# Developing a Methodology to Prioritize Texas Watersheds for Environmental Restoration Efforts

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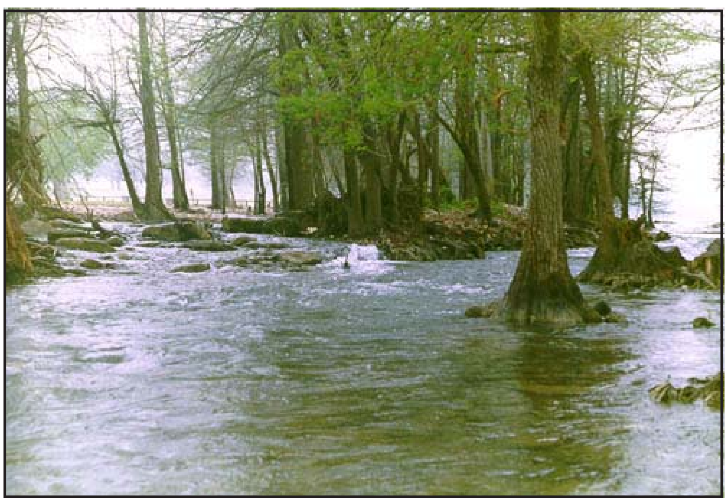

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## Introduction

During the past 150 years, several Texas watersheds have undergone significant changes that affect land use, the amount of water flowing through these systems, water quality, and the numbers and types of fish and aquatic species that live in rivers and lakes (McKinney, 2002). For the most part, these changes can be attributed to human activities such as dam building and reservoir management, population growth and resulting increased water use, increased runoff from paved surfaces, the introduction of non-native plant species, and others (Jensen, 2003a). As a consequence, competition for waters between human uses and environmental purposes has now increased to such an extent that some habitats and ecosystems that rely on water may be in peril, especially in semi-arid and arid regions of Texas (TWDB, 2002).

Recently, there has been increased public interest in investigating whether policies and management strategies could be implemented to restore watersheds, riparian zones, and other natural areas critically important to support wildlife, fisheries, and forests (Brown, 2000 and Alnwick, 2003). Often, the goal is to restore these sites to conditions that approximate conditions that existed prior to intensive human settlement in the 1800s. Interest in restoring watersheds and ecosystems has been expressed by several agencies including the U.S. EPA (2000 and 2001) and the U.S. Fish and Wildlife Service (2000).

At a local or regional level, efforts have been undertaken to identify restoration opportunities along the Texas Gulf Coast by General Land Office Natural Resources Inventory program (1998). In addition, organizations including the Nature Conservancy (2000), the National Wildlife Federation (1998), and the Galveston Bay Foundation (19980 have also examined the need to set priorities for environmental restoration. For example, the Nature Conservancy published a report, Designing a Geography of Hope (Groves et al, 2000), that describes one method of assessing restoration opportunities across ecosystems and watersheds.

A special challenge facing restoration efforts is in developing management strategies that will benefit ecological conditions in watersheds while, at the same time, preserving existing land uses (including homes and businesses) as well as dams and other infrastructure. Activities to identify estuaries and other watersheds that may be in need of restoration efforts have been initiated by the U.S. Army Corps of Engineers (2000) and the National Oceanic and Atmospheric Administration (2002).

To deal with these public concerns, the U.S. Army Corps of Engineers Fort Worth District Office has expressed interest in determining how watershed restoration programs could be designed and implemented. One of the primary needs in this regard is to develop a science-based process that could objectively evaluate, prioritize, and identify watersheds that most need restoration efforts as well as regions where these measures are most likely to succeed. If such a methodology were developed, the Corps could use these recommendations, in conjunction with non-Federal sponsors, to develop full-fledged feasibility studies within targeted watersheds. Obviously, such a method could potentially be used by other natural resources agencies and organizations in Texas and elsewhere.

It should be noted that the Corps is already engaged in ecosystem restoration studies and projects in some parts of Texas, though these efforts are developed as a part of comprehensive Corps projects. Some of these Texas projects include efforts in San

Antonio (Salado Creek), Dallas, Houston, the North Bosque River watershed, and other regions. This project seeks to create a methodology that can be used to prioritize watersheds throughout Texas for possible restoration projects, the feasibility of which would be determined in subsequent detailed studies.

Environmental operating principles that should guide the Corps in its public works and water resources projects were identified in a March 2002 speech in Louisiana by Lt. General Robert Flowers (Corps of Engineers, 2002). Some of the main points he addressed include the following:

- The Corps should strive to achieve environmental sustainability,
- Balance should be sought between human activities and natural systems
- Potential problems should be resolved by designing environmental and economic solutions that complement one another.
- The Corps should seek ways to assess and mitigate potential adverse affects caused by Corps of Engineers projects on the environment.

**Objectives of the Project**

1) To develop data about a number of parameters indicative of watershed values and watershed threats throughout Texas,

2) To develop a method by which these data could be used to compare and prioritize watersheds which would be the best candidates for restoration activities, and

3) To gather feedback from key stakeholders about the extent to which the data developed in this effort and the methods used are appropriate to prioritize watersheds in terms of watershed values and the need for restoration efforts.

**Methodology**

In August 2002, the Texas Water Resources Institute (TWRI) began efforts to coordinate the data gathering and analyses associated with this project.

Key partners were identified who would meet regularly to define and adjust (as needed) the scope of the project and associated data gathering tasks. Individuals who cooperated with TWRI on an ongoing basis throughout the project include the following:

- Becky Griffith and Kevin Craig, U.S. Army Corps of Engineers, Fort Worth
- Raghavan Srinivasan and Jennifer Hadley Jacobs, Texas A&M University Spatial Sciences Laboratory.
- Ralph Wurbs and Gaurav Garg, Texas A&M University Civil Engineering Department.
- Andy Manale, U.S. Environmental Protection Agency Headquarters, Washington, DC
- Andrew Sansom, Texas State University
- Allan Jones, B.L. Harris, and Ric Jensen, TWRI
- Ron Lacewell, Texas Agricultural Experiment Station
- Jim Bergan, the Nature Conservancy of Texas
- Karen Chapman and Linda Brock, Environmental Defense
- Kirby Brown, Texas Wildlife Association
- Steve Manning, Central Texas Cattleman’s Association
- David Burnett, Petroleum Engineering Department, Texas A&M University.

An initial task associated with this project was to identify the types of data that would be needed to identify watershed threats and values. As the project evolved, watershed values were represented by data associated with aquatic and terrestrial "portfolios" developed by the Nature Conservancy, major rivers, aquifer recharge zones, major reservoirs, and critical stream segments. At the same time, watershed threats were identified by assessing data on such factors as water and wind erosion, impaired streams, human populations, confined animal feeding operations (CAFOs), land fragmentation, the presence of nuisance brush species, and the extent to which flows have been altered by human activity in rivers and streams.

Early in this project, TWRI began working with the Texas A&M University Spatial Sciences Laboratory to develop data layers associated with the watershed values and threats (mentioned above) into a geographic information system (GIS) framework. This work was led by researcher R. Srinivasan and graduate student Jennifer Hadley Jacobs. In this effort, the State of Texas was divided into a series of 207 8-digit hydrologic unit code (HUC) watersheds that are displayed on the maps presented in this report. In a very broad sense, 8-digit watersheds are at a scale that represents sub-watersheds.

Throughout the course of the project, some of the initial data sets were modified to better reflect the factors that need to be considered when prioritizing watersheds for restoration activities. For example, early in the project a data layer was created that shows priority groundwater management areas designated by the Texas Commission on Environmental Quality. This data layer was omitted from the final report because it was thought to pertain more to regulations and policy than an important science-based issue. Data were developed by researcher Ralph Wurbs and graduate student Gaurav Garg (both of the Texas A&M University Civil Engineering Department) to show the ratio of regulated naturalized flow during high flow, median flow, and low flow conditions upstream of dams. However, the data on the extent to which high flow and median flow conditions had been altered was omitted from the final analyses because the hydrologic modeling upon which it is based does not cover the entire state.

During this project, several members of the working group expressed an interest in developing data that would show the extent to which conditions have changed over time so that trends could be identified. However, most of the GIS layers and data sets developed for this project depict conditions at one point in time. Part of the reason for showing static conditions, not trends, is that data about these issues are often not available over a period of years that would allow such comparisons to be made.

**Brief Description of Data Sets Developed for the Project**

Throughout this project, the following data sets were developed. Each data layer consists of a GIS-generated map and related information. For most of the maps, threshold values were identified on the basis of "natural breaks" selected by ArcView GIS software. Where thresholds were not identified, the top 20% of values or the presence of a parameter within a HUC was determined to be significant.

These threshold values were determined for the following variables:

- Water Erosion (the threshold value is greater than 0.85 tons per acre),
- Wind Erosion (threshold is greater than 3 tons per acre),

- Projected change in human population density (threshold is greater than 225 people per square mile),
- Confined Animal Feeding Operations or CAFOs (threshold is greater than 7 CAFOs per 8-digit watershed),
- Fragmentation Index (threshold is an annual increase of 8% or more in ranches less than 500 acres),
- Percent of cropland near streams (threshold is 30% of cropland or more within 120 meters of National Hydrography Dataset or NHD streams),
- Ratio of regulated to naturalized flow (acre-feet per month) during low-flow conditions (threshold is 0 to 0.6).

In contrast, several indicator variables did not use threshold values. These data sets merely count the presence of absence of specific conditions within each HUC. Maps employing this approach include:

The presence of impaired streams that do not meet designated uses, as identified by the Texas Commission on Environmental Quality or TCEQ (i.e., the draft 303 (d) list,

The occurrence of mesquite, juniper and saltcedar infestation (three separate maps)

The presence of major rivers

The occurrence of groundwater recharge zones,

The presence of reservoirs,

The occurrence of ecologically significant stream segments, as identified by TPWD.

The presence of Texas Nature Conservancy (TNC) Aquatic, Terrestrial and Marine Portfolios

Finally, for each HUC the percentage of riparian cropland was determined. Those HUCs within the top 20% were determined to be significant for this application.

**Indicators of Watershed Values**

Texas Nature Conservancy Aquatic Portfolio (Figure 1) – The Nature Conservancy has created data about watersheds and areas where water resources are vitally important to maintain environmental quality. The Nature Conservancy provided these data to the Spatial Sciences Lab (SSL) in a shapefile format. However, TNC data did not initially include a significant portion of the Texas Gulf Coast or East Texas. In the final version, this data layer was presented for illustration purposes only and was not used as a weighing factor to identify watersheds most in need of restoration. This was done because this data set did not provide statewide coverage.

Texas Nature Conservancy Terrestrial Portfolio (Figure 2) – These data provide information on the presence of land-based or terrestrial ecological resources of importance throughout Texas, as identified by TNC. It is unclear whether water resources may always have a direct link to the ecological quality of these sites. At the time of this study, TNC had not gathered extensive data on terrestrial resources in East Texas and along the Upper Texas Gulf Coast. In the final version, this data layer was presented for illustration purposes only and was not used as a weighing factor to identify watersheds most in need of restoration. This was done because this data set did not provide statewide coverage.

Texas Nature Conservancy Marine Portfolio (Figure 3) – The marine portfolio identifies coastal waters and bay and estuary systems where water resources are necessary to support ecological and environmental functions. Initial TNC data largely identified marine sites along the Southern Texas coast, and not bay and estuary systems north of Galveston Bay. In the final version, this data layer was presented for illustration purposes only and was not used as a weighing factor to identify watersheds most in need of restoration. This was done because this data set did not provide coverage of all the bay and estuary systems of Texas.

Major Rivers (Figure 4) – Data for this layer were supplied by the Texas Water Development Board in shapefile format. Rivers included in this data layer include the Brazos, Canadian, Colorado, Guadalupe, Lavaca, Medina, Neches, Nueces, Red, Rio Grande, Sabine, San Antonio, San Jacinto, Sulphur, and Trinity, as well as Cypress Creek.

Selected Aquifer Recharge Zones (Figure 5) – Aquifer boundaries were obtained from the Texas Water Development Board (TWDB). This data was supplied to the SSL in shapefile format and modified by the SSL to show only selected aquifer recharge zones determined to be significant to Texas. Recharge areas are shown for the Carrizo, Edwards, Seymour and Trinity aquifer groups.

Existing Reservoirs (Figure 6) – This data layer was created using information from the Texas Water Development Board about all the existing reservoirs throughout Texas. The existence of a reservoir was thought to be a watershed value since dams provide year-round aquatic habitat. Some workshop members contended that the presence of reservoirs should alternatively be viewed as a watershed threat since the building of a dam does alter the natural habitat.

Ecologically Significant River and Stream Segments (Figure 7) This data layer depicts ecologically important river and stream segments identified by the Texas Parks and Wildlife Department. As a result of Senate Bill 1 (1997), TPWD allowed regional water planning groups to designate ecologically unique river and stream segments in their geographic area, based on biological and hydrological function, the presence of riparian conservation areas, high quality waters and/or aesthetic values, and the fact that threatened or endangered species were found in the waters of the region.

**Indicators of Watershed Threats and Impairments**

Total Water Erosion (Figure 8) – Data for this layer was provided by the U.S. Department of Agriculture Natural Resource Conservation Service's Natural Resources Inventory. This data layer shows the amount of soil erosion (expressed in tons per acre) caused by runoff.

Total Wind Erosion (Figure 9) – Data for this layer was provided by the U.S. Department of Agriculture Natural Resource Conservation Service's Natural Resources Inventory. This data layer shows the amount of soil erosion (expressed in tons per acre) caused by wind.

Impaired Water Bodies (Figure 10) – This data layer shows river and stream segments in Texas that have been identified by the Texas Commission on Environmental Quality as not meeting designated uses due to water quality impairments. These stream segments are listed on the draft 2002 Section 303 (d) list developed by TCEQ to comply with the federal Clean Water Act.

Projected Percent Change in Human Population Density (Figure 11) – This data layer was created based on information provided by the U.S. Census Bureau for the year 2000 and population trends for the year 2040 developed by the Office of the State Demographer at Texas A&M University. The map shows the average projected percent change in population displayed over the 207 8-digit HUC boundaries.

Confined Animal Feeding Operation or CAFO Locations (Figure 12) – This data layer was developed from information provided by the Texas Commission on Environmental Quality (TCEQ). It includes the locations of various types of CAFOs, including cattle feedlots, dairies, poultry operations (both chicken and turkey), and sites where sheep and swine are raised. This map is presented only for illustration purposes and was not used as a weighing factor.

Confined Animal Feeding Operation Density (Figure 13) – This map depicts the number of CAFOs per HUC. It does not differentiate between CAFOs with various numbers of animals. This was map and data set were used as a weighing factor and were incorporated into the matrix of watershed values and impairments.

Fragmentation Index (Figure 14) – This data layer was developed using analyses carried out by Neal Wilkins of Texas Cooperative Extension and the Texas A&M University Wildlife and Fisheries Sciences Department. The information shows areas in which there have been increases in ranches less than 500 acres in size from 1992 to 1997. These data suggest that larger tracts of agricultural lands are being subdivided, thus perhaps affecting ecosystem quality. In the final version, this data layer was presented for illustration purposes only. At the suggestion of the San Angelo project review panel, this map was not used as a weighing factor to identify watersheds most in need of restoration.

Percent Riparian Cropland (Figure 15) –This data layer was developed using 1992 information from the National Land Cover Dataset created by the U.S. Geological Survey. The data layer displays the percent of lands used to grow crops within 120 meters of streams in the National Hydrography Dataset (NHD). This information suggests watersheds in which agricultural activities might affect stream water quality.

