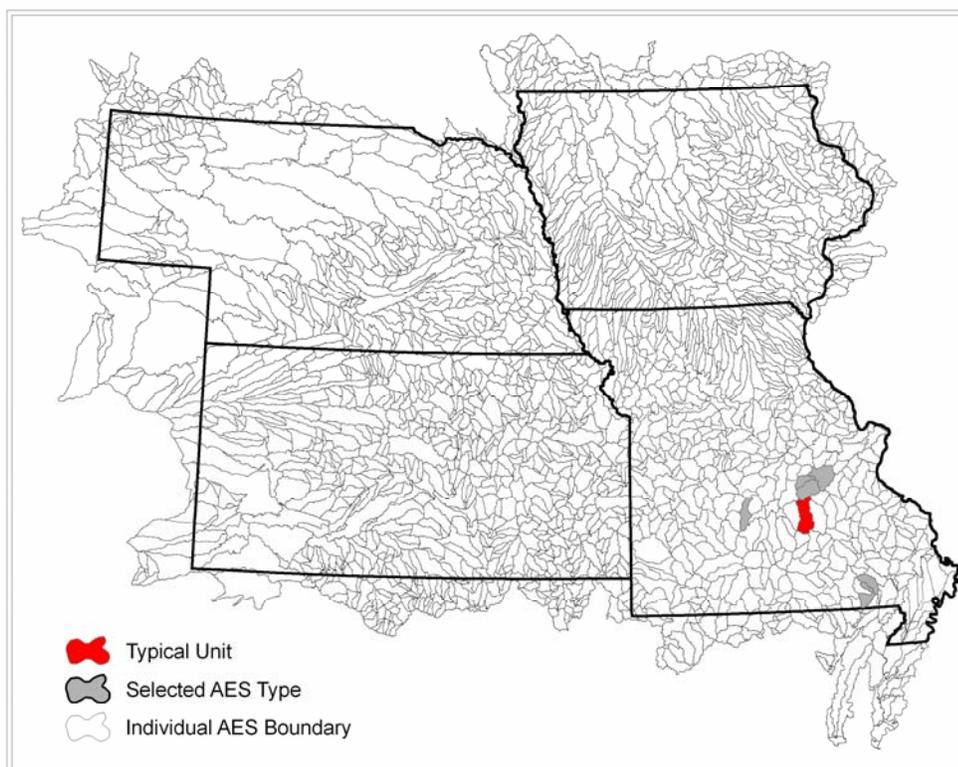
### **Description:**

This AES-Type is located in the upper St. Francis drainage of the Ozark Aquatic Subregion and like the Little St. Francis River AES-Type encompasses a portion of the USFS's St. Francois Knobs and Basins Ecological Subsection. Local relief is concentrated between 30 and 150 meters, but can approach or exceed 215 meters in some locations. This AES contains some igneous rock, but receives most of its igneous influence from the Little St. Francis River AES-Type that is located directly upstream. The Big Creek of the St. Francis AES-Type is moderately dissected with hills and contains dolomite of the Eminence-Potosi Formation and some Cambrian Bonne Terre chert-free dolomite and shale. Ridges are broad and side slopes are steep. Soils are fairly deep and comprised of very cherty silty loams with variable infiltration rates. The streams here carry large bed loads of chert gravel. Coldwater is an important ecological feature of this Type. Springs are relatively abundant within this AES-Type. There are 64 headwater/creek springs and three main stem springs scattered throughout the two individual units comprising this AES-Type. The median spring count is 33.5. The combined headwater and creek mean stream gradient is relatively high at

18.1 meters per kilometer. The area was historically, and is still presently, vegetated with oak-pine woodlands and an occasional glade opening.

**Typical Unit:** 2094 – Big Creek of the St. Francis

## AES-Type 21 (Dry Fork of the Meramec)

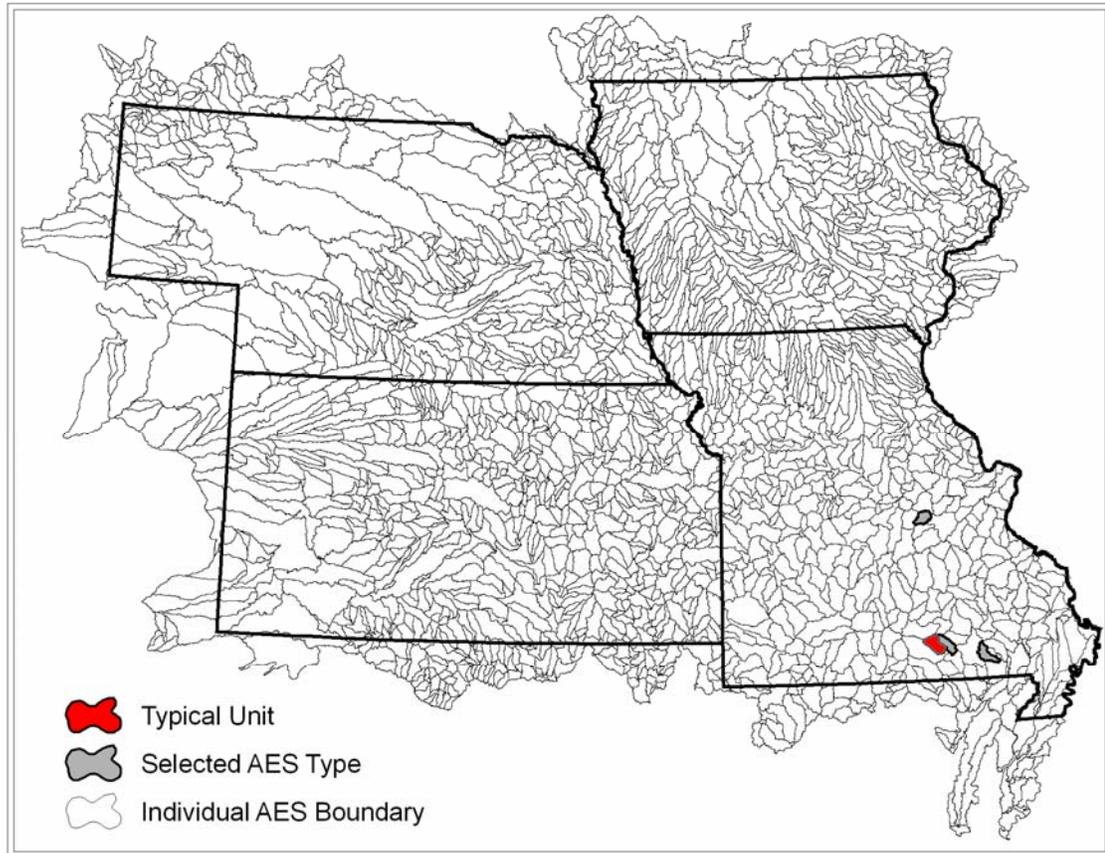


### **Description:**

This AES-Type consists of relatively small clusters of units scattered over parts of the central and eastern Ozarks. Local relief generally ranges from 15 to 60 meters. This area is a portion of the Ozarks that is not heavily dissected and consists of generally gentle slopes that steepen approaching major drainage divides. Most of this AES consists of carbonate bedrock over which sits residuum with lots of chert fragments. Sinkholes exist in some portions of this AES that are located in the more central part of the Ozarks. Soils formed from weathered Ordovician dolomite with some silty loess. Surface soil textures consist primarily of silt loams and cherty soils with infiltration rates ranging from very slow to moderate. Floodplains tend to be narrow and streams are often intermittent or ephemeral. Flows may be near zero in the drier summer months with streams reverting to strings of disconnected pools. Flash floods are not uncommon after heavy rain events. Spring densities are variable; although overall they are not common with relatively small flows. There are 45 headwater/creek springs and six main stem springs scattered throughout the Missouri portion of this Type. This AES contains one known spring over 10 cfs. The median spring count is 3.5. The combined headwater and creek mean stream gradient is relatively average at 10.5 meters per kilometer. Historically, most of this AES was savannah or grassy and oak woodland.

**Typical Unit:** 2011 – Dry Fork of the Meramec

## AES-Type 22 (Spring Creek of the Eleven Point)

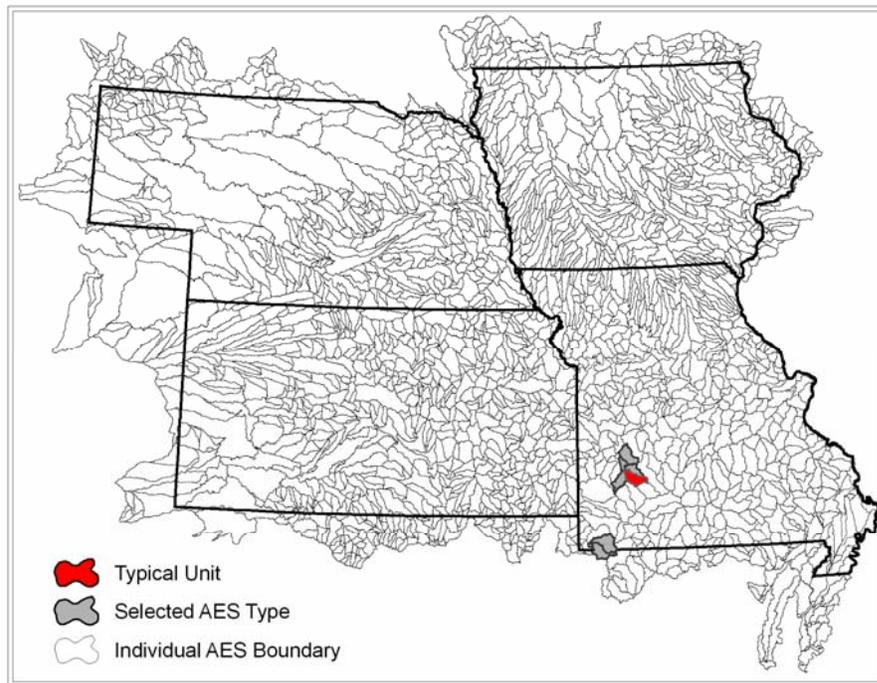


### **Description:**

Despite the geographically disperse nature of this AES-Type, the individual units are similar with respect to a number of landscape variables. This AES-Type is characterized by dolomites and sandstones of the Gasconade and Roubidoux formations. The dolomite tends to be soluble creating karst conditions in these areas. Local relief is concentrated between 15 and 60 meters, but occasionally approaches 90 meters. Soils formed in residuum and often contain cherty rock fragments. Surface soil texture consists of silt loam and cherty soils with slow to moderate infiltration rates. Smaller streams are intermittent or ephemeral while the larger streams are perennial. Streams generally have steep gradients and carry sand and gravel bedloads with very little suspended sediment. Sand and gravel bars are common. Large rain events may produce flooding. Coldwater is an important ecological feature of this Type. Springs are common and groundwater is generally abundant and alkaline. There are 84 headwater/creek springs and five main stem springs scattered throughout the four individual units comprising this AES-Type. The median spring count is 12. The combined headwater and creek mean stream gradient is 14.1 meters per kilometer.

***Typical Unit:*** 1942 – Spring Creek of the Eleven Point

## AES-Type 23 (Middle Upper Little Sac)

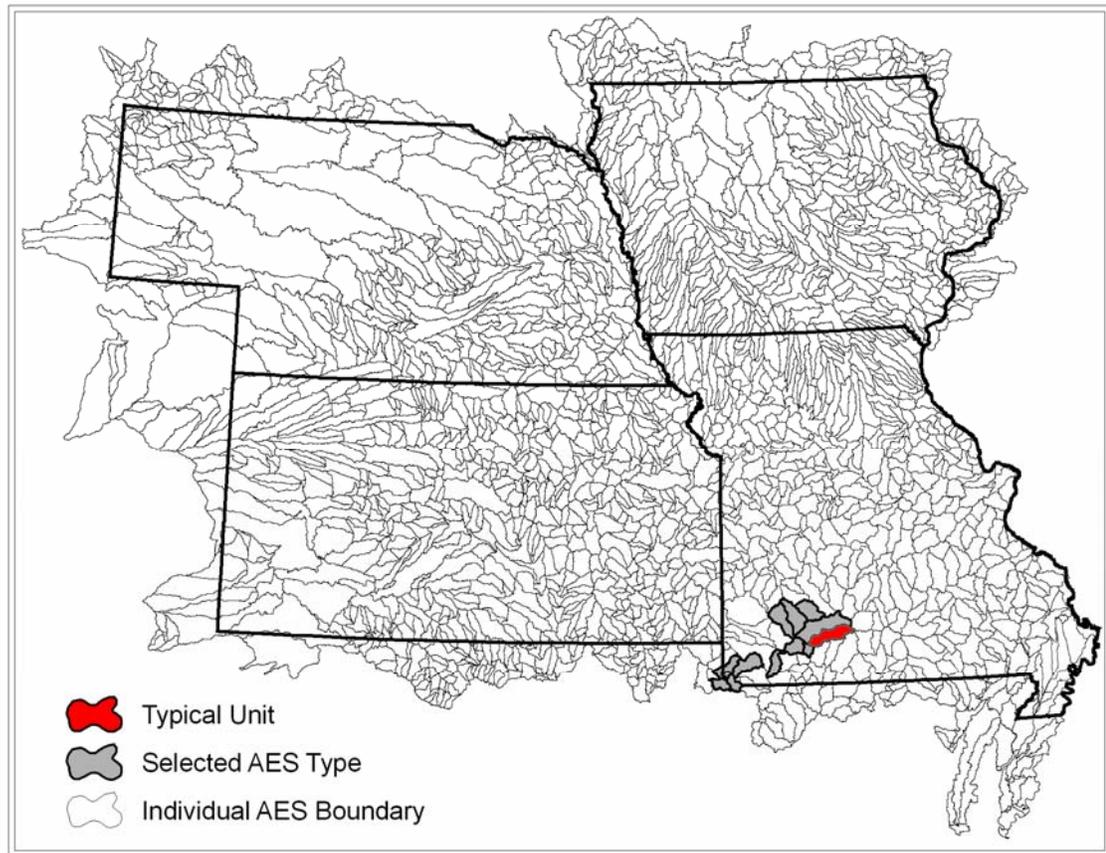


### **Description:**

This AES-Type is located within the Ozarks in southwest Missouri. Local relief is variable, but typically ranges from 15 to over 60 meters. This area consists of Mississippian cherty limestone geologic formations with some karst features. Some of the deeper stream valleys cut down into the Ordovician Jefferson City – Cotter Formation. Soils in this AES-Type were formed in weathered cherty limestone and are deep. Surface soil texture consists of cherty soils and silt loams with moderate to slow infiltration rates. Streams have narrow floodplains and carry bedloads of gravel and sand that form bars. Stream flows are highest at the end of winter and into spring and diminish the rest of the year. Flash floods can occur after large rain events. Springs are common and can be quite large contributing greatly to stream base flows. Groundwater is relatively abundant and of good quality. There are 43 headwater/creek springs with no main stem springs scattered throughout the Missouri portion of this AES-Type. The median spring count is 3.5. The combined headwater and creek mean stream gradient is relatively high at 13.0 meters per kilometer. Historically the vegetation within this AES-Type consisted of prairie on the flatter portions with oak savanna and woodlands on the more rugged sections.

**Typical Unit:** 2053 – Middle Upper Little Sac

## AES-Type 24 (Finley Creek)



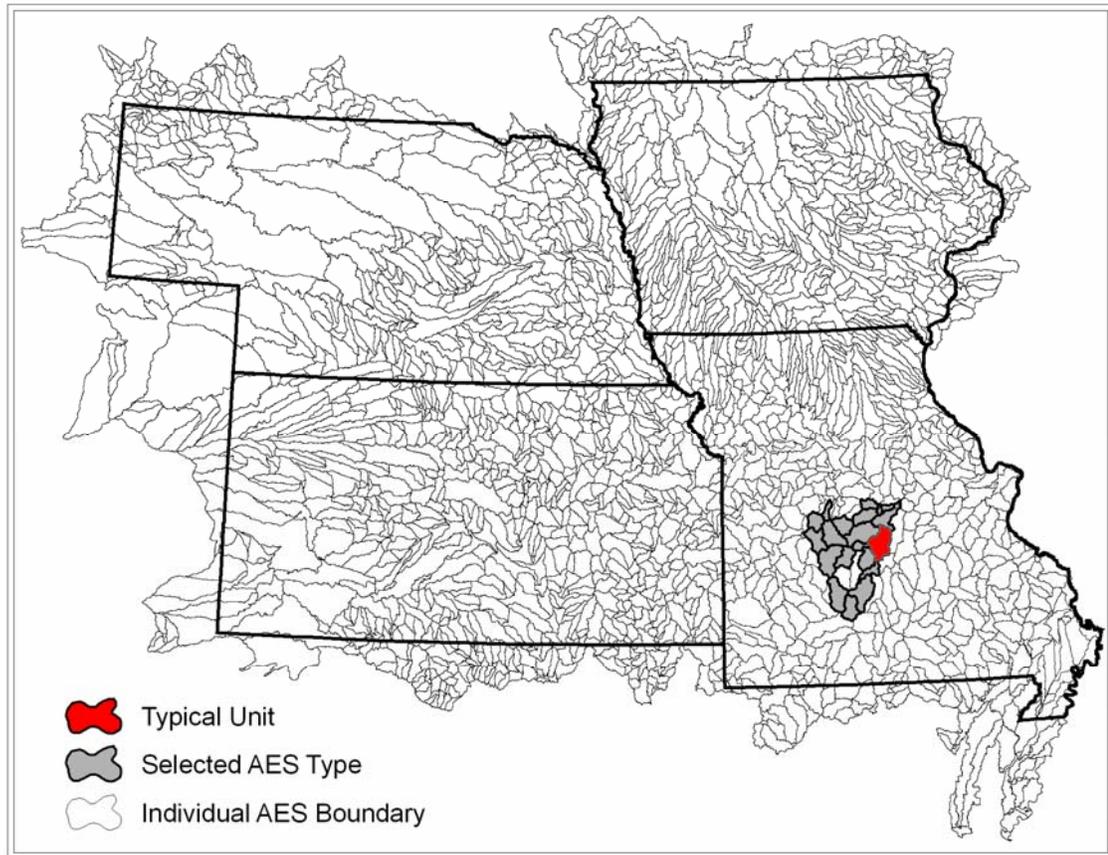
### **Description:**

This AES-Type is located in the Ozarks of southwest Missouri and roughly follows the south-eastern edge of the USFS's Springfield Plain Ecological Subsection. Local relief ranges from nearly zero to slightly over 60 meters. The geology here consists of Mississippian period cherty limestones with significant karst features including sinkholes, caves and springs. Some of the highest densities of sinkholes in the state of Missouri can be found within this AES-Type. Minor amounts of dolomite and sandstone are also present. The deep soils were formed in weathered cherty limestone and often have loess as the surface material. Surface soil textures consist of cherty and silt loam soils with moderate to slow infiltration rates. Stream discharge is highest at the end of winter and early spring and subsequently diminishes throughout summer and into fall. Heavy rain events can produce flash flooding. Streams carry bed loads consisting of sand and chert gravel, but carry very little suspended sediment. Some of the highest densities of losing streams in the state are found in this Type, especially in the James River and Indian Creek drainages. Springs are common and can be quite large contributing significantly to stream base flows. Groundwater is abundant and of good quality. Coldwater is an important

ecological feature of this Type. There are 489 headwater/creek springs and one main stem spring scattered throughout the Missouri portion of this Type. This AES-Type contains one spring over 10 cfs. The median spring count is 29.5. The combined headwater and creek mean stream gradient is 13.2 meters per kilometer. The historic vegetation consisted primarily of prairie, but timber was located along the stream valleys.

***Typical Unit:*** 2104 – Finley Creek

## AES-Type 25 (Tavern Creek)



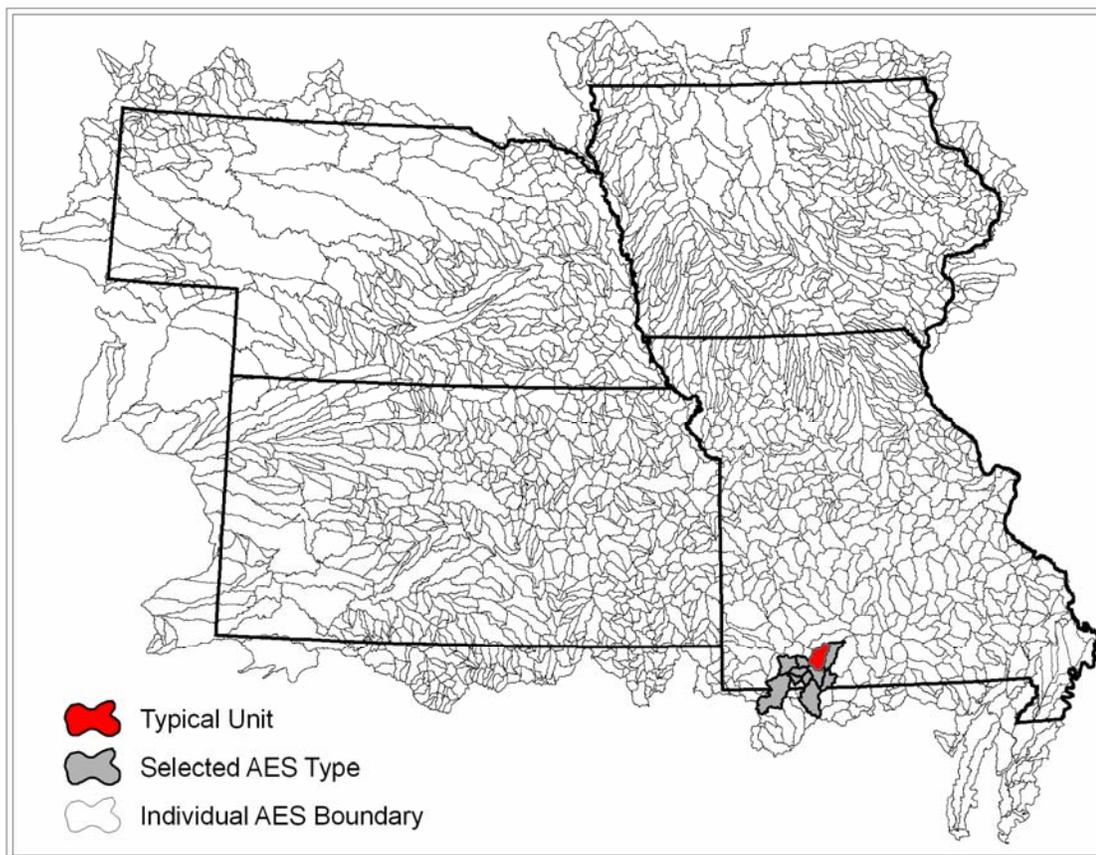
### **Description:**

This AES-Type is concentrated in the eastern portion of the Osage Ecological Drainage Unit and the margins of adjacent Ecological Drainage Units. Both the USFS's Osage River Hills and Central Plateau Ecological Subsections are represented within this Type. Local relief is generally less than 60 meters, but occasionally surpasses that. This AES-Type consists of cherty dolomites and sandstones of the Gasconade and Roubidoux formations of the Ordovician. Karst features are present and springs are very numerous and often quite large. The land is heavily dissected and consists of steep slopes with rock outcroppings. Soils are variable and are a product of their parent materials. Surface soil textures consist of cherty or silt loam soils with moderate to slow infiltration rates. Streams of moderate to steep gradient carry bedloads of gravel and sand that form bars of these same materials. Stream flow is highest in the spring. Stream base flows are supported by springs that consist of good quality albeit alkaline water. There are 177 headwater/creek springs and 14 main stem springs scattered throughout the 20 individual units comprising this AES-Type. This AES-Type contains one spring over 10 cfs. The median spring count is 6.5. The

combined headwater and creek mean stream gradient is relatively high at 14.7 meters per kilometer. Historic vegetation was varied.

**Typical Unit:** 2071 – Tavern Creek

## AES-Type 26 (Bull Creek)



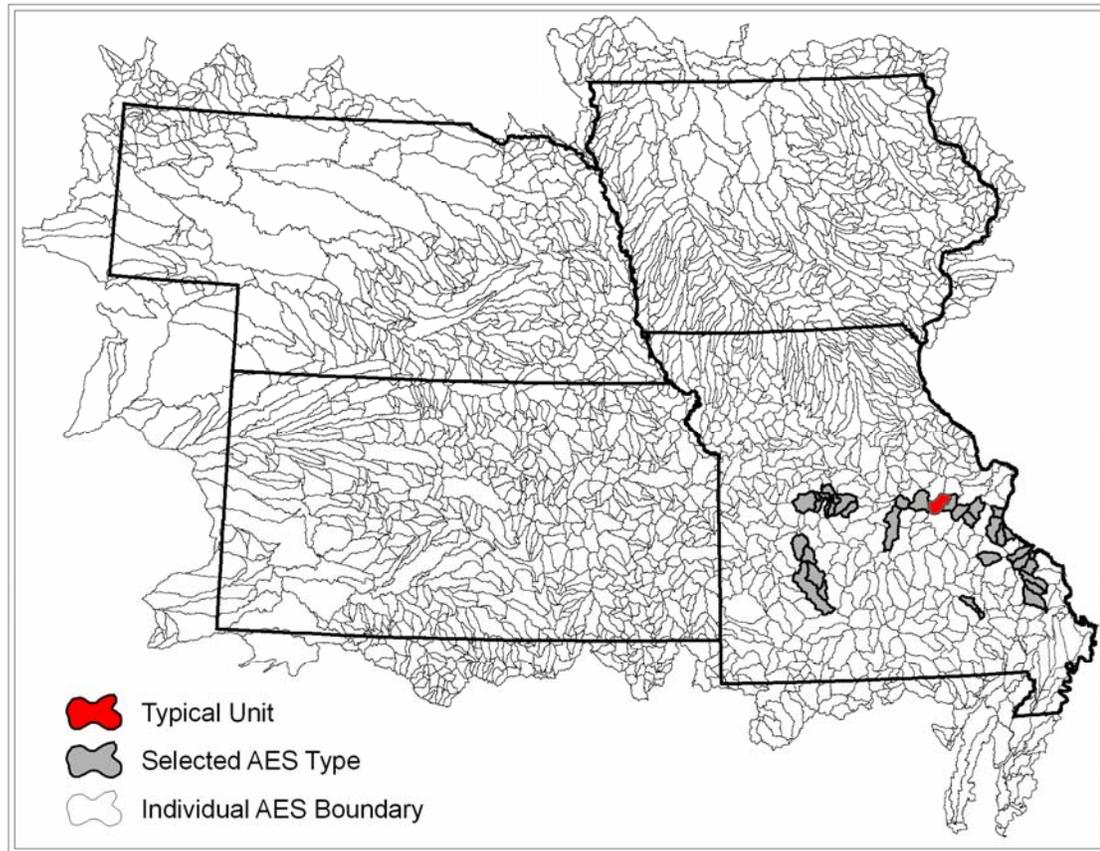
### **Description:**

This AES-Type is completely contained within the Upper White Ecological Drainage Unit. Local relief ranges from 15 to nearly 150 meters. This AES-Type consists of cherty, shaley dolomites of the Ordovician Jefferson City Cotter Formation with karst features and numerous chert fragments. The land surface is thoroughly dissected by drainage networks. Soils were formed from weathered Mississippian and Ordovician limestone and dolomite. Surface soil textures are typically cherty, silty loam, or stony and exhibit slow to moderate infiltration rates. Streams have relatively narrow floodplains and very steep gradients while carrying bedloads of sand and gravel which accumulate into bars. Flows are highest in the late winter and early spring. Flash floods occur after periods of intense rainfall. There are a large number of springs that contribute a significant portion of water to stream base flows throughout much of the year. Headwater streams are often dry, as a result of karst, and lose much of their water to the ground. According the Missouri Department of Conservation's White River Watershed Inventory and Assessment plan, Bull Creek's substrate consists of gravel, cobble, pebble, boulder, and bedrock in relatively equal proportions. The combined headwater and creek mean stream gradient is very high at 22.0 meters

per kilometer. Historical vegetation consisted largely of glade and woodland complexes.

***Typical Unit:*** 2110 – Bull Creek

## AES-Type 27 (Boeuf Creek)



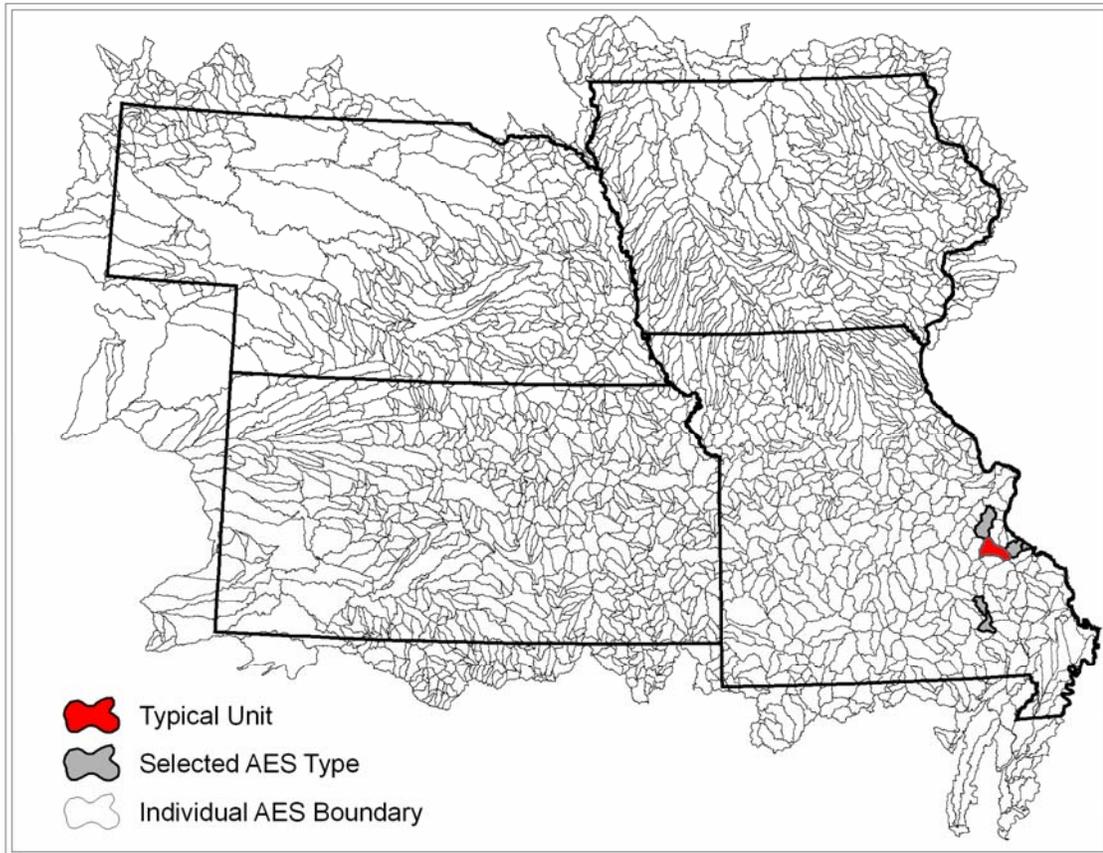
### **Description:**

This AES-Type forms a rough belt around much of the core Ozarks. Local relief is variable and is concentrated between 15 and 60 meters, but does frequently exceed this range. Bedrock geology is dominated by cherty dolomites of the Ordovician Jefferson City-Cotter Formation, although sandstone and limestone are also occasionally present. This bedrock geology is often exposed at the surface. There are some sinkholes, but they are not particularly common in most areas. Adjacent to the Missouri River are thick silty loess deposits that tend to thin with increasing distance from the river. Soils are variable according to both parent material and their position in the landscape. Surface soil textures consist of silty loams or occasionally cherty soils and tend to have slow to moderate infiltration rates. Streams draining to the Great Rivers in the AES-Type consist of headwaters and creeks and the lower ends of larger rivers. In these instances the stream valleys are often deeply entrenched with relatively steep gradients. Stream flow is usually highest in the spring and lowest in the fall. Flash floods may occur after heavy rain events. Spring influence is variable and is not as characteristic as in some of the other Ozark units. There are 113 headwater/creek springs and eight main stem springs scattered throughout the

38 individual units comprising this AES-Type. The median spring count is 2. The combined headwater and creek mean stream gradient is 13.0 meters per kilometer. Historic vegetation consisted of oak savanna, woodlands and smaller amounts of prairie and glades.

***Typical Unit:*** 2041 – Boeuf Creek

## AES-Type 28 (Middle Upper Big River)



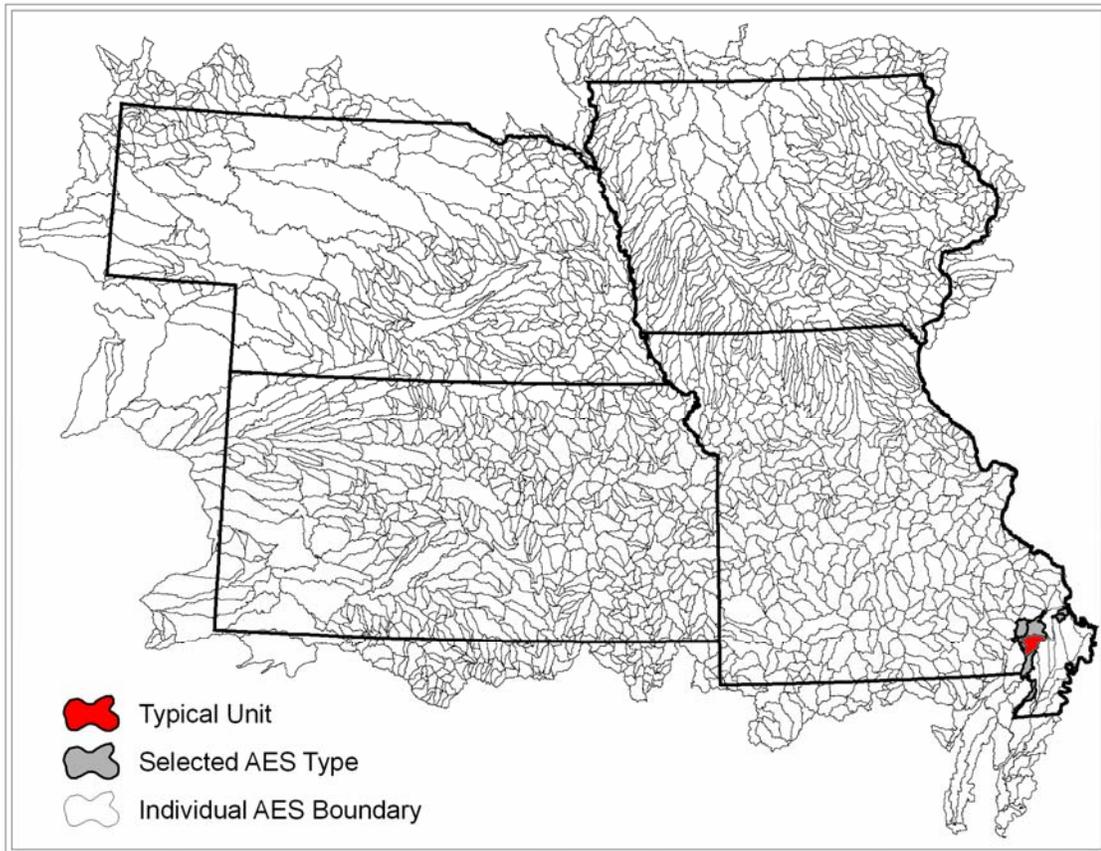
### ***Description:***

This AES-Type is located in the east-central Ozark Aquatic Subregion of Missouri. Local relief is concentrated between 15 and 150 meters. Surface soil textures vary but consist predominantly of silt loams with some cherty and stony soils. These soils exhibit slow to moderate infiltration rates. Bedrock geology consists mainly of dolomite with varying amounts of limestone and sandstone. Coldwater is an important ecological feature of this Type. There are 85 headwater/creek springs and six main stem springs scattered throughout the six individual units comprising this AES-Type. The median spring count is 11.5. The combined headwater and creek mean stream gradient is 17.0 meters per kilometer.

### ***Typical Unit:***

2004 – Middle Upper Big River

## AES-Type 29 (Crowley's Ridge)



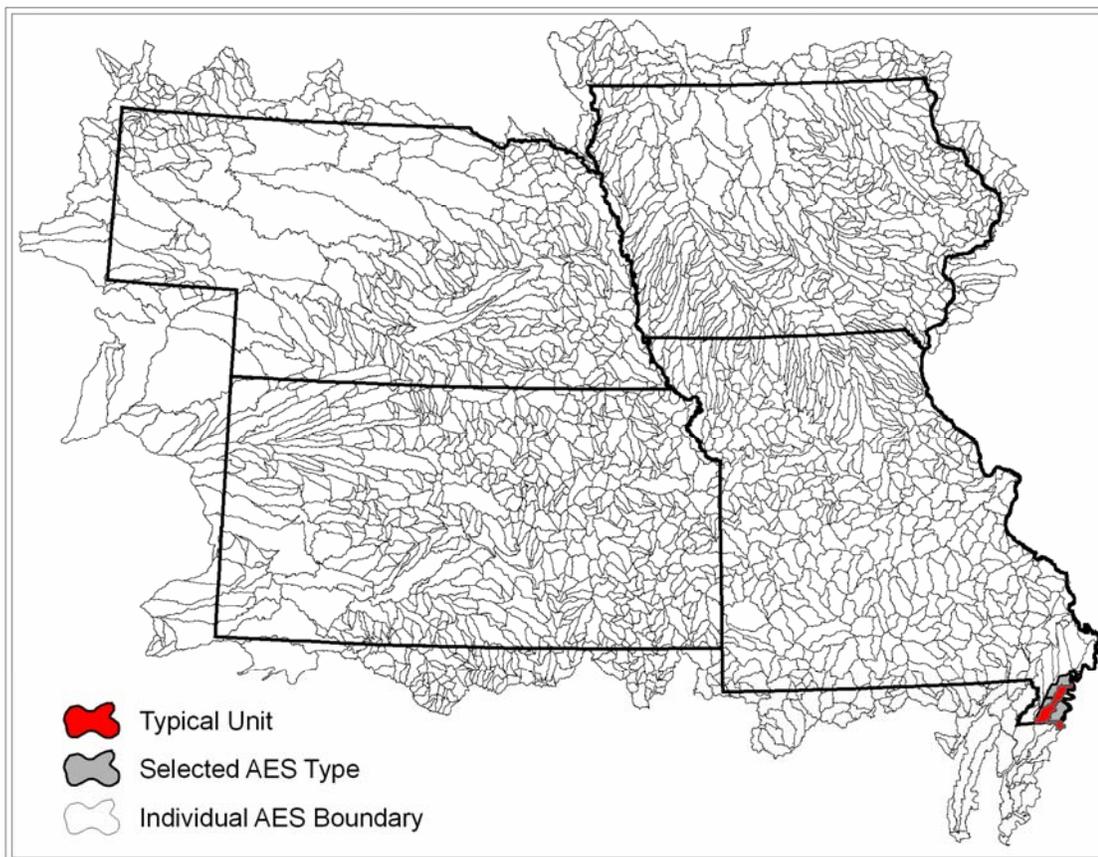
### **Description:**

This AES-Type is located east of the St. Francis River and encompasses most of Crowley's Ridge and the Benton Hills. Local relief ranges from 15 to 60 meters in Crowley's Ridge and the Benton Hills, but there is almost no relief in the lowlands off the Ozark uplands and Crowley's Ridge. The bedrock core of Crowley's Ridge consists of Ordovician dolomite and limestone on the northwest with Cretaceous and Tertiary sandstone and clays to the east. The bedrock is overlain by Quaternary alluvial gravel and sands which in turn is overlain by loess. Crowley's Ridge soils are fairly deep and formed in loess under forest conditions with a silt loam surface layer. In the lowland portions of this AES-Type the soils were formed in alluvial deposits, whereas soils on the ridges are underlain by sandstone and minor dolomite components. Areas adjacent to Crowley's Ridge in this AES-Type are very flat low relief plains composed of silts and sands sitting above deep bedrock which in turn are capped by alluvium. Generally for this AES-Type soils are deep and have surface textures consisting of silty loams that have very slow to moderate infiltration rates. Stream valleys occasionally cut through the loess and expose the underlying materials. Crowley's Ridge consists mainly of intermittent or ephemeral headwater streams that drain down to the

lower alluvial plains. The exception to this scenario is the Castor River that cuts through Crowley's Ridge. Natural streams are/were very meandering. There are six headwater/creek springs and zero main stem springs known to exist within the eight individual units comprising this type. The median spring count is 0. The combined headwater and creek mean stream gradient is 5.8 meters per kilometer. Historically a large portion of the lowland area was inundated permanently or at least seasonally. The historic vegetation consisted of mixed hardwood forest on Crowley's Ridge with bottomland forest, swamps, marshes and sand prairies on the lowland areas.

