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Aquatic Ecosystems, Water Quality, and Global Change: Challenges of Conducting Multi-stressor Global Change Vulnerability Assessments

National Center for Environmental Assessment
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PREFACE

This report investigates the issues and challenges associated with identifying, calculating, and mapping indicators of the relative vulnerability of water quality and aquatic ecosystems, across the United States, to the potential adverse impacts of external forces such as long-term climate and land-use change. We do not attempt a direct evaluation of the potential impacts of these global changes on ecosystems and watersheds. Rather, we begin with the assumption that a systematic evaluation of the impacts of existing stressors will be a key input to any comprehensive global change vulnerability assessment, as the impacts of global change will be expressed via often complex interaction with such stressors: through their potential to reduce overall resilience, or increase overall sensitivity, to global change. This is a well established assumption, but to date there has been relatively little exploration of the practical challenges associated with comprehensively assessing how the resilience of ecosystems and human systems in the face of global change may vary as a function of existing stresses and maladaptations. The work described in this report is a preliminary attempt to begin such an exploration.

To do so we gathered, from the literature, a set of more than 600 indicators of water quality and aquatic ecosystem condition and changes in condition, along with numerous datasets from EPA, other federal agencies, and NGOs, and we have used all of this as a testbed for identifying best practices and challenges for calculating and mapping vulnerability nationally. We investigated gaps in ideas, methods, data, and tools as well. Specifically, we explored:

- Challenges associated with identifying those indicators that speak specifically to vulnerability, as opposed to those reflecting simply a state or condition;

- Challenges associated with calculating and estimating the values of these vulnerability indicators, including establishing important indicator thresholds that reflect abrupt or large changes in the vulnerability of water quality or aquatic ecosystems;

- Challenges associated with mapping these vulnerability indicators nationally, including data availability and spatial aggregation of the data; and

- Challenges associated with combining and compositing indicators and developing multi-indicator indices of vulnerability.

We hope that this report will be a useful building block for future work on multi-stressor global change vulnerability assessments. Ultimately, we believe the work described here can contribute to bridging disconnects between the decision support needs of the water quality and aquatic ecosystem management communities and the priorities and capabilities of the global change science data and modeling communities. In addition, we hope it will help to synthesize lessons learned from more detailed, place-based, system-based, or issue-based case studies. Such studies include those conducted on individual watersheds, on wetlands, and on urban ecosystems. This synthesis will be used to obtain national-scale insights about impacts and adaptation; and to prioritize future work in developing adaptation strategies for global change impacts.

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AUTHORS, CONTRIBUTORS, AND REVIEWERS

AUTHORS

Julie Blue   The Cadmus Group, Inc.
Nupur Hiremath
Jeff Maxted
Matthew Diebel
Charles Hernick
Jonathan Koplos

Chris Weaver   EPA/ORD/NCEA

CONTRIBUTORS

David Allan   University of Michigan
John Day   Louisiana State University
Thomas Meixner   University of Arizona

David Gochis   National Center for Atmospheric
Kathleen Miller   Research
David Yates

EPA REVIEWERS

Robert Hall   EPA/R9
Rachael Novak   EPA/OW/OST
Douglas Norton   EPA/OW/OWOW
Betsy Smith   EPA/ORD/NERL
Rick Ziegler   EPA/ORD/NCEA

EXTERNAL PEER REVIEWERS

Paul H. Kirshen   Battelle Memorial Institute
Michael Mallin   Center for Marine Science\ University of
                                                North Carolina at Wilmington
Hans Paerl   University of North Carolina at Chapel Hill
                                                Institute of Marine Sciences

1. INTRODUCTION

The U.S. Environmental Protection Agency (EPA) Global Change Research Program (GCRP), located within the Office of Research and Development (ORD), is a national-scale program that supports decision-making about adapting to potential climate change and other global change impacts on air and water quality, aquatic ecosystems, and human health. GCRP collaborates with EPA Program and Regional offices, and state, local, municipal, and tribal natural resource managers, to provide scientific support for these efforts. There is a large body of literature suggesting that improvements to measuring, modeling, and understanding climate changes relevant to the hydrologic cycle, water quality, and aquatic ecosystems are needed (e.g., Barsugli et al., 2009; Bates et al., 2008; Lettenmaier et al., 2008; Kundzewicz et al., 2007; Miller and Yates, 2005; Poff et al., 2002). The management strategies of the past will not necessarily be adequate given increased awareness of stressors such as climate change and land-use change. As emphasized by a number of recent publications, top-down, prediction-based assessments of the interactions between climate change and hydrologic systems, ecosystems, and human communities will likely be of limited usefulness for local decision-making. This is due to current and foreseeable limits on reducing climate uncertainties, and because these kinds of assessments are not necessarily compatible with conclusions from the social sciences about how information is used in decision-making (e.g., see Dessai et al., 2009; Johnson and Weaver, 2009; NRC, 2009; Moser and Luers, 2008; Sarewitz et al., 2000; Fischhoff, 1994).

Effective decision support will instead start with a commitment to understand the systems we manage or aim to protect and a willingness to use what we know now for decision-making, while working to learn more. In general, comparing relative vulnerabilities fits in well with this framework, because direct evaluation of the absolute effects of climate change on water quality and aquatic ecosystems is out of reach given the state of the science for many of our vulnerability indicators. Yet policy decisions must continue to be made in the absence of perfect information. Understanding the current condition of and threats posed to our environment now can be the lens through which we view the potential risks posed by global change. This can be achieved through systematic, quantitative planning frameworks that help us to understand and evaluate various management strategies across a wide range of plausible futures. The result of such planning should be the selection of management strategies that alleviate, or at least do not

exacerbate, existing and anticipated vulnerabilities of water quality and aquatic ecosystems. In other words, we should seek strategies that are robust with respect to the inherent uncertainties of the problem (e.g., Brown et al., 2010; Lempert et al., 2004).

Informed by this philosophy, GCRP has developed and is implementing a multi-year research effort designed to improve national-scale understanding of the multiple complex interactions between global change and the nation's waters. Part of this work is a major effort devoted to the development of scenarios of future climate, land-use, and hydrologic change. For example, GCRP is conducting hydrologic modeling in 20 large, U.S. watersheds in an attempt to provide broad, national-scale scenarios of streamflow and nutrient/sediment loading across a wide range of potential climate and land-use changes, to improve our understanding of the plausible range of hydrologic sensitivity to global change. Such scenarios can be used, in principle, to investigate the potential negative water quality and aquatic ecosystem impacts that we must prepare to remedy, nationally, given existing and likely future vulnerabilities of our aquatic ecosystems.

But what are these existing vulnerabilities? The idea for this report began with a seemingly simple question: *How easy would it be to assess, and map, the relative vulnerability of watersheds, across a number of dimensions, for the whole United States in a meaningful, self-consistent way?* In this report, we summarize the lessons learned to date in our attempts to answer this question.

There are two main outcomes that we report on here. First, we have collected, evaluated the quality of, processed, and aggregated a large quantity of data on water quality and aquatic ecosystem indicators across the nation. Second, we have attempted to identify best practices, challenges, and gaps in ideas, methods, data, and tools for calculating and mapping vulnerability nationally. In both contexts, we hope that this report will be a useful building block for future work on multi-stressor global change vulnerability assessments.

To measure relative vulnerability, we identified indicators that reflect the three components of vulnerability as identified by the IPCC (2007a): sensitivity, exposure, and adaptive capacity. Sensitivity is the extent to which a system responds either positively or negatively to external stimuli; exposure is the degree to which a system is exposed to stressors (and in some cases, specifically climatic variations); and adaptive capacity is the ability of a system to cope with stress. Most vulnerability indicators identified in this report measure the

exposure or sensitivity of water quality and aquatic ecosystems to stressors. An understanding of exposure and sensitivity may facilitate the development of adaptive capacity within a system.

It is important to clarify here that this report does not evaluate impacts of climate change on ecosystems and watersheds. Instead, it deals only with the question of how to estimate the relative effects of other, existing stressors and their potential to reduce overall resilience, or increase overall sensitivity, to climate change. It examines this question by looking at indicators of vulnerability to such stressors. We argue that a systematic evaluation of the impacts of existing stressors is a key input to any comprehensive climate change vulnerability assessment, as the impacts of climate change will be expressed via interaction with such stressors.

While the idea that existing stressors reduce resilience and increase vulnerability to climate change remains an assumption for many systems, it is an established one, deeply embedded in recent large climate change assessment efforts. For example, the IPCC 4th Assessment Working Group II report states that: "Vulnerability of ecosystems and species is partly a function of the expected rapid rate of climate change relative to the resilience of many such systems. However, multiple stressors are significant in this system, as vulnerability is also a function of human development, which has already substantially reduced the resilience of ecosystems and makes many ecosystems and species more vulnerable to climate change through blocked migration routes, fragmented habitats, reduced populations, introduction of alien species and stresses related to pollution" (IPCC, 2007a). It then goes on to provide examples from terrestrial, marine, and coastal ecosystems.

Reducing the impact of current stressors is also frequently considered to be a "no regrets" adaptation strategy for enhancing ecosystem resilience to climate change. The U.S. Climate Change Science Program (USCCSP, 2008) reviewed adaptation options for six federally managed programs in the United States: national forests, national parks, national wildlife refuges, national estuaries, marine protected areas, and wild and scenic rivers. Adaptation options were studied by reviewing available literature, data, and models, as well as by assessing the consensus within the scientific community. Decreasing current anthropogenic stresses was the adaptation approach deemed most likely to lead to good outcomes in the face of climate change uncertainties. Numerous studies confirmed that this approach was likely to be the most successful of those considered.

The idea that existing stressors reduce resilience and increase vulnerability to climate change informs both the definition of "vulnerability" that we use, and the selection of individual indicators we examine. It is key to providing the link between what these indicators measure and an understanding of the ecological and watershed impacts of climate change, and we expand upon this idea at other points in this report.

Returning to our framing question, "*How easy would it be to assess, and map, the relative vulnerability of watersheds, across a number of dimensions, for the whole United States in a meaningful, self-consistent way?*", our strategy for addressing it was as follows:

We conducted a literature search and compiled a comprehensive list of broadly defined indicators of the vulnerability of water quality or aquatic ecosystems, including those relating to ambient surface and groundwater quality, drinking water quality, ecosystem structure and function, individual species, and the provision of ecosystem services. This then formed the set of indicators for exploring a number of subsequent challenges. These challenges fall into four broad categories:

1. Challenges associated with identifying those indicators that speak specifically to vulnerability as opposed to those reflecting simply a state or condition.;

2. Challenges associated with calculating and estimating the values of these vulnerability indicators, including establishing important indicator thresholds that reflect abrupt or large changes in the vulnerability of water quality or aquatic ecosystems;

3. Challenges associated with mapping these vulnerability indicators nationally, including data availability and spatial aggregation of the data; and

4. Challenges associated with combining and compositing indicators and developing multi-indicator indices of vulnerability.

For this work, we relied on published research and on studies by EPA, other federal agencies, and well-respected institutions like the Heinz Center and the Pew Center, both for indicator definitions and for the data to support the mapping of indicators. While each study reviewed had a slightly different objective, much of the information was relevant to the goals of this project. The intent was to examine what could be accomplished with existing indicators and data sets, and for the most part we did not attempt at this point to conceive of new indicators or

collect new data. As part of this work we developed a number of example maps, and we use some of these maps in this report for illustrative purposes. We recognize that approaches other than the one we took are possible, but the lessons we learned while developing strategies for compiling and mapping national-level indicator data sets under this project would likely be useful for an array of alternative approaches. This project was a starting point and its findings have broad applicability.

The next section (Section 2) briefly describes a number of EPA efforts that informed this work, and with which we could usefully integrate the ideas in this report more closely in the future. Section 3 describes the compilation and examination of the extensive set of indicators for water quality and aquatic ecosystems that was the starting point for the analyses in this report. Sections 4 through 7 then discuss the four broad categories of challenges described above. We summarize our findings and propose some recommendations in Section 8. Finally, several appendices document the following: the literature reviewed (Appendix A); the full set of more than 600 indicators initially evaluated (Appendix B); the data sources and supporting information for the 53 vulnerability indicators that were evaluated for data availability and mapping potential (Appendix C); the methodological details for how the various maps were produced (Appendix D); example maps displayed using 4-digit Hydrologic Units and their descriptions (Appendix E); example maps displayed using ecoregions and their descriptions (Appendix F); vulnerability categories for each indicator by each HUC (Appendix G); and the steps for evaluating and modifying vulnerability indicators (Appendix H).

2. SYNERGIES WITH OTHER EPA EFFORTS

There are a number of EPA efforts devoted to indicator-based assessment of environmental condition and impairment. This report draws from these efforts in a number of direct and indirect ways. In addition, greater integration of the work described here with these efforts has the potential for a number of significant benefits. Here, we briefly summarize some of these connections.

The valued role of environmental indicators in environmental resource assessment and management is evidenced in recent years by several prominent reports from both within the government sector and outside it (e.g., Heinz Center, 2008). Notably, EPA tracks roughly 83 indicators of environmental and human health for its Report on the Environment (U.S. EPA, 2008a). For example, Chapter 3 of the ROE is a report card on trends in the extent and condition of the nation's waters (U.S. EPA, 2008a). The ROE indicators are revisited roughly once every three to four months and subsequently updated online to assess changes over time. They are generally reported as national averages or representative examples, rather than as mapped distributions. The long-term goal for the ROE is to report all indicators as temporal trends. The ROE has its roots in the Environmental Monitoring and Assessment Program (U.S. EPA, 2010a), a research program within EPA's Office of Research and Development that was designed to develop the tools necessary to monitor and assess the status and trends of national ecological resources. EMAP collected field data from 1990 to 2006, and focused on developing the scientific understanding for translating environmental monitoring data from multiple spatial and temporal scales into assessments of current ecological condition and forecasts of future risks to our natural resources. We drew a number of the indicators discussed in this report, as well as general indicator definitions, from the ROE.

Monitoring of the nation's aquatic resources is now conducted by the EPA Office of Water's National Aquatic Resource Surveys (U.S. EPA, 2010b), which publishes a series of studies that report on core indicators of water condition. These studies use standardized field and lab methods that are designed to yield unbiased, statistically-representative estimates of the condition of the whole water resource, such as rivers and streams, lakes, ponds, reservoirs, and wetlands. Products of this program include the National Coastal Condition reports, the National

Wetland Condition Assessment, the Wadeable Streams Assessment, and a number of other reports. Again, as with the ROE, we drew a number of indicators from these assessments.

One of the largest and most important efforts within the agency that has relevance for indicator-based work is the Impaired Waters listing (U.S. EPA, 2010c). Section 303(d) of the Clean Water Act (CWA) requires states, territories, and authorized tribes to assess their waters and identify all water bodies (e.g., streams and rivers) that are impaired. Impaired waters are those that do not meet water quality standards because they are too polluted or otherwise degraded. Waters that do not meet state, territory, or tribal Water Quality Standards due to such impairments are placed on the CWA Section 303(d) list, scheduled for Total Maximum Daily Load (TMDL) development, and eventually restored. EPA maintains responsibility for implementing the 303(d) regulations by ensuring that impaired waters lists are developed. All impaired waters information is then provided to the public via EPA's online data system known as ATTAINS (U.S. EPA, 2010d). For this report, we considered using or developing indicators based on the 303(d) impaired waters lists from each state. Our intent was to use these lists to determine the degree to which waters are impaired for a given unit of spatial aggregation and to frame these identified impairments within a vulnerability context. This link has been previously discussed by EPA during evaluations of how water programs may need to adapt to changes in climate – e.g., EPA's National Water Program Strategy: Response to Climate Change report states that warmer air and water temperatures may lead to "increased pollutant concentrations and lower dissolved oxygen levels will result in additional waterbodies not meeting water quality standards and, therefore, being listed as impaired waters requiring a total maximum daily load (TMDL)" (U.S. EPA, 2008b, p. 9). However, we decided to forego using 303(d)-based indicators because of significant gaps in the impaired waters data, which are not comprehensive. This lack of national data is compounded by the variation in assessment programs across states. See Section 6.1.4 and Figure 6-1 for additional discussion of these issues.

EPA's Regional Vulnerability Assessment (ReVA) program (U.S. EPA, 2009a) seeks to characterize vulnerability through investigation of ecosystem dynamics, the connectivity between ecosystems and the broader landscape, and ecosystem interactions with socioeconomic factors. The purpose of the ReVA program is to examine the probability of future problems at a regional scale, even when precise environmental conditions at a given location cannot be predicted. The ReVA program also aims to help decision-makers assess the degree and types of

stress posed by human actions on a region's environmental resources. The program's methodology evaluates indicators of vulnerability, aggregates them into indices, and evaluates the likelihood of exacerbation of vulnerability as a result of future stressors. To date, the ReVA program's methodology has been applied to a comprehensive analysis of the Mid-Atlantic region (U.S. EPA, 2000a). EPA plans to conduct similar assessments in other regions.

The ReVA program is an outstanding source of vulnerability metrics and indicators. The present study complements the ReVA program by building on its extensive work on vulnerability and investigating a similar methodology for national scale investigations of vulnerability focused on climate change. Both the ReVA program and the current study present relative measures of vulnerability and identify future research opportunities that would result in measures of absolute vulnerability. Future efforts may include integration of ReVA tools and data with the indicators presented in the current report.

EPA's just-released 2010 report, *Climate Change Indicators in the United States* (U.S. EPA, 2010e), is a new effort that is intended to track and interpret a set of 24 indicators, each describing trends related to the causes and effects of climate change. It focuses primarily on the United States, but in some cases also examines global trends. EPA intends to begin using these indicators to monitor the effects and impacts of climate change in the United States, assist decision-makers on how to best use policymaking and program resources to respond to climate change, and assist EPA and its constituents in evaluating the success of their climate change efforts. We did not use these indicators in this report, but we envision integrating them with the methodologies discussed here in future efforts to assess vulnerability of water quality and aquatic ecosystems to climate change.

Finally, there is a pressing need for objective strategies to prioritize agency efforts by comparing different geographic locations in terms of their expected responses to future conditions and various management options. This can be done with regard, for example, to stream restoration (Norton et al., 2009) and to climate change adaptation (Lin and Morefield, 2011). As Norton et al. (2009) write, "Tens of thousands of 303(d)-listed waters, many with completed TMDLs, represent a restoration workload of many years. State TMDL scheduling and implementation decisions influence the choice of waters and the sequence of restoration. Strategies that compare these waters' recovery potential could optimize the gain of ecological resources by restoring promising sites earlier." Norton et al. (2009) then explore ways that states,

tribes, and territories can use measurable metrics of ecological, stressor, and social context to estimate the relative recovery potential of sites, as a key input into decisions that set priorities for the selection and sequence of restoration efforts. Similarly, Lin and Morefield (2011), using the Atlantic and Gulf Coast National Estuaries as their example, propose a framework for assessing and prioritizing management recommendations that might be made in response to communities' vulnerability to climate change and their wishes to develop adaptation strategies. In our view, attention to the issues and challenges discussed in this report is likely to aid in the task of developing objective measures that can inform a broad range of prioritization decisions.

3. INDICATORS CONSIDERED FOR THIS REPORT

This section describes the approach used to compile a comprehensive list of potential indicators of water quality and aquatic ecosystem vulnerability from those identified in published sources. Figure 3-1 outlines the general methodology in the selection of indicators for this study.

3.1. LITERATURE SEARCH

We performed an extensive literature search to identify recent studies related to the monitoring and evaluation of water quality and ecosystem conditions. The types of literature reviewed included journal articles, studies, and reports. The literature ranged widely in study area, from local to international. It ranged in technical field from biological, hydrological, and chemical, to human aspects, and included both primary and secondary literature. The literature sources also varied, including individual researchers, public institutions, and non-governmental organizations. Studies reviewed spanned a decade of relevant literature from 1998 through 2008.

The literature reviewed was primarily obtained from the GCRP research team members and through internet and library database searches conducted by Cadmus. Literature identified by GCRP as relevant was considered to be "core literature" and was given high priority in the review process. Thereafter, other references were reviewed to identify additional indicators for possible inclusion. The citations within the core literature were also useful as sources of additional relevant literature.

3.1.1. Core Literature

As noted above, the GCRP research team identified a short list of studies as core literature that served as a starting point for identifying vulnerability indicators. These studies are listed in Table 3-1.

Table 3-1. List of core literature

List of Core Literature (see Appendix A for full references)	
• Coastal States Organization, 2007	• Millennium Ecosystem Assessment, 2005b
• Ebi et al., 2007	• Millennium Ecosystem Assessment, 2005c
• Frumhoff et al., 2007	• National Assessment Synthesis Team, 2000a
• Gilliom et al., 2008	• National Assessment Synthesis Team, 2000b
• Gleick and Adams, 2000	• Poff et al., 2002
• Hamilton et al., 2004	• U.S. EPA, 2006
• Heinz Center, 2002	• U.S. EPA, 2008a
• Heinz Center, 2008	• U.S. EPA, 2008b
• Hurd et al., 1998	• USGAO, 2005
• Hurd et al., 1999	• United States Geologic Survey (USGS), 1999
• Lettenmaier et al., 2008	• Zogorski et al., 2006
• Millennium Ecosystem Assessment, 2005a	

Figure 3-1. Flowchart of methodology used to identify and map vulnerability indicators.

Step 1: Conduct literature search.
Extensive literature search conducted.

86 documents

Step 2: Identify indicators of water quality and aquatic ecosystem condition.
Literature review conducted and indicators of water quality and aquatic ecosystem condition identified.

623 indicators

66 indicators eliminated

Step 3: Delete duplicate indicators
If identical indicators cited by different literature sources, a single best indicator selected for further evaluation. Remaining duplicate indicators (which were either not defined, poorly defined, or were specific to a geographic region) deleted.

557 indicators

504 indicators eliminated

Step 3: Classify indicators of vulnerability
Indicators of vulnerability identified. State variables (i.e., those measuring condition at a point in time)

53 indicators

28 indicators eliminated

Step 4: Assess data availability.
Data sources identified and some indicators eliminated because: (a) no indicator data were available; (b) data collection was in progress; (c) data were not national; (d) data were not recent, or were a projection; (e) combination of multiple data sets entailed complex methods; (f) indicator required extensive modeling using raw data.

Step 5: Create example maps.
Data obtained and manipulated to create maps using GIS software for readily mappable indicators.

FINAL 25 MAPPABLE INDICATORS

Some studies, typically those that were specifically geared towards identifying indicators of ecosystem change or documenting the results of national environmental monitoring studies, served as a source for many of the indicators in this EPA study. Some key studies in the core literature and how they were used are described below.

Hurd et al., 1998 and Hurd et al., 1999

The report, *Water Climate Change: A National Assessment of Regional Vulnerability*, prepared for EPA by Hurd et al. (1998), identified key aspects of water supply and quality that could be adversely affected by climate change, developed indicators and criteria useful for assessing the vulnerability of regional water resources to climate change, created a regional database of water-sensitive variables consistent with the vulnerability measures, and applied the criteria in a comparative national study of the vulnerability of U.S. water resources. The result of this study was a series of national-scale maps attempting to demonstrate the vulnerability of different U.S. regions to climate change for each indicator of vulnerability of water supply and quality. An abbreviated version of this study, presenting a few select indicators and outlining the general methodology used in creating national-scale maps for each indicator, was later published in the Journal of the American Water Resources Association (Hurd et al., 1999). The spatial resolution of vulnerability estimates used by Hurd et al. (1998) was a 4-digit Hydrologic Unit Code (HUC) or hydrologic subregion, of which there are 222 nationwide.

Heinz Center, 2002 and Heinz Center, 2008

The State of the Nation's Ecosystems 2008: Measuring the Land, Waters, and Living Resources of the United States prepared by the H. John Heinz Center for Science, Economics, and the Environment (hereafter referred to as the Heinz Center), was the most recent publication in an effort aimed at developing a comprehensive evaluation of the condition of the nation's ecosystems. Aspects of this effort were a model for the methodology used in the present study. We also used an older publication from the same effort (Heinz Center, 2002) to incorporate indicators that were not considered in the Heinz Center 2008 study.

The indicators in the Heinz Center reports often described the state of ecosystem attributes. Because current state was considered a component of vulnerability, the selection of these indicators typically represented the first screening step in identifying useful vulnerability

indicators. The state indicators used by the Heinz Center did not explicitly describe stressors that affected those indicators, although stressors were implied for ecosystem attributes that were in a degraded state.

The Heinz Center described several indicators for which adequate data were not available. We also adopted the approach of identifying ongoing collection efforts or proposing data collection priorities for indicators of potential importance. The Heinz Center report includes terrestrial ecosystem types; the present study does not. However, the "Coasts and Oceans" and "Fresh Waters" sections of the Heinz Center report included many specific indicators that we used here.

U.S. EPA, 2006

Wadeable Streams Assessment (WSA): A Collaborative Survey of the Nation's Streams summarizes the results of a collaborative effort led by EPA (2006) to provide a statistically defensible report on the condition of the nation's smaller streams. Standardized methods were used to measure several physical, chemical, and biological attributes at 1,392 sites that represent the small streams in the U.S.

The database that accompanied WSA was used as a data source for mapping several of the indicators in the present study. As with some indicators from the Heinz reports, the measures reported in EPA's WSA report (2006) reflect the current condition of the wadeable streams, rather than their specific vulnerability to future changes.

U.S. EPA, 2008a

As described in Section 2, EPA tracks roughly 83 indicators of environmental and human health, and reported on those indicators in *U.S. EPA's 2008 Report on the Environment.* The Report on the Environment (ROE) is published less frequently in hardcopy form, but continually updated online (www.epa.gov/roe). Chapter 3 of the ROE is a report card on trends in the extent and condition of the nation's waters. The indicators in this report were generally reported as national averages or representative examples, rather than mapped distributions. Some indicators were reported as temporal trends. Indicator data were derived from multiple sources, and no new data were collected as part of this chapter. The indicators in this report are revisited roughly once every three to four months and subsequently updated online to assess changes over time. The

ROE provided several indicators for this report. Some ROE indicators of temporal trends are closely tied to the concept of vulnerability.

United State Geologic Survey (USGS), 1999

  The Quality of our Nation's Waters: Nutrients and Pesticides, the first summary report from the USGS' National Water-Quality Assessment (NAWQA) program, reports on the geographic distribution, environmental drivers, and temporal trends of nutrients and pesticides in surface waters. The NAWQA data include several useful summary statistics from the broad range of physical and chemical water quality parameters measured as a part of the NAWQA program.

  Under the NAWQA program, 51 sites are broken up into smaller groups that are sampled in multiple rounds (20 study units in 1991; 16 study units in 1994; and 15 study units in 1997). NAWQA is also considered the best source of information on the occurrence of pesticides in surface and groundwater. However, even with the full complement of study units (including units that were not completed at the time of the present study), the spatial coverage of NAWQA sites is relatively sparse. As with most of the literature used in the present study, NAWQA reports primarily on current condition, rather than vulnerability to future change.

3.1.2. Protocol for Collecting Additional Relevant Literature

  To develop a comprehensive list of indicators cited in the published literature, an extensive and representative sample of recent studies was needed. We conducted a literature search using publicly available (e.g., Google Scholar) and non-public (e.g., ScienceDirect) search tools to identify studies with a primary or secondary focus on water quality and aquatic ecosystems. We selected studies based on their likelihood of containing water quality and aquatic ecosystem indicators.

Along with the core literature, we identified 86 studies that could be used as potential sources of indicators, including:

- 19 government reports;

- 40 peer-reviewed journal articles; and

- 27 other reports including those by non-governmental or inter-governmental organizations.

See Appendix A (List of Literature Reviewed) for a complete list of the reviewed literature.

3.2. CREATION OF A COMPREHENSIVE LIST OF INDICATORS

We reviewed the literature collected and identified indicators relevant to the present study. This section describes the guidelines we used to identify relevant indicators, and the details of the choices we made to select only certain indicators from particular studies based on these general guidelines.

We use the term, "indicator" in this report as it is commonly used in the published literature (Adger et al., 2004; Villa and McLeod, 2002; Hurd et al., 1998), to define a variable or a combination of variables that can be used to measure the change in an environmental attribute. Similar terms, such as "metric" are also widely used in the literature (Norton et al., 2009; Luers, 2005), while metric and indicator are used interchangeably in other studies (Adger, 2006; Nicholson and Jennings, 2004). For the purposes of this report, we use the terms metric and indicator interchangeably.

3.2.1. Identifying Indicators of Water Quality and Aquatic Ecosystem Condition

We reviewed all of the studies indentified in the literature search to develop a comprehensive list of indicators. Unlike a typical literature review, we reviewed these studies for indicators of water quality and aquatic ecosystem condition, rather than for their contributions to the body of knowledge on this topic. Therefore, they were reviewed for their explicit or implicit

description of indicators that could potentially be used to assess the vulnerability of water quality and aquatic ecosystems to environmental change. We selected indicators following the guidelines for good indicators from EPA's Report on the Environment (ROE) as presented in Figure 3-2 (Indicator definition from EPA's 2008 Report on the Environment).

- *Useful.* It answers (or makes an important contribution to answering) a question in the ROE.
- *Objective.* It is developed and presented in an accurate, clear, complete, and unbiased manner.
- *Data Quality.* The underlying data are characterized by sound collection methodologies, data management systems to protect their integrity, and quality assurance procedures.
- *Data Availability.* Data are available to describe changes or trends, and the latest available data are timely.
- *Representative Data.* The data are comparable across time and space and representative of the target population. Trends depicted in this indicator accurately represent the underlying trends in the target population.
- *Transparent and Reproducible Data.* The specific data used and the specific assumptions, analytical methods, and statistical procedures employed are clearly stated.

Figure 3-2. Indicator definition from EPA's 2008 Report on the Environment.

This selection process resulted in a comprehensive list of 623 indicators (presented in Appendix B: Comprehensive List of Indicators). Each indicator was assigned a unique indicator identification number (Indicator ID#) – this was necessary given the large number of indicators and to avoid confusion among indicators with similar names. In subsequent sections of this report, each indicator name is associated with its parenthetical ID# (e.g., Acid Neutralizing Capacity [#1]). These identification numbers also facilitate easier referencing of each indicator in the appendices of this report.

Most water quality and aquatic ecosystem indicators found in the literature were included in the comprehensive list. However, it is important to discuss why we excluded some indicators from this list and chose not to examine them in subsequent steps of this methodology. We discuss these reasons immediately below.

3.2.2. Selection of Indicators

In the interest of thoroughness, we made broad determinations regarding whether or not each indicator, measure, or metric in a particular study could be used to characterize, evaluate, or assess water quality or aquatic ecosystems. On the rare occasions when we excluded indicators

from a particular study from the comprehensive list, we documented the reasons for such exclusions – for example, indicators related to air quality were generally not considered relevant to this project, and have been well-studied elsewhere. The wide range of characteristics that describe the comprehensive list of indicators for this project can be summarized as follows:

- Indicators covered a variety of different disciplines;

- Indicators were of varying scales, from local to national;

- Indicators had varying amounts of data associated with them;

- Indicators were aggregated (made up of smaller input indicators) or disaggregated;

- Indicators were drinking water indicators or indicators related to aquatic ecosystems;

- Some were indicators related to infrastructure; and

- Indicators were potentially important to decision-makers at a variety of levels, ranging from federal, to regional and local levels.

Indicators included in the list were vetted in the literature, although to varying extents. Some studies focused solely on identifying robust water quality and ecosystem condition indicators that could be used to observe and explain changes in the natural environment. Other studies merely provided a theoretical rationale for needing the development of new indicators.

In addition to selecting specific indicators, we also reviewed the literature to obtain the following indicator-related information:

- Indicator definition, as specified in the literature, or written based on supporting text in the literature;

- Level at which it is adopted (i.e., local, state, or national);

- Whether the indicator is currently in use;

- Geographic scope (i.e., local, state, or national);

- Spatial resolution;

- Target audience (e.g., scientists, policymakers, risk analysts); and

- Rationale for the indicator's inclusion on the comprehensive list of indicators (based on information in the literature) to corroborate the indicator's relevance as an indicator of the vulnerability of waterbodies to environmental degradation.

In addition, a team of technical experts classified the potential application of each indicator to climate change as high, medium, or low. These experts, listed on page iii of this report, represent multi-disciplinary fields related to the impacts of climate change on various aspects of human life and the natural environment.

In addition to the steps described above, we took two specific actions to ensure the most comprehensive indicator list possible:

- *Creation of Indicator Categories:* Different indicators measure different aspects of potential vulnerability. By grouping like indicators, it was possible to determine which aspects of water quality and aquatic ecosystem condition were reasonably covered by the selected indicators and to identify potential coverage gaps. Therefore, to facilitate reviews of the indicator list, we established indicator categories and sub-categories, as shown in Table 3-2 (Indicator primary and secondary categories).

- *Review of Indicator List by Technical Experts:* The technical advisors reviewed a draft list of indicators and were asked to add indicators where they perceived gaps. Through this process, one indicator (Total Withdrawal Information by Source & Type of Use [#622]) was added to the comprehensive list, and a significant amount of additional detail and new information was added for the indicators already in the comprehensive list.

Table 3-2. Indicator primary and secondary categories

Ecological (161)	Hydrological (104)	Chemical (96)
• Condition of Plant Species • Distribution of Plants • Exposure to Contaminants • Habitat Condition • Non-Native Species • Species at Risk • Species Diversity • Species Populations	• Duration of Natural Events • Engineered Structures • Precipitation • Sea Level Rise • Temperature • Water Flow • Water Levels • Waves	• Carbon • Chlorophyll a • Contaminants in Sediment • Microbes • Multiple Contaminants • Nutrients • Oxygen • Pesticides • pH • Salinity • Turbidity/Clarity
Land Cover/Use (61)	**Socioeconomic (57)**	**Extreme Weather Events (16)**
• Agricultural • Coastal • Forest • Freshwater • Glaciers • Grasslands/Shrublands • Natural Cover • Urban/Suburban • Wetlands	• Housing • Policy • Recreation • Resource Use	• Drought • Fire • Flood • Storm
	Air (19)	**Soil (27)**
	• Aerosols • Ozone • Temperature	• Composition • Erosion • Sediment
	Human Populations (14)	
Other (2 [1]	• Population Size • Susceptible Populations	

[1]Note: The "Other" category has no secondary categories.

3.2.3. Exclusion of Certain Indicators and Studies

In some cases, we excluded from the comprehensive list particular indicators, groups of indicators, or all indicators from a particular study. Table 3-3 (Rationale for exclusion of certain indicators) presents the rationale for not selecting some indicators from particular studies.

3.2.4. Deletion of Duplicate Indicators

As indicators for the comprehensive list were identified from various literature sources, some redundancy was noted in some groups of indicators. When two or more indicators were

identified as being very similar, one was selected to represent the group, and the others were removed from further consideration for mapping. Selected representative indicators were most often those that had a clear definition, were relevant at the national level (i.e., not limited to a small geographic region), could be quantified easily, or were obtained from this study's core literature sources. Sixty-six indicators were deleted because they were redundant with other indicators in the comprehensive list.

Table 3-3. Rationale for exclusion of certain indicators

Reasons for Exclusion of Indicators	Literature Sources (see Appendix A for full references)	
Indicators were modeled projections, specific to a non-U.S. location, or were too broadly defined.	• Arnell, 1998 • Arnell, 1999 • Barnett et al., 2005 • Bergstrom et al., 2001 • Conway and Hulme, 1996 • de Wit and Stankiewicz, 2006	• Gleick and Adams, 2000 • Kundzewicz et al., 2008 • Lettenmaier et al., 2008 • Nicholls and Hoozemans, 1996 • Palmer et al., 2008 • Roderick and Farquhar, 2002
Indicators were of human adaptive capacity or socioeconomic indicators, rather than of aquatic ecosystems or water quality.	• Adger at al., 2004 • Brooks et al., 2005 • Ebi et al., 2007 • Frumhoff et al., 2006 • Frumhoff at al., 2007 • Gleick and Adams, 2000 • Jacobs et al., 2000	• Kling et al., 2003 • Millennium Ecosystem Assessment, 2005a • Millennium Ecosystem Assessment, 2005b • Twilley et al., 2001
Indicators were identical or very similar to those in another study, or indicators were better defined in another study.	• Bradbury et al., 2002 • Bunn and Arthington, 2002 • Chesapeake Bay Program, 2008 • Dai et al., 1999 • Frumhoff et al., 2007 • Grimm et al., 1997 • Hamilton et al., 2004 • Hayslip et al., 2006	• Huntington et al., 2004 • Hurd et al., 1998 • Kling et al., 2003 • Long Island Sound Study, 2008 • Ojima et al., 1999 • U.S. EPA, 1995 • U.S. EPA, 2002 • Zogorski et al., 2006
Indicators and their associated data sources were not adequately detailed as the study was primarily a policy/funding-oriented document.	• Coastal States Organization, 2007 • Luers et al., 2006 • Murdoch et al., 1999 • National Assessment Synthesis Team, 2000b • Poff et al., 2002 • U.S. EPA, 2008c	• USGAO, 2000 • USGAO, 2002 • USGAO, 2004 • USGAO, 2005 • Vincent and Pienitz, 2006 • Yamin et al., 2005
Indicators were large aggregates of smaller indicators.	• Gleick and Adams, 2000	• U.S. EPA, 2008d

4. CHALLENGES PART I: INDICATOR CLASSIFICATION

This section describes how we evaluated the indicators introduced in the previous section to determine whether they were suitable, in principle, for assessing relative vulnerability to large-scale environmental degradation due to external stressors (of which climate change would be one example). First we considered how to define vulnerability. We then applied that definition to each of the 623 indicators that resulted from the process described in the previous section, resulting in a small subset being classified as "vulnerability" indicators.