Mesquite, Juniper and Salt Cedar Infestation (Figures 16, 17, and 18) – In earlier versions, this data layer consisted of one map that combined data on the spatial extent of mesquite, juniper and saltcedar. In the final product, however, separate data layers and maps have been created for each of these species (Figure 16 shows mesquite infestation, Figure 17 displays juniper, and Figure 18 shows saltcedar coverage). This data layer was created using information from the Texas Parks and Wildlife Department’s statewide vegetation survey, which was conducted in 1984 and the NRCS 1982 brush survey. The SSL extracted data for mesquite and juniper from the TPWD database, and plotted each on a separate map. The map for salt cedar infestation was created from the TPWD database and the NRCS brush survey. Saltcedar was assigned the highest weight (3x) while mesquite and juniper were each assigned a weight of 2x, based on the suggestions of the San Angelo project review panel.

Ratio of Regulated Flows to Naturalized Flows During Low Flow Conditions (Figure 19) This data layer was created by researcher Ralph Wurbs and graduate student Gaurav Garg of the Texas A&M University Civil Engineering Department. The researchers used the Texas A&M Water Rights Analysis Package (WRAP) to compare the extent to which streamflows during low-flow conditions (75% of flows are greater) have been altered upstream of dams. The streamflow data were then entered into a GIS framework and were displayed over the 207 8-digit watersheds. In the final version of this report, this data layer is presented only for information purposes and is not used as a factor to weigh or prioritize watersheds that need to be restored. This was done because the dataset does not cover the entire State, since WAM and WRAP modeling have not been performed for the Rio Grande watershed.

Ratio of Regulated Flows to Naturalized Flows During Median Flow Conditions (Figure 20) – This data layer was created by researcher Ralph Wurbs and graduate student Gaurav Garg of the Texas A&M University Civil Engineering Department. The researchers used the Texas A&M Water Rights Analysis Package (WRAP) to compare the extent to which streamflows during median flow conditions (50% of flows are greater) have been altered upstream of dams. The streamflow data were then entered into a GIS framework and were displayed over the 207 8-digit watersheds. In the final version of this report, this data layer is presented only for information purposes and is not used as a factor to weigh or prioritize watersheds that need to be restored. This was done because the dataset does not cover the entire State, since WAM and WRAP modeling have not been performed for the Rio Grande watershed.

Ratio of Regulated Flows to Naturalized Flows During High Flow Conditions (Figure 21) -- This data layer was created by researcher Ralph Wurbs and graduate student Gaurav Garg of the Texas A&M University Civil Engineering Department. The researchers used the Texas A&M Water Rights Analysis Package (WRAP) to compare the extent to which streamflows during high flow conditions (25% of flows are greater) have been altered upstream of dams. The streamflow data were then entered into a GIS framework and were displayed over the 207 8-digit watersheds. . In the final version of this report, this data layer is presented only for information purposes and is not used as a factor to weigh or prioritize watersheds that need to be restored. This was done because the dataset does not cover the entire State, since WAM and WRAP modeling have not been performed for the Rio Grande watershed.

Earlier in this project, several scenarios were attempted to simulate the extent to which human activities altered streamflows. This included attempts to model, using WRAP, the ratio of regulated flows to naturalized flows under low-flow, median-flow, and high-flow conditions. However, as the project progressed it was decided that the choice of control points was critical in determining how flows had been affected by dam building and other human activities; hence efforts were made to identify control points immediately upstream of reservoirs. Efforts are now under way to refine these modeling exercises to carefully select the most appropriate control points in a way that will best reflect the influence of human influence on instream flows.

**Developing a Framework to Use this Data to Prioritize Watersheds**

The data layers described above were used to develop a matrix that provided a way for the working group to rank the relative importance of these factors and create comprehensive maps of watershed threats and values.

Tables 1 and 2 present information on the percentage of sub-basins in which each parameter was defined as having significant value or causing significant impairment. The table provides the parameter weights suggested by partners who reviewed the methodology. Parameters present in early versions have been removed from the final report at the suggestion of reviewers and are not included in the weighing tables.

Based on the weights assigned to these data layers, and a merging of this information, cumulative maps were developed showing watershed values (Figure 22), and watershed impairments (Figure 23). In addition, a map was developed that combines the weighted watershed threats and values (Figure 24). River basin and HUC reference maps can be found in Figures 25 and 26, respectively.

**Gathering Feedback about the Project**

To confirm whether the data developed for this project and the methods proposed to rank and prioritize watersheds were viewed as being valid by key stakeholders, TWRI hosted half-day workshops in San Angelo, San Antonio, and College Station.

In these workshops, TWRI invited natural resources and watershed experts from academia, agencies, and organizations to review and discuss the processes and products associated with this study. Presentations about this project were given by TWRI Director Allan Jones and R. Srinivasan and Jennifer Jacobs of the SSL. Throughout these presentations, participants were encouraged to ask questions, provide observations and comments, and offer suggestions about how the data sets and the priority-setting process could be improved. At each workshop, naturalistic methods commonly used in focus group research were employed (Edmunds, 2000, Lincoln & Carpenter, 1999, and Proctor, 1997).

A total of 26 people (in addition to TWRI and SSL personnel) met in the three workshops. They included 10 individuals from higher education, 7 from federal agencies, 6 from state agencies, 2 from local agencies, and 1 person from the private sector.

The first workshop was held in College Station in November 2003 and involved nine participants. Thirteen people participated in the San Antonio workshop while 12 people took part in the San Angelo workshop.

The participants included the following individuals:

**College Station workshop--**Allan Jones, B.L. Harris, and Ric Jensen (all TWRI), Jennifer Hadley Jacobs and Raghavan Srinivasan (both TAMU Spatial Sciences Lab); Kevin Craig, U.S. Army Corps of Engineers; Bill Neill, TAMU Wildlife and Fisheries Sciences Department; Nicky Dixon, TAMU Rangeland Ecology and Management Department; and Brian Crook, USDA Farm Security Administration.

**San Antonio Workshop --** Allan Jones and Ric Jensen (both TWRI); Jennifer Hadley Jacobs, SSL; John Burgin, University of Texas—San Antonio; Kathy Boydston, Tom Hagger, and Rollin McRae (TPWD); Philip Wright, U.S. Department of Agriculture Natural Resource Conservation Service (NRCS); Comer Tuck, Texas Water Development Board; Janet Black, Texas Engineering Extension Service; Paul Barnes, Texas State University—San Marcos; Dana Nicholls, San Antonio Water System, and Darwin Ockerman, U.S. Geological Survey.

**San Angelo workshop –** Allan Jones and Ric Jensen (TWRI); John Walker and Darrell Ueckert, (both TAMU Agricultural Research and Extension Center in San Angelo); Mike Mecke, TWRI and Texas Cooperative Extension; Steve Nelle, USDA NRCS; Sonny Kretzschmar, HDR Engineering; Paul Loeffler, Texas General Land Office; Ruben Cantu, Texas Parks and Wildlife Department; Kevin Craig, US Army Corps of Engineers; Tim Schumann, U.S. Fish and Wildlife Service; Ned Strenth, Angelo

State University; Okla Thornton, Colorado River Municipal Water District, and Mark Ensor, Texas Cooperative Extension.

At each workshop, Ric Jensen of TWRI gathered and recorded by hand the comments made by all participants. A written transcript was created that identifies which individuals offered specific comments. Action items (suggestions on how the data sets or the priority setting process could be improved) were taken from the transcripts and incorporated into a comprehensive list of items for future study. That list is available from TWRI. From this list of action items, themes were identified using principles of naturalistic inquiry. Other comments (including observations that are not tied to action items and criticisms of this project) will be analyzed in the near future.

The comments most often given about data layers and maps are presented below.

Fifteen comments were made about the maps of brush infestation. The most-frequent comment was that data on saltcedar needed to be added, especially for the Pecos River basin and the Lower Rio Grande Valley. Others commented that the map needed to be broken up into separate layers for saltcedar, mesquite, and juniper (this was done for the final product). Several participants wondered if more up-to-date data might be available than the 1984 data from the Texas Parks and Wildlife Department used in this project, and urged that efforts be begun to develop more recent data on this issue.

Twelve observations were given about the land fragmentation map. Several people had a difficult time understanding what this data layer was showing (the increase in ranches and farms of less than 500 acres) and how this might yield insights on watershed impairments. Other participants commented that the trends they expected to see from this data set (the proliferation of ranchettes and subdivisions in the Hill Country and the Houston area) were not reflected on the map. Often, respondents suggested other datasets that might better reflect the breakup of agricultural lands, including numbers of septic systems, development of subdivisions, miles of roads, and changes in land value. As a result of these comments, this data layer was omitted from the final analysis.

Eight comments were offered about the conservation portfolio data layers provided by the Texas Nature Conservancy. Several participants were concerned that these data did not provide statewide coverage (work was incomplete or missing for the Rio Grande Valley, East Texas, and the Gulf Coast) and felt they had to know more about how these portfolios were developed. Still others, to a lesser extent, wondered if data from special interest groups might not be as objective as information developed by agencies or higher education. As a result, these data were omitted from the final analysis.

In addition to the comments made about individual data layers, a number of observations were offered about the maps that combine values plus impairments, the need to capture data trends, and what types of restoration projects participants want the Corps to consider.

Thirteen comments were given about the use of weighting factors to prioritize watersheds. Several people commented that the maps of watershed priorities undervalue sub-basins in the Lower Rio Grande Valley and the Gulf Coast, perhaps because TNC data were not developed for these regions. Conversely, two people noted that omitting TNC maps from the analyses results in shifting the highest priority watersheds from West Texas to East Texas. Others suggested that the data sets do not pay enough attention to industrial and urban pollutants and that there seems to be more information on watershed impairments than watershed values.

Although only six comments were given about the need to capture trends, attention should be paid to this issue. The Corps repeatedly said they would prefer that, whenever possible, data sets should be created that show changes over time as well as projections for areas of concern. TWRI and SSL staff attempted to identify sources of longitudinal data that could be used to generate statewide trends. It was found, however, that that the data layers needed for such trend analyses are often simply not available.

An especially intriguing part of the workshop discussions focused on exploring the types of restoration programs participants wanted the Corps to consider. Ten comments were given in this regard. Types of restoration work participants wanted the Corps to consider included the development and implementation of vegetative buffers, brush control, restoring bottomland hardwood forests, restoration of uplands and other habitats, buying out lands in floodplains, developing “soft” solutions to flood control, putting oxbows and bends back in rivers that have been channelized, removal of obsolete dams, increasing streamflows, putting more water back in streams, weather modification, and education.

Finally and perhaps most importantly, 14 of the 36 participants said during the focus groups that the processes used in this study, the methodologies used to create the maps of values plus impairments, and the cumulative maps were excellent screening tools. If all the comments about this project had been recorded (conversations during breaks or after the workshops had broken up), it would show that the vast majority of participants agreed that this project had created an excellent tool to provide an initial comparison of watersheds for prioritization efforts.

Some of these comments included the following:

“I like this process because you can see the issues in the maps and clearly identify watersheds that might be good candidates for restoration” (College Station participant).

“You’re on the right track...This process has created quality data layers that can be used to examine important issues on a watershed scale” (San Antonio participant).

“This data set outlines the issues and helps prioritize them...It gets you thinking and tells you there is a lot more work to do, but it points you in the right direction” (San Antonio participant).

“I like this project a lot and think it’s important, useful, and valuable...I will take it back to my agency and see if and how we can use it” (San Angelo participant).

**Summary and Next Steps**

This project presents comprehensive data about conditions in Texas watersheds. It represents a thorough and wide-ranging effort to gather data on watershed values (i.e., conditions that enhance the quality of water-based ecosystems) as well as watershed threats (i.e., human activities and other factors that might threaten or limit watershed quality).

The methods used to develop these data sets include the latest technological tools, such as GIS, analysis of remotely sensed data, and complex hydrologic and water use models.

Equally important, this project proposes a method through which comprehensive watershed data can be used to identify watersheds that might most need restoration efforts, by allowing stakeholders to make value judgments about the relative importance of these parameters.

Finally, the project included significant provisions for obtaining feedback from key stakeholders (i.e., scientists, water resources managers, natural resource professionals, and individuals in the private sector) to comment on whether the results of this effort have merit. At the same time, involving participants also allowed the research team to gather data about the types of watershed restoration projects that stakeholders and the public might most want to pursue.

Ultimately, it is hoped that the Corps of Engineers, other agencies, and entities pursuing environmental planning work might be able to use the data and methodologies developed in this project to identify and prioritize watersheds for in-depth restoration feasibility studies.

**Recommendations for Future Study**

At the workshops, a number of participants suggested that additional data layers could be created to further refine the prioritization tool developed in this effort. In addition, others recommended that the method used to rank watersheds might also be improved. Some of these comments are presented here as actions that could be undertaken to further develop and advance this data set and prioritization process.

It must be stated that these items are outside the scope of this study and probably cannot be developed unless additional resources are acquired.

Data could be gathered on populations of key aquatic species in watersheds,

Information could be displayed about surface- and ground-water interactions (i.e., streams that contribute to aquifer recharge, and groundwaters that increase baseflows of streams).

A map could be developed showing springs that have dried up.

A data layer is needed showing the total number of animals in CAFOs.

Threatened and endangered species could be mapped and displayed, using data from TPWD.

Maps are needed to reflect trends in land development, including the number of septic systems, the spread of subdivisions, and the miles of roads. In contrast, perhaps a dataset could be assembled about large rural land tracts that have been left intact.

In early 2004, the USDA Farm Service Agency will have data about a variety of issues concerning crop acreage, rural land use, and agricultural production. This information could be developed into data sets.

More data are needed on industrial and urban pollution. Data sets could be developed from the EPA Toxic Release Inventory and Superfund databases as well as industrial pollution permits granted by state agencies.

Maps showing Corps activities in Texas (e.g., for wetlands mitigation, flood control, and dredge and fill operations) could be created that would show opportunities to specifically mitigate some of adverse environmental affects of Corps projects.

The draft 303 (d) list could be transformed into two or more maps showing different types of impairments (bacteriological versus others).

More work needs to be done to characterize the spread of nuisance brush species throughout Texas on a statewide basis.

Additional work using the WRAP and WAM computer simulation models needs to be performed, especially in the Rio Grande, in order to provide a statewide assessment of how human activities have influenced flows.

The prioritization tool developed through this project could be used to analyze other environmental policy issues, including the positive affects of federal and state agricultural policies (i.e., CRP and EQIP) on water supplies and water quality.