**Typical Unit:** 2145 – Crowley's Ridge

## AES-Type 30 (City of Hayti)



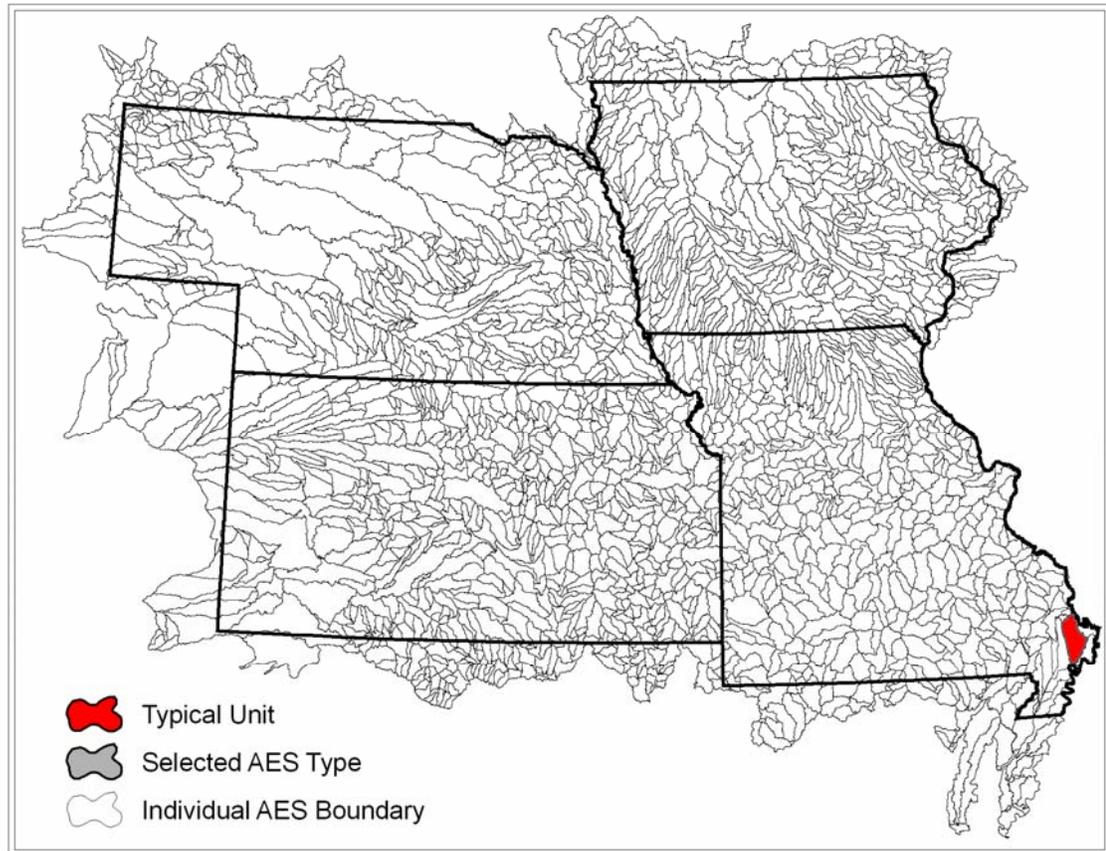
### **Description:**

This AES-Type is located in the southeast Mississippi Alluvial Basin Aquatic Subregion. The area is extremely flat with the slope of the land ranging only between 1/3 and 1/2 meter per kilometer. This area is the historic and present-day alluvial plain of the Mississippi River and consists of thick alluvium with clays in the lower areas and sands in higher areas. Surface soil textures consist of silty clay, silty clay loam, and silty loam with very slow and slow infiltration rates. These soils formed in the alluvial deposits characteristic of much of the Mississippi Alluvial Basin. Natural stream channels here were intensely meandering. Groundwater is abundant. There are no known springs within the four individual units comprising this type. The combined headwater and creek mean stream gradient is 0.8 meters per kilometer. Historically the area consisted of wet bottom-land forest, swamps, and marshes.

### **Typical Unit:**

236 – City of Hayti

## AES-Type 31 (St. Johns Diversion Ditch)

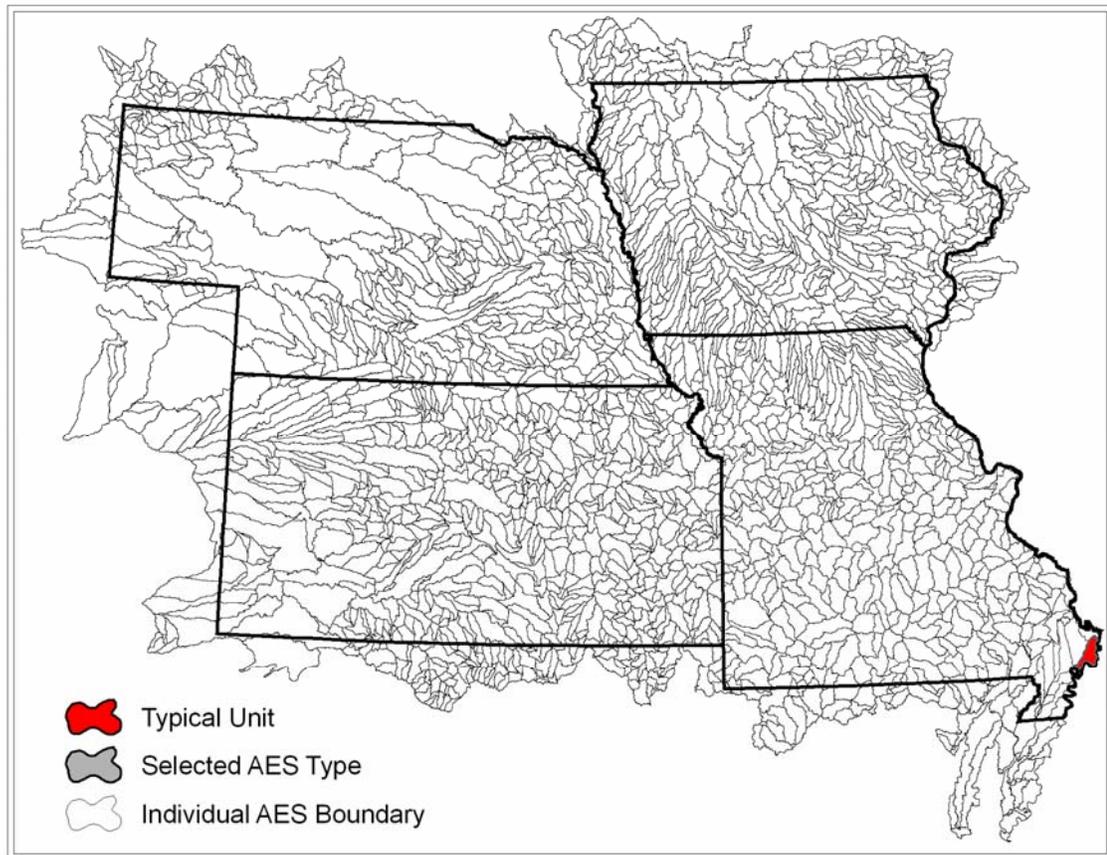


### **Description:**

This AES-Type occupies an area drained by the St. Johns Diversion Ditch in the northeast portion of the Mississippi Alluvial Basin Aquatic Subregion. The northern edge of this AES-Type abuts up to the Benton Hills. The slope of the land is only about 1/3 to 1/2 meter per kilometer. Local relief is generally less than ten feet. The area is comprised of thick alluvium with clays in the lower areas and sands on the slightly higher ridges or natural levees. Soils are deep and have surface soil textures consisting of sandy, loamy, and clayey soils. These soils exhibit varied infiltration rates from high to very slow. The soils formed in alluvial deposits. A few headwater streams begin in the Benton Hills. Groundwater is abundant. There are no known springs within the one individual unit comprising this type. The combined headwater and creek mean stream gradient is 1.3 meters per kilometer.

**Typical Unit:** 2132 – St. Johns Diversion Ditch

## AES-Type 32 (Wilkerson Ditch)

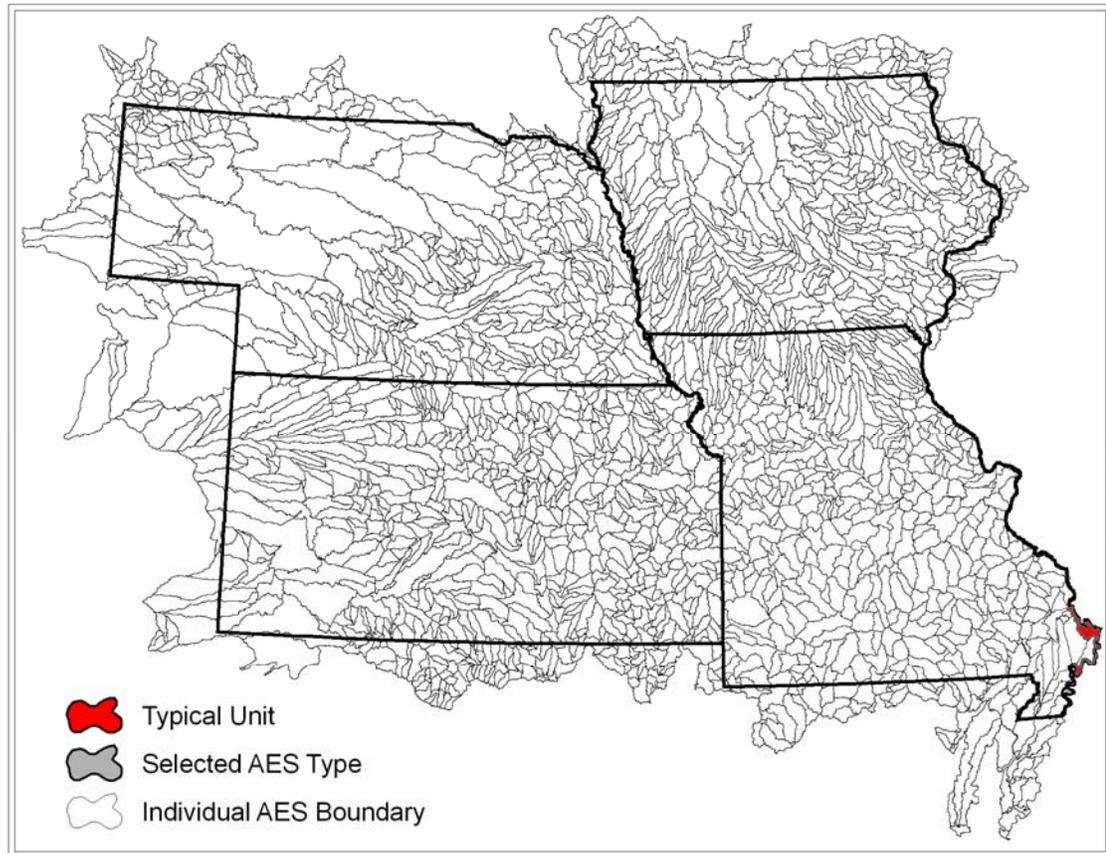


### **Description:**

This AES-Type is located in an area drained by present day Wilkerson Ditch in the east central portion of the Mississippi Alluvial Basin Aquatic Subregion. Local relief is generally less than 10 feet. The area is composed of thick alluvium with clays in the lower areas and sands in the slightly higher locations. The general slope of the land is  $1/3$  to  $1/2$  meter per kilometer. The soils are deep and formed in alluvial deposits. Surface soil texture consists of silty clays and sandy soils. These soils exhibit very slow, slow and even some moderate infiltration rates. Groundwater is abundant. There are no known springs within the single unit making up this AES-Type. The combined headwater and creek mean stream gradient is 0.6 meters per kilometer.

**Typical Unit:** 2133 – Wilkerson Ditch

## AES-Type 33 (City of Charleston)

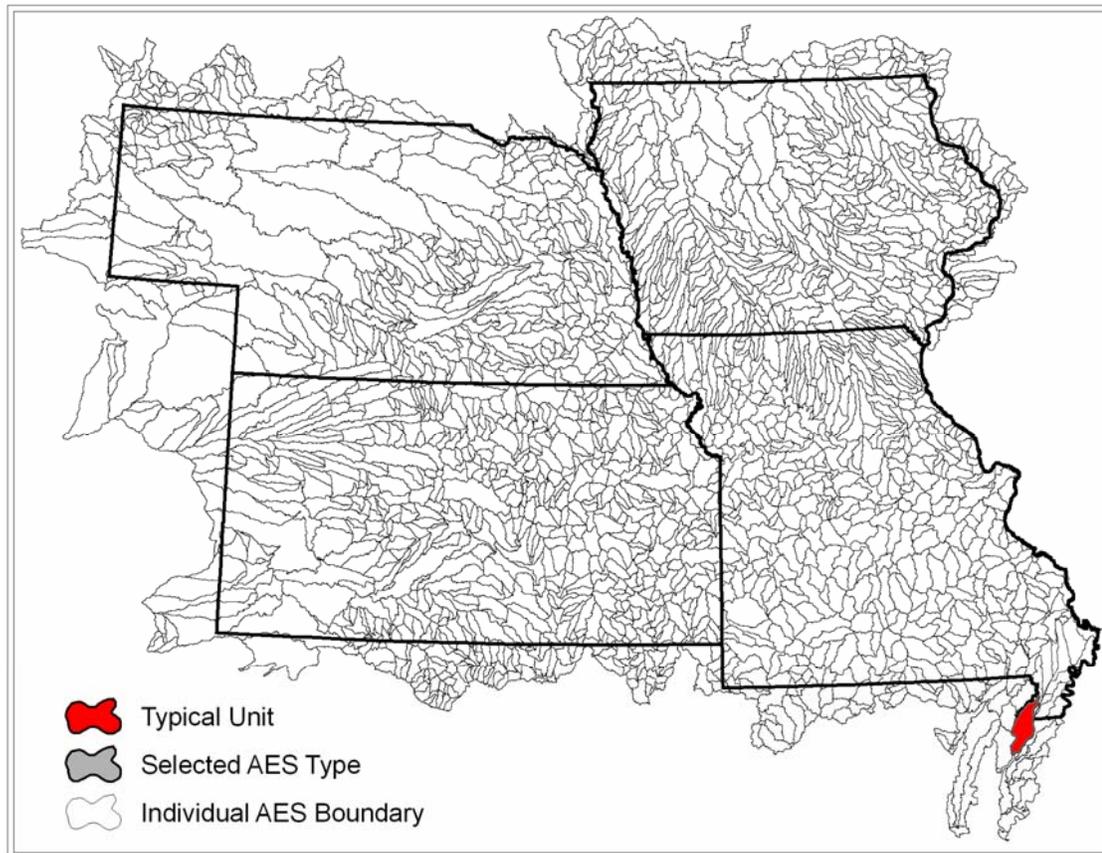


### **Description:**

This AES-Type consists of a narrow belt of very small lateral tributaries draining to the Mississippi River within the Mississippi Alluvial Basin Aquatic Subregion. The northwest edge of this unit contains a very small portion of the Benton Hills. Local relief is generally less than 3 meters. The area generally consists of thick alluvium with clays in the lower areas and sands in the higher. Surface soil textures consist primarily of silty clays with minor amounts of silty loams and sandy soils. These soils exhibit slow and very slow infiltration rates and were formed in alluvial sediments. Groundwater is abundant. There are no known springs within the two individual units comprising this AES-Type. The combined headwater and creek mean stream gradient is 2.0 meters per kilometer.

**Typical Unit:** 2138 – City of Charleston

## AES-Type 34 (City of Senath)

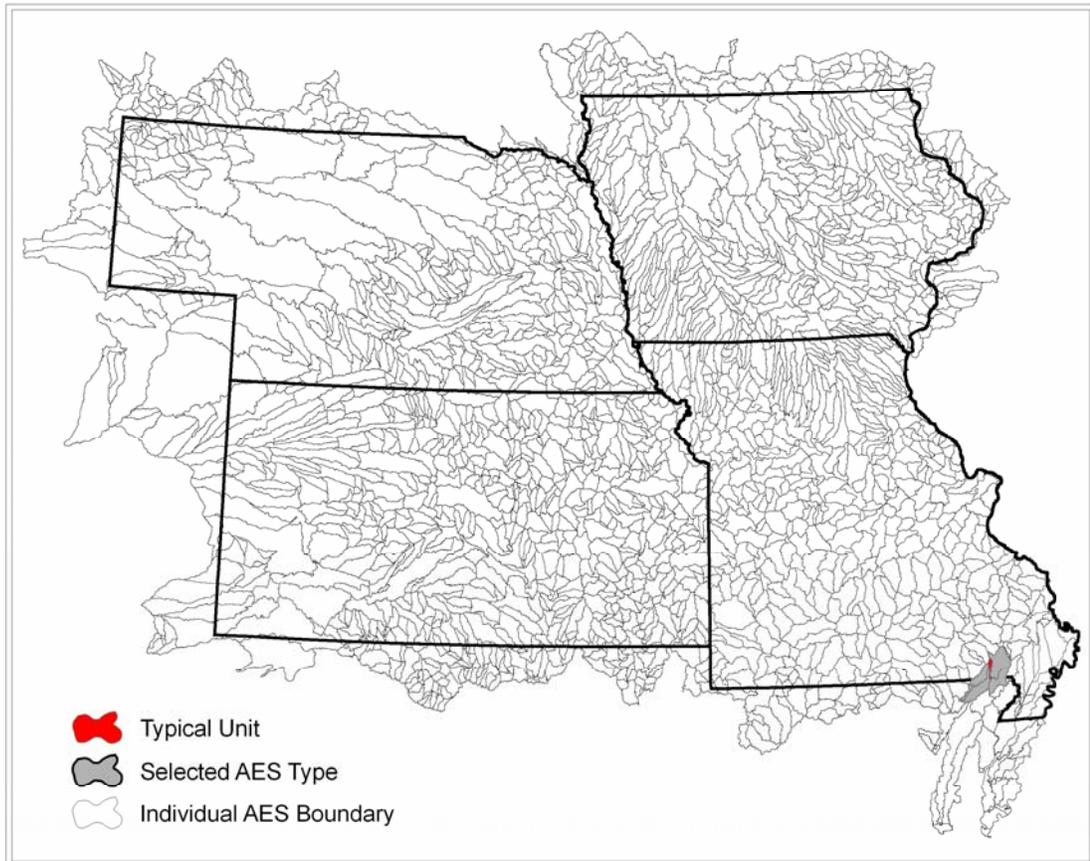


### **Description:**

This AES-Type occupies an area in extreme southern Missouri and northern Arkansas between the St. Francis and Little Rivers. This is the northern portion of the USFS's St. Francis River Alluvial Plain Ecological Subsection. Local relief is generally less than 3 meters. This area is part of an old sandy and loamy alluvial terrace. Surface soils consist of silty loams and sandy soils with very slow or moderate infiltration rates. These soils formed in alluvial sediments. Soil distribution patterns are related to the historic stream networks, natural levees, back swamps, and terraces that were formed by the ancient Mississippi and Ohio Rivers. Bedrock is very deep. There are no known springs within the one unit comprising this AES-Type. The combined headwater and creek mean stream gradient is 0.3 meters per kilometer.

**Typical Unit:** 239 – City of Senath

## AES-Type 35 (Cane Creek)



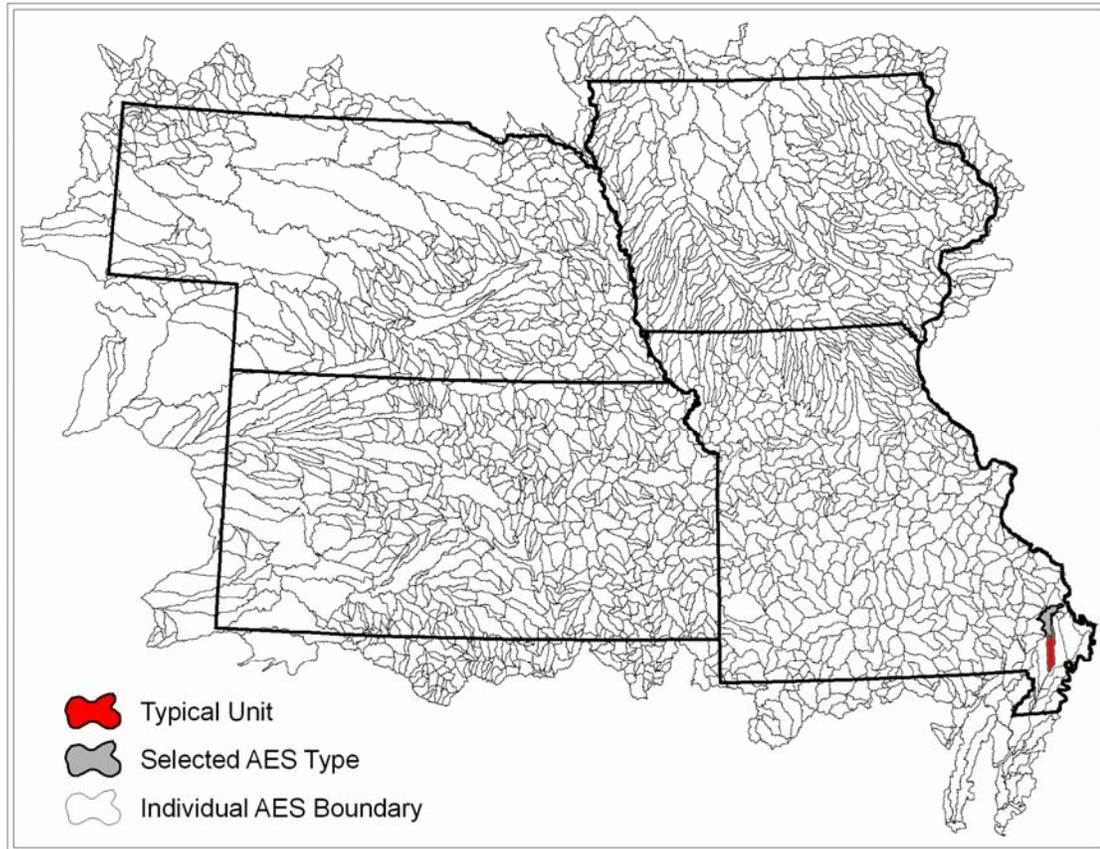
### **Description:**

This AES-Type occupies an area in the Mississippi Alluvial Basin Aquatic Subregion along the Black River and Cane Creek south of the Ozarks. This area represents the northern portion of the Black/Cache Ecological Drainage Unit. Local relief is generally less than 3 meters, but a few areas may approach 6 meters. The soils in this AES-Type are deep and formed in alluvial deposits above bedrock that is very deep. Thousands of years ago this AES-Type was part of the Mississippi River alluvial plain when that river flowed along the base of the Ozarks. Today, streams including Cane Creek and the Black River flow from the Ozarks and deposit their coarser alluvial materials on top of the alluvium deposited in the past by the Mississippi River. The same streams that begin in the Ozarks take on a new character with drastically reduced gradients and begin to pick up finer silts and clays. Surface soil textures consist of silty loams and sandy soils with very slow infiltration rates. These soils formed in alluvium or, in the upper portions, are underlain by sandstone. Natural channels are very meandering and historically flowed through bottomland forest, swamps, marshes, and sand prairies. A good portion of this AES-Type would have been seasonally or permanently inundated historically. There is only one headwater/creek spring within the Missouri portion of this AES-Type. The median spring count is 0. The

combined headwater and creek mean stream gradient is 1.2 meters per kilometer.

**Typical Unit:** 182 – Cane Creek

## AES-Type 36 (City of Chaffee)

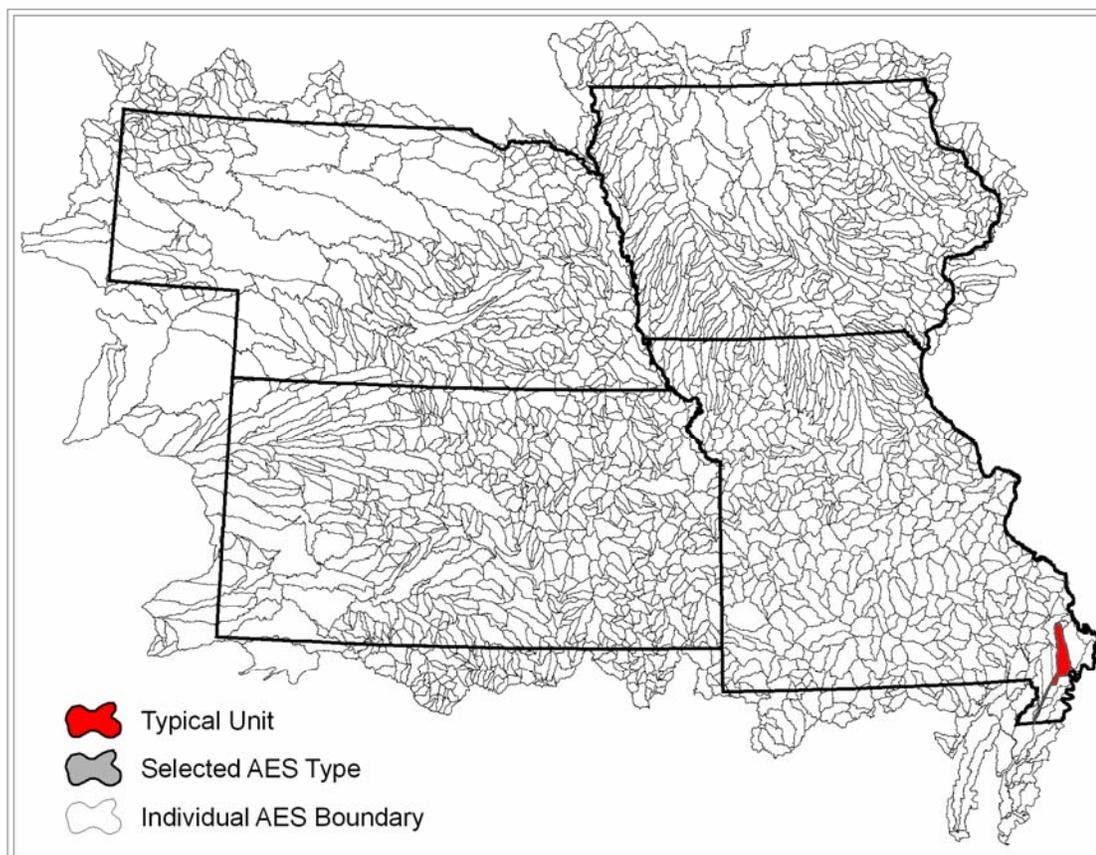


### **Description:**

This AES-Type consists of a north-south trending unit located in the central part of the Mississippi Alluvial Basin Aquatic Subregion. This Type contains a very small part of Crowley's Ridge on the north and west edges with a few headwater tributaries commencing on the ridges. Local relief is generally less than 3 meters. The area consists of thick alluvium with clays in the lower areas and sands in the higher terraces and ridges. Soils are deep and were formed in alluvium from the Mississippi and Ohio Rivers. The silty clay and silty loam surface textured soils exhibit very slow to moderate infiltration rates. Groundwater is abundant. There are no known springs within the two individual units comprising this AES-Type. The median spring count is 0. The combined headwater and creek mean stream gradient is 1.6 meters per kilometer. Much of this AES-Type was historically swampland, sloughs and bottomland forest.

**Typical Unit:** 2137 – City of Chaffee

## AES-Type 37 (Little River)

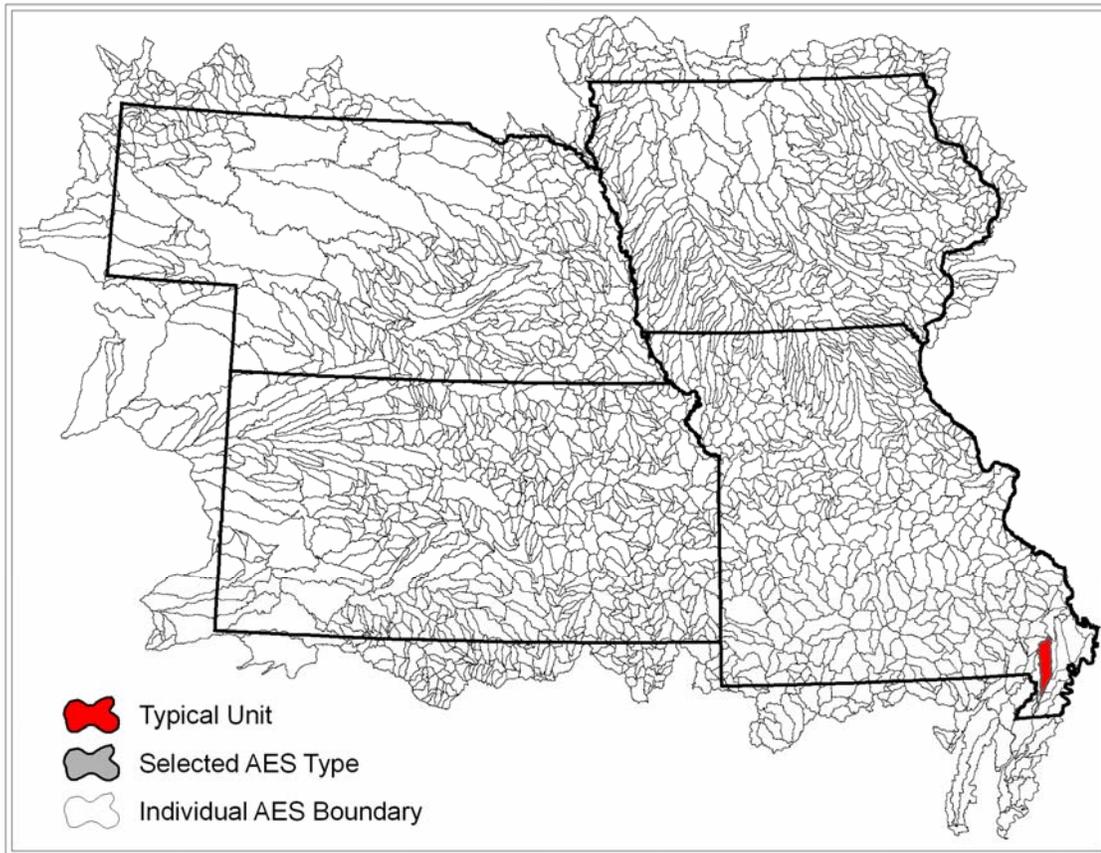


### **Description:**

This AES-Type occupies an area in the Mississippi Alluvial Basin Aquatic Subregion along the northeast boundary of the St. Francis/ Little Ecological Drainage Unit. The extreme northeast edge of this AES-Type contains a very small portion of the Benton Hills. A handful of headwater tributaries begin in the hills. Local relief is generally less than 3 meters. The plains areas consist of thick alluvium with clays in the lower alluvial plains and sands on the terraces and ridges. Soils formed in alluvial deposits. Surface soil textures are varied and range from sandy, to clayey, and even loamy. Equally varied are the soil infiltration rates that range from very slow to high. As with most of the Mississippi Alluvial Basin groundwater is abundant. There is only one known headwater/creek spring within the one unit comprising this AES-Type. The median spring count is 1. The combined headwater and creek relative stream gradient is 1.0 meters per kilometer.

**Typical Unit:** 234 – Little River

## AES-Type 38 (City of Gideon)

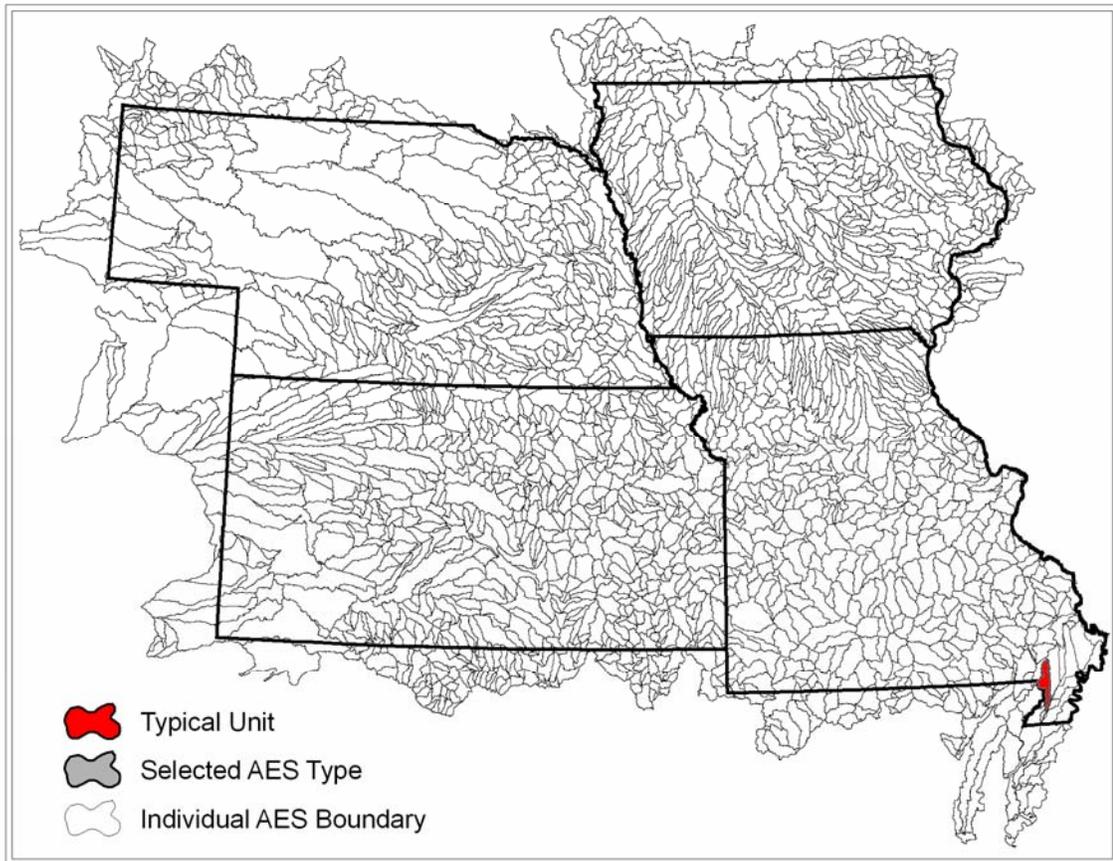


### **Description:**

This AES-Type transitions between the lower areas to the east and Crowley's Ridge to the west. This Type is located in the central portion of the Mississippi Alluvial Basin Aquatic Subregion with a geographic extent very similar to the Parma Dissected Terrace Land Type Association. Local relief is generally less than 3 meters. The loamy and sandy textured soils exhibit slow to moderate infiltration rates. These soils formed in alluvial deposits. Along the interface with Crowley's Ridge 19 headwater/creek springs issue forth. One individual unit comprises this AES-Type. Groundwater is abundant. The median spring count is 19. The combined headwater and creek mean stream gradient is 2.0 meters per kilometer. Historically, much of the AES was swamp, marsh and bottomland forest.

**Typical Unit:** 2130 – City of Gideon

## AES-Type 39 (West Ditch)

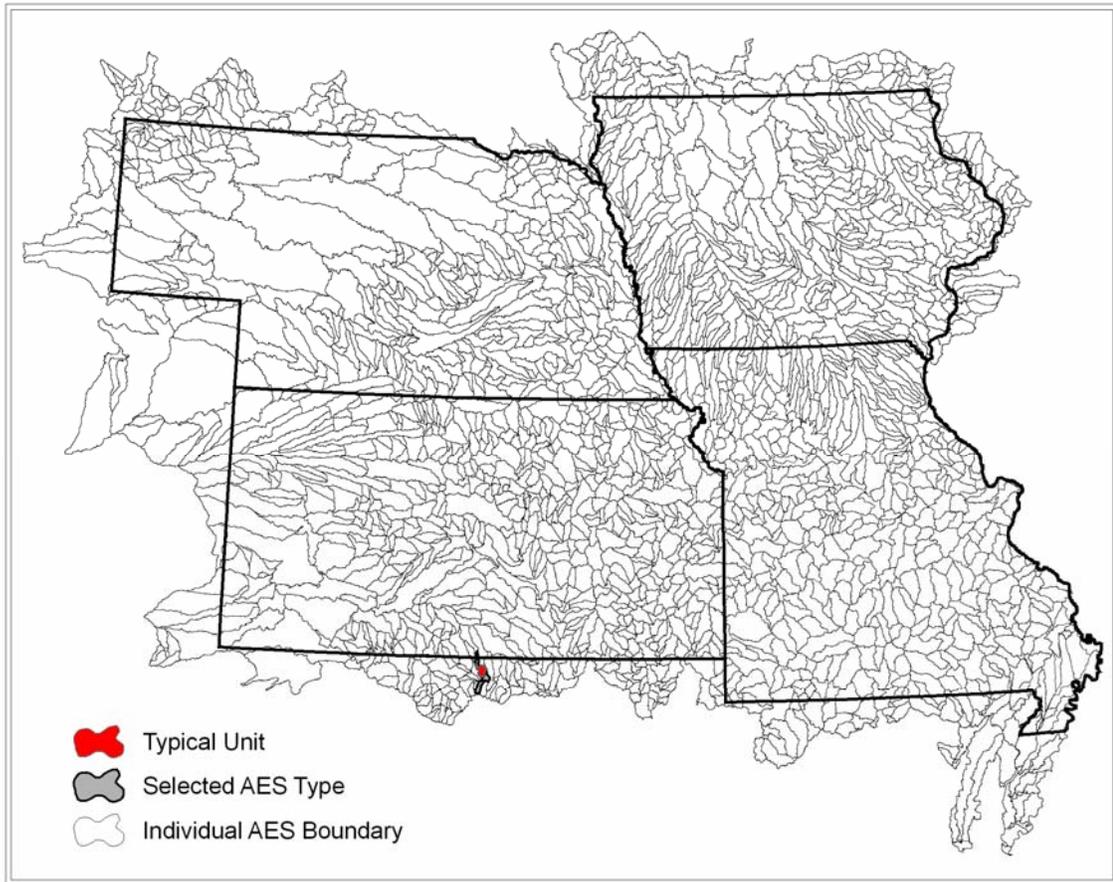


### **Description:**

This AES-Type is located between the St Francis River and Little River Ditch. The unit contains a very small portion of Crowley's Ridge. A few headwater tributaries commence on the ridge. Local relief is generally less than 3 meters within this AES-Type. The area comprises a sand and loamy alluvial terrace with bedrock that is very deep. The soil patterns are a result of historic drainage patterns, natural levees, back swamps, and terraces. Surface soil textures are varied and consist of sandy, loamy and clayey soils with moderate to very slow infiltration rates. These soils have developed in alluvial deposits. Historically, the St. Francis River meandered extensively throughout much of this AES. There are no known springs within the one individual unit comprising this AES-Type. The combined headwater and creek mean stream gradient is 2.0 meters per kilometer.