4.1. DEFINING VULNERABILITY

There has been considerable debate in the literature on the meaning of vulnerability in the context of environmental systems and stressors (climate change in particular) and the elements of which it is composed. We summarize some of that discussion here as background.

It has been argued that the lack of a common definition has hindered interdisciplinary discourse on the topic and the development of a common framework for vulnerability assessments (Füssel, 2007; Brooks, 2003). Others have argued that the purpose of the analysis should guide the selection of the most effective definition or conceptualization (Kelly and Adger, 2000).

Some of the purposes for which climate change vulnerability assessments may be performed include: increasing the scientific understanding of climate-sensitive systems under changing climate conditions; informing the specification of targets for the mitigation of climate change; prioritizing political and research efforts to particularly vulnerable sectors and regions; and developing adaptation strategies that reduce climate-sensitive risks independent of their attribution. Each of these purposes has specific information needs and thus might require a targeted approach to provide this information.

Below is a summary of discussions about the definition of vulnerability in the literature on climate change, including:

- Determinants of vulnerability;

- Defining a vulnerable situation;

- Biophysical and socioeconomic domains; and

- Predictability and uncertainty.

4.1.1. Determinants of Vulnerability

The IPCC definition of vulnerability is: "The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity." (IPCC, 2007a, p. 995) (IPCC Def. 1). Three terms are defined further in the IPCC report: sensitivity, exposure, and adaptive capacity.

The IPCC defines sensitivity as "the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli." This definition is generally supported by much of the literature on the topic, but there are two subtly different interpretations. The first considers sensitivity as the probability or likelihood of passing a critical threshold in a variable of interest (e.g., the probability of exhausting water supplies) (Fraser, 2003; Jones, 2001). The second considers sensitivity to be the degree to which outputs or attributes change in response to changes in climate inputs (Moss et al., 2001). This second interpretation incorporates an understanding that some stresses may increase gradually, instead of emphasizing the passing of one critical threshold value as the only kind of important change. In both cases, a system's sensitivity to stress is separate from its exposure to stress.

Similarly, exposure is "The nature and degree to which a system is exposed to significant climatic variations." A system may be currently exposed (or predicted to be exposed in the future) to significant climatic variations. Because there are multiple factors related to climate and climate change that may cause stress (e.g., temperature, precipitation, winds, changes in spatial and temporal variability and extremes, etc.), the type of exposure ("hazard" in Füssel's [2007] terminology) should be specified. In this definition, exposure is separate from sensitivity. A system may be exposed to significant climate changes, but if it is not sensitive to those changes, it is not vulnerable. The socioeconomic literature on vulnerability tends to lump these factors together (e.g., "Social vulnerability to climate change is defined as the exposure of groups or individuals to stress as a result of the impacts of climate change" [Adger, 1999]).

Finally, adaptive capacity is "The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences." In the socioeconomic literature, vulnerability is often defined primarily by adaptive capacity, particularly as it is linked to poverty (e.g., "…the vulnerability of any individual or social grouping to some particular form of natural hazard is determined primarily by their existent state, that is, by their capacity to respond to that hazard, rather than by what may or may not happen in the future." Kelly and Adger, 2000; see also Olmos, 2001; and Tompkins and Adger, 2004). This conceptualization views sensitivity to most hazards as a given, exposure to some hazard(s) as inevitable, and therefore the need for adaptation will arrive sooner or later. Other authors have argued that because adaptive capacity is not necessarily static (i.e., it can be developed), vulnerability assessments should focus on sensitivity and exposure, with the goal of identifying locations to focus the development of adaptive strategies (O'Brien et al., 2004; Kelly and Adger, 2000).

4.1.2. Defining a Vulnerable Situation

There is general agreement in the literature that the term, "vulnerability," by itself, may not be sufficiently descriptive (Moreno and Becken, 2009; Füssel, 2007; Polsky et al., 2007; Brooks, 2003). Instead, a *vulnerable situation* should be defined. This definition should include the following components (Füssel, 2007):

- **Temporal reference:** the point in time or time period of interest. Specifying a temporal reference is particularly important when the risk to a system is expected to change significantly during the time horizon of a vulnerability assessment, such as for long-term estimates of climate change.

- **Sphere:** Internal (or 'endogenous' or 'in place') vulnerability factors refer to properties of the vulnerable system or community itself, whereas external (or 'exogenous' or 'beyond place') vulnerability factors refer to something outside the vulnerable system that adds to the vulnerability of the system.

- **Knowledge domain:** socioeconomic (e.g., poverty) vs. biophysical (e.g., flow regime sustainability).

- **System:** the system of analysis, such as a coupled human–environment system, a population group, an economic sector, a geographical region, or a natural system.

- **Attribute of concern:** the valued attributes of the vulnerable system that are threatened by its exposure to a hazard. Examples of attributes of concern include human lives and health; the existence, income and cultural identity of a community; and the biodiversity, carbon sequestration potential, and timber productivity of a forest ecosystem.

- **Hazard:** a potentially damaging physical event, phenomenon, or human activity that may cause the loss of life or injury, property damage, social and economic disruption, or environmental degradation.

An example of a fully specified vulnerable situation is: 'vulnerability of the incomes of the residents of a specific watershed to drought'. In practice, only the components of the definition that are not clear from the context (or uniformly applied to multiple situations) need be defined. The advantage of a specific definition of a vulnerable situation is that it is unambiguous. The disadvantage is that it makes it difficult to conduct holistic vulnerability comparisons among locations.

4.1.3. Biophysical and Socioeconomic Domains

In the climate change literature, the term "vulnerability" has more frequently been applied to socioeconomic situations; the term "risk" has been used to describe biophysical condition situations (e.g., Jones, 2001). Biophysical vulnerability or risk is primarily related to sensitivity and exposure, while socioeconomic vulnerability is more a function of adaptive capacity. Biophysical vulnerability may encompass effects on humans, such as increase in population at risk of flooding due to sea level rise. However, it is related to human exposure to hazard rather than to the ability of people to cope with hazards once they occur (Brooks, 2003). The view of vulnerability as a state (i.e., as a variable describing the internal state of a system) has arisen from studies of the structural factors that make human societies and communities susceptible to damage from external hazards. Social vulnerability encompasses all those properties of a system independent of the hazards to which it is exposed that mediate the outcome of a hazardous event (Brooks, 2003). In theory, this idea could be applied to biophysical systems, inasmuch as previous stress has rendered the system more susceptible to any new hazard.

Most of what we define as "vulnerability indicators" in this report are biophysical indicators. They therefore primarily encompass sensitivity and exposure to environmental

stresses. Adaptive capacity can be developed in locations that are sensitive and exposed to stress. In addition, while much of the literature on ecosystem vulnerability, particularly as it relates to climate change, focuses exclusively on the degradation of ecosystem components that directly serve human needs (Füssel, 2007), several of the indicators in this report focus on the direct, inherent vulnerability of the aquatic ecosystems themselves, independent of the ecosystem services provided to humans. We also examine other indicators that focus on the vulnerability of drinking water quality, and are thus more obviously and directly related to human needs.

4.1.4. Predictability and Uncertainty

The future behavior of socio-ecological systems is difficult, or perhaps impossible, to predict because the components of these systems are constantly adapting to changing conditions. As a result, a system may contain non-linearities, inter-dependencies, and feedback loops that make its overall behavior unpredictable (Moreno and Becken, 2009; Fraser et al., 2003; Holling, 2001). A vulnerability assessment itself may reduce future vulnerabilities by helping target the development of adaptive capacity in systems that are sensitive and exposed to external stressors such as climate change.

For climate change in particular, many of the adverse effects on ecosystems and human systems are expected to occur as a result of stochastic events that may or may not happen, but to which a subjective probability of occurrence could in principle be assigned. Because these probabilities are conditioned on, for example, predictions of future climate and on models of how the system will respond to climate changes (Jones et al., 2001), it may not be possible to constrain them very much given the current limitations of climate prediction, as discussed in the Introduction. This report focuses on the challenges associated with assessing vulnerability across the nation without depending on accurate environmental prediction. That is, for most of the report we evaluate the vulnerability of water quality and aquatic ecosystems in the absence of specific future scenarios of global climate, population, and land use changes. This bottom-up approach of focusing on indicators vetted in the scientific literature, available data, and current vulnerability, can be used in follow-up studies in combination with approaches focused on improving our ability to predict environmental changes.

4.2. CLASSIFYING VULNERABILITY INDICATORS

In the early phases of this project, we held a workshop[1] to develop rules of thumb for classifying the comprehensive suite of 623 indicators into two broad categories. The first category is "vulnerability indicators" that, at least in principle, could measure the degree to which the resource being considered (e.g., watershed, ecosystem, human population) is susceptible to, and unable to cope with, adverse effects of externally forced change. Such change could potentially include climate or any other global change stressor. The second category constitutes state variables or indicators of condition that merely measure the current state of a resource without relating it to vulnerability.

Informed by the literature above, the workshop participants concluded that, in practical terms, to qualify as a measure of "vulnerability," an indicator should inherently include some relative or value judgment. Examples include comparing one watershed to another, comparing the indicator to some objectively defined threshold or possible state, or reporting on the indicator's change over time. Measures of water quality or ecological condition at a point in time without reference to a baseline would not make good vulnerability indicators. Viewed from the perspective of indicator measurement, this can be achieved by such methods as computing a ratio of two quantities, at least one of which is a time rate of change or a measure of variation, or computing the portion of a distribution that lies above or below a defined threshold. Examples abound, including the ratio of the standard deviation of annual streamflow to mean annual streamflow (to measure degree of variability in the stream), the ratio of stream withdrawals of water to mean annual streamflow (to measure the portion of the flow that is being used), the ratio of mean annual baseflow to mean annual total flow (to measure the susceptibility to dry periods), and the average number of days in a year that a metric such as temperature, dissolved oxygen, or salinity in coastal wetlands exceeds a particular threshold.

Applying these rules of thumb is straightforward for some of the indicators and less so for others. Many could arguably fall into either the "vulnerability" or the "state" category. For example, when assessing vulnerability to flooding, we might examine the total number of people

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[1]The workshop took place at the National Center for Environmental Assessment (NCEA), in Washington, DC, on December 18, 2008. Participants included members of the Cadmus team, members of the EPA Global Change Research Program (GCRP) staff from NCEA, and the outside expert consultants acknowledged in this report.

living within the 100- or 500-year floodplain in a given watershed; when measuring ecosystem health, we might look at the total number of species in each watershed classified as "at risk." The key for these examples is that, by embedding an implied threshold in these indicators – i.e., by choosing the particular flood frequency (e.g., 100-year or 500-year) that we consider to be damaging, or a particular classification of "at risk" – we have made a judgment about the system that goes beyond assessing its condition to assessing its susceptibility to harm. Not all vulnerability indicators incorporate implied thresholds, and those that vary over a gradual gradient are still of great value and can inform assessments of relative vulnerability, as discussed in Section 5.1.

This classification exercise winnowed the original list of 623 indicators down to 53 indicators shown in Table 4-1 (List of vulnerability indicators). Examples illustrating these classification principles include the following:

Vulnerability Indicators:

- Stream Habitat Quality (#284) – compares stream habitat conditions in a given area to those in a relatively undisturbed habitat in a similar ecosystem;

- Groundwater Depletion (#121) – compares the average groundwater withdrawals to annual average baseflow, reflecting the extent to which groundwater use rates may be exceeding recharge; or

- Wetland Species At-Risk (#326) – examines the number of threatened and endangered species inhabiting a particular wetland area.

State Variables:

- Nitrogen and Phosphorus - large rivers (#186) – measurement of nitrogen and phosphorus in all streams without a reference value; or

- Instream fish habitat (#138) – a measure of instream fish concealment features (e.g., undercut banks, boulders, large pieces of wood, brush) within a stream and along its banks, without specifying reference conditions, such as, for example, concealment features at undisturbed sites.

Table 4-1. List of vulnerability indicators

Indicator (See Appendix B for definitions)	Literature Source (See Appendix A for full citations)
Acid Neutralizing Capacity (ANC) (#1)	U.S. EPA, 2006
Altered Freshwater Ecosystems (percent miles changed) (#17)	Heinz Center, 2008
At-Risk Freshwater Plant Communities (#22)	Heinz Center, 2008
At-Risk Native Freshwater Species (#24)	Heinz Center, 2008
At-Risk native marine species (relative risk) (#27)	Heinz Center, 2008
Coastal Vulnerability Index (to sea level rise) - CVI (#51)	Day et al., 2005
Commercially important fish stocks (size) (#55)	Heinz Center, 2008
Fish and Bottom-Dwelling Animals (comparison to baseline) (#95)	Heinz Center, 2008
Flood events (frequency) (#100)	Lettenmaier et al., 2008
Freshwater Rivers and Streams with Low Index of Biological Integrity (ecosystem condition) (#116)	Heinz Center, 2008
Groundwater Depletion - Ratio of Withdrawals/ Baseflow (#121)	Hurd et al., 1998
Groundwater reliance (#125)	Hurd et al., 1998
Harmful algal blooms (occurrence) (#127)	Heinz Center, 2008
Invasive species - Coasts affected (area, ecosystem condition) (#145)	Heinz Center, 2008
Invasive species in estuaries (percent influenced) (#149)	Heinz Center, 2008
Low flow sensitivity (mean baseflow) (#159)	Hurd et al., 1998
Meteorological drought indices (#165)	Jacobs et al., 2000
Number of Dry Periods in Grassland/Shrubland Streams and Rivers (Percent of streams with dry periods over time) (#190)	Heinz Center, 2008
Ratio of Snow to Precipitation (S/P) (#218)	Lettenmaier et al., 2008
Ratio of water withdrawals to annual streamflow (level of development) (#219)	Hurd et al., 1998
Riparian Condition (Riparian Condition Index) (#231)	Heinz Center, 2008
Status of Animal Communities in Urban and Suburban Streams (Percent of urban/suburban sites with undisturbed and disturbed species) (#276)	Heinz Center, 2008
Streamflow variability (annual) (#279)	Hurd et al., 1998
Stream habitat quality (#284)	Heinz Center, 2008
Water Clarity Index (real vs. reference) (#318)	NEP, 2006
Water Quality Index (5 components) (#319)	NEP, 2006
Waterborne human disease outbreaks (events) (#322)	Heinz Center, 2008
Wetland loss (#325)	MEA, 2005

Indicator (See Appendix B for definitions)	Literature Source (See Appendix A for full citations)
Wetland and freshwater species at risk (number of species) (#326)	Hurd et al., 1998
Ratio of water use to safe yield (#328)	Schmitt et al, 2008
Erosion rate (#348)	Murdoch et al., 2000
Instream use/total streamflow (#351)	Meyer et al., 1999
Total use/total streamflow (#352)	Meyer et al., 1999
Snowmelt reliance (#361)	IPCC, 2007
Pesticide toxicity index (#364)	USGS, 2006
Population Susceptible to Flood Risk (#209)	Hurd et al., 1998
Herbicide concentrations in streams (#367)	USGS, 1999
Insecticide concentrations in streams (#369)	USGS, 1999
Organochlorines in Bed Sediment (#371)	USGS, 1999
Herbicides in Groundwater (#373)	USGS, 1999
Insecticides in Groundwater (#374)	USGS, 1999
Salinity intrusion (coastal wetlands) (#391)	Poff et al., 2002
Heat-Related Illnesses Incidence (#392)	Pew Center, 2007
Precipitation Elasticity of Streamflow (#437)	Sankarasubramanian et al., 2001
Ratio of reservoir storage to mean annual runoff (#449)	Lettenmaier et al., 2008
Runoff Variability (#453)	Lettenmaier et al., 2008
Macroinvertebrate Index of Biotic Condition (#460)	U.S. EPA, 2006
Macroinvertebrate Observed/Expected (O/E) Ratio of Taxa Loss (#461)	U.S. EPA, 2006
Coastal Benthic Communities (#462)	U.S. EPA, 2008
Threatened & Endangered Plant Species (#467)	U.S. EPA, 2008
Vegetation Indices of Biotic Integrity (IBI) (#475)	U.S. EPA, 2008
Instream Connectivity (#620)	Heinz Center, 2008
Water Availability: Net Streamflow per capita (#623)	Hurd et al., 1998

All of the indicators listed in Table 4-1 were further examined for data availability and mappability, as discussed in detail in Section 6.

4.3. HOW DO THESE INDICATORS REFLECT VULNERABILITY?

All of the 53 vulnerability indicators vary in their responses to environmental stress and in the degrees to which they reflect vulnerability of water quality and aquatic ecosystems. Here we discuss, for the subset of 25 vulnerability indicators that were mappable at the national scale, how the literature characterizes the link between each indicator and the potential vulnerability of ecosystems or human systems.

Acid Neutralizing Capacity (#1)

Definition: The Acid Neutralizing Capacity or ANC (#1) indicator is a measure of the ability of stream water to buffer acidic inputs (U.S. EPA, 2006). Streams may be naturally acidic due to the presence of dissolved organic compounds (U.S. EPA, 2006). However, acid deposition arising from anthropogenic sources may increase the acidity of the stream (U.S. EPA, 2006). Acid mine drainage, formed by water passing through mines and mine tailings, is the primary source of acid in surface water, and results in the formation of concentrated sulfuric acid. Acidity is also caused by acid rain formed by dissolution of industrial and automotive emissions, such as nitrogen oxide and sulfur dioxide, in rain water (U.S. EPA, 2006).

Measurement/Calculation: The ANC indicator is calculated as the percent of stream sites that have been deemed to be at risk, i.e., that have ANC values of 100 milliequivalents (a baseline condition) or less. The data used to map this indicator were collected every five years.

Impacts of global climate change and other stressors: Acid deposition from anthropogenic sources may lower the pH of a stream with low ANC, thereby affecting aquatic vegetation and organisms, as well as water quality, particularly in sensitive watersheds. Changes in precipitation due to global climate change may result in increased acid deposition or drainage from acid mines. Areas with a low percentage of streams with suitable buffering capacity could experience disproportionately large adverse effects resulting from increased acid exposure. In contrast, well-buffered streams with higher ANC may not be as sensitive to increased acidity from external sources.

At-Risk Freshwater Plant Communities (#22)

Definition: This indicator describes the risk of elimination faced by wetland and riparian plant communities. The condition of these communities is considered important because of the ecosystem services they provide, including habitat for a variety of species, flood storage, water quality improvements, carbon storage, and other benefits (Heinz Center, 2008; Johnson et al., 2007; NRC, 1992). Loss of community types reduces ecological diversity and may eliminate habitat for rare and endangered species. At-risk status is a vulnerability indicator for aquatic ecosystems by definition, identifying communities that may have less resistance to stressors because they are already compromised.

Measurement/Calculation: Identifying which communities are at risk and their degree of endangerment is useful for planning conservation measures (Grossman et al., 1998). The Heinz Center (2008) describes three risk categories: vulnerable (moderate risk), imperiled (high risk), and critically imperiled (very high risk). Factors that were used to assign these risk categories include range, the number of occurrences, whether steep declines have occurred, and other threats.

Impacts of global climate change and other stressors: A number of environmental changes might alter the risk status of a plant community. Changes in land use and climate-related changes may decrease the range of a given plant community. The ranges of some plants may shift with temperature changes. Drying would reduce the ranges of some plants, but increased precipitation may allow some species to expand their ranges. Sea level rise associated with global climate change or a reduction in the input of freshwater may allow drought-resistant or salt-resistant plants to move into areas once dominated by freshwater plants (Lucier et al., 2006). Many potential effects on at-risk freshwater plant communities are poorly understood, including alterations in biogeochemical cycling and the effects of increased severity of storms.

At-risk Native Freshwater Species (#24)

Definition: Similar to the previous entry, this indicator describes the risk of extinction faced by 4,100 native freshwater species, including fish, aquatic mammals, aquatic birds, reptiles and amphibians, mussels, snails; crayfishes, shrimp, and insects (Heinz Center, 2008). Plants are

not included. The status of these species is important because of their value both individually (e.g., as food or for other purposes) and as part of aquatic ecosystems. The at-risk status assigned to these species again directly reflects vulnerability, identifying organisms that may have less resistance to stressors because they are already compromised and have experienced a decline; further declines for some may result in extreme rarity or even extinction.

Measurement/Calculation: The Heinz Center (2008) describes four risk categories: vulnerable, imperiled, critically imperiled, and extinct. Assignment to the "vulnerable," "imperiled," and "critically imperiled" categories is based on up to twelve factors, including population size, number of populations, range, steep or widespread decline, or other evidence of risk.

Impacts of global climate change and other stressors: A number of external stressors might affect risk category. For example, changes in the hydrologic cycle, whether induced by climate or land-use change, may reduce available habitat and alter the range and number of locations where species occur. Sea level rise may flood freshwater habitats. Degradation of water quality and presence of certain contaminants may affect the health and long-term stability of sensitive species. If habitat is already fragmented by land use, further stress may further endanger freshwater species.

Various taxa may be sensitive to environmental change, including climate change. Fish are sensitive to temperature, and changes in temperature may shift the ranges of some species, possibly causing local extinctions (Fiske et al., 2005). Changes in water chemistry and limnology may also affect fish. For example, increased temperature reduces dissolved oxygen and increases thermal stratification (Fiske et al., 2005). Some amphibians may experience reproductive issues, such as interference with their life cycles or temperature effects on gender determination (Lind, undated). Climate-related changes in the ranges of pathogens or increases in emerging pathogens may also endanger freshwater species.

Coastal Vulnerability Index (#51)

Definition: The Coastal Vulnerability Index, created by Thieler and Hammar-Klose (2000), is intended to be a measure of the relative vulnerability of U.S. coastal areas to the physical changes caused by relative sea-level rise (RSLR) (Thieler and Hammar-Klose, 2000).

Measurement/Calculation: The CVI at a particular location is calculated based on the values of six variables at that location: geomorphology, coastal slope, rate of RSLR, shoreline erosion and accretion rates, mean tidal range, and mean wave height (Thieler and Hammar-Klose, 2000). Each location on the coastline is assigned a risk value between 1 (low risk) and 6 (high risk) for each data variable. The CVI is then calculated as the square root of the product of the ranked variables divided by the total number of variables: $CVI = [(a*b*c*d*e*f*)/6)]^{1/2}$. Thus, a higher value of the CVI indicates a higher vulnerability of coast at that location. The data for each of the six variables used to map this indicator were collected at various frequencies.

The CVI changes based on changes in the following variables (see Thieler and Hammar-Klose, 2000):

- Geomorphology, which is a measure of the relative erodibility of different landforms. Landforms may be of the following types, listed in order of increasing vulnerability to erosion or increasing value of CVI: rocky, cliffed coasts, fiords, or fiards; medium cliffs or indented coasts; low cliffs, glacial drifts, or alluvial plains; cobble beaches, estuaries, or lagoons; barrier beaches, sand beaches, salt marshes, mud flats, deltas, mangroves, or coral reefs. For instance, the value of the CVI is relatively higher along the Louisiana coast due to its lower-lying beaches and marshy areas with shallow slopes that are more prone to erosion.

- Coastal slope (percentage), which is a measure of the relative risk of inundation and of the rate of shoreline retreat. Shallower slopes are more vulnerable as they retreat faster than steeper ones, and will result in a higher value of the CVI. The lower and upper bounds for the coastal slope are <0.025% and >0.2% for the Atlantic Coast, <0.022% and >0.115% for the Gulf Coast, and <0.6% and >1.9% for the Pacific Coast.

- Rate of RSLR (mm/year), which is the change in mean water elevation at the coast. Higher rates of RSLR, resulting in a higher value of the CVI, cause loss of land and destruction of the coastal ecosystem. The lower and upper bounds for RSLR are <1.8 mm/yr and >3.16 mm/yr for the Atlantic Coast, <1.8 mm/yr and >3.4 mm/yr for the Gulf Coast, and <-1.21 mm/yr and >1.36 mm/yr for the Pacific Coast. In contrast, the value of CVI is relatively lower along the Eastern Gulf of Mexico coast mostly due to lower rates of RLSR.

- Shoreline erosion and accretion rates (m/year), which is the rate at which the shoreline changes due to erosion or sediment deposition. Positive accretion rates (resulting in lower values of the CVI) lead to more stable shorelines that are less vulnerable to erosion, while positive erosion rates (resulting in higher values of the CVI) lead to loss of coastal land. The lower and upper bounds for shoreline erosion or accretion rates are <–2.0 m/yr (erosion) and >2.0 (accretion) for all U.S. coasts.

- Mean tidal range (m), which is the average distance between high tide and low tide. Coastal areas that have higher tidal ranges (resulting in lower CVI values) are less vulnerable to sea-level rise (Kirwan and Guntenspergen, 2010). The lower and upper bounds for mean tidal range are <1.0 m and >6.0 for all U.S. coasts.

- Mean wave height (m), which is a measure of the energy of the wave. A higher energy wave (resulting in higher values of CVI) has a greater tendency to mobilize sediments along the coasts, thereby increasing erosion. The lower and upper bounds for mean wave height are <0.55 m and >1.25 for the Atlantic Coast and the Gulf Coast, and <1.1 and >2.60 for the Pacific Coast.

Impacts of global climate change and other stressors: The CVI is, as noted above, a direct measure of the vulnerability of coastal ecosystems to RSLR induced by climate change, and it also captures a change in the ecological condition of the coastal area with respect to previous conditions (e.g., lower sea-levels). RSLR, exacerbated by long-term temperature increases, is expected to increase flooding duration as well as salinity stress caused by saltwater intrusion (Mendelssohn and Morris, 2000, as cited in Day et al., 2005). These factors, in turn, will lead to increased RSLR, destroying coastal wetlands, which may not be able to accrete upwards at the same rate (Day et al., 2005).

Erosion Rate (#348)

Definition: Erosion rate is a measure of the rate of long-term soil loss due to erosion. Land use patterns, such the use of land for agricultural purposes or deforestation, can also cause erosion (Yang et al., 2003). Soil erosion is a major non-point pollution source of surface water (Yang et al., 2003). Erosion from runoff events may cause higher levels of nutrients, dissolved organic carbon, and sediment loads in surface water sources (Murdoch et al., 2000). The Erosion Rate indicator can, thus, be used to assess differences in the potential vulnerability of surface water sources as a result of erosion effects.

Measurement/Calculation: The Erosion Rate can be estimated using Yang et al.'s (2003) Revised Universal Soil Loss Equation (RUSLE). This estimate is based on four independent variables: rainfall erosivity, soil erodibility, topography, and vegetation. This indicator only takes into account soil erosion caused by rainfall and flowing water, and for a grid cell with coordinates (i, j) it can be calculated as follows (Yang et al., 2003):

A (i, j) = R (I, j) x LS (i, j) x K (i, j) x C (i, j) x P (i, j)

where R = average rainfall erosivity factor,

LS = average topographical parameter,

K = average soil erodibility factor,

C = average land cover and management factor,

P = average conservation practice factor.

These variables affect the Erosion Rate in the following manner:

- Average topographical parameter is a measure of the slope length and steepness. Erosion Rate increases with steeper slopes and greater slope length.

- Soil erodibility is the average long-term erosive tendency of rainfall and runoff. This, in turn, depends on the texture, proportion of organic matter, soil structure, and permeability. Erosion rate increases with greater erodibility.

- Rainfall erosivity represents the erosive force caused by rainfall and runoff. This, in turn, is dependent on the annual precipitation. Greater rainfall erosivity causes a higher rate of soil erosion.

- Average land cover and management factor is a measure of land use and is calculated as the average soil-loss ratio weighted by the distribution of annual rainfall.

- Average conservation practice factor is a measure of practices that control erosion. For RUSLE, P is assigned a value of 0.5 for agricultural land and 0.8 for mixed agricultural and forest land. Erosion rate decreases with active conservation practices.

Impacts of global climate change and other stressors: Increased precipitation and greater storm intensities induced by global climate change may result in increased transport of sediment, leading to higher erosion rates.

Groundwater Reliance (#125)

Definition: Groundwater Reliance is a measure of the dependence of a community on available groundwater resources. It is defined as the share of total annual withdrawals from groundwater. This indicator is particularly important as a measure of vulnerability in those regions that depend primarily on groundwater for drinking water, irrigation, and industrial and commercial purposes, because surface water supplies may be limited, contaminated, or expensive to use (Hurd et al., 1998).

Measurement/Calculation: This indicator is calculated as the ratio of withdrawals from groundwater to total annual withdrawals from groundwater and surface water (Hurd et al., 1998). The data used to map this indicator were collected every five years.

Impacts of global climate change and other stressors: Long-term changes in the hydrologic cycle, specifically groundwater recharge and surface flows, may make regions with higher groundwater reliance more vulnerable to water shortages. In addition, urbanization may have a significant impact on groundwater availability and stream baseflow. Increased impervious surface area may intercept rainfall that would normally recharge aquifers. The intercepted rainfall may be directed into storm drains and carried to streams, urban lakes, or estuaries (Klein, 1979; Simmons and Reynolds, 1982).

Herbicide Concentrations in Streams (#367) and Insecticide Concentrations in Streams (#369)

Definition: These indicators are defined as the average concentrations of herbicides and insecticides, respectively, in US streams. Pesticides are of acknowledged concern for human health as well as the health of aquatic organisms. Their ingestion may lead to a number of health concerns, including kidney problems, reproductive problems, and cancer. These compounds have been studied primarily in laboratory animals, although some information is based on epidemiological data. Pesticides are a primary drinking water quality indicator, with Maximum Contaminant Levels (MCLs) in place for 24 pesticides, mostly in the µg/L range.

Measurement/Calculation: This indicator is calculated as the average concentration of herbicides (herbicides, herbicide degradates, and fungicides) or insecticides (insecticides,

insecticide degradates, and acaricides) for all sampling sites and all sampling events. The data used to map this indicator were collected at various frequencies depending on purpose and collection site.

Impacts of global climate change and other stressors: Environmental changes that may affect the concentrations of pesticides in streams include alterations to the hydrologic cycle (Noyes et al., 2009). Lower precipitation in the summer may lower streamflow and reduce dilution, leading to higher concentrations, although higher temperatures may offset this by increasing pesticide degradation (Bloomfield et al., 2006). If winter precipitation increases, dilution will tend to increase as well. Climate change may also alter how water moves over the land. For example, increased precipitation, or more extreme wet events, may increase overland flow because the capacity of the soil to infiltrate water will be exceeded. Intense summer storms may promote increased runoff if the antecedent conditions are dry because the soil will be more hydrophobic (Boxall et al., 2009). These effects may promote a greater input of suspended solids into streams, increasing the loading of particle associated pesticides. Climate-induced changes to pest migration or ranges may prompt changes in pesticide usage, which may be reflected in inputs to surface water (Chen and McCarl, 2001). Bloomfield et al. (2006) note, however, that direct climate change effects would be difficult to predict, and that secondary effects from land use changes associated with climate change may be more important as controls on inputs of pesticides to surface water.

Herbicides in Groundwater (#373) and Insecticides in Groundwater (#374)

Definition: These indicators are defined as the average concentrations of herbicides and insecticides, respectively, in shallow groundwater. Because groundwater can contribute herbicides and pesticides to streams, concentrations of these compounds in groundwater need to be considered in evaluations of surface waters and aquatic ecosystems. The presence of these toxics provides an indication of potential contributions of these chemicals to streams. As described in the previous entry, they are also a primary drinking water concern, and EPA has set MCLs for 24 of these compounds.

Measurement/Calculation: This indicator is calculated as the average concentration of herbicides (herbicides, herbicide degradates, and fungicides) or insecticides (insecticides, insecticide degradates, and acaricides) for all sampling sites and all sampling events. The data used to map this indicator were collected at various frequencies depending on purpose and collection site.

Impacts of global climate change and other stressors: Changes in precipitation brought on by global climate change may affect groundwater herbicide and insecticide concentrations. Greater winter precipitation would promote the movement of these substances through the soil towards the water table, and large storms in particular may rapidly transport them into groundwater. In addition, during drier summers, less biodegradation occurs in the unsaturated zone, leaving greater amounts of pesticides available to be transported to groundwater. Finally, herbicide and insecticide use may increase if climate change leads to increased prevalence of pests and weeds.

Instream Use/ Total Streamflow (#351)

Definition: A primary consideration for healthy aquatic ecosystems is having adequate water to maintain fish and wildlife habitat, and competing demands for water can be a significant stressor to these ecosystems (Meyer et al., 1999). This indicator describes the competition by expressing instream water needs for fish and wildlife as a percentage of total available streamflow.

Measurement/Calculation: The ratio of instream use to total streamflow can be calculated using three variables: total groundwater withdrawals, mean annual runoff, and groundwater recharge. Groundwater overdraft values can be calculated based on the definition in the WRC (1978) report: Groundwater Recharge – Groundwater Withdrawals. Instream use can be calculated based on the definition in the WRC (1978) report: Streamflow * 0.6. Streamflow is assumed to be equal to runoff. This indicator is then calculated using the formula described in WRC (1978): Instream use / (Streamflow – Groundwater overdraft). The data for these variables were collected at various frequencies: data on groundwater withdrawals were collected every 5

years, data on mean annual runoff were collected as a one-time effort in 1975, and groundwater recharge data were collected as a one-time effort between 1951 and 1980.

Impacts of global climate change and other stressors: Changes in water withdrawals due to population change can decrease the streamflow available for instream use. Alterations in the hydrologic cycle due to climate change might also decrease streamflow in some areas. This would cause the instream use/total streamflow ratio to increase. A WRC (1978) report notes that a ratio > 100 (based on 1975 data) indicates that withdrawals of water are having a deleterious effect on the instream environment. DeWalle et al. (2000), however, discuss the scenario of concurrent urbanization and climate change. They note that urbanization can significantly increase mean annual streamflow and may offset reductions in flow caused by climate change. This indicator serves as a good vulnerability indicator because regions with greater competition between instream flow uses and consumptive uses are more vulnerable to decreases in streamflow resulting from climate change.

Macroinvertebrate Index of Biotic Condition (#460)

Definition: The Macroinvertebrate Index of Biotic Condition indicator (#460) is a composite measure of the condition of macroinvertebrates in streams. Assessing the condition of these macroinvertebrate species is a good measure of the overall condition of the aquatic ecosystem as they often serve as the basic food for aquatic vertebrates and are, therefore, essential to aquatic ecosystems with vertebrate species (U.S. EPA, 2010f ; U.S. EPA, 2006; U.S. EPA, 2004).

This indicator allows qualitative measurements of macroinvertebrate condition to be represented as a numerical value. It can be considered a good indicator of relative vulnerability as it compares macroinvertebrate condition at study sites with those at undisturbed reference sites located in similar ecoregions (U.S. EPA, 2006). Furthermore, this indicator may be tracked over time to determine temporal changes in vulnerability relative to a baseline (U.S. EPA, 2010b).

Measurement/Calculation: The Macroinvertebrate Index indicator is represented by the average Macroinvertebrate Index value in a given area. It depends on field observations of six

variables: taxonomic richness, taxonomic composition, taxonomic diversity, feeding groups, habits, and pollution tolerance (U.S. EPA, 2006). Each variable is assessed using the benthic macroinvertebrate protocol in which stream samples are collected and the characteristics of macroinvertebrates in them are assessed (U.S. EPA, 2004). Each variable is assigned a score based on field observations and individual scores are summed to obtained the value of the Macroinvertebrate Index, ranging from 0 to 100 (U.S. EPA, 2006). The data used to map this indicator were collected every five years.

The Macroinvertebrate Index changes based on the following variables:

- Taxonomic richness, which is the number of distinct taxa or groups of organisms. A stream with more taxa, which indicates a wider variety of habitats and food requirements, will be less vulnerable to stress.

- Taxonomic composition, which is a measure of the relative abundance of ecologically important organisms to those from other taxonomic groups. For example, a polluted stream will likely have a higher abundance of organisms that are resilient to pollution with lower representation from other taxa and will be more vulnerable to stress.

- Taxonomic diversity, which is a measure of the distribution of organisms in a stream amongst various taxonomic groups. Higher taxonomic diversity represents a healthier stream that is less vulnerable to stress.

- Feeding groups, which is a measure of the diversity of food sources that macroinvertebrates depend on. A more diverse food chain is representative of a more stable aquatic environment that is less vulnerable to stress.

- Habits, which is measure of the characteristics of different organisms and their preferences for different habitats. A stream environment with more diverse habitats (e.g., streambed sediment, rocks, woody tree roots, debris) supports a wider variety of macroinvertebrates and will be less vulnerable to stress.

- Pollution tolerance, which is a measure of the degree of resilience to pollution of macroinvertebrate species in a stream. Highly sensitive organisms will be more vulnerable to contamination in streams, compared to pollution-resistant ones.