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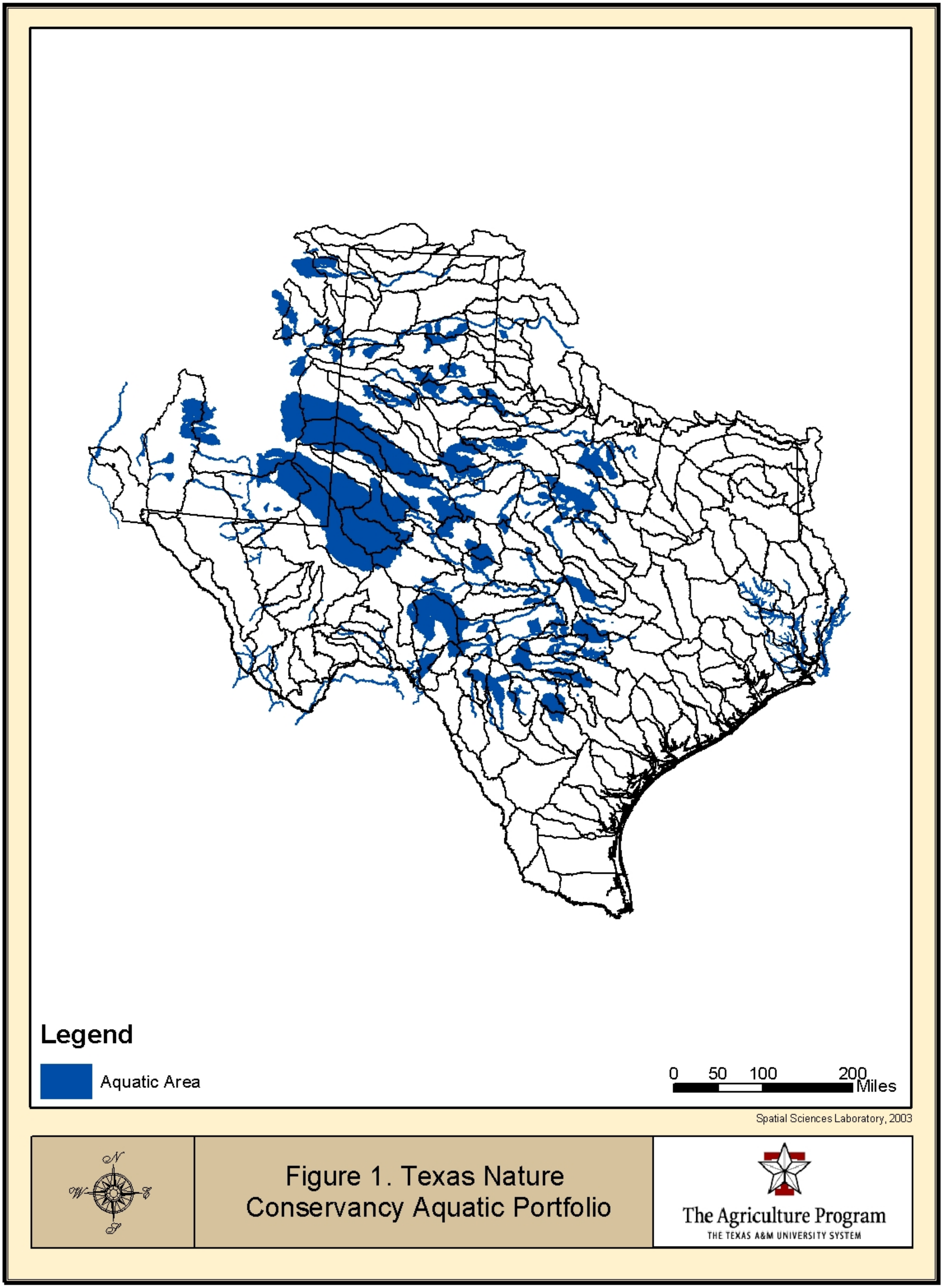


Figure 1. Texas Nature Conservancy Aquatic Portfolio

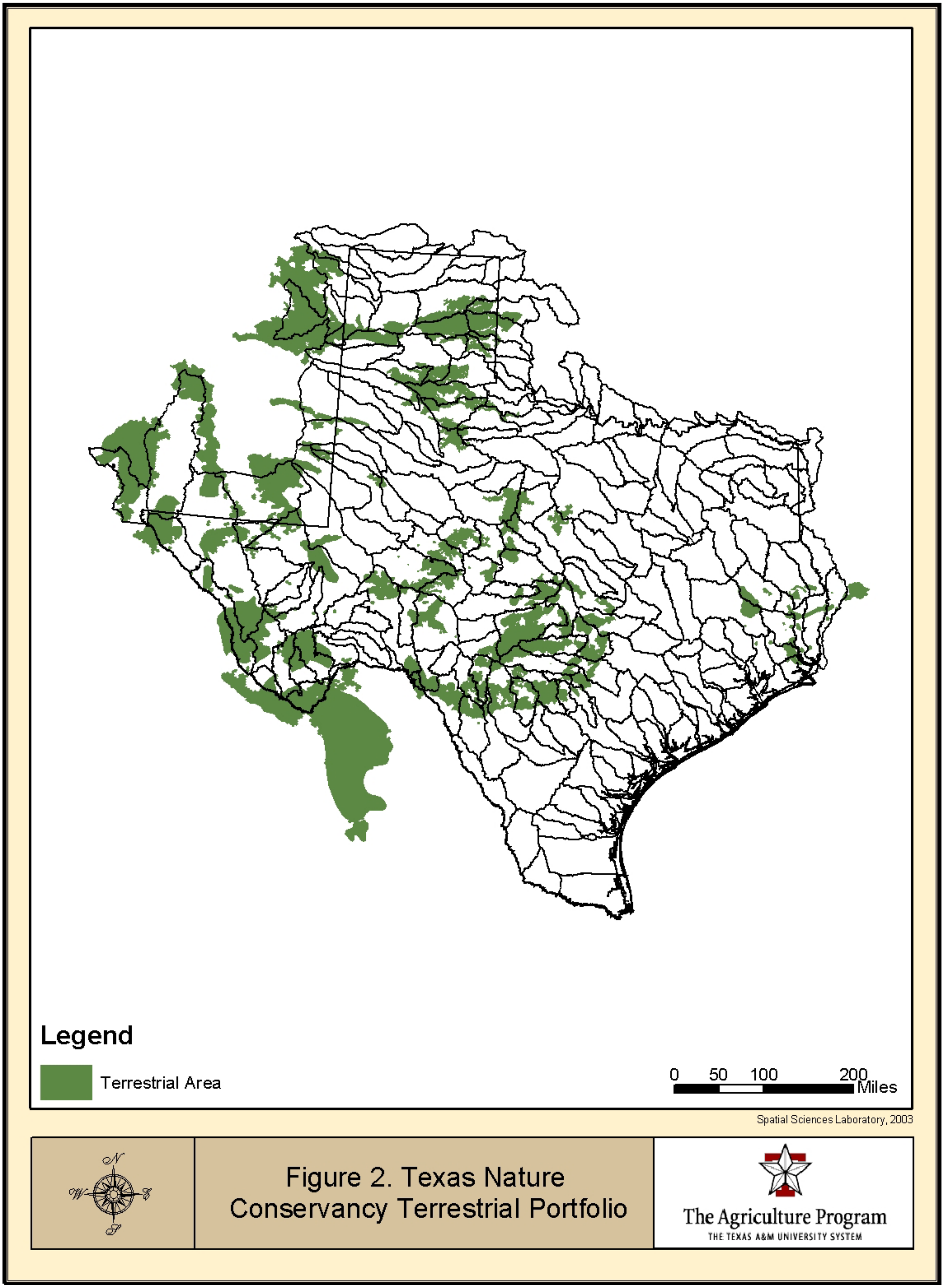


Figure 2. Texas Nature Conservancy Terrestrial Portfolio

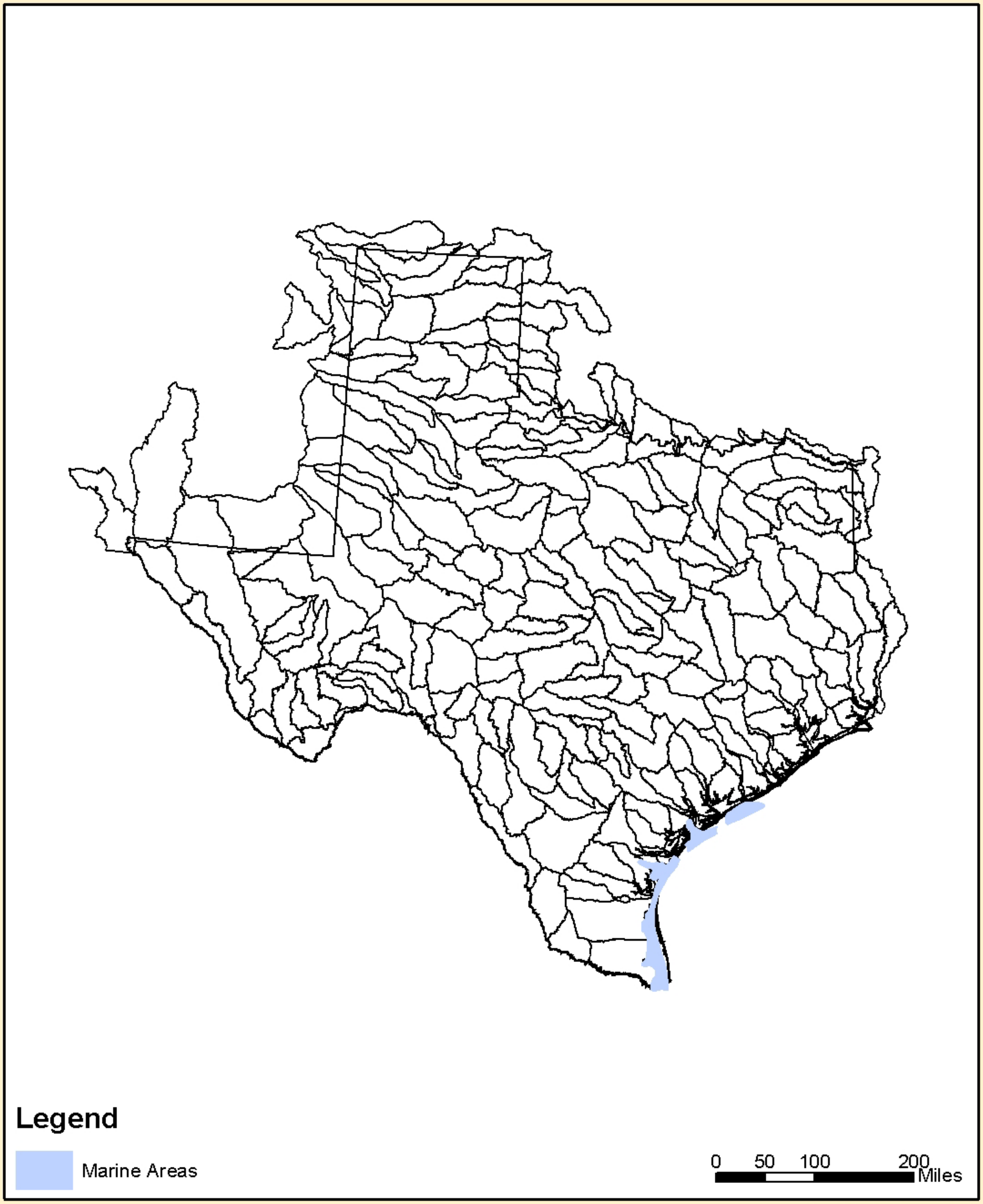


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Figure 3. Texas Nature Conservancy Marine Portfolio

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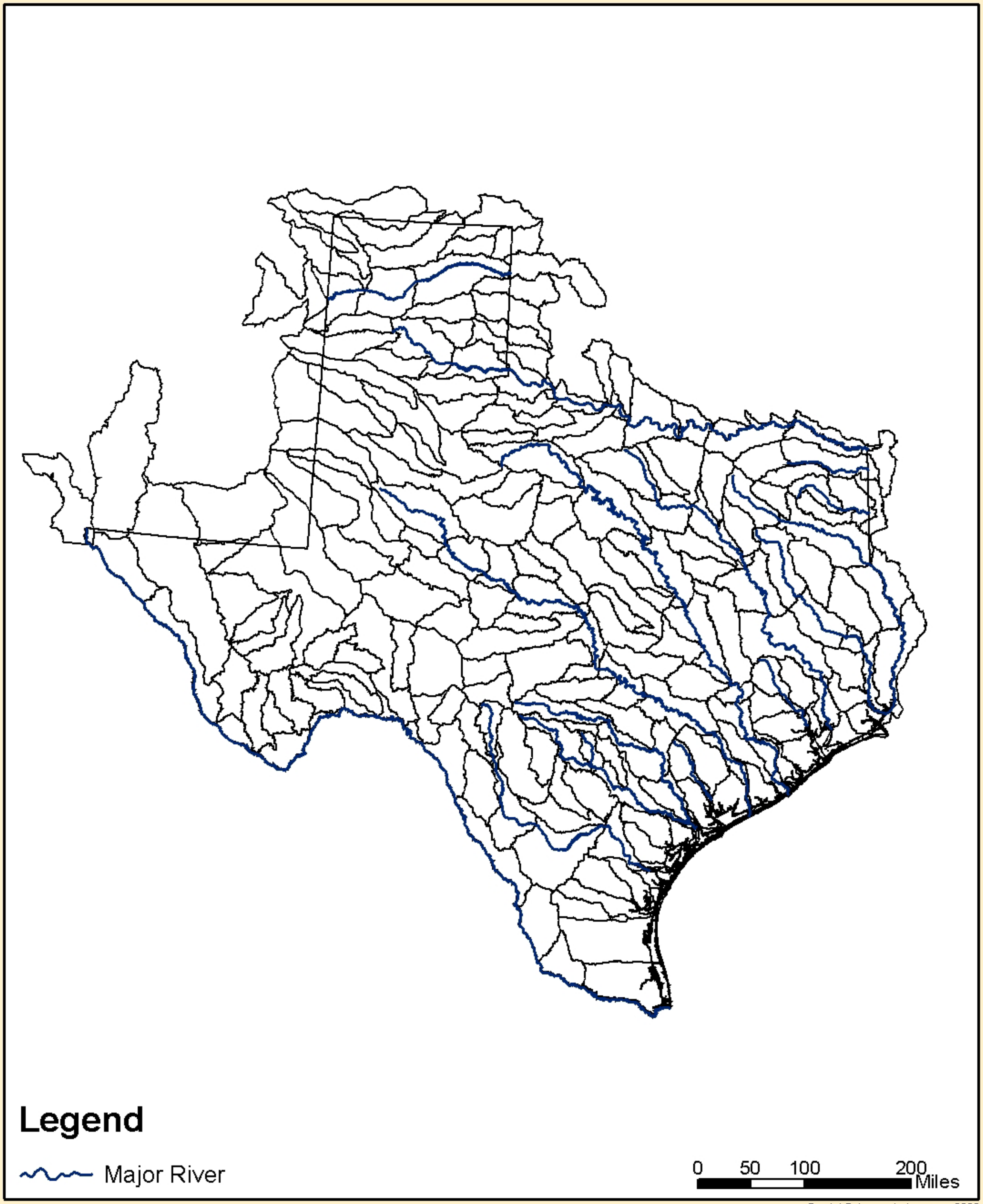


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## Figure 4. TWDB Major Rivers

Brazos, Canadian, Colorado, Cypress Creek, Guadalupe, Lavaca, Medina, Neches, Nueces, Red, Rio Grande, Sabine, San Antonio, San Jacinto, Sulphur, and Trinity