**Typical Unit:** 2135 – West Ditch

## AES-Type 40 (Lower Sandy Creek)

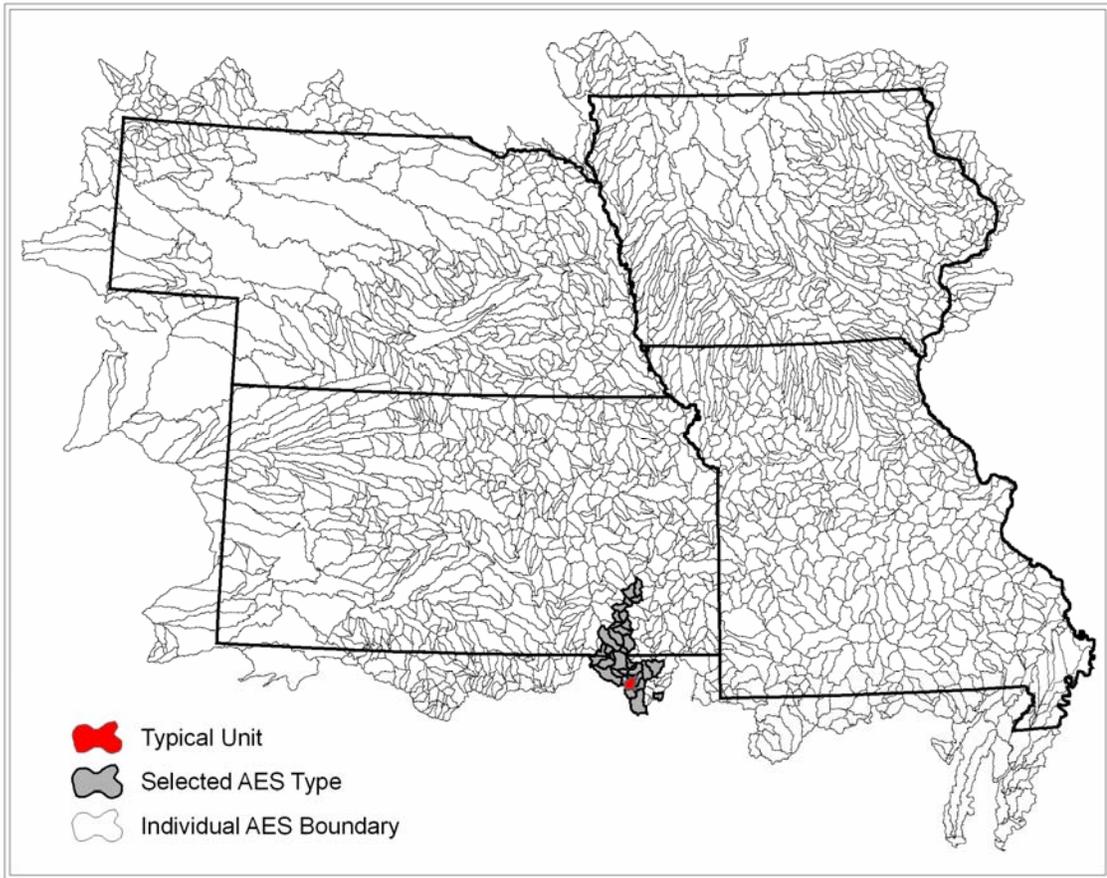


### **Description:**

This AES-Type is located in one compact area in extreme south central Kansas with most of its area in Oklahoma. This Type is located entirely within the USFS's Eastern South Central and Red Bed Plains Ecological Subsection. The AES encompasses a portion of Sandy Creek and the Salt Fork of the Arkansas River. Local relief within the watershed is typically less than 30 meters with most less than 15. Locally, soil textures are largely sandy with some silt loams. These soils exhibit high to moderate infiltration rates. Rock fragment volume in these soils is generally less than 10%. The combined headwater and creek mean stream gradient is 8.3 meters per kilometer. Historic vegetation consisted of plains grassland.

**Typical Unit:** 436 – Lower Sandy Creek

## AES-Type 41 (Fish Creek)

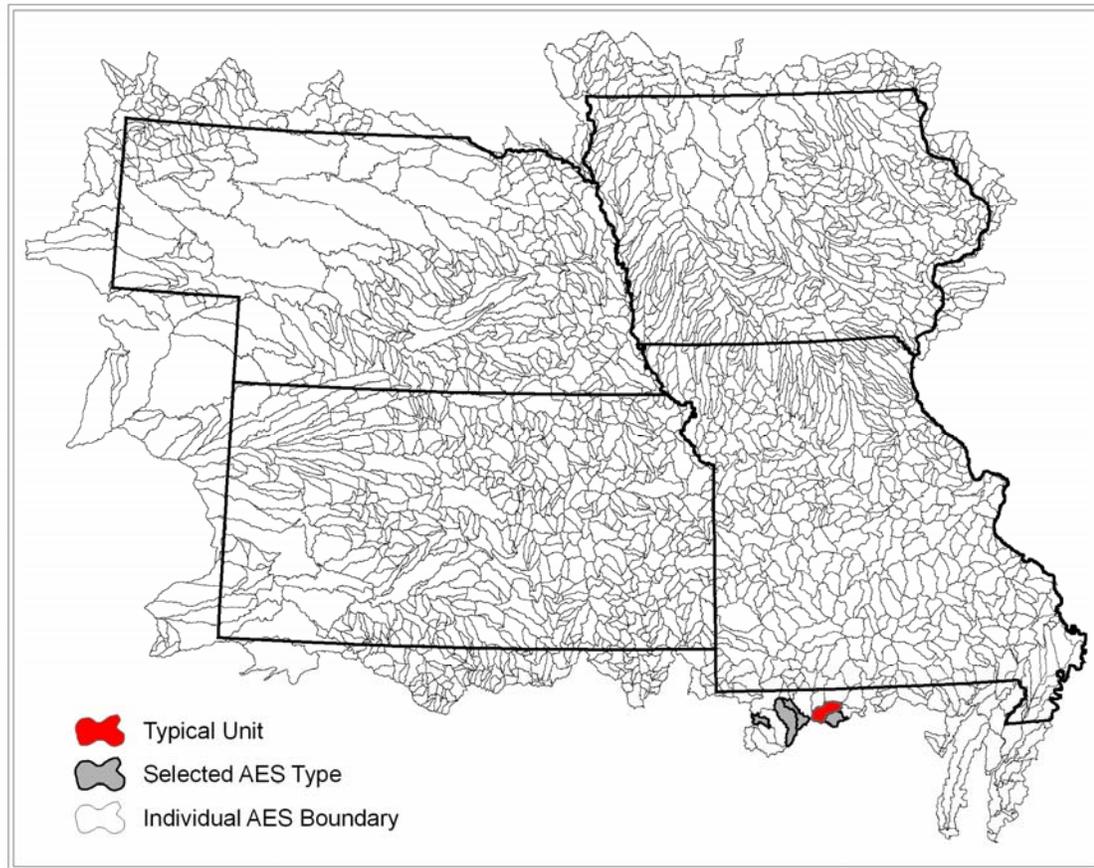


### **Description:**

This AES-Type is located in southern Kansas and crosses into Oklahoma. It contains much of the Caney River drainage. This Type contains portions of the USFS's Central Tall Grass Prairie and Scarped Osage Plains Ecological Subsections. Local relief varies but is concentrated between 15 and 60 meters. Soil surface textures are primarily silt loams and sandy loams with very slow to slow infiltration rates. Rock fragment volume in these soils is generally less than 20%, while depth to bedrock can be less than 90 centimeters in places. The combined headwater and creek mean stream gradient is 10.1 meters per kilometer. Historic vegetation consisted of prairie, post oak woodland, savanna, and a mosaic of bluestem prairie and oak-hickory forest.

**Typical Unit:** 381 – Fish Creek

## AES-Type 42 (Huzzah Creek)

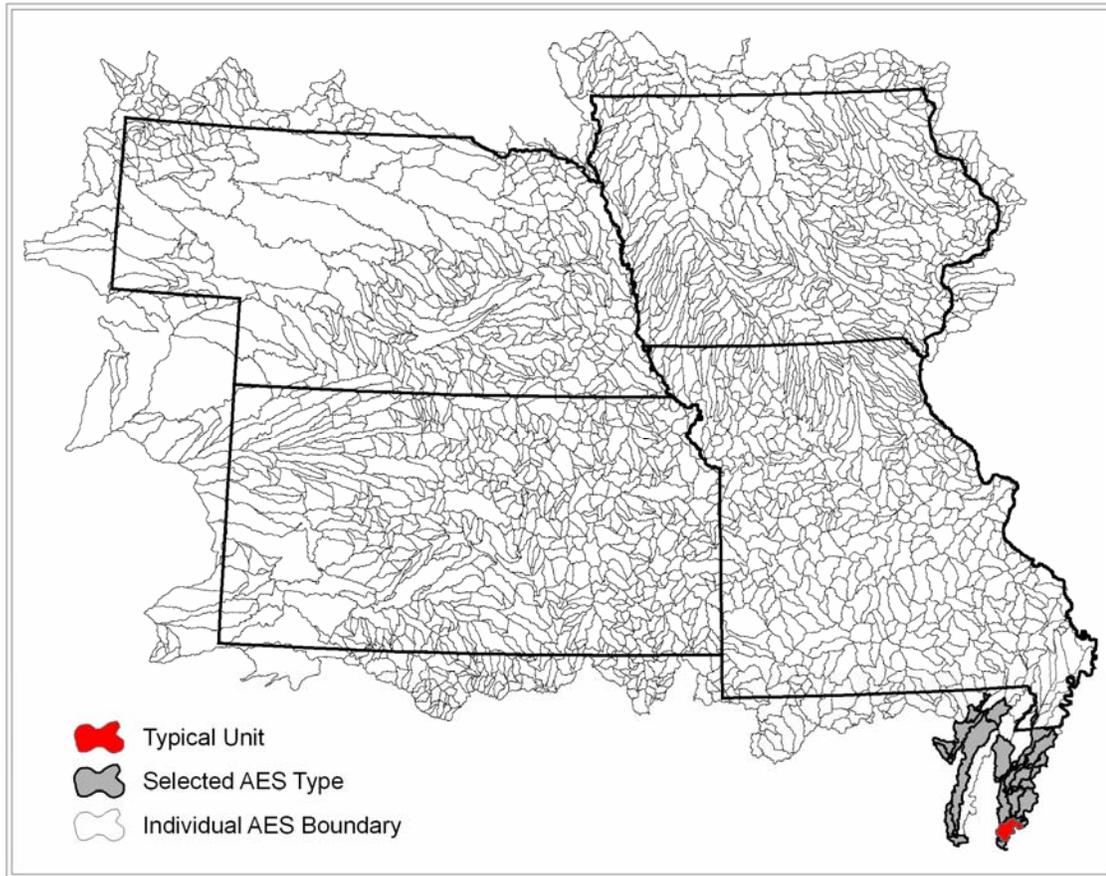


### **Description:**

This AES-Type is located in the White River drainage within Arkansas and contains portions of both the USFS's Ozark Highlands and Boston Mountains Ecological Sections. Three small drainages are encompassed in part by this AES-Type including a portion of the upper White River, Kings River, and Crooked Creek watersheds. This area is generally characterized as having steep hills comprised on sandstone, limestone and dolomite. Local relief is quite variable, but concentrated between 30 and 150 meters. Soil surface textures consist of silt loams and sandy loams with moderate to slow infiltration rates. Rock fragment volume in these soils is generally between 30% and 50%, while depth to bedrock can be less than 120 centimeters in places. The combined headwater and creek mean stream gradient is 23.7 meters per kilometer. Historic vegetation consisted of oak-hickory forest.

**Typical Unit:** 172 – Huzzah Creek

## AES-Type 43 (City of Osceola)



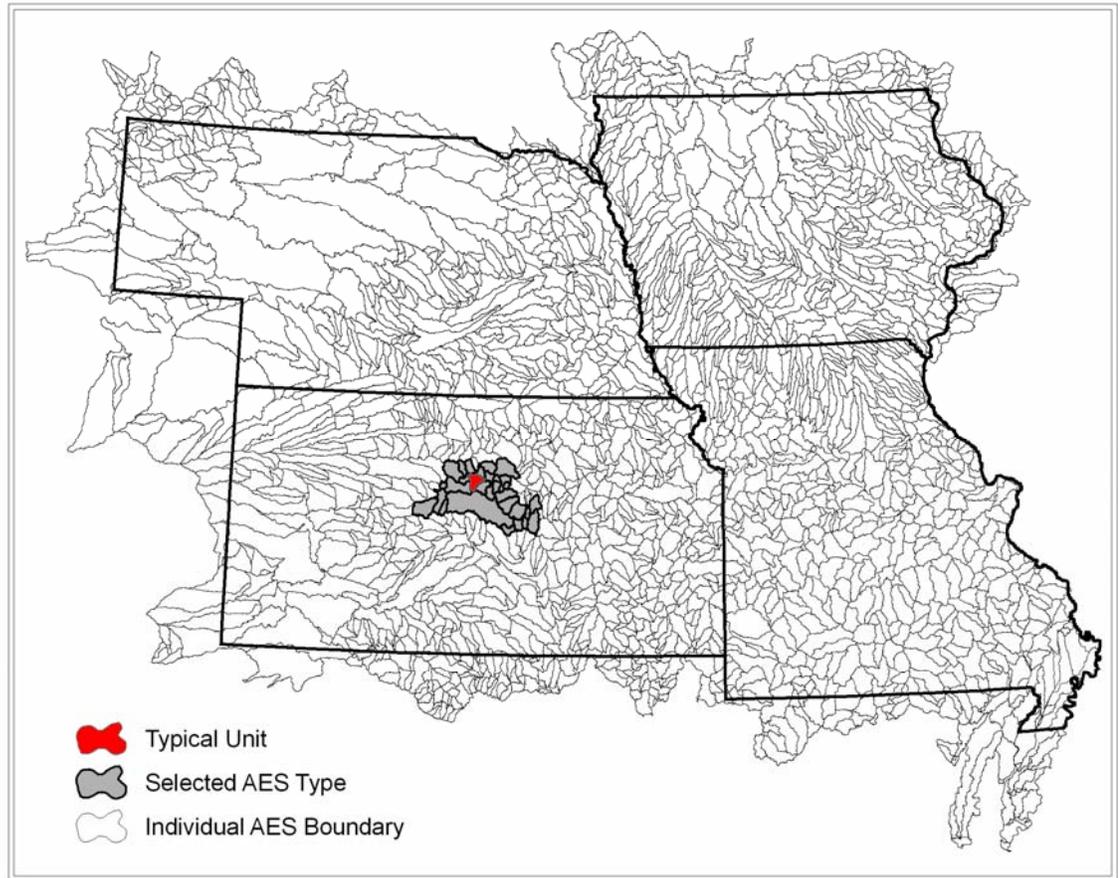
### ***Description:***

This AES-Type is located in the Mississippi Alluvial Basin Aquatic Subregion within Arkansas. The Type encompasses portions of the USFS's White and Black Rivers Alluvial Plains Ecological Section that is generally a flat slightly dissected alluvial plain. Local relief is generally less than 5 meters per kilometer. Soil surface textures are primarily silt loams and silty clay with very slow infiltration rates. Rock fragment volume in these soils is generally 0%. The combined headwater and creek mean stream gradient is 2.7 meters per kilometer. Historic vegetation consisted of southern floodplain forest.

### ***Typical Unit:***

245 – City of Osceola

## AES-Type 44 (West Twin Creek)



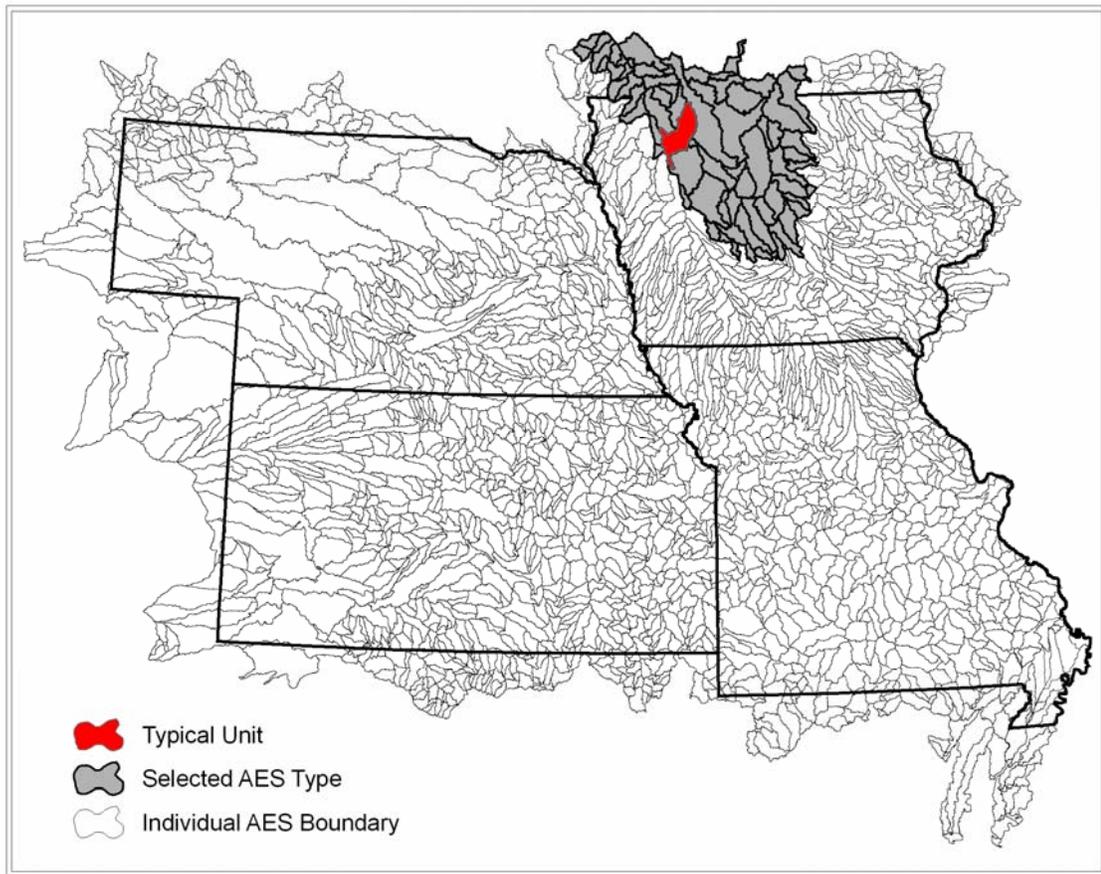
### **Description:**

This AES-Type is located in central Kansas and contains portions of Saline and Smoky Hill Rivers. This Type encompasses portions of the USFS's Smokey Hills and Eastern Sand Sage-Mixed Prairie Ecological Subsections. Local relief ranges from 16 to 60 meters. Soil surface textures are primarily silt loams and loams with moderate infiltration rates. Rock fragment volume in these soils is generally less than 10%, while depth to bedrock can be less than 120 centimeters in places. The combined headwater and creek mean stream gradient is 8.1 meters per kilometer. Historic vegetation consisted of plains grasslands and prairie.

### **Typical Unit:**

813 – West Twin Creek

## AES-Type 45 (Willow Creek)



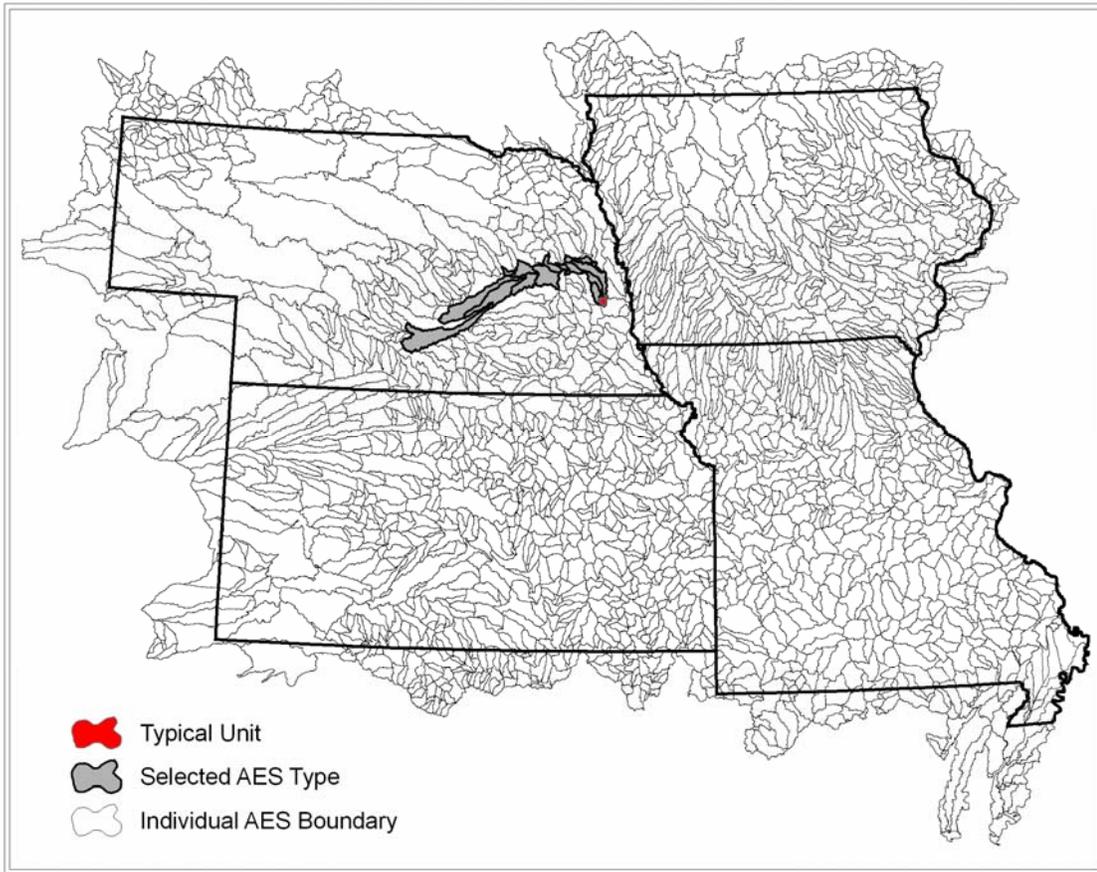
### **Description:**

This AES-Type is one of the predominant Types of the USFS's North Central Glaciated Plains Ecological Section and is essentially contained in one large cluster that incorporates much of the upper Des Moines River basin, the Blue Earth River basin, and portions of basins to the east and west of the upper Des Moines River basin. This area corresponds with the Des Moines Lobe glacial extent. The area can be characterized as a level to rolling plain with glacial features. Surficial material consist of till, drift, and sands. Local relief is most often less than 15 meters, although occasionally higher. Soil surface textures consist of loams and silty clay loams with mixed moderate and very slow infiltration rates. Rock fragment volume in these soils is generally less than 10%. The combined headwater and creek mean stream gradient is 5.3 meters per kilometer. Historic vegetation consisted of prairie, lesser areas of oak and hickory, and mosaics of bluestem prairie and oak-hickory forest along the major rivers.

### **Typical Unit:**

1074 – Willow Creek

## AES-Type 46 (Lower Clear Creek)

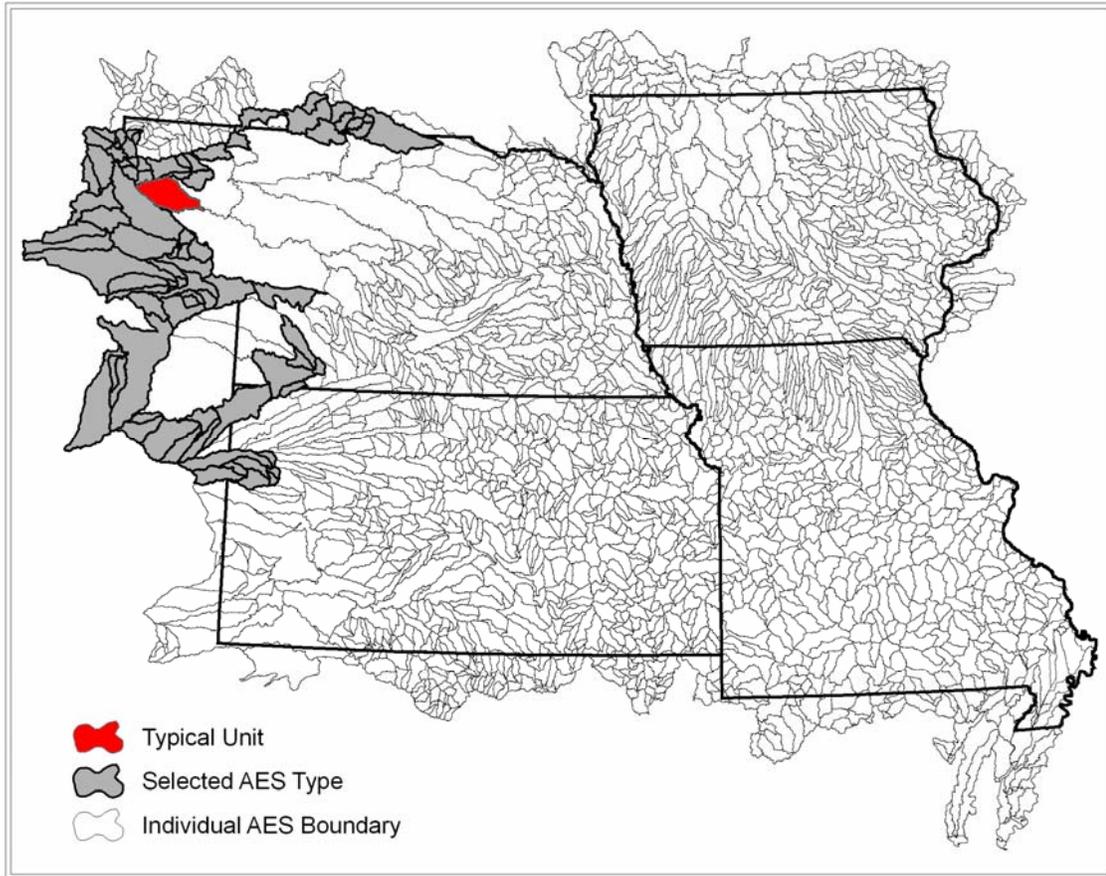


### **Description:**

This AES-Type is located along a portion of the lower Platte River in east central Nebraska from just below Elm Creek to Wahoo Creek. This Type encompasses portions of the USFS's Central Platte Valley and Lower Platte Valley Ecological Subsections. This area can be characterized as a wide alluvial valley with shallow braided streams over sand. Local relief is most often less than 30 meters within any polygon comprising this type. Local soil surface textures are relatively varied within this AES-Type with portions of silty clay loam, silt loam, sandy loam and sand scattered throughout. These varied soils exhibit primarily moderate with some high infiltration rates. Rock fragment volume in these soils is generally less than 10%. The combined headwater and creek mean stream gradient is 3.3 meters per kilometer. Historic vegetation consisted of plains grasslands and prairie with northern floodplain forest along the major rivers. From a watershed perspective soils are slightly less varied and consist mostly of silt loams, sand, and sandy loams. Infiltration rates for the overall watershed are moderate to high, while local relief throughout the entire watershed still averages less than 60 meters.

***Typical Unit:*** 1543 – Lower Clear Creek

## AES-Type 47 (Snake Creek)

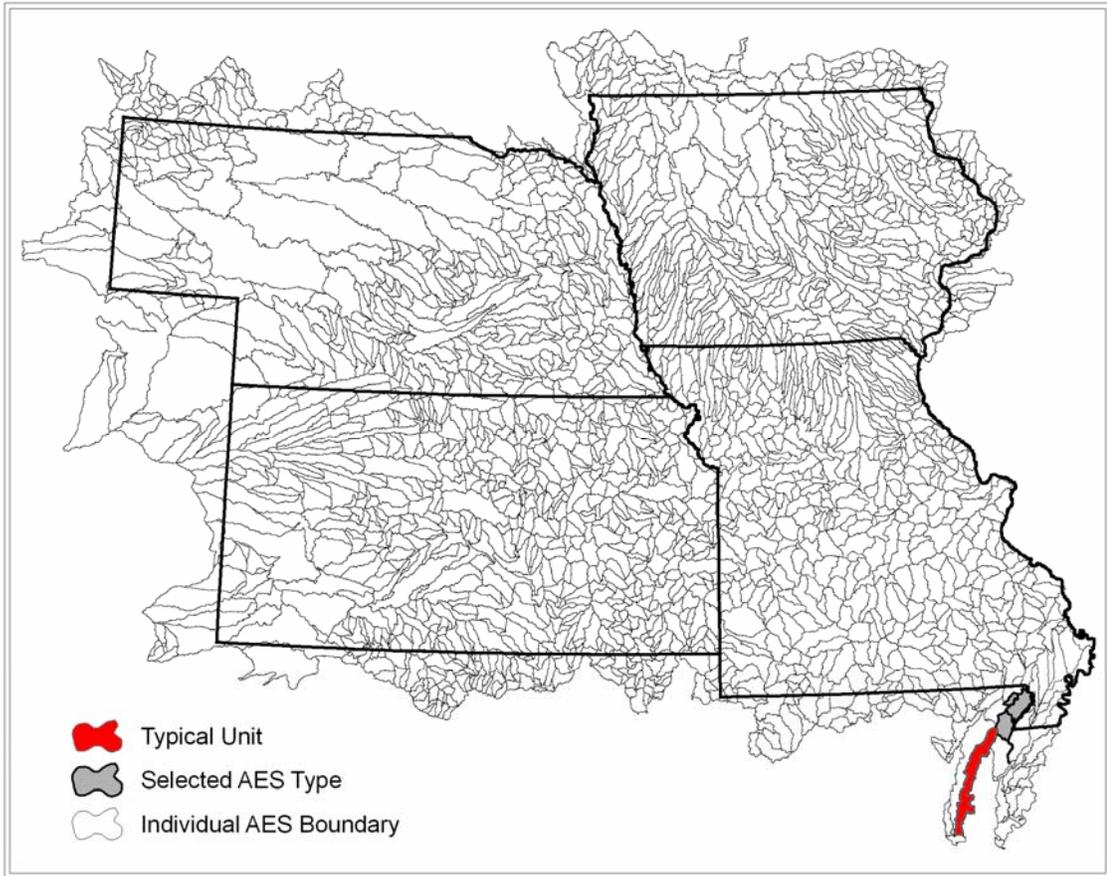


### **Description:**

This AES-Type comprises a rough belt around much of the perimeter of western Nebraska and the Sand Hills extending south to portions of Colorado and northwest Kansas. It is found as far east as the Keya Paha River's confluence with the Niobrara River. Local relief is rarely above 60 meters and usually much less. Soil surface textures are somewhat varied within this AES-Type and consist of varying amounts of loam, silty loam, and sandy loam, with lesser amounts of loamy sand and sand. These soils exhibit mainly moderate infiltration rates. Rock fragment volume in these soils is generally less than 10%, while depth to bedrock can be less than 120 centimeters in places. The combined headwater and creek mean stream gradient is 11.1 meters per kilometer. Although not characteristic of the Type as a whole, there are scattered areas with coldwater streams within this AES-Type. The historic vegetation consisted of plains grasslands with some prairie along the periphery of the Nebraska Sandhills.

**Typical Unit:** 1440 – Snake Creek

## AES-Type 48 (Lost Creek)

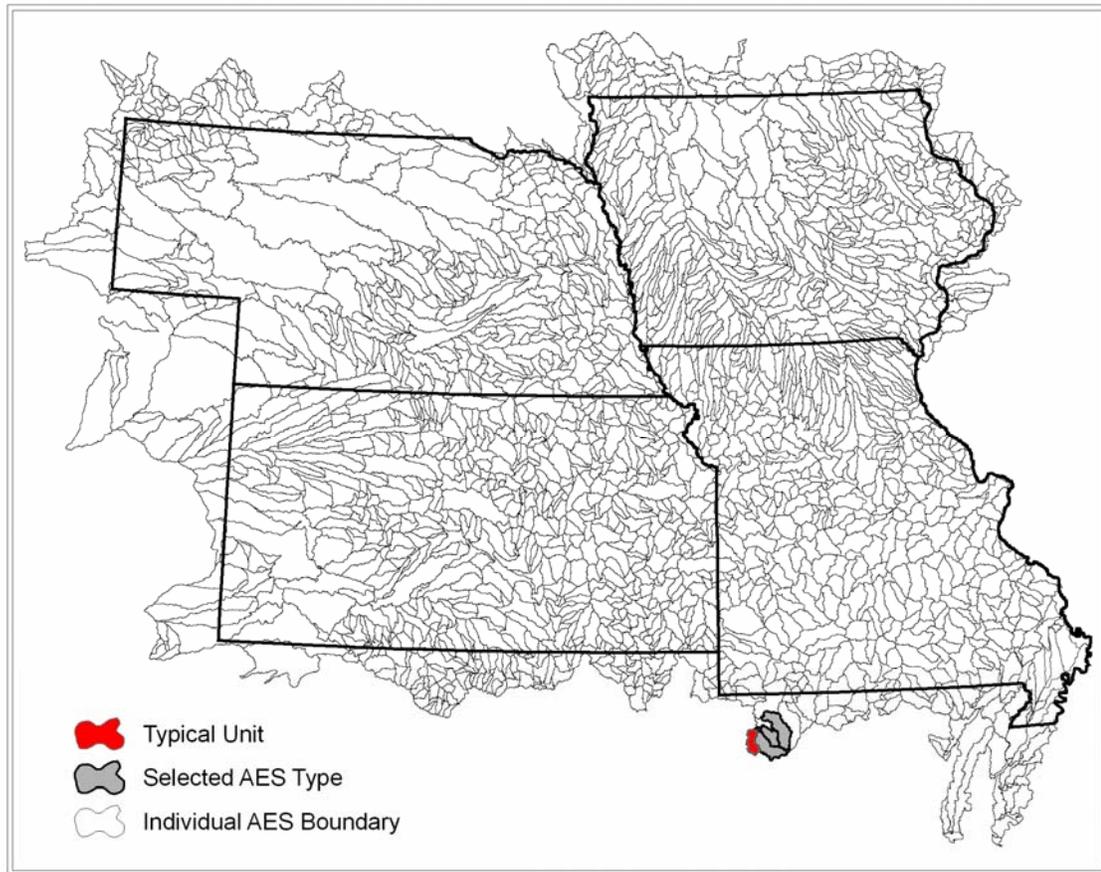


### **Description:**

This AES-Type is located in northeast Arkansas and incorporates much of the transition area between Crowley's Ridge and the USFS's White and Black Rivers Alluvial Plain. Local relief is generally less than 15 meters, although portions that encompass more of Crowley's Ridge exhibit slightly more relief and can be greater than 30 meters. Soil surface textures are dominated by silty loams with slow to very slow infiltration rates. Rock fragment volume in these soils is generally less than 10%. The combined headwater and creek mean stream gradient is 5.4 meters per kilometer. Historic vegetation consisted of southern floodplain forest with oak-hickory-pine on Crowley's Ridge.

**Typical Unit:** 219 – Lost Creek

## AES-Type 49 (Winn Creek)

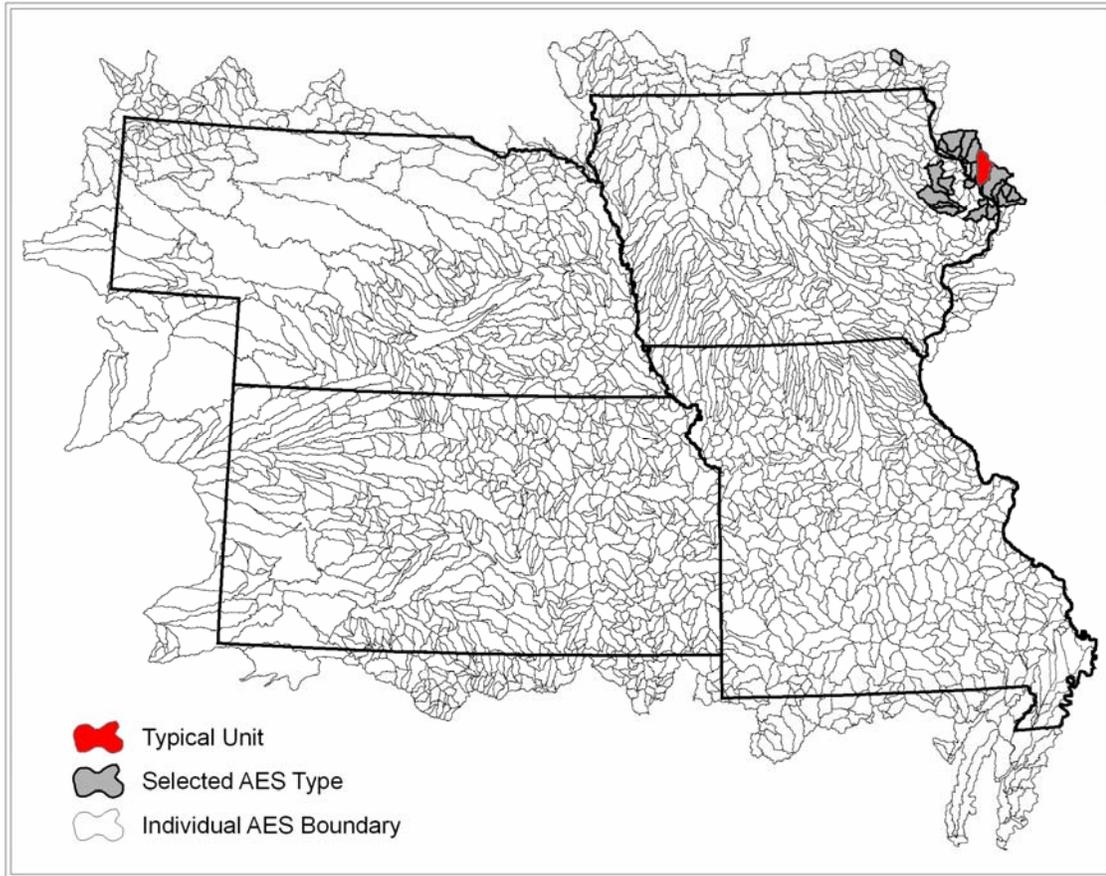


### **Description:**

This AES-Type is located in the southern most portion of the Upper White River Basin in Arkansas and encompasses portions of the USFS's Boston Hills and Boston Mountains Ecological Subsections. Local relief is relatively high with most centered between 60 and 150 meters. Soil surface textures are almost exclusively sandy loams with a small amount of silt loam in the northern portion of this Type. These soils exhibit moderate infiltration rates. Rock fragment volume in these soils is generally between 20% and 40%, while depth to bedrock can be less than 120 centimeters in places. The combined headwater and creek mean stream gradient is high at 26.7 meters per kilometer. Historic vegetation consisted of oak-hickory forest.