Impacts of global climate change and other stressors: The structure and function of macroinvertebrate assemblages is a reflection of their exposure to various stressors over time, as these organisms have long life-cycles over which they change in response to stress (U.S. EPA, 2004). Stable ecosystems are likely to contain a variety of species, some of which are sensitive to

environmental conditions. These sensitive taxa are most likely to be subject to local extirpations when exposed to climate-induced changes in temperature or flow conditions. Similarly, these species may not tolerate increases in precipitation or temperature variation, which subsequently increase the frequency of disturbance events.

Macroinvertebrate Observed/Expected (O/E) Ratio of Taxa Loss (#461)

Definition: The Macroinvertebrate Observed/Expected (O/E) Ratio of Taxa Loss indicator (#461; also known as O/E Taxa Loss) is a measure of the biodiversity loss in a stream (U.S. EPA, 2006). The O/E Taxa Loss directly reflects the vulnerability of an ecosystem based on its loss of biodiversity (U.S. EPA, 2006). It also reflects a change in ecological condition relative to undisturbed reference sites (U.S. EPA, 2006).

Measurement/Calculation: This indicator is represented by the ratio of the taxa observed at a site to the ratio of the taxa expected to be present at that site as predicted by a region-specific model (U.S. EPA, 2006). Observed taxa are assessed using the benthic macroinvertebrate protocol in which stream samples are collected and the characteristics of macroinvertebrates present in them are assessed (U.S. EPA, 2004). Expected taxa are predicted by models developed from data collected at undisturbed or least disturbed reference sites within a region, for each of three major U.S. regions – Eastern Highlands, Plains and Lowlands, and the West (U.S. EPA, 2006). O/E Taxa Loss ratios are represented as a percentage of the expected taxa present, and they range from 0% (i.e., none of the expected taxa are present) to greater than 100% (i.e., more taxa than expected are present) (U.S. EPA, 2006). The data used to map this indicator were collected every five years.

Impacts of global climate change and other stressors: Stable ecosystems are likely to contain a variety of species, some of which are sensitive to environmental conditions. These sensitive taxa are most likely to be subject to local extirpations when exposed to climate-induced changes in temperature or flow conditions. Similarly, these species may not tolerate increases in precipitation or temperature variation, which subsequently increase the frequency of disturbance events. A measure of the loss of sensitive species may thus serve as an important indicator of vulnerability to climate change and other stressors.

Meteorological Drought Indices (#165)

Definition: This indicator is defined as the average value of the Palmer Drought Severity Index between 2003 and 2007. Meteorological Drought Indices provide a representation of the intensity of drought episodes brought on by a lack of precipitation (Heim, 2002). For example, the Palmer Drought Severity Index (PDSI) takes into account precipitation and soil moisture data from a water balance model as well as a comparison of meteorological and hydrological drought (Heim, 2002). The PDSI can be used as a proxy for surface moisture conditions and streamflow (Dai et al., 2004). PDSI trends are also linked to climate patterns such as the El Niño-Southern Oscillation (Dai et al., 1998).

Measurement/Calculation: PDSI values can be calculated per the methodology in Karl et al., 1996. Calculated PDSI values can be obtained from NOAA's NCDC Divisional Data for each of 344 climate divisions. The data used to map this indicator were collected monthly.

Impacts of global climate change and other stressors: Because drought is a well recognized stressor for natural and human systems, indicators of the spatial and temporal distribution of drought severity are relevant to vulnerability to additional external stressors. This is particularly true for climate change, as drought is directly linked to changes in meteorology that themselves are likely to be affected by climate change.

Organochlorines in Bed Sediment (#371)

Definition: This indicator is defined as the average concentrations of organochlorines in bed sediments. As part of its National Water Quality Assessment (NAWQA) program, the U.S. Geological Survey has analyzed organochlorines in bed sediment (USGS, 1999). Although they have not been used for decades, organochlorine insecticides linger in sediments, posing a potential threat to humans and aquatic organisms. For example, any increase of organochlorines in shellfish may find its way into the human food chain. As a vulnerability indicator, organochlorines in sediment are deleterious compounds that can cause ecological condition to deviate from what would be expected in an undisturbed system.

Measurement/Calculation: This indicator is calculated as the average concentration of organochlorines in bed sediments for all sampling sites and all sampling events. The data used to map this indicator were collected at various frequencies depending on purpose and collection site. Long et al. (1995) derived critical levels or breakpoints for sediment metals and chemical contaminants such as pesticides, PAHs, and PCBs for estuarine systems. MacDonald et al. (2000) conducted similar work for freshwater systems.

Impacts of global climate change and other stressors: Any environmental factor that disturbs bed sediment or affects its transport may affect the exposure of humans or aquatic organisms to organochlorines. Dredging of rivers and harbors may resuspend sediments, increasing contact with aquatic organisms. More intense storms may also resuspend sediment. On the other hand, climate-related increase of sediment input to larger water bodies may provide some "burial" of contaminated sediments, especially if the new sediment is uncontaminated.

Pesticide Toxicity Index (#364)

Definition: This indicator combines pesticide concentrations for a stream water sample with toxicity estimates to produce a number (the Pesticide Toxicity Index or PTI value) that indicates the sample's relative toxicity to aquatic life. This method, developed by Munn and Gilliom (2001), allows data for multiple pesticides to be linked to the health of an aquatic ecosystem, and it allows streams to be rank ordered by their PTI values (Gilliom et al., 2006). The PTI value for a stream increases as pesticide concentrations increase. It is a suitable vulnerability indicator in that it attempts to estimate the potential damage to an ecosystem's resilience as a result of pesticides.

Measurement/Calculation: The PTI for each sampling event is calculated by summing the toxicity quotients for all pesticides. The toxicity quotient is the measured concentration of a pesticide divided by its toxicity concentration from bioassays (e.g., a Lethal Dose 50 (LD_{50}) or Effective Concentration 50 (EC_{50}) value) for a selected species. For the present study, the toxicity quotient used was an EC_{50} value for each pesticide for the species *Daphnia*.

Impacts of global climate change and other stressors: Concentrations may change due to environmental factors such as urbanization, whereby increased streamflow may decrease concentrations due to greater dilution or produce greater pesticide inputs through increased sediment input. Potential climate-related effects include decreased streamflow, which may increase concentrations through reduced dilution, or increased precipitation, leading to increased streamflow and hence sediment inputs. Conversely, increased temperature may accelerate pesticide degradation, leading to lower concentrations. However Noyes et al. (2009) note that if water temperature increases, pesticides can become more toxic to aquatic organisms. It is not known if this effect would apply to humans. Determining the toxicity of mixtures of pesticides to humans is extremely challenging; exploring toxicity changes as a result of climate change is an important direction for future research.

Precipitation Elasticity of Streamflow (#437)

Definition: The Precipitation Elasticity of Streamflow indicator is designed to assess the sensitivity of streamflow to changes in precipitation patterns. It measures the sensitivity of streamflow to climate change and is useful in assessing the vulnerability of regions where maintaining relatively constant streamflow is critical (Sankarasubramanian et al., 2001).

Measurement/Calculation: The Precipitation Elasticity of Streamflow (E_P) is defined as a change in streamflow caused by a proportional change in precipitation. It can be calculated as follows:

$$E_P(P, Q) = \frac{dQ}{dP} \frac{P}{Q}$$

where P = precipitation and Q = streamflow.

An indicator value greater than 1 indicates that a large change in precipitation is accompanied by a relatively smaller change in streamflow, and thus, streamflow is elastic or sensitive to precipitation changes. An indicator value of less than 1 indicates that a small change in the precipitation is accompanied by a relatively larger change in the streamflow, and thus

streamflow is inelastic or less sensitive to precipitation changes. The data for these variables were collected at various frequencies: data on streamflow were collected annually, and data on precipitation were collected monthly.

Impacts of global climate change and other stressors: Streams do not respond uniformly to increased precipitation due to underlying differences in geology, terrain, and other factors. Precipitation elasticity can be used to predict how increased precipitation brought on by global climate change might affect streams in a given region. Increases in precipitation and storm intensity could result in disproportionately large adverse effects, such as flooding, in areas with high precipitation elasticity. Further, these effects could be enhanced or offset by changes in temperature. Climate change, as well as anticipated increases in urbanization, both contribute to the expected increase in the intensity of storms in some areas, leading to more flooding and severe erosion in flashier stream systems.

Ratio of Reservoir Storage to Mean Annual Runoff (#449)

Definition: The Ratio of Reservoir Storage to Mean Annual Runoff indicator is a measure of the storage capacity of reservoirs relative to runoff within the basin (Graf, 1999). Dams can be used to manage water resources to ensure a reliable supply of water to regions that depend on surface water (Lettenmaier et al., 2008). On the other hand, dams can also alter riparian ecosystems and hydrologic processes, causing unnatural variability in streamflow when water is released, fragmenting aquatic ecosystems, and causing erosion and sedimentation (Graf, 1999). The ability to store a large portion of water from land runoff indicates that a community already has the capacity to harness more surface water if needed and may, therefore, be less vulnerable to changes in hydrologic processes. Arid or semi-arid regions, where water is scarce, tend to have larger reservoirs, some of which may be able store up to three or four times the volume of annual runoff (Graf, 1999). This indicator is a good indicator of the vulnerability of water supply. However, it may have a limited ability to predict the vulnerability of water quality and aquatic ecosystems as dams tend to adversely affect both these variables, while they benefit water supply or availability.

Measurement/Calculation: The Ratio of Reservoir Storage to Mean Annual Runoff is determined by the magnitude of its individual components, reservoir storage capacity and mean annual runoff. The storage capacity of reservoirs in a given region is determined by the size of the dam, and the mean annual runoff is determined largely by precipitation and snowmelt. The data used to map this indicator include runoff data that were collected as a one-time effort between 1951 and 1980, and dam inventory data for which the collection frequency is unknown.

Impacts of global climate change and other stressors: Climate change may introduce increased inter- and intra- annual variation in runoff. Areas with relatively low reservoir storage compared to the availability of runoff may be more vulnerable to intense and prolonged droughts or changes in the seasonal timing of runoff.

Ratio of Snow to Precipitation (#218)

Definition: The Ratio of Snow to Precipitation is the ratio of the amount of snowfall to the amount of total precipitation. It can also be described as the percentage of precipitation falling as snow. As such, a decreasing ratio can indicate either a relative decrease in snowfall or relative increase in rainfall, although annual trends in the Ratio of Snow to Precipitation primarily reflect the former (Huntington et al., 2004).

Measurement/Calculation: The data used to map this indicator were collected annually.

Impacts of global climate change and other stressors: Changes in the Ratio of Snow to Precipitation are driven by temperature variations (Karl et al., 1993). Thus, the ratio will be affected by temperature changes associated with global climate change. Trends in the Ratio of Snow to Precipitation can lead to changes in runoff and streamflow patterns because of the effect on the timing and amount of spring snowmelt (Knowles et al., 2006; Huntington et al., 2004). Because of this, areas with decreasing ratios can be more vulnerable to summer droughts (Feng and Hu, 2007).

Ratio of Water Withdrawals to Annual Streamflow (#219)

Definition: The Ratio of Water Withdrawals to Annual Streamflow indicator is a measure of a region's water demand relative to the potential of the watershed to supply water. This indicator is defined as the share of total annual water withdrawals (from surface water and groundwater) to the unregulated mean annual streamflow (Hurd et al., 1998). Streamflow is important for the sustenance of surface water supply as well as for riparian ecosystems. It is also important for aquifers that are fed by streamflow.

Measurement/Calculation: Unregulated mean annual streamflow is calculated based on drainage area, mean annual precipitation, and mean annual temperature using regional regression models specified by Vogel et al. (1999). The ratio of water withdrawals to annual streamflow can then be calculated using water-use data. The data for these independent variables were collected at various frequencies: mean annual precipitation data were collected monthly, mean daily maximum temperature data were collected monthly, and water-use data were collected every five years.

Impacts of global climate change and other stressors: Regions with higher water demand will withdraw higher amounts of water from streamflow both for immediate use as well as for storage in reservoirs. These regions also rely on institutional management to maintain the critical flow in rivers and streams (Hurd et al., 1998). In the long-term, such regions are likely to be more vulnerable to climate changes that lead to large changes in streamflow. Regions where water demand is a smaller proportion of the unregulated streamflow are likely to be less vulnerable to climate-induced changes in streamflow because there is greater available supply from which to draw without affecting the critical flow (Hurd et al., 1998).

Runoff Variability (#453)

Definition: Runoff Variability is defined as the coefficient of variation of annual runoff. This indicator largely reflects the variation of annual precipitation (Lettenmaier et al., 2008; Maurer et al., 2004). Small or moderate changes in precipitation can lead to larger changes in runoff amounts, increasing runoff variability (Burlando and Rosso, 2002; Karl and Riebsame, 1989). Runoff is also linked to and affected by other factors, such as temperature,

evapotranspiration, snowmelt, and soil moisture, and it is a critical component of the annual water balance (Gedney et al., 2006; Maurer et al., 2004; Wolock and McCabe, 1999; Karl and Riebsame, 1989). Furthermore, clearcutting and urbanization also lead to increased runoff.

Measurement/Calculation: Annual runoff can be calculated by aggregating the monthly runoff values for each year. Mean and standard deviation of the annual runoff are calculated, following which the coefficient of variation (i.e., the runoff variability) is calculated by dividing the standard deviation by the mean annual runoff. It is easier to measure runoff than it is to measure other variables in the water balance, such as precipitation and evapotranspiration, thus making it a more reliable indicator (Wolock and McCabe, 1999). The data used to map this indicator were collected every three hours.

Impacts of global climate change and other stressors: Understanding inter-annual variation in runoff is important for future scenarios in which climate change will affect precipitation and temperature, both of which affect runoff (Maurer et al., 2004). The spatial and temporal variability of runoff is also essential for predicting droughts and floods (Maurer et al., 2004).

Stream Habitat Quality (#284)

Definition: The Stream Habitat Quality (#284) indicator is used to assess the condition in and around streams. Physical features such as instream vegetation, sediment, and bank vegetation create diverse riparian habitats that can support many plant and animal species (Heinz Center, 2008). Streams degraded by human use are characterized by decreased streambed stability, increased erosion of stream banks, and loss of instream vegetation. Such streams are marginal habitats for most species (Heinz Center, 2008) and hence may be particularly vulnerable to additional stresses. Stream habitat can be altered quickly due to stochastic events such as major flooding, or slowly over time due to subtle changes in flow regime.

Measurement/Calculation: The Stream Habitat Quality indicator is represented by the Rapid Bioassessment Protocol score, an index that can be used to assess the condition of underwater and bank habitats. The Rapid Bioassessment Protocol is a methodology developed by

EPA to assess habitat conditions based on field observations of ten variables: epifaunal substrate/ available cover, embeddedness (for riffles) or pool substrate characterization (for pools), velocity and depth regimes (for riffles) or pool variability (for pools), sediment deposition, channel flow status, channel alteration, frequency of riffles or bends (for riffles) or channel sinuosity (for pools), bank stability, bank vegetative protection, and riparian vegetated zone width (U.S. EPA, 2004). Each of these variables is observed and assigned a qualitative category and score: Poor (0-5), Marginal (6-10), Sub-optimal (11-15), or Optimal (16-20) (U.S. EPA, 2004). The scores for all the parameters are summed to obtain the Rapid Bioassessment Protocol score for that stream (U.S. EPA, 2004). A higher Rapid Bioassessment Protocol score indicates higher Stream Habitat Quality, while a lower Rapid Bioassessment Protocol score indicates a degraded stream.

Stream Habitat Quality changes based on changes in the following variables (U.S. EPA, 2004):

- Epifaunal substrate or available cover, which measures the relative quantity and variety of natural structures in the stream, such as cobble (riffles), large rocks, fallen trees, logs and branches, and undercut banks, available as refugia, feeding, or sites for spawning and nursery functions of aquatic macrofauna. The abundance of these structures in the stream creates niches for animals and insects, and it allows for a diversity of species to thrive in the same habitat.

- Embeddedness in riffles, which measures the extent to which rocks (gravel, cobble, and boulders) and snags are buried in the silt or sand at the bottom of the stream. Fewer embedded features increase the surface area available to macroinvertebrates and fish for shelter, spawning, and egg incubation. Similarly, pool substrate characterization is a measure of the type and condition of bottom sediment in pools. Firmer sediment, such as gravel, and rooted aquatic vegetation support more organisms.

- Velocity and depth regimes for riffles, which measure the variety of habitats caused by different rates of flow and stream depth, such as slow-deep, slow-shallow, fast-deep, and fast-shallow. The ideal stream habitat will exhibit four patterns which represent the stream's ability to maintain a stable environment. Pool variability is a measure of the different pool types, such as large-shallow, large-deep, small-shallow, and small-deep. The more diverse the pool types, the greater the diversity of the habitat that can be supported by the stream.

- Sediment deposition, which is a measure of the amount of sediment accumulation in streams. More sediment deposition is indicative of unstable streambeds which are an unfavorable environment for aquatic organisms.

- Channel flow status, which is the extent to which the stream channel is filled with water. Low channel flow may not cover the streambed and vegetation, leaving them exposed and reducing available habitat for organisms. Optimal channel flow covers the streambed, creating more available habitat in which organisms can thrive.

- Channel alteration, which is a measure of the significant changes, typically human-induced, in the shape of the stream channel, such as straightening, deepening, diversions, or conversion to concrete. Altered channels are often degraded and limit the natural habitat available to organisms.

- Frequency of riffles, which is a measure of the number of riffles in a stream. Riffles provide diverse habitats in which many organisms can thrive. Similarly, channel sinuosity in pools is a measure of the degree to which the stream meanders. More sinuous streams allow for diverse natural habitats and can also adapt to fluctuations in water volumes, thereby providing a more stable environment for aquatic organisms.

- Bank condition, which measures the extent to which banks are eroded. Eroded banks indicate moving sediments and unstable stream habitat for aquatic animals and plants.

- Bank vegetative protection, which is a measure of the vegetative cover of the stream bank and near stream areas. Banks with dense plant growth prevent erosion, control nutrients in the stream, and provide shade, thus maintaining a healthier riparian ecosystem. In contrast, banks that are covered with concrete in urban areas or experience high grazing pressure from livestock in agricultural areas prevent vegetative growth along the stream, thereby creating a poorer aquatic environment.

- Riparian vegetated zone width, which is a measure of the extent of the vegetative zone from the edge of the stream bank through to the outer edge of the riparian zone. The riparian vegetated zone buffers the riparian environment from surrounding areas, minimizes runoff, controls erosion, and shades the riparian habitat.

The Stream Habitat Quality indicator allows qualitative measurements of habitat condition to be represented as a numerical value. However, most measurements of independent variables that affect the score are "visual-based", that is they are dependent on the visual assessment by the field team that will score the study sites for each variable (U.S. EPA, 2004). Despite this, Stream Habitat Quality can be considered a good indicator of relative vulnerability for our purposes as it compares stream conditions at study sites with those at undisturbed reference sites located in similar regions (Heinz Center, 2008; U.S. EPA, 2006). Furthermore, this indicator may be tracked over time to determine temporal changes in relative vulnerability, thus allowing one to assess the impacts of future stressors in relation to present stressors. The data used to map this indicator were collected every five years.

Impacts of global climate change and other stressors: Climate-induced changes in storm intensity, runoff seasonality, average flows, or flow variation could result in disproportionately large negative effects on high quality stream habitats.

Total Use/Total Streamflow (#352)

Definition: This is the second indicator expressing the competition between water needs and water availability in streamflow. According to WRC (1978), the ratio of total use to total streamflow is a measure of the water available for "conflict-free development of offstream uses." It is similar to Indicator #351 (Instream Use/Total Streamflow), except that the numerator includes the needs for both instream and offstream use. It is a good vulnerability indicator because regions that have high offstream needs may be less able to withstand decreases in streamflow that may occur due to climate change.

Measurement/Calculation: The ratio of total use to total streamflow can be calculated using three variables: mean annual runoff, groundwater recharge, and water use. Groundwater overdraft values can be calculated based on the definition in the WRC (1978) report: Groundwater Recharge – Groundwater Withdrawals. Instream use can be calculated based on the definition in the WRC (1978) report: Streamflow * 0.6. Streamflow is assumed to be equal to runoff. This indicator is then calculated using the formula described in WRC (1978): (Instream use + Total Consumptive Use) / (Streamflow – Groundwater overdraft). The data for these variables were collected at various frequencies: mean annual runoff data were collected as a one-time effort from 1951-1980, groundwater recharge data were collected as a one-time effort in 1975, and water-use data were collected every five years.

Impacts of global climate change and other stressors: Meyer et al. (1999) note that climate-induced changes in water availability will occur in a context in which human-induced changes in water demand are also occurring. A reduction in streamflow (e.g., due to changes in climate) or an increase in offstream use (due to greater withdrawals for consumptive use) will increase this ratio. According to WRC (1978), a ratio > 100% indicates a conflict between offstream uses and instream flow needs. As with instream use/total streamflow, total streamflow

may be increased by urbanization. This is presumably due to increased impervious area. This may offset any flow reductions due to climate change in areas undergoing population expansion.

Wetland and Freshwater Species at Risk (#326)

Definition: The Wetland and Freshwater Species at Risk is a measure of the level of stress that a watershed is experiencing based on the number of water-dependent species "at risk" (Hurd et al., 1998). The Wetland and Freshwater Species at Risk indicator is defined as the number of aquatic and wetland species that are classified by NatureServe (a non-profit conservation organization that maintains biological inventories for animal and plant species in the U.S.) as vulnerable, imperiled, or critically imperiled. A watershed with a higher value of this indicator might be considered to be more vulnerable than a watershed with the lower value of this indicator.

Assessing the condition of species in a watershed can be a good indication of the health of the watershed. However, the indicator is not necessarily a very strong indicator of the vulnerability of aquatic ecosystems, as it only looks at the absolute number of at-risk species, regardless of the total number of species that occupy that habitat (Hurd et al., 1998). Furthermore, this indicator does not account for the inherent diversity in the watershed; watersheds that historically have more species may be less vulnerable to species loss (Hurd et al., 1998).

Impacts of global climate change and other stressors: Watersheds may be stressed due to changes in the hydrological cycle related to global climate change and encroachment or other disturbances from human activities (Hurd et al., 1998). This may cause populations dependent on affected niches to diminish, and may even lead to extinction of species in some cases (Hurd et al., 1998).

Water Availability: Net Streamflow per Capita (#623)

Definition: Water availability is a measure of the availability of freshwater resources per capita to meet water demand for various human consumptive uses (Hurd et al., 1998). This indicator is defined as the net streamflow per capita.

Measurement/Calculation: This indicator can be calculated as follows:

Water Availability = (Unregulated annual streamflow – Annual water withdrawals)
Population

This indicator depends on three variables: unregulated mean annual streamflow, water withdrawals, and population living in the watershed. Unregulated mean annual streamflow is calculated based on drainage area, mean annual precipitation, and mean annual temperature using regional regression models specified by Vogel et al. (1999). The data for these variables were collected at various frequencies: mean annual precipitation data were collected monthly, mean daily maximum temperature data were collected monthly, and water-use data were collected every five years.

Impacts of global climate change and other stressors: We might reasonably assume that regions with abundant per capita water availability are less vulnerable to long-term changes in the hydrologic cycle brought on by climate change as well as to population growth, and, conversely, regions with lower per capita water availability are more vulnerable.

5. CHALLENGES PART II: DETERMINING RELATIVE VULNERABILITY

5.1. VULNERABILITY GRADIENTS AND THRESHOLDS

A variety of approaches are available to water quality and natural resource managers who must interpret indicator values and indicator-based vulnerability assessments. These approaches vary depending on the state of available knowledge for a given indicator. In many cases, research suggests that responses of water quality or ecosystem condition to external stressors are linear, meaning that changes in condition (or in indicators of condition) occur over a gradual gradient rather than abruptly. Thus, management decisions can be made based on the value of the indicator along the gradient. In other cases, the response may be non-linear, but the thresholds that distinguish acceptable from unacceptable conditions are not yet fully understood. Given this state of knowledge, management decisions to prevent ecosystem degradation or a risk to human health may be based on the relative value of an indicator along the gradient of known values. For example, managers may act out of an abundance of caution when the value of an indicator increases following a long period of stability, even if the risks associated with inaction are unclear. Managers may also choose to act if an indicator value appears to be significantly different from values in other, more pristine locations.

Another approach is the use of known thresholds to facilitate indicator interpretation by indicating points at which management action is required to prevent adverse impacts to human health and the environment (Kurtz et al., 2001). Vulnerability thresholds *reflect abrupt or large changes in the vulnerability of water quality or aquatic ecosystems.* EPA's Office of Research and Development (ORD) Evaluation Guidelines, which describes key concepts in environmental indicator development, describes the role that thresholds can play in interpreting the values of indicators of ecological condition:

> To facilitate interpretation of indicator results by the user community, threshold values or ranges of values should be proposed that delineate acceptable from unacceptable ecological condition. Justification can be based on documented thresholds, regulatory criteria, historical records, experimental studies, or observed responses at reference sites along a condition gradient. Thresholds may also include safety margins or risk considerations. (U.S. EPA, 2000b).

In this study, we attempted to divide the range of values calculated for appropriate indicators into different classes based on evidence in the literature of abrupt or large changes in vulnerability associated with certain values of the indicator. These functional break points (i.e., objective thresholds that distinguish between acceptable and unacceptable conditions) can be highly useful to decision makers. The literature reviewed for this study, however, most often presented arbitrary cutoffs based on round numbers or frequency distributions. It is not surprising that functional break points do not currently exist for many indicators. Groffman et al. (2006) point out that determining such break points can be challenging due to the non-linear response of many indicators and the multiple factors that can affect the value of functionally relevant indicator break points. For example, natural variation in water chemistry and ecosystem types across the nation leads to spatial variation in critical thresholds for dissolved oxygen (DO). Persistently low DO levels in any one ecosystem can yield a community of flora and fauna that are unaffected by DO levels that would be detrimental to another ecosystem. Blackwater river systems of the Southeastern U.S. illustrate this variation. These systems have high levels of dissolved organic matter that may exceed ecologically relevant thresholds elsewhere in the nation, but locally these are high quality systems that are free from the impoundments that alter other systems in the U.S. (Meyer, 1990).

In some cases, objective break points in non-linear system responses may be characterized through additional research, either through meta-analysis of previous research efforts or through new data collection and analysis. In either case, collection of indicator values associated with a range of ecological responses is required to establish functionally relevant break points. There are several statistical approaches for identifying thresholds in non-linear relationships, including regression tree analysis (Breiman et al., 1984) and two-dimensional Kolmogorov-Smirnov techniques (Garvey et al., 1998). Future research may yield additional insights into how these break points vary spatially (Link, 2005).

In general, we considered three different types of thresholds for the suite of indicators evaluated in this project.

Human health-based thresholds, such as Maximum Contaminant Level Goals (MCLGs) or Health Advisories (HAs), which are set based on scientific studies, can potentially be used as thresholds for water quality indicators. EPA establishes MCLGs for contaminants detected in

drinking water based on an extensive review of available data on the health effects of these contaminants.

The MCLG is the maximum concentration of a contaminant in drinking water which has no known or anticipated adverse health effect on the population consuming this water, (U.S. EPA, 2010g; U.S. EPA, 2009b). MCLGs for carcinogens are set to zero, based on any evidence of carcinogenicity, as these effects typically manifest over a lifetime of exposure. MCLGs for non-carcinogens are often based on a Reference Dose (RfD), which is the amount of contaminant that a person can be exposed to daily without experiencing adverse health effects over a lifetime (expressed in units of mg of substance/kg body weight/day). MCLGs are non-enforceable and are based purely on the risk posed by a contaminant to human health (U.S. EPA, 2010c; U.S. EPA, 2009a). The MCLG is, thus, a threshold based on scientific data (as opposed to a Maximum Contaminant Level [MCL] that takes other factors into account[2]).

Similarly, HAs are estimates of acceptable concentrations of drinking water contaminants that are developed by EPA as guidelines to help Federal, State, and local entities better protect their drinking water quality (U.S. EPA, 2009a). Like MCLGs, HAs are not enforceable, but are determined solely based on health effects data, such as exposure and toxicity. Unlike MCLGs, HAs are revised from year to year as new data become available.

Other parameters could also be used to assess the toxicity of a drinking water contaminant (U.S. EPA, 2009c):

- Median Lethal Dose (LD_{50}), which is the oral dose of a contaminant that will cause 50 percent of the population it is administered to die (expressed in mg per kg of body weight);

- Cancer Potency (for carcinogens), which is the concentration of a contaminant in drinking water that poses a risk of cancer equivalent to 1 in 10,000 individuals or 10^{-4};

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[2]In contrast MCLs are National Primary Drinking Water Regulations (NPDWRs) established by EPA as legally enforceable standards that can be applied to public water systems to ensure safe drinking water supply to the public (U.S. EPA, 2010c). An MCL is defined as the "highest level of a contaminant that is allowed in drinking water" (U.S. EPA, 2009a). While the MCL is set such that it is as close to the MCLG as possible, it is typically higher than the MCLG as it is determined based not only on health considerations, but also on the sensitivity of analytical techniques available to detect the contaminant as well as on the availability of treatment technologies and the extent to which they can remove the contaminant from drinking water (U.S. EPA, 2009a).

- No Observed Adverse Effect Level (NOAEL), which is the highest dose at which no adverse health effects are observed; and

- Lowest Observed Adverse Effect Level (LOAEL) associated with the RfD, which is the lowest dose at which adverse health effects are observed.

These parameters are considered preliminary or less developed thresholds than an RfD value but could still, potentially, be used as thresholds for drinking water indicators.

Ecological thresholds are central to the ecological theory of "alternate stable states" (Scheffer et al., 2001; May, 1977; Sutherland, 1974; Holling, 1973; Lewontin, 1969), where the biotic and abiotic conditions within an ecosystem can reach multiple equilibria. It is believed that the transition between stable states occurs when a significant perturbation results in the breaching of one or more ecological thresholds. The "ball-in-cup" model is commonly used to illustrate this concept (Beisner et al., 2003). A stable ecosystem can be thought of as a ball that resides at the bottom of a cup. There may be many adjoining cups (i.e., the alternate stable states) that the ball could reside in. Small perturbations may push the ball up the side of the current cup, but the ball will eventually return to the bottom – this steep slope illustrates the concept of *resilience.* If the perturbation is large enough, the ball may be pushed across the lip of the cup (i.e., the ecological threshold) and eventually settle into the bottom of a different cup.

Identifying precise ecological thresholds is widely considered to be a difficult task. Ecosystems can be, and often are, a complex mix of biotic and abiotic elements that are difficult to evaluate. Aside from the complex logistics of examining multiple variables simultaneously over ecologically-relevant timescales, ecosystem evaluations can be complicated by the influence of exogenous factors (e.g., climate, human interference) that introduce uncertainty into observations. Furthermore, it is reasonable to believe that many ecosystems are truly unique, meaning that even if ecological thresholds are well understood, they are not widely applicable for the purposes of understanding vulnerability at broad scales. Finally, in many cases, ecological thresholds are difficult to observe unless breached, and the alternate stable state may not be desirable for social, environmental, or economic reasons. Thus, experiments designed to observe ecological thresholds through artificial induction of an alternate stable state are not commonly implemented.

As the science of alternate stable states advances, it may be possible to define objective thresholds for some of the aquatic ecosystem vulnerability indicators in this study. In the meantime, relative comparisons of indicator values can be made, and the range of values may or may not extend across thresholds that could be used to distinguish between vulnerable and less vulnerable areas.

Sustainability thresholds differentiate between sustainable and unsustainable conditions. In the context of this study, sustainability thresholds are most useful in determining where a water resource may currently be being used unsustainably. The construction of indicators that use sustainability thresholds differs somewhat from other indicators. Instead of directly measuring an environmental condition, they frequently use ratios that attempt to identify whether or not a system is in balance. These ratios may help answer basic questions for a given area, such as "Do groundwater withdrawals exceed groundwater recharge?" Or "Do surface water discharges equal surface water withdrawals?"

The critical value for many ratios centered on these questions is one. For example, for a theoretical indicator evaluating the balance between groundwater withdrawals and groundwater recharge, the indicator values may be calculated as Recharge / Withdrawals. Areas where the value of this ratio is greater than one have more groundwater available than is currently be used and could be considered sustainable (i.e., providing a "safe yield"). These areas could also be considered less vulnerable to additional exposure to stresses that reduce groundwater availability. Conversely, values less than one indicate areas where groundwater withdrawals exceed recharge – a potentially unsustainable condition. These areas would be more vulnerable to further exposure to climate-related stresses that reduce recharge.

We calculated values and produced maps for the 25 indicators described in Section 4.3, and included in Appendix E (displayed using 4-digit Hydrologic Units) and Appendix F (displayed using ecoregions). When available, we applied objective threshold values identified in the literature, as shown in Table 5-1. In these cases, data were divided into two or more categories as specified in the literature. Appendix H includes an evaluation of the extent to which objective functional thresholds may be applicable for each of the mapped indicators. In cases where objective thresholds were not available and visualization of changes in indicator values

along a gradual gradient was more appropriate, we produced maps using a continuous grayscale color ramp.

Table 5-1. Indicators with objective thresholds and their vulnerability categories

Indicator	Literature Source	Vulnerability Categories and Thresholds
Instream Use/ Total Streamflow (#351)	Meyer et al., 1999	No thresholds were provided in Meyer et al. (1999). However, the original data source (WRC, 1978) used a threshold of one to indicate regions where water exports are already adversely affecting the instream environment. We displayed this indicator in Appendices E and F with the following categories: <1.00 (sustainable) and ≥1.00 (unsustainable).
Precipitation Elasticity of Streamflow (#437)	Sankarasubramanian et al., 2001	Sankarasubramanian (2001) identified a value of one as a breakpoint between elastic and non-elastic responses in streamflow to precipitation. We displayed this indicator in Appendices E and F with the following categories: <1 (inelastic) and ≥1 (elastic).
Total Use/ Total Streamflow (#352)	Meyer et al., 1999	No thresholds were provided in Meyer et al. (1999). However, the original data source (WRC, 1978) used a threshold of one to indicate a potential conflict between offstream uses and the estimated instream flow needs. We displayed this indicator in Appendices E and F with the following categories: <1.00 (sustainable) and >1.00 (unsustainable).

5.2. MODIFYING AND REFINING INDICATORS TO INCORPORATE THRESHOLDS

A major strength of the approach pursued in this study is the use of readily available data, much of which has been vetted by other researchers, agencies, or institutions. Few indicators, however, directly incorporate objective thresholds. Such thresholds, as noted above, can be highly useful to decision makers, especially when they distinguish between acceptable and unacceptable conditions. In some cases, slight **modification of an indicator definition** can facilitate the identification of objective thresholds. For example, the pesticide indicators (#367, #369, #371, #373, and #374) do not incorporate regulatory or human health thresholds because these indicators are calculated as aggregates of multiple pesticides, some of which are unregulated, and whose health effects are less well understood. As an alternative, a predictive model (Larson et al., 2004) is used to map the average probability of exceeding the human health threshold (maximum contaminant level (MCL)) for atrazine, which is the most commonly used herbicide (Figure 5-1). The predictive modeling approach is currently being expanded by USGS to other pesticides. Because these models are built from variables that may be affected by climate

change, they may be particularly well-suited to assessing changes in vulnerability across different scenarios of climate and land-use change.

In addition, new indicators may be developed by **integrating multiple existing data sets**. For example, methylmercury production potential could be a useful indicator of vulnerability of aquatic animals to anthropogenic waste. Currently, there is no existing data source that describes methylmercury potential across the entire U.S. However, a new analysis could be conducted using data for wet soils, temperature, and methylmercury deposition, to assess exposure of aquatic life to this contaminant. Existing data sets could be used for the variables in such an analysis, such as wet soils data from the United States Department of Agriculture-Natural Resources Conservation Service (USDA-NRCS, http://soils.usda.gov/); temperature data from NOAA's NCDC (http://www.ncdc.noaa.gov/oa/ncdc.html); and atmospheric deposition data from the University of Illinois Urbana-Champaign's National Atmospheric Deposition Program (NADP; http://nadp.sws.uiuc.edu/). Development of such aggregate indicators using easily available existing data sets may yield additional useful indicators that are critical for assessing regional vulnerability.

An alternative approach would be to **define ideal water quality and aquatic ecosystem vulnerability indicators**, and then appropriately transform existing data or collect new data to assess vulnerability. Development of indicators that more directly compare the sensitivity and exposure components of vulnerability would facilitate a quantitative comparison of their relative importance. For instance, in an effort to understand the relative importance of temperature and population changes on groundwater availability, water use indicators may have to be scaled relative to water availability or per capita demand. As an example, *groundwater availability per capita* could accommodate adjustments from these diverse influences: precipitation effects on recharge, temperature effects on evaporation, and population effects on demand. The hydrologic component of this evaluation would require a model whose drivers include climate variables, scenarios of whose future values can be developed. Creating primary indicators of ecological function would allow for similar evaluations. Although an approach that defines ideal indicators may yield objective thresholds/breakpoints and clear connections to the three aspects of vulnerability, it is likely that difficulties in collecting all requisite data would limit the number of indicators that could be constructed. However, Figure 5-2 and Figure 5-3 represent examples of two indicators that can be developed using existing data. Figure 5-2 depicts total water use

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efficiency, a modification of the industrial water use efficiency indicator cited in Hurd et al., 1998. Figure 5-3 depicts total water demand for human uses. Both indicator maps were created using the USGS National Water-Use Dataset to provide a more complete picture of U.S. water use.