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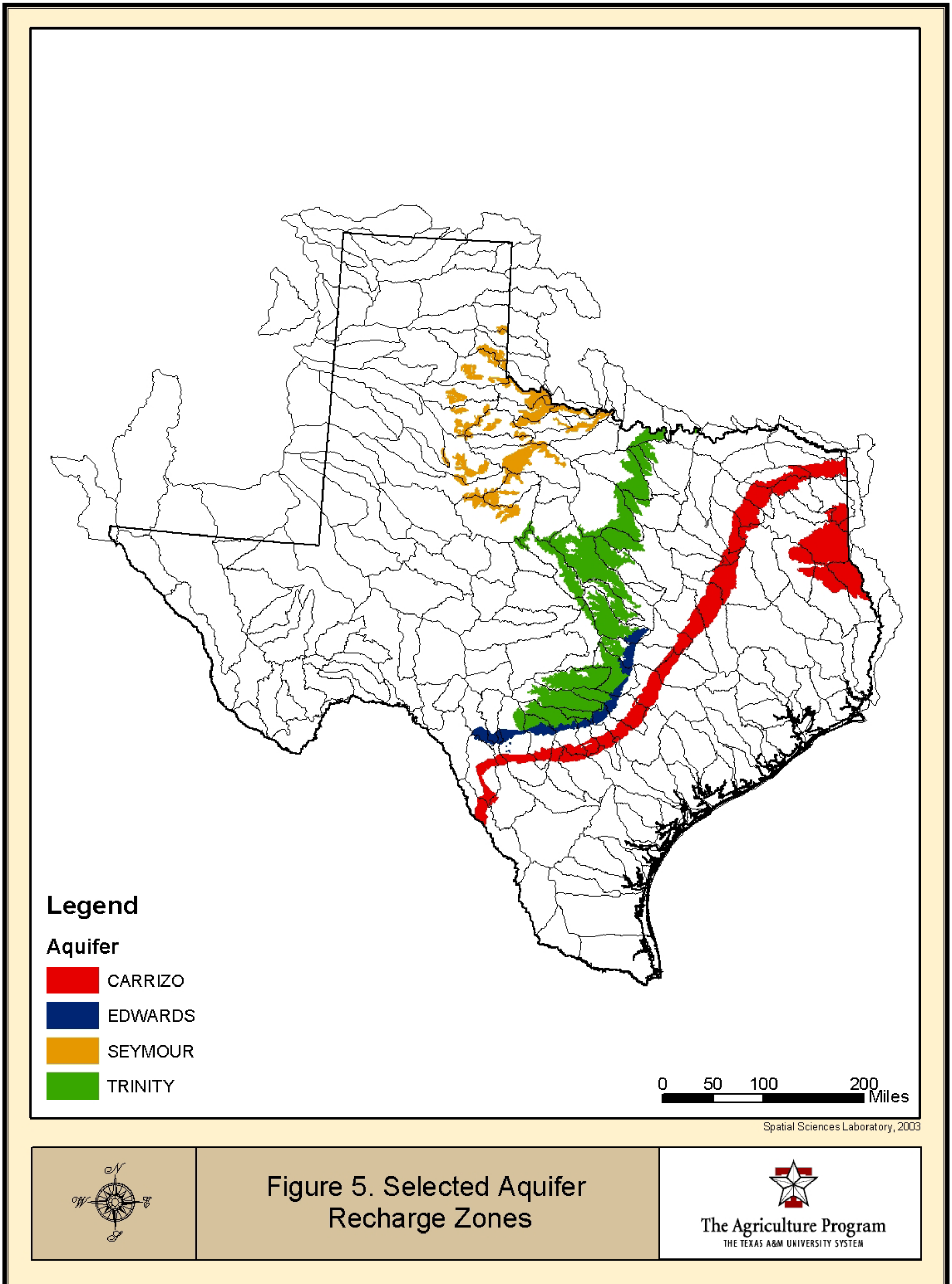


Figure 5. Selected Aquifer Recharge Zones

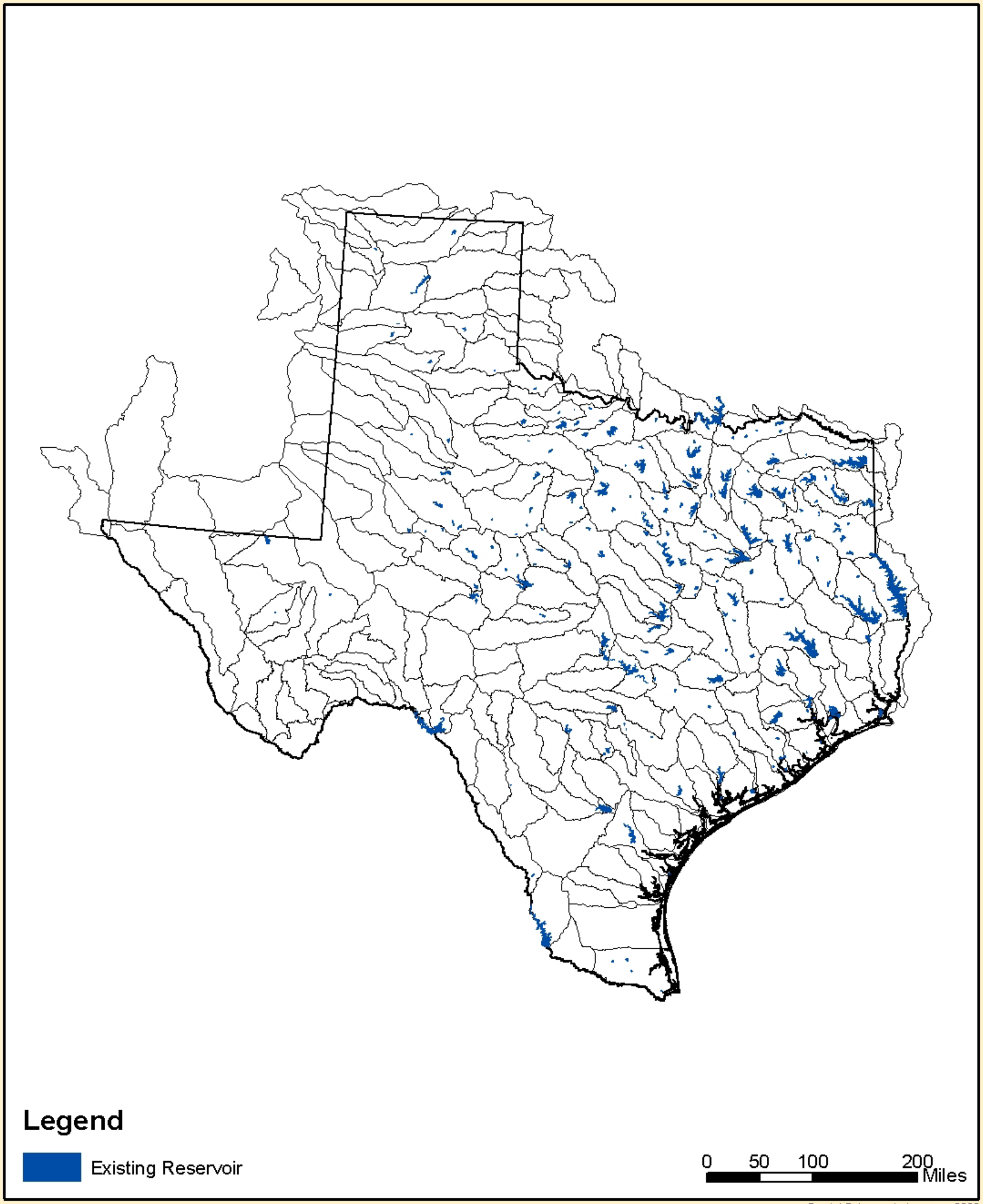


Figure 6. Existing Reservoirs

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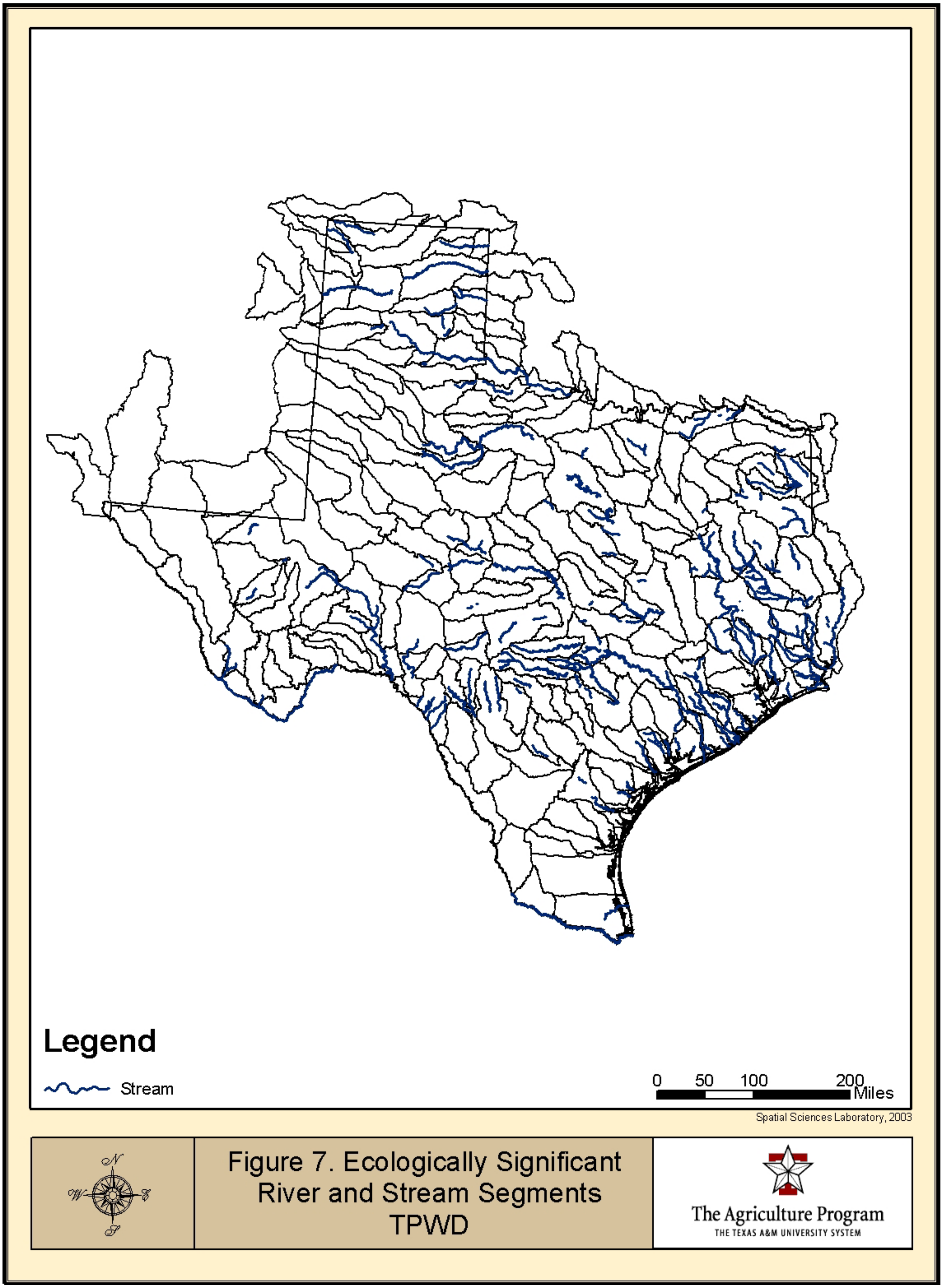


Figure 7. Ecologically Significant River and Stream Segments TPWD

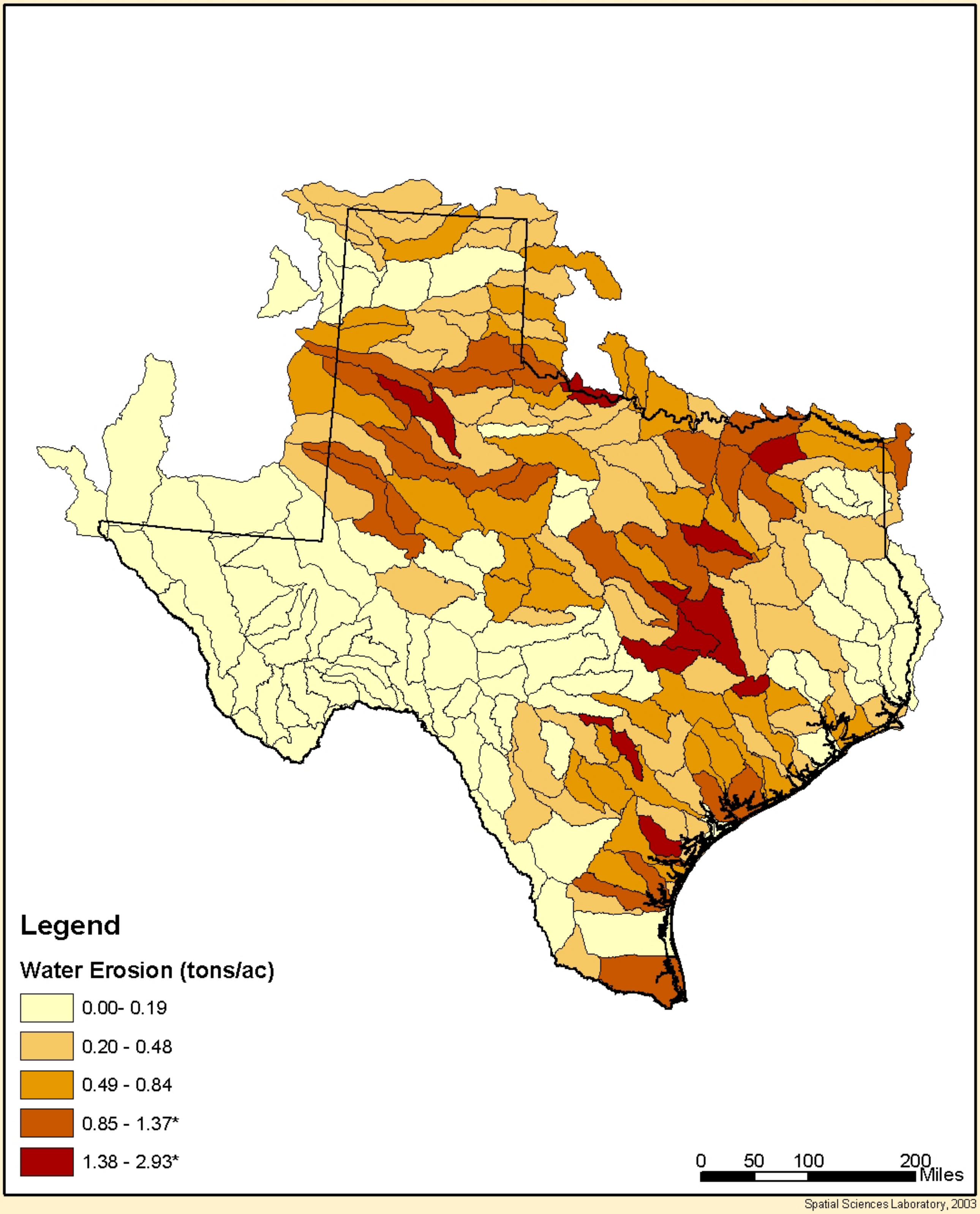


Figure 8. Total Water Erosion
USDA - NRCS
Natural Resources Inventory (NRI)