**Typical Unit:** 180 – Winn Creek

## AES-Type 50 (Smallpox Creek)

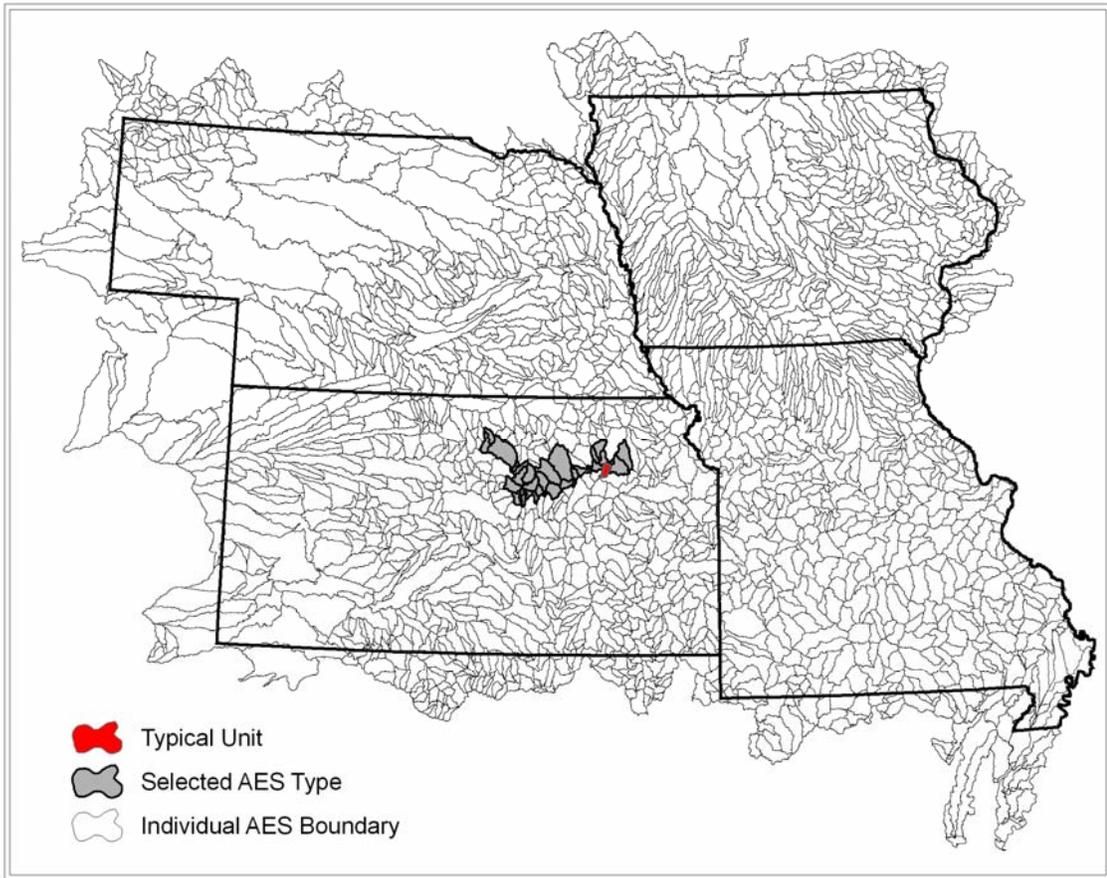


### **Description:**

This AES-Type has a somewhat disjointed distribution in northeast Iowa, southwest Wisconsin and northeast Illinois. Major streams that are contained in this Type include the Maquoketa River (Iowa), Apple River (Illinois), and Grant River (Wisconsin). Local relief ranges from 16 to 60 meters, but does fluctuate outside of this range to some degree. Soil surface textures consist of silt loams with moderate infiltration rates. Rock fragment volume in these soils is generally less than 20%, while depth to bedrock can be less than 120 centimeters in places. The combined headwater and creek mean stream gradient is 13.8 meters per kilometer. Historic vegetation was varied and consisted of mosaics of bluestem prairie and oak-hickory forest, some oak savanna, and prairie in the extreme west.

**Typical Unit:** 1239 – Smallpox Creek

## AES-Type 51 (Antelope Creek)

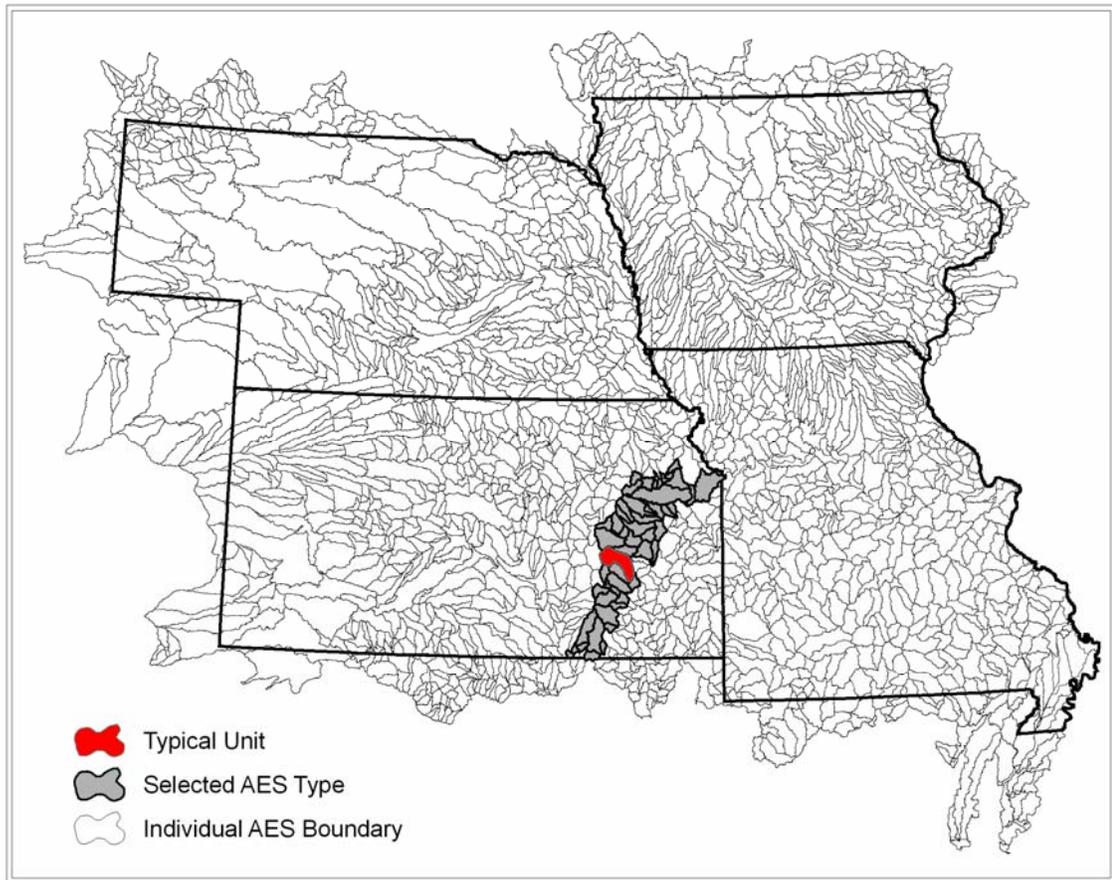


### **Description:**

This AES-Type is located in central Kansas and contains portions of the Solomon, Smoky Hill, Republican, and Kansas Rivers. Local relief is typically less than 30 meters. Soil surface textures are divided almost equally between silt loams in the west and along the Smoky Hill River and silty clay loams to the east. These soils exhibit infiltration rates that range from moderate to very slow. Rock fragment volume in these soils is generally less than 10%, while depth to bedrock can be less than 90 centimeters in places. The combined headwater and creek mean stream gradient is 8.1 meters per kilometer. Historic vegetation was quite varied and consisted of plains grasses, prairie, and northern floodplain. From a watershed perspective, soils are similar with silt loams, silty clay loams and some loam. From the same perspective these soils exhibit moderate to slow infiltration rates. Local relief within the watershed is primarily less than 60 meters.

**Typical Unit:** 581 – Antelope Creek

## AES-Type 52 (North Branch Verdigris River)

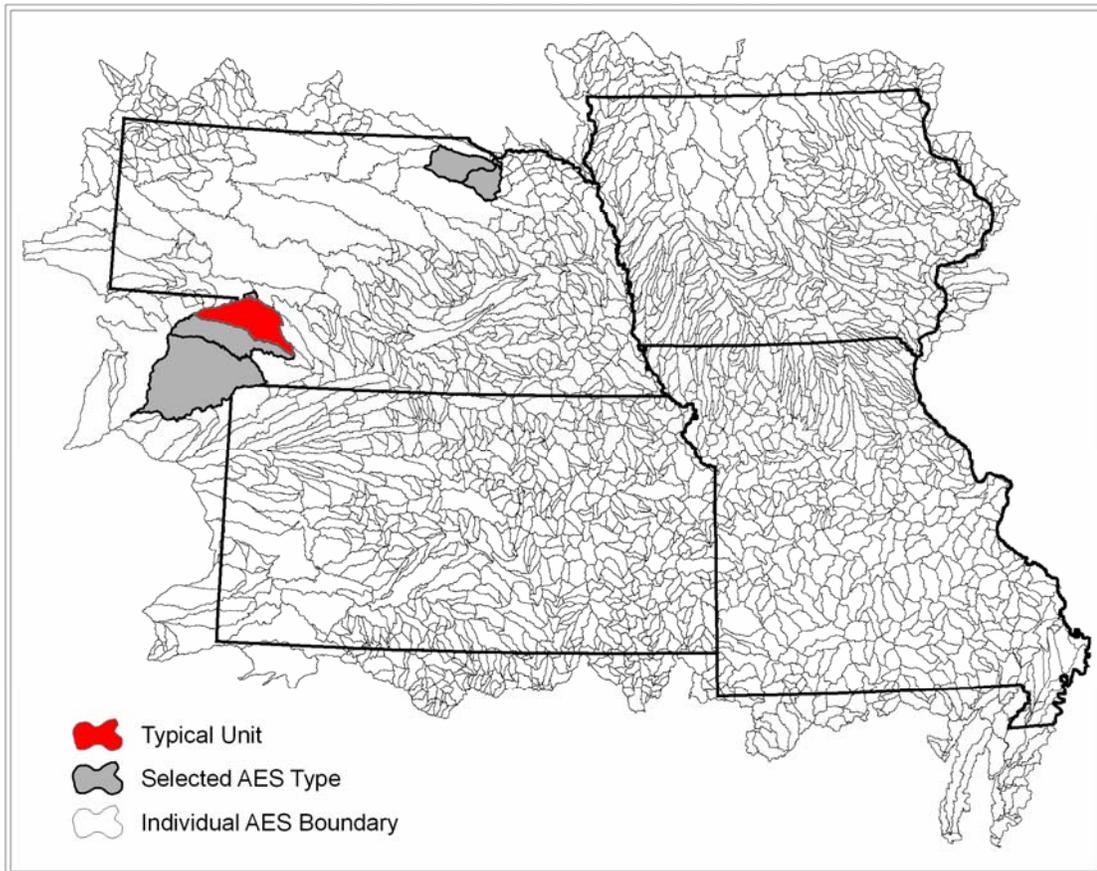


### **Description:**

This AES-Type is located in southeastern Kansas and runs in a northeast to southwesterly direction. This AES-Type basically encompasses the headwaters of a number of river basins including the Verdigris, Neosho, Marais des Cygnes, and Wakarusa rivers. Local relief is typically less than 45 meters. The soil surface texture is primarily silty clay loam with some silt loam. These soils exhibit slow to very slow infiltration rates. Rock fragment volume in these soils is generally less than 10%. The combined headwater and creek mean stream gradient is 9.0 meters per kilometer. Historic vegetation consisted of prairie and mosaics of bluestem prairie and oak-hickory forest.

**Typical Unit:** 979 – North Branch Verdigris River

## AES-Type 53 (Stinking Water Creek)

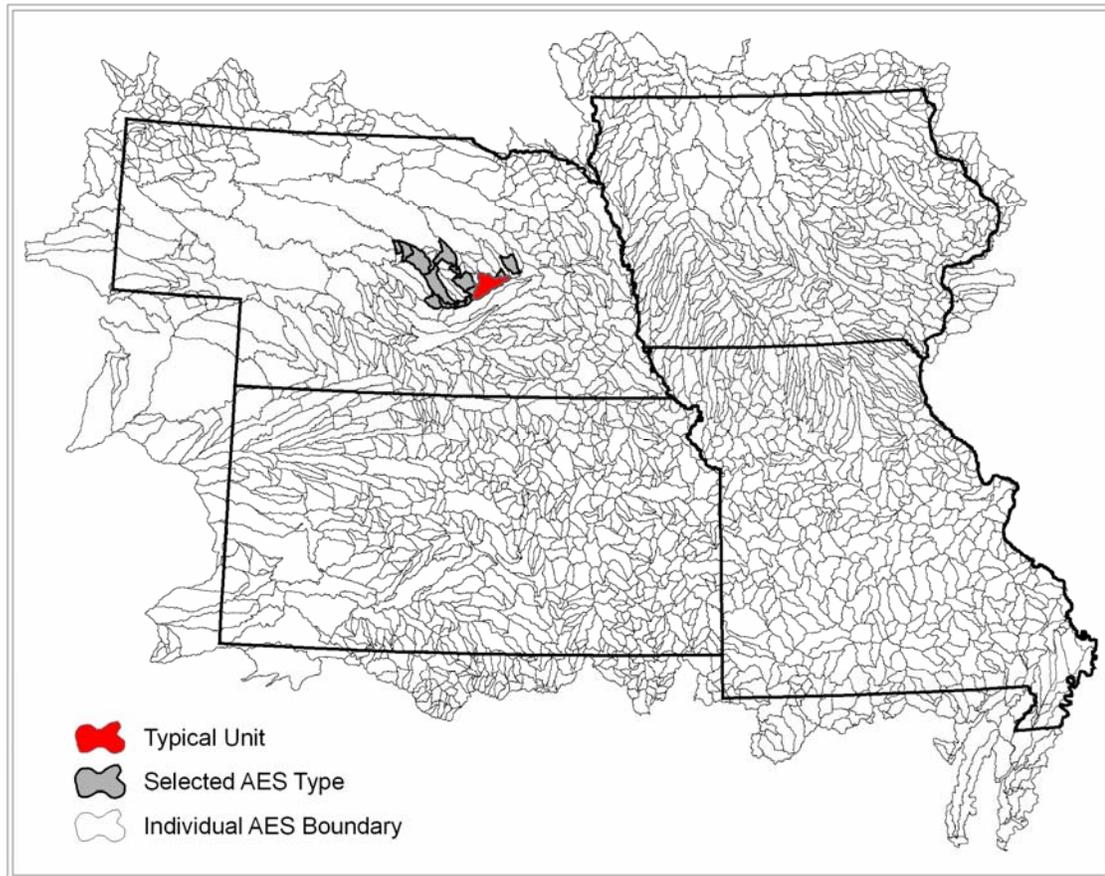


### **Description:**

This AES-Type is located in two distinct locations; one in southwest Nebraska, containing portions of the Stinking Water, Frenchman, and upper Republican Rivers, while the other group is located in north central Nebraska and contains portions of the lower Niobrara River. Local relief is less than 60 meters with the vast majority less than 30 meters. This Type consists of mostly sandy plains with the north central group having a bit more loam and loess than the western portion of this AES-Type. Surface soil textures consist of sand, silt loam and loam. These soils exhibit moderate to high infiltration rates. Rock fragment volume in these soils is generally less than 10%. The combined headwater and creek mean stream gradient is 8.2 meters per kilometer. Coldwater streams are prominent within the northern most units of this Type. Historic vegetation consisted mainly of prairie and plains grasslands.

**Typical Unit:** 1643 – Stinking Water Creek

## AES-Type 54 (Cottonwood Creek)

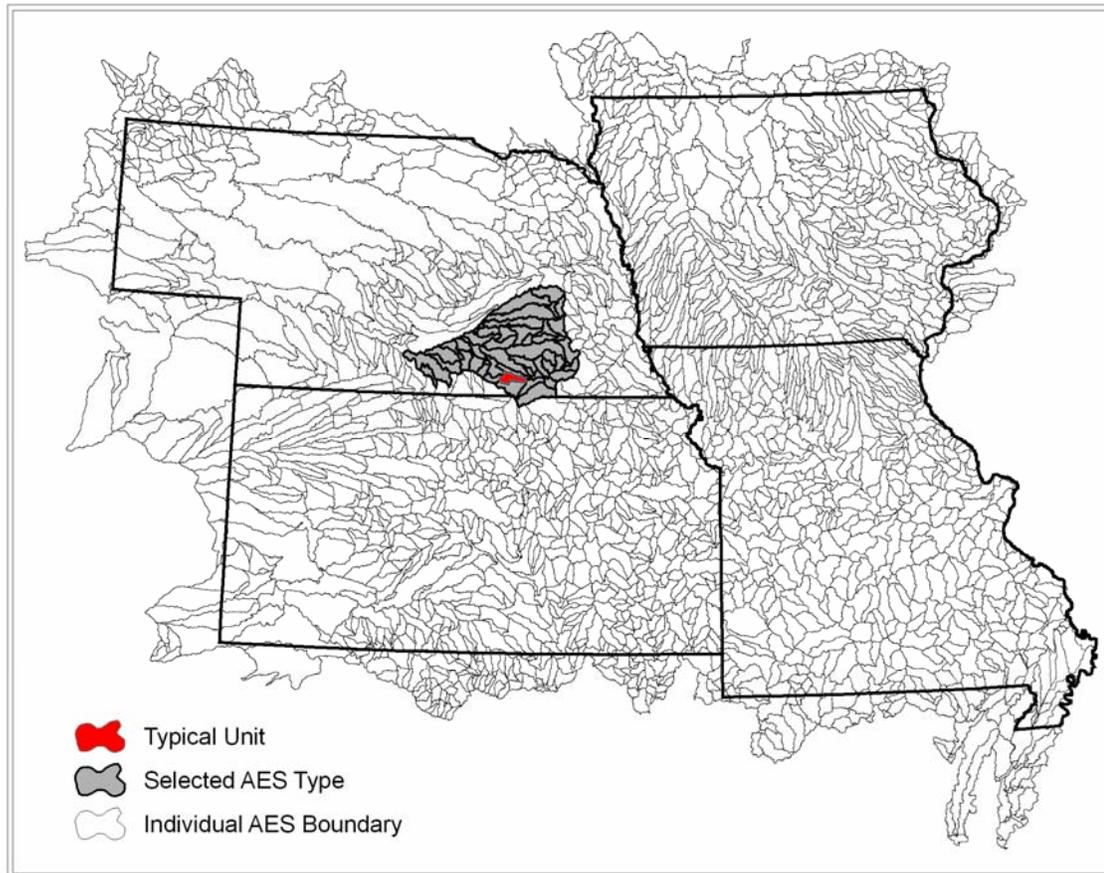


### **Description:**

This AES-Type encompasses several main stem rivers draining out the Nebraska Sand Hills. These rivers include the Middle Loop River, North Loop, the lower Mud Creek, extreme lower Cedar River, lower Beaver Creek, and a portion of the Loup Rivers. Local relief is less than 60 meters and primarily less than 30 meters. Soil surface texture consists mainly of silt loam with some sand along the rivers draining the Sand Hills. These soils exhibit moderate and high infiltration rates respectively. Rock fragment volume in these soils is generally less than 10%. The combined headwater and creek mean stream gradient is 8.1 meters per kilometer. Historic vegetation consisted of mainly of plains grassland with some prairie. From the broader watershed perspective soil textures are primarily sands (from the Sand Hills) with high infiltration rates and silt loams with moderate infiltration rates lower in the watersheds.

**Typical Unit:** 1541 – Cottonwood Creek

## AES-Type 55 (Thawes Creek)

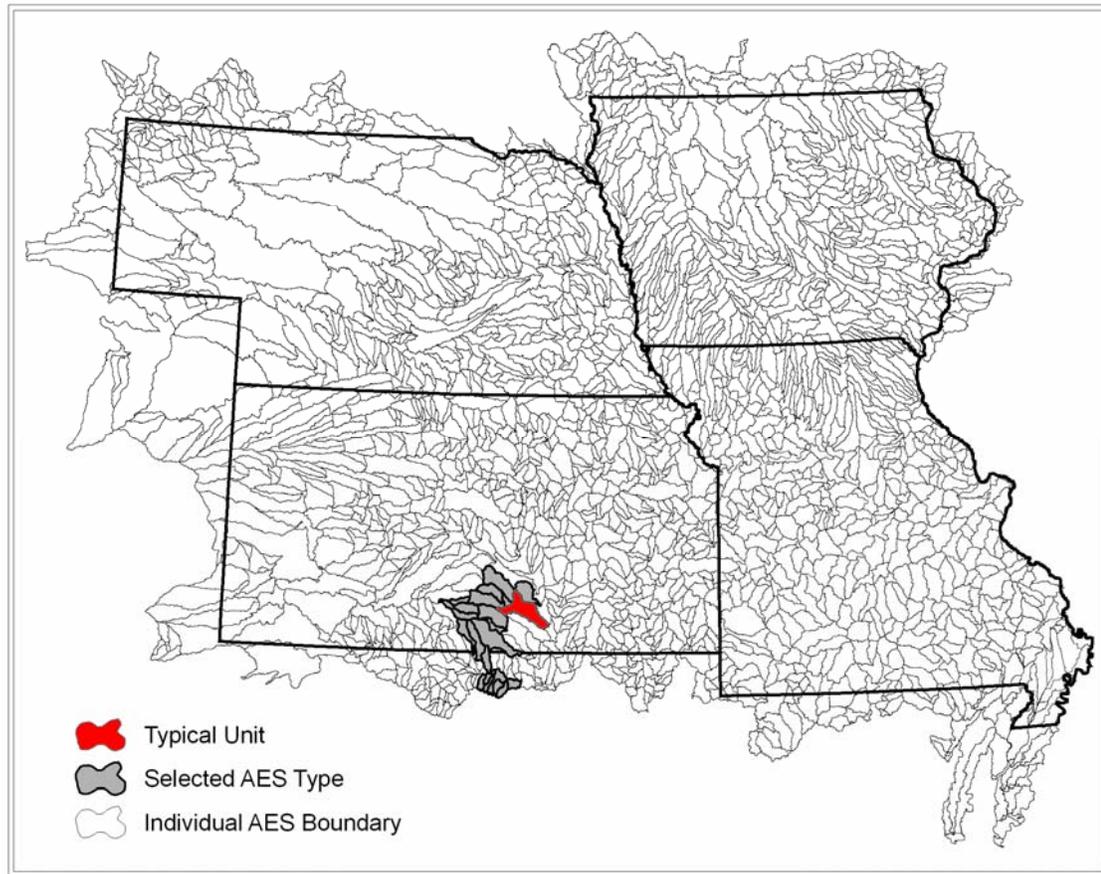


### **Description:**

This AES-Type is located in south central Nebraska and encompasses an area consisting of relatively smooth plains that is drained by the Little Blue and Big Blue Rivers. This Type encompasses most of the northern portion of the USFS's Eastern Sand Sage-Mixed Prairie Ecological Subsection as well as the northern 2/3 of the USFS's York Plains Ecological Subsection. Local relief is mostly less than 20 meters. The entire area is dominated by silt loam soil surface textures that exhibit moderate to slow infiltration rates. Rock fragment volume in these soils is generally 0%. The combined headwater and creek mean stream gradient is 5.1 meters per kilometer. Historic vegetation consisted of plains grasslands and prairie.

**Typical Unit:** 746 – Thawes Creek

## AES-Type 56 (Ninnescah River)

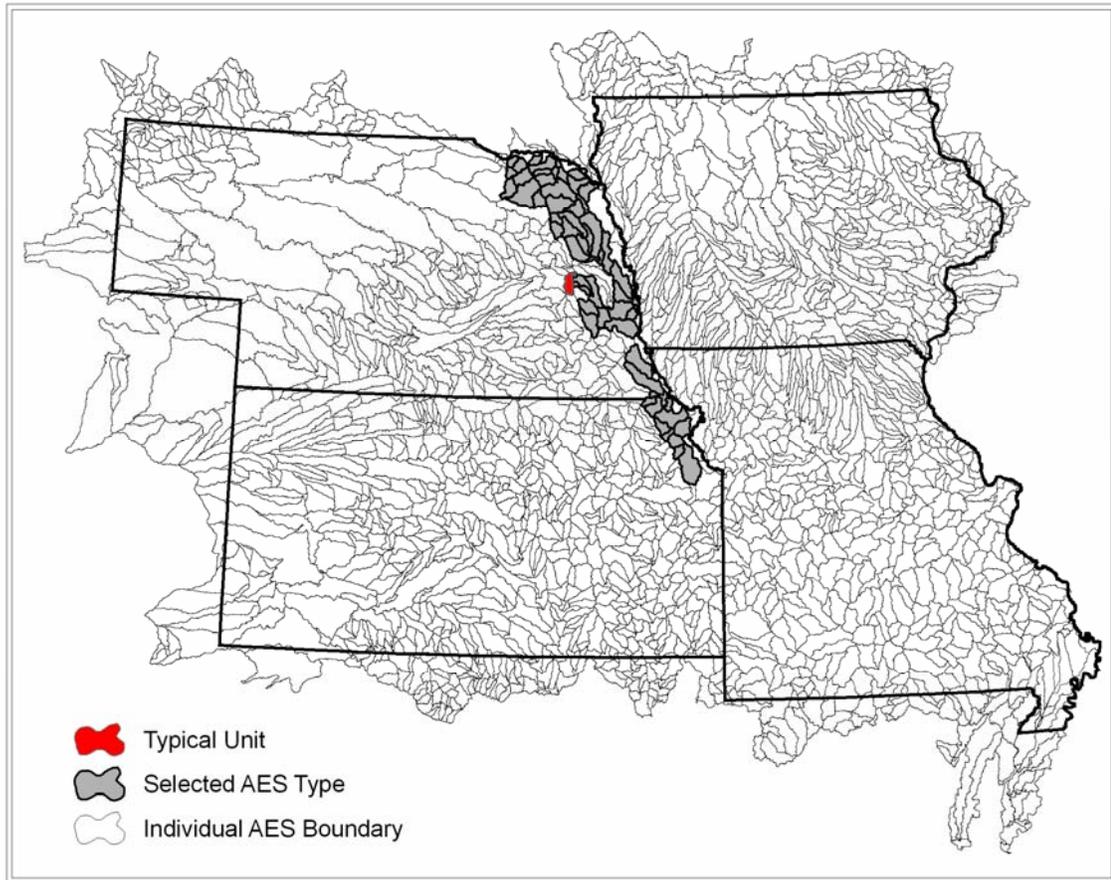


### **Description:**

This AES-Type encompasses the north and west portions of the USFS's Eastern South Central and Red Bed Plains Ecological Subsection. Local relief is most often less than 20 meters. Soil surface textures consist of silt loams, sandy loams, and some sand. These soils exhibit moderate infiltration rates although some minor areas exhibit high infiltration rates. Rock fragment volume in these soils is generally less than 10%. The combined headwater and creek mean stream gradient is 5.5 meters per kilometer. Historic vegetation consisted of plains grasslands.

**Typical Unit:** 344 – Ninnescah River

## AES-Type 57 (Skull Creek)

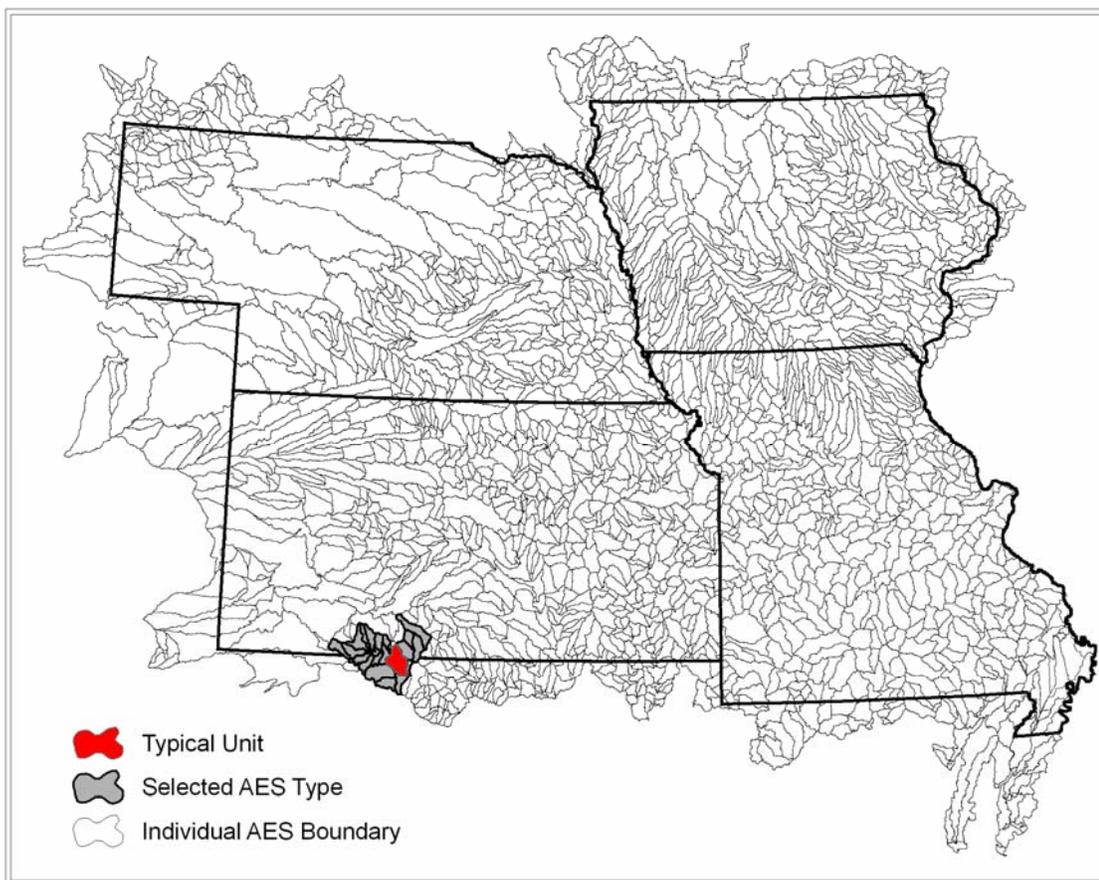


### **Description:**

This AES-Type runs in a northwest to southeast belt along the Missouri River beginning roughly at Beaver Creek in northeast Nebraska southward to Independence Creek in northeast Kansas. Its area encompasses large portions of both the USFS's Yankton Hills and Valleys and Pawnee-City-Seneca Rolling Hills Ecological Subsections. Local relief can be as high as 60 meters. Soils formed in glacial till on the uplands and on loess or alluvium in the floodplains. Soil surface textures consist of silty clay loams and silt loams. These soils primarily exhibit moderate infiltration rates. Rock fragment volume in these soils is generally less than 10%. The combined headwater and creek mean stream gradient is 8.5 meters per kilometer. Historic vegetation consisted of oak-hickory forest, prairie, and mosaics of bluestem prairie and oak-hickory forest.

**Typical Unit:** 1566 – Skull Creek

## AES-Type 58 (Keno Creek)

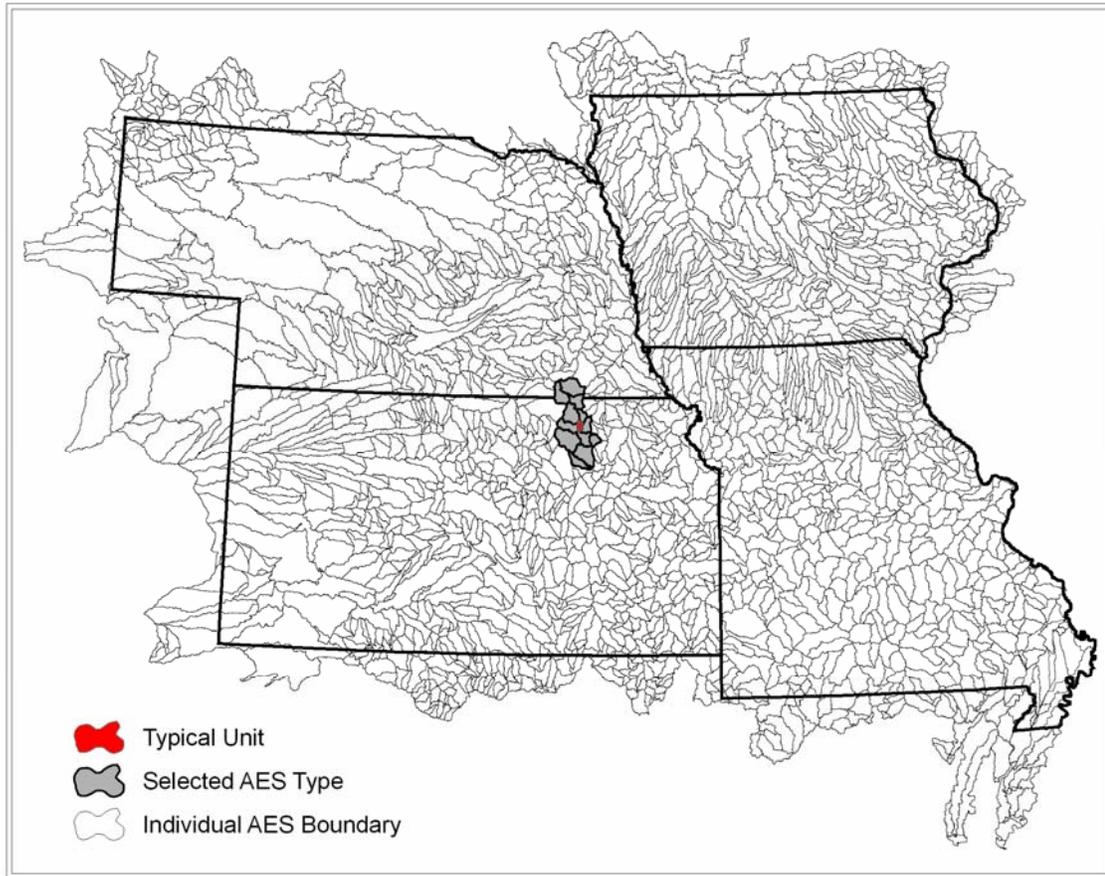


### **Description:**

This AES-Type straddles the Kansas Oklahoma border and encompasses a good part of the northern portion of the USFS's South Central and Red Bed Plains Ecological Section. The principal drainages found within this Type include portions of the Cimarron River and Salt Fork Arkansas River. Local relief is generally less than 50 meters. Soil surface textures include slightly more loam than sand. These soils exhibit moderate and high infiltration rates. Rock fragment volume in these soils is generally less than 10%. The combined headwater and creek mean stream gradient is 9.1 meters per kilometer. Historic vegetation consisted of plains grasslands.

**Typical Unit:** 388 – Keno Creek

## AES-Type 59 (Fawn Creek)

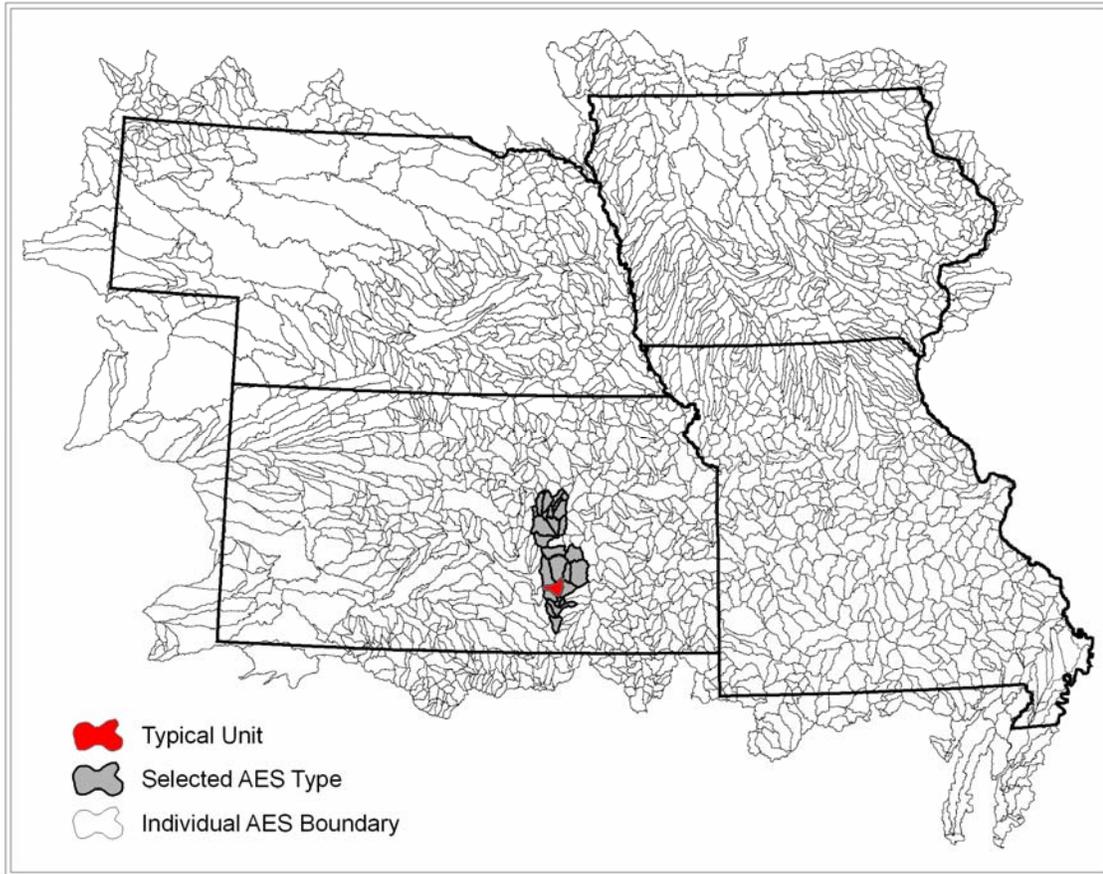


### **Description:**

This AES-Type is located in north central Kansas and incorporates a good portion of the lower Big Blue River down to its confluence with the Kansas River. This Type encompasses portions of the USFS's York Plains and Northeastern Flint Hills Ecological Subsections. Local relief is concentrated between 15 and 60 meters. Soil surface textures are primarily silty clay loams that exhibit slow to very slow infiltration rates. Rock fragment volume in these soils is generally less than 10%, while depth to bedrock can be less than 120 centimeters in places. The combined headwater and creek mean stream gradient is 10.1 meters per kilometer. Historic vegetation consisted of prairie. From the watershed perspective this AES-Type receives drainage from both silt loams and silty clay loams with slow to moderate infiltration rates. Local relief is comparable in the watershed and between 15 and 60 meters.

**Typical Unit:** 564 – Fawn Creek

## AES-Type 60 (Dry Creek)

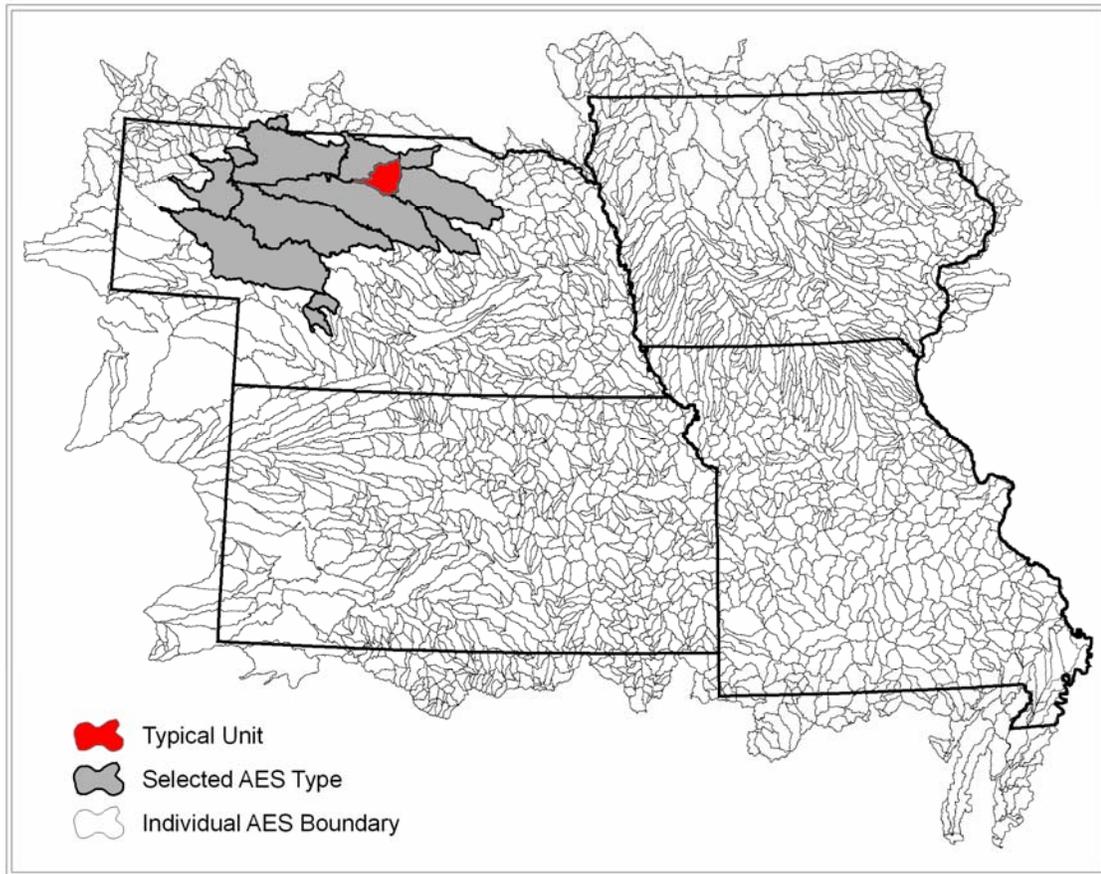


### **Description:**

This AES-Type is located in central Kansas and encompasses a good portion of the USFS's Western Flint Hills Ecological Subsection. This Type contains most of the upper portion of the Walnut River drainage and a few spurious drainages to the north. Local relief is generally less than 30 meters. Soil surface textures within this Type consist mainly of silty clay loams and loams. These soils exhibit varied infiltration rates, but most of the area experiences very slow infiltration. Rock fragment volume in these soils is generally less than 10%, while depth to bedrock can be less than 120 centimeters in places. The combined headwater and creek mean stream gradient is 5.8 meters per kilometer. Historic vegetation was prairie.