The National Environmental Status and Trend (NEST) Indicator Project used another approach to assemble a suite of indicators. The process used in that project included the distillation of many perspectives on water into five **categorical questions** (Table 5-2) that guided the search and development of indicators. All of the questions are addressed to some extent by the indicators mapped during this project, although some key subcategories do not have representative indicators. Some of these indicator classes could be filled by further examination of existing data, but others would require additional data collection efforts. Several published examples of these indicator classes were included in the comprehensive list of indicators first assembled for this project, but were subsequently eliminated based on a lack of data, data gaps, or unreliable quality of the available data sets, or inadequate or incomplete data collection efforts. Data collection or manipulation efforts geared specifically towards informing these indicators, such as those discussed below, might provide the necessary data for creating national-scale maps.

Table 5-2. Vulnerability indicators categorized in the National Environmental Status and Trend (NEST) Framework

Vulnerability indicators from this project categorized according to the question framework from the National Environmental Status and Trend (NEST) Indicator Project.

NEST Question	Example Indicators	Subcategories Not Represented
How much water do we have?	• Meteorological Drought Indices (#165) • Ratio of Snow to Precipitation (S/P) (#218) • Precipitation Elasticity of Streamflow (#437) • Ratio of Reservoir Storage to Mean Annual Runoff (#449) • Runoff Variability (#453)	• Flooding (e.g., Population Susceptible to Flood Risk [#209]) • Groundwater availability (e.g., Groundwater Depletion [#121])
How much water do we use?	• Groundwater Reliance (#125)	• Total water use (e.g., Ratio of Water Use to Safe Yield [#328])
What is the condition of aquatic ecological communities?	• At-Risk Freshwater Plant Communities (#22) • At-Risk Native Freshwater Species (#24) • Stream Habitat Quality (#284) • Wetland and Freshwater Species at Risk (#326) • Macroinvertebrate Index of Biotic Condition (#460) • Macroinvertebrate Observed/Expected Ratio of Taxa Loss (#461)	• Habitat Fragmentation (e.g., InStream Connectivity [#620])
What is the physical and chemical quality of our water?	• Acid Neutralizing Capacity (ANC) (#1)	• Nutrients (e.g., Water Quality Index [#319])
Is the water we have suitable for human use and contact?	• Herbicide Concentrations in Streams (#367) • Insecticide Concentrations in Streams (#369) • Organochlorines in Bed Sediment (#371) • Herbicides in Groundwater (#373) • Insecticides in Groundwater (#374)	• Recreational water quality • Waterborne pathogens (e.g., Waterborne Human Disease Outbreaks [#322])
No clear fit to above questions	• Coastal Vulnerability Index (#51)	

This map displays the probability of predicted concentrations of atrazine, a pesticide, exceeding its regulatory threshold (i.e., its Maximum Contaminant Level or MCL). The resulting map places pollutant concentrations into a human health context.
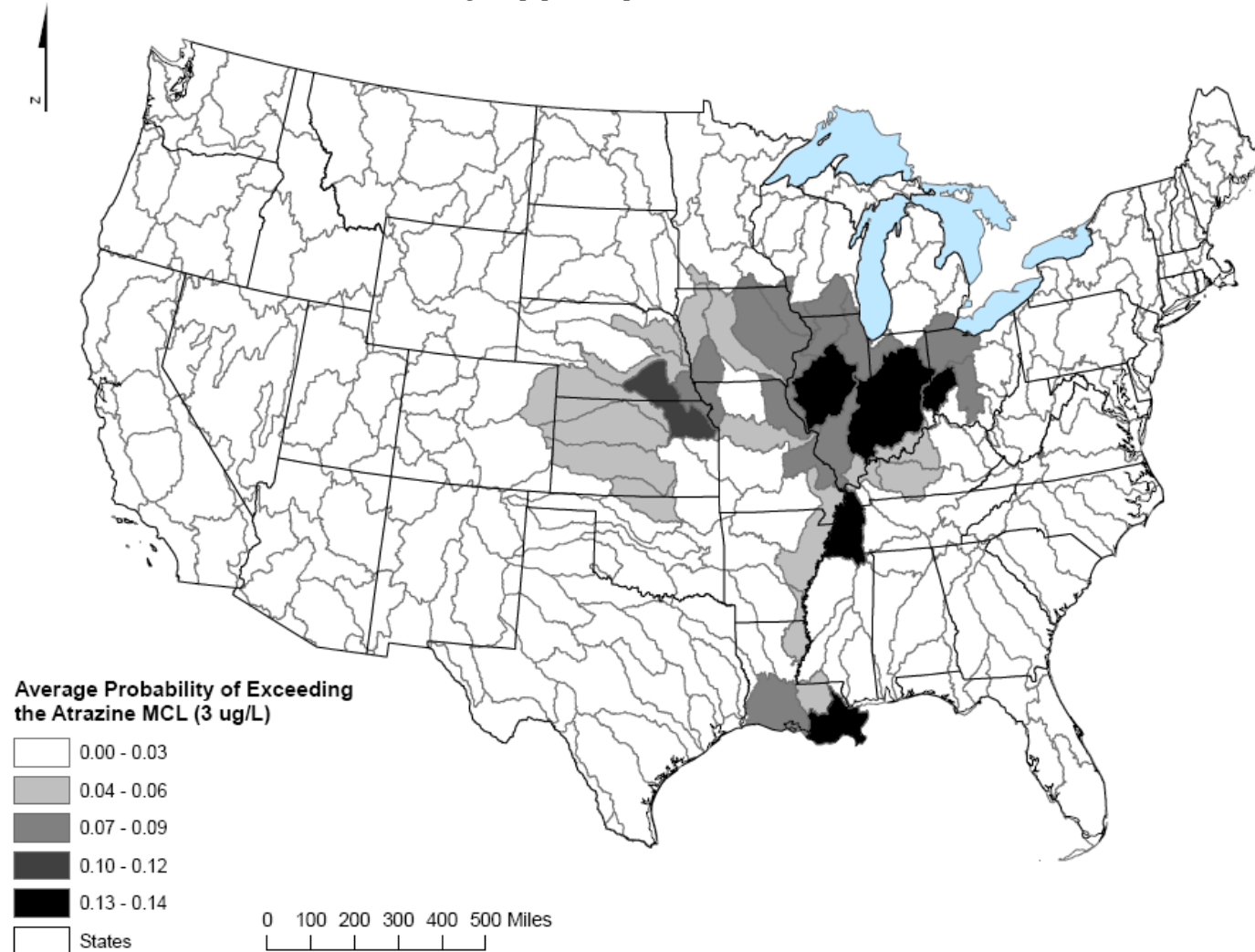
Figure 5-1. Mapping data relative to regulatory thresholds.

This map of 1995 Water Use Efficiency is a refinement of indicator #135. This example demonstrates how minor refinements using existing data sets may result in indicators that more directly assess vulnerability.
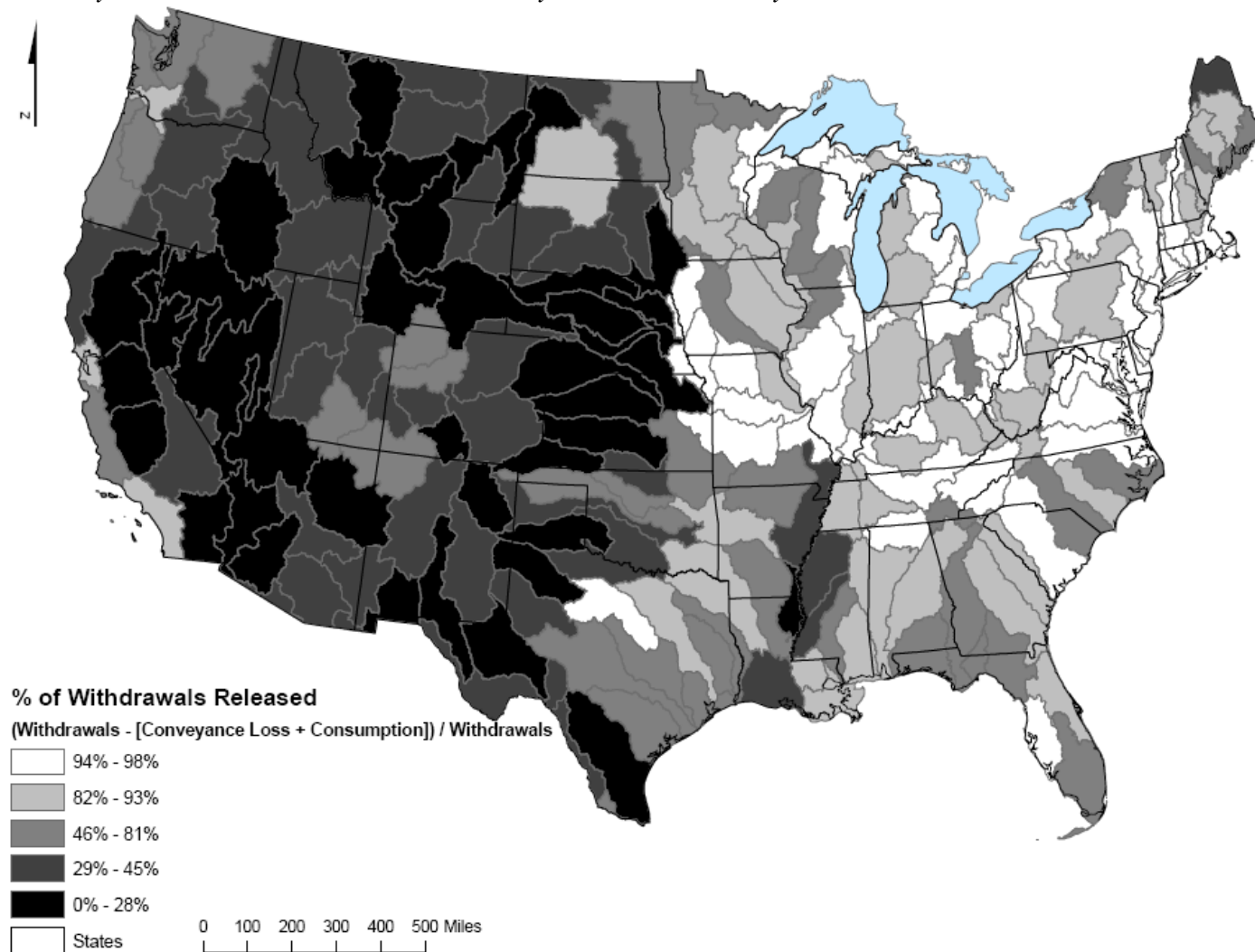
Figure 5-2. Modification of indicator definitions using existing data.

This map of 1995 Water Demand was developed using data sets that were also used to develop indicators #125 and #135. Many of the available data sets used to develop the indicator maps can be used to develop additional indicators of vulnerability.

Total Water Withdrawals
MGal/Day

	2.1 - 330
	340 - 910
	920 - 1,700
	1,800 - 3,200
	3,300 - 11,000
	States

0   100 200 300 400 500 Miles
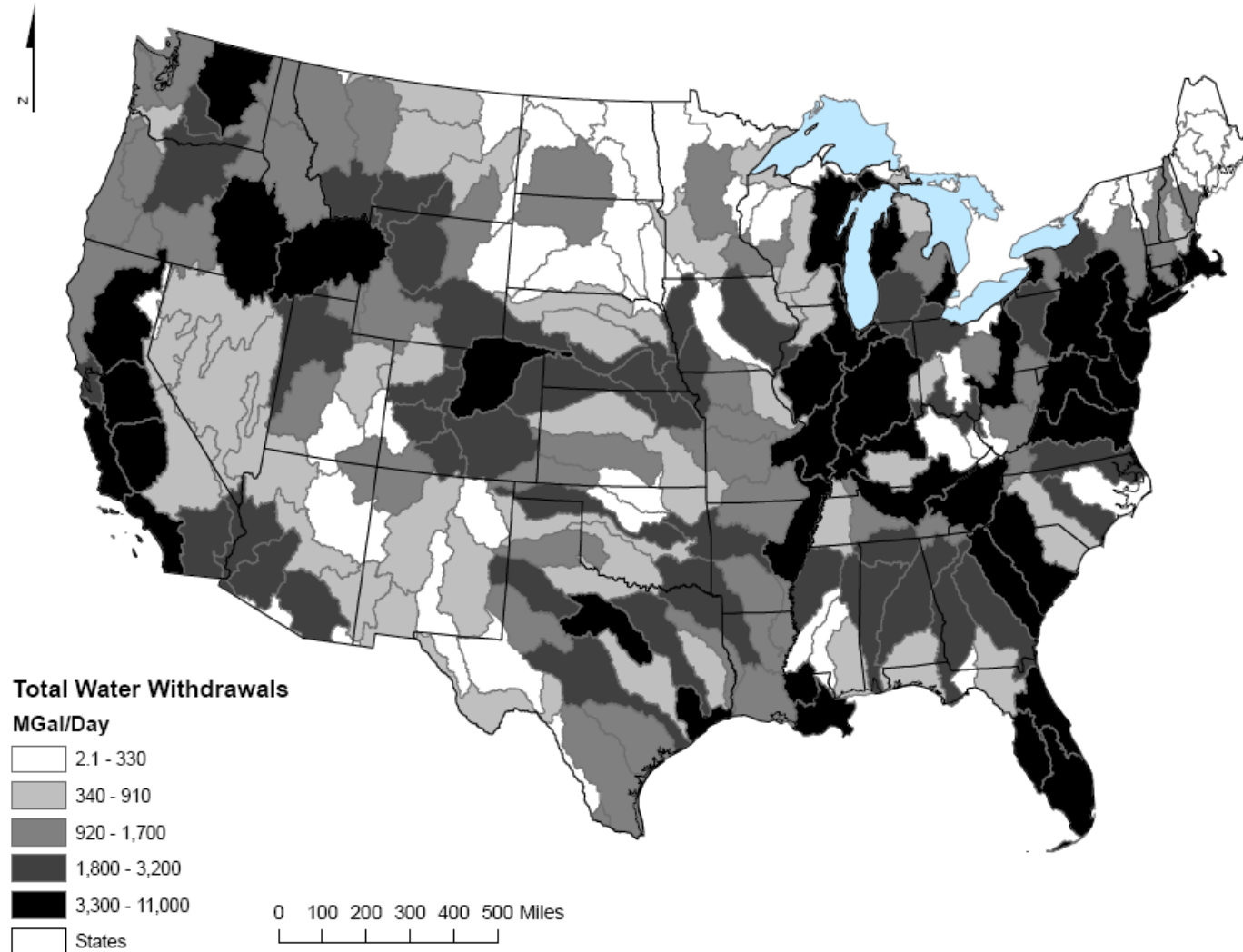
Figure 5-3. Modification of indicator definitions using existing data.

6. CHALLENGES PART III: MAPPING VULNERABILITY

Producing a single map to represent numerical data from disparate sources in an accurate and unbiased manner is a classic cartographic challenge. This challenge is rooted in the fact that "a single map is but one of an indefinitely large number of maps that might be produced…from the same data" (Monmonier, 1996). The choices made with regard to the metrics calculated, the categories used to generalize those metrics, the spatial units used to aggregate localized data, and the symbols used to display map features can all lead to substantially different maps. Furthermore, these choices can be used to emphasize or minimize spatial trends and patterns.

The effort to produce indicator maps for this study was met with these same cartographic challenges. The following sections discuss these challenges in greater detail and provide example maps, using the indicators discussed above, to illustrate how these challenges can affect use of indicators for assessments of vulnerability across the nation.

Mapping the above-described indicators at the national scale requires the compilation of multiple reliable data sets that provide consistent sample density at this scale. In recent years, agencies such as EPA, USGS, and NOAA have invested considerable resources to develop such data sets. These are immensely informative and were used to develop many of the maps contained in this report.

6.1. ASSESSMENT OF INDICATOR DATA AVAILABILITY AND MAPPABILITY AT THE NATIONAL SCALE

We examined the 53 vulnerability indicators (see Table 4-1 and Figure 3-1) for data availability and mappability, in the process identifying existing, available data that could potentially be used for creating national maps for each of these indicators.

6.1.1. Identification of Data Sources for Indicators

We determined data availability for each indicator by re-examining the literature in which the indicator was cited. In most cases, the study that cited the indicator also cited a data set, either one that was collected and assembled during the study itself or a publicly available data set containing data compiled by the authors of the study or by one or more private or public entities. If no specific data set was cited in the original literature, data sets recommended by team

members or technical advisors were used. If a data set was not available or could not be recommended, the indicator was marked as having no associated data and was not evaluated for mapping.

Data availability was the most serious limitation in evaluating whether or not we could produce maps for the 53 vulnerability indicators. Of these, only 32 indicators were initially assessed as having adequate data (using data sources identified in the literature) for nationwide mapping. Furthermore, not all of these 32 indicators could be mapped, as the data sources referenced in the literature were not always tailored specifically to the indicator. This was frequently the case with indicators that were identified by one entity and whose data were collected by another entity. In contrast, several indicators identified in USGS' The Quality of Our Nation's Waters report (e.g., Herbicide Concentrations in Streams [#367]; Insecticide in Groundwater [#374]; Organochlorines in Bed Sediment [#371]) are based on NAWQA data that are also collected by USGS.

For indicators that met minimum criteria for availability and for which we identified data sets, nationwide mappability at the level of 4-digit HUC watersheds (as a minimum screening criterion) was assessed simultaneously with data availability. This was because we found that it was not possible to establish mappability without beginning the process of manipulating and mapping the data to determine what obstacles there may be to mapping.

6.1.2. Description of Major Data Sources

The data sets identified for these 53 indicators varied in size, level of detail, quality, and relevance to the indicator. Some data sets were collected specifically with the concerned indicator in mind; in other cases, the indicator was designed with a specific data source in mind. From an initial assessment of data sources, it was evident that major national organizations, such as EPA, USGS, NOAA, and NatureServe, were key players in national-scale data collection efforts for indicators of water quality and aquatic ecosystems. For some indicators, we used data sets produced by other organizations or published in peer-reviewed literature.

A distribution of how often we used data sources from these organizations and other entities for assessing indicator mappability is shown in Table 6-1 (Distribution of data sources). The following 14 indicators (out of 53) had no data available and are, therefore, not included in the 39 indicators in the table: Flood Events (#100), At-Risk Native Marine Species (#27),

Freshwater Rivers and Streams with Low Index of Biological Integrity (#116), Harmful Algal Blooms (#127), Invasive Species-Coasts Affected (#145), Invasive Species in Estuaries (#149), Riparian Condition (#231), Status of Animal Communities in Urban and Suburban Streams (#276), Streamflow Variability (#279), Snowmelt Reliance (#361), Salinity Intrusion (#391), Threatened and Endangered Plant Species (#467), Vegetation Indices of Biotic Integrity (#475), and Instream Connectivity (#620). See Appendix C for a complete and more detailed listing of data sources for each of the 39 indicators in Table 6-1.

Table 6-1. Distribution of data source

Indicator	Data Source Organization				
	EPA	*USGS*	*NOAA*	*NatureServe*	*Other*
Acid Neutralizing Capacity (ANC) (#1)	**X** – Wadeable Streams Assessment				
Altered Freshwater Ecosystems (#17)	**X** – National Land Cover data set (NLCD)	**X** – National Hydrography data set (NHD)			**X** – U.S. Fish & Wildlife Service's (USFWS) National Wetlands Inventory (NWI)
At-Risk Freshwater Plant Communities (#22)				**X** – Customized data set	
At-Risk Native Freshwater Species (#24)				**X** – Customized data set	
Coastal Benthic Communities (#462)	**X** – Sampling data in National Coastal Assessment (NCA) database				
Coastal Vulnerability Index – CVI (#51)					**X** – Carbon Dioxide Information Analysis Center's (CDIAC) Coastal Hazards Database
Commercially Important Fish Stocks (#55)			**X** – Annual Commercial Landing Statistics		

Indicator	Data Source Organization				
	EPA	*USGS*	*NOAA*	*NatureServe*	*Other*
Erosion Rate (#348)					**X** – Yang, D. W., S. Kanae, T. Oki, T. Koike, and K. Musiake. 2003. Global Potential Soil Erosion with Reference to Land Use and Climate Changes. Hydrological Processes 17:2913–2928.
Fish and Bottom-Dwelling Animals (#95)	**X** – Wadeable Streams Assessment (WSA)				
Groundwater Depletion (#121)		**X** – National Water-Use Dataset			
Groundwater Reliance (#125)		**X** – National Water-Use data set			
Heat-Related Illnesses Incidence (#392)					**X** – National Center for Health Statistics (NCHS)'s Mortality data
Herbicide Concentrations in Streams (#367)		**X** – NAWQA			
Herbicides in Groundwater (#373)		**X** – NAWQA			
Insecticide Concentrations in Streams (#369)		**X** – NAWQA			
Insecticides in Groundwater (#374)		**X** – NAWQA			
Instream Use/ Total Streamflow (#351)					**X** – Water Resources Council. 1978. The Nation's Water Resources: The Second National Water Assessment, 1975–2000. Volume 2.
Low Flow Sensitivity (#159)		**X** – National Water-Use Dataset			
Macroinvertebrate Index of Biotic Condition (#460)	**X** – Wadeable Streams Assessment				

Indicator	Data Source Organization				
	EPA	*USGS*	*NOAA*	*NatureServe*	*Other*
Macroinvertebrate Observed/ Expected (O/E) Ratio of Taxa Loss (#461)	**X** – Wadeable Streams Assessment				
Meteorological Drought Indices (#165)			**X** – Divisional Data on the Palmer Drought Severity Index (PSDI)		
Number of Dry Periods in Grassland/ Shrubland Streams and Rivers (#190)		**X** – Hydro Climatic Data Network (HDCN) & Stream Gauge Data			
Organochlorines in Bed Sediment (#371)		**X** – NAWQA			
Pesticide Toxicity Index (#364)		**X** – NAWQA			**X** – EPA's ECOTOX database
Population Susceptible to Flood Risk (#209)					**X** – FEMA's Q3 Flood Data & ESRI ArcUSA's U.S. Census tract data
Precipitation Elasticity of Streamflow (#437)		**X** – HDCN			**X** – Oregon State University's PRISM Climate Modeling System
Ratio of Reservoir Storage to Mean Annual Runoff (#449)		**X** – Mean Annual Runoff Data			**X** – USACE's National Inventory of Dams (NID)
Ratio of Snow to Total Precipitation (#218)			**X** – Monthly Climate Data		
Ratio of Water Use to Safe Yield (#328)					**X** – Schmitt, C. V., Webster, K. E., Peckenham, J. M., Tolman, A. L., and J. L. McNelly. 2008. Vulnerability of Surface Water Supplies in Maine to the 2001 Drought. *Journal of the New England Water Works Association.* 122(2): 104–116.

Indicator	Data Source Organization				
	EPA	*USGS*	*NOAA*	*NatureServe*	*Other*
Ratio of Water Withdrawals to Annual Streamflow (#219)		**X** – National Water-Use Dataset			**X** – Oregon State University's PRISM Climate Modeling System
Runoff Variability (#453)					**X** – University of Washington's Variable Infiltration Capacity (VIC) Land Surface Data Set
Stream Habitat Quality (#284)	**X** – Wadeable Streams Assessment				
Total Use/ Total Streamflow (#352)					**X** – Water Resources Council. 1978. The Nation's Water Resources: The Second National Water Assessment, 1975–2000. Volume 2.
Water Availability: Net Streamflow per Capita (#623)		**X** – National Water-Use Dataset			**X** – Oregon State University's PRISM Climate Modeling System
Water Clarity Index (#318)	**X** – NCA				
Water Quality Index (#319)	**X** –NCA				
Waterborne Human Disease Outbreaks (#322)					**X** – Centers for Disease Control and Prevention (CDC)'s Waterborne Disease and Outbreak Surveillance System (WBDOSS)
Wetland and Freshwater Species at Risk (#326)				**X** – Customized data set	
Wetland Loss (#325)					**X** –USFWS National Wetlands Inventory (NWI)

As can be seen in Table 6-1, some data sources furnished data for multiple indicators. These major data sources are discussed in greater depth below.

EPA's Wadeable Streams Assessment (WSA)

EPA's WSA was designed to be the first statistically defensible summary of the condition of the nation's streams and small rivers. Chemical, physical, and biological data were collected at 1,392 wadeable perennial stream locations in the coterminous United States. Data were collected by field crews during summer index periods between 2000 and 2004. Sample sites were selected using a probability-based sample design; rules for site selection included weighting based on the 1st- through 5th-order stream size classes and controlled spatial distribution. Due to this sampling system, the sampling effort for the WSA varies across HUC-4 units. Because a probability-based sampling design was used, the WSA data set may have avoided the bias that may occur with ad hoc data sets. However, it is still less than ideal for mapping average conditions in 4-digit HUCs because lakes, reservoirs, and large rivers were not sampled, and because some HUCs had few or no sampling sites.

USGS's National Water-Quality Assessment (NAWQA) Program

USGS's NAWQA Program collects chemical, biological, and physical water quality data. From 1991 to 2001, the NAWQA program collected data from 51 study units (basins) across the United States; after 2001, data collection continued at 42 of the study units. Although the program spanned 10 years, not all 51 sites were sampled every year, but were, instead, broken up into smaller temporal frames (20 study units in 1991; 16 study units in 1994; and 15 study units in 1997).

The NAWQA data warehouse currently contains sampling information from 7,600 surface water sites (including 2,700 reach segments for biological studies) and 8,800 wells. The NAWQA sampling design uses a rotational sampling scheme; therefore, sampling intensity varies year to year at the different sites. In general, about one-third of the study units are intensively investigated at any given time for 3–4 years, followed by low-intensity monitoring. Due to this sampling scheme, the sampling effort for the NAWQA Program varies across HUC-4 units.

USGS' National Water-Use Dataset

USGS's National Water-Use Dataset contains water-use estimates for each county in the United States, the District of Columbia, Puerto Rico, and the U.S. Virgin Islands. USGS publishes reports every five years (starting in 1985) that present water-use information aggregated at the county, state, and national levels. USGS study chiefs from each state are responsible for collecting and analyzing information, as well as making estimates of missing data and preparing documentation of data sources and methods used to collect those data. The study chiefs are also responsible for determining the most reliable sources of information available for estimating water use for each state. Because of this, data sources and quality may vary by location.

NOAA's Monthly Climate Data

NOAA's National Climatic Data Center (NCDC) is the world's largest active archive of weather data. NCDC's Monthly Climate Data Set contains information collected for 18,116 sites across the United States from 1867 to the present. The data set includes an assortment of parameters such as measurements of rain, snow, evaporation, temperature, and degree days. NCDC Monthly Climate data are primarily intended for the study of climate variability and change. NOAA reports that, whenever possible, NCDC observations have been adjusted to account for effects from factors such as instrument changes, station relocations, observer practice changes, and urbanization.

NatureServe Data Set Customized for EPA

NatureServe collects and manages detailed local information on plants, animals, and ecosystems though natural heritage programs and conservation data centers operating in all 50 U.S. states, Canada, Latin America, and the Caribbean. The data sets were originally customized for the Heinz Center for publication in the 2008 *State of the Nation's Ecosystems* report. We obtained updated state-level data on At-Risk Native Freshwater Species (#24) and on At-Risk Freshwater Plant Communities (#22) to produce the maps for these indicators in this study. These data sets were provided in Excel format by NatureServe on July 29, 2009. Data on freshwater species were updated from those presented in the Heinz Center, 2008 report, and

included counts of at-risk (GX-G3) and total native freshwater animal species by state for the U.S. Due to incomplete state distribution, the data set did not include giant silkworm moths, royal moths, sphinx moths, or grasshoppers. NatureServe did not update data on plant communities as they determined that plant community data have not changed significantly since the original analysis for the Heinz Center.

6.1.3. Supporting Information Collected for Data Sources

To assess data availability, we isolated information about the underlying data on which the indicators were based. This information is also presented in Appendix C (Data Sources, Supporting Information, and Technical Notes). Information considered when assessing the mappability of data included:

- Data sets used and the organizations or individuals who published or own the data;

- How to obtain the data (download online or contact a specific person/organization) and whether or not payment was necessary to obtain the data set;

- Spatial resolution of data (e.g., state, study sites, HUC level, ecoregion);

- Temporal resolution of data (i.e., frequency of data points and duration of data collection);

- Extent of coverage of data (e.g., national, regional, state, local);

- Type of data source (e.g., survey, census, database, modeled data set);

- Format of data (e.g., Excel tables, GIS shapefiles); and

- Relevant metadata (either as a website or a supporting document).

In many cases, the supporting documentation accompanying the data did not provide all of the abovementioned details. However, the available information has proven useful for prioritizing indicators for further investigation into their mappability.

6.1.4. Lack of Data and Other Unresolved Data Problems

6.1.4.1. *Data Availability Issues*

To streamline the process of determining indicator mappability, we identified issues with data availability and how data were presented as early in the process as possible. We encountered problems both in the effort to locate, access, and download indicator data and in the effort to manipulate, transform, or modify the data so that they could be mapped using GIS software at the appropriate scale. Based on our assessment of data availability, 28 indicators were determined to be non-mappable. Although data sets were available for a few of these indicators, the problems with the data sets could not be reconciled, even with greater time and effort spent on data manipulation and mapping, and, therefore, these indicators were considered non-mappable. These 28 indicators presented one or more of the problems listed in Table 6-2 (Indicators eliminated due to lack of data or unresolved data problems).

Table 6-2. Indicators eliminated due to lack of data or unresolved data problems

Data Availability Problem	Description of the Problem	Example Indicators	Specific Data Availability Problem
Data reported by individual states	Reporting, sampling, and assessment methods vary between states. These indicators are likely to reflect programmatic differences instead of differences in vulnerability.	Fish and Bottom-Dwelling Animals (#95)	The indicator is derived from STORET, a database that relies substantially on self-reported data.
		Waterborne Human Disease Outbreaks (#322)	The WBDOSS datasets relies on voluntary reporting from public health departments within the United States.
		303(d) Impaired Waters[3]	The ATTAINS database relies on data reported by individual states.
Multiple Data Sets	Complete data set could only be obtained by combining more than one data set, as specified in the literature. The effort necessary to combine the data ranges widely.	Population Susceptible to Flood Risk (#209)	This would require combining digital flood data from FEMA (unavailable at time of inquiry) and Census Bureau demographic data.
		Water Quality Index (#319)	Five data sets combined into an index.
		Wetland Loss data (#325)	USFWS' National Wetlands Inventory data are at different scales at different locations.

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[3]This indicator was not assigned an indicator ID# because it was not derived from the scientific literature. The indicator was added to incorporate EPA's extensive water quality assessment database.

Data Availability Problem	Description of the Problem	Example Indicators	Specific Data Availability Problem
		Coastal Benthic Communities (#462)	Benthic indices vary by region and it is unclear whether regional indices are comparable.
Data set derived from extensive modeling	Complete data set needed to be recreated with extensive modeling using raw data.	Groundwater Depletion (#121)	Indicator based on a modeled base-flow data set developed by Vogel et al. (1999) and presented in Hurd et al. (1998).
		Low Flow Sensitivity (#159)	Indicator based on a modeled base-flow data set developed by Vogel et al. (1999) and presented in Hurd et al. (1998).
		Streamflow Variability (#279)	Indicator based on a model developed by Vogel et al. (1999) and presented in Hurd et al. (1998).
Data collection in progress	Data are unavailable because collection efforts are in progress.	Instream connectivity (#620)	USGS is currently collecting data on indicator as a part of its National Hydrography Dataset.
Not national in scope	Data are unavailable nationally	Number of Dry Periods in Grassland / Shrubland Streams and Rivers (#190)	The data set identified by the Heinz Center contained an analysis of grassland and shrubland watershed areas for Western ecoregions only.
		Water Clarity Index (#318)	Data are only available for certain U.S. coastal regions.
		Invasive Species – Coasts Affected (#145)	This indicator evaluates invasive species within the context of local land use, a scale that is relatively uncommon. No national datasets have been identified that simultaneously evaluate local land management and the presence of invasive species.
		Ratio of Water Use to Safe Yield (#328)	Data set identified by the source only contains data for the state of Maine.
		Salinity Intrusion (#391)	Data sources cited in the information source, (Poff et al., 2002) are local studies with limited (and non-comparable) data sets. No comprehensive national data sets are known to exist.
Data no longer collected, or are not for	Data are not recent enough (cutoff date varies with the indicator) or are based on future projections.	Waterborne Human Disease Outbreaks (#322)	Data are no longer reported (most recent data are from 2006).

Data Availability Problem	Description of the Problem	Example Indicators	Specific Data Availability Problem
the current time period.		Heat-Related Illnesses Incidence (#392)	Data consist of projections for the years 2020 and 2050.
No data set available.	Data for the indicator are unavailable.	At-Risk Native Marine Species (#27)	The Heinz Center (2008) study, which is the source of this indicator, identifies NatureServe as a potential source of information relevant to this indicator, but acknowledges that data availability is limited to a small set of species.
		Flood Event Frequency (#100)	No data source was identified in this study that could be used to map this indicator at a national scale.
		Freshwater Rivers and Streams with Low Index of Biological Integrity (#116)	There are currently no regional or national data bases that assemble this information for a broad range of taxa.
		Harmful Algal Blooms (#127)	Currently, there are no nationwide monitoring or reporting programs for harmful algal events.
		Invasive Species in Estuaries (#149)	Currently, there are no national monitoring programs for invasive species in estuaries and no agreed-upon methods for combining information on the number of species and the area they occupy into a single index.
		Status of Animal Communities in Urban and Suburban Streams (#276)	The Heinz Center (2008) study, which is the source of this indicator, states that currently available data are not adequate for national reporting.
		Riparian Condition Index (#231)	The Heinz Center (2008) study, which is the source of this indicator, identifies four literature sources that outline various ways to create such an index, but acknowledges that no raw data are currently available.
		Snowmelt Reliance (#361)	The information source (IPCC, 2007a) only has theoretical discussion of indicator. No specific data source is cited.
		Threatened & Endangered Plant Species (#467)	This indicator was provided as an example EPA's National Wetland Condition Assessment. This report does not identify a specific data source for this indicator.
		Vegetation Indices of Biotic Integrity (#475)	This indicator was provided as an example EPA's National Wetland Condition Assessment. This report does not identify a specific data source for this indicator.

Data Availability Problem	Description of the Problem	Example Indicators	Specific Data Availability Problem
		Altered Freshwater Ecosystems (percent miles changed) (#17)	A national database with the number of impounded river miles does not exist. Data from three sources need to be integrated, one of which currently does not provide data in electronic form.
		Commercially important fish stocks (#55)	Data for change in fish stock size over time are not currently available. The change in a fish stock size over time would need to be calculated for each area where fish stock data are available.
Duplicate Indicator	Data are available, but the indicator was a duplicate of another indicator.	Fish and Bottom Dwelling Animals (#95)	

This table highlights two challenges to the adoption and use of indicators at a national scale. First, it draws attention to the issue of measurability. In many cases, a measurable indicator requires a substantial effort to calculate the value at a single location. This may be due to the need for prolonged observation periods, complex sampling protocols, or other factors. For example, Vegetation Indices of Biotic Integrity (#475) uses the relationships between anthropogenic disturbances and observations of plant species, plant communities, plant guilds, vegetation structure, etc. to describe wetland condition. Typically, the highest IBI values represent reference standards or least-disturbed ecological conditions. To collect the data required to calculate an IBI, a trained observer must record multiple parameters in the field for each local IBI score. Though the indicator is measurable and highly useful in the locations where data exist, the effort required to collect data for this indicator at a national scale may be prohibitive.

Second, Table 5-2 highlights how data sources that may otherwise be excellent may be problematic for the purposes outlined in this study. We will discuss the issue of self-reported data in further detail as an example. Data sets that rely on individual state reports are problematic for three reasons. First, the monitoring activities and subsequent reporting may be limited by the availability of the state's resources. This can result in data gaps stemming from varying levels of reporting activity across states. Second, state-based assessments that require sampling from a population (e.g., stream assessments) may not rely on statistically rigorous sampling methods,

resulting in sampling that may not be representative. Third, assessment methods may vary from state to state. For example, the assessment and classification methods used by states during the development of the 303(d) impaired waters lists vary substantially among states. Together, these inconsistencies in reporting, sampling, and assessment result in maps that may reflect programmatic differences instead of actual differences in vulnerability. For these reasons, indicators based on national data sets that had national coverage but rely on individual entities to voluntarily report data, (e.g., EPA's Storage and Retrieval [STORET] database for water quality data, CDC's Waterborne Disease and Outbreak Surveillance System [WBDOSS], and EPA's Assessment, TMDL Tracking and ImplementatioN System [ATTAINS] database), were not used in the present study.