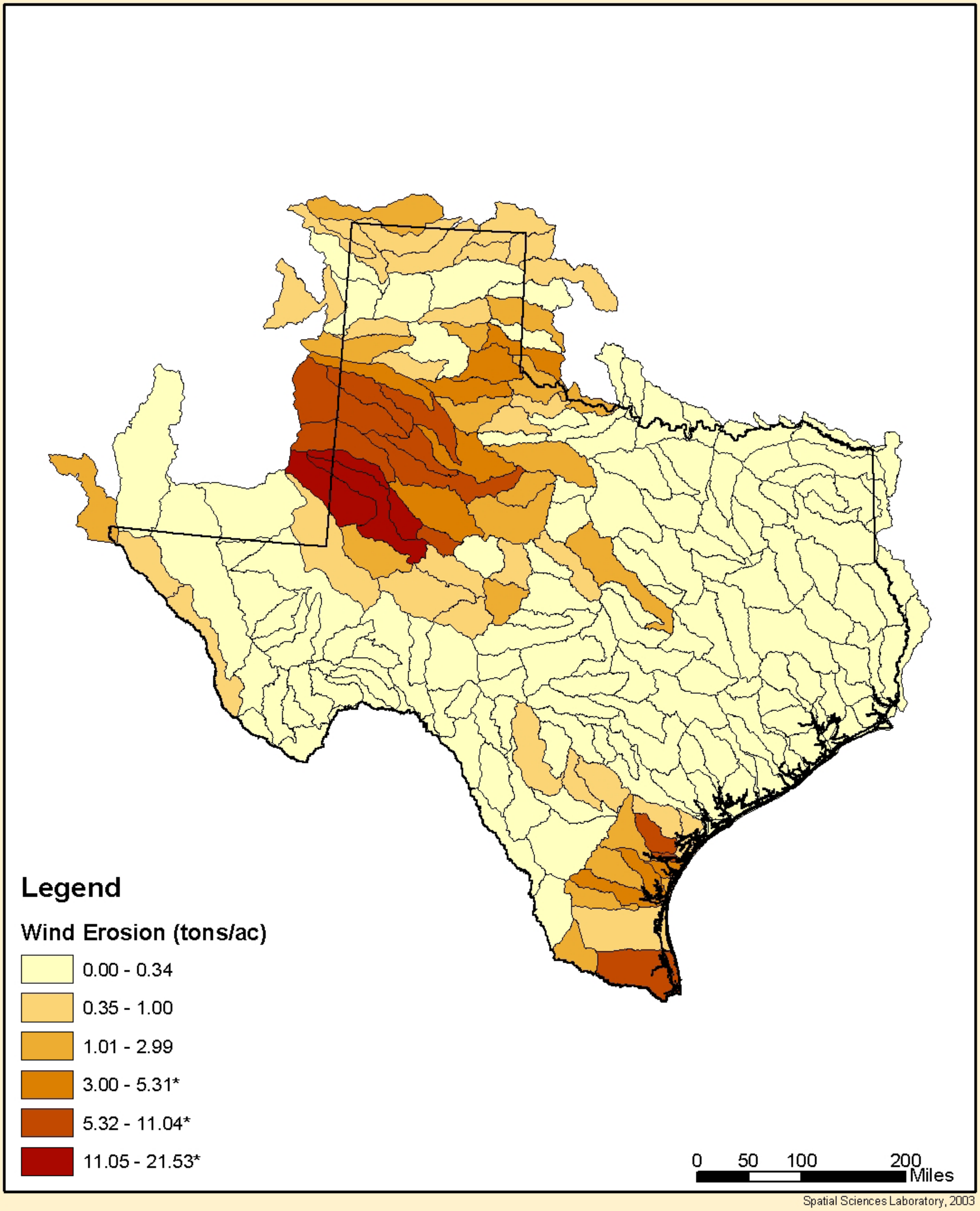


Figure 9. Total Wind Erosion
USDA - NRCS
Natural Resources Inventory (NRI)

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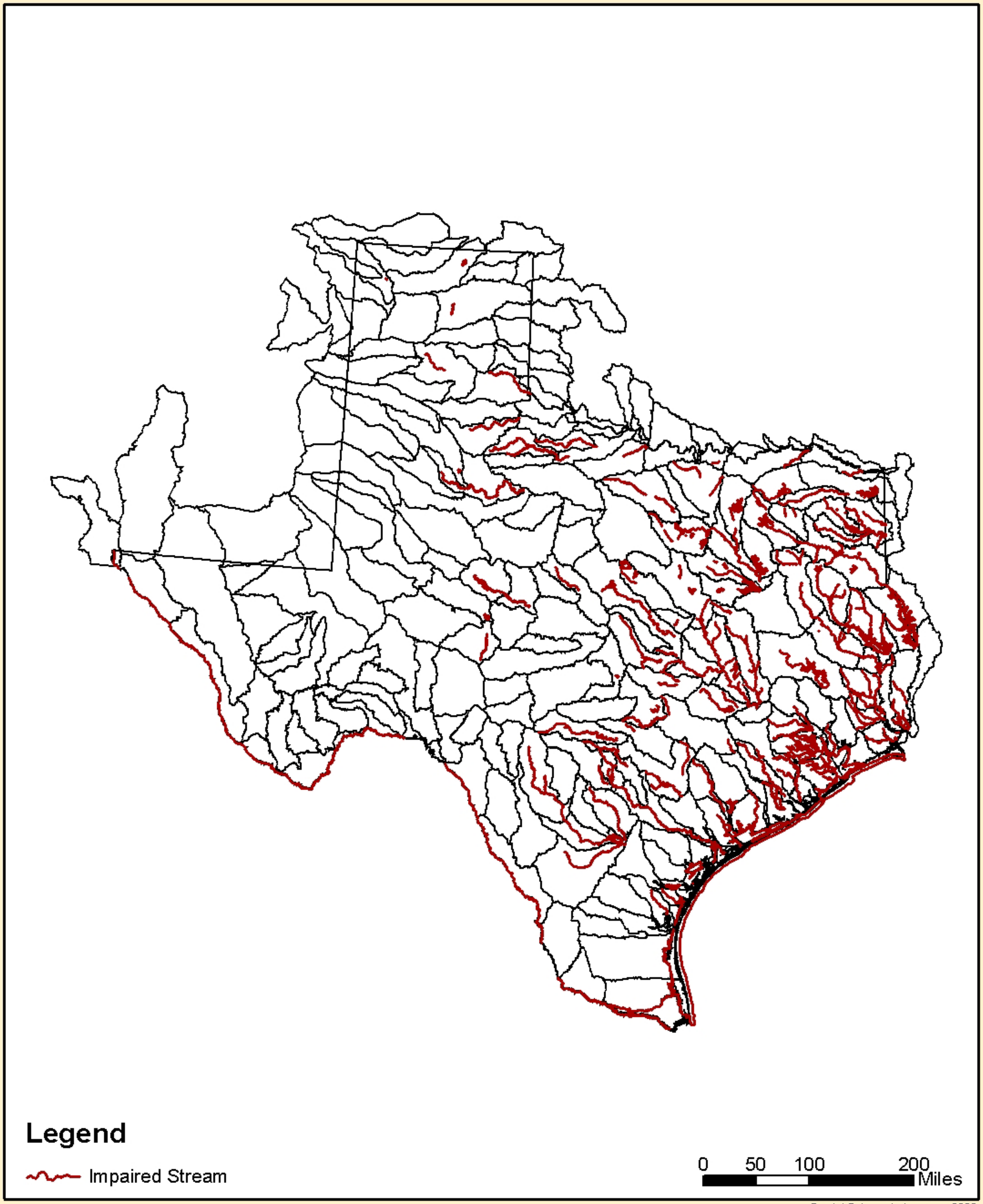


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Figure 10. Impaired Water Bodies
2002 Clean Water Act § 303(d)
TCEQ

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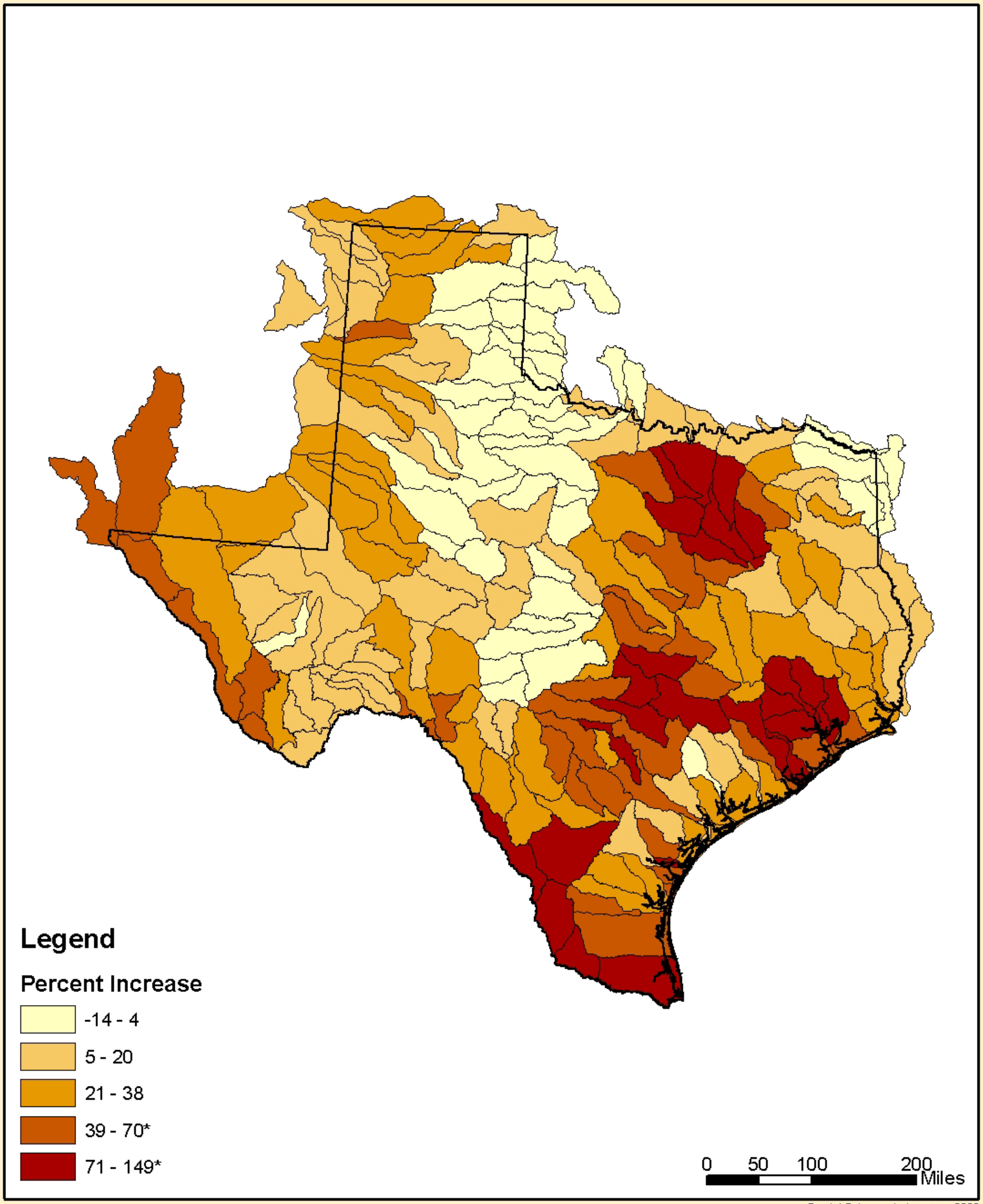


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Figure 11. Average Projected Percent Population Increase per HUC from 2000 to 2040

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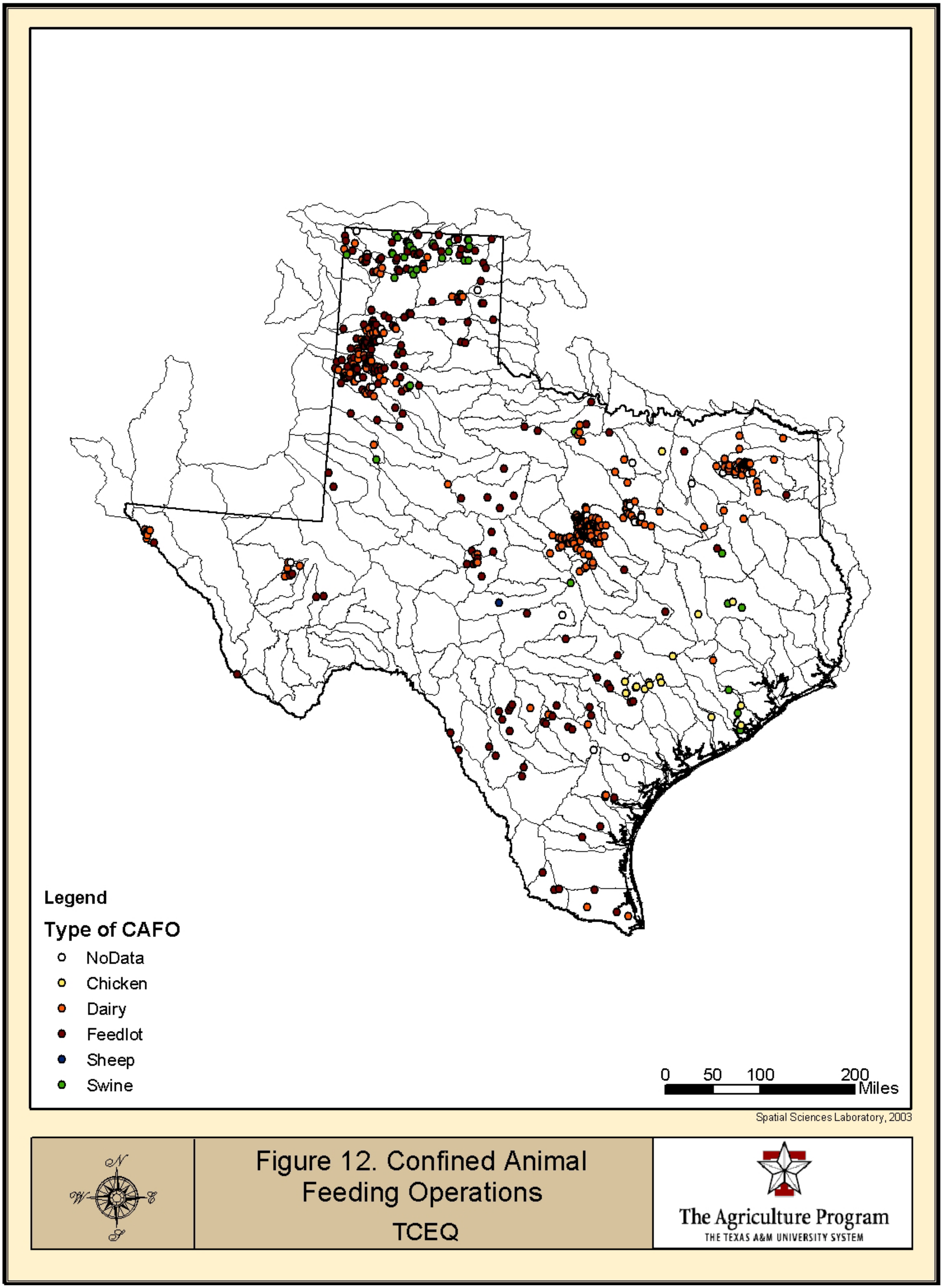