**Typical Unit:** 274 – Dry Creek

## AES-Type 61 (Long Pine Creek)

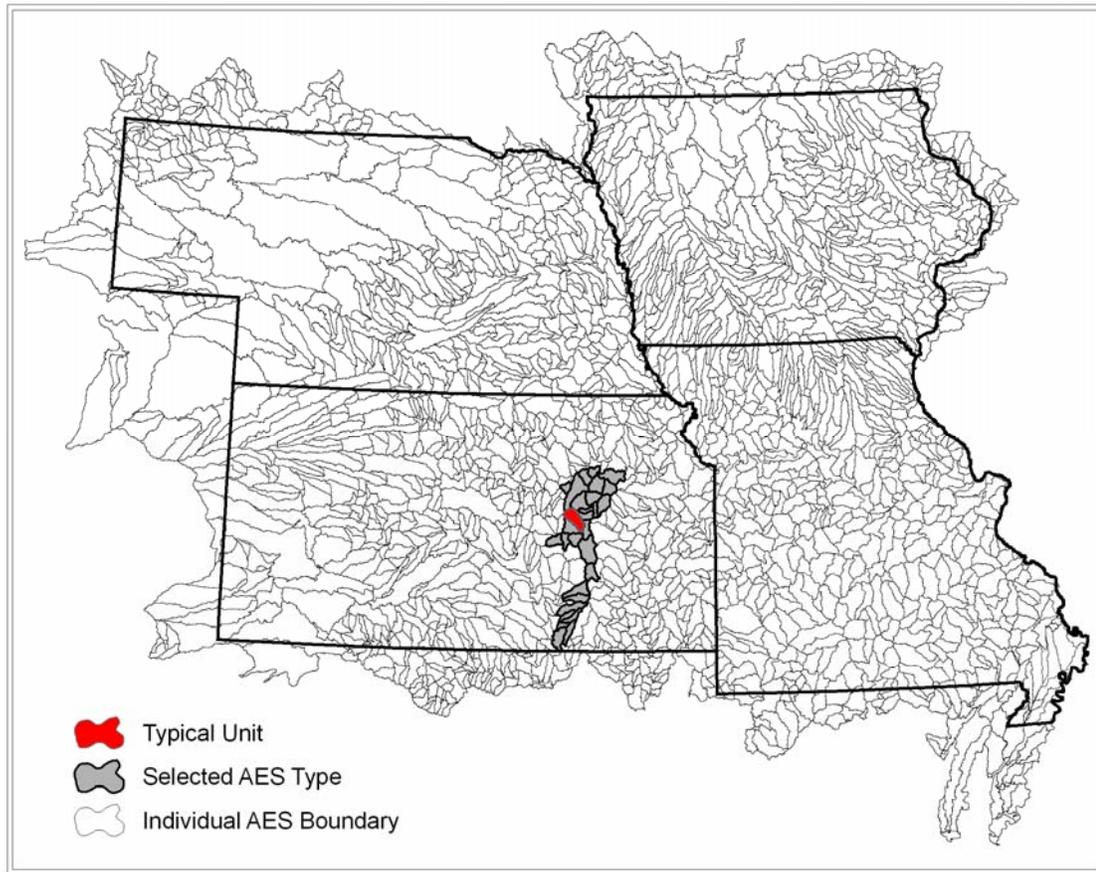


### **Description:**

This AES-Type comprises much of the USFS's Nebraska Sand Hills Ecological Section. Large portions of this Type are nearly devoid of streams. Lakes and wetlands are scattered across the area. This is a semiarid area consisting of rolling to steep and irregular ground. Most of the area consists of sand sheets and sand dunes stabilized by grass. Eolian dune sand, Pliocene and Pleistocene alluvial silt, and sand and gravel over sandstone are the predominant geologic materials. Local relief is typically less than 60 meters. As would be expected, sand is the dominant soil surface texture, although there are also minor areas with sandy and silty loams. These soils exhibit predominantly high to moderate infiltration rates. Rock fragment volume in these soils is generally less than 10%. The combined headwater and creek mean stream gradient is 7.9 meters per kilometer. There are a number of coldwater streams along the northern and southern portions of this Type. Historic vegetation was generally treeless prairie consisting of Great Plains grasslands with aspen and birch along the larger streams.

**Typical Unit:** 1426 – Long Pine Creek

## AES-Type 62 (Diamond Creek)

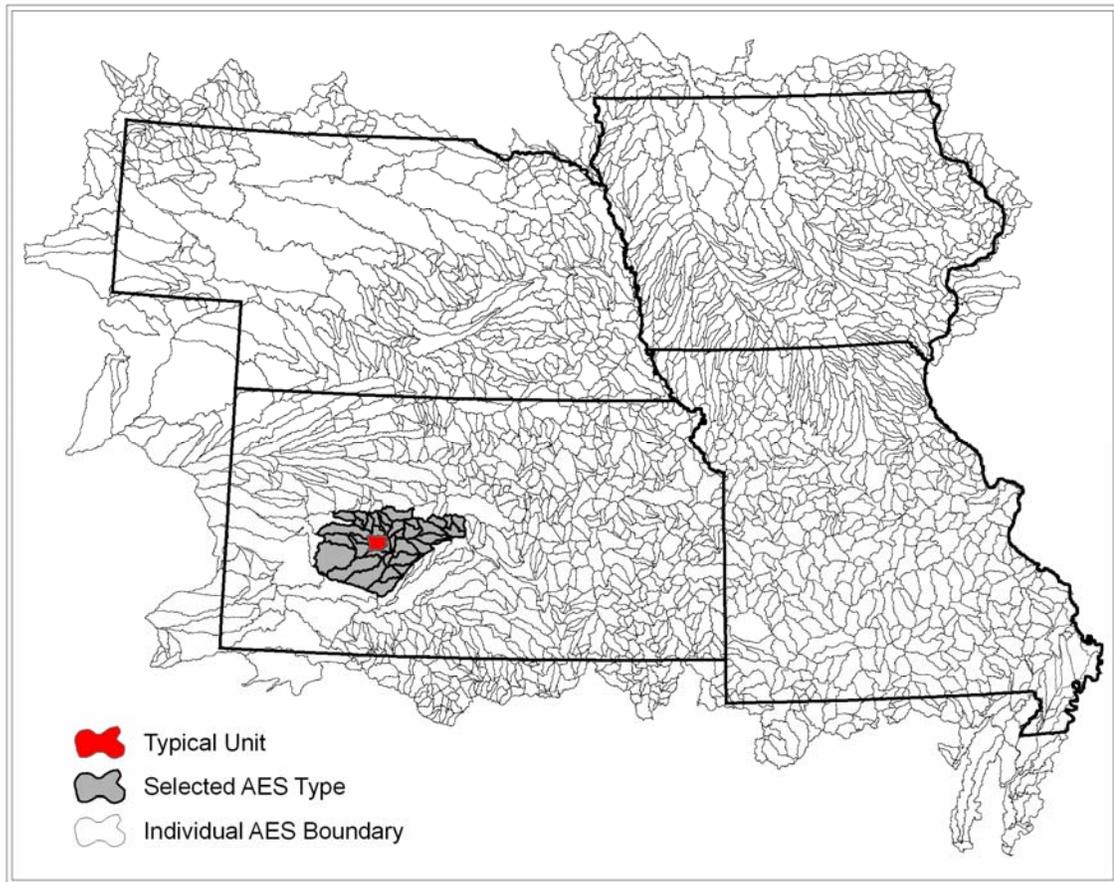


### **Description:**

This AES-Type comprises most of the USFS's Eastern Flint Hills Ecological Subsection and runs in a north-south belt within central Kansas. This area consists of gently sloping hills with stony soils. Local relief varies, but is usually less than 50 meters. This area is generally underlain by lower Permian limestone and shale. Soils are formed in weathered bedrock, alluvial materials and loess. Soil surface textures consist largely of silty clay loams with slow infiltration rates. Rock fragment volume in these soils is generally less than 20%, while depth to bedrock can be less than 90 centimeters in places. Stream valleys tend to be deeply entrenched. The combined headwater and creek mean stream gradient is 10.0 meters per kilometer. Historic vegetation consisted of prairie.

**Typical Unit:** 690 – Diamond Creek

## AES-Type 63 (Sand Creek)

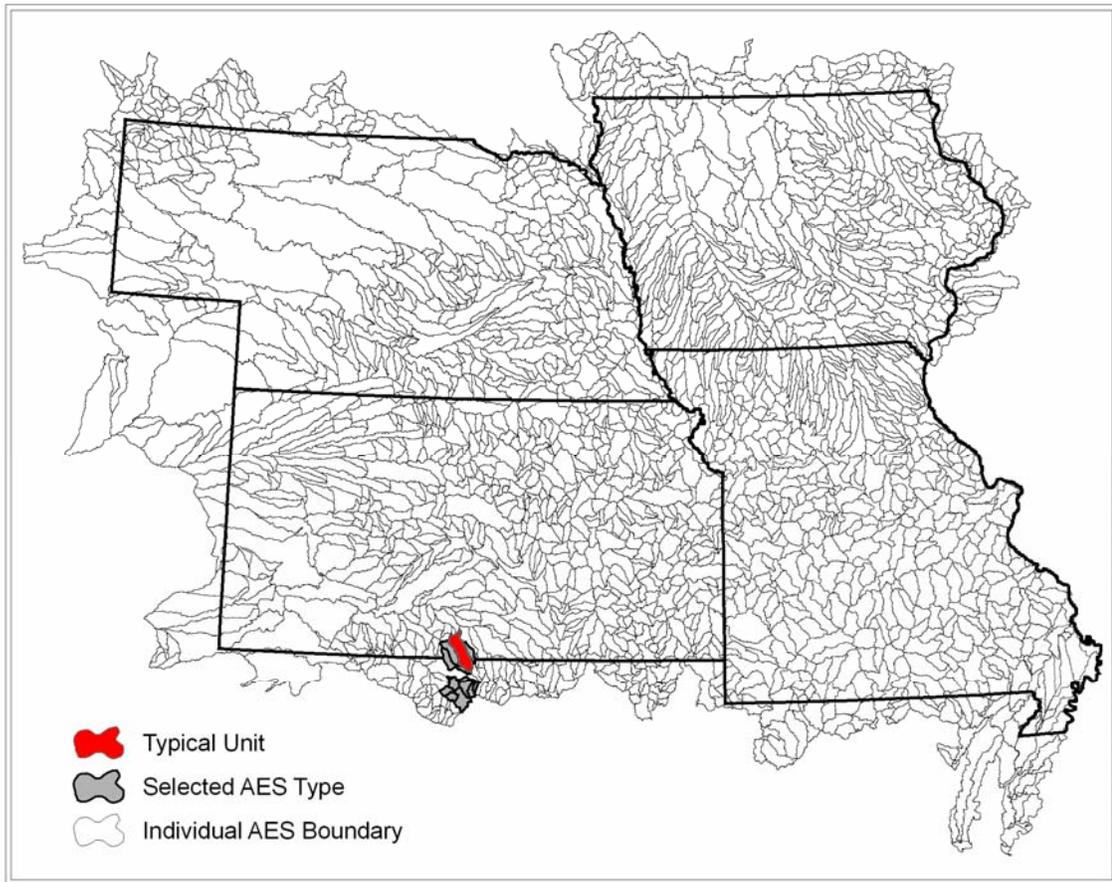


### **Description:**

This AES-Type is located in the USFS's Smokey Hills Ecological Subsection within central Kansas and incorporates most of the Pawnee River and Walnut Creek drainages, both tributaries to the Arkansas River. Local relief is generally less than 20 meters. Soil surface textures are primarily silt loams with moderate infiltration rates. Rock fragment volume in these soils is generally less than 5%. The combined headwater and creek mean stream gradient is 6.0 meters per kilometer. Historic vegetation consisted of plains grasslands.

**Typical Unit:** 261 – Sand Creek

## AES-Type 64 (Lower Medicine Lodge River)

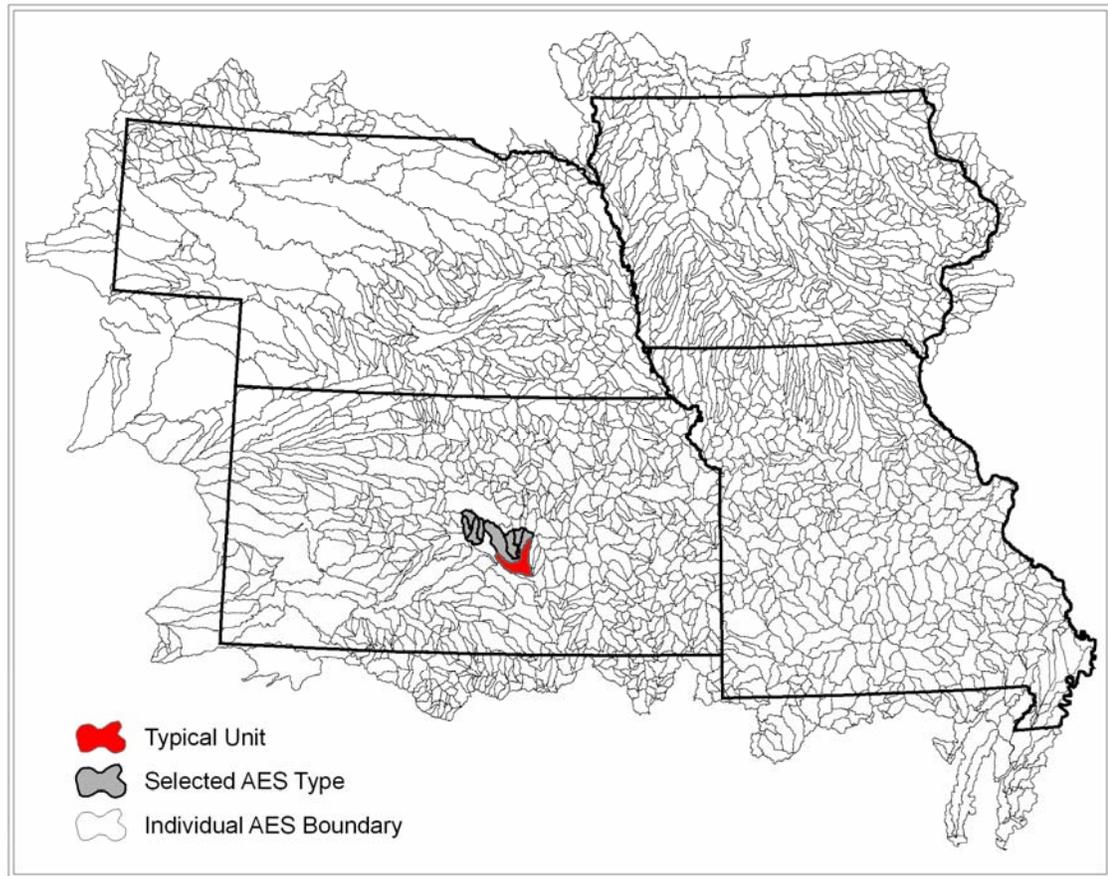


### **Description:**

This AES-Type straddles the Kansas Oklahoma border and consists of two adjacent clusters bisected by the Salt Fork of the Arkansas River. It comprises part of the USFS's Eastern South Central and Red Bed Plains Ecological Subsection and contains portions of Medicine Lodge River, Driftwood Creek, Clay Creek, and Eagle Chief Creek watersheds. Most local relief is less than 15 meters. Soil surface textures consist of silt loam and sand with moderate and high infiltration rates respectively. Rock fragment volume in these soils is generally less than 10%. The combined headwater and creek mean stream gradient is 6.2 meters per kilometer. Historic vegetation consisted of plains grasslands and prairie.

**Typical Unit:** 421 – Lower Medicine Lodge River

## AES-Type 65 (Kisiwa Creek)

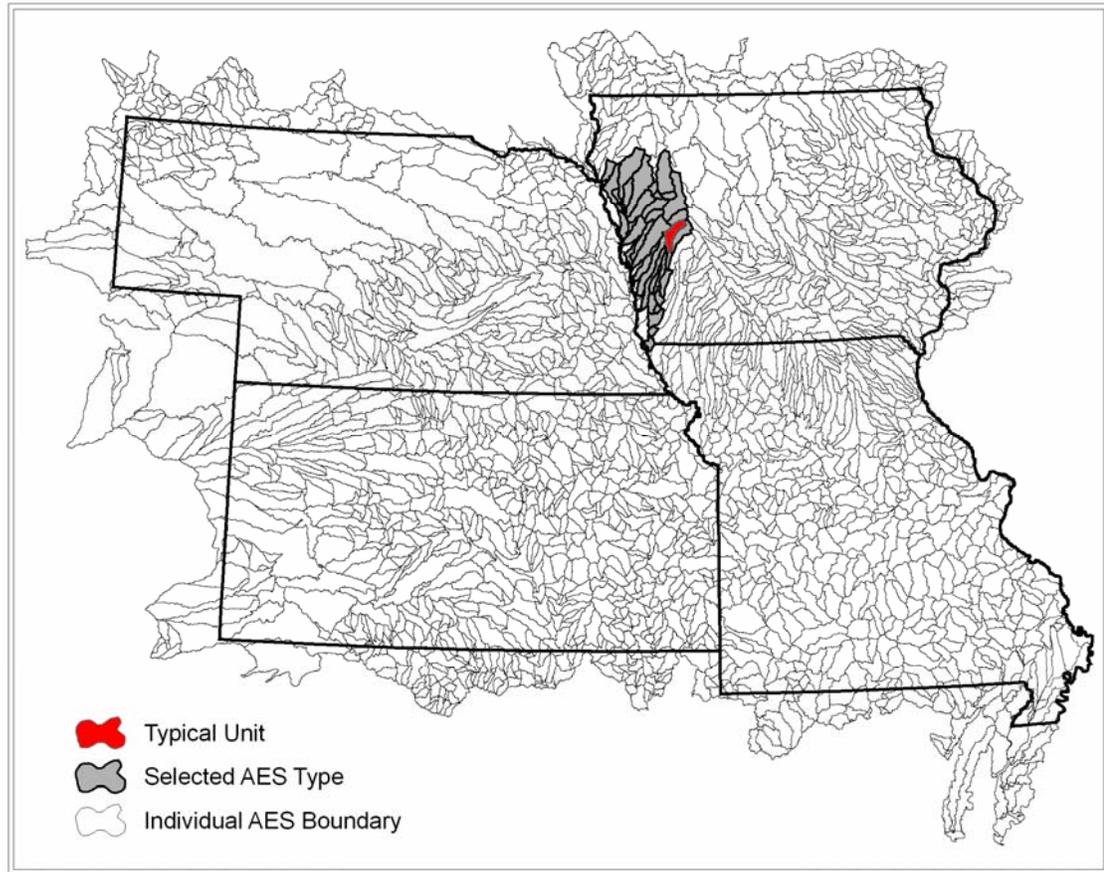


### **Description:**

This AES-Type is located in central Kansas within a southeast portion of the USFS's Smokey Hills Ecological Subsection and contains the upper watersheds of the Little Arkansas River and Cow Creek. Local relief is usually less than 15 meters. Soil surface textures consist of silt loams and sandy loams with roughly equal amounts of moderate and slow infiltration rates. Rock fragment volume in these soils is generally less than 5%. The combined headwater and creek mean stream gradient is 3.3 meters per kilometer. Historic vegetation consisted of plains grassland.

**Typical Unit:** 283 – Kisiwa Creek

## AES-Type 66 (West Fork of the West Nishnabotna River)

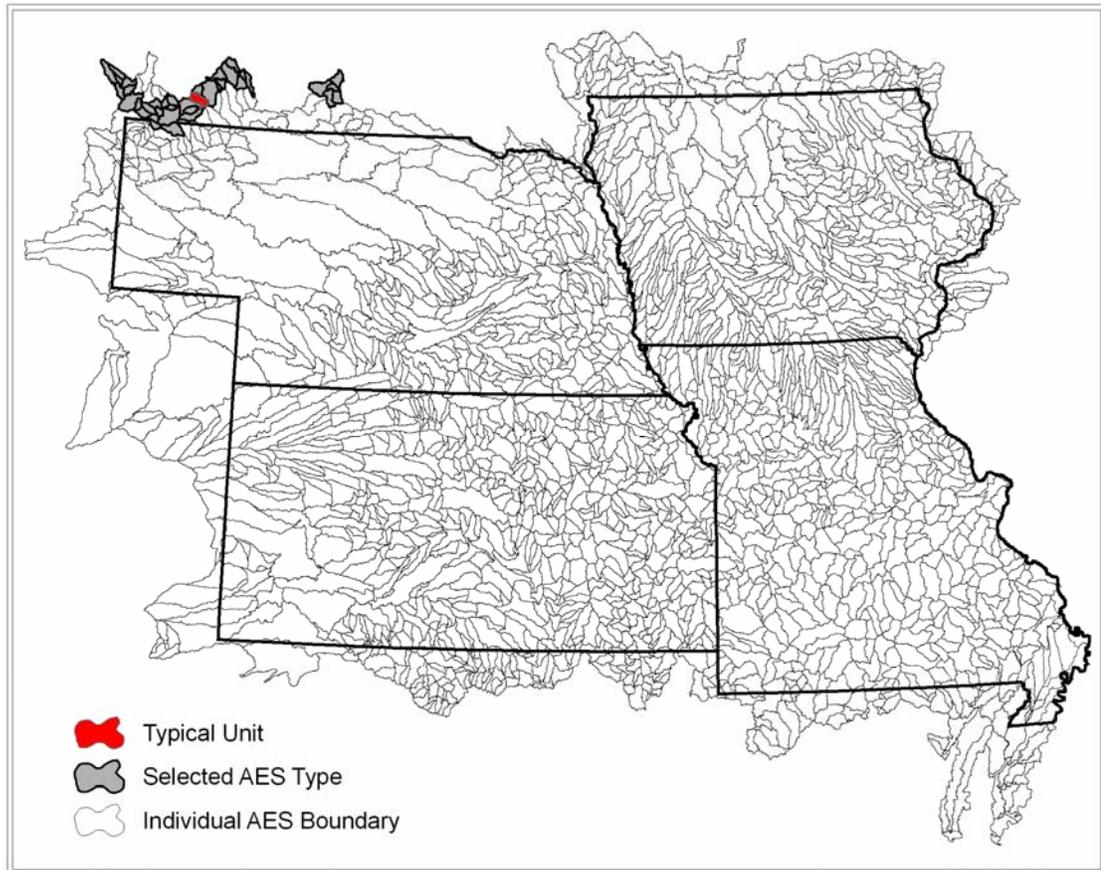


### **Description:**

This AES-Type is located in western Iowa just east of the Missouri River and incorporates a large portion of the USFS's Deep Loess Hills Ecological Subsection. Local relief varies, but is usually less than 50 meters. Soil surface textures consist of silt loams and silty clay loams with moderate to slow infiltration rates respectively. Rock fragment volume in these soils is generally 0%. The combined headwater and creek mean stream gradient is 10.8 meters per kilometer. Historic vegetation consisted of prairie with mosaics of bluestem prairie and oak-hickory forest along the streams and to the south.

**Typical Unit:** 32 – West Fork of the West Nishnabotna River

## AES-Type 67 (Cedar Bluff Creek)

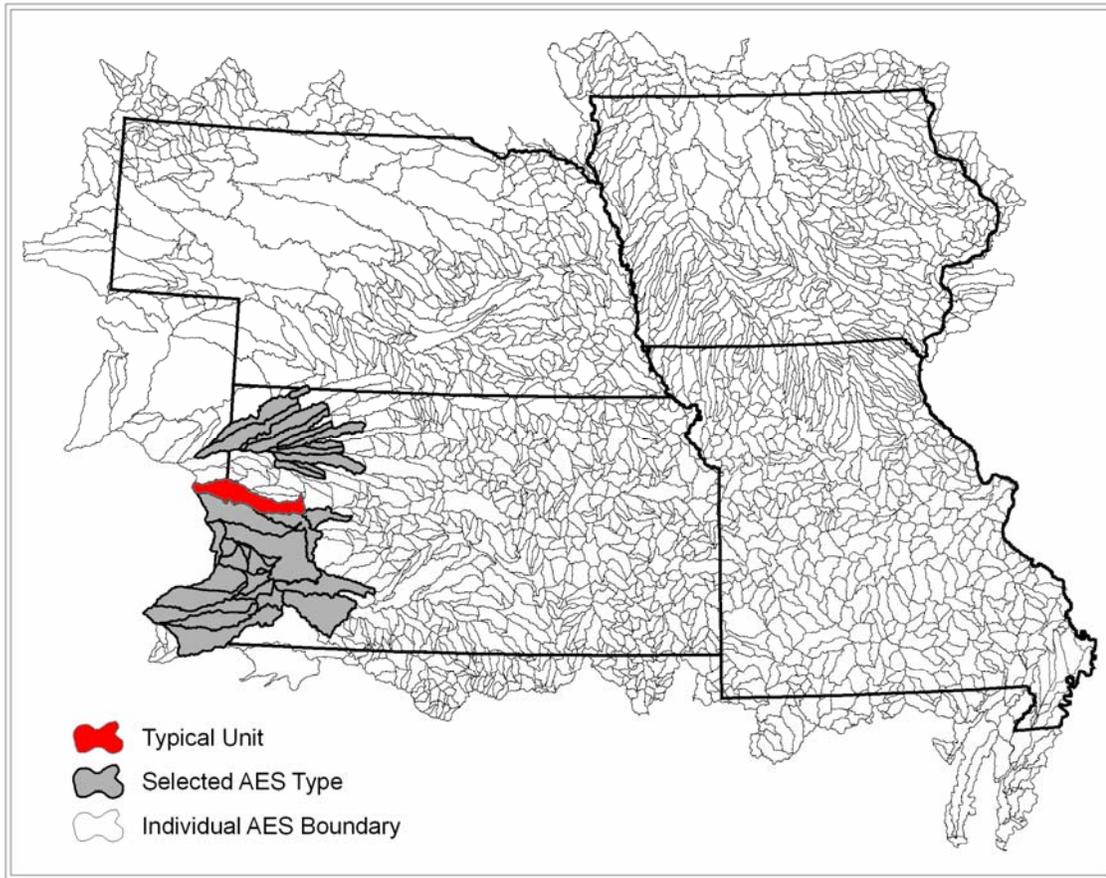


### **Description:**

This AES-Type is located in southwest and central South Dakota and contains portions of the Cheyenne, White, and Little White Rivers. It encompasses a portion of the USFS's Western Great Plains Ecological Section. Local relief is primarily between 16 and 50 meters. Soil surface textures are quite variable and consist of silty clay, clay, and silt loams. As might be expected these soils have varied infiltration rates, but are mainly very slow and moderate. Rock fragment volume in these soils is somewhat variable, but is generally less than 10%. Depth to bedrock can be less than 60 centimeters in places. The combined headwater and creek mean stream gradient is 13.4 meters per kilometer. Historic vegetation consisted of plains grasslands.

**Typical Unit:** 1621 – Cedar Bluff Creek

## AES-Type 68 (South Ladder Creek)

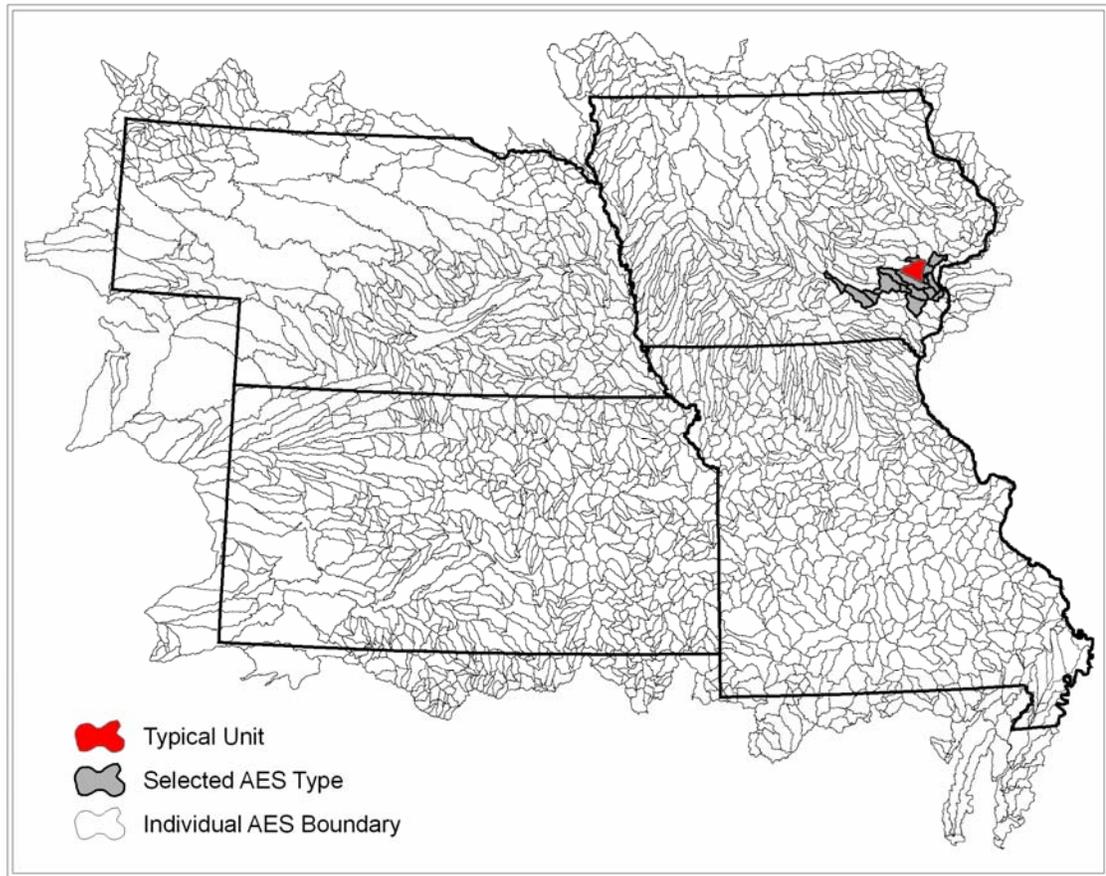


### **Description:**

This AES-Type comprises a large portion of western Kansas within the USFS's South Ogallala High Plains and Sand Hill – Ogolla Plateau Ecological Subsections. Local relief is most often less than 15 meters, although some areas are as high as 30 meters. Soil surface textures are primarily silt loams, but small amounts of sand, sandy loam, and clay loam also exist. Soils in this Type exhibit primarily moderate infiltration rates, but there are areas with both high and slow infiltration rates as well. Rock fragment volume in these soils is generally less than 10%. The combined headwater and creek mean stream gradient is 8.1 meters per kilometer. Historic vegetation consisted of plains grasslands and prairie.

**Typical Unit:** 853 – South Ladder Creek

## AES-Type 69 (Goose Creek)

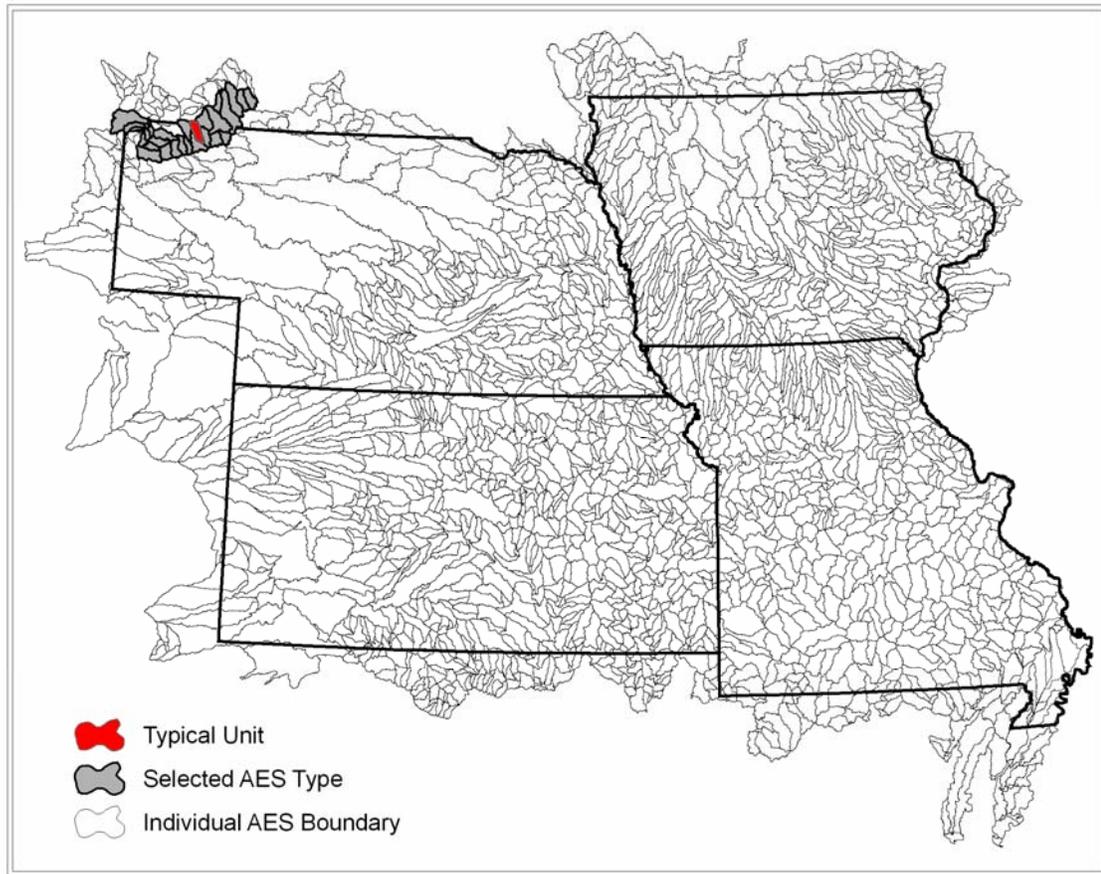


### **Description:**

This AES-Type is located in southeast Iowa mostly within the USFS's Southeast Iowa Rolling Loess Hills Ecological Subsection. A number of watersheds are included within this Type including the lower portion of the Iowa River and Crooked Creek among others. Local relief is generally less than 30 meters, although occasionally more. Soil surface textures are comprised of silty clay loams and silty loams with lesser parts of sand. These soils exhibit moderate infiltration rates overall. Rock fragment volume in these soils is generally less than 10%. The combined headwater and creek mean stream gradient is 6.0 meters per kilometer. Historic vegetation consisted of a mosaic of bluestem prairie and oak-hickory forest with more oak-hickory along the streams.

**Typical Unit:** 1123 – Goose Creek

## AES-Type 70 (Alkali Creek)

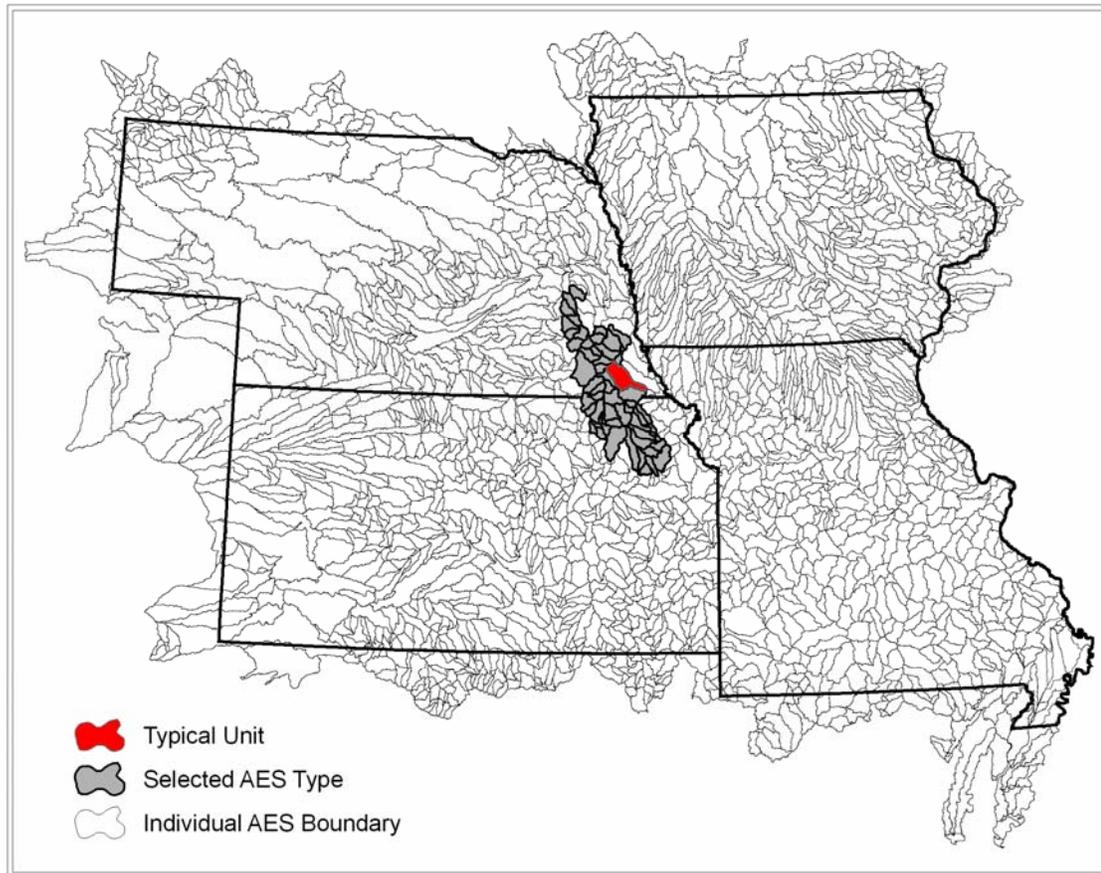


### **Description:**

This AES-Type is located in northwest Nebraska and southwest South Dakota and encompasses much of the USFS's Pine Ridge Escarpment Ecological Subsection. Many of the north flowing tributaries to the White River are contained within this Type. This area is much more rugged than adjacent areas to the south. Local relief is mostly between 16 and 60 meters. Soil surface textures are variable, but consist mainly of silt loams, loams, and silty clay. These soils exhibit vary slow to moderate infiltration rates. Rock fragment volume in these soils is generally less than 10%, while depth to bedrock can be less than 90 centimeters in places. The combined headwater and creek mean stream gradient is 16.5 meters per kilometer. Coldwater streams are an important component of this AES-Type. Historic vegetation consisted of plains grasslands with pine forests located in the uplands.