Figure 6-1 shows a national map that relies on one such national data set, the ATTAINS database. Panel A shows a map that relies on the total stream-miles designated as 303(d) impaired waters. This first map is problematic because it does not account for large differences in assessment rates across states, or for the fact that overall assessment rates are low. According to the EPA ATTAINS database, only 26.4% of the nation's streams and rivers and 42.2% of the nation's lakes and reservoirs have been assessed for impairments, making it difficult to create national-scale indicators. Panel B attempts to account for differences in assessment rates by showing the percentage of assessed stream-miles that are designated as 303(d) impaired waters. Though this second map is an improvement over the first because it normalizes the assessment effort, the programmatic differences still result in areas that may not appear to be vulnerable simply because sampling and assessment methods vary substantially between states.

The following maps display number (panel A) and percent (panel B) of stream-miles designated as 303(d) impaired waters using data from EPA's Assessment, TMDL Tracking and ImplementatioN System (ATTAINS) database.

A.

Stream-miles designated as impaired
- 0 - 699
- 700 - 1,590
- 1,600 - 20,900
- States

B.

Percent of assessed stream-miles designated as impaired
- 0% - 20.7%
- 20.8% - 44.6%
- > 44.6%
- States

0 200 400 600 800 1,000 Miles
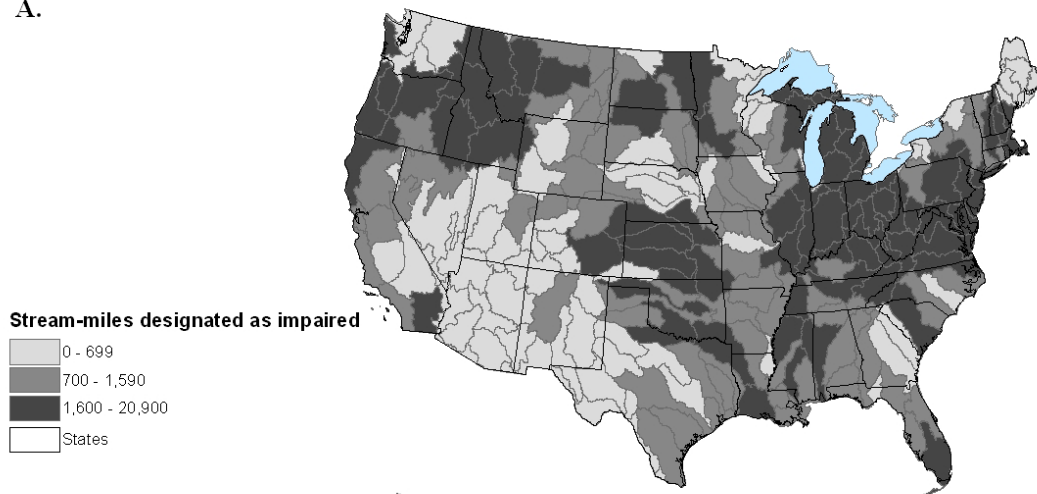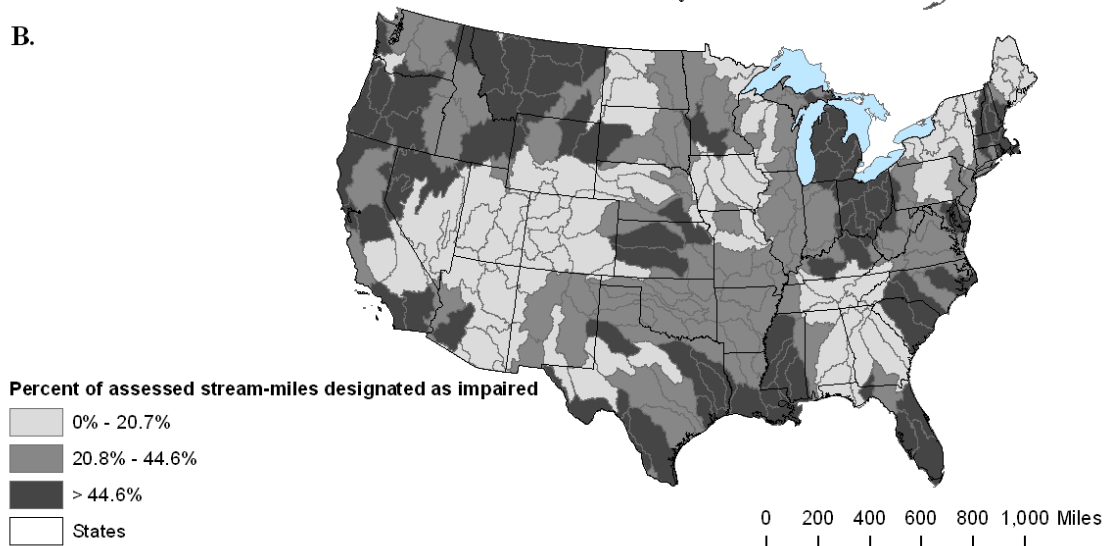
Figure 6-1. Limitations of data sets containing self-reported data.

6.1.4.2. *Data Sets Without National Coverage*

In some cases, the data required to calculate indicator metrics were incomplete in terms of national coverage. Indicators based on a particular ecosystem or land cover type (e.g., grassland or shrubland) may not extend to all parts of the country. For example, few, if any, streams in Eastern ecoregions are grassland or shrubland streams. Other national coverage data gaps stemmed from data availability. For example, although 500 year flood plains can be

identified for all parts of the country, GIS-compatible digital flood plain data from FEMA are only available for certain parts of the country where paper maps have been digitized.

Other data gaps were the result of incomplete data collection. For example, for the indicator Commercially Important Fish Stocks (#55), the Heinz Center (2008) study evaluated only about 21% of the commercially important fish landings found in U.S. waters. Similarly, for the indicator Number of Dry Periods in Grassland/Shrubland Streams and Rivers (#190), the data set provided by the Heinz Center contained an analysis of grassland and shrubland watershed areas for Western ecoregions only. Although the reasons for mapping Western ecoregions only are unclear, it is likely that few, if any, sites in Eastern ecoregions satisfied the definition of a "grassland" or "shrubland" watershed used in the 2001 National Land Cover Dataset.

In some cases national coverage was unavailable because data collection efforts are still in progress. For the indicator Wetland Loss (#325), wetlands in 13 states are either unmapped or are recorded only on hardcopy maps. Similarly, data for the indicator Coastal Benthic Communities (#462) (from EPA's National Coastal Assessment [NCA]) and digital flood data for the indicator Population Susceptible to Flood Risk (#209) (from the Federal Emergency Management Administration [FEMA]) were not available at the time of this study for several areas within the U.S.

6.1.4.3. *Non-uniform Spatial Distribution of Data*

In some cases, the national-scale data required to calculate a vulnerability metric are available, however the data are not distributed homogeneously across the country. As a result, varying amounts of data are available within each of the HUC-4 units. This variation can be substantial, and in cases where only few sample points are available within a HUC-4 boundary, individual sites may exert a large influence on the calculated metric value.

The indicator Acid Neutralizing Capacity (#1), for example, is calculated using data from 1,601 stream sites across the country that were sampled as part of EPA's Wadeable Streams Assessment. The number of sites sampled within each of the 204 HUC-4 units varies from 0 to 93, with a median value of 5 sample sites. The calculated vulnerability metrics for HUC-4 units containing the median number of samples (or fewer) are particularly sensitive to measurements at individual sites. A change in the status of a single site from "not at risk" to "at risk" changes the calculated metric (percentage of "at risk" sites) by 20%. This could result in the entire HUC-

4 unit being placed in a different category of vulnerability as a result of a single measurement. A mapping challenge emerges when vulnerability metrics calculated from a small pool of data are mixed with those calculated from a larger pool. It is difficult, and sometimes impossible, to illustrate on a single map where low density would be most likely to result in an erroneous vulnerability classification.

6.1.4.4. *Temporal Gaps*

Many indicators are derived by comparing data contained in two separate data sets, or by comparing data from one data set collected over two distinct time periods. In the first case, it is important to consider the time period in which the data are collected, especially if the information collected may change over time. Temporal gaps between data sets may result in erroneous vulnerability assessments and inaccurate maps. For example, Net Streamflow Availability per Capita (#623) depends on time-sensitive information from a range of data sets. Evaluating streamflow, withdrawals, and population figures from different time periods may provide a different assessment of vulnerability when compared to data collected from the same year. In the second case, indicators based on comparisons to a historical condition are dependent on the existence of historical data. For some indicators considered during the course of this project, this historical information was not available. The Wetland Loss (#325) indicator provides an example of such a case. Information regarding wetland extent is not available at the national scale in a format suitable for mapping with a GIS.

Another issue related to temporal gaps pertains to future data collection. One objective of this project is to identify indicators that can be updated over time to track changes in vulnerability. In cases where data collection and reporting have been discontinued, the indicator no longer meets this key objective. The Waterborne Human Disease Outbreaks (#322) and Runoff Variability (#453) indicators fall into this category. If future data collection efforts are proposed, these indicators may become more useful for national level assessments.

6.1.5. Data Problems that Could be Resolved

Of the 53 indicators that were examined for data availability, twenty-five indicators were mapped. Data sources and supporting information for 32 indicators that had some form of data

available that could be examined for mapping are presented in Appendix C (Data Sources, Supporting Information, and Technical Notes).

We identified various types of data gaps in the search for data to represent our vulnerability indicators at the national scale. In some cases, additional assessment of an indicator suggested that there were too many obstacles to nationwide mapping at the present time. Because one rule of thumb for this project was to identify those vulnerability indicators that could be readily mapped, we did not consider indicators that appeared to be mappable but only with extensive data processing efforts. The extent of the data gaps that affected the production of maps differed from one indicator to another, and prohibited production of maps for some indicators. In other cases the problems were minor and maps could be produced (with a few accompanying caveats). The data gaps for this project could typically be placed into one of the three categories shown in Table 6-3.

Table 6-3. Data gaps

Data Availability Problem	Description of the Problem	Example Indicators	Specific Data Availability Problem
Data Sets Without National Coverage	National data collection is incomplete or indicator is location-specific.	Population Susceptible to Flood Risk (#209)	At time of inquiry, GIS-compatible digital flood plain data from FEMA were only available for certain parts of the country.
		Number of Dry Periods in Grassland/Shrubland Streams and Rivers (#190)	Heinz Center data identifies grassland and shrubland watershed areas for Western ecoregions only.
Non-uniform Spatial Distribution of Data	Data are not distributed homogeneously across the country (therefore, number of data points within each HUC varies).	Acid Neutralizing Capacity (#1)	EPA Wadeable Streams Assessment data were collected at 1,601 sites. However, the number of sites within HUC-4 units ranged between 0 and 93 sites.
Temporal Gaps	Lack of historical data (which are needed as a baseline) or time-sensitive data which must be updated frequently.	Wetland Loss (#325)	Historical data on the extent of wetlands is not available.
		Water Availability: Net Streamflow Availability per Capita (#623)	Variables that this indicator depends on (streamflow, water withdrawals, and population) are all time-sensitive. Indicator maps are not useful if recent data are not available.

Mapped indicators typically used nationally recognized data sets or data sets created by national agencies, such as EPA, USGS, and NOAA. While these data sets are comprehensive in

nature and cover the entire country, they still have data gaps as well as data quality issues. Nevertheless, the data issues associated with the mapped indicators were either resolved or considered minor enough that a map would still provide useful information for a vulnerability assessment. Minor data issues were carefully documented for the mapped indicators.

6.2.   CREATION OF EXAMPLE MAPS

We evaluated for mapping purposes 32 indicators for which national data had been collected. Twenty-five indicators were considered to be mappable (Table 6-4). Six of the remaining indicators were not mapped for this project due to challenges with acquiring data or representing the source data spatially. One of these indicators was mappable, but had substantial gaps in coverage that limited our ability to assess relative vulnerability at a national scale.

Table 6-4. List of mapped vulnerability indicators

Indicator (See Appendix B for definitions)	Literature Source (See Appendix A for full citations)
Acid Neutralizing Capacity (ANC) (#1)	U.S. EPA, 2006b
At-Risk Freshwater Plant Communities (#22) [1]	Heinz Center, 2008
At-Risk Native Freshwater Species (#24)[1]	Heinz Center, 2008
Coastal Vulnerability Index (CVI) (#51) [2]	Day et al., 2005
Erosion Rate (#348)	Murdoch et al., 2000
Groundwater Reliance (#125)	Hurd et al., 1998
Herbicide Concentrations in Streams (#367) [1, 3]	USGS, 1999
Herbicides in Groundwater (#373)[1, 3]	USGS, 1999
Insecticide Concentrations in Streams (#369) [1, 3]	USGS, 1999
Insecticides in Groundwater (#374)[1, 3]	USGS, 1999
Instream Use/Total Streamflow (#351)	Meyer et al., 1999
Macroinvertebrate Index of Biotic Condition (#460)[1]	U.S. EPA, 2006b
Macroinvertebrate Observed/Expected (O/E) Ratio of Taxa Loss (#461)	U.S. EPA, 2006b
Meteorological drought indices (#165)[2]	National Assessment Synthesis Team, 2000a
Organochlorines in Bed Sediment (#371)[1, 3]	USGS, 1999
Pesticide Toxicity Index (#364)	Gilliom et al., 2006
Precipitation Elasticity of Streamflow (#437)	Sankarasubramanian et al., 2001
Ratio of Reservoir Storage to Mean Annual Runoff (#449)[1, 3]	Lettenmaier et al., 2008
Ratio of Snow to Total Precipitation (#218)[2]	Lettenmaier et al., 2008
Ratio of Water Withdrawals to Annual Streamflow (#219)[3]	Hurd et al., 1998
Runoff Variability (#453)	Lettenmaier et al., 2008
Stream Habitat Quality (#284)[1]	Heinz Center, 2008
Total Use / Total Streamflow (#352)	Meyer et al., 1999
Water Availability: Net Streamflow per Capita (#623)[1, 3]	Hurd et al., 1998
Wetland and freshwater species at risk (number of species) (#326)[1]	Hurd et al., 1998

[1]Indicator definition changed based on available data.
[2]Indicator not defined in information source. Definition obtained from primary literature cited in the information source or new definition created based on available data.
[3]Indicator name changed to more appropriately match its definition or the available data.

The software we used for creating the maps for the 25 indicators was ArcMap 9.2 (©

1999–2006 ESRI). For most indicators, data were available either in a GIS format, such as

shapefiles, or in tabular form. In some cases, we processed tabular data in Microsoft Excel 2002 or Microsoft Access 2002 prior to importing into ArcMap. In other cases, we manipulated these data and calculated summary statistics directly in ArcMap. We used ArcMap to overlay different data sets, and we ultimately overlaid all data sets with HUC-4 boundaries. The data layer for such boundaries was obtained from the USGS.

For illustrative purposes, we had to choose a spatial unit of analysis. We chose to use USGS hydrologic units at the 4-digit scale here, for three practical reasons. First, USGS hydrologic units provide complete, continuous coverage of the continental U.S., which we established as a requirement of this project. Second, hydrologic units are usually synonymous with watersheds. Using a spatial unit with an inherent link to existing hydrography seems appropriate for a project that is evaluating indicators of vulnerability for drinking water and aquatic ecosystems. HUCs are frequently used by EPA, USGS, and other agencies to monitor water-related phenomena across the country. Finally, 4-digit HUCs were chosen because they balance the need to convey interpretable regional patterns with the objective of providing detailed local information. In other words, in our judgment, they do not over-generalize regional patterns and they do not over-extend the underlying data by providing more local resolution than is warranted. However, we reiterate that the maps we show are to illustrate the various issues we discuss, and we are not advocating any particular spatial aggregation as a matter of best practice. Alternative spatial frameworks or resolutions of course exist, and we discuss the implications for mapping of using such alternatives in more detail in sub-section E (Spatial Aggregation) below.

We aggregated or dis-aggregated the data, depending on their native scale (e.g., state-level data [where there is one data value provided for each state] vs. point data), to obtain a single value of the indicator for each HUC-4 watershed. Using Symbology, we assigned different colors or gray shades to represent the HUC-4 watersheds in different vulnerability categories on each indicator map. The detailed step-by-step methodology for each indicator is documented in Appendix D (Mapping Methodology).

We produced 25 complete example maps by HUC-4 watershed (see Appendix E). In addition, we produced an incomplete map for one indicator for which data suitable for mapping were available for portions of the country. However, substantial gaps in national coverage limit the ability to assess the relative vulnerability of ecosystems to environmental change at a national scale using this indicator. The remaining five indicators were not mapped for this project due to

challenges with acquiring data or representing the source data spatially. These issues are discussed in detail below.

The mapped indicators fall into five categories established during the evaluation of the literature (see Section 3), though the indicators we mapped are not distributed evenly across these categories. The categories (with number of indicators mapped shown in parentheses) are: chemical (7); ecological (6); hydrological (8); soil (1); socioeconomic (3).

Assuming that vulnerability can be inferred from metric values that were at the high (or low, depending on the indicator) end of the range of mapped values, regional differences in relative vulnerability were apparent for some of the mapped indicators. For example, the map for the indicator Meteorological Drought Indices (#165) displays high vulnerability in the Western United States, an area that has historically been exposed to prolonged drought. The map also shows high vulnerability for the Southeastern U.S., an area that has experienced a severe drought in recent years.

In some cases, there are no strong regional patterns. For example, the map for Stream Habitat Quality (#284) displays a spatially heterogeneous pattern, with no particular portion of the country strongly distinguished from any other.

Regions for which a single indicator might suggest greater vulnerability may not appear as vulnerable across a full suite of indicators. An examination of the full set of maps by HUC-4 watershed in Appendix E suggests determining overall water quality- and aquatic ecosystem-related vulnerability across all of these dimensions may be complicated. Appendix E also contains detailed descriptions of each of the 25 maps created for the mappable indicators. We return to the issue of combining indicators in more detail in Section 7.

6.3. SPATIAL AGGREGATION

To create a national map illustrating an indicator of vulnerability, it is necessary to aggregate data collected at discrete locations and calculate summary statistics that describe conditions across a larger area. Examples of such statistics may include the mean value of an indicator or the percentage of sites that exceed a threshold value. In many cases, this aggregation process results in a slightly different metric. For example, Acid Neutralizing Capacity is reported in milliequivalents/L at the site scale. However, an aggregate statistic that can be calculated, and is both referred to in EPA's Wadeable Streams Assessment report and mapped for this report, is

the percentage of sites with ANC less than 100 milliequivalents/L. When developing maps using aggregated metrics, it is important for both the producers and consumers of maps to understand how the underlying data and the aggregation methods may affect the validity of objective thresholds and the patterns illustrated in the final map. In the above example, the threshold of 100 milliequivalents/L is a relevant threshold at the scale of an individual site. However, no objective thresholds are defined for the range of aggregated *percentage* values calculated for each HUC. Appendix H includes an evaluation of the effects of aggregation on the validity of theoretical breakpoints for each of the mapped indicators. These issues of aggregation underscore the concept that a single set of data can be used to produce many different maps. The following sections discuss additional factors to be considered when aggregating data.

6.3.1. Local Variation

Measurements at individual sample sites are affected by local factors such as land use, the presence of an industrial facility, an urban center, a protected region (e.g., a National Park), or other features that exist in a heterogeneous landscape. Within a large area (like a HUC-4 unit) that contains a wide variety of these local factors, measurements collected at individual sites may vary substantially. When a group of values within such an area are aggregated into a single value, local variation can be masked. Understanding the degree of local variation is an important component of interpreting vulnerability. For this reason, it may be necessary to simultaneously consider maps that illustrate the vulnerability metric and the variation in raw data values present within each spatial unit.

6.3.2. Extent of Spatial Units (HUC Levels)

Aggregation of individual local measurements into a single metric frequently involves the extrapolation of information. Extrapolation may be appropriate in areas where sampling density is large enough to accurately describe the conditions, and that the extent of the local measurements coincides with the extent of the larger areal unit used to aggregate data. However, extrapolation may also result in the masking of low data density in cases where the extent of the aggregate unit is significantly different from the extent of the underlying data. The producers of maps must be sensitive to the limits of aggregation (and subsequent extrapolation) when choosing a spatial framework to represent a data source comprised of local measurements.

For example purposes, we rely here on 4-digit HUCs to illustrate patterns of vulnerability - we apply it consistently to compare across indicators. For some indicators, however, aggregation of data into this framework may mask low data density. Figure 6-2 illustrates this issue using 3 different scales of HUC units and the same underlying data set. The visual contrast between the top and bottom maps demonstrates how low data density can be masked through aggregation into larger spatial units.

All of the indicators we selected for mapping were chosen based on their ability to provide information on the relative vulnerability of water quality and aquatic ecosystems. As environmental measurements, the data collected and used for each indicator has an inherent level of uncertainty and error associated with it. Selecting a particular unit for presenting information in a set of maps is useful for making comparisons across the set. However, the data collected for the indicators were not available at consistent scales across the set of indicators. The data for most of the indicators was thus altered to present it at a consistent scale. Although manipulating the data changes the accuracy of the information, the manipulations help make the information presented more useful. For the most part, data manipulation required either a scaling up or down of data or transformation of the data from different geographic boundaries.

Data needing to be scaled up included point data. In all cases, the sample data used to calculate metrics for these indicators is not distributed homogeneously. As a result, dissimilar amounts of data are available within the HUC-4 unit boundaries. In cases where there are few sample points within a HUC-4 boundary, individual sites have a greater influence on the metric value that is calculated.

Data presented at the state level needed to be scaled down or transformed to match the HUC-4 geographic boundary. Transforming the data from a state-based representation to a HUC-4 representation requires an assumption that the distribution of the indicator is uniform within each state. Although this assumption is unlikely to be accurate, it allows for area-weighted metrics to be calculated for HUC-4 units that intersect more than one state.

Coastal data presented a unique challenge in mapping. As a watershed geographic unit, HUC-4 has limited or no coverage for coastal and nearshore area data. This makes aggregation for the purposes of reporting at the HUC-4 scale problematic. To address this issue, we developed a special reporting unit for one indicator, the Coastal Vulnerability Index (#51).

Although necessary for creating useful and comparable maps, data manipulations change the quality of the data presented through assumptions about coverage and the representativeness of the data to nearby geographic areas. In most cases, data manipulations are likely to yield greater error and uncertainly than the original data. However, problems associate with data manipulation are likely to be more important for some indicators than others. For example, an indicator based on fine-scale data within a HUC-4 boundary will likely present a more accurate picture of relative regional vulnerability than an indicator based on transformed state-level data.

The following maps display the Stream Habitat Quality (#284) indicator at various scales of HUC units, illustrating how low data density can be masked through aggregation into larger spatial units.
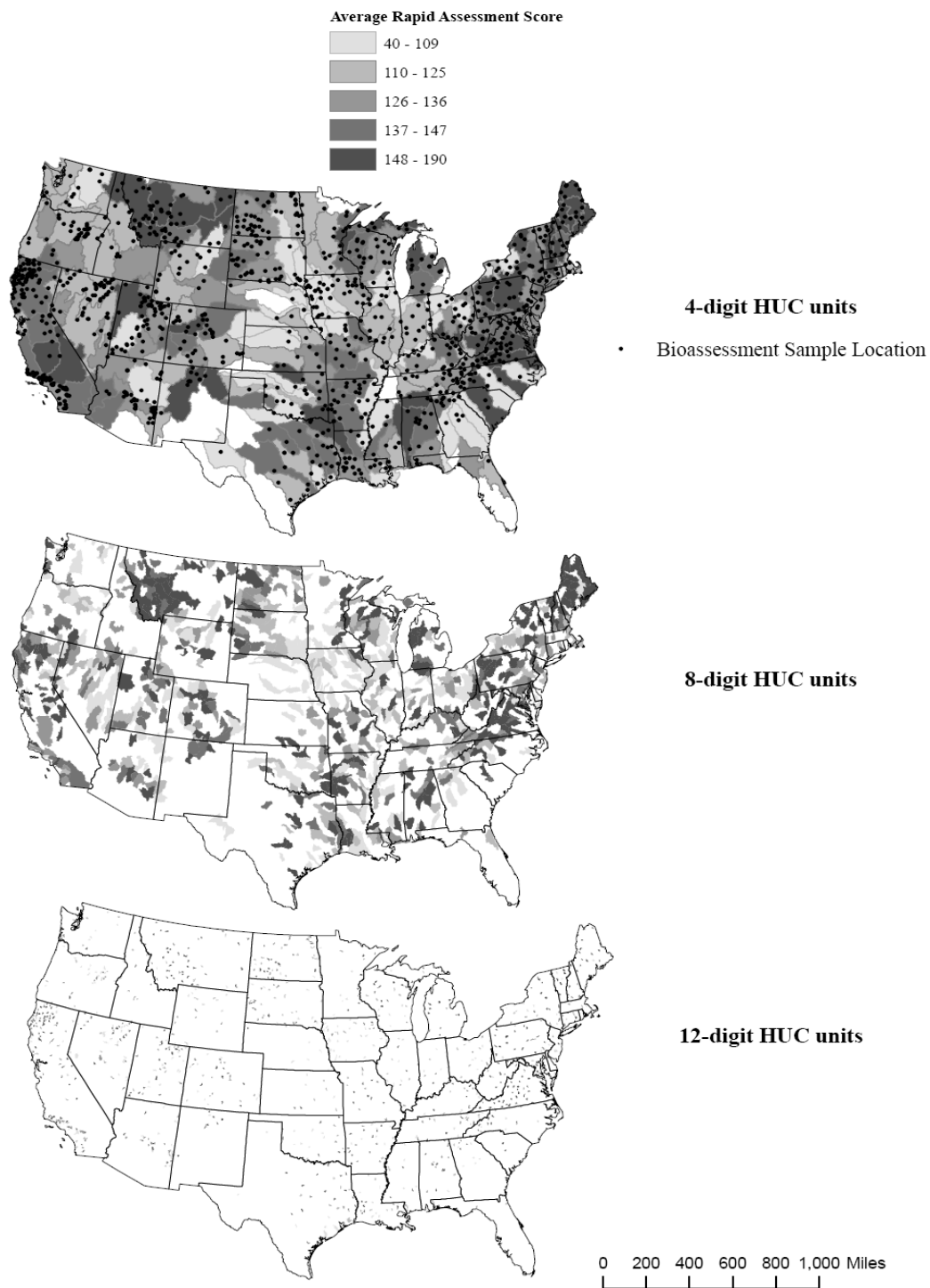
Figure 6-2. Aggregation, precision, coverage, and data density.

6.3.3. Alternate Spatial Frameworks

The selection of the spatial framework used to evaluate geographically-based data can have a significant influence on the graphical display of spatial information and for the assessment and management of resources (Omernik and Griffith, 1991). In some cases, different units of analysis can result in maps that provide difference perceptions using the same set of underlying data. Two spatial frameworks, watersheds and ecoregions, are often associated with ecosystem management. Each of these frameworks has advantages, and the tradeoffs between the two systems reinforce the concept that there is no single best spatial framework for displaying indicators of water quality and aquatic ecosystem condition or vulnerability.

6.3.3.1. *Watersheds (and Hydrologic Units)*

Watersheds are often advocated as the appropriate unit for ecosystem management because they encompass the area of land that influences a connected system of water bodies (Montgomery et al., 1995; U.S. EPA, 1995). To address the practical need for a system of management units that serve as a standardized base for inventorying hydrologic data, the US Geological Survey delineated hydrologic units. These units are commonly identified by their hydrologic unit codes (HUCs) (Seaber et al., 1987). The term "HUC" is often used to describe the hydrologic unit, not just the unit code). HUCs are assigned at several hierarchical spatial scales. The HUC-4 units (n = 204) used in this study have a mean area of 38,542 km^2.

It is noteworthy that many HUCs are true watersheds, while others are combinations of multiple smaller watersheds or segments of a larger watershed. HUCs provide non-overlapping, continuous coverage of a given area, and are typically used in place of true watersheds for mapping environmental data.

6.3.3.2. *Ecoregions*

Ecoregions are alternative spatial units, introduced by Omernik (1987), that are specifically designed to be internally homogeneous with regard to factors that affect water quality, such as vegetation, soils, land forms, and land use. Similar to HUCs, ecoregions are designated at several hierarchical spatial scales. The size of individual ecoregions varies more

than individual HUCs. For example, the 87 ecoregions at the Level 3 scale range in size from 649 to 357,000 sq. km.

The shortcoming of ecoregions is that they rarely encompass a single hydrologically connected area, making it difficult to identify the location(s) where cumulative stresses will be felt.

Figure 6-3 illustrates differences resulting from the use of different spatial frameworks. Although the national spatial patterns are similar, there are local differences that may influence vulnerability interpretations. Specifically, differences between the maps are most evident in the western United States – particularly within the Rocky Mountains – and in northern Wisconsin. These differences are reasonable, given the basis for delineating individual areas within each of these frameworks. HUCs, which are based loosely on watershed boundaries, tend to integrate a wider range of physical/topographical characteristics than ecoregions. These local physical characteristics may have a significant influence on the ratio of snow to total precipitation at any one point, resulting in a wide range of values within a HUC. Ecoregions, on the other hand, are specifically intended to describe regions with physical/topographical similarities. Thus, one would expect that ecoregions would contain less within-unit variation for Indicator #218. Maps of the 25 mappable indicators by ecoregion are presented in Appendix F. Appendix F also contains detailed descriptions of each of these maps. From a visual comparison of these maps with the HUC maps presented in Appendix E, it is evident that the choice of similarly sized spatial units (i.e., HUC4 vs. Ecoregion Level 3) has little effect on our results at the national scale.

6.3.3.3. *Coastal Areas*

Coastal areas are worthy of focus in national scale vulnerability assessments because they are of great national importance and pose unique challenges. Coastal areas may be more prone to the effects of climate change, but the limited geographic extent of coastal areas necessitates the use of a different analysis framework. For example, the indicator Coastal Vulnerability Index (#51) uses data available from a USGS database. The data are limited to only coastal and nearshore areas. Although this indicator provides complete coverage of coastal areas, aggregation into HUC-4 units or ecoregions would not provide meaningful results. To address this issue, a set of special reporting units for coastal areas was developed for this indicator. Each

unit extends approximately 20 miles inland and includes approximately 150 miles of coastline (Figure 6-4).

6.4. CATEGORICAL AGGREGATION

It is common to symbolize numerical data using chloropleth maps, which use a range of colors that correspond to the underlying data values. Determining how each color is assigned to the range of data values is classic cartographic challenge that applies to most any mapping project, this study included. For numerical data, the methods used to delineate breaks between data classes can affect the spatial patterns conveyed in a map, and the subsequent interpretation of those data. Thus, care must be taken in the development of maps based on numerical data, especially if the resulting spatial patterns may be used to develop policy.

Figure 6-5 illustrates how a single set of data can be used to create alternate maps simply by altering the number of data classes and the breaks used to distinguish between individual data classes.

The following maps display the Ratio of Snow to Precipitation (#218) indicator using 4-digit HUC units and Omernik's (1987) ecoregions, illustrating how the same underlying data appear different when using different spatial frameworks.
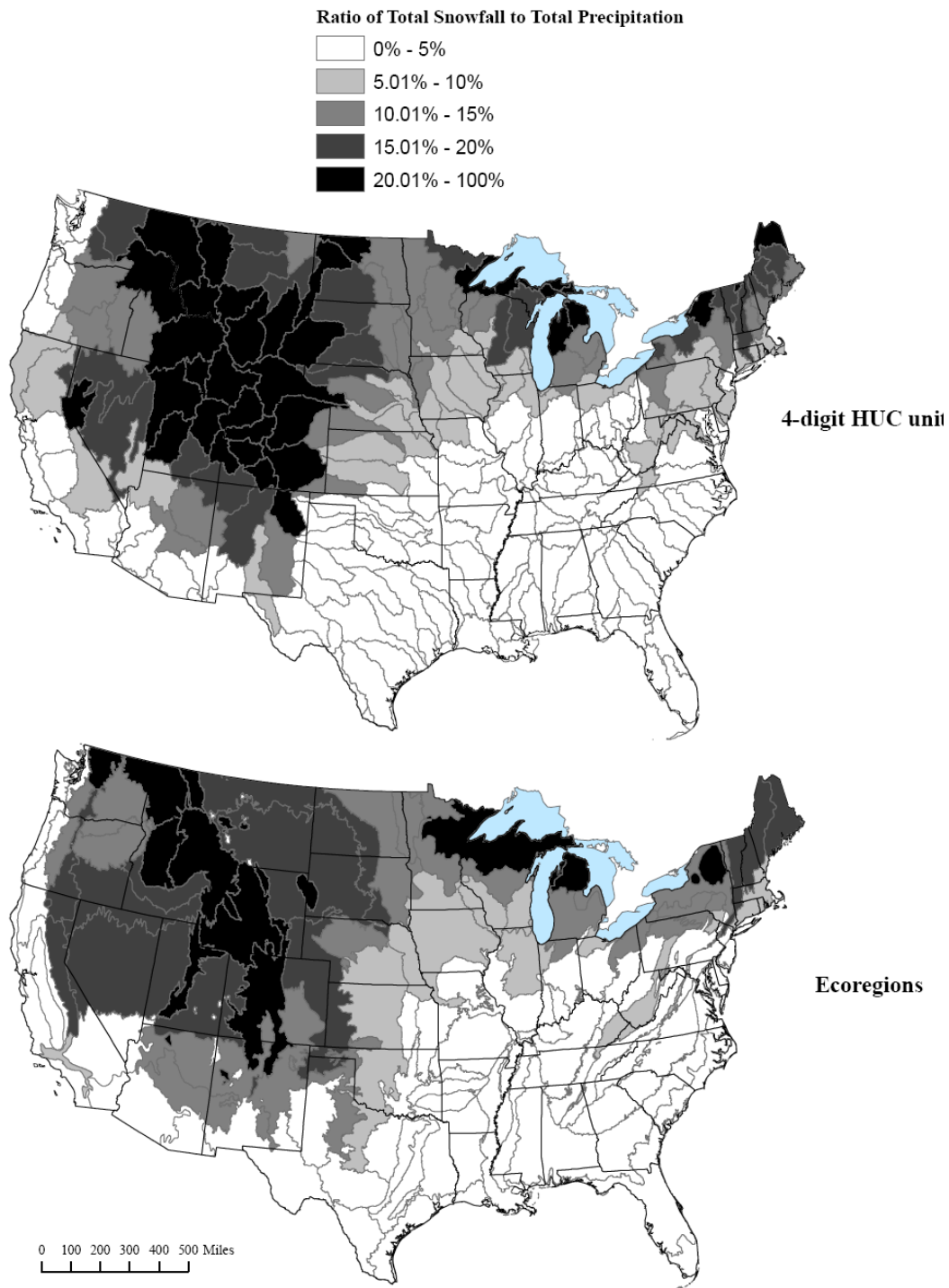
Figure 6-3. Data represented by different spatial frameworks.

The following map displays the Coastal Vulnerability Index (#51), a coastal indicator, for which a set of special reporting units for coastal areas was developed. Each coastal unit extends 20 miles inland and includes approximately 150 miles of coastline.

Coastal Vulnerability Index

- Low Vulnerability
- Medium Vulnerability
- High Vulnerability

0   100 200 300 400 500 Miles

Figure 6-4. Spatial framework for coastal zone indicators.

The following map displays the Stream Habitat Quality (#284) indicator, illustrating how the same underlying data appear different when displayed using three different data breaks (quantiles, equal intervals, and natural breaks or jenks).
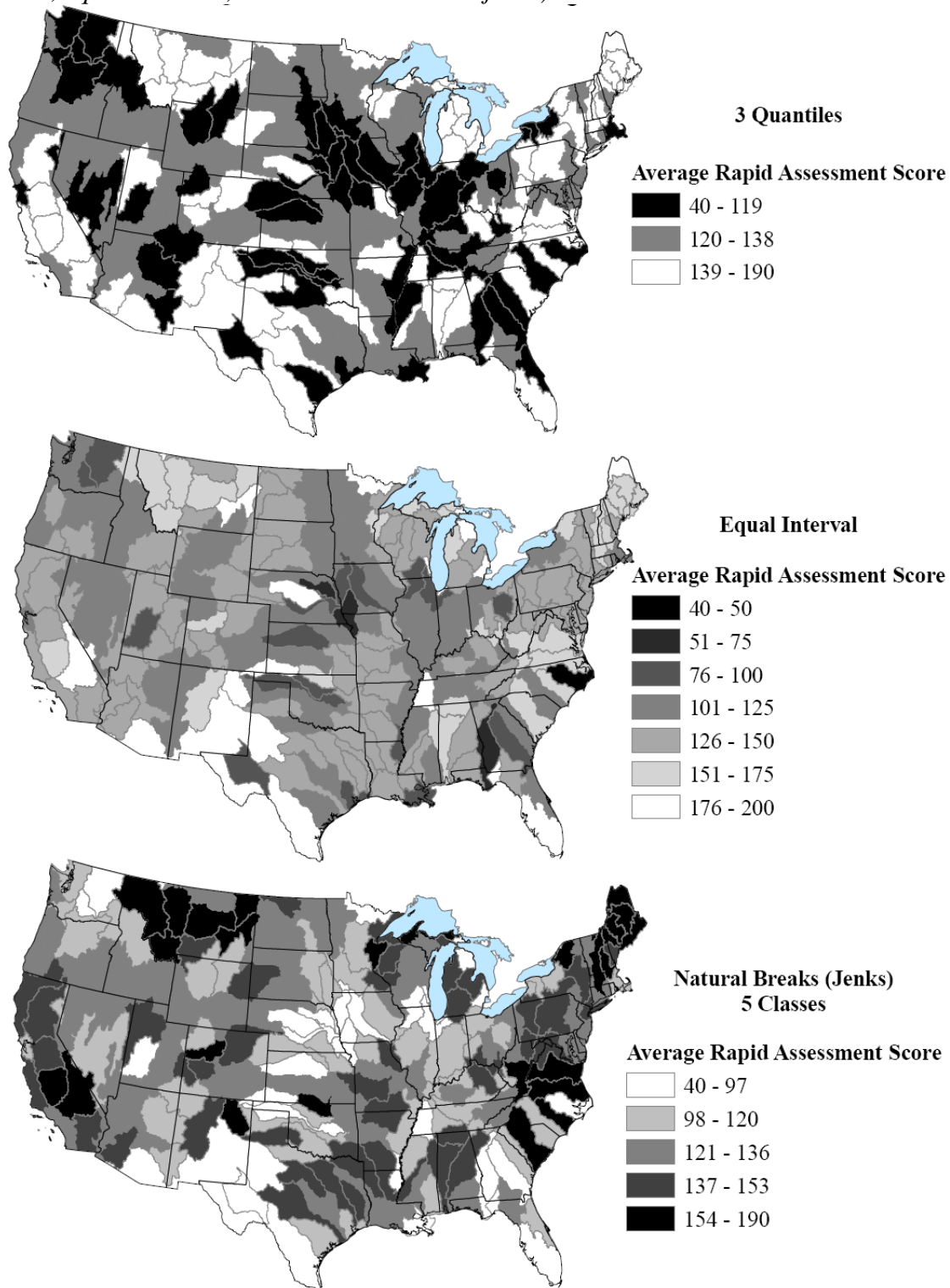
Figure 6-5. Different breaks to distinguish data classes.