Figure 12. Confined Animal Feeding Operations

TCEQ

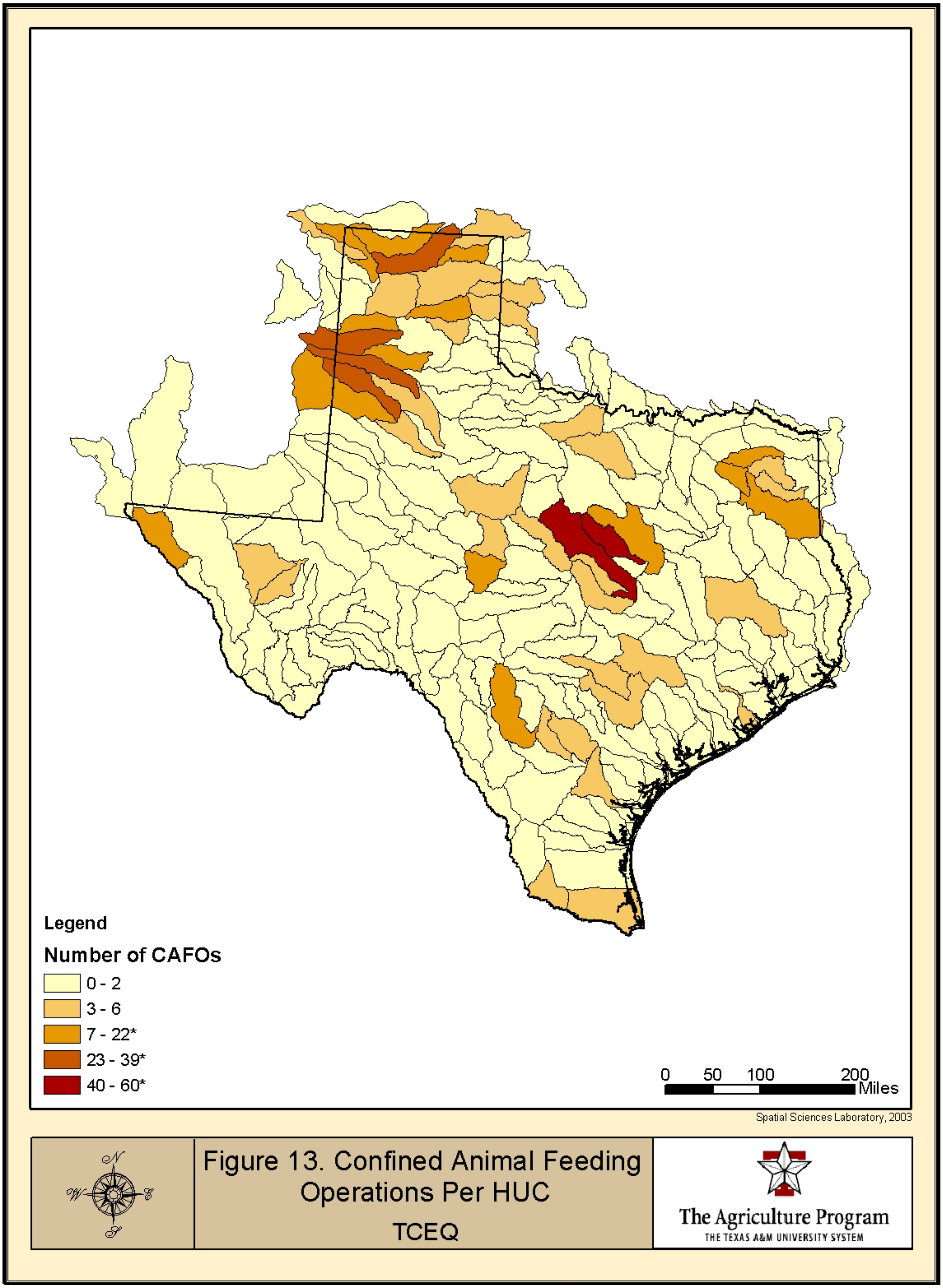


Figure 13. Confined Animal Feeding Operations Per HUC

TCEQ

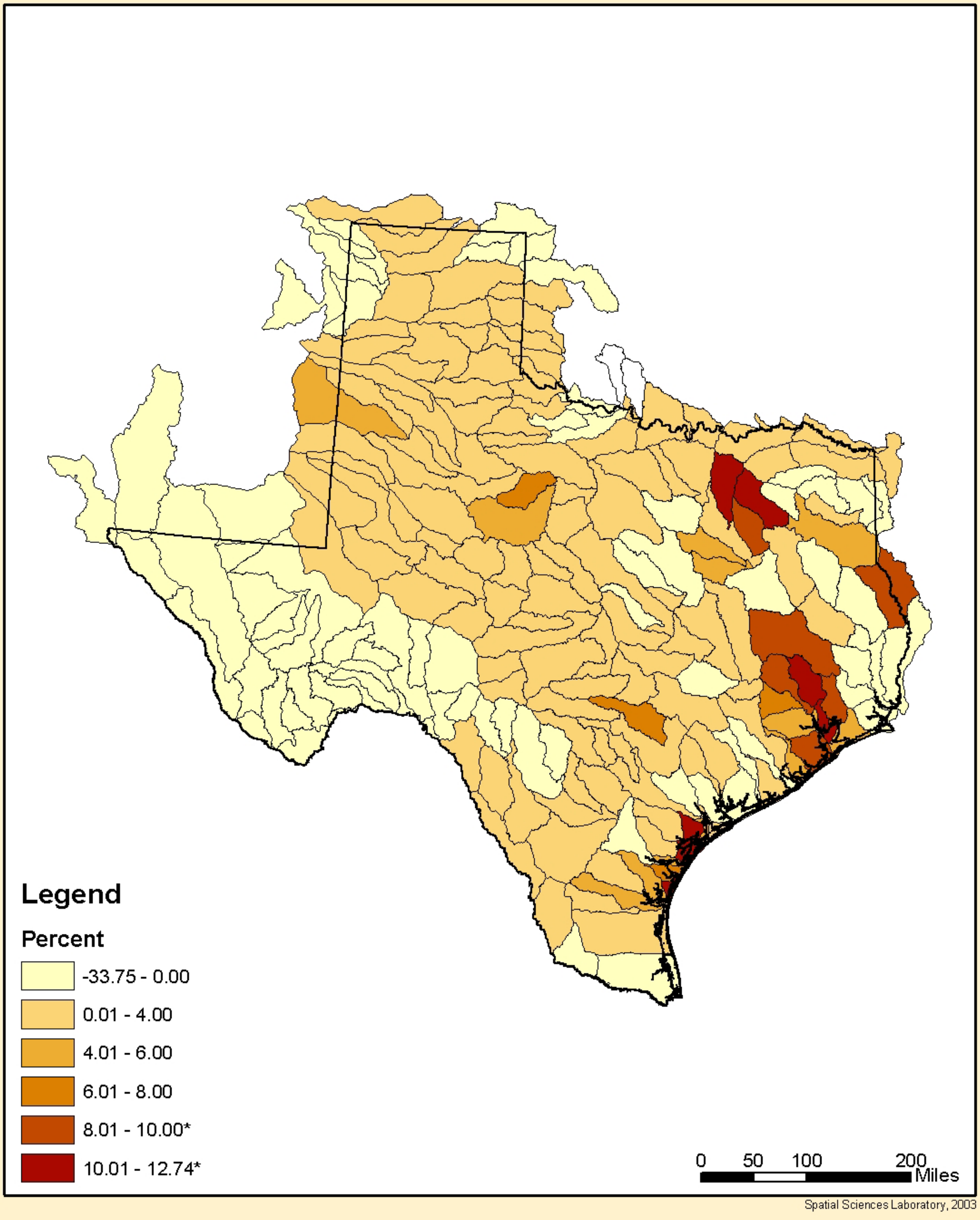


Figure 14. Fragmentation Index

Average Percent Increase in Ranches Less than 500 acres

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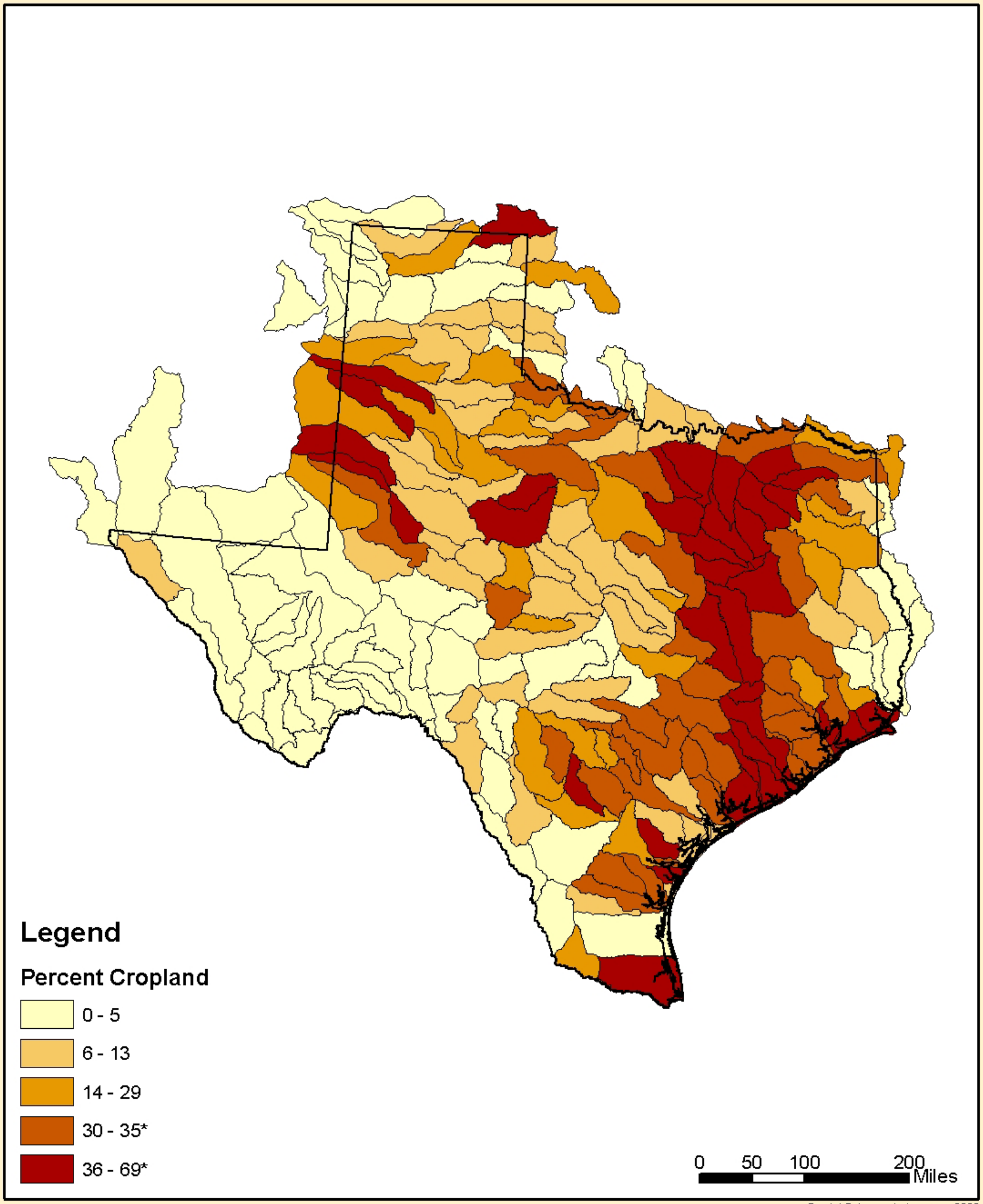


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Figure 15. Percent Cropland within 120 m of NHD Streams NLCD Landuse - USGS

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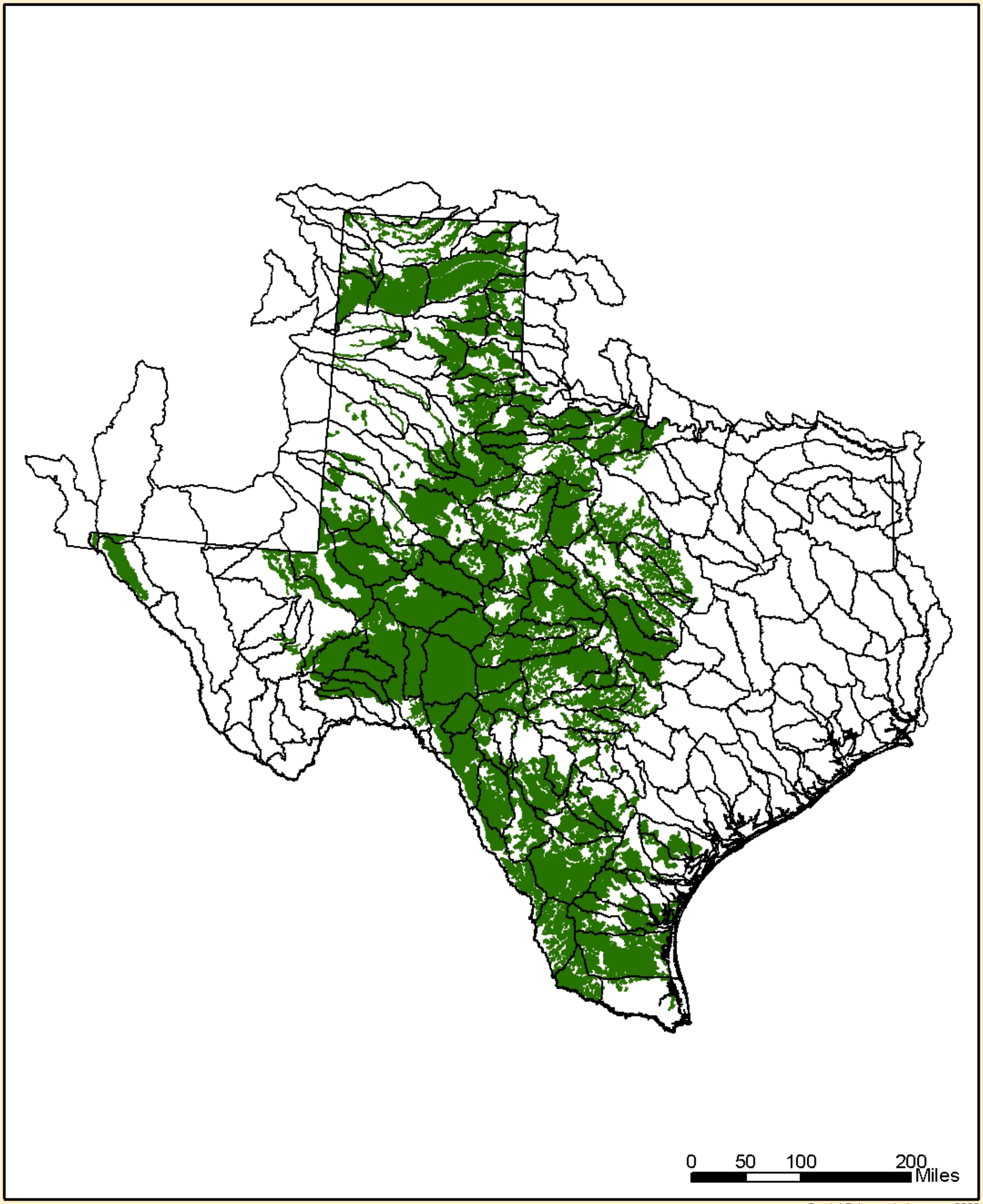


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Figure 16. Mesquite
TPWD Vegetation Types of Texas
1984