**Typical Unit:** 1628 – Alkali Creek

## AES-Type 71 (Badger Branch)

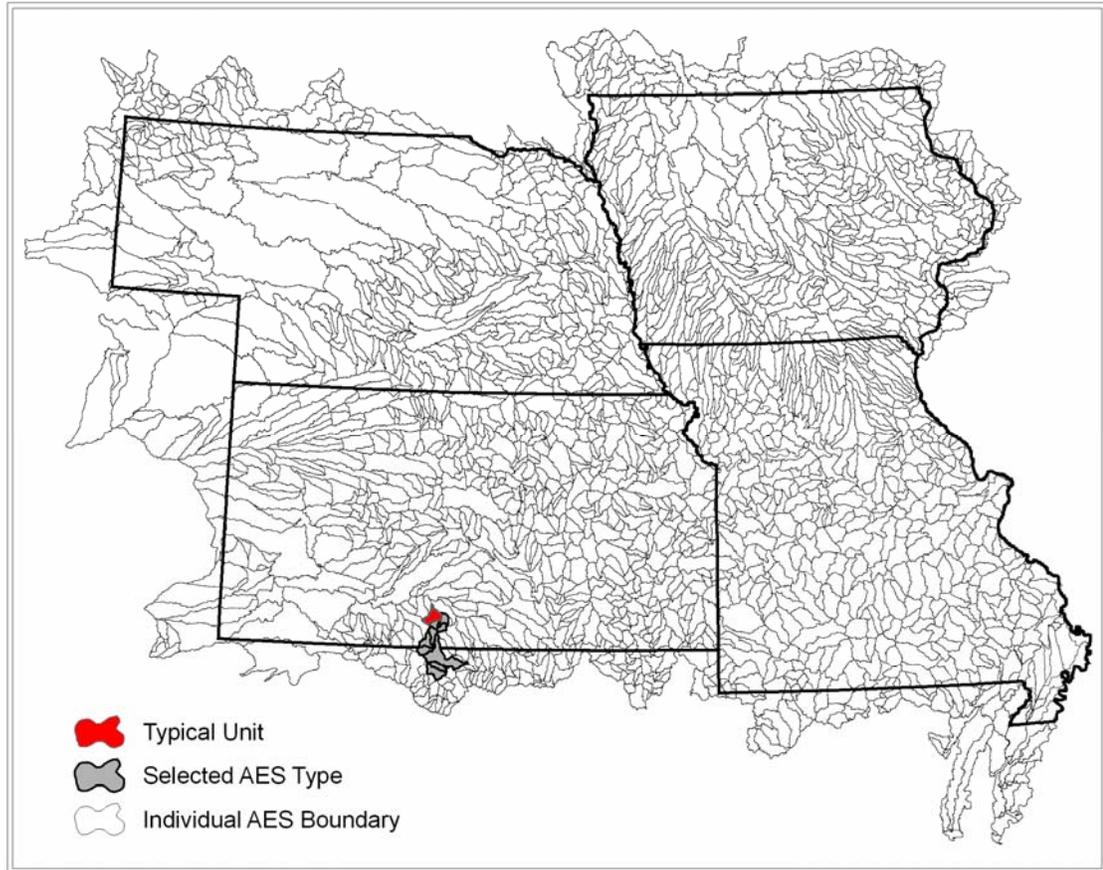


### **Description:**

This AES-Type runs in a wide belt that roughly parallels, although is not immediately adjacent to, the Missouri River in eastern Kansas and Nebraska. This Type encompasses a majority of the USFS's Pawnee-City-Seneca Rolling Hills Ecological Subsection. Local relief is concentrated between 16 and 40 meters. Soil surface textures consist mainly of clay loams, but also silty clay loams and silt loams. Overall these soils exhibit very slow to moderate infiltration rates. Rock fragment volume in these soils is generally less than 10%. The combined headwater and creek mean stream gradient is 9.1 meters per kilometer. Historic vegetation consisted of prairie and mosaics of bluestem prairie and oak-hickory forest.

**Typical Unit:** 658 – Badger Branch

## AES-Type 72 (Mulberry Creek)

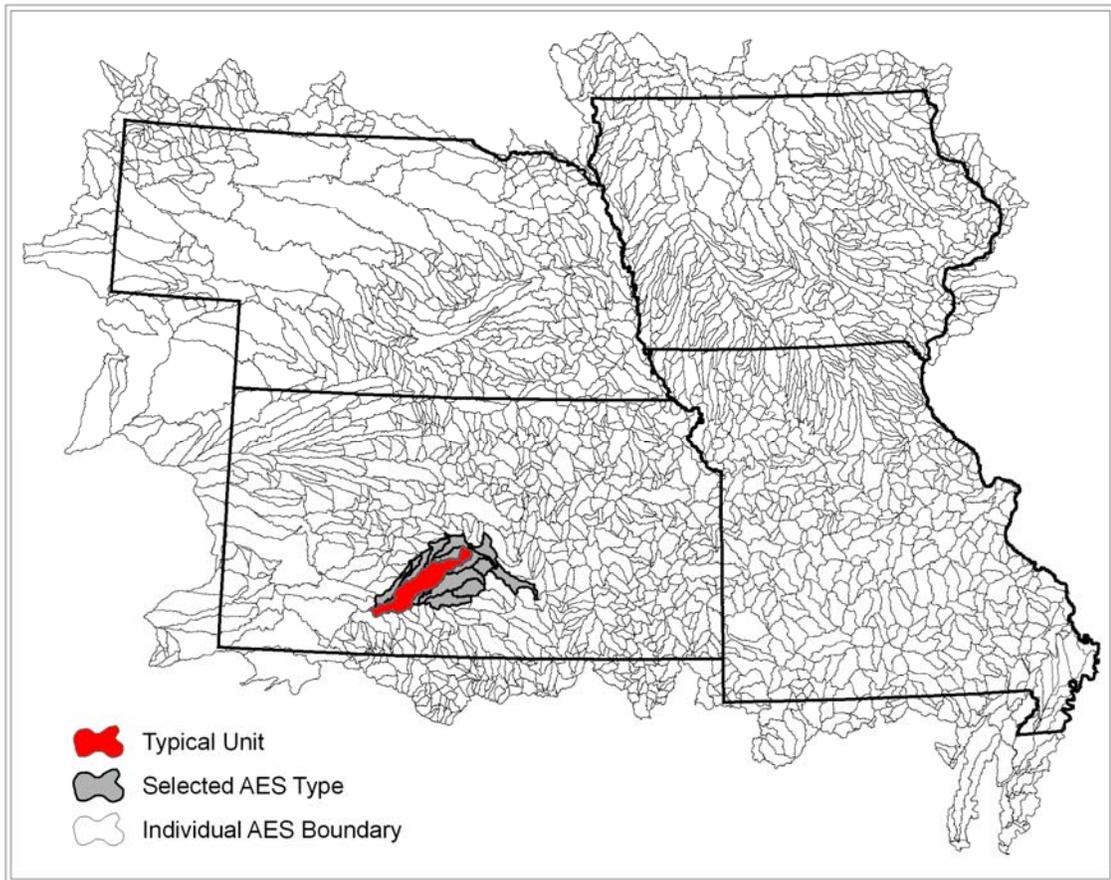


### **Description:**

This AES-Type straddles the Kansas Oklahoma border in south central Kansas and includes portions of the Salt Fork Arkansas River, Medicine Lodge River and Eagle Chief Creek watersheds. Local relief is generally between 15 and 60 meters. Soil surface textures are varied and consist, in decreasing amounts, of clay loam, sand, loam, and sandy loam. These soils exhibit a wide range of infiltration rates from very slow to high. Rock fragment volume in these soils can be as much as 20%, while depth to bedrock can be less than 120 centimeters in places. The combined headwater and creek mean stream gradient is 9.4 meters per kilometer. Historic vegetation consisted of plains grassland and prairie.

**Typical Unit:** 744 – Mulberry Creek

## AES-Type 73 (Rattlesnake Creek)

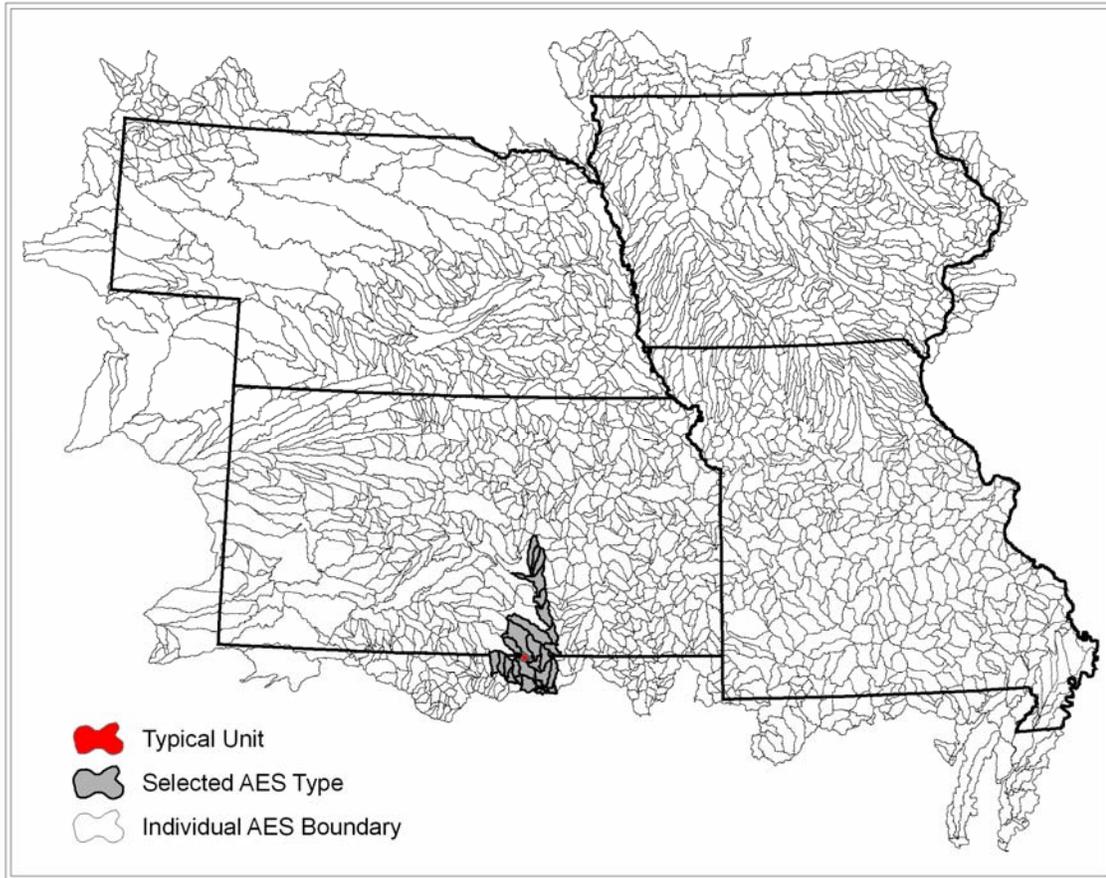


### **Description:**

This AES-Type corresponds very closely with the USFS's Eastern Arkansas River Lowlands Ecological Subsection and encompasses the entire Rattlesnake Creek drainage and other adjacent watersheds. Local relief is generally less than 15 meters. Soil surface textures consist primarily of sandy loams, sand, and silt loams. These soils exhibit moderate to high infiltration rates. Rock fragment volume in these soils is generally less than 10%. The combined headwater and creek mean stream gradient is 3.6 meters per kilometer. Historic vegetation in this area was prairie.

**Typical Unit:** 290 – Rattlesnake Creek

## AES-Type 74 (Lower Bluff Creek)

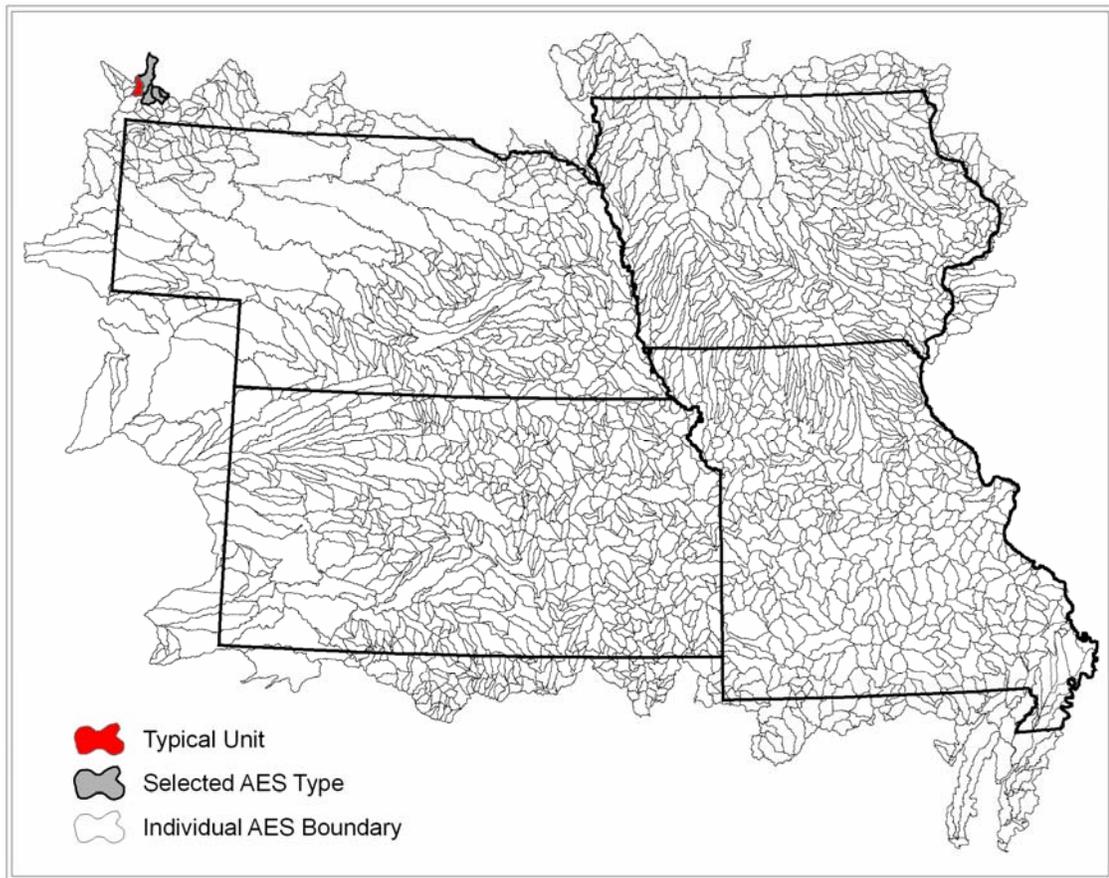


### **Description:**

This AES-Type incorporates a portion of the Arkansas River within the southern portion of the USFS's Smokey Hills Ecological Subsection as well as portions of the USFS's Central Red Rolling Prairies and Eastern South Central and Red Bed Plains Ecological Subsections. Overall, local relief is generally less than 15 meters. Soil surface textures consist of silt loams and silty clay loams that exhibit very slow and moderate infiltration rates. Rock fragment volume in these soils is generally less than 10%. The combined headwater and creek mean stream gradient is 4.3 meters per kilometer. Historic vegetation consisted of plains grasslands.

**Typical Unit:** 733 – Lower Bluff Creek

## AES-Type 75 (Driftwood Creek)

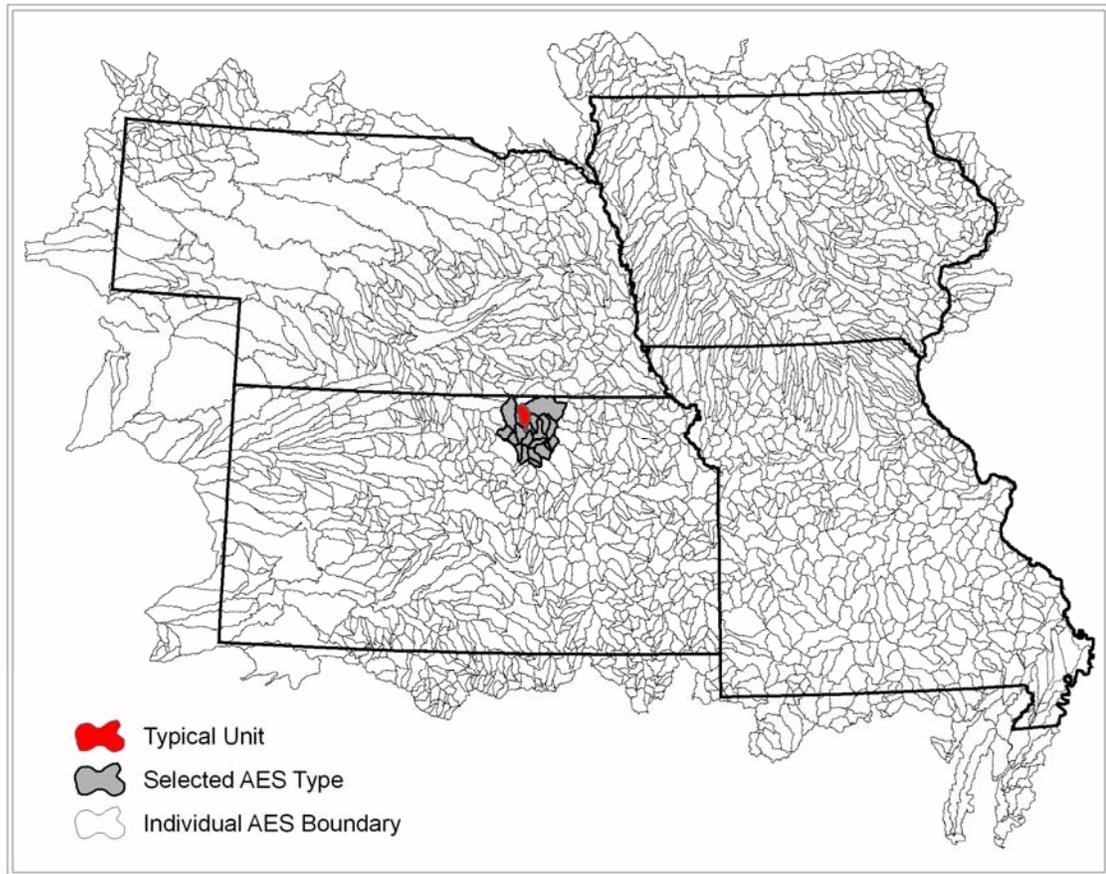


### **Description:**

This AES-Type is located in southwest South Dakota, and encompasses a portion of the USFS's Black Hills Foothills Ecological Subsection and contains a portion of the Cheyenne River. Local relief is also very diverse and can be as high as 152 meters or more. Geologic materials consist of sandy shale and sandstones. Soil surface textures are rather varied and consist in decreasing amounts of sandy loam, loamy sand, loam, and silt loams. These soils exhibit equally varied infiltration rates including moderate, very slow, and high. Rock fragment volume in these soils can be as high as 40%. Bedrock depth is variable, and bedrock can occasionally be exposed at the surface. The combined headwater and creek mean stream gradient is 27.6 meters per kilometer. Historic vegetation consisted of plains grasslands and pine forests.

**Typical Unit:** 1360 – Driftwood Creek

## AES-Type 76 (Riley Creek)

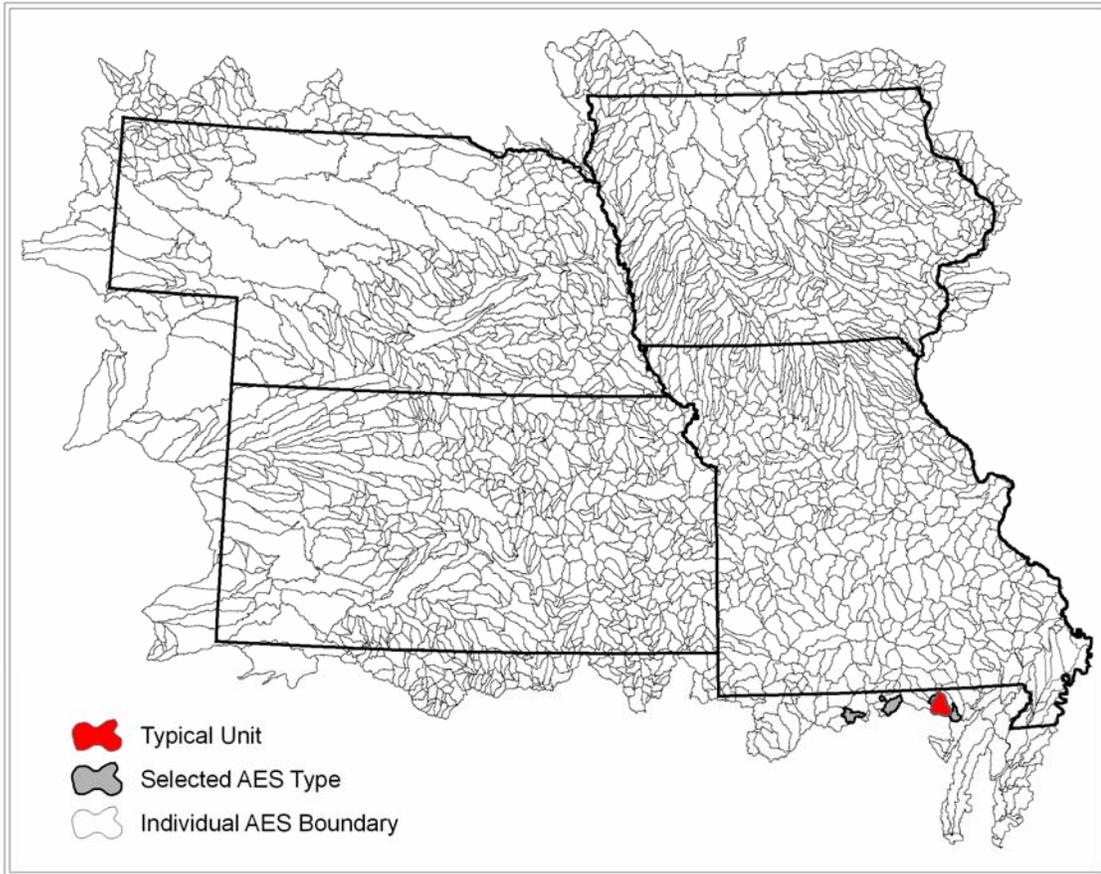


### **Description:**

This AES-Type is largely encompassed by a portion of the USFS's Eastern Sand Sage-Mixed Prairie Ecological Subsection in north central Kansas. A substantial portion of the Republican River drainage can be found in this Type. Local relief is generally less than 60 meters. Soil surface textures consist of silty clay loams, silt loams, and sandy loams to a lesser degree. These soils exhibit moderate to slow infiltration rates overall. Rock fragment volume in these soils is generally less than 10%. The combined headwater and creek mean stream gradient is 6.7 meters per kilometer. Historic vegetation consisted of plains grasslands and prairie.

**Typical Unit:** 627 – Riley Creek

## AES-Type 77 (Martins Creek)

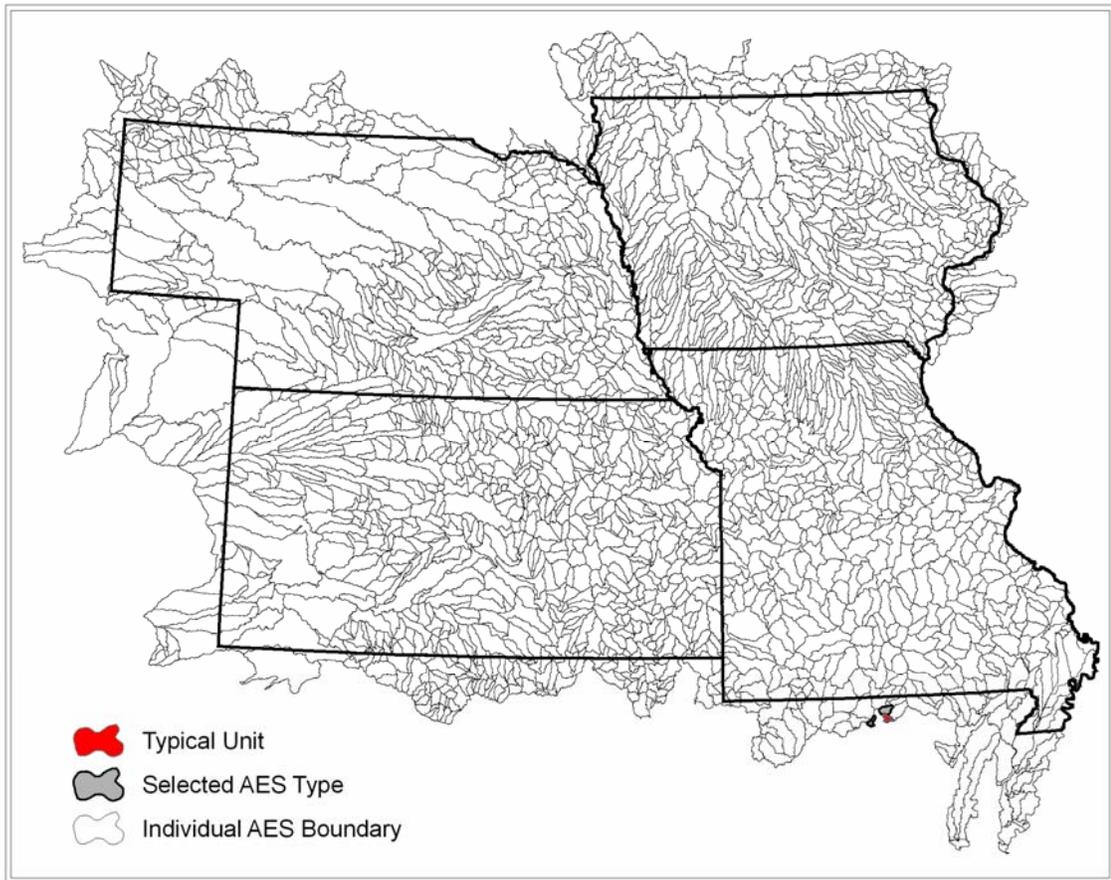


### **Description:**

This AES-Type is scattered just south of Missouri's border in northern Arkansas and contains portions of Crooked Creek and the Spring River and a few other minor drainages. Local relief is fairly high with most relief centered between 30 and 90 meters. Soil surface textures are primarily silt loams with some sandy loams. These soils exhibit moderate to slow infiltration rates. Rock fragment volume in these soils is generally between 20% and 60%. The combined headwater and creek mean stream gradient is 16.6 meters per kilometer. Historic vegetation consisted of oak-hickory and oak-pine forest with lesser amounts of prairie.

**Typical Unit:** 191 – Martins Creek

## AES-Type 78 (Otter Creek)

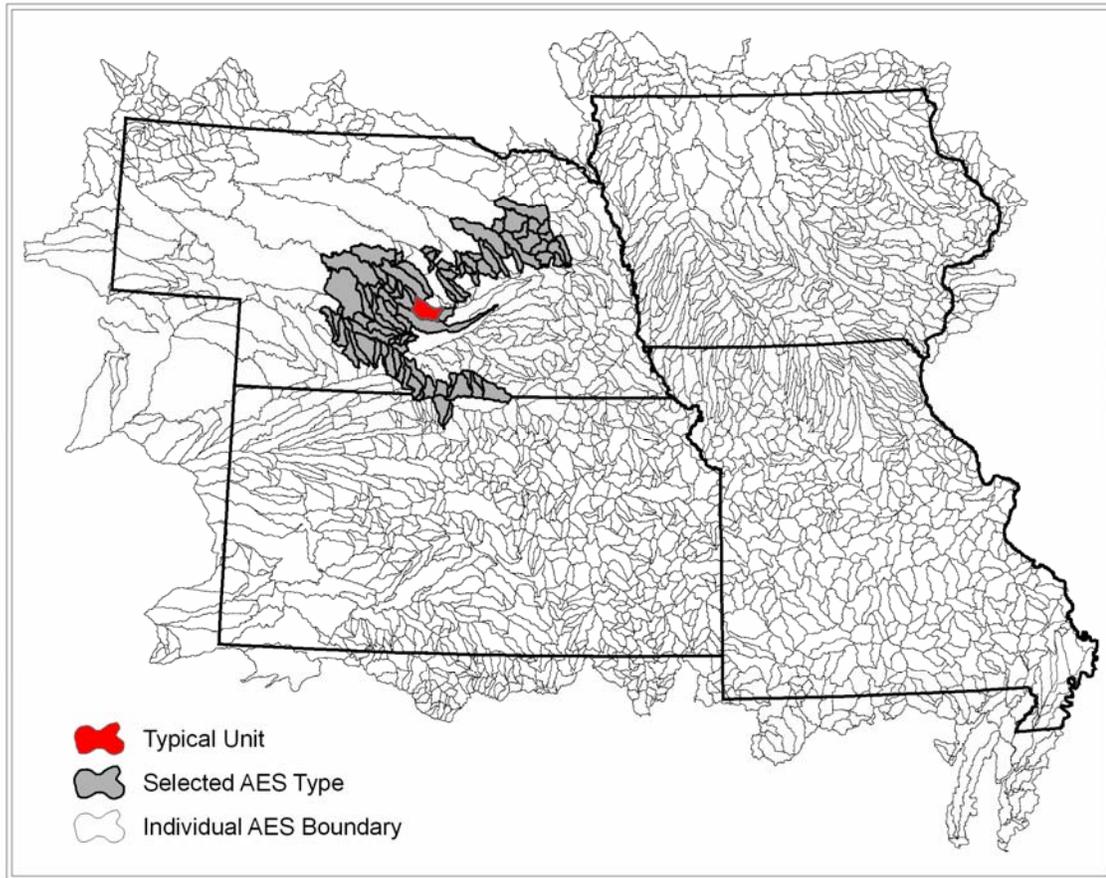


### **Description:**

This AES-Type is located just south of the Missouri border in northern Arkansas and incorporates a small portion of the White and North Fork Rivers within the USFS's White River Hills Ecological Subsection. Local relief can be as high as 150 meters. Soil surface textures consist of silt loams and sandy loams. These soils exhibit slow to very slow infiltration rates. Rock fragment volume in these soils is generally between 20% and 60%, while depth to bedrock can be less than 90 centimeters in places. The combined headwater and creek mean stream gradient is 21.8 meters per kilometer. Historic vegetation consisted of oak-hickory forest. Looking at the entire watershed draining to this AES Type, soil textures, infiltration rates and local relief is much the same as the area contained solely in this Type.

**Typical Unit:** 1666 – Otter Creek

## AES-Type 79 (Swenson Creek)

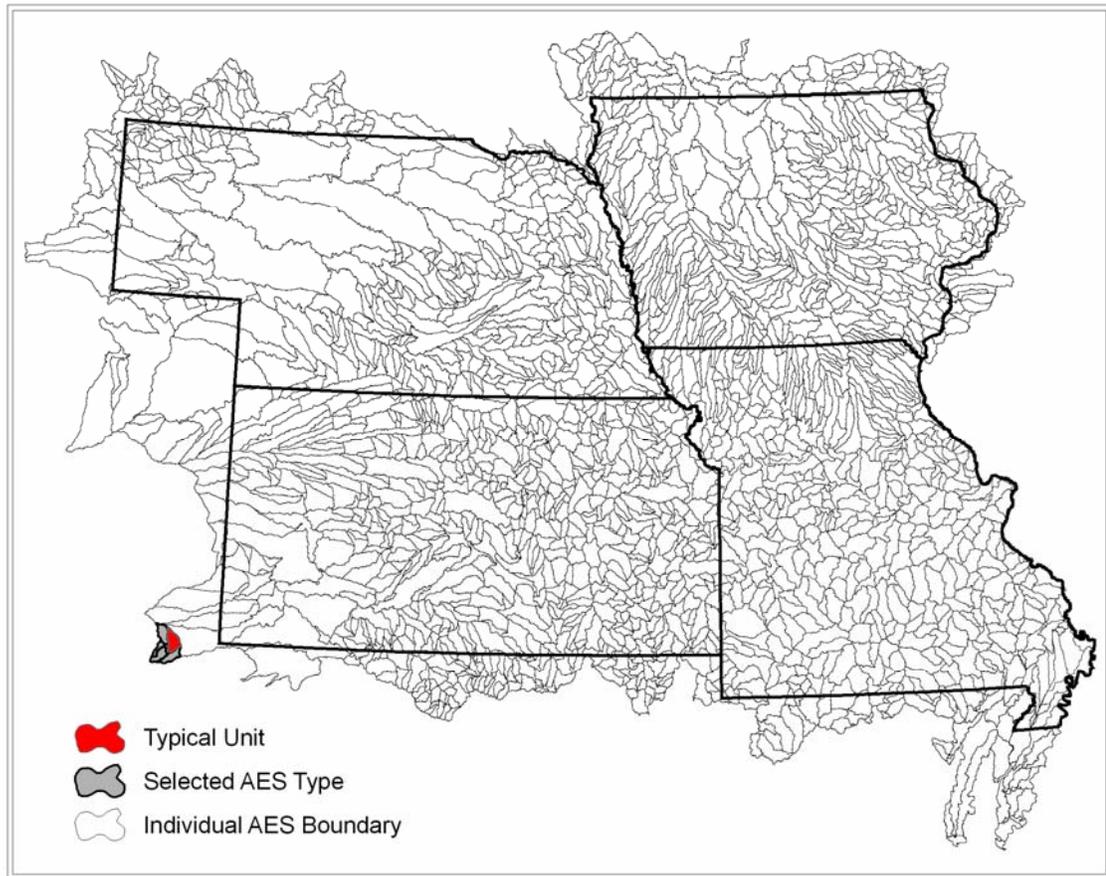


### **Description:**

This AES-Type encompasses a large portion of central Nebraska, most of which receives drainage from the Nebraska Sand Hills. A number of the USFS's Ecological Subsections are partially contained in this Type including portions of the Central Nebraska Loess Hills, the Central Platte Valley, the Western Loess and Till Plains, and a northern portion of the Smokey Hills. Local relief is generally less than 50 meters. Soil surface textures consist mainly of silt loams, with lesser parts of sand and sandy loam. These soils exhibit primarily moderate infiltration rates overall. Rock fragment volume in these soils is generally 0%. The combined headwater and creek mean stream gradient is 8.1 meters per kilometer. Historic vegetation consisted of plains grasslands and prairie.

**Typical Unit:** 1495 – Swenson Creek

## AES-Type 80 (Upper Cimarron River)

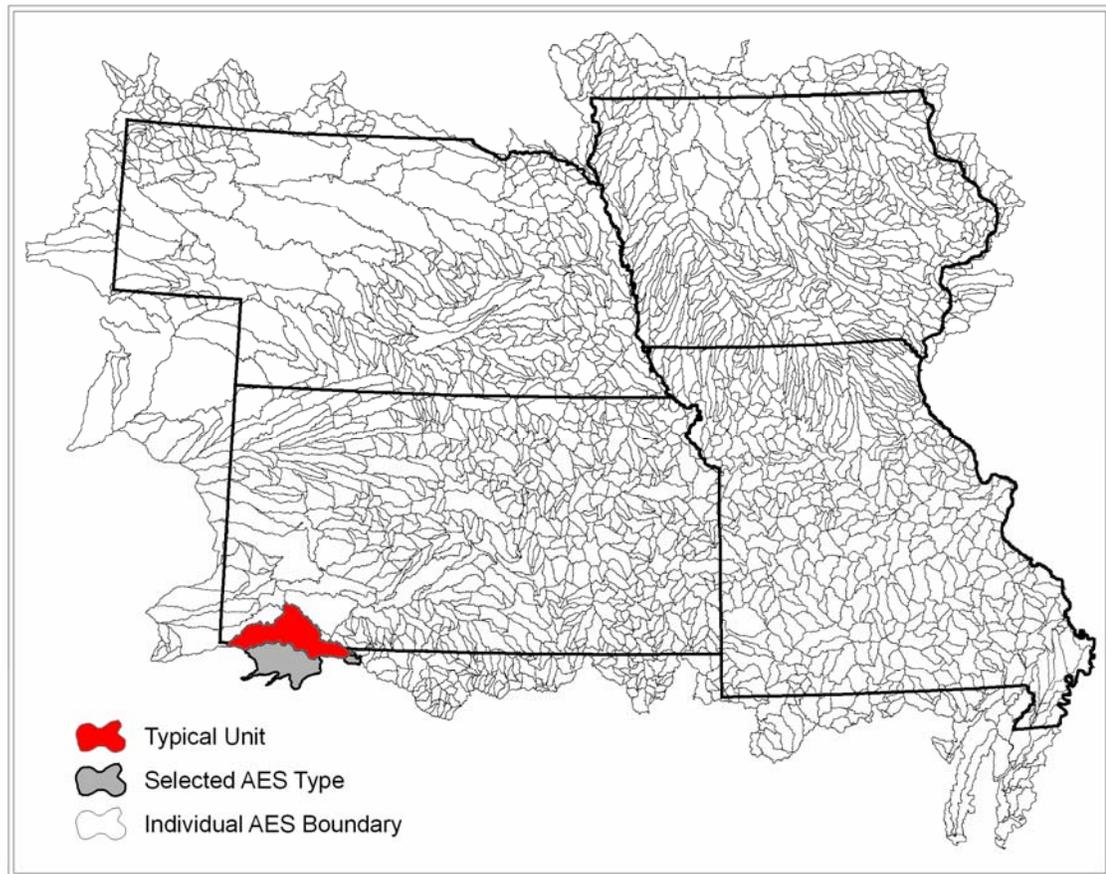


### **Description:**

This AES-Type is located in northwest Oklahoma and south-central Colorado mainly within the USFS's Tablelands-Red Hills Ecological Subsection of the Southern High Plains Ecological Section. The largest river flowing through this Type is the Cimarron River. Local relief is generally less than 60 meters. Soil surface textures consist almost exclusively of loams and to a lesser extent sandy loams. These soils exhibit moderate to very slow infiltration rates overall. Rock fragment volume in these soils is varied between 20% and 40% or less than 10%. Depth to bedrock can be under 60 centimeters. The combined headwater and creek mean stream gradient is 14.8 meters per kilometer. Historic vegetation consisted of juniper and pinyon with plains grasslands in the uplands.