7. CHALLENGES PART IV: COMBINING INDICATORS

7.1. COMBINING INDICATORS WITH OTHER DATA

Exposure to future stresses associated with external stressors such as climate and land-use change is likely to vary spatially. Scenarios derived from climate models can be used to map changes in exposure across the plausible range of future changes. A more comprehensive evaluation of future stresses could directly incorporate such scenarios in a vulnerability indicator-based assessment. Figure 7-1 displays an approach for combining indicators identified in this report with other variables. This approach allows the identification of locations that are both vulnerable to stress and are likely to experience additional stress in the future. Four indicators that are related to potential water shortages are presented in the context of simulated changes in temperature and precipitation derived from the IPCC 4th Assessment Report (IPCC, 2007b) and population derived from EPA's Integrated Climate and Land Use Scenarios (ICLUS) project (U.S. EPA, 2009d). Increasing temperature and population and decreasing precipitation all tend to increase the likelihood of water shortages. These plots are examples meant to illustrate how one might go about highlighting regions where we might see a convergence between an already stressed water supply system, a warmer, drier climate, and significant population growth.

While all of the indicators in Figure 7-1 relate to water supply, they deal with different aspects of vulnerability. For example, Precipitation Elasticity of Streamflow (#437) is based only on natural variation in water availability, whereas Groundwater Reliance (#125), Ratio of Withdrawals to Streamflow (#219), and Water Availability: Net Streamflow per Capita (#623) either directly incorporate current rates of water use or infer it through population. These plots illustrate how high water withdrawals in some regions may be unsustainable under a given temperature and precipitation scenario, or how locations that have low water availability per capita might also be places where we expect to see the greatest population increases in the future. In general, under the scenarios used here, current sensitivity and future exposure tend to co-vary, and thus the places that are vulnerable now are likely to become more vulnerable in the future.

The following plots displays values of some example indicators with a sample scenario of temperature and precipitation (based on the B1 greenhouse gas storyline) drawn from the IPCC Summary for Policymakers (IPCC, 2007b) and a population scenario from the Integrated Climate and Land Use Scenarios (ICLUS) project. All variables are scaled as changes over a 100 year period from 2000 to 2100. Each point represents a single HUC-4 and is shaded according to values of the indicator.

A. Groundwater Reliance (#125) (white, 0–10%; grey, 11–60%; black, 61–100%).
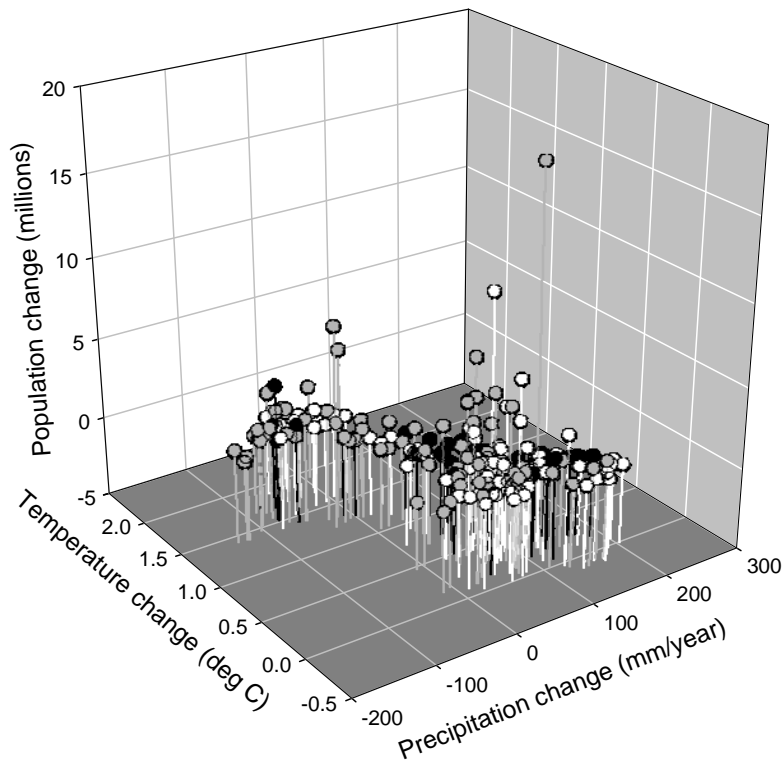
Figure 7-1. Current and future vulnerability to water shortages.

B. Ratio of Withdrawals to Streamflow (#219) (white, 0–0.11; grey, 0.12–0.75; red, 0.75–59).
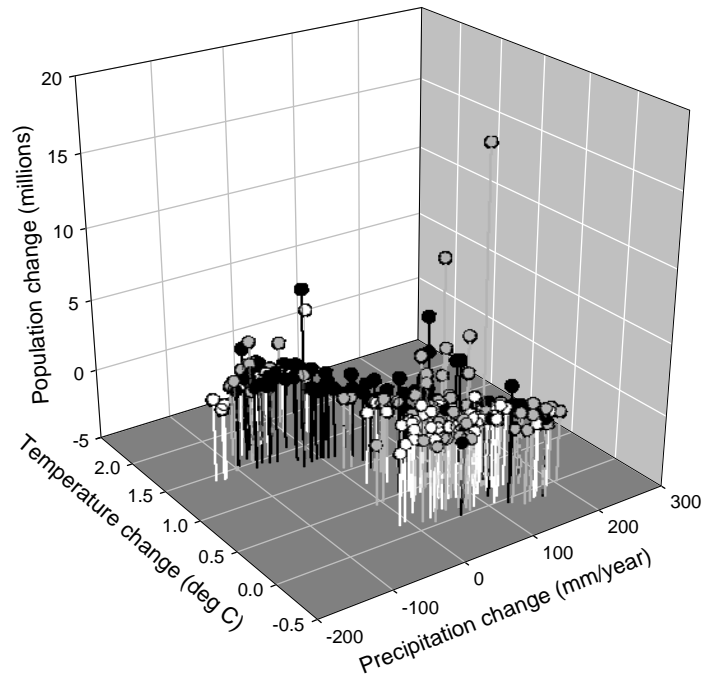
C. Precipitation Elasticity of Streamflow (#437) (white, 0.43–1.59; grey, 1.60–2.06; black, 2.07–2.96).
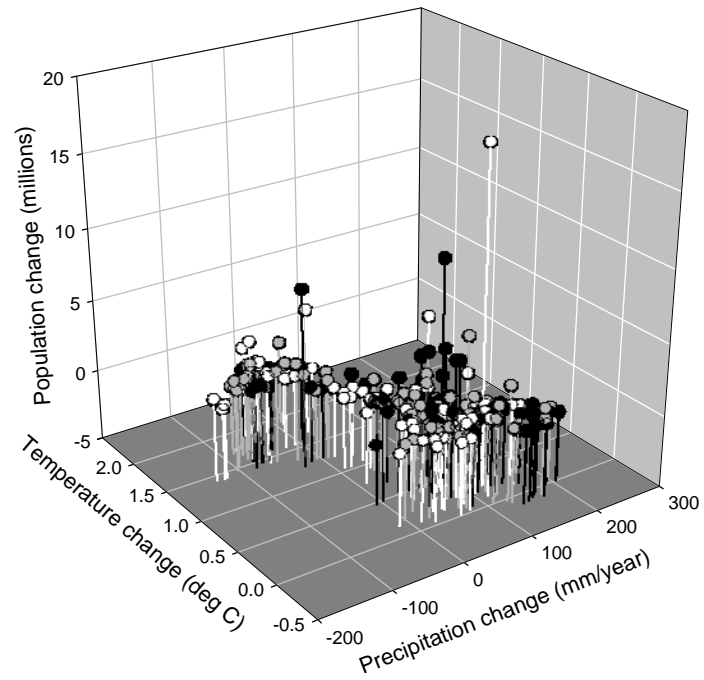
D. Net Streamflow per Capita (#623) (white, 8,493–1,779,536; grey, 888–8,493; black, 0–877).
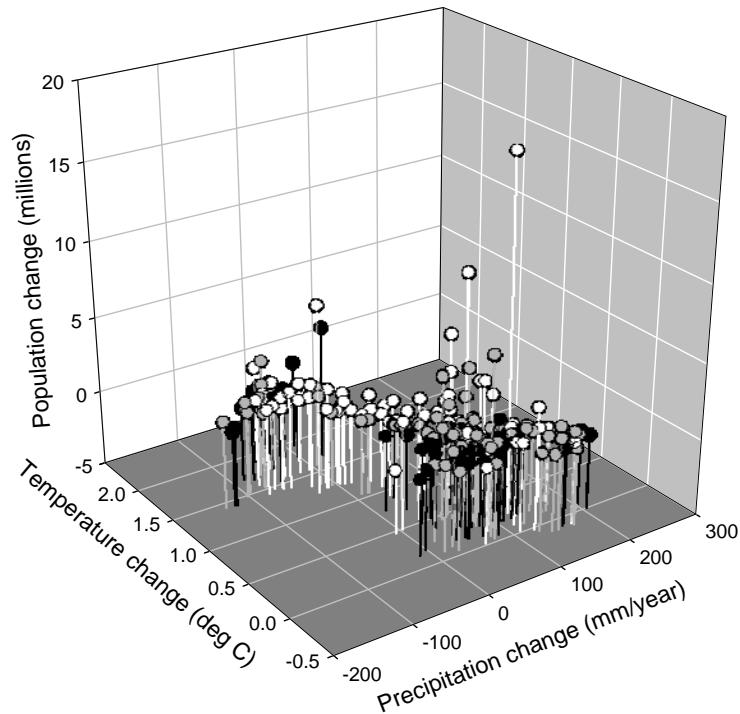
Figure 7-1. Current and future vulnerability to water shortages. (continued)

7.2.   COMPOSITES OF VULNERABILITY INDICATORS

Because individual indicators only provide information on limited dimensions of aquatic ecosystem and water quality vulnerability, effective management planning would likely require that these dimensions be integrated into a more holistic perspective on vulnerability. Assuming issues specific to individual indicators can be resolved, there are several possible quantitative methods for integrating multiple indicators.

7.2.1. Creating a Composite Map

Mapped indicators could, potentially, be overlayed into a composite map, such that the averages of all indicator values for each of the HUC units are represented on a single map. This is the approach taken in Hurd et al. (1999). This is challenging, however, for a number of reasons. One major reason is that the distinction between relative and real (i.e., functionally significant) differences in vulnerability, while not necessarily as critical for interpretation of individual indicator maps, is extremely important for the construction of a composite vulnerability map. For example, if the range of values for an indicator only reflect one category of vulnerability (e.g., very high vulnerability), differences in relative vulnerability may be functionally insignificant. If this type of indicator is given equal importance in a composite score to one whose values span a functionally significant range, the composite score will be inaccurate. As a consequence, the vulnerability of individual locations may be under- or over-estimated, depending on the relative frequency of high vulnerability values from these two classes.

Another way to aggregate indicators could be by identifying geographic units where further stresses (including climate change) will cause the most harm across all system dimensions (e.g., see Lin and Morefield, 2011). This can be done as follows:

- Assign numeric scores to the vulnerability categories (e.g., 3 for highest, 2 for medium, and 1 for lowest). Sum the scores across all indicators.

- For each geographic unit, calculate the percentage of indicators that are in the highest vulnerability category.

Once any technical deficiencies and data gaps have been addressed through data collection efforts, construction of a composite vulnerability map should consider the following:

- *The relative importance of system dimensions.* The relative weighting of individual indicators is dependent on management objectives and the degree to which indicators are redundant with one another.

- *Range of indicator values.* Only indicators whose values span functionally significant ranges should be used for a composite vulnerability map. This will lead to a more accurate representation of relative vulnerability.

- *How an integrated vulnerability rating will translate into management or adaptation efforts.* Locations with high integrated vulnerability may either be moderately vulnerable for most attributes, or highly vulnerable for a few attributes. While both of these scenarios point to the need for planning, the specific suite of relevant strategies would differ. Thus, the production of multiple visualization tools may often be a helpful exercise.

7.2.2. Characterizing Vulnerability Profiles

The aim of this type of integrative procedure is to identify commonalities in the types of vulnerabilities among regions. A vulnerability profile for a given location can be defined as the set of values for all the vulnerability indicators. Such an analysis allows watersheds with similar vulnerability profiles to be identified, and might be useful in the transfer of successful management or adaptation strategies from one location to another. Specifically, if a selected watershed is vulnerable in certain ways and in need of an adaptation strategy, other locations with similar vulnerability profiles could be identified. Successful adaptation strategies in those other locations could then be assessed for their applicability in the selected watershed.

Similarities in vulnerability profiles among locations can be summarized numerically through multivariate statistical analyses useful for finding patterns in data, such as Principal Components Analysis (PCA). PCA is used to consolidate the information in a large number of variables into a smaller number of artificial variables (called principal components) that will account for most of the variability in the original variables. The first component extracted in a PCA accounts for the greatest amount of total variance in the original variables, and the second and subsequent components account for progressively less variance.

The principal components (PCs) are described in terms of loadings of the original variables. A PC may be heavily loaded on at least one variable, and usually on more than one. A high loading indicates that the PC is strongly related to that variable (either negatively or positively depending upon the sign of the loading). Variables for which a PC is heavily loaded are correlated with each other, creating clusters of related variables that should be interpretable from a conceptual standpoint. The PCs themselves, however, are uncorrelated with one another. One benefit of conducting a PCA for this study is that reducing the full set of indicators to its principal components helps to avoid overemphasis on system properties that are represented by multiple similar indicators.

As an example, we conducted a PCA on 24 of the 25 mapped indicators (we excluded the Coastal Vulnerability Index (#51) because of its unique spatial units). We normalized indicators with non-normal frequency distributions with log or square root transformations. We inverted the scales of some indicators so that high vulnerability was always represented by high values of the indicator. We used the correlation matrix of these standardized variables for the PCA. When no data were available for an indicator, the HUC was assigned the median value for that indicator. We rotated the PCA (Varimax) and specified a maximum of six principal components – these six cumulatively account for about 57% of the total variance, with 35 % coming from the first three.

Table 7-1 shows the six PCs generated in the PCA analysis. These PCs help demonstrate which types of processes or environmental factors are driving a large part of the variability in the data. PC1 is heavily loaded on indicators related to at-risk species, which are negatively correlated with the ratio of snow to total precipitation (see bolded loadings in Table 7-1). PC2 is correlated with variables indicative of streamflow availability and usage. PC3 represents pesticides in surface water. PC4 is loaded on indicators related to macroinvertebrates and stream habitat quality. For PC5, the most heavily loaded indicator is meteorological drought indices, which is moderately correlated with at-risk freshwater plant communities. Finally, PC6 is loaded on herbicides in groundwater, but not pesticides in groundwater.

Table 7-1. Principal components loadings for the twenty four indicators included in the PCA analysis

Indicator	PC1	PC2	PC3	PC4	PC5	PC6
Acid neutralizing capacity (#1)	0.166	-0.367	-0.231	-0.071	-0.233	-0.265
At-risk freshwater plant communities (#22)	0.401	0.220	-0.007	0.153	0.604	0.090
At-risk native freshwater species (#24)	**0.863**	0.167	0.068	0.051	0.149	0.117
Groundwater reliance (#125)	0.087	0.196	0.242	0.291	-0.033	-0.313
Meteorological drought indices (#165)	0.006	0.182	-0.138	-0.038	**0.771**	0.019
Ratio of snow to total precipitation (#218)	**-0.774**	0.033	-0.167	-0.193	0.120	0.300
Ratio water withdrawal to annual streamflow (#219)	-0.071	**0.873**	-0.089	0.036	0.035	0.056
Stream habitat quality (#284)	0.092	-0.018	0.170	**0.687**	0.196	0.056
Wetland species at risk (#326)	**0.789**	-0.102	0.017	0.026	-0.204	0.200
Erosion rate (#348)	0.387	-0.056	-0.058	-0.076	0.131	0.504
Instream use/total streamflow (#351)	0.132	0.262	0.144	-0.104	0.005	-0.456
Total use/total streamflow (#352)	0.017	**0.753**	0.048	0.126	-0.052	-0.211
Pesticide toxicity index (#364)	0.082	0.009	**0.889**	-0.027	-0.003	-0.041
Herbicide concentrations in streams (#367)	0.078	-0.112	**0.769**	0.111	-0.028	-0.112
Insecticide concentrations in streams (#369)	0.070	0.025	**0.870**	-0.033	-0.020	0.033
Organochlorines in bed sediment (#371)	0.092	0.089	0.515	0.016	-0.358	0.109
Herbicides in groundwater (#373)	0.018	0.212	0.160	-0.009	-0.239	**0.721**
Insecticides in groundwater (#374)	0.191	0.080	0.078	-0.139	-0.537	0.355
Precipitation elasticity of streamflow (#437)	0.628	-0.073	0.156	0.207	0.153	-0.107
Ratio of reservoir storage to mean annual runoff (#449)	-0.117	-0.250	-0.090	0.074	-0.151	0.110
Runoff (variability) (#453)	0.160	0.504	0.036	-0.056	0.256	0.137
Macroinvertebrate index of biotic condition (#460)	0.051	0.074	-0.043	**0.845**	0.007	-0.112
Macroinvertebrate observed/expected (#461)	-0.156	0.030	0.080	**-0.754**	0.066	-0.055
Water availability: streamflow per capita (#623)	-0.150	**0.839**	-0.127	0.002	-0.009	-0.005
Proportion of variability explained	**0.120**	**0.117**	**0.113**	**0.085**	**0.073**	**0.065**

The map in Figure 7-2 is another way of using and displaying the results of the PCA. This map shows the similarity of an example focal watershed (shown in blue) to watersheds across the U.S. We defined the similarity of two watersheds as the weighted Euclidean distance (D_w) among the values of the first six principal components:

$$D_w = \sqrt{\sum_{i=1}^{i} w_i (x_i - y_i)^2}$$

where x_i and y_i are the values of component i for the two watersheds, and w_i is the weight for component i, which is defined as the proportion of the total variance in the entire dataset explained by that component. This approach is similar to the methods used by Tran et al. (2006).

As discussed above, because this kind of analysis and map allows watersheds with similar vulnerability profiles to be identified, it might be useful in the transfer of successful adaptation strategies from one location to another. Specifically, the map could help to identify locations with the most similar multi-dimensional vulnerability profiles to that of a selected focal watershed in need of adaptation strategies. Successful adaptation strategies in those other locations could then be assessed for their applicability at the focal watershed.

While relative similarity could identify the closest matches to the focal watershed, its mean absolute similarity to all other locations would be a measure of its uniqueness. The similarity of all pairwise combinations of watersheds could be cataloged in a vulnerability similarity matrix to expand the applicability of this approach. Such a matrix would include every watershed on the horizontal axis, and these same watersheds on the vertical axis. Each central cell of the matrix would contain a value that documents (according to the formula above) the similarity of the two watersheds defined by that cell. In addition, the vulnerability profile approach could be further refined by applying weights to indicators to account for differences in accuracy or relevance to climate change or other stressors of interest.

The following map displays the results of the PCA conducted on 24 of the 25 mapped indicators. It shows the similarity of the focal HUC watershed (blue) to the remaining 203 watersheds.
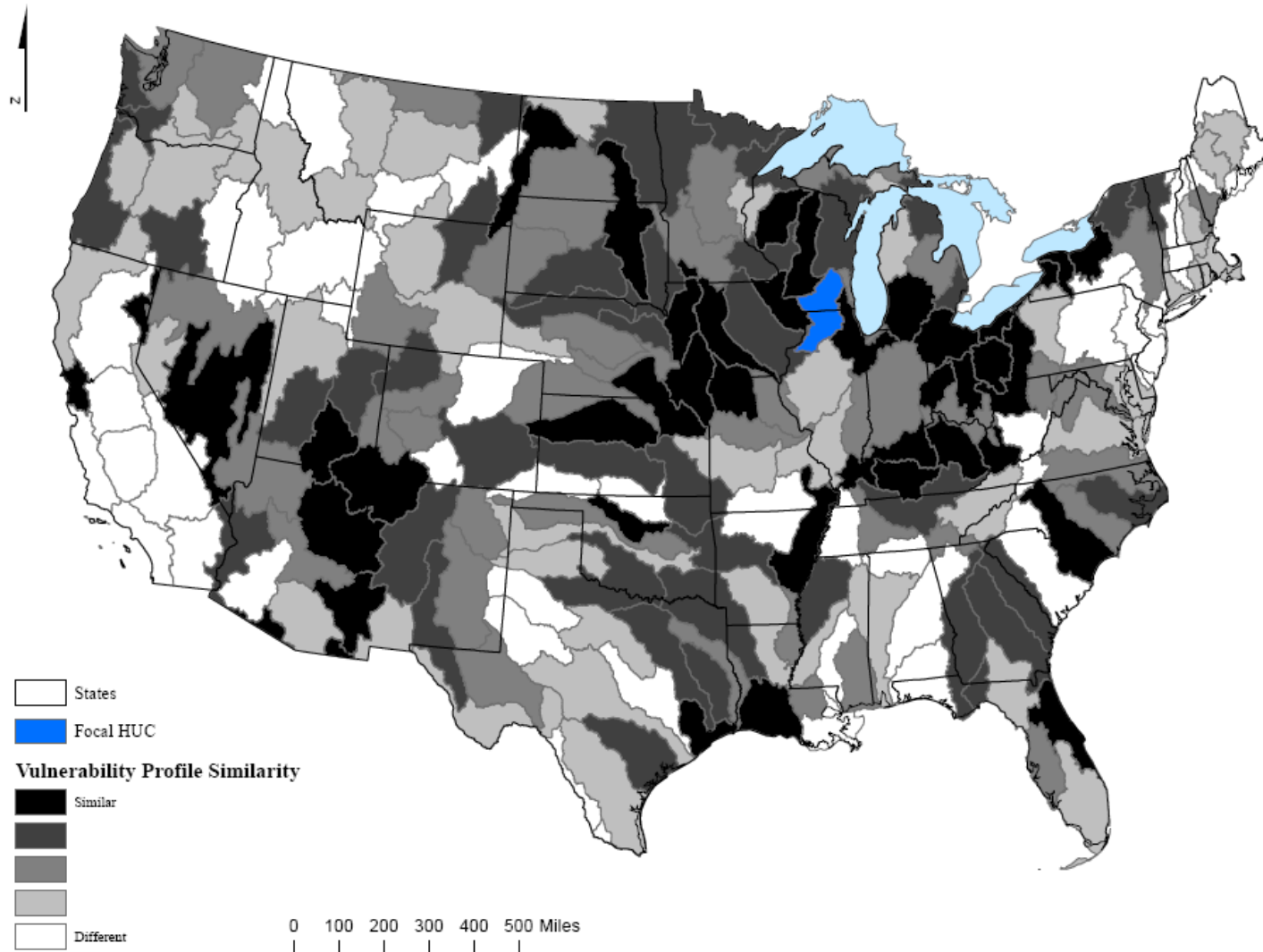
Figure 7-2. Vulnerability profile similarity.

8. SUMMARY AND RECOMMENDATIONS

This report investigates issues, challenges, and lessons associated with identifying, calculating, and mapping indicators of the relative vulnerability of watersheds across the United States to the potential adverse impacts of external stresses such as long-term climate and land-use change. It is our hope that this report will be a useful building block for future work on multi-stressor global change vulnerability assessments.

It is important to clarify here that this report does not attempt any kind of direct evaluation of the potential impacts of climate change or other global change stressors on ecosystems and watersheds. Instead, it deals only with the question of how to estimate the impacts of current stressors. We argue that a systematic evaluation of the impacts of existing stressors is a key input to any comprehensive climate change vulnerability assessment, as the impacts of climate change will be expressed via often complex interaction with such stressors – i.e., through their potential to reduce overall resilience, or increase overall sensitivity, to climate change. This argument is not new, and in fact it has been a staple of writing on climate change impacts, vulnerability, and adaptation, particularly of large assessments like those of the IPCC and U.S. Global Change Research Program. However, to date there has been relatively little exploration of the practical challenges associated with comprehensively assessing how the resilience of ecosystems and human systems in the face of global change may vary as a function of existing stresses and maladaptations.

8.1. SUMMARY OF CHALLENGES

Our approach in this report has two basic elements. First, we have collected, evaluated the quality of, processed, and aggregated a large quantity of data on water quality and aquatic ecosystem indicators across the nation that have been reported on in the ecological, hydrological, and management literature. Second, we have used this set of indicators as a testbed for identifying best practices, challenges, and gaps in ideas, methods, data, and tools for calculating and mapping vulnerability nationally.

Specifically, we compiled a list of 623 indicators of the vulnerability of water quality or aquatic ecosystems that were defined in the literature, focusing our search on expanding the list

of indicators rather than reviewing literature for its more general contributions to the body of knowledge on a topic. The indicators compiled relate to drinking water and source water quality, ecosystem structure and function, individual species, and ecosystem services. We explored challenges associated with using these indicators to assess vulnerability of water quality and aquatic ecosystems nationally. These challenges fall into four broad categories:

1. Challenges associated with identifying those indicators that speak specifically to vulnerability, as opposed to those reflecting simply a state or condition;

2. Challenges associated with determining relative vulnerability using indicators, including interpreting gradients of indicator values, and, when possible, establishing important indicator thresholds that reflect abrupt or large changes in the vulnerability of water quality or aquatic ecosystems;

3. Challenges associated with mapping these vulnerability indicators nationally, including data availability and spatial aggregation of the data; or

4. Challenges associated with combining and compositing indicators and developing multi-indicator indices of vulnerability.

Sources of indicator definitions and data used to map the indicators included published research and studies by EPA, other federal agencies, the Heinz Center, the Pew Center, etc. We limited the study to existing indicators and datasets, and for the most part did not attempt to develop new indicators or collect new data. As part of this work, we developed a number of example maps, and we use some of these maps in this report for illustrative purposes. We hope that the lessons we learned while developing strategies for compiling and mapping national-level indicator datasets under this project will be useful for indicator-based vulnerability assessments in general. Here we summarize the main findings of the report, organized according to the four challenges listed above.

8.1.1. Challenges Part I: Indicator Classification

There is on ongoing debate in the literature on the meaning of vulnerability and the elements of which it is composed, particularly in the context of climate change. For the purposes of this report, we generally took as our starting point the IPCC definition, i.e., "The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change,

including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity" (IPCC, 2007a). Most of what we define as "vulnerability indicators" in this report primarily encompass sensitivity and exposure to environmental stresses, and we do not focus on adaptive capacity. The indicators we discuss relate generally to the vulnerability of aquatic ecosystems, ecosystem services, and drinking water supplies.

Our first challenge was to identify guidelines for classifying the comprehensive suite of 623 indicators. The goal was to divide them into vulnerability indicators versus those indicators that merely measure the current state of a resource. The vulnerability indicators, at least in principle, could measure the degree to which the resource being considered (e.g., watershed, ecosystem, human population) is susceptible to, and unable to cope with, adverse effects of externally forced change. Such change potentially includes climate or any other global change stressor.

We determined that, in practical terms, the essence of a vulnerability indicator is that it should inherently include some kind of relative or value judgment, e.g., comparing one watershed to another, comparing it to some objectively defined threshold or possible state, or reporting on its change over time, as opposed to measuring water quality or ecological condition at a point in time without reference to anything else. Applying these criteria, we winnowed the original list of 623 indicators down to 53, and in the report we discuss the degree to which indicators from this reduced set might reflect vulnerability of water quality and aquatic ecosystems to challenges from long-term global change stresses.

8.1.2. Challenges Part II: Determining Relative Vulnerability

Determination of the relative vulnerability of a particular location using a given vulnerability indicator (or an index, if multiple indicators have been combined), can be accomplished by comparing the value of the indicator to a gradient of values measured at different locations. Alternatively, one can capitalize on objective vulnerability thresholds for some indicators. Such thresholds reflect abrupt or large changes in the vulnerability of water quality or aquatic ecosystems in response to a small change in a stressor, sometimes but not always associated with a particular regulatory threshold. Such thresholds are most useful when they distinguish between acceptable and unacceptable conditions.

We searched for thresholds for our 53 vulnerability indicators from three different categories: human health-based thresholds, ecological thresholds, and sustainability thresholds. In the literature, we most often encountered the use of arbitrary cutoffs to separate relative vulnerability categories (e.g., high, medium, and low). We were only able to map objective thresholds for a small subset of the indicators, though in some cases we suggested modification of an indicator definition to facilitate the identification of thresholds. The lack of available functional break points for most indicators is to be expected. Many indicators respond to stress linearly or along a gradual gradient. For others, objective break points may be characterized through additional research, either through meta-analysis of previous research efforts or through new data collection and analysis. Future research may also yield additional insights into how break points for some indicators vary spatially (Link, 2005).

8.1.3. Challenges Part III: Mapping Vulnerability

The effort to produce indicator maps for this report faced a number of classic cartographic challenges. Most of these challenges fell into the following two major categories: data availability and mappability, and spatial aggregation.

8.1.3.1. *Data and Mappability*

Data availability and suitability were the most serious limitations in evaluating whether or not we could produce maps for the 53 vulnerability indicators. Issues we encountered included the following:

- Lack of national coverage;

- Varying scales of the data;

- Varying duration of the data records;

- Multiple datasets needed to be combined;

- Extensive modeling effort was required to generate values for the indicator;

- No dataset available for the indicator; and

- Data collection was in progress.

These data availability and suitability issues were often identified during the literature review. For example, study authors sometimes explicitly noted the need for data for particular indicators that were potentially useful. In other cases, these issues emerged only after beginning the process of attempting to create maps. For example, the limited spatial extents of some datasets were identified during the mapping process. A major lesson we learned from this project was that it may often be impossible to establish mappability without beginning the process of manipulating and mapping the various datasets involved.

Overall, these data and mappability issues reduced the starting set of 53 vulnerability indicators to a set of 25 vulnerability indicators for which we were able to create example maps.

8.1.3.2. *Spatial Aggregation*

To create a national map for a given indicator of vulnerability, one must aggregate data collected at discrete locations and calculate summary statistics that describe conditions across a larger area, such as the mean value of an indicator or the percentage of sites that exceed a threshold value. As noted above, a major research gap is the lack of objective, functional thresholds between "vulnerable" and "not vulnerable" for most of the indicators we investigated. A complementary challenge is that, even if such functional breakpoints can be found, it may be difficult to aggregate in such a way that these breakpoints remain meaningful.

The major issues we encountered were the following:

- Local variation and spatial heterogeneity in data collection sites;

- The choice of spatial frameworks (e.g., watersheds, ecoregions, coasts); and

- The extent (resolution) of the spatial unit chosen.

As illustrated with a variety of example maps, these methodological choices can lead to very different results, and hence different conclusions about relative vulnerability in one location compared to another.

A systematic process for refining or re-defining indicators of vulnerability to account for the challenges summarized above is likely to be valuable. Such a process is presented in Figure

7-2. For example, the Acid Neutralizing Capacity (#1) indicator is defined as the ability of a stream to buffer acidic inputs from acid rain or acid mine drainage. This indicator can be refined to measure the percentage of sites that with ANC less than 100 millequivalents/L to account for the aggregation challenge. In addition, indicators can be refined to more explicitly incorporate the exposure component of vulnerability. If elements of environmental change, such as temperature or precipitation, can be explicitly incorporated into the indicator, then future changes in this indicator can be modeled using predicted changes in the values of these elements. This strengthens the ties between the indicator and changes that may occur in the future, and facilitates the generation of more useful forecasts for decision-makers.

8.1.4. Challenges Part IV: Combining Indicators

Ultimately, the value for global change assessments of a database of indicators, and their maps, rests in how they can be examined holistically. Such indicators and their maps can also be examined in combination with scenarios of changes in critical external stressors, such as climate and land use. We showed some simple examples of how one might use such scenario data to highlight locations around the country where, for example, we might see a convergence between an already stressed water supply system, a warmer, drier climate, and significant population growth. One of several more sophisticated approaches involves designing indicators that explicitly include a functional dependence on a stressor that is expected to change over time, such as temperature, precipitation, or population.

We also considered the challenges associated with compositing multiple indicators in some way and mapping the result. This brings up issues of determining the functional equivalency of the different levels of relative vulnerability measured by the very different indicators, with no absolute standard as an anchor point for weighting their contributions. Creation of a uniform scoring system (e.g., 1, for lowest, and 5 for highest, vulnerability) resolves the practical difficulties of mapping but not the conceptual ones of establishing the relative contribution of each indicator to overall vulnerability. Appendix H includes an evaluation of the effects of aggregation on the validity of theoretical breakpoints for each of the mapped indicators based on the process outlined in Figure 8-1.

A possible way forward is in the development of what we refer to as "vulnerability profiles," based on multivariate statistical analyses such as PCA. As a simple example, we

conducted a PCA on the mapped indicators. The six principal components we extracted tended to be associated with different potential dimensions of vulnerability: i.e., PC1 with at-risk species; PC2 with streamflow availability and usage; PC3 with pesticides in surface water; PC4 with macroinvertebrates and stream habitat quality; PC5 with meteorological drought indices; and PC6 with herbicides in groundwater. This kind of analysis allows the identification of watersheds or other geographic units with similar vulnerability profiles. This has the potential to be useful in the transfer of successful management or adaptation strategies from one location to another.

This process can be used to evaluate and guide the modification of potential indicators. The questions are oriented around the definition of vulnerability and the suitability of the indicator for mapping. Appendix H provides an evaluation of each of the 25 mappable indicators within the framework of the five questions presented in this flowchart.
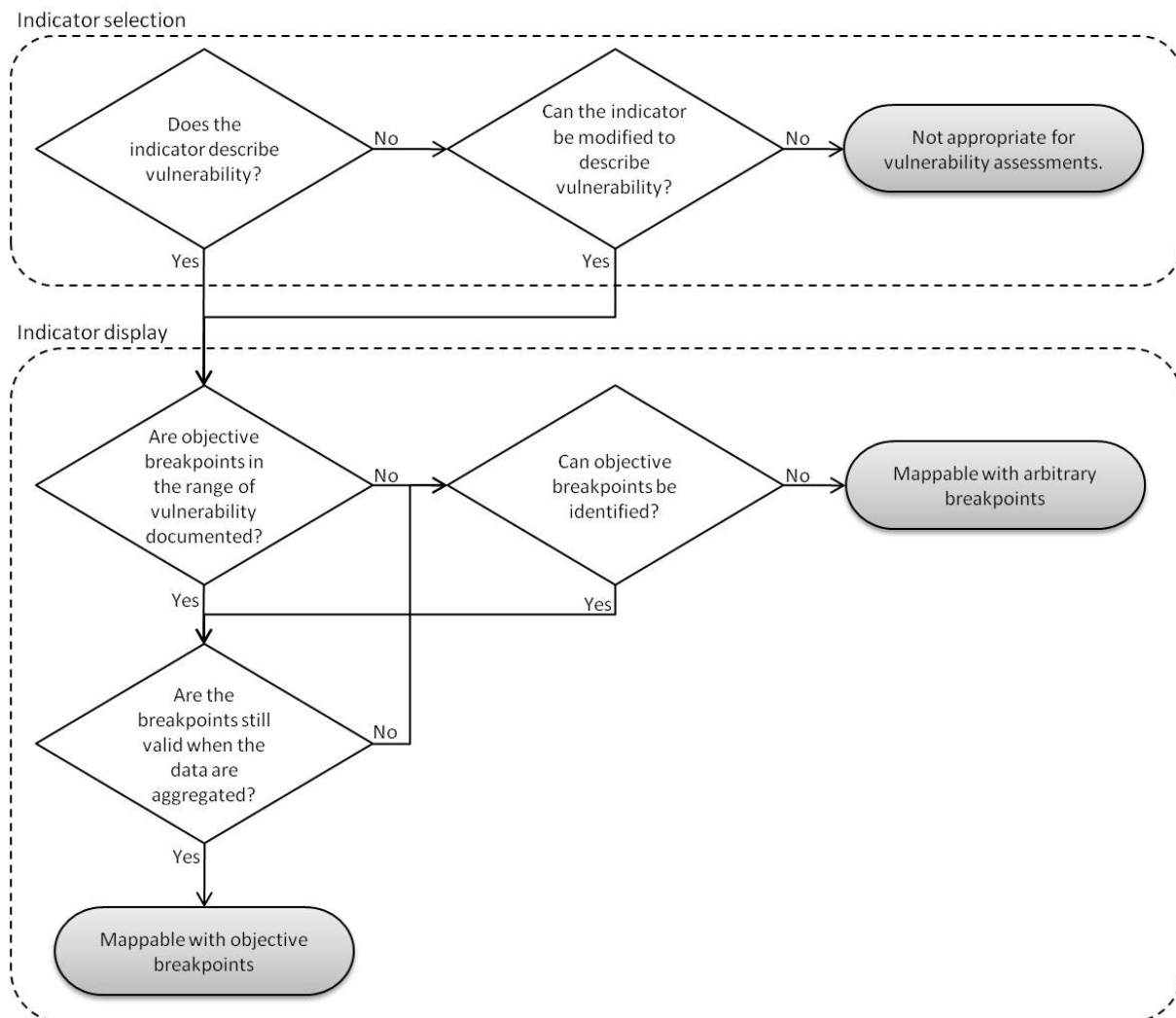
Figure 8-1. Indicator evaluation process.