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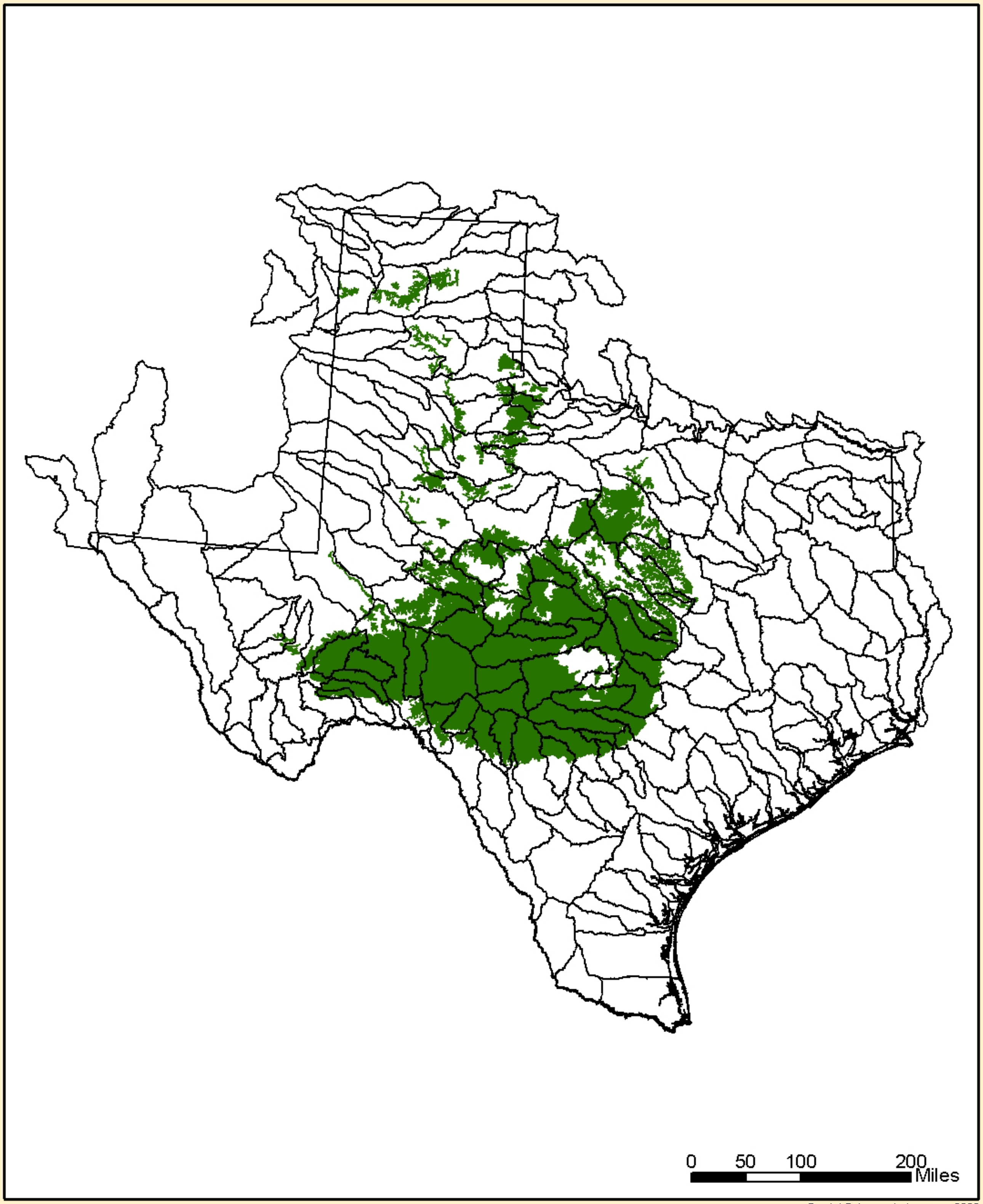


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Figure 17. Juniper
TPWD Vegetation Types of Texas
1984

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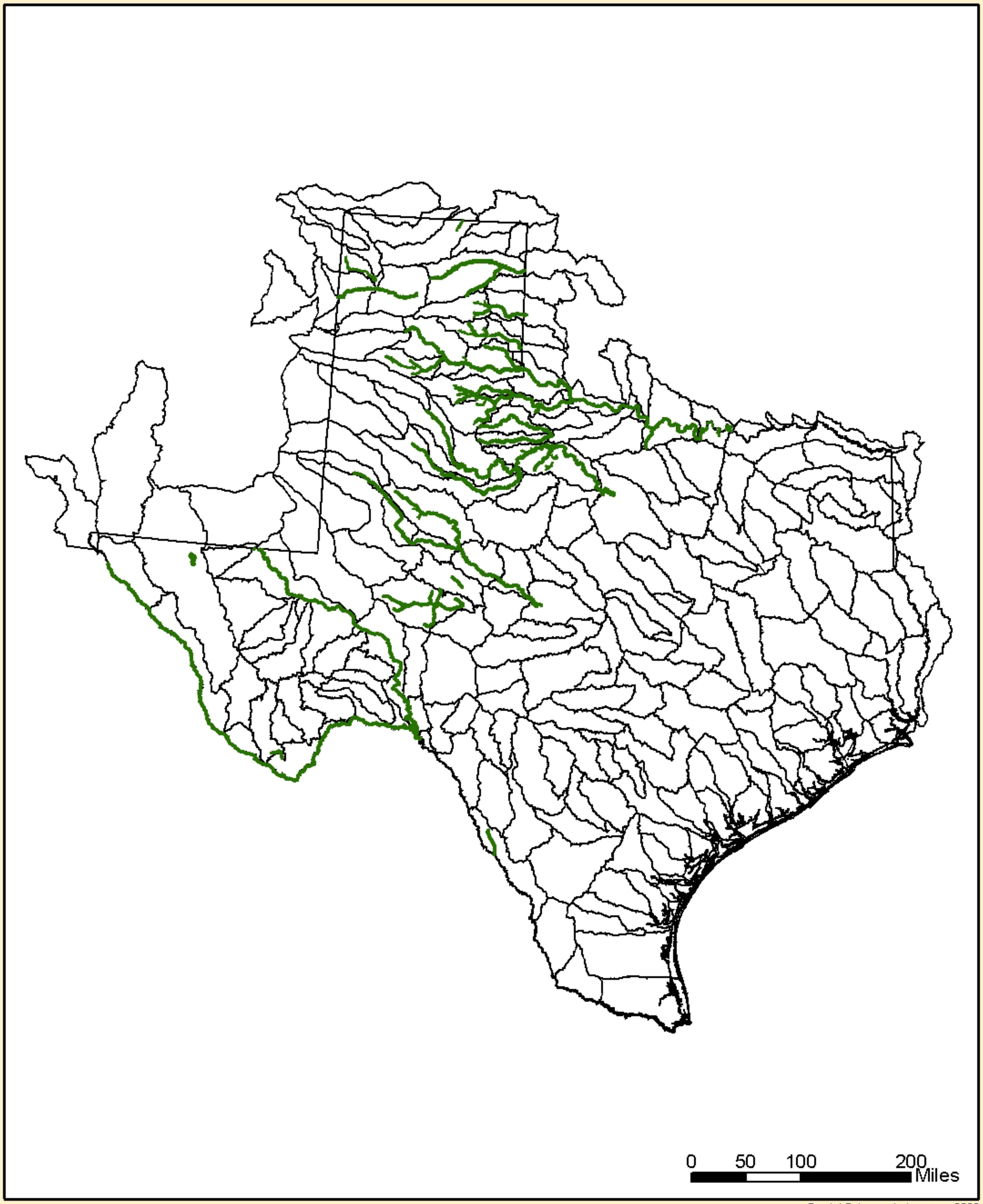


Figure 18. Salt Cedar
TPWD Vegetation Types of Texas 1984; NRCS Brush Survey 1982

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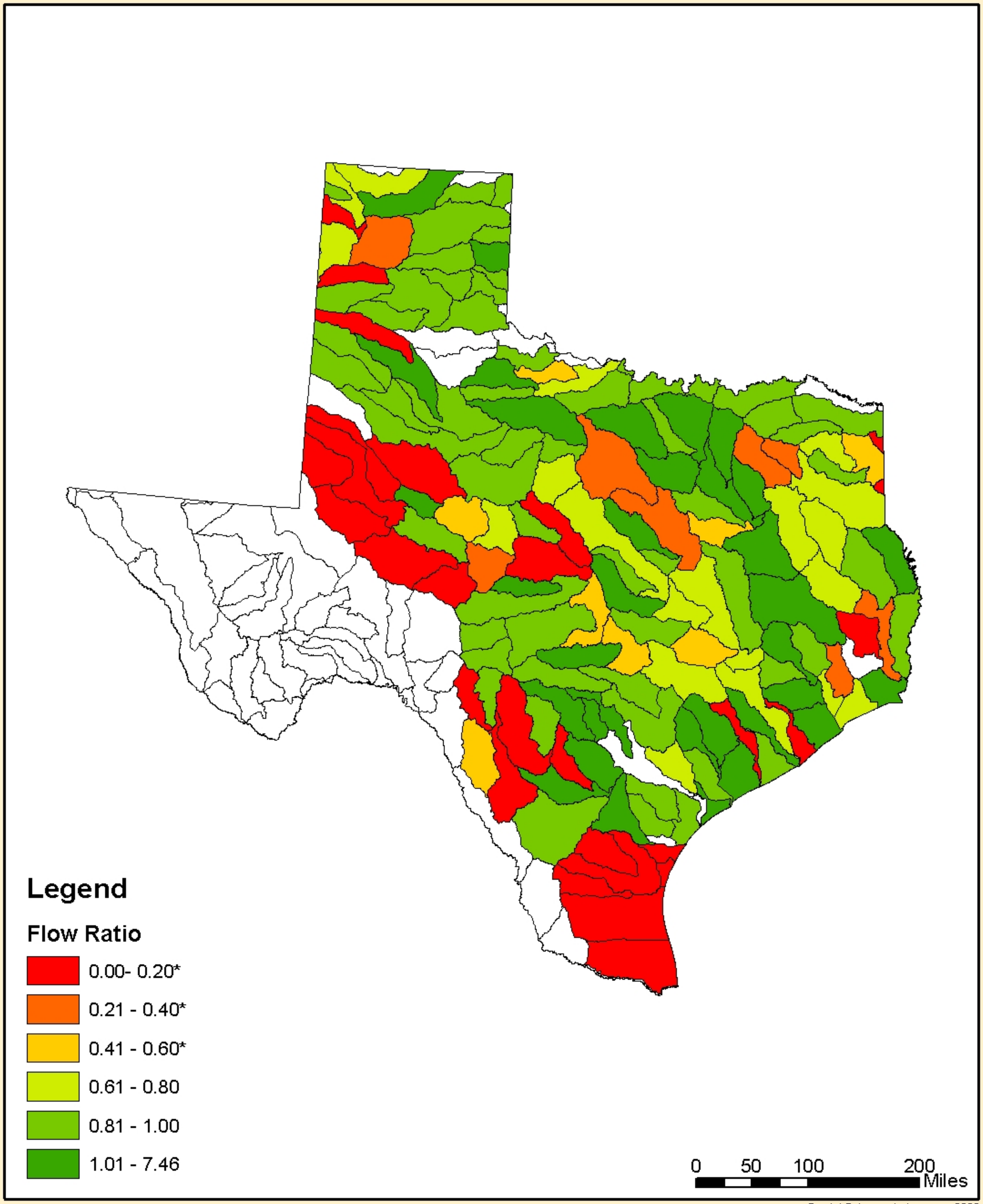


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Figure 19. Ratio of Regulated to Naturalized Flow (ac/ft per month) During Low Flow Conditions

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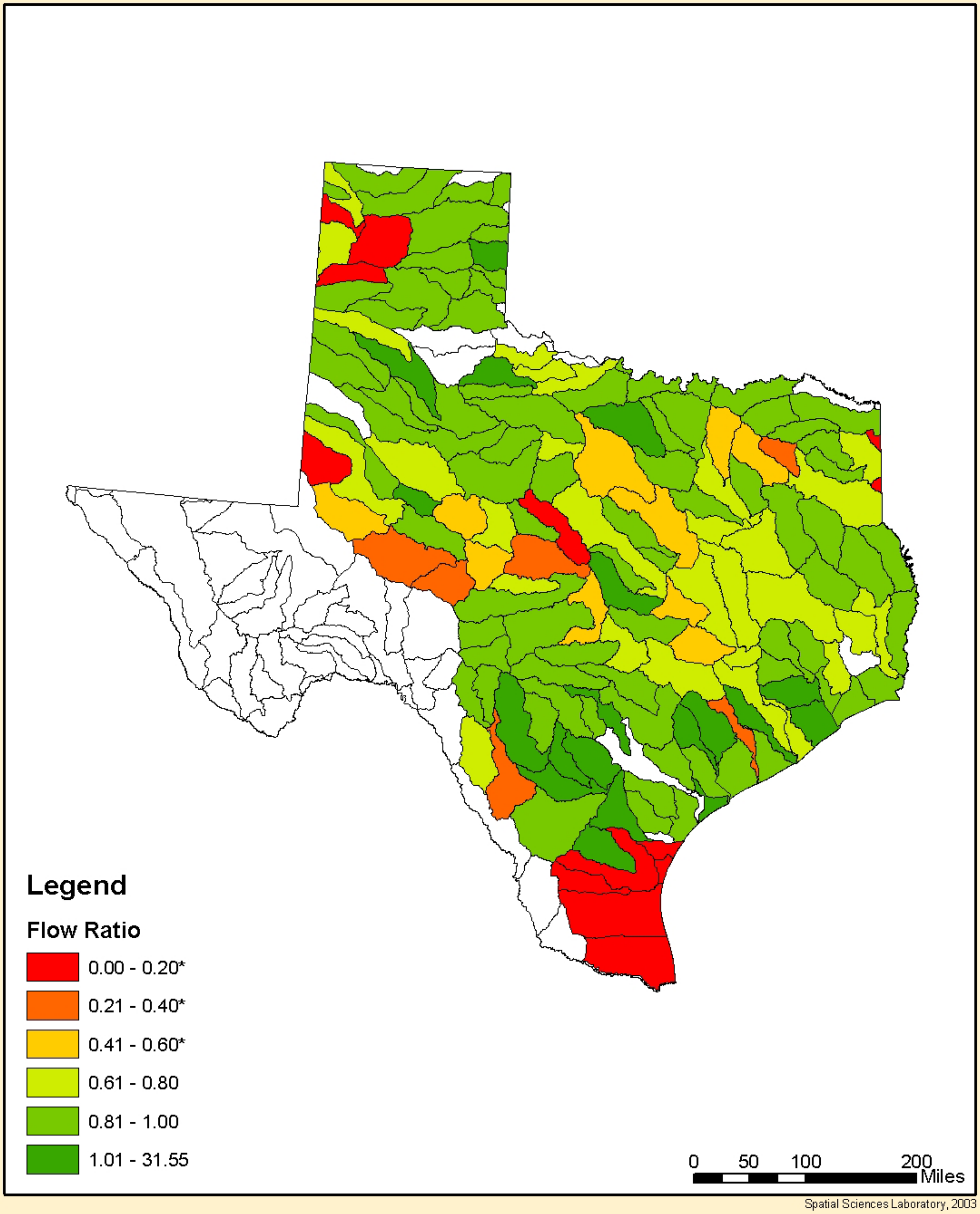


Figure 20. Ratio of Regulated to Naturalized Flow (ac/ft per month) During Median Flow Conditions