**Typical Unit:** 491 – Upper Cimarron River

## AES-Type 81 (Taintor Creek)

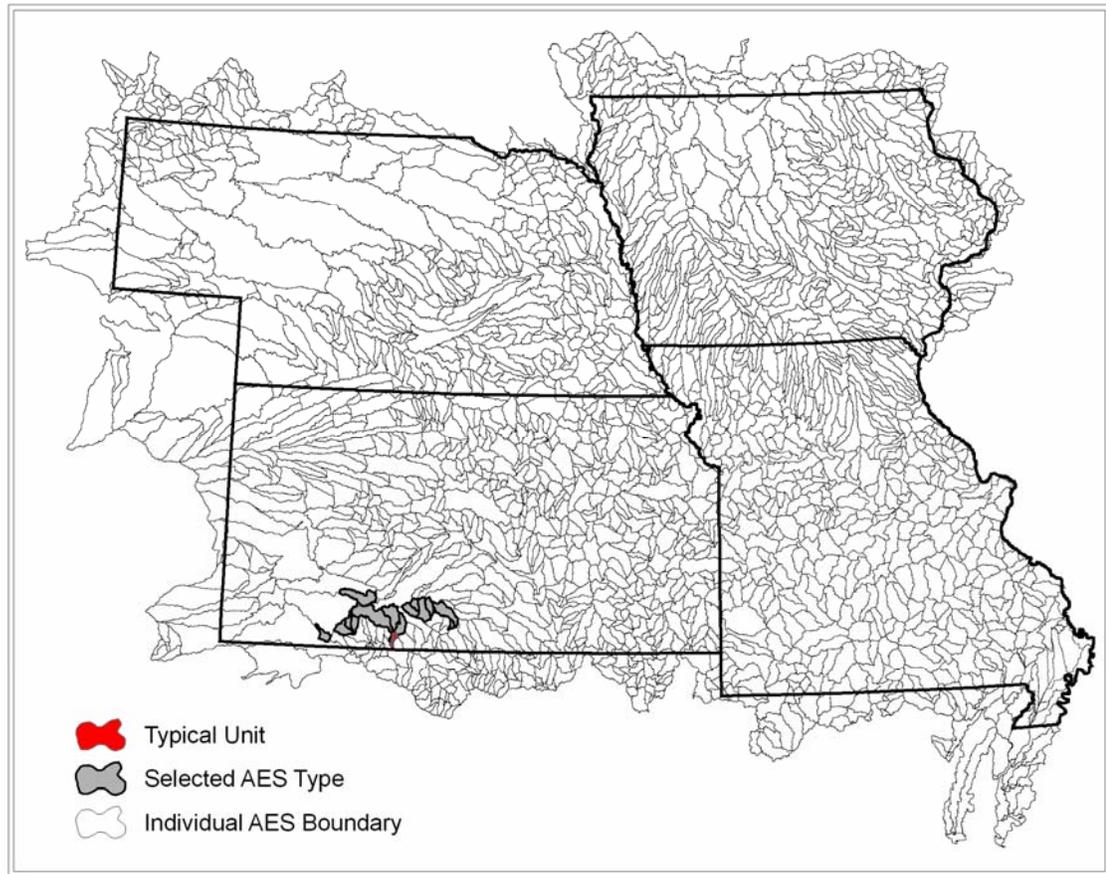


### **Description:**

This AES-Type is located in southwest Kansas and northern Oklahoma mainly within the USFS's Sandy-Smooth High Plains and Canadian-Cimarron Breaks Ecological Subsections. Although the Cimarron River flows through this Type much of the area is nearly devoid of streams. Local relief is typically less than 30 meters with most less than 15. Soil surface textures are varied within this Type and consist of silt loams, sandy loams, sand, and silty clay loams. Overall these soils exhibit moderate infiltration rates. Rock fragment volume in these soils is generally less than 10%. The combined headwater and creek mean stream gradient is 10.9 meters per kilometer. Historic vegetation consisted of prairie and plains grasslands.

**Typical Unit:** 517 – Taintor Creek

## AES-Type 82 (Lower Kiowa Creek)

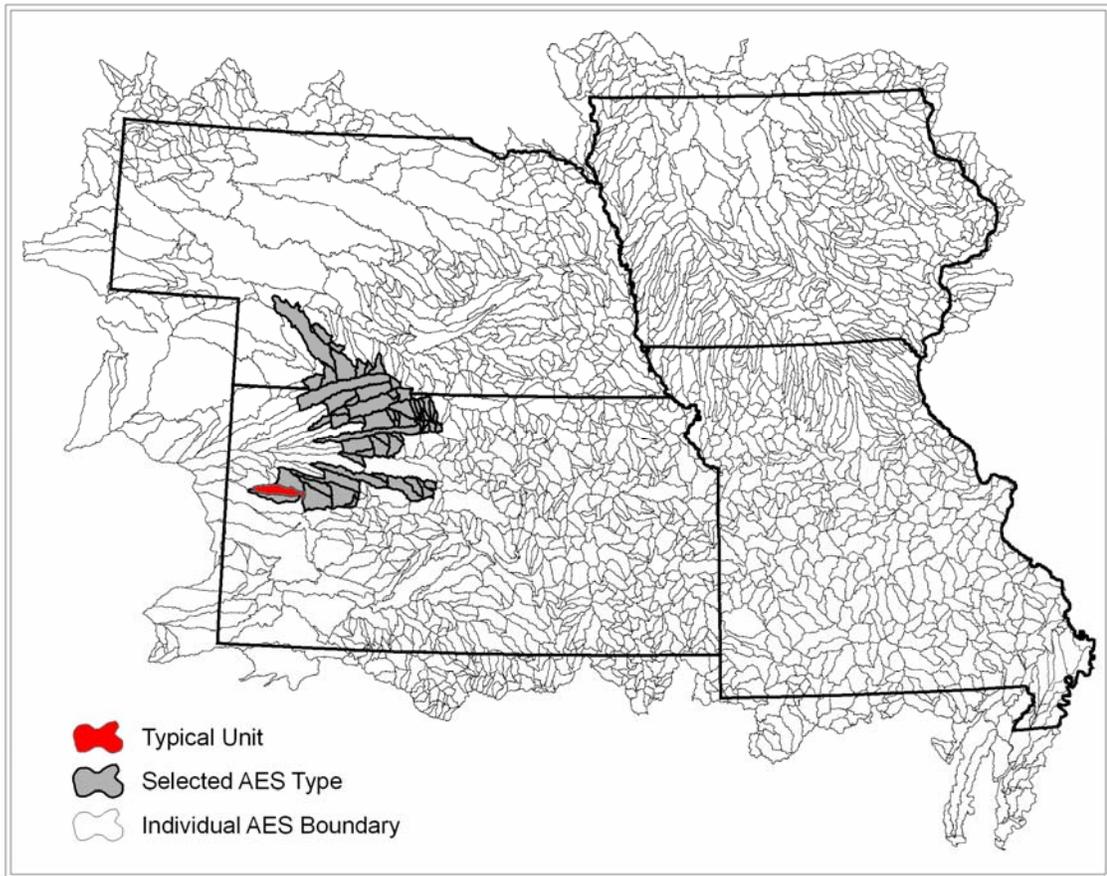


### **Description:**

This AES-Type is located in south-central Kansas primarily within the USFS's Smoky Hills and Northern South Central Red Bed Plains Ecological Subsections. Some of the major drainages included within this Type are portions of Bluff Creek, Medicine Lodge River, and Mulberry Creek. These are transitional area watersheds that drain from the South-Central Great Plains to the South Central and Red Bed Plains Ecological Sections. Local relief is generally less than 15 meters, but can be as high as 40 meters or more. Soil surface textures consist of silt loams, sand, sandy loam, and lesser amounts of loam. These soils exhibit mainly moderate and high infiltration rates. Rock fragment volume in these soils is generally less than 10%. The combined headwater and creek mean stream gradient is 8.9 meters per kilometer. Historic vegetation consisted of plains grasslands.

**Typical Unit:** 503 – Lower Kiowa Creek

## AES-Type 83 (Twin Butte Creek)

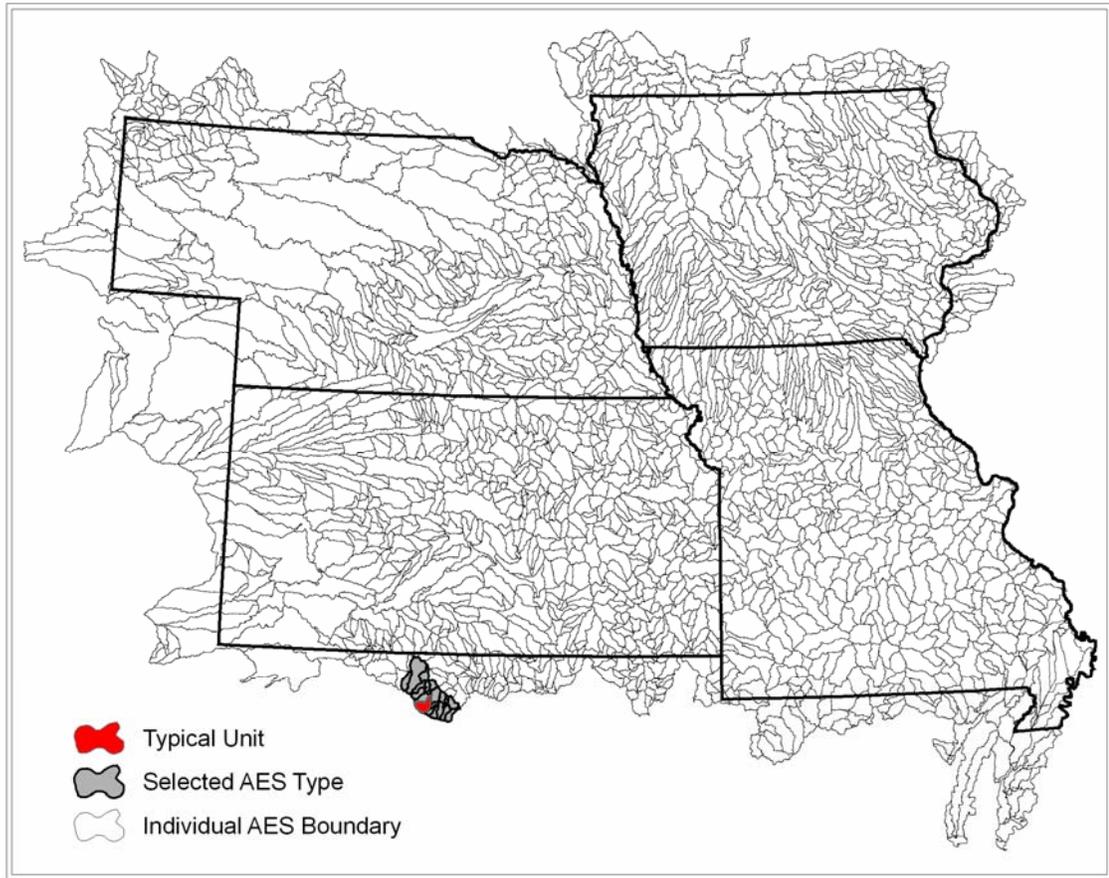


### **Description:**

This AES-Type comprises a large area in west-central Kansas and Nebraska mainly within the USFS's Smokey Hills Ecological Subsection. Many streams and drainages are located in this Type and include the Republican River, North Fork Solomon River, and Smoky Hill River. Local relief is generally less than 40 meters. Soil surface textures are mostly silt loams with moderate infiltration rates. Rock fragment volume in these soils is generally less than 10%. The combined headwater and creek mean stream gradient is 9.4 meters per kilometer. Historic vegetation consisted of plains grasslands.

**Typical Unit:** 851 – Twin Butte Creek

## AES-Type 84 (Main Creek)

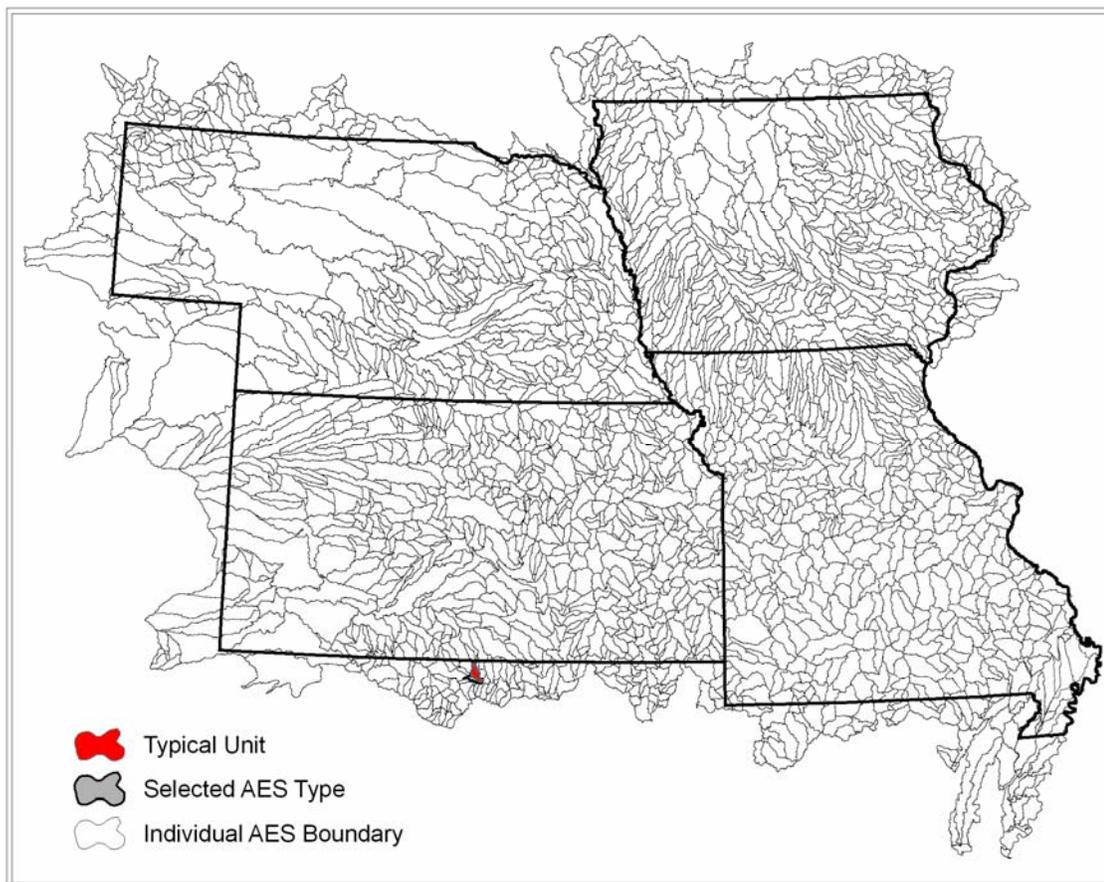


### **Description:**

This AES-Type is exclusive to the Cimarron River in north-central Oklahoma and contains portions of the USFS's Canadian River Dune Belt and Southern South Central and Red Bed Plains Ecological Subsections. Local relief is less than 60 meters. Soil surface textures are somewhat varied and consist of sand, clay loam, and loam. These soils also exhibit varied infiltration rates ranging from high to very slow. Rock fragment volume in these soils is generally less than 10%, while depth to bedrock can be less than 120 centimeters in places. The combined headwater and creek mean stream gradient is 11.0 meters per kilometer. Historic vegetation consisted mainly of plains grasslands with some prairie.

**Typical Unit:** 410 – Main Creek

## AES-Type 85 (Middle Salt Fork of the Arkansas River)

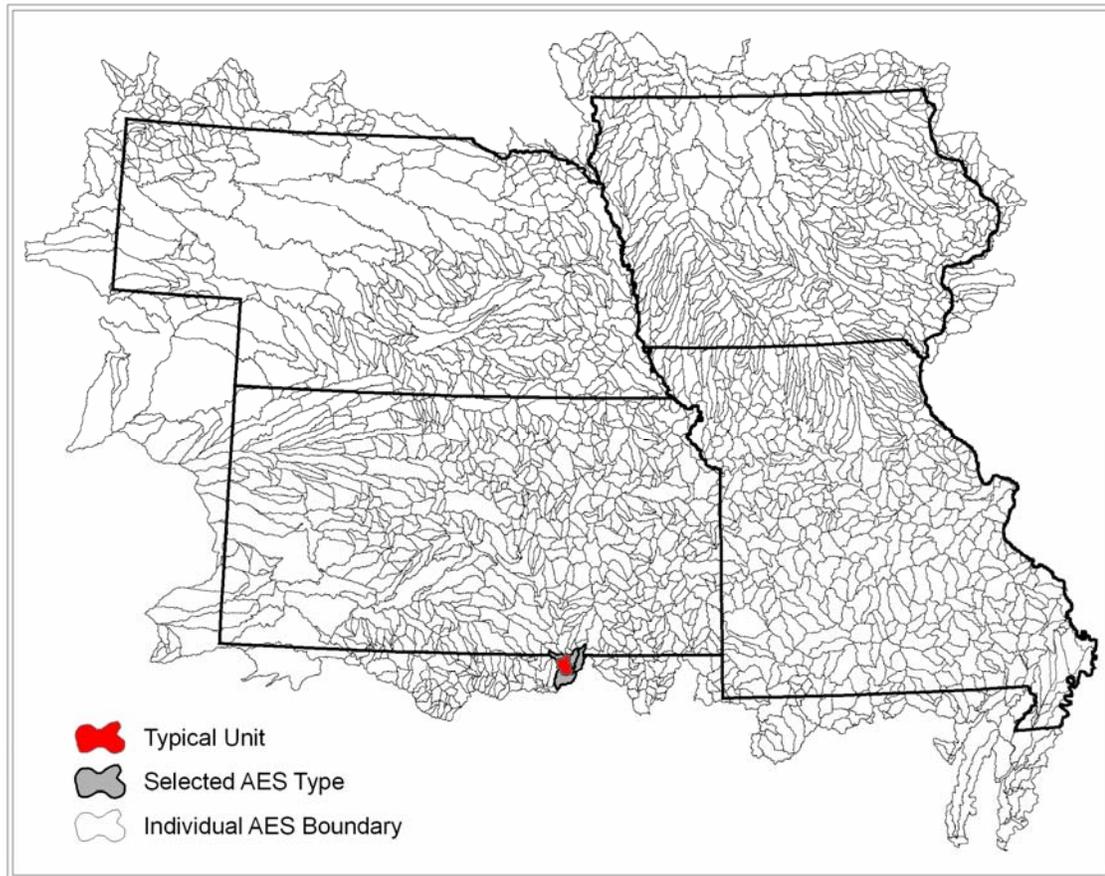


### **Description:**

This AES-Type has a relatively small geographic area located in northern Oklahoma just below the confluence of the Salt Fork of the Arkansas River and Driftwood Creek. This Type is encompassed in the USFS's Eastern South Central and Red Bed Plains Ecological Subsection. Local relief is almost exclusively less than 15 meters. Soil surface textures consist of sand, sandy loam, and silt loams. These soils exhibit varied infiltration rates ranging from high to very slow. Rock fragment volume in these soils is generally less than 10%. The combined headwater and creek mean stream gradient is 1.5 meters per kilometer. Historic vegetation consisted of plains grasslands. Considering the entire contributing area for this AES-Type soil textures consist of more loams and clay loams with moderate or very slow infiltration rates. In addition the local relief can be as high as 30 meters or more.

**Typical Unit:** 726 – Middle Salt Fork of the Arkansas River

## AES-Type 86 (Sweetwater Creek)

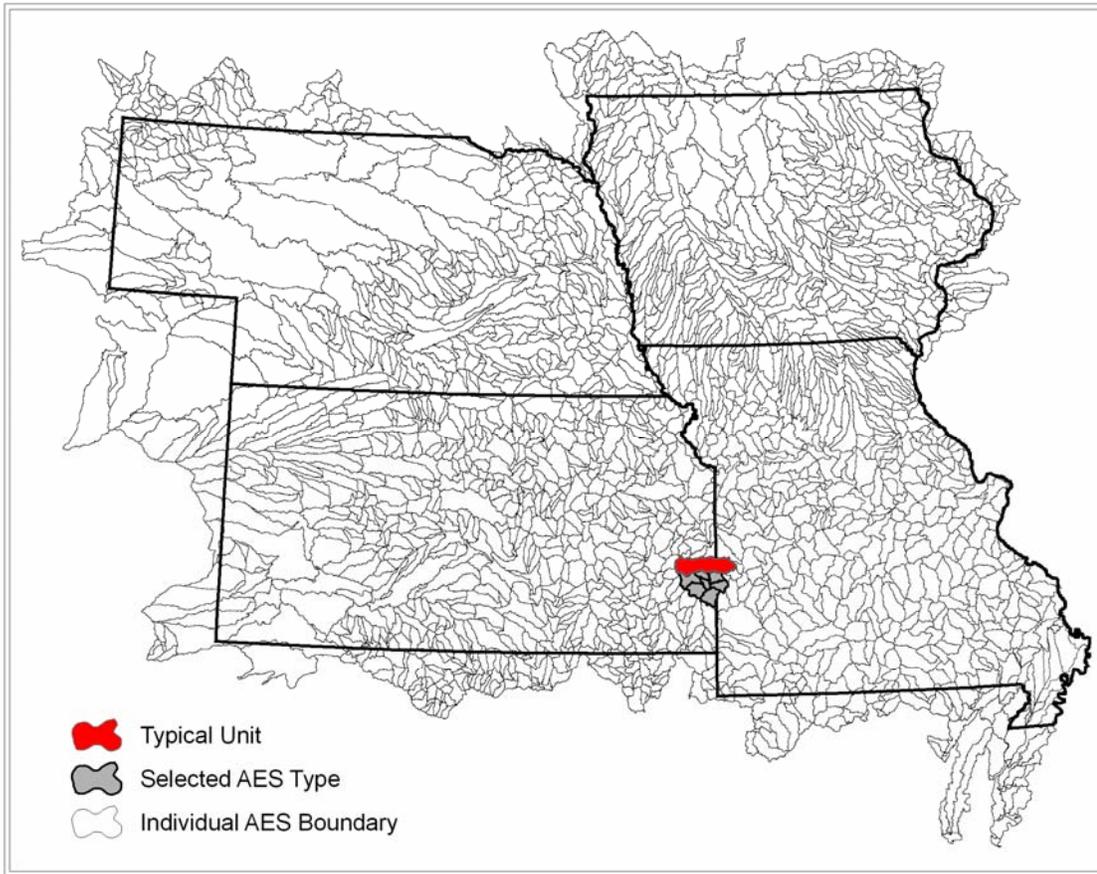


### **Description:**

This AES-Type is located on the northern Oklahoma border within the USFS's Eastern Flint Hills Ecological Subsection just below the confluence of the Arkansas River with Grouse Creek. Local relief is most often less than 40 meters. Soil surface textures are silty clay loams and silt loams with very slow and moderate infiltration rates respectively. Rock fragment volume in these soils is generally less than 10%, while depth to bedrock can be less than 120 centimeters in places. The combined headwater and creek mean stream gradient is 9.4 meters per kilometer. Historic vegetation consisted of prairie. Considering the entire drainage soil surface textures are silty clay loams and silt loams with moderate to slow infiltration rates. Local relief within the entire watershed can be as high as 60 meters.

**Typical Unit:** 430 – Sweetwater Creek

## AES-Type 87 (Pryor Creek)

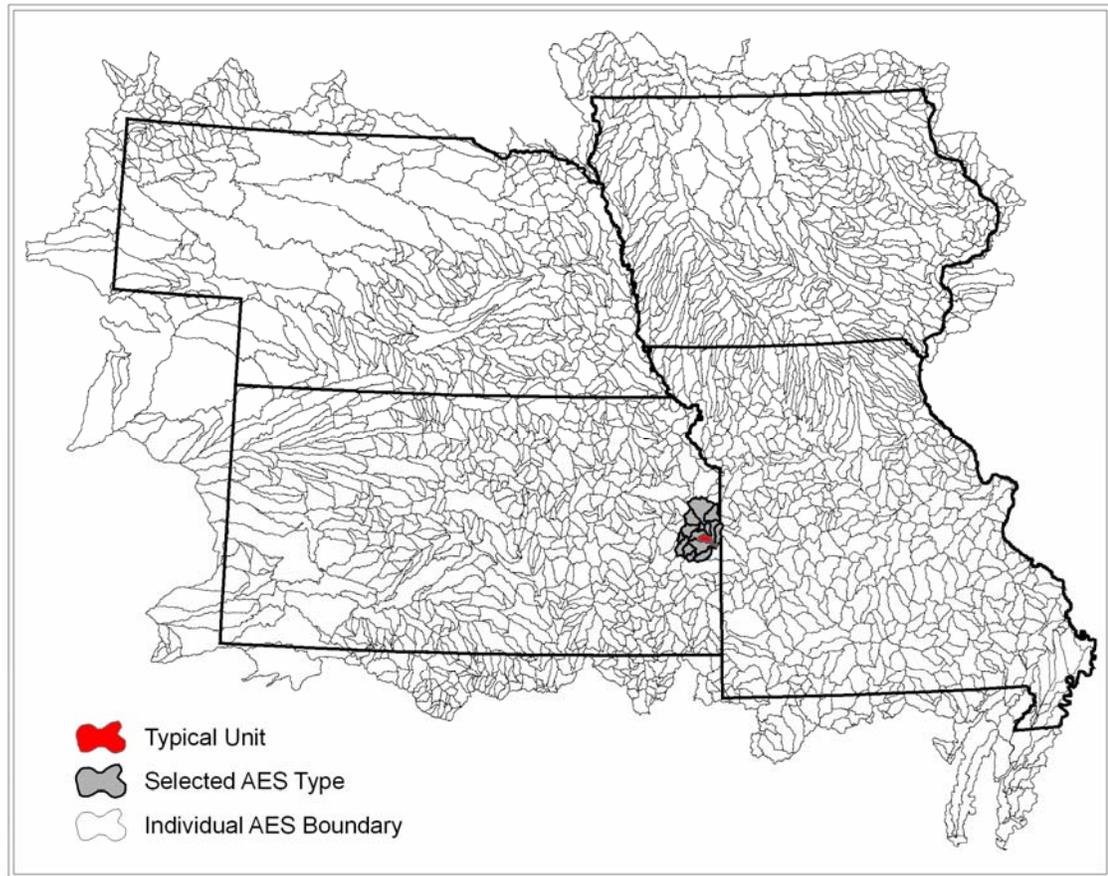


### **Description:**

This AES-Type consists of most of the Little Osage River drainage and much of the Upper Marmaton River drainage within Kansas and Missouri. Most of the upper portions of this watershed are in the USFS's Scarped Osage Plains Ecological Subsection with a lesser amount of the lower drainage in the Cherokee Plains Ecological Subsection. Local relief is concentrated between 15 and 30 meters. Soil surface textures consist of silt loams and silty clay very slow and slow infiltration rates. Rock fragment volume in these soils can approach 20%, while depth to bedrock can be less than 120 centimeters in places. The combined headwater and creek mean stream gradient is 7.1 meters per kilometer. Historic vegetation was quite mixed and consisted of mosaics of bluestem prairie and oak-hickory forest.

**Typical Unit:** 102 – Pryor Creek

## AES-Type 88 (Elm Creek)

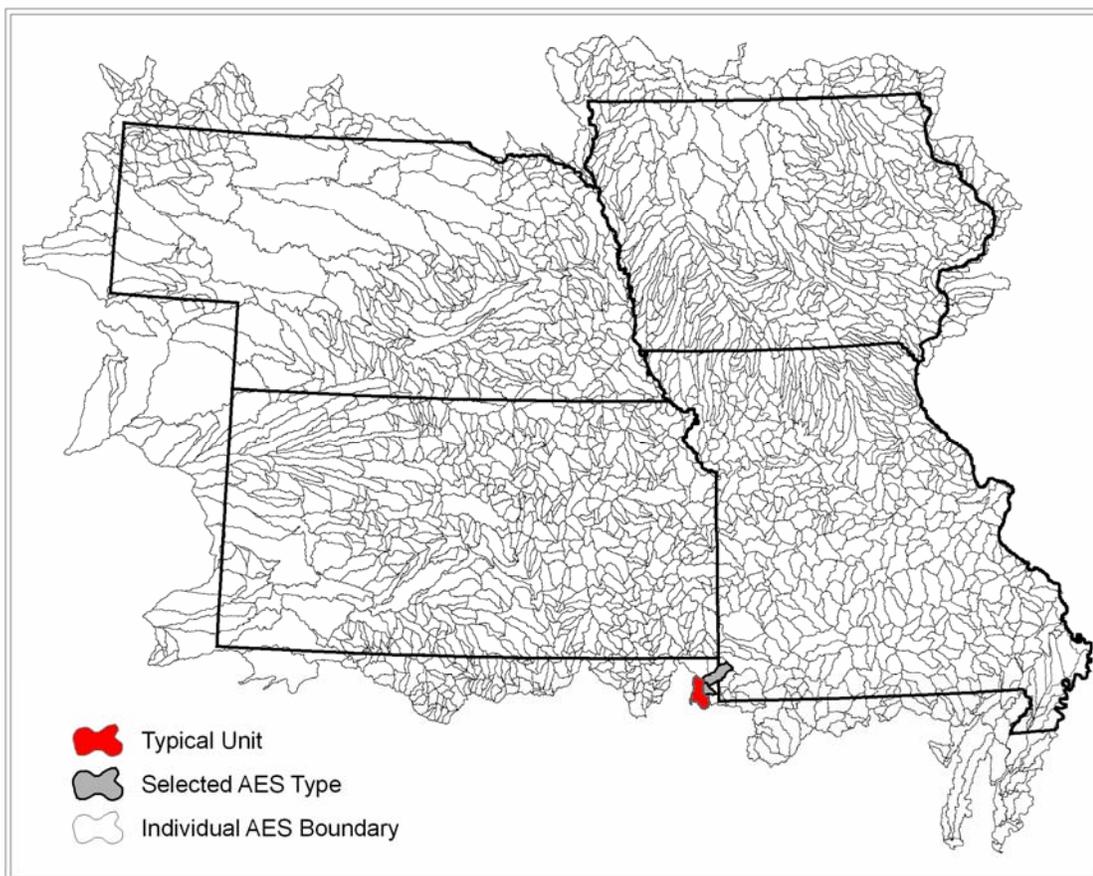


### **Description:**

This AES-Type contains a portion of the Marais des Cygnes River drainage in Kansas between Middle Creek and the Missouri state border. This Type is located entirely within the USFS's Scarped Osage Plains Ecological Subsection. Local relief is generally less than 50 meters. Soil surface textures are silty clay loams and silt loams with slow to very slow infiltration rates. Rock fragment volume in these soils is generally less than 10%, while depth to bedrock can be less than 120 centimeters in places. The combined headwater and creek mean stream gradient is 9.1 meters per kilometer. Historic vegetation consisted of mosaics of bluestem prairie and oak-hickory forest.

**Typical Unit:** 96 – Elm Creek

## AES-Type 89 (Drowning Creek)

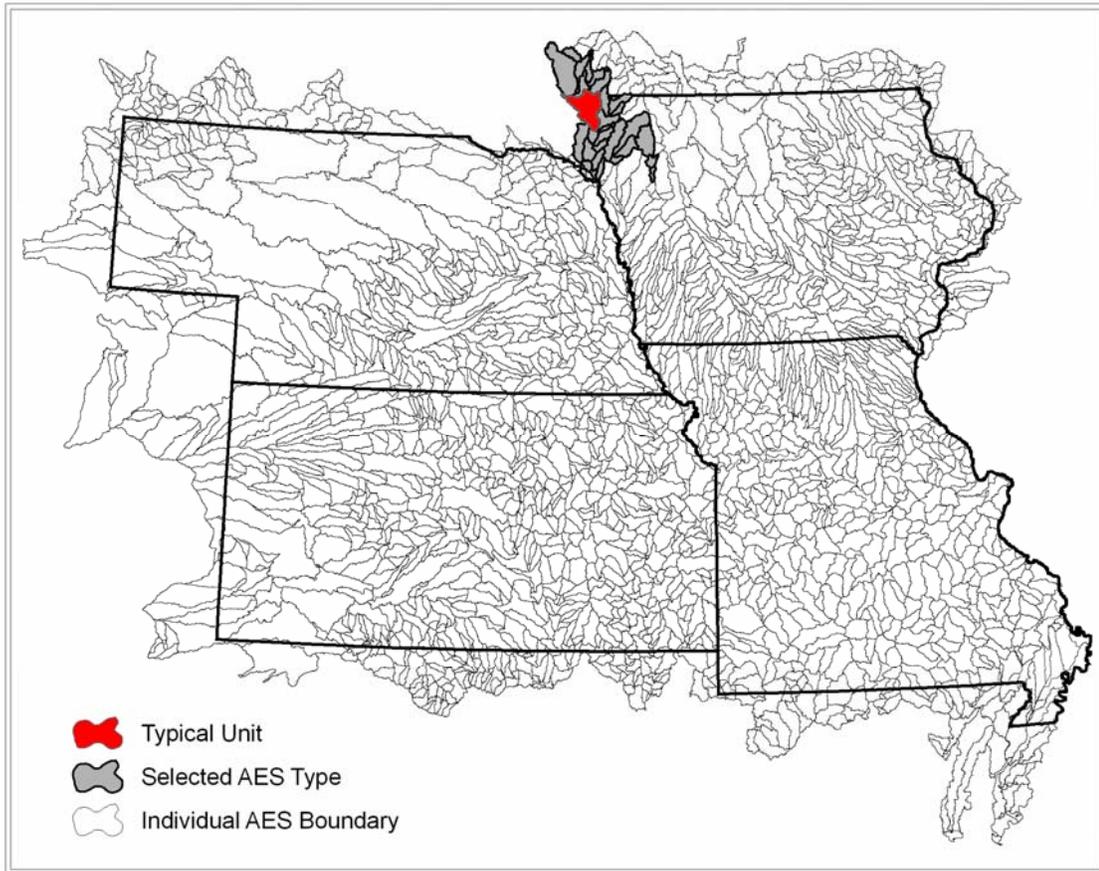


### **Description:**

This AES-Type contains a portion of the Neosho River drainage mainly within northeast Oklahoma and includes portions of both the USFS's Springfield Plain and Springfield Plateau Ecological Subsections. Local relief is generally less than 50 meters. Soil surface textures are primarily silt loams which exhibit moderate infiltration rates. Rock fragment volume in these soils is quite varied, but can be as much as 50%. The combined headwater and creek mean stream gradient is 9.2 meters per kilometer. Historic vegetation consisted of mosaics of bluestem prairie and oak-hickory forests. Considering the entire watershed above this AES-Type soil surface texture consists primarily of silt loam and silty clay loams with moderate to very slow infiltration rates. Local relief within this contributing area can be as high as 60 meters.

**Typical Unit:** 155 – Drowning Creek

## AES-Type 90 (Pattee Creek)

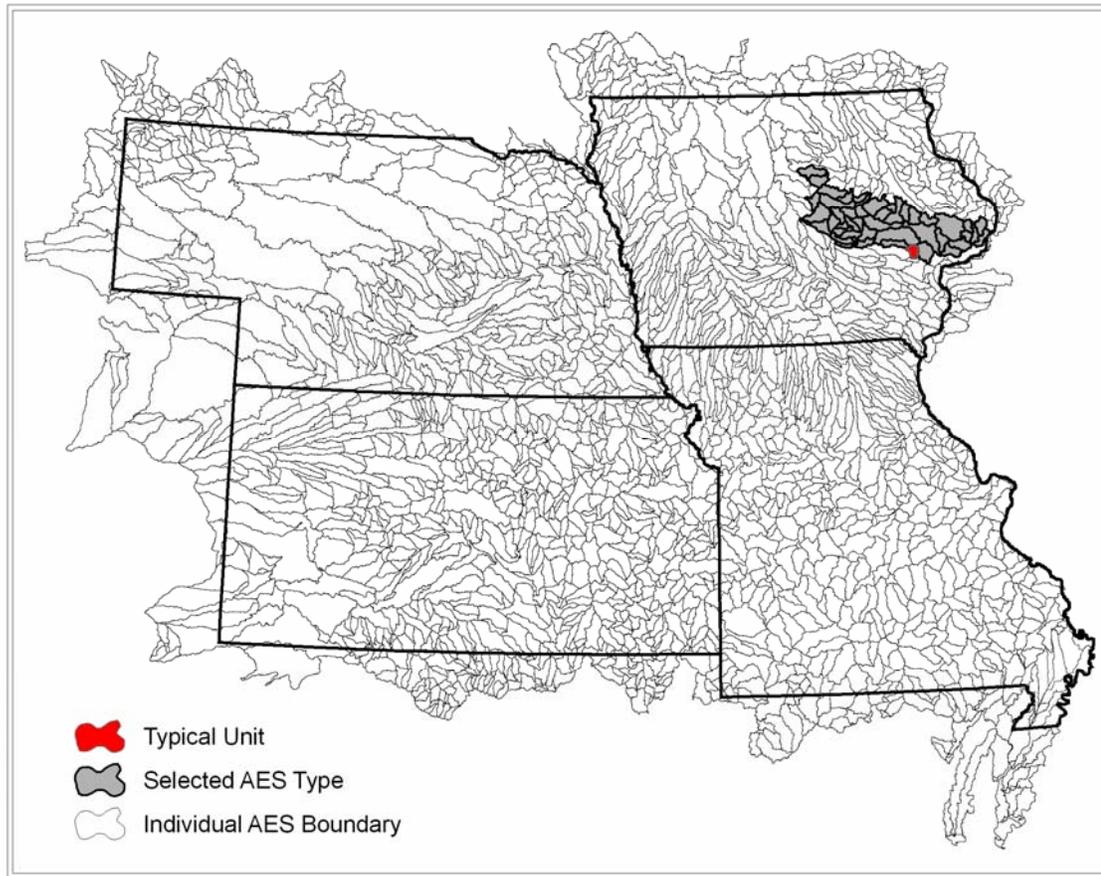


### **Description:**

This AES-Type is located in northwestern Iowa mainly within the USFS's Northwest Iowa Plains Ecological Subsection and incorporates much of the Big Sioux River drainage. Local relief is generally less than 30 meters. Soil surface textures are mainly silty clay loam and silt loams with moderate infiltration rates. Rock fragment volume in these soils is generally less than 10%. The combined headwater and creek mean stream gradient is 6.9 meters per kilometer. Historic vegetation consisted of prairie.

**Typical Unit:** 1004 – Pattee Creek

## AES-Type 91 (Snyder Creek)

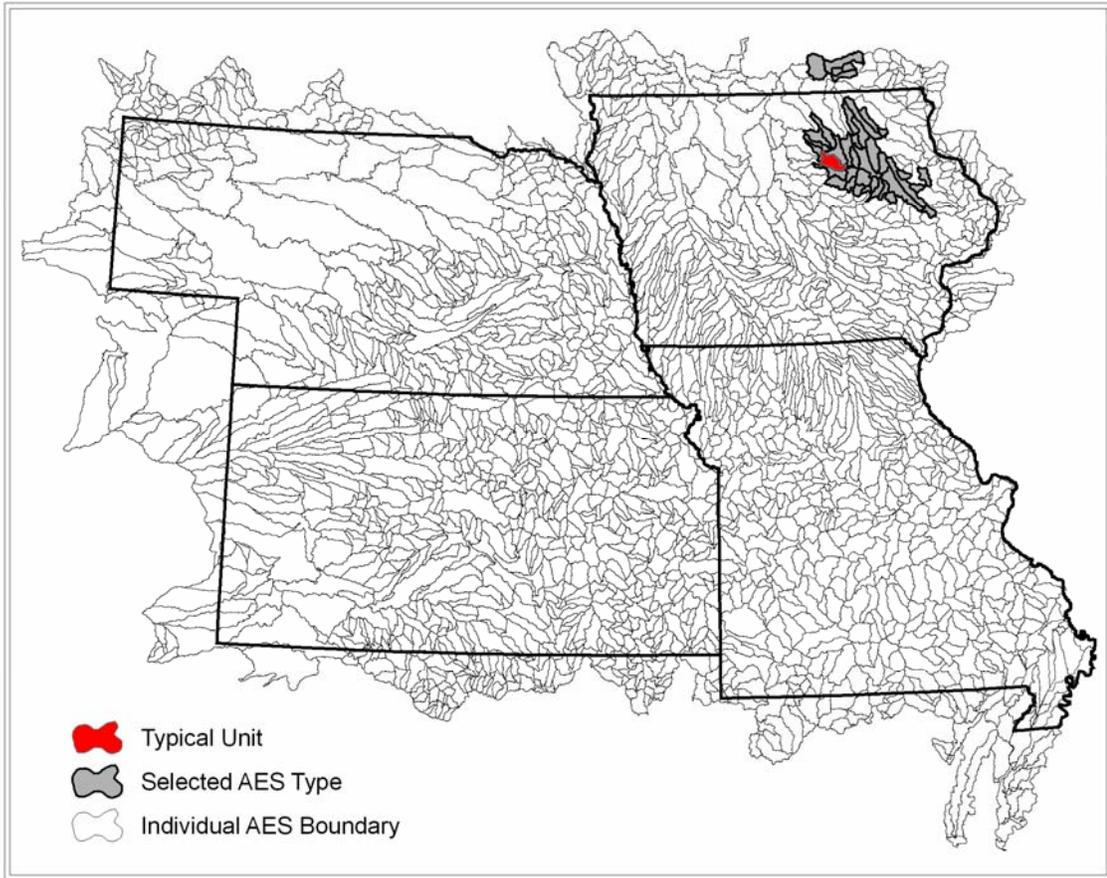


### **Description:**

This AES-Type is located in eastern Iowa and encompasses portions of the USFS's Southeast Iowa Rolling Loess Hills Ecological Subsection and lesser amounts of the Oak Savannah Till and Loess Plains Ecological Subsection. Three major river drainages that are partially included within this AES-Type are the Wapsipinicon River, Cedar River, and Iowa River. Local relief is mainly less than 30 meters, although occasionally more. Soil surface textures consist primarily of silty clay loams and, to a lesser degree, silt loam. These soils exhibit moderate infiltration rates. Rock fragment volume in these soils is generally less than 10%. The combined headwater and creek mean stream gradient is 6.5 meters per kilometer. Historic vegetation consisted mainly of mosaics of bluestem prairie and oak-hickory forests.