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8.2. RECOMMENDATIONS FOR FUTURE RESEARCH

As a result of exploring the challenges and issues described above, we have identified a number of areas where additional research is likely to contribute significantly to our ability to carry out indicator-based vulnerability assessments – both in the specific context of the indicators discussed in this report, and more generally.

8.2.1. Assessment of Non-mappable Indicators

Some indicators were designated as non-mappable due to the need for additional processing of available data, statistical analyses, evaluation of modeled data, or other tasks that were beyond the scope of this study. Enhanced modeling efforts that combine probabilistic (Bayesian) and mechanistic approaches may be particularly useful in defining minimum data collection requirements and for characterizing the interactions between physical, chemical, and biological processes. Additional effort to address these needs may yield highly useful maps of these indicators.

Examples of the data evaluation needs include:

- Acquiring and assembling national-scale wetland data: Wetlands may be significantly affected by climate and land-use change. Unfortunately, one important indicator for wetlands, Wetland Loss (#325), was designated as non-mappable, due to the effort required to download and process the data from the National Wetlands Inventory (NWI). The online ordering system requires users to download individual datasets at the 7.5 minute (1:24K) or 15 minute (1:100K) scales. In the lower 48 states, the USGS has designated approximately 56,500 1:24K-scale quadrangles. It may be possible to acquire national wetlands coverage from the U. S. Fish & Wildlife Service, and conduct subsequent analyses that would result in a national wetlands indicator.

- Assessment of the National Inventory of Dams database: Instream connectivity (#620) is an important measure that can be used to make inferences about drinking water availability (e.g. large reservoirs) and aquatic ecosystem functions (e.g. migration of species). To produce an accurate assessment of connectivity, it is important to have a comprehensive source of dam locations and diversions in the United States. The National Inventory of Dams, managed by the U.S. Army Corps of Engineers, is an attempt at such a data set, but some data (especially data pertaining to small dams) is absent from the database, available digital maps of the stream network are of varying quality and detail across the country, and the available data for dams are frequently inaccurate. An assessment of this database is needed and, if

possible, additional dam data should be obtained to produce a map for this indicator. Work by the USGS on the National Hydrography Dataset and the NHD-plus is currently underway and should provide useful data in the coming years. A challenge to reporting this indicator will be evaluating what percentage of dams is omitted because they are too small to be registered in the national database on dams.

- Digitization and analysis of national flood plain data: The Population Susceptible to Flood Risk (#209) indicator evaluates the human population currently residing within a 500-year flood plain. A map for this indicator could be obtained by overlaying estimates of the 500-year flood plain from the Federal Emergency Management Agency (FEMA) with population data from the U.S. Census Bureau. However, according to FEMA's Map Service Center, GIS-compatible digital flood plain data were not available at the time of this study for several areas within the U.S. FEMA is currently working on a multi-year project to update and digitize national flood plain data. In the absence of a national flood plain data set, it would be useful to utilize existing digital flood plain data for urbanized areas to evaluate the percentage of metropolitan populations that may be prone to flooding.

8.2.2. Identifying Opportunities to Enhance Source Data

The indicators evaluated during this study were associated with data sets with varying degrees of completeness, ranging from large national assessment efforts, to indicators with no clear data source. Additional research is needed to identify opportunities to enhance the utility of national data sets and fill significant data gaps.

Examples of large national data sets that were used for this study include the EPA Wadeable Streams Assessment or the USGS National Water Quality Assessment (NAWQA) Program. These are unique data sets that yield high-quality data, but even these excellent data collection efforts fall short of providing the data density required to produce robust analyses of vulnerability over large scales, e.g., at the scale of a 4-digit HUC unit, as calculated values may be highly sensitive to a few or even a single measurement taken at a discrete location within the spatial aggregation unit. Additional research is needed to evaluate data collection effort required to enhance the statistical power of these key datasets.

In addition, some example maps produced for this study could be improved by addressing significant gaps in the source data. For example, the data set used to produce Instream Use / Total Streamflow (#351) did not include estimates of groundwater recharge, one of the input variables for this indicator, for some regions. For these regions, we assumed recharge was equal

to withdrawals. The accuracy of this indicator in these areas would be improved by acquiring better estimates for the missing variable.

Furthermore, some data sets that are regularly updated through ongoing data collection activities may have quality problems. For example, the Centers for Disease Control and Prevention's (CDC) Waterborne Disease and Outbreak Surveillance System (WBDOSS), a potential data set for the Waterborne Human Disease Outbreaks (#322) indicator, relies on voluntary reporting of water-related disease outbreaks by public health departments of U.S. states, territories, and local governments. The data are inconsistent and of variable quality. Ideally, data would be reported regularly for all parts of the country and consistently documented by a single responsible entity. Alternatively, if voluntary data collection by multiple entities continues, stringent guidelines might be set forth to ensure the quality of the data in this database.

Finally, some of the indicators that we deemed to be non-mappable because we could not identify any existing data source have the potential to be highly useful measures. Additional research to identify the data needed to calculate appropriate vulnerability metrics, collect new data, or transform existing data to calculate and map these indicators would be valuable.

8.2.3. Development of New Indicators from Available Data Sets

A direct follow-up effort to the methodology employed for this study would be a review of existing national-scale environmental data sets to determine which might lend themselves to the development of new, useful indicators. This would allow for more opportunities to create indicators that are specifically tailored to the needs of local planners and decision-makers. For example, a new indicator, Water Demand, defined as the total water withdrawals in millions of gallons per day, can be created based on data available from the USGS' National Water-Use Data set. A map of this indicator is shown in Figure 5-3. Assessment of vulnerability using this indicator, perhaps in combination with indicators of water availability such as Groundwater Depletion (#121) and Net Streamflow per Capita (#623), may be useful at a variety of scales, from national to local, for understanding the water budgets of communities. This would facilitate responses with, for example, improved conservation policies in areas subject to severe water shortages.

Using available data as a starting point would also enhance our ability to work with indicators with objective thresholds that distinguish between acceptable and degraded condition. For example, in the present study a set of five pesticide indicators [#367, #369, #371, #373, and #374] were mapped using USGS' NAWQA data set. These indicators were designed by USGS to provide a cumulative assessment of multiple pesticides present in ambient water by calculating an average concentration. It is difficult to determine thresholds for these indicators given the diversity of pesticides and the varying levels of risks they pose. Instead, the development of new indicators for individual pesticides, using the same data set, would allow us to map the data using established thresholds, such as MCLs, to categorize vulnerability. Individual pesticide indicators may present regional patterns and identify regional water quality concerns, whereas the combined indicators developed by USGS and used in this study may mask local and regional vulnerability.

8.2.4. Need for Additional Study and Data Collection in Coastal and Other Areas

We note that the example indicators mapped for this study do not represent an even distribution across the possible categories of water quality and aquatic ecosystem vulnerability indicators. Our heavy focus on areas such as water quantity, freshwater ecosystems, and certain aspects of water quality is a result of the methodology applied, and not a reflection of bias on the part of the investigators or advisors selecting indicators and mapping data. Furthermore, as we have emphasized throughout the report, the selection of indicators that were mapped is not intended to imply anything about which indicators are inherently more important for assessing vulnerability to global climate change and other stressors. Rather, the example maps are for illustration of our methodology, and the selection of indicators for mapping was based on the ready availability of data.

Data on the location of streams and quantity of surface water flow were generally readily available in readily usable formats. There are several critical areas within the study of water quality and aquatic ecosystems, however, which suffer more than other areas from the challenges and data limitations discussed in this report. Additional research is needed in the areas of coastal aquatic systems, wetlands, freshwater tidal marshes, and the fish and animal habitats they support. Additional data collection over longer time periods and greater spatial extents is needed

to capture the characteristics and trends in the condition and vulnerability of these important systems.

8.2.5. Use of Indicators for Future Studies

The focus of the present study was to identify indicators of water quality and aquatic ecosystem condition that represented vulnerability and could be mapped at the national scale. 598 indicators were eliminated from the original comprehensive list of indicators for various reasons that made them unsuitable for a national-scale vulnerability assessment. However, many of these indicators may be valuable for other studies or purposes.

Many indicators were eliminated because their associated data sets did not have comprehensive national coverage or may only be relevant in some areas. Although these indicators had limited utility for the present study, they are likely to be valuable for conducting vulnerability assessments at regional or local scales. For example, EPA National Coastal Assessment data for the Water Clarity Index [#318] and Water Quality Index [#319] indicators are only available for the Gulf coast region. Similarly, Snowpack Depth [#440] is only measured in regions where rivers and other surface water sources are primarily fed by snowmelt, such as in the Colorado River basin. Mangrove Cover [#63] is only relevant where these trees grow – a small portion of the Gulf Coast. Each of these indicators may be highly useful for monitoring changes over time in local systems and for guiding local decisions in response to observed or expected changes. A useful follow-up effort to this study would be the development of an indicator compendium that would describe the geographic extent and available data sources for indicators that are relevant at local and regional scales. Local decision makers could use this resource in conjunction with the national-scale indicators presented in this study to guide local planning efforts.

Indicators whose data were based on future projections were also eliminated because the present study only examined current vulnerability. For example, data for Heat-Related Illnesses Incidence [#392] are available as estimates of mortality from the National Center for Health Statistics (NCHS) based on three climate change scenarios for the years 2020 and 2050. Data for land cover or land use indicators, such as Coastal Wetlands (acreage) (#52) and Urban and Suburban Areas (acreage) (#308), Population susceptible to flood risk (#209), and other population-related indicators, may be projected into the future using output data from climate

and earth system models. These data, while not useful for the present study, are useful in understanding future vulnerability, particularly when taking into account the effects of climate change on human and natural environments. Understanding future vulnerability is a crucial component of many ongoing and planned research studies aimed at strategic planning for adaptation to the effects of global climate change.

8.2.6. Establishment of Stress-response Curves, Vulnerability Thresholds, and Baseline Conditions

In this report we focused on the development of methods to assess relative vulnerability. Additional research to evaluate how individual indicators respond to stress (e.g., sensitivity, threshold response, resistance, etc.) will facilitate assessments of absolute vulnerability linked to system function. There is a large body of basic ecological and sociological research that will need to be created before this issue can be comprehensively addressed. The issue of thresholds, much discussed above, is of course intimately related.

Furthermore, observationally establishing baseline conditions, and implementing more routine monitoring for locally relevant indicators, would enable water resource managers to identify significant water quality and ecological changes over time, which would allow the development of additional indicators, or more accurate calculation of existing indicators, for assessment.

8.2.7. Drawing on other Established Approaches for Combining Indicators

In particular, a comparison of the traditional multivariate approaches for combining indicators to the approaches used by EPA's ReVA program, such as the generalized weighted distance method, may be fruitful. Future research efforts could apply the ReVA aggregation methods to the indicators in this report, which are topically and spatially broader. Such aggregation would also allow relationships between components of vulnerability for the indicators specified in this study to be addressed. Future work could include the design of new, robust indicators using existing data sources.

8.2.8. Incorporating Landscape and Land Use Metrics

Landscape metrics, such as percent natural cover, roads crossing streams, and agriculture on slopes, can provide additional context for the indicators presented in the report. Metrics such as these may assist with the interpretation of sensitivity. Land use metrics that specify the sources of polluted runoff (e.g., urban areas, Concentrated Animal Feeding Operation areas) and of polluted groundwater (e.g., septic systems in low-lying areas) are useful for assessing the vulnerability of surface and subsurface water quality, respectively. Measurements of human impact may explain an indicator's vulnerability score or may suggest an alternative interpretation. In addition, some metrics, such as population growth rate, can be used to assess future exposure to stress (see, for example, Figure 7-1).

8.2.9. Incorporating Information Based on Remote Sensing Technologies

Remote sensing technologies have facilitated measurement of a variety of landscape and land use indicators. They are commonly used to measure fragmentation of forests, the influence of urbanization and suburbanization on the landscape, and for quantification of land cover / land use categories (e.g., how the extent of forests or croplands have changed over time). Remote sensing can also be used to investigate how local ecologies have been disturbed by human encroachment. Remote sensing is currently being employed for the measurement of chlorophyll a and turbidity.

8.2.10. Incorporating Metrics of Adaptive Capacity

Vulnerability to future changes depends in part on choices made by society today and into the future. In the context of climate change in particular, adaptive capacity is the ability of an ecosystem or society to continue to perform its range of functions despite changes in factors that affect those functions. A system has inherent adaptive capacity when its natural attributes make it resilient to stress, whereas institutional adaptive capacity includes policies, practices, and infrastructure that create options for meeting human and ecosystem needs in the face of an uncertain future. The specific attributes or actions that create adaptive capacity are largely different for aquatic life and human uses of water, although there is some overlap among these categories.

Differentiating inherent and institutional adaptive capacity is useful because it points to two different management approaches. Systems with inherent adaptive capacity are less vulnerable, even when they are sensitive and exposed to stress. Thus, many advocate directing planning and management efforts toward systems lacking this capacity. Institutional adaptive capacity can be built in many ways (for examples, see IPCC, 2007a). Many of these strategies require a significant shift from short to long term planning, which is typically resisted by institutional and infrastructural inertia. Many specific practices involve diversification and the creation of redundancy, which can be hard to justify in the context of current conditions. Some also require acknowledgement of fundamental uncertainty about the future.

Community-based analyses have shown that the conditions that interact to shape exposures, sensitivities, adaptive capacities, and hence create needs and opportunities for adaptation, are community-specific (Smit and Wandel, 2006). This finding suggests that any attempt to transfer adaptive strategies among regions must look for commonalities both in the magnitude of vulnerability and in its qualitative, multi-dimensional profile. As described above, some of the techniques described in this report (e.g., the development of vulnerability profiles and similarity maps) could, in principle, be used to identify such commonalities among regions, which, in combination with case studies of successful adaptation, would provide guidance for potential policy transfer, or serve as a screening tool for the feasibility of adaptive strategy transfer.

As we said above, we hope that this report will be a useful building block for future work on multi-stressor global change vulnerability assessments. Ultimately, we believe the work described here is a preliminary contribution toward bridging disconnects between the decision support needs of the water quality and aquatic ecosystem management communities and the priorities and capabilities of the global change science data and modeling communities; to the synthesis of insights across more detailed, place-based, system-based, or issue-based case studies (e.g., in individual watersheds, wetlands, urban ecosystems) to obtain national-scale insights about impacts and adaptation; and to prioritization of future work in developing adaptation strategies for global change impacts.

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Aquatic Ecosystems, Water Quality, and Global Change:
Challenges of Conducting Multi-Stressor Global Change Vulnerability Assessments

Final Report
August 2011

X.   Appendices

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The following appendices accompany the report entitled *Aquatic Ecosystems, Water Quality, and Global Change: Challenges of Conducting Multi-stressor Global Change Vulnerability Assessments.*

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Appendix A. List of Literature Reviewed

Aquatic Ecosystems, Water Quality, and Global Change:
Challenges of Conducting Multi-Stressor Global Change Vulnerability Assessments

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Aquatic Ecosystems, Water Quality, and Global Change:
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The literature sources in the following list were reviewed to identify indicators of vulnerability of water quality and aquatic ecosystems. Core Literature studies (i.e., those identified by the Global Change Research Program (GCRP) as starting points for compiling indicators for this study) are identified by a * before the authors' names.

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Appendix B. Comprehensive List of Indicators

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The following table lists the 623 indicators gathered from a review of the 86 documents cited in Appendix A. Each indicator was randomly assigned an Indicator ID#. This unique identifier serves as an easy way to identify and refer to the indicator throughout the report. Indicator definitions included in this table were obtained, when possible, from the literature source that identified the indicator. (Note: Some text is verbatim from the source.) Definitions for some indicators had to be revised when the data used were different (e.g., more recent) than those cited by the literature. These revised definitions are marked with a * in the Indicator Definition column.

The references in the Literature Source column refer to the literature source from which the indicator was obtained. Full citations for these references can be found in Appendix A. Some indicators from this list were determined to be duplicates; for these, the ID# of the corresponding duplicate indicator is listed in the Duplicate Indicator column. After selection of one indicator for further assessment from each duplicate group, the remaining duplicates were eliminated from further consideration. Selection of indicators from groups of duplicates was based on completeness of the indicator definition, national (as opposed to regional or local) focus of the literature source, etc. Eliminated duplicate indicators are marked with an [X] next to the indicator ID#.

The 53 indicators identified as vulnerability indicators in the report appear in boldface font in this table. (The remaining 559 indicators were considered to be state variables). Of these, the 25 example indicators that were mapped have a ** next to the indicator ID#.

Indicator ID#	Indicator	Definition	Literature Source [See Appendix A for full citation]	Duplicate
1**	**Acid Neutralizing Capacity (ANC)**	**Percent of streams with low acid-neutralizing capacity (ANC) i.e., below 100 milliequivalents/liter. ANC is a measure of the water's ability to buffer additional acid deposition or drainage from acid mines.***	**USEPA, 2006b.**	
2	Agricultural Inputs - Durable Goods (Units of durable goods per unit of output)	Tractors are an example of durable goods. This indicator reports the amount of inputs used to produce one unit of output, with 1975 as the base year. For example, all fertilizers used on U.S. farms were divided by all agricultural outputs — even if different amounts of fertilizer were used to produce each commodity. So, for any input, the index value for a given year describes whether more or less of that input was used to produce a unit of output in that year than in 1975.	Heinz Center, 2002; Heinz Center, 2008	

Indicator ID#	Indicator	Definition	Literature Source *[See Appendix A for full citation]*	Duplicate
3	Agricultural Inputs - Energy (Units of energy per unit of output)	This indicator reports the amount of energy inputs used to produce one unit of output, with 1975 as the base year. For example, all fertilizers used on U.S. farms were divided by all agricultural outputs — even if different amounts of fertilizer were used to produce each commodity. So, for any input, the index value for a given year describes whether more or less of that input was used to produce a unit of output in that year than in 1975.	Heinz Center, 2002; Heinz Center, 2008	
4	Agricultural Inputs - Fertilizers (Units of fertilizers per unit of output)	This indicator reports the amount of fertilizer inputs used to produce one unit of output, with 1975 as the base year. For example, all fertilizers used on U.S. farms were divided by all agricultural outputs — even if different amounts of fertilizer were used to produce each commodity. So, for any input, the index value for a given year describes whether more or less of that input was used to produce a unit of output in that year than in 1975.	Heinz Center, 2002; Heinz Center, 2008	
5	Agricultural Inputs - Labor (Units of labor per unit of output)	This indicator reports the amount of labor inputs used to produce one unit of output, with 1975 as the base year. For example, all fertilizers used on U.S. farms were divided by all agricultural outputs — even if different amounts of fertilizer were used to produce each commodity. So, for any input, the index value for a given year describes whether more or less of that input was used to produce a unit of output in that year than in 1975.	Heinz Center, 2002; Heinz Center, 2008	
6	Agricultural Inputs - Land (Units of land per unit of output)	This indicator reports the amount of land inputs used to produce one unit of output, with 1975 as the base year. For example, all fertilizers used on U.S. farms were divided by all agricultural outputs — even if different amounts of fertilizer were used to produce each commodity. So, for any input, the index value for a given year describes whether more or less of that input was used to produce a unit of output in that year than in 1975.	Heinz Center, 2002; Heinz Center, 2008	

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Indicator ID#	Indicator	Definition	Literature Source *[See Appendix A for full citation]*	Duplicate
7	Agricultural Inputs - Pesticides (Units of pesticides per unit of output)	This indicator reports the amount of pesticide inputs used to produce one unit of output, with 1975 as the base year. For example, all fertilizers used on U.S. farms were divided by all agricultural outputs — even if different amounts of fertilizer were used to produce each commodity. So, for any input, the index value for a given year describes whether more or less of that input was used to produce a unit of output in that year than in 1975.	Heinz Center, 2002; Heinz Center, 2008	
8	Agricultural Outputs - Crops (Units of output per year)	The indicator reports agricultural outputs over time, with 1975 as the base year.	Heinz Center, 2002; Heinz Center, 2008	
9	Agricultural Outputs - Meat, Dairy, Eggs, and Other Products (Units of output per year)	The indicator reports U.S. agricultural outputs over time, with 1975 as the base year.	Heinz Center, 2002; Heinz Center, 2008	
10	Agricultural Outputs - Total (Units of output per year)	The indicator reports U.S. agricultural outputs over time, with 1975 as the base year.	Heinz Center, 2002; Heinz Center, 2008	
11	Agricultural products (economic production)	This indicator reports the production of food and fiber and the withdrawals of water (agricultural products), using an index with 1980 as the base year.	Heinz Center, 2002; Heinz Center, 2008	
12	Agricultural water use share	Agricultural sector withdrawals (QWag) as a share of total average annual withdrawals. Method of calculation: QWag/QW	Hurd et al., 1998.	
13	Air Quality - High Ozone Levels: At least 1 day per year (Percent of urban/suburban air monitoring stations with 1 day exceedance)	This indicator reports the percentage of air pollution monitoring stations in urban and suburban areas with "high" ozone concentrations at least 1 day a year. Ground-level ozone is considered high when the 8-hour average concentration exceeds 0.08 parts per million (ppm).	Heinz Center, 2002; Heinz Center, 2008	

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Indicator ID#	Indicator	Definition	Literature Source [See Appendix A for full citation]	Duplicate
14	Air Quality - High Ozone Levels: At least 2 days per year (Percent of urban/suburban air monitoring stations with 2 day exceedance)	This indicator reports the percentage of air pollution monitoring stations in urban and suburban areas with "high" ozone concentrations at least 2 days a year. Ground-level ozone is considered high when the 8-hour average concentration exceeds 0.08 parts per million (ppm).	Heinz Center, 2002; Heinz Center, 2008	
15	Air Quality - High Ozone Levels: At least 3 days per year (Percent of urban/suburban air monitoring stations with 3 day exceedance)	This indicator reports the percentage of air pollution monitoring stations in urban and suburban areas with "high" ozone concentrations at least 3 days a year. Ground-level ozone is considered high when the 8-hour average concentration exceeds 0.08 parts per million (ppm).	Heinz Center, 2002; Heinz Center, 2008	
16	Air Quality - High Ozone Levels: At least 4 days per year (Percent of urban/suburban air monitoring stations with 4 day exceedance)	This indicator reports the percentage of air pollution monitoring stations in urban and suburban areas with "high" ozone concentrations at least 4 days a year. Ground-level ozone is considered high when the 8-hour average concentration exceeds 0.08 parts per million (ppm).	Heinz Center, 2002; Heinz Center, 2008	
17	**Altered Freshwater Ecosystems (percent miles changed)**	**This indicator of alteration reports the percentage of:**	**Heinz Center, 2002; Heinz Center, 2008**	
18	Ambient toxicity (chemical concentration)	Metals, pesticides, PCBs, and organic contaminants.	USEPA, 2006a.	
19	Animal Deaths and Deformities (events)	This indicator reports on unusual mortality events for waterfowl, fish, amphibians, and mammals, and on deformity events for amphibians. Only data on waterfowl mortality can be reported at this time.	Heinz Center, 2002; Heinz Center, 2008	
20	Aquatic life mobility	N/A	MEA, 2005c.	

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Indicator ID#	Indicator	Definition	Literature Source *[See Appendix A for full citation]*	Duplicate
21	Areas with depleted oxygen (percent monthly exposure)	The percentage of brackish water exposed to a range of oxygen concentrations for at least 1 month will be reported as anoxic (no oxygen), hypoxic (>0 and <2 parts per million [ppm]), low (2–4 ppm), or sufficient (>4 ppm).	Heinz Center, 2002; Heinz Center, 2008	
22**	**At-Risk Freshwater Plant Communities**	**This indicator reports on the percentage of wetland and riparian plant communities that are at risk of extinction. These status ranks are based on such factors as the remaining number and condition of occurrences of the community, the remaining acreage, and the severity of threats to the community type.***	**Heinz Center, 2002; Heinz Center, 2008**	**467**
23	At-Risk Native Forest Species (Percent of all forest species that are at risk)	This indicator reports on the relative risk of extinction of native forest species. The risk categories are based on such factors as the number and condition of individuals and populations, the area occupied by the species, population trends, and known threats. Degrees of risk reported here range from very high ("critically imperiled" species are often found in five or fewer places or have experienced very steep declines) to moderate ("vulnerable" species are often found in fewer than 80 places or have recently experienced widespread declines). In all cases, a wide variety of factors contribute to the overall ratings. "Forest species" live in forests during at least part of their life and depend on forest habitats for survival.	Heinz Center, 2002; Heinz Center, 2008	
24**	**At-Risk Native Freshwater Species (relative rank)**	**This indicator reports on percentage of native freshwater species that are at risk of extinction. The risk categories are based on such factors as the number and condition of individuals and populations, the area occupied by the species, population trends, and known threats.***	**Heinz Center, 2002; Heinz Center, 2008**	

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Indicator ID#	Indicator	Definition	Literature Source *[See Appendix A for full citation]*	Duplicate
25	At-Risk Native Grassland and Shrubland Species - By Category (Percent of all at-risk species in a certain category)	Categories include: Extinct, Critically Imperiled, Imperiled, Vulnerable, and All At-Risk. This indicator reports on the status of native grassland and shrubland species with respect to their relative risk of extinction. These status ranks are based on multiple factors: the number and condition of individuals and populations, the area occupied by the species, population trends, and known threats. Degrees of risk reported here range from very high ("critically imperiled" species often are found in five or fewer places or have experienced very steep declines) to moderate ("vulnerable" species often are found in fewer than 80 places or have recently experienced widespread declines). In all cases, a wide variety of factors contribute to overall ratings. "Grassland and shrubland species" live in these habitats during at least part of their life cycle and depend on them for survival.	Heinz Center, 2002; Heinz Center, 2008	
26	At-Risk Native Grassland and Shrubland Species - By Region (Percent of all at-risk species in a certain region)	Regions include: Northeast/Mid-Atlantic, Southeast, Midwest, Southwest, Rocky Mountain, Pacific Coast, and Hawaii. This indicator reports on the status of native grassland and shrubland species with respect to their relative risk of extinction. These status ranks are based on multiple factors: the number and condition of individuals and populations, the area occupied by the species, population trends, and known threats. Degrees of risk reported here range from very high ("critically imperiled" species often are found in five or fewer places or have experienced very steep declines) to moderate ("vulnerable" species often are found in fewer than 80 places or have recently experienced widespread declines). In all cases, a wide variety of factors contribute to overall ratings. "Grassland and shrubland species" live in these habitats during at least part of their life cycle and depend on them for survival.	Heinz Center, 2002; Heinz Center, 2008	
27	**At-Risk native marine species (relative risk)**	**Relative risk of extinction of native marine species, both plants and animals. The risk categories are based on such factors as the number and condition of individuals and populations, the area occupied by the species, population trends, and known threats.**	**Heinz Center, 2002; Heinz Center, 2008**	
28	At-Risk native species (relative rank)	This indicator reports on the relative risk of extinction of native plant and animal species.	Heinz Center, 2002; Heinz Center, 2008	

Indicator ID#	Indicator	Definition	Literature Source *[See Appendix A for full citation]*	Duplicate
29	Bay grasses	N/A	Chesapeake Bay Program, 2008.	
30	Beach closings (driven by bacterial contamination)	Measure of bacterial contamination.	USEPA, 1995.	
31	Benthic Index (several)	Shannon-Weiner Diversity Index, and other Indices.	USEPA, 2006a.	
32[x]	Benthic Macroinvertebrates	Benthic communities are largely composed of macroinvertebrates, such as annelids, mollusks, and crustaceans. These organisms inhabit the bottom substrates of estuaries and play a vital role in maintaining sediment and water quality. They also are an important food source for bottom-feeding fish, invertebrates, and birds.	USEPA, 2008b.	461, 33
33[x]	Benthic organisms (abundance, diversity)	Benthic abundance, species richness/diversity.	Hayslip et al., 2006.	32, 461
34	Bottom habitat (diversity, abundance, biomass)	Attainment of the benthic restoration goal was determined by examining: benthic biodiversity measures, measures of assemblage abundance and biomass, life history strategy measures, activity beneath the sediment surface, and feeding guild measures.	Chesapeake Bay Program, 2008.	
35	Carbon Storage - Forests (Weight of carbon stored over time)	This indicator reports how much carbon—an essential component of all organisms—is stored in forests, including trees, soil, and plant litter on the forest floor, and in wood products.	Heinz Center, 2002; Heinz Center, 2008	36, 617
36[x]	Carbon Storage - Grasslands/Shrublands (Weight of carbon stored over time)	This indicator will report the total amount of carbon stored in soil and plants in grasslands and shrublands.	Heinz Center, 2002; Heinz Center, 2008	35, 617
37	Chemical contaminants (exceedence of regulatory value)	Metals, PCBs, tributyltin, and priority organics found exceeding total maximum daily loads (TMDLs).	Chesapeake Bay Program, 2008.	

Indicator ID#	Indicator	Definition	Literature Source *[See Appendix A for full citation]*	Duplicate
38	Chemical Contamination in Urban Streams - Contaminant Occurrence (Number of contaminants detected)	This indicator reports on contaminants found in urban and suburban streams. Compounds reported here include many pesticides, select pesticide breakdown products, ammonia, and nitrate (because nitrate and ammonia occur naturally, they are not included in the graphs showing contaminant occurrence).	Heinz Center, 2002; Heinz Center, 2008	
39	Chemical Contamination in Urban Streams - Contaminant Concentrations above Standards or Guidelines (Percent sites with exceedances)	This indicator reports on contaminants found in urban and suburban streams. Compounds reported here include many pesticides, select pesticide breakdown products, ammonia, and nitrate (because nitrate and ammonia occur naturally, they are not included in the graphs showing contaminant occurrence).	Heinz Center, 2002; Heinz Center, 2008	
40	Chemical Contamination in Urban/Suburban Soils	This indicator reports on contaminants found in urban and suburban soils. Compounds reported here include many pesticides, selected pesticide breakdown products, ammonia, and nitrate (because nitrate and ammonia occur naturally, they are not included in the graphs showing contaminant occurrence).	Heinz Center, 2002; Heinz Center, 2008	
41[x]	Chlorophyll a	N/A	Chesapeake Bay Program, 2008.	42
42	Chlorophyll a (surface concentration)	Good: Surface concentrations are less than 5 µg/L (less than 0.5 µg/L for tropical ecosystems). Fair: Surface concentrations are between 5 µg/L and 20 µg/L (between 0.5 µg/L and 1 µg/L for tropical ecosystems). Poor: Surface concentrations are greater than 20 µg/L (greater than 1 µg/L for tropical ecosystems).	USEPA, 2006a.	41
43	Chlorophyll concentrations (within 25 miles of shore)	Chlorophyll concentration in estuaries and ocean waters within 25 miles of shore. For ocean waters, the indicator reports the average value for the season with the highest concentration, for each region. For estuaries, the indicator reports the percentage of area in three ranges: below 5 parts per billion (ppb), between 5 and 20 ppb, and above 20 ppb, using data for the season with the highest average concentration.	Heinz Center, 2002; Heinz Center, 2008	

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Indicator ID#	Indicator	Definition	Literature Source *[See Appendix A for full citation]*	Duplicate
44	Climate, storm, and extreme event variability	Climate fluctuations, mostly related to flood and drought events.	Gleick and Adams, 2000.	
45	Coastal Bird Populations (2 indicator species)	Indicators consist of two birds (piping plover and least tern) that inhabit Long Island Sound beaches, plus wading birds that forage in tidal marshes.	Long Island Sound Study, 2008.	46
46[x]	Coastal birds	N/A	MEA, 2005b.	45
47	Coastal erosion (managed vs. unmanaged area)	How much of the U.S. coast is managed in an attempt to control erosion and how much remains in a "natural" state, with no erosion control. For unmanaged areas, the indicator reports what fraction is eroding, accreting (gaining land area), or stable.	Heinz Center, 2002; Heinz Center, 2008	
48[x]	Coastal Fish Tissue Contaminants	N/A	USEPA, 2008b.	58, 99, 579
49	Coastal land loss	N/A	Twilley et al., 2001.	
50[x]	Coastal Sediment Quality	N/A	USEPA, 2008b.	250
51**	**Coastal Vulnerability Index (to sea level rise)**	**Index of coastal ecosystem vulnerability to sea level rise. he index allows the six physical variables to be related in a quantifiable manner that expresses the relative vulnerability of the coast to physical changes due to sea-level rise. This method yields numerical data that cannot be equated directly with particular physical effects. It does, however, highlight those regions where the various effects of sea-level rise might be the greatest. The six variables are: a = Geomorphology; b = Coastal Slope (%); c = Relative sea-level change (mm/year); d = Shoreline erosion/accretion (m/year); e = Mean tide average (m); e = Mean wave height (m). Once each section of coastline is assigned a risk value based on each specific data variable, the coastal vulnerability index is calculated as the square root of the geometric mean, or the square root of the product of the ranked variables divided by the total number of variables as: $CVI = [(a*b*c*d*e*f*)/6)]^{1/2}$. ***	**Day et al., 2005.**	

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Indicator ID#	Indicator	Definition	Literature Source *[See Appendix A for full citation]*	Duplicate
52	Coastal wetlands (extent/acreage)	Acreage of coastal habitats whose defining feature is that they are composed of living organisms (such as seagrasses, mangrove forests, and coastal wetlands) or are built by them (such as coral reefs or shellfish beds).	Heinz Center, 2002; Heinz Center, 2008	53
53[x]	Coasts and Oceans (extent/acreage)	This indicator presents the area coastal land as a percentage of the total U.S. land area, for the most recent 50-year period and compared to presettlement estimates.	Heinz Center, 2002; Heinz Center, 2008	52
54	Commercial fish and shellfish landings (weight)	Reports the weight of fish, shellfish, and other products taken from U.S. waters. Landings, plus certain aquaculture harvests, are shown for five regions that cover all waters out to the 200-mile territorial limit.	Heinz Center, 2002; Heinz Center, 2008	
55	**Commercially important fish stocks (size)**	**Tracks the percentage of commercially important fish species, or "stocks," that are increasing or decreasing in size. Only stocks whose population increased or decreased by at least 25% are reported. Trends are based on the estimated weight, or "biomass," of the entire stock.**	**Heinz Center, 2002; Heinz Center, 2008**	
56	Condition of bottom-dwelling animals (percent area inhabited)	Describes the condition of worms, clams, snails, and shrimplike animals in bottom sediments ("benthic communities") by reporting the percentage of area in which these communities are in "undegraded," "moderate," and "degraded" condition. The index reflects changes in benthic community diversity and the abundance of pollution-tolerant and pollution-sensitive species. A low benthic index rating indicates that the benthic communities are less diverse than expected, are populated by more than expected pollution-tolerant species, and contain fewer than expected pollution-sensitive species. The data in this report reflect an assessment of benthic communities as "good" (high index score), "fair" (moderate index score), or "poor" (low index score).	Heinz Center, 2002; Heinz Center, 2008	
57	Constructed Materials - 30% or Greater Area Covered by Constructed Materials (area)	This indicator would report on the percentage of land area covered by 30% or more constructed materials.	Heinz Center, 2002; Heinz Center, 2008	