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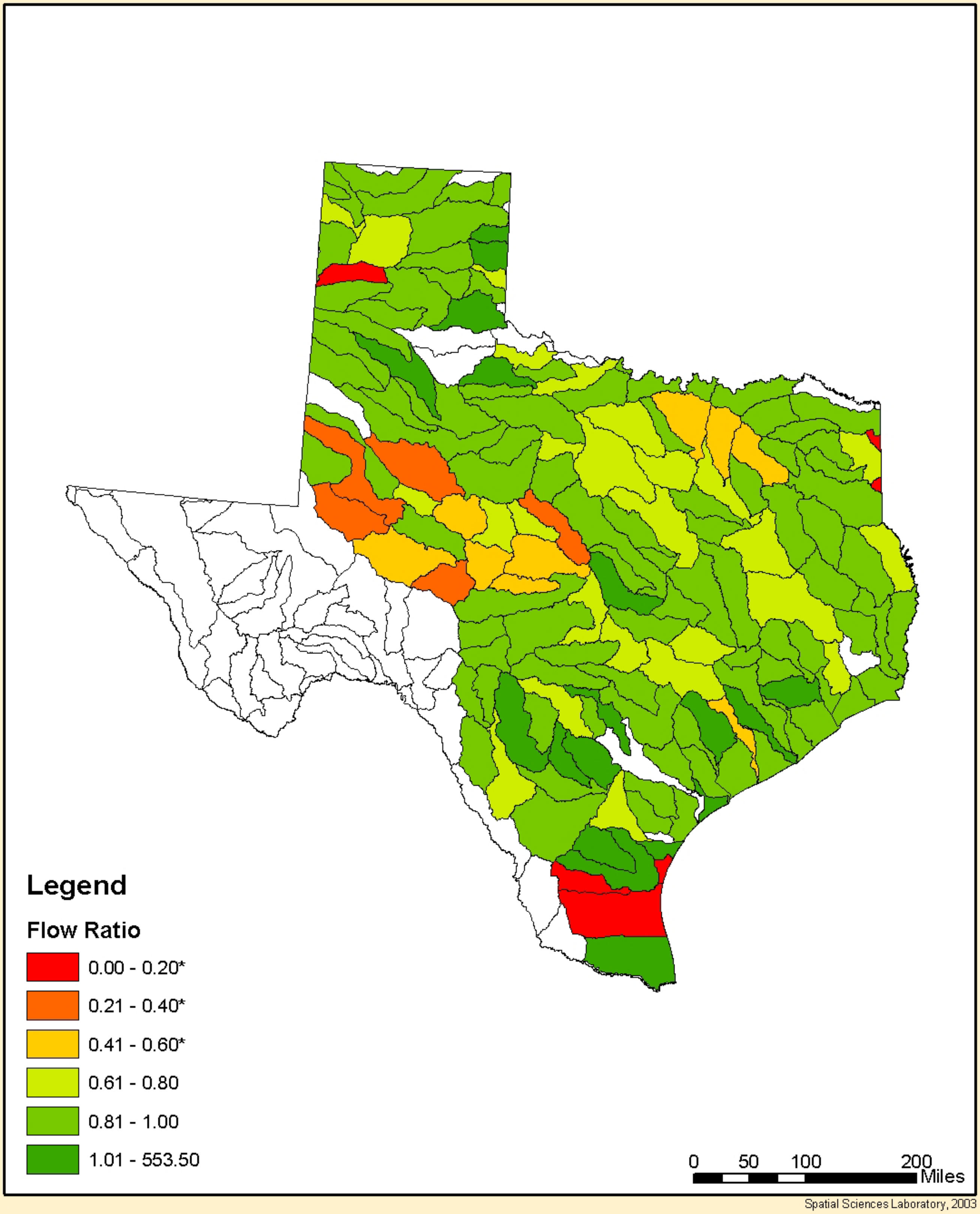


Figure 21. Ratio of Regulated to Naturalized Flow (ac/ft per month) During High Flow Conditions

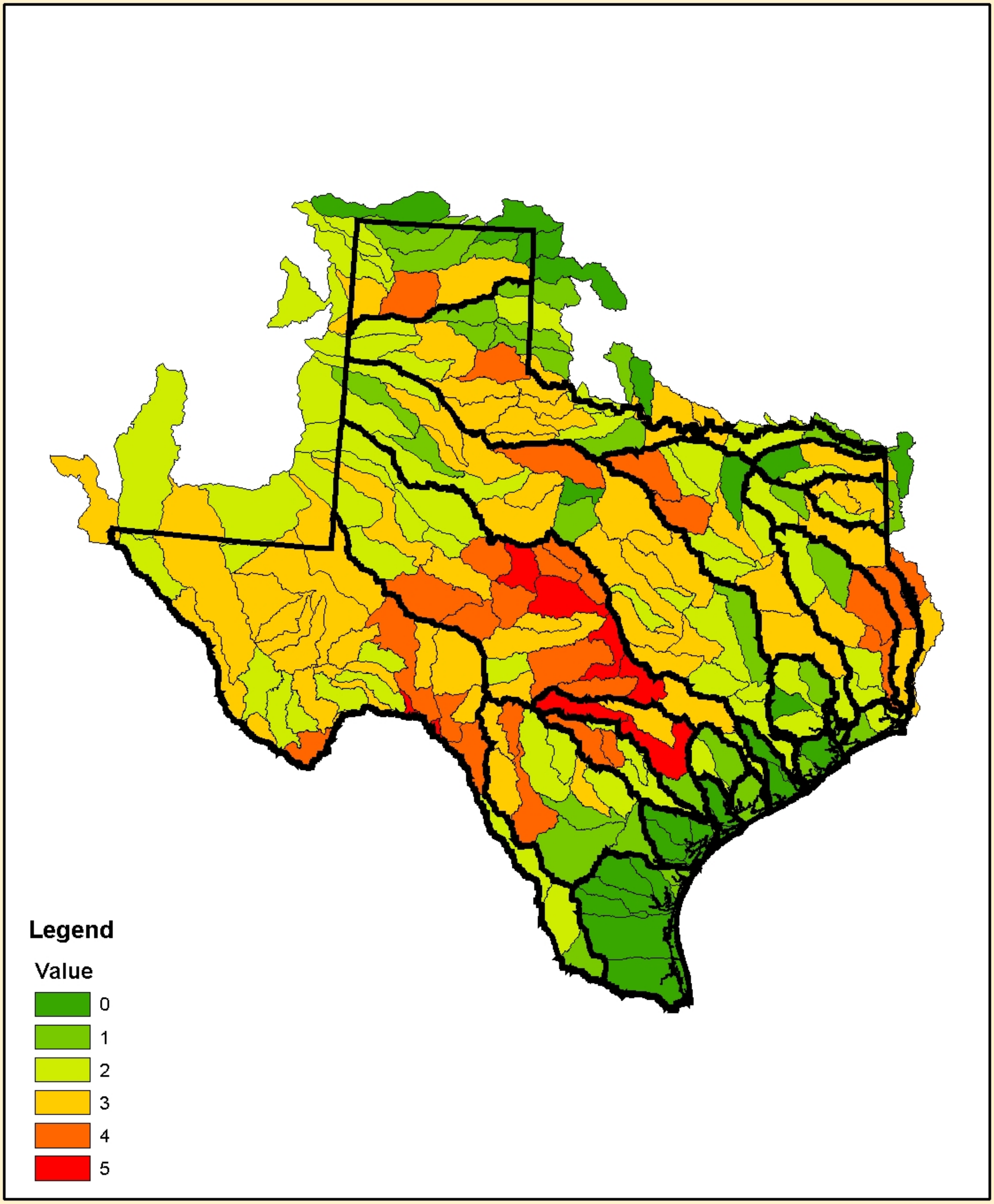


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**Figure 22. Texas Watershed Value Index**

Major Rivers, Aquifer Recharge Zones, Existing Reservoirs, and Critical Stream Segments

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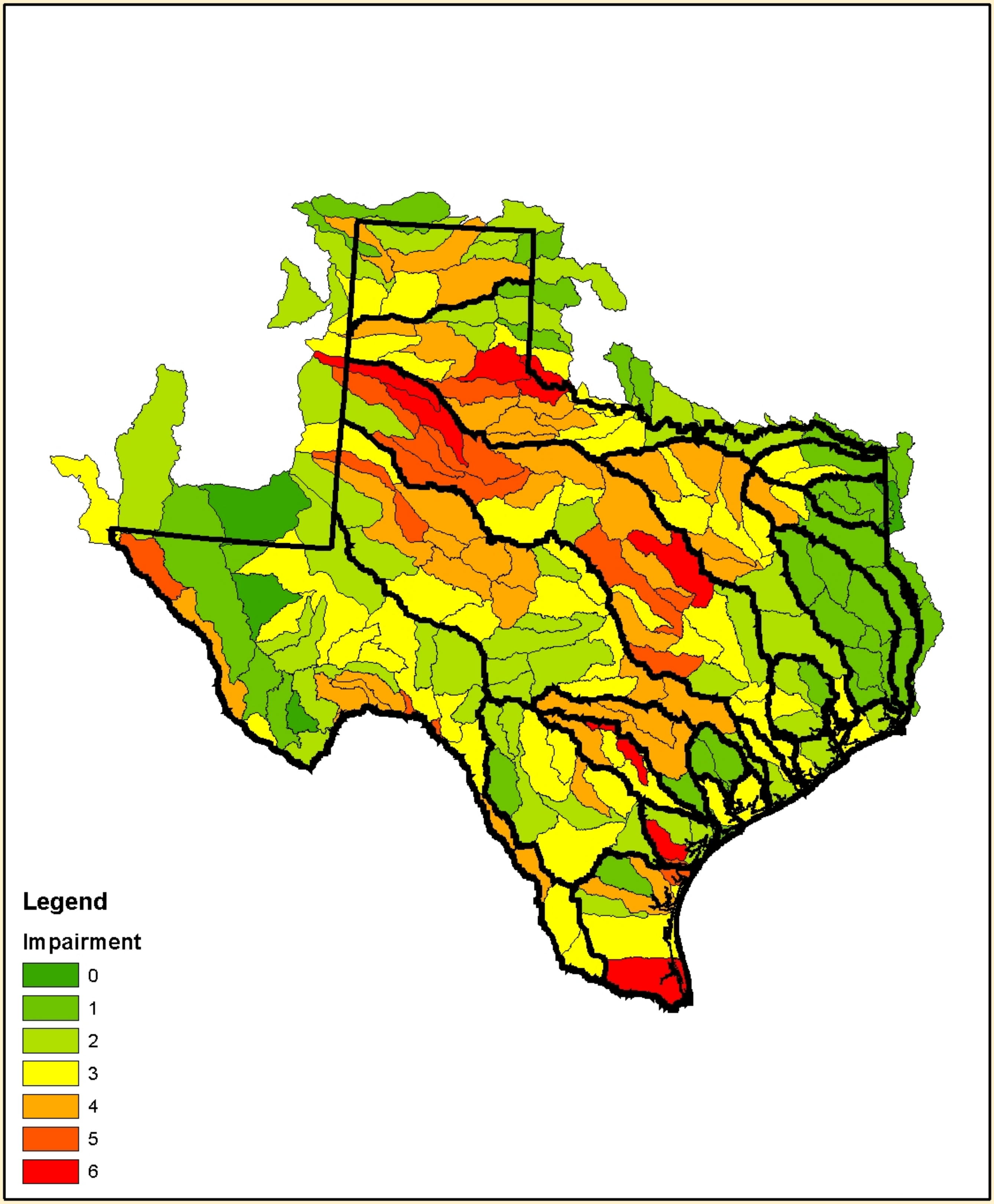


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**Figure 23. Texas Watershed Impairment Index**
Riparian Cropland, High Population Change, Impaired Streams, Soil Erosion (Wind and Water), CAFOs, and Invasive Brush Species

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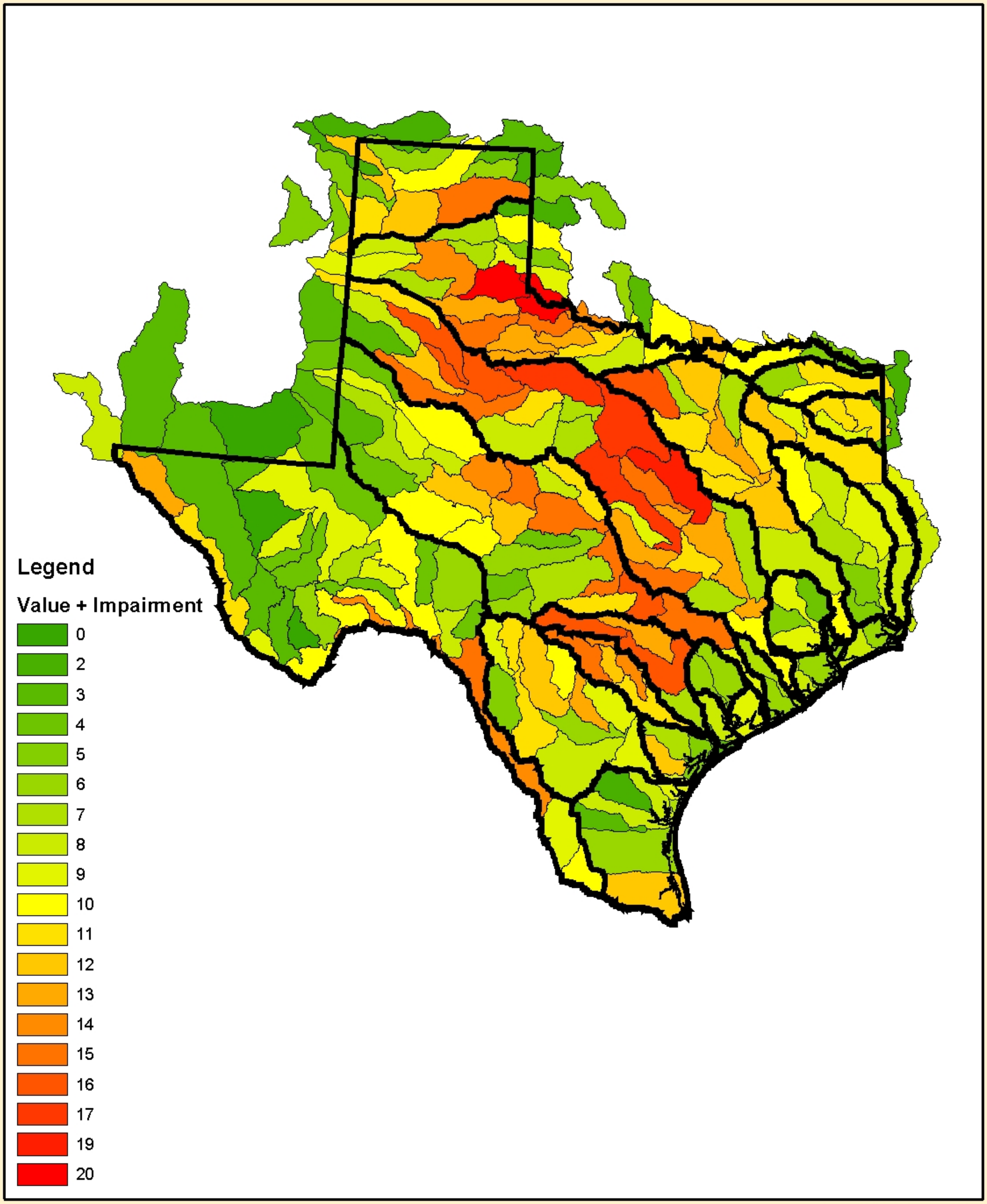


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**Figure 24. Weighted Texas Watershed Value + Impairment Index**

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Table 1. Weighted Value Parameters.

| | Major Rivers 32%* | Aquifer Recharge Zone 39% | Existing Reservoirs 29% | Critical Stream Segments 50% |
|---|---|---|---|---|
| Weighted Average | 2 | 3 | 1 | 2 |

Table 2. Weighted Impairment Parameters.

| | Total Water Erosion/HUC area (NBV > 0.85) 16% | Total Wind Erosion/HUC area (NBV > 3) 10% | Impaired Streams w/in Watershed Boundary 60% | Average projected percent population change from 2000 -2040 (NBV > 38%) 29% | Number of CAFOs within Watershed Boundary 7% | Percent Cropland in 120 m buffer area (NBV > 0.3) 20% | Invasive Brush Species Mesquite 67% | Invasive Brush Species Juniper 39% | Invasive Brush Species Salt Cedar 32% |
|---|---|---|---|---|---|---|---|---|---|
| Weighted Average | 2 | 1 | 3 | 1 | 2 | 1 | 2 | 2 | 3 |

* represents the percentage of total watersheds identified as having significant threats or values for each parameter.

Figure 25. River Basin Reference Map

Figure 26. HUC Reference Map