**Typical Unit:** 1115 – Snyder Creek

## AES-Type 92 (Kilson Creek)

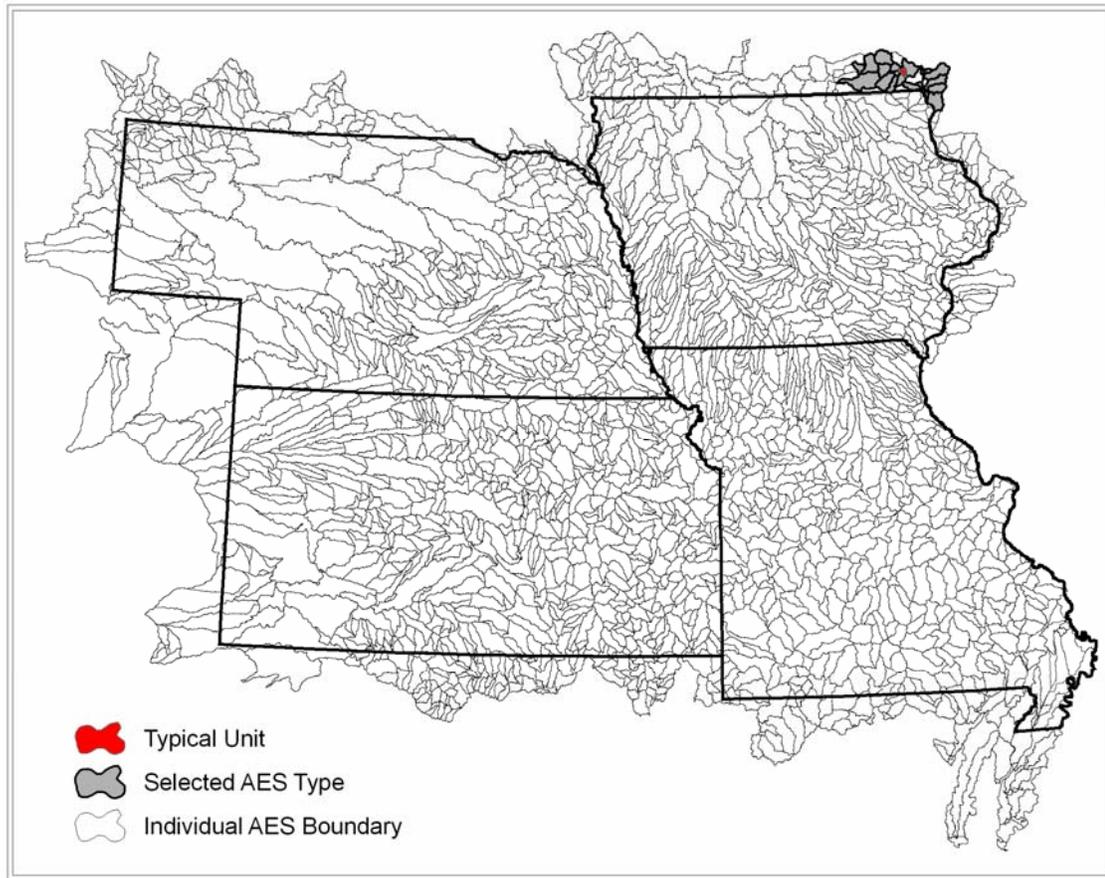


### **Description:**

This AES-Type consists of two patches, one in northeast Iowa that is encompassed almost entirely by the USFS's Oak Savannah Till and Loess Plains Ecological Subsection and one in southeast Minnesota that contains portions of the Oak Savannah Till and Loess Plains and the Western Paleozoic Plateau Ecological Subsections. The primary drainages consist of the Wapsipinicon River and the West Fork of the Cedar River in Iowa and upper portions of the Root and Cedar Rivers in Minnesota. Local relief is generally less than 25 meters. Soil surface textures are somewhat varied, but consist mainly of loam and silt loams with moderate infiltration rates. Rock fragment volume in these soils is generally less than 10%. The combined headwater and creek mean stream gradient is 6.2 meters per kilometer. Historic vegetation consisted primarily of prairie with oak and hickory along the major streams. Minor components of oak-savanna existed as well.

**Typical Unit:** 1099 – Kilson Creek

## AES-Type 93 (Swede Bottom Creek)

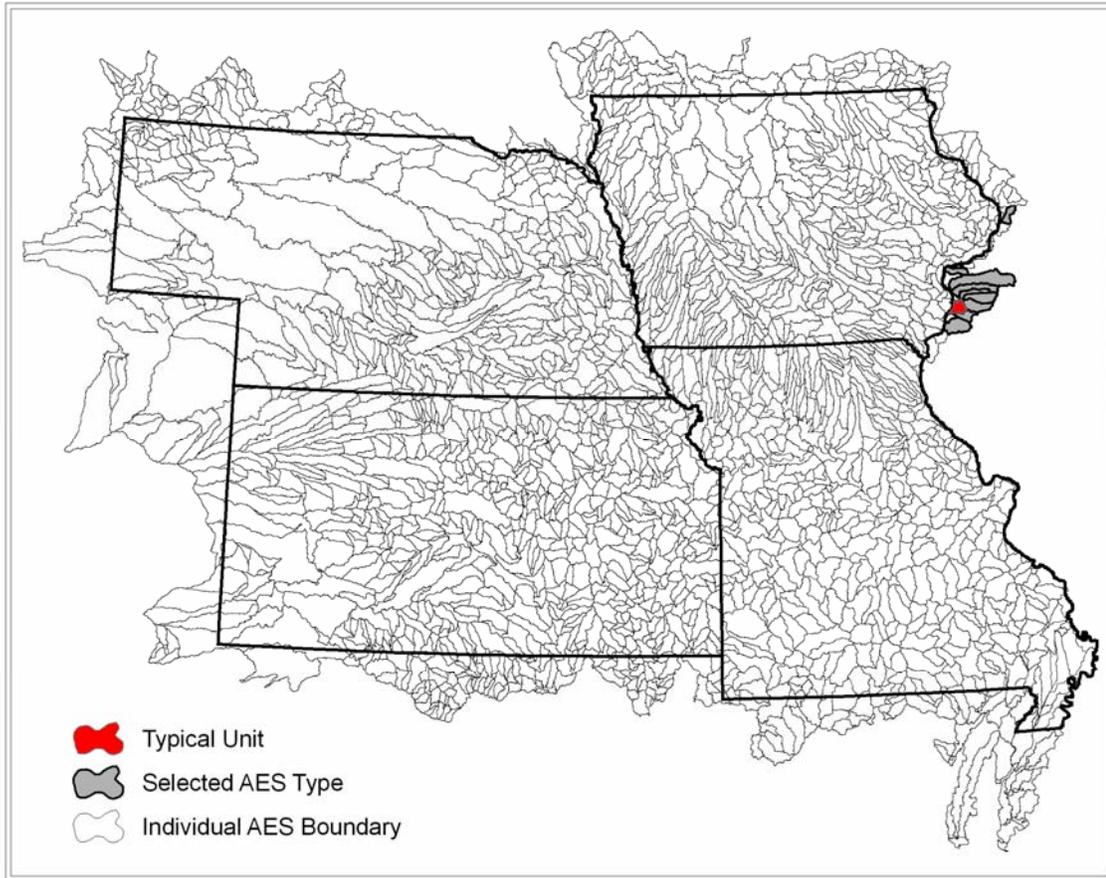


### **Description:**

This AES-Type is located at the junction of Iowa, Wisconsin and Minnesota mainly within the USFS's Mississippi-Wisconsin River Ravines Ecological Subsection. The Root River of Minnesota is the primary river basin encompassed by this Type. Local relief can be quite variable and as high as 100 meters or more. Soil surface textures are mainly silt loams with moderate infiltration rates. Rock fragment volume in these soils is generally less than 10%. The combined headwater and creek mean stream gradient is 21.1 meters per kilometer. Historic vegetation consisted of mosaics of bluestem prairie and oak-hickory forests.

**Typical Unit:** 1192 – Swede Bottom Creek

## AES-Type 94 (Fall Creek)

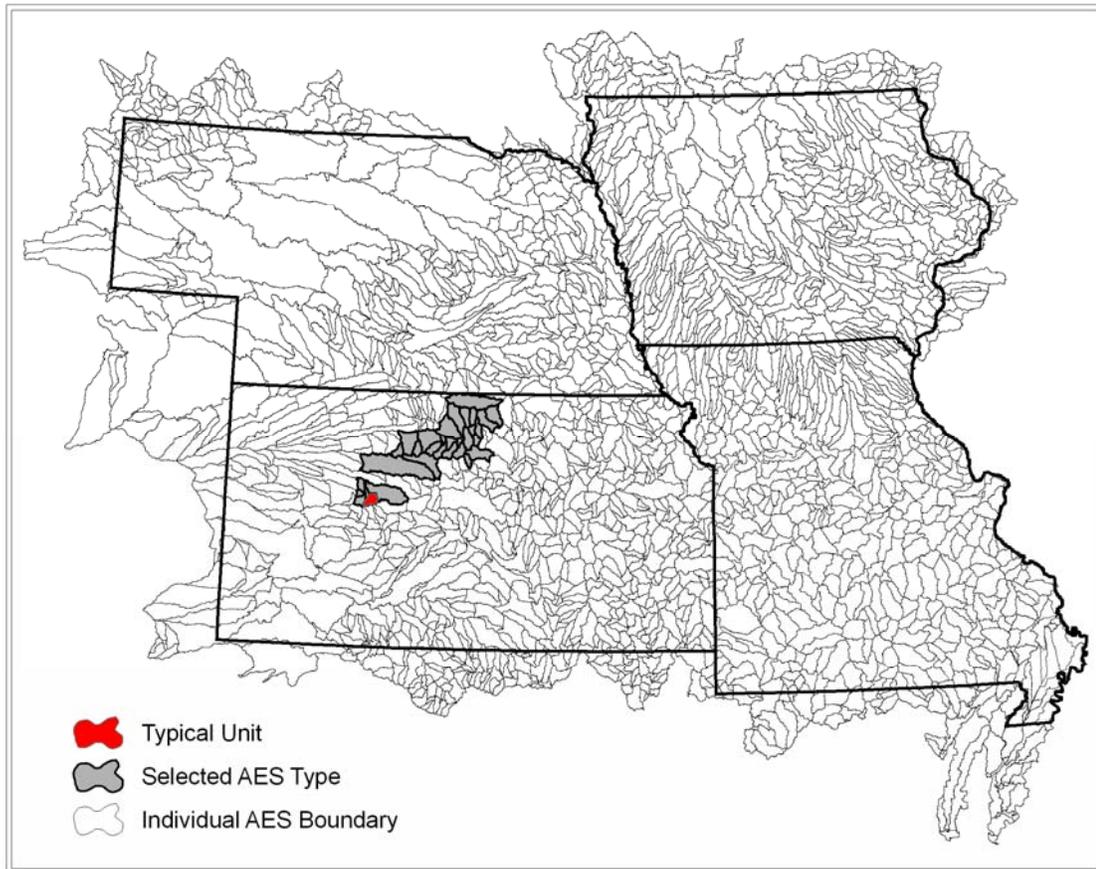


### **Description:**

This AES-Type is located in western Illinois mainly within the USFS's East Mississippi River Hills and Galesburg Dissected Till Plain Ecological Subsections. A number of small tributaries to the Mississippi River are included in this Type including Mud Creek, Johnson Creek, and Ellison Creek. Local relief is generally less than 20 meters. Soil surface textures are primarily silt loams with moderate infiltration rates. Rock fragment volume in these soils is generally less than 10%. The combined headwater and creek mean stream gradient is 5.2 meters per kilometer. Historic vegetation consisted of mosaics of bluestem prairie and oak-hickory forests with more oak-hickory nearer the Mississippi River.

**Typical Unit:** 1157 – Fall Creek

## AES-Type 95 (Page Creek)

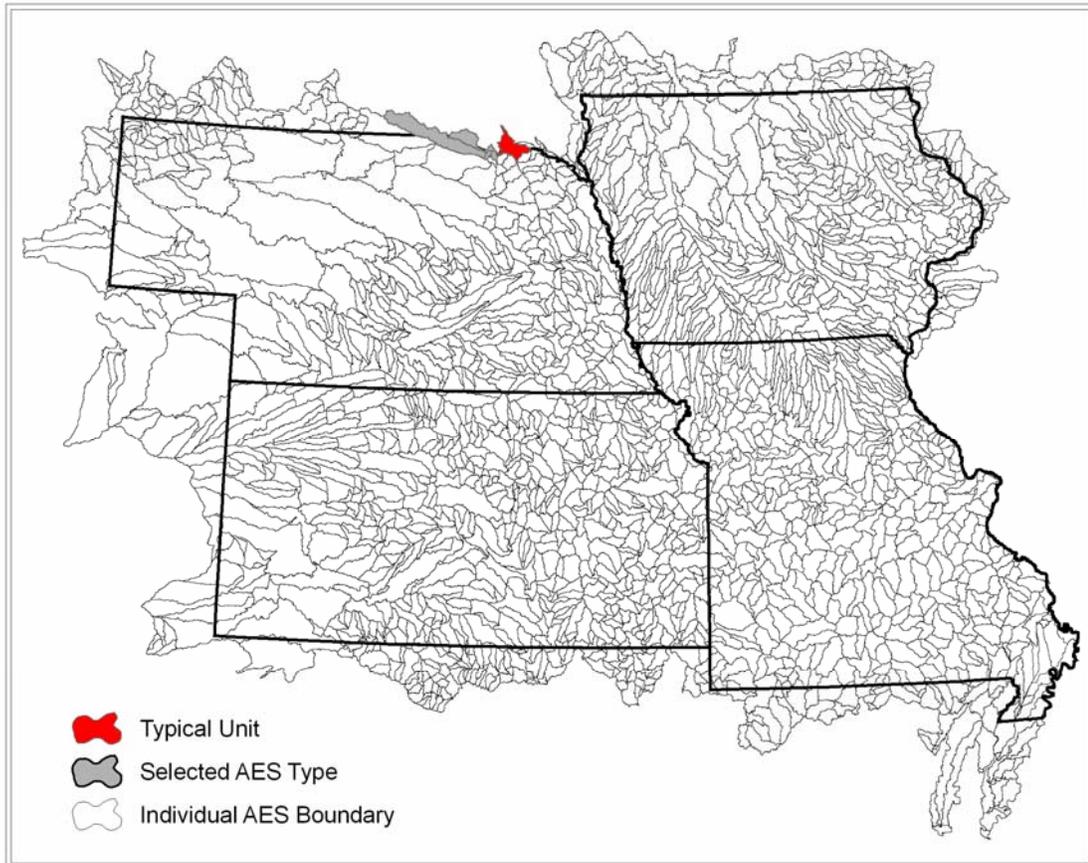


### **Description:**

This AES-Type is located in north-central Kansas within the USFS's Smokey Hills Ecological Subsection. Portions of three primary drainages are included within this Type including the Solomon River, Saline River, and Smoky Hill River. Local relief is mostly less than 30 meters. Soil surface textures are mainly silt loams and loams with moderate infiltration rates. Rock fragment volume in these soils can be as high as 20%, while depth to bedrock can be less than 120 centimeters in places. The combined headwater and creek mean stream gradient is 8.3 meters per kilometer. Historic vegetation consisted of plains grasslands.

**Typical Unit:** 902 – Page Creek

## AES-Type 96 (Deadman Creek)

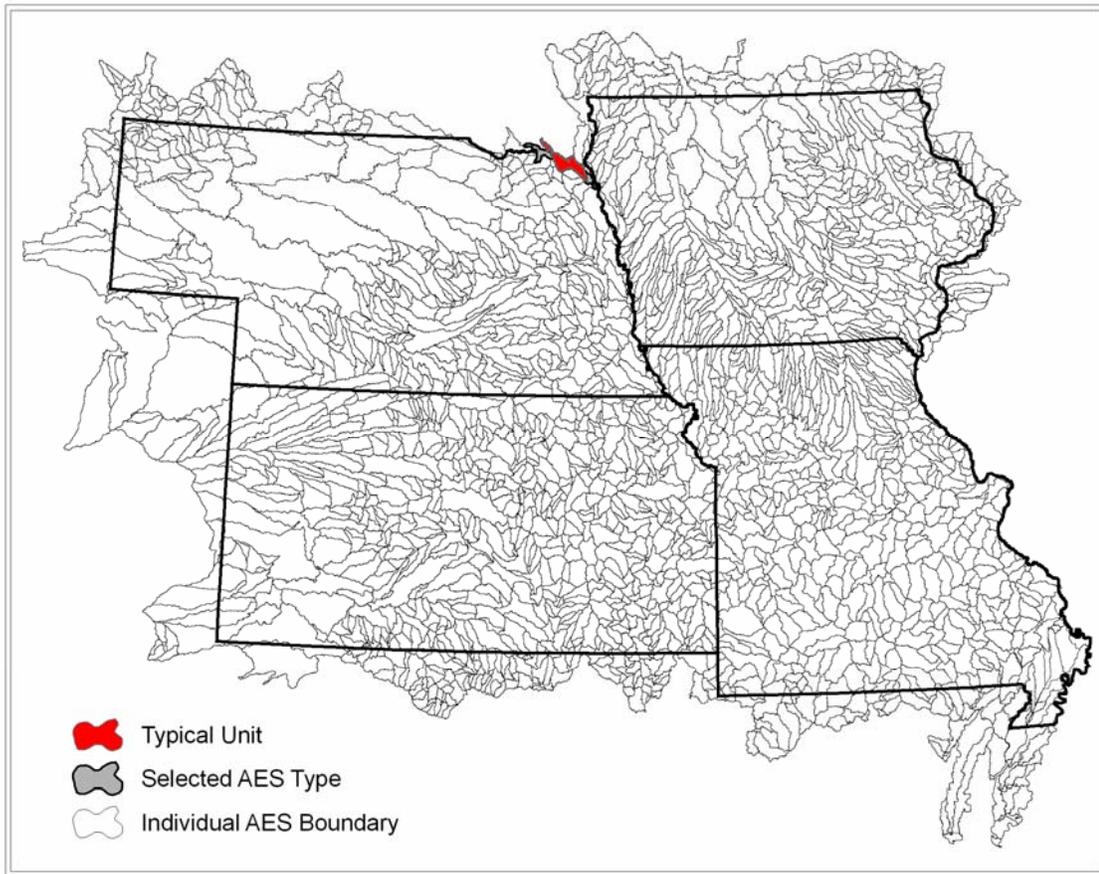


### **Description:**

This AES-Type sits on the Nebraska South Dakota border mostly within the USFS's North-Central Great Plains Ecological Section and incorporates parts of several small drainages including Ponca Creek. Local relief can be as much as 90 meters and sometimes more. Soil surface textures are quite varied and consist, in decreasing amounts, of silty clay, clay, silt loam, loam, and silty clay loam. These soils exhibit moderate to very slow infiltration rates overall. Rock fragment volume in these soils is generally less than 10%, while depth to bedrock can be less than 90 centimeters in places. The combined headwater and creek mean stream gradient is 9.4 meters per kilometer. Historic vegetation consisted of plains grasslands and prairie.

**Typical Unit:** 1662 – Deadman Creek

## AES-Type 97 (Lime Creek)

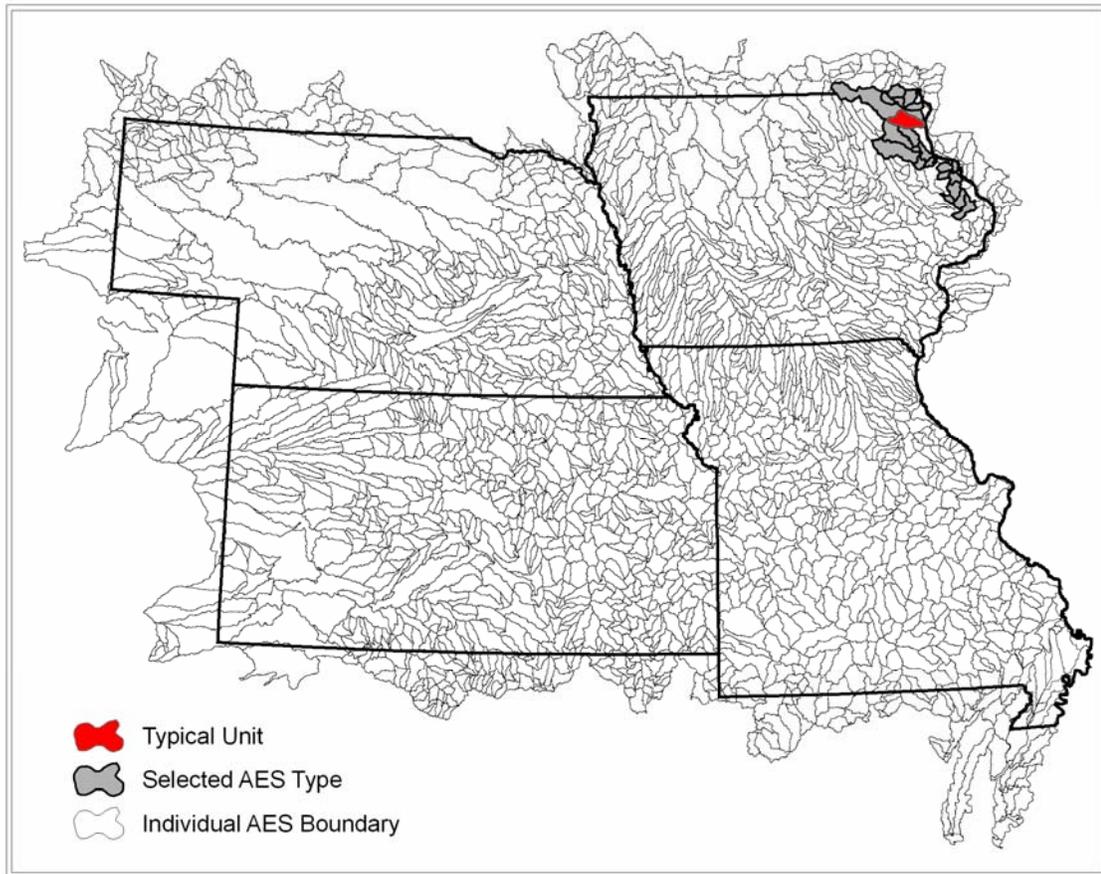


### **Description:**

This AES-Type rests along the Missouri River between Nebraska and South Dakota mainly within the USFS's Missouri River Alluvial Plain Ecological Subsection. Only minor tributaries to the Missouri River are contained in this Type. Local relief is mostly less than 15 meters. Soil surface textures consist of silty clay, silt loam, and silty clay loam. These soils exhibit moderate to very slow infiltration rates. Rock fragment volume in these soils is generally 0%. The combined headwater and creek mean stream gradient is 7.7 meters per kilometer. Historic vegetation consisted of prairie and northern floodplain forest.

**Typical Unit:** 1674 – Lime Creek

## AES-Type 98 (Yellow River)

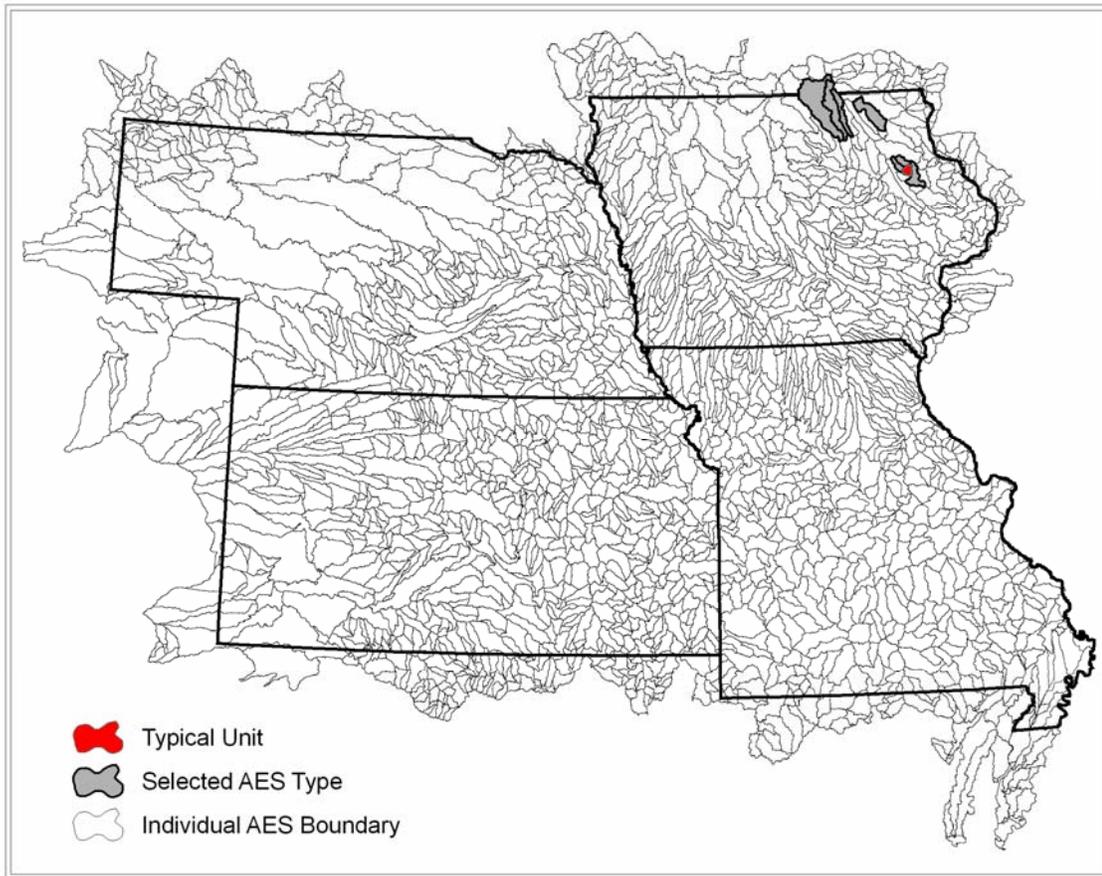


### **Description:**

This AES-Type is located in northeast Iowa and is mostly within the USFS's Western Paleozoic Plateau and Mississippi-Wisconsin River Ravines Ecological Subsections. The major river drainages that are partially within this Type consist of the Turkey River and Upper Iowa River. Local relief is centered between 30 and 90 meters. Generally this is an area of loess covered glacial till with karst and deeply entrenched valleys. The Paleozoic rocks include formations from the Devonian, Silurian, Ordovician, and Cambrian systems. The more resistant sandstones and carbonates comprise the cliffs and escarpments, while the gentler slopes are formed from the more easily weathered shales. Soil surface textures are almost exclusively silt loams with moderate infiltration rates. Rock fragment volume in these soils can be as much as 20%, while depth to bedrock can be less than 120 centimeters in places. The combined headwater and creek mean stream gradient is 15.9 meters per kilometer. Coldwater is an important characteristic of many of the streams located within this AES-Type. Historic vegetation consisted of mosaics of bluestem prairie and oak-hickory forest.

**Typical Unit:** 1213 – Yellow River

## AES-Type 99 (Sand Hagen Creek)

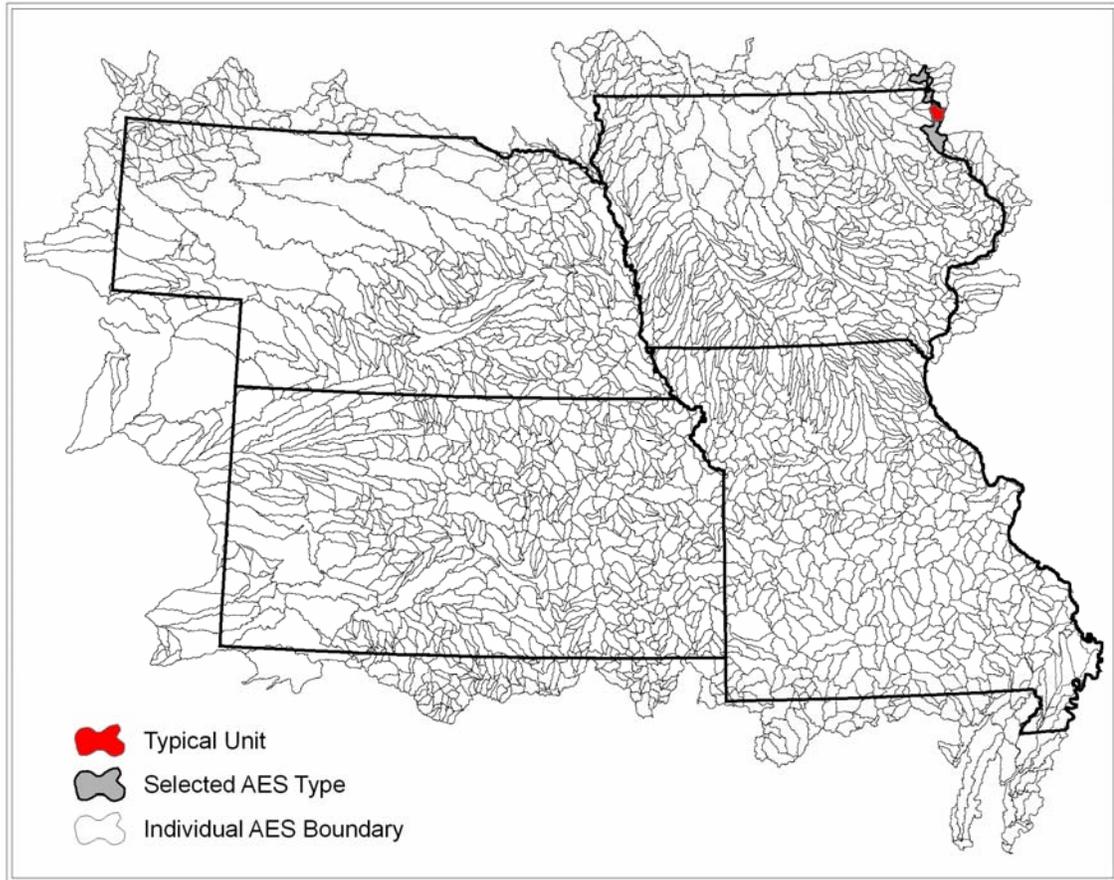


### **Description:**

This AES-Type is located in northeast Iowa within the USFS's Oak Savannah Till and Loess Plains Ecological Subsection. Portions of several river drainages are included within this Type including Cedar River, Wapsipinicon River, Turkey River, and the Maquoketa River. Local relief is generally less than 30 meters. Soil surface textures are primarily loams and silt loams with moderate infiltration rates. Rock fragment volume in these soils is generally less than 10%. The combined headwater and creek mean stream gradient is 5.6 meters per kilometer. Several coldwater streams can be found in this Type. Historic vegetation consisted of prairie along with mosaics of bluestem prairie and oak-hickory forest.

**Typical Unit:** 1251 – Sand Hagen Creek

## AES-Type 100 (Du Charme Creek)

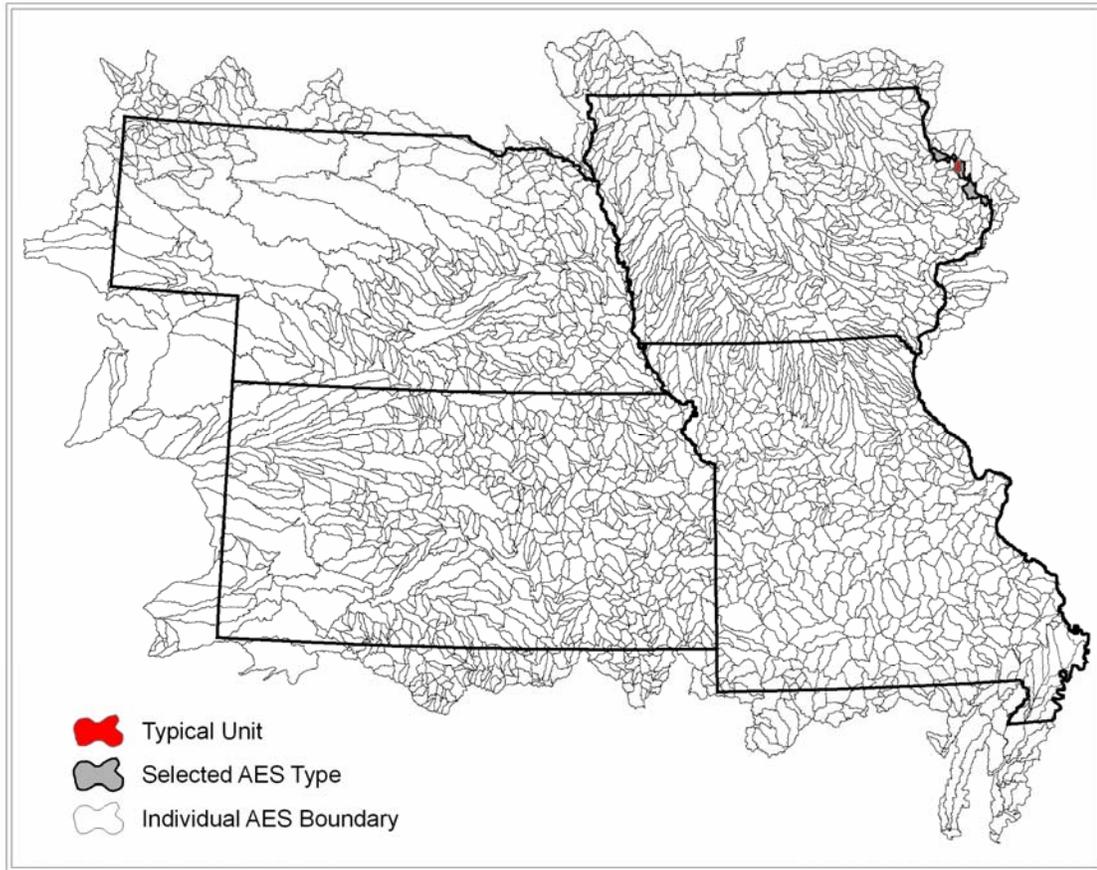


### **Description:**

This AES-Type is located along the Mississippi River at the junction of Iowa, Wisconsin and Minnesota within the USFS's Mississippi-Wisconsin River Ravines Ecological Subsection. Only small lateral tributaries to the Mississippi River are found in this Type. Local relief is quite variable and can be as much as 150 meters along the Mississippi River. Soil surface textures are silt loams with moderate infiltration rates. Rock fragment volume in these soils is generally less than 10%, while depth to bedrock can be less than 90 centimeters in places. The combined headwater and creek mean stream gradient is 19.7 meters per kilometer. Historic vegetation consisted of mosaics of bluestem prairie and oak-hickory forest.

**Typical Unit:** 1212 – Du Charme Creek

## AES-Type 101 (Bee Branch)

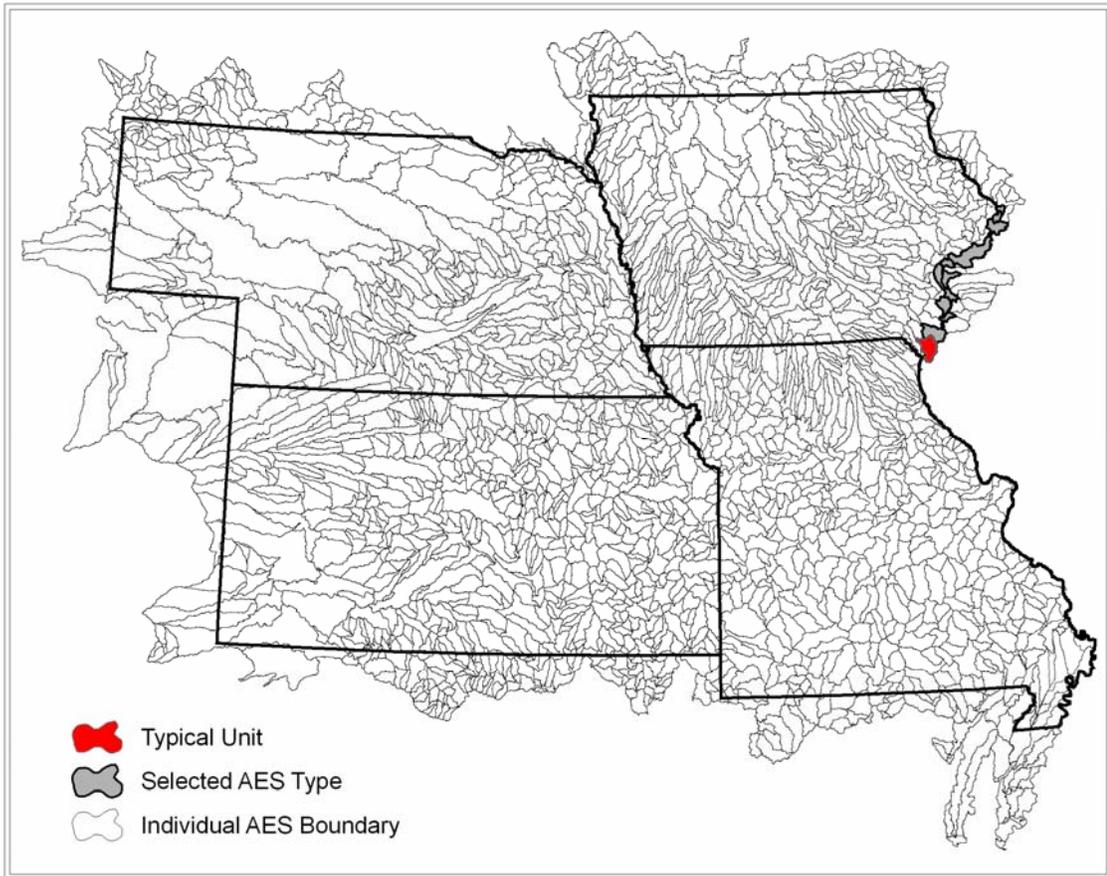


### **Description:**

This AES-Type contains a number of small lateral tributaries to the Mississippi River at the junction of Iowa, Illinois, and Wisconsin. Most of this Type is located within the USFS's Mississippi-Wisconsin River Ravines Ecological Subsection. Local relief is variable and can be as much as 90 meters. Soil surface textures consist of silt loams with moderate infiltration rates. Rock fragment volume in these soils can approach 20%, while depth to bedrock can be less than 120 centimeters in places. The combined headwater and creek mean stream gradient is 18.2 meters per kilometer. Historic vegetation consisted of mosaics of bluestem prairie and oak-hickory forest.

**Typical Unit:** 1240 – Bee Branch

## AES-Type 102 (Chaney Creek)



### ***Description:***

This AES Type consists of small tributaries to the Mississippi River along the Iowa – Illinois border. Most of this Type falls within the USFS’s Mississippi River and Illinois Alluvial Plains Ecological Subsections. Local relief is generally less than 30 meters. Soil surface textures consist of silt loams and loams with moderate and sometimes very slow infiltration rates. Rock fragment volume in these soils is generally less than 10%. The combined headwater and creek mean stream gradient is 6.7 meters per kilometer. Historic vegetation consisted of mosaics of bluestem prairie and oak-hickory forest.

***Typical Unit:*** 1669 – Chaney Creek

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