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Indicator ID#	Indicator	Definition	Literature Source [See Appendix A for full citation]	Duplicate
58	Contaminants in fish and shellfish (chemical concentration)	Measures the concentration of PCBs, mercury, and DDT in the edible tissue of seafood from U.S. coastal waters.	Heinz Center, 2002; Heinz Center, 2008	48, 99, 579
59	Contamination in bottom sediments (concentration)	Information on the concentration, in coastal bottom sediments, of four major classes of contaminants that can harm fish and other aquatic organisms and can adversely affect human health if ingested while consuming fish or shellfish.	Heinz Center, 2002; Heinz Center, 2008	
60	Cropland (total area of land used for crops)	This indicator reports the amount of land used for crops, including pasture and hay. Acreage that is enrolled in long-term set-aside programs, such as the Conservation Reserve Program (CRP) is not considered to be part of this indicator.	Heinz Center, 2002; Heinz Center, 2008	
61	Croplands (extent/acreage)	This indicator presents the area of croplands as a percentage of the total U.S. land area, for the most recent 50-year period and compared to presettlement estimates.	Heinz Center, 2002; Heinz Center, 2008	
62	Cropped Land (area, ecosystem condition)	This indicator would report on the percentage of land area that is cropped land (not including interspersed natural areas).	Heinz Center, 2002; Heinz Center, 2008	
63	Delta accretion rate	The rate of sediment accretion in a river delta.	Day et al., 2008.	
64	Depth to Shallow Groundwater (Percent of shallow groundwater with a certain depth)	This indicator will describe the depth to shallow groundwater in grassland and shrubland areas. Specifically, it will report the percentage of grassland and shrubland areas where the depth to groundwater falls within several ranges (less than 5 feet, 5 to 10 feet, 10 to 20 feet and more than 20 feet).	Heinz Center, 2002; Heinz Center, 2008	
65	Disruptive Species - By Region (Number of disruptive species by region)	This indicator would report the number and type of "disruptive" species found in metropolitan areas. Disruptive species are those that have negative effects on natural areas and native species or cause damage to people and property. This indicator would report the number of disruptive native and non-native plant and animal species on a regional basis, for the most current year.	Heinz Center, 2002; Heinz Center, 2008	

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66	Disruptive Species in Metropolitan Areas (Number of disruptive species over time)	This indicator would report the number and type of "disruptive" species found in metropolitan areas. Disruptive species are those that have negative effects on natural areas and native species or cause damage to people and property. Specifically, the indicator will report the number of larger metropolitan areas with 5 or fewer, from 6 to 10, from 11 to 20, and more than 20 disruptive plant and animal species.	Heinz Center, 2002; Heinz Center, 2008	
67[x]	Dissolved inorganic nitrogen	N/A	Hayslip et al., 2006.	68
68	Dissolved Inorganic Nitrogen (DIN) (surface concentration)	Good: Surface concentrations are less than 0.1 mg/L (NE, SE, Gulf), 0.5 mg/L (West), or 0.05 mg/L (tropical). Fair: Surface concentrations are 0.1–0.5 mg/L (NE, SE, Gulf), 0.5–1.0 mg/L (West), or 0.05–0.1 mg/L (tropical). Poor: Surface concentrations are greater than 0.5 mg/L (NE, SE, Gulf), 1.0 mg/L (West), or 0.1 mg/L (tropical).	USEPA, 2006a.	67
69	Dissolved Inorganic Phosphorus (DIP) (surface concentration)	Good: Surface concentrations are less than 0.01 mg/L (NE, SE, Gulf), 0.01 mg/L (West), or 0.005 mg/L (tropical). Fair: Surface concentrations are 0.01–0.05 mg/L (NE, SE, Gulf), 0.01–0.1 mg/L (West), or 0.005–0.01 mg/L (tropical). Poor: Surface concentrations are greater than 0.05 mg/L (NE, SE, Gulf), 0.1 mg/L (West), or 0.01 mg/L (tropical).	USEPA, 2006a.	
70	Dissolved Organic Carbon	N/A	Lettenmaier et al., 2008.	
71[x]	Dissolved oxygen	Good: Concentrations are greater than 5 mg/L. Fair: Concentrations are between 2 mg/L and 5 mg/L. Poor: Concentrations are less than 2 mg/L.	USEPA, 2006a.	72, 73, 74, 75, 337, 131
72[x]	Dissolved oxygen	N/A	Chesapeake Bay Program, 2008.	71, 73, 74, 75, 337, 131
73[x]	Dissolved oxygen	N/A	Hayslip et al., 2006.	71, 72, 74, 75, 337, 131

Indicator ID#	Indicator	Definition	Literature Source *[See Appendix A for full citation]*	Duplicate
74	Dissolved Oxygen	Percent of observations of ambient concentrations less than 5 mg/L.	Hurd et al., 1999.	71, 72, 73, 75, 337, 131
75[x]	Dissolved oxygen concentration	N/A	USEPA, 1995.	71, 72, 73, 74, 337, 131
76[x]	Dissolved solids (total)	N/A	USEPA, 2006b.	345
77	Drained or Impounded Wetlands (area, ecosystem condition)	This indicator would reports the percentage of land area drained or impounded wetlands (areas that remain wetlands but have been highly altered).	Heinz Center, 2002; Heinz Center, 2008	
78	Drought events (severity)	N/A	Lettenmaier et al., 2008.	
79	Dryness Ratio (ratio of precipitation/evapotranspiration)	Share of total average annual precipitation (P) that is lost through evapotranspiration (ET), where ET is defined as P-QS.	Hurd et al., 1999.	
80	Duration of Dry Periods in Grassland/Shrubland Streams and Rivers (Percent of streams with substantially shorter/longer dry-periods over time)	Duration of dry-period compared to a 50-year average). The indicator tracks the frequency and duration of zero-flow conditions for streams and rivers in grassland/shrubland regions. It reports the percentage of streams and rivers that have at least one no-flow day per year, and the percentage where the duration of zero-flow periods for a given period is substantially longer or shorter than the long-term (50-year) average.	Heinz Center, 2002; Heinz Center, 2008	
81	Ecosystem extent (classification of area)	Type of ecosystem.	U.S. Climate Change Science Program, 2008.	
82	Ecosystem heat sensitivity	The average annual number of days with maximum temperatures exceeding 90°F (32°C). *	Hurd et al., 1998.	
83	Ecosystem ice cover sensitivity	The average annual number of days with average temperatures below 32°F (0°C). *	Hurd et al., 1998.	

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Indicator ID#	Indicator	Definition	Literature Source *[See Appendix A for full citation]*	Duplicate
84	Electrical Conductivity	N/A	USEPA, 2006b.	603
85	Estuarine Waters Contamination (chemical occurrence)	This indicator reports on contaminants found in estuarine waters. Contaminants reported here include many pesticides, selected degradation products, polychlorinated biphenyls (PCBs), polyaromatic hydrocarbons (PAHs), volatile organic compounds, other industrial contaminants, trace elements, nitrate, and ammonium. (Because nitrate, ammonium, and trace elements such as cadmium and chromium occur naturally, they are not included in the contaminant occurrence graphs).	Heinz Center, 2002; Heinz Center, 2008	
86	Evaporation and Transpiration	N/A	Lettenmaier et al., 2008.	87
87[x]	Evaporation and Transpiration	N/A	Gleick and Adams, 2000.	86
88	Expenditure on Dredging Activities in Waterways (economy)	Average annual expenditures on dredging activities in navigable waterways.	Hurd et al., 1999.	
89	Extreme temperatures (number)	Number of Threshold Exceedances per Year —Thresholds: Daily Maximum Temperature of 97°F/36°C.	Kling et al., 2003 using data from Wuebbles and Hayhoe, 2003.	
90	Extreme/heavy rainfall events (number)	Number of 24-hour and 7-day intense rainfall events.	Kling et al., 2003 using data from Wuebbles and Hayhoe, 2003.	

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Indicator ID#	Indicator	Definition	Literature Source *[See Appendix A for full citation]*	Duplicate
91	Farmland Landscape (Cropland as a percentage of total farmland)	This indicator reports the percentage of the farmland landscape that is actively used for crop production, pasture, or haylands. The "farmland landscape" includes croplands and the forests or woodlots, wetlands, grasslands and shrublands, and the like that surround or are intermingled with them. This indicator describes the degree to which croplands dominate the landscape, or, conversely, the degree to which these other lands are intermingled. This indicator also describes the composition of the noncropland portion of the farmland landscape by reporting the percentage of these lands that are forests, grasslands and shrublands, wetlands, developed areas, and other lands and waters. The noncropland elements of the farmland landscape (other than developed) provide wildlife habitat, serve as streamside buffers and windbreaks, and lend a distinctive visual character to the landscape. (Pasture and haylands are intermediate in character between "natural" grasslands and cultivated croplands; for this indicator, they are counted as croplands.)	Heinz Center, 2002; Heinz Center, 2008	
92	Finfish (abundance, biomass)	Indicators include abundance of popular sport fish (such as striped bass and bluefish), fish biomass, and abundance of fish that spawn in rivers in the Sound's watershed.	Long Island Sound Study, 2008.	
93	Fire Frequency (Percent of forest land burned over time)	This indicator describes the frequency with which forests are burned by wildfire. It would report the fraction of forest lands that experience wildfire much more or less frequently, moderately more or less frequently, or with about the same frequency as in presettlement times. Thus, a forest that, historically, burned every 50 years on average will be considered moderately altered if it burns every 100 years, and significantly altered if it burns only every 150 years, and about the same if it burns once every 50 years.	Heinz Center, 2002; Heinz Center, 2008	

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Indicator ID#	Indicator	Definition	Literature Source *[See Appendix A for full citation]*	Duplicate
94	Fire Frequency (Percent of grasslands/shrublands by area that are burned over time)	This indicator will describe how often grassland and shrublands are burned by wildfire. Specifically, it will report the fraction of grassland and shrubland areas that burn much more or less often, moderately more or less often, or about as often as before European settlement. So, for example, an area that historically burned every 5 years on average might be considered moderately altered if it now burns every 10 years and significantly altered if it now burns only every 25 years. An area that historically burned every 80 years might be considered moderately altered if it now burns every 40 years and significantly altered if it now burns every 20 years. (Presettlement conditions are used here as a reference against which to compare current conditions, not as an implied management goal).	Heinz Center, 2002; Heinz Center, 2008	
95	**Fish and Bottom-Dwelling Animals (comparison to baseline)**	**This indicator reports on "biological integrity"—the degree to which the suite of fish and bottom-dwelling animals in a lake or stream resembles what one might find in a relatively undisturbed lake or stream in the same region. Tests assess the number of different species, the number and condition of individuals, and food chain interactions for fish and bottom-dwelling (or benthic) animals, which include insects, worms, mollusks, and crustaceans.**	**Heinz Center, 2002; Heinz Center, 2008**	
96	Fish and shellfish populations (5 species)	Blue Crab, Oyster, Striped Bass, Shad, and Juvenile Menhaden population characteristics.	Chesapeake Bay Program, 2008.	
97	Fish range distribution (species)	Northern/southern limit.	Kling et al., 2003.	
98	Fish Tissue Contaminants Index (exceedence of regulatory value)	Good: Concentrations of all chemical contaminants fall below the range of the EPA Advisory Guidance. Fair: Concentration of at least one chemical contaminant falls within the range of the EPA Advisory Guidance. Poor: Concentrations of at least one chemical contaminant exceeds the maximum value in the range of the EPA Advisory Guidance.	USEPA, 2006a.	
99[x]	Fish-tissue contaminants (chemical levels)	Inorganic arsenic, cadmium, lead, mercury, selenium, silver, zinc, DDT.	Hayslip et al., 2006.	58, 48, 579

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Indicator ID#	Indicator	Definition	Literature Source *[See Appendix A for full citation]*	Duplicate
100	**Flood events (frequency)**	**N/A**	**Lettenmaier et al., 2008.**	
101	Forest Age (Percent of forest lands by age group)	This indicator reports the percentage of forest lands with stands in several age classes.	Heinz Center, 2002; Heinz Center, 2008	
102	Forest Area and Ownership (Area of forest lands)	This indicator reports how much forest land there is in the United States and who owns it.	Heinz Center, 2002; Heinz Center, 2008	
103	Forest Community Types with Significantly Reduced Area (Area occupied by community type)	This indicator would report whether those forest community types that cover significantly fewer acres than they did in presettlement times are increasing or decreasing in area, and by how much. It would also report the total area occupied by these much-reduced forest community types—those that have been reduced by 70% or more in area.	Heinz Center, 2002; Heinz Center, 2008	
104	Forest Disturbance: Fire, Insects, Disease (Area affected by disturbance)	This indicator reports the acreage of forest affected each year by several important types of disturbance: forest fires, insects, and diseases of trees.	Heinz Center, 2002; Heinz Center, 2008	
105	Forest Management Categories (Change in percent of forested area with time)	This indicator reports the percentage of forest area in several different management categories. These range from "reserved lands" (forests in national parks, wilderness areas, and other similar areas) to forests under intensive management involving replanting after harvest. Other forest lands in intermediate categories are subject to a wide variety of both management practices and restrictions on use.	Heinz Center, 2002; Heinz Center, 2008	

Indicator ID#	Indicator	Definition	Literature Source *[See Appendix A for full citation]*	Duplicate
106	Forest Pattern and Fragmentation (Percent of a tree's surroundings that are forested)	This indicator describes a tree's forest neighborhood according to the degree of forest cover within various distances. Thus, the "immediate neighborhood" of a particular tree is everything within about 250 feet in all directions. This "immediate neighborhood" is "mostly forest" if the land is at least 90% forested. A tree's "local neighborhood" extends about 1/4 mile in all directions, and its "larger neighborhood" extends about 2 1/2 miles. This analysis relies upon computer analyses of satellite data on millions of individual forest points. While these points (called "pixels") are not individual trees—they are squares about 100 feet on a side—they serve much the same purpose.	Heinz Center, 2002; Heinz Center, 2008	
107	Forest products (economic production)	This indicator reports the production of food and fiber and the withdrawals of water (forest products), using an index with 1980 as the base year.	Heinz Center, 2002; Heinz Center, 2008	
108	Forest Types (Area covered by a certain forest type)	This indicator reports the acreage of a variety of forest "cover types." Cover types describe the dominant species of trees found in the forests (e.g., oak–hickory forests are dominated by oaks and hickories, but include other kinds of trees as well).	Heinz Center, 2002; Heinz Center, 2008	
109	Forests (extent/acreage)	This indicator presents the area of forests as a percentage of the total U.S. land area, for the most recent 50-year period and compared to presettlement estimates.	Heinz Center, 2002; Heinz Center, 2008	
110	Forests with Nursery Stock (area, ecosystem condition)	This indicator reports the percentage of land area that is comprised of forests planted with nursery stock.	Heinz Center, 2002; Heinz Center, 2008	
111	Fragmentation and Landscape Pattern	N/A	Heinz Center, 2002; Heinz Center, 2008	

Indicator ID#	Indicator	Definition	Literature Source *[See Appendix A for full citation]*	Duplicate
112	Fragmentation of Farmland Landscapes by Development (Ratio of cropland: developed land)	This indicator would report the degree to which suburban development and other built-up areas break up (fragment) the farmland landscape (defined as croplands plus intermingled "natural" areas such as forests, wetlands, and grasslands and shrublands). Areas with a mosaic of cropland and intermingled natural areas— but little or no development—would be rated as "low" on the "fragmentation index" used for this indicator, while those in which small patches of cropland are mixed into a backdrop of suburban development would be rated as "high."	Heinz Center, 2002; Heinz Center, 2008	
113	Fresh Water Resources Contamination (chemical occurrence)	This indicator reports on contaminants found in freshwater resources. Contaminants reported here include many pesticides, selected degradation products, polychlorinated biphenyls (PCBs), polyaromatic hydrocarbons (PAHs), volatile organic compounds, other industrial contaminants, trace elements, nitrate, and ammonium. (Because nitrate, ammonium, and trace elements such as cadmium and chromium occur naturally, they are not included in the contaminant occurrence graphs).	Heinz Center, 2002; Heinz Center, 2008	
114	Fresh Waters (extent/acreage)	This indicator presents the area of fresh waters.	Heinz Center, 2002; Heinz Center, 2008	
115	Freshwater input to coastal ecosystems	Rate of freshwater input into coastal ecosystems.	Day et al., 2008.	
116	**Freshwater Rivers and Streams with Low Index of Biological Integrity (ecosystem condition)**	**This indicator would report on the percentage of freshwater rivers and streams with low IBI (Index of Biological Integrity, a species-based measure of disturbance).**	**Heinz Center, 2002; Heinz Center, 2008**	
117	Glaciers	N/A	Gleick and Adams, 2000.	
118	Grassland and Shrubland Areas (extent/acreage)	This indicator presents the area of grasslands and shrublands as a percentage of the total U.S. land area, for the most recent 50-year period and compared to presettlement estimates.	Heinz Center, 2002; Heinz Center, 2008	

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Indicator ID#	Indicator	Definition	Literature Source *[See Appendix A for full citation]*	Duplicate
119	Grassland Patches (Percent of grassland patches that cover a certain area)	This indicator will describe the fraction of grassland area and shrubland area that is in patches of different sizes. The total area occupied by patches of a certain size will be reported as a percentage of the total area of either grasslands or shrublands.	Heinz Center, 2002; Heinz Center, 2008	
120	Grasslands and Shrublands (Area covered by grasslands/shrublands)	This indicator reports the acreage of U.S. grasslands and shrublands (although data are not available for Hawaii).	Heinz Center, 2002; Heinz Center, 2008	
121	**Groundwater Depletion - Ratio of Withdrawals/Baseflow**	**Ratio of average groundwater withdrawals (QGW) in 1990 to annual average baseflow (QBase), reflecting the extent that groundwater use rates may be exceeding recharge.**	**Hurd et al., 1999.**	
122	Groundwater Levels - Area of Aquifer subject to Change in Groundwater Levels	This indicator would report the percentage of the area of the nation's major regional aquifers in which water levels are increasing, decreasing, or stable. The indicator would report what fraction of the aquifer area declined, increased, or remained stable in comparison to a previous period, and it would be reported every 5 years.	Heinz Center, 2002; Heinz Center, 2008	
123	Groundwater recharge	Rate of groundwater recharge (mm/year) based on WaterGAP Global Hydrology Model and mapped on a 0.5 degree grid. It accounts for spatial variation in precipitation, infiltration capacity, hydrogeology, topography, and permafrost. *	Lettenmaier et al., 2008.	124
124[X]	Groundwater recharge	N/A	Gleick and Adams, 2000.	123
125**	**Groundwater reliance**	**Share of total annual withdrawals derived from groundwater in 1995. Method of calculation: QGW/QW. ***	**Hurd et al., 1998.**	
126	Growing season length	Number of days between last spring frost and first autumn frost.	Kling et al., 2003 using data from Wuebbles and Hayhoe, 2003.	

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127	**Harmful algal blooms (occurrence)**	**Defined as (1) an increase in the abundance of species that are known to produce toxins harmful to marine animals or humans; (2) the occurrence of lesions or mass mortalities of marine animals caused by HAB species; and (3) the occurrence of human pathologies caused by HAB species. A single event counts only once toward the relative intensity scale, even if it produces multiple impacts (e.g., an increase in the abundance of a HAB species that causes mass mortalities and an increased human health risk will be counted as a single event).**	**Heinz Center, 2002; Heinz Center, 2008**	
128	Highest spring streamflow date	Peak streamflow in early spring, indicative of maximum baseflow and/or maximum snowmelt rate in a basin.	Frumhoff et al., 2006.	
129	Hydrologic isolation	Indicates whether a system is a closed basin, or "isolated water" (i.e., a single spring that flows for a short distance before re-infiltrating into ground).	MEA, 2005b.	
130	Hydropower capacity	Distribution of regional hydroelectric power capacity, in megawatts (MW).	Hurd et al., 1998.	
131[x]	Hypoxia (dissolved oxygen concentration)	Levels of dissolved oxygen below 2 milligrams per liter (mg/L).	USEPA, 2008b.	71, 72, 73, 74, 75, 337
132	Ice cover duration (freeze and ice-out dates)	Number of days waterbodies are covered by ice, or are ice-free.	Kling et al., 2003.	
133	Ice cover on rivers	N/A	Frumhoff et al., 2006.	
134[x]	Ice -out date	Date of spring ice-out on lakes in the Northeast.	Frumhoff et al., 2006.	275, 423
135	Industrial water use (average annual share consumed)	Share of total industrial water use that is consumed (i.e., not returned to the system). *	Hurd et al., 1999.	
136	Inland water extent	Total areal extent of inland waters (could be divided by area to calculate density).	MEA, 2005b.	

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Indicator ID#	Indicator	Definition	Literature Source *[See Appendix A for full citation]*	Duplicate
137	Institutional Barriers to Water Trading	Flexibility score (on a scale of integers from zero to five) is assigned to each state based on the relative degree of barriers to water trading.	Hurd et al., 1999.	
138	Instream fish habitat	Instream fish concealment features consisting of undercut banks, boulders, large pieces of wood, brush, and cover from overhanging vegetation within a stream and its banks.	USEPA, 2006b.	
139	Intactness of coastal buffer	The degree to which natural coastal landforms and vegetation are intact.	Day et al., 2007.	
140	Intensively Grazed Grassland (area, ecosystem condition)	This indicator would report on the percentage of land area that is intensively grazed grassland/shrubland.	Heinz Center, 2002; Heinz Center, 2008	
141	Invasive Plant Cover - Grasslands and Shrublands (Percent of non-native plant cover)	This indicator will report the percentage of plant cover in grasslands and shrublands that is made up of non-native species. The indicator will report on both invasive non-native species (those that spread aggressively) and all non-native species.	Heinz Center, 2002; Heinz Center, 2008	
142	Invasive plant coverage - Forests (Percent area of non-native cover)	This indicator describes the degree to which non-native plants are found in U.S. forests. It will report the percentage of the total area covered by overstory (large trees that form the canopy) and understory (shrubs, ground plants, and smaller trees) that is made up of non-native plants.	Heinz Center, 2002; Heinz Center, 2008	
143[x]	Invasive species	N/A	Twilley et al., 2001.	463, 144, 618
144	Invasive species	This indicator reports the percentage of watersheds with different numbers of nonnative species with established breeding populations. "Non-native" includes species not native to North America and those that are native to this continent but are now found outside their historic range.	Heinz Center, 2002; Heinz Center, 2008	618, 143, 463
145	**Invasive species - Coasts affected (area, ecosystem condition)**	**This indicator would report on the percentage of coastline length that is heavily affected by invasive species.**	**Heinz Center, 2002; Heinz Center, 2008**	
146	Invasive species - Forests	This indicator would report on the percentage of land area that is forests	Heinz Center, 2002; Heinz	

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	Affected (area, ecosystem condition)	heavily affected by invasive species.	Center, 2008	
147	Invasive species - Grasslands and Shrublands Affected (area, ecosystem condition)	This indicator would report on the percentage of land area that is grasslands and shrublands heavily affected by invasives.	Heinz Center, 2002; Heinz Center, 2008	
148	Invasive species (range expansion)	N/A	MEA, 2005b.	
149	**Invasive species in estuaries (percent influenced)**	**Percentage of major estuaries with high, medium, or low influence by non-native species. Ratings of the degree of influence should incorporate both the number of different species present and the degree to which they occupy available habitat.**	**Heinz Center, 2002; Heinz Center, 2008**	
150[X]	Irrigation withdrawal rate	N/A	MEA, 2005b.	444
151[X]	Lake and Stream Acidity	N/A	USEPA, 2008b.	604, 621

Indicator ID#	Indicator	Definition	Literature Source [See Appendix A for full citation]	Duplicate
152	Lake Levels and Conditions	N/A	Gleick and Adams, 2000.	
153[x]	Lake stratification (thermal structure)	N/A	Kling et al., 2003.	343
154	Land use	N/A	U.S. Climate Change Science Program, 2008.	
155	Lands and Waters with Highly Altered Species Mix (area, ecosystem condition)	This indicator would report on the percentage of lands and waters with highly altered species mix, such as would be characteristic of altered fire or hydrologic regimes.	Heinz Center, 2002; Heinz Center, 2008	
156	Latitude/altitude	N/A	MEA, 2005b.	
157	Lined and Culverted Streams (area)	This indicator would report on the percentage of land area and stream length that is lined and culverted streams.	Heinz Center, 2002; Heinz Center, 2008	
158	Living Planet Index	N/A	MEA, 2005b.	
159	**Low flow sensitivity (mean baseflow)**	**Unregulated mean baseflow in cfslmi2, i.e. the amount of streamflow originating from groundwater outflow.**	**Hurd et al., 1999.**	
160	Low-flow events	N/A	Frumhoff et al., 2006.	
161	M&I water use share	Municipal and industrial sector share of total average annual withdrawals.	Hurd et al., 1998.	
162	Major Crop Yields (Tons or bushels per acre of land)	This indicator reports the yields of corn, soybeans, wheat, hay, and cotton (which account for 95% of crop production in the US), as an index with 1975 as the base year. Values above 1.0 indicate higher yields, typically measured as tons or bushels per acre, than in 1975; values below 1.0 indicate lower yields than in 1975.	Heinz Center, 2002; Heinz Center, 2008	
163	Mangrove cover	N/A	MEA, 2005b.	

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164	Marine fish landings (economic production)	Specifically refers to marine fish landings. This indicator reports the production of food and fiber and the withdrawals of water, using an index with 1980 as the base year.	Heinz Center, 2002; Heinz Center, 2008	
165**	**Meteorological drought indices**	**Average Palmer Drought Severity Index value, 2003-2007. ***	**National Assessment Synthesis Team, 2000a.**	
166	Mid-channel clarity	N/A	Chesapeake Bay Program, 2008.	
167	Migratory bird use	N/A	MEA, 2005b.	
168	Miles of Hardened Coastline	This indicator would report on the percentage of coastline length that is hardened coastline.	Heinz Center, 2002; Heinz Center, 2008	
169	Miles of Streams Impounded to Lakes (area, ecosystem condition)	This indicator would report on the percentage of stream length (at some last baseline date) that has since been impounded into lakes.	Heinz Center, 2002; Heinz Center, 2008	
170	Modification of water regimes	A measure of the degree of anthropogenic influence, which may be worsened by climate change.	MEA, 2005b.	
171	Monetary Value of Agricultural Production - Time-related (Billions of 1999 $ per year)	This indicator reports the dollar value of the annual output of major crops and livestock, in billions of 1999 dollars per year. The value is determined by multiplying the amount of output by the prices received by farmers (in 1999 dollars).	Heinz Center, 2002; Heinz Center, 2008	
172	Monetary Value of Agricultural Production - Area-related (Thousands of 1999 $ per square mile)	This indicator reports the dollar value of the annual output of major crops and livestock, in thousands of 1999 dollars per square mile. The value is determined by multiplying the amount of output by the prices received by farmers (in 1999 dollars).	Heinz Center, 2002; Heinz Center, 2008	
173	Native Vegetation in Areas Dominated by Croplands (Percentage of vegetation native to a specific area)	This indicator would report, for areas where croplands account for a large percentage of the land cover, how much of the remaining vegetation (outside of croplands) is native to the area.	Heinz Center, 2002; Heinz Center, 2008	

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174	Natural coastal wetlands	N/A	MEA, 2005b.	
175	Natural Ecosystem Services	This indicator would report on the levels of key services provided by "natural" ecosystems—forests, grasslands and shrublands, fresh waters, and coasts and oceans. The goods, or products, these ecosystems provide—such as fish, wood products, and food—can be counted, and a monetary value often placed upon them.	Heinz Center, 2002; Heinz Center, 2008	176
176[x]	Natural Ecosystem Services - Urban/Suburban Lands	Urban and suburban areas are defined by what people have built, but the remaining "natural" components—trees, meadows, streams, wetlands, and the like—provide valuable services to the residents of these developed areas. Ecosystem services are the benefits, both tangible and intangible, that these natural elements provide. For example, forested areas reduce stormwater runoff, when compared to paved areas, and trees cool streets and buildings, reducing energy consumption; trees also reduce urban noise levels. Natural areas, including forests, grasslands and shrublands, beaches, lakes, streams, and wetlands, also provide recreational opportunities, increase property values and community amenities, and are aesthetically pleasing.	Heinz Center, 2002; Heinz Center, 2008	175
177	Nitrate and Pesticides in Shallow Ground Water in Agricultural Watersheds	N/A	USEPA, 2008b.	
178	Nitrate concentration - major aquifers on agricultural lands (Percent of samples with drinking water exceedances)	Percentage of samples exceeding drinking-water standard for nitrate (10 milligrams per liter).	USGS, 1999.	
179	Nitrate concentration - shallow groundwater	Median concentration of nitrate (in milligrams per liter).	USGS, 1999.	

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180	Nitrate in Farmland Streams and Groundwater	This indicator reports on the concentration of nitrate in representative farmland streams and groundwater sites. Specifically, the indicator reports the percentage of streams and groundwater wells with average nitrate concentrations in one of four ranges, in areas that are primarily farmland.	Heinz Center, 2002; Heinz Center, 2008	
181	Nitrate in Grassland and Shrubland Groundwater (Percent of groundwater sites tested)	This indicator reports on the concentration of nitrate in groundwater in grassland and shrubland areas. Specifically, the indicator reports the percentage of groundwater sites with average nitrate concentrations in one of four ranges, in areas that are primarily grassland or shrubland.	Heinz Center, 2002; Heinz Center, 2008	
182	Nitrate in Streams (Average nitrate concentration)	This indicator reports on the concentration of nitrate in representative streams in forested areas. Specifically, the indicator reports the percentage of streams with average nitrate concentrations in one of four ranges, for streams draining watersheds that are primarily forested.	Heinz Center, 2002; Heinz Center, 2008	
183	Nitrate in Urban and Suburban Streams (Percent of streams with certain level of detects)	This indicator reports the concentration of nitrate in streams in representative urban areas. Specifically, the indicator reports the percentage of streams with average nitrate concentrations in one of four ranges, for streams draining watersheds that are primarily urban.	Heinz Center, 2002; Heinz Center, 2008	
184	Nitrogen (movement, yield/load)	This indicator reports the yield of nitrogen from major watersheds: pounds of nitrogen per square mile of watershed area that enters rivers and streams through discharges, runoff, and other sources. It also reports the load of nitrate, a common form of nitrogen, from major rivers: tons of nitrate carried to the ocean each year by the four largest U.S. rivers.	Heinz Center, 2002; Heinz Center, 2008	
185	Nitrogen (total)	This indicator reports the total nitrogen concentration in a system.	USEPA, 2006b.	
186[x]	Nitrogen and Phosphorus -large rivers	This indicator reports the nitrogen and phosphorus content of large rivers.	USEPA, 2008b.	459
187	Nitrogen and Phosphorus -streams in agricultural watersheds	This indicator reports the nitrogen and phosphorus content of streams and rivers in agricultural watersheds.	USEPA, 2008b.	
188	Nitrogen and Phosphorus -wadeable streams	This indicator reports the nitrogen and phosphorus content of wadeable streams.	USEPA, 2008b.	

Indicator ID#	Indicator	Definition	Literature Source *[See Appendix A for full citation]*	Duplicate
189	Nitrogen concentration - streams (total)	Average annual concentration of total nitrogen (in milligrams per liter).	USGS, 1999.	
190	**Number of Dry Periods in Grassland/Shrubland Streams and Rivers (Percent of streams with dry periods over time)**	**The indicator tracks the frequency and duration of zero-flow conditions for streams and rivers in grassland/shrubland regions. It reports the percentage of streams and rivers that have at least one no-flow day per year, and the percentage where the duration of zero-flow periods for a given period is substantially longer or shorter than the long-term average.**	**Heinz Center, 2002; Heinz Center, 2008**	
191	Nutrient enrichment (coastal wetlands)	Nutrient enrichment of coastal wetland ecosystems.	Day et al., 2008.	
192	Open Mines, Quarries, and Gravel Pits (area)	This indicator would report on the percentage of land area that is open mines, quarries, and gravel pits, measured from satellite.	Heinz Center, 2002; Heinz Center, 2008	
193	Patches of Forest, Grassland and Shrubland, and Wetlands - By Region (Percent area of natural lands in urban/suburban areas by region)	This indicator reports how much of the "natural" area within urban and suburban lands is in patches of varying size, from less than 10 acres to greater than 10,000 acres. Natural areas include forests, grasslands and shrublands (including most pasturelands — especially in the west), and wetlands.	Heinz Center, 2002; Heinz Center, 2008	
194	Patches of Forest, Grassland and Shrubland, and Wetlands - National (Percent area of natural lands in urban/suburban areas)	This indicator reports how much of the "natural" area within urban and suburban lands is in patches of varying size, from less than 10 acres to greater than 10,000 acres. Natural areas include forests, grasslands and shrublands (including most pasturelands — especially in the west), and wetlands.	Heinz Center, 2002; Heinz Center, 2008	
195	Permafrost	N/A	Gleick and Adams, 2000.	
196	Permafrost temperatures	N/A	Lettenmaier et al., 2008.	

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Indicator ID#	Indicator	Definition	Literature Source *[See Appendix A for full citation]*	Duplicate
197	Pesticide Exceedances in Farmland Streams and Groundwater (Percent of waterbodies with regulatory exceedances)	This indicator reports on pesticides and pesticide degradates found in farmland streams and groundwater as the percentage of streams and shallow groundwater wells with contaminant concentrations that exceeded standards and guidelines (benchmarks) set for the protection of human health or aquatic life. Data report currently used agricultural pesticides and selected breakdown products of these pesticides, as well as selected organochlorine insecticides that were widely used in the past but whose use is no longer permitted in the United States.	Heinz Center, 2002; Heinz Center, 2008	
198	Pesticide Occurrence in Farmland Streams and Groundwater (Number of pesticides detected in waterbodies)	This indicator reports on pesticides and pesticide degradates found in farmland streams and groundwater as the average number of such contaminants detected throughout the year in streams and shallow groundwater wells. Data report currently used agricultural pesticides and selected breakdown products of these pesticides, as well as selected organochlorine insecticides that were widely used in the past but whose use is no longer permitted in the United States.	Heinz Center, 2002; Heinz Center, 2008	199
199[x]	Pesticides in Streams in Agricultural Watersheds	N/A	USEPA, 2008b.	198
200	Phosphorus (total)	Indicator reports total phosphorus concentration in water body	USEPA, 2006b.	
201	Phosphorus in Farmland Streams	This indicator reports on the concentration of phosphorus in representative farmland streams. Specifically, the indicator reports the percentage of streams with average annual concentrations in one of four ranges, for streams draining watersheds that are primarily farmland.	Heinz Center, 2002; Heinz Center, 2008	
202	Phosphorus in Urban and Suburban Streams (Percent of streams with certain level of detects)	This indicator reports the concentration of phosphorus in representative streams in urban areas. Specifically, the indicator reports the percentage of streams with average annual concentrations in one of four ranges, for streams draining watersheds that are primarily urban.	Heinz Center, 2002; Heinz Center, 2008	
203	Phosphorus -lakes, reservoirs (concentration)	This indicator reports the average concentration of phosphorus in lakes and rivers.	Heinz Center, 2002; Heinz Center, 2008	
204	Phosphorus -large rivers	This indicator reports the average concentration of phosphorus in large	Heinz Center, 2002; Heinz	

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	(concentration)	rivers.	Center, 2008	
205	Phytoplankton	N/A	Chesapeake Bay Program, 2008.	
206	Plant Growth Index	This indicator reports a plant growth index, based on satellite measurements of the amount of solar energy absorbed by vegetation and potentially used for photosynthesis. The index shows, for any given year, whether plant growth in a region or for an ecosystem type was above or below the 11-year average	Heinz Center, 2002; Heinz Center, 2008	
207	Population	N/A	Twilley et al., 2001.	208
208	Population (human)	This indicator reports the human population, using an index with 1980 as the base year.	Heinz Center, 2002; Heinz Center, 2008	207
209	**Population (human) susceptible to flood risk**	**Population within the 500-year flood plain.**	**Hurd et al., 1999.**	**360**
210	Population Trends in Invasive and Non-invasive Grassland/Shrubland Birds (Percent change in population size of species over time)	This indicator describes population trends for selected grassland/shrubland bird species by comparing trends for selected "invasive" species with those that are not invasive.	Heinz Center, 2002; Heinz Center, 2008	
211	Potential for wetland migration	Area of tidal wetlands compared to area of land within one-half tide range above spring high water. Ratio of tidal wetlands to dry land and all land.	U.S. Climate Change Science Program, 2008.	
212[X]	Precipitation	N/A	Twilley et al., 2001.	213, 214, 215
213[X]	Precipitation	N/A	Lettenmaier et al., 2008.	212, 214, 215

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214[x]	Precipitation	N/A	Gleick and Adams, 2000.	212, 213, 215
215	Precipitation (average daily)	N/A	Kling et al., 2003 using data from Wuebbles and Hayhoe, 2003.	212, 213, 214
216	Production of Cattle on Grasslands and Shrublands (Number of cattle over time)	This indicator reports the number of cattle grazing on grasslands and shrublands (including pastures), rather than at feedlots, during July of each year.	Heinz Center, 2002; Heinz Center, 2008	
217	Publicly Accessible Open Space per Resident (Percent of metropolitan areas with a certain amount of open space per resident)	This indicator would report the amount of open space—land that is dominated by "natural" surfaces, like grass or woods, along with lakes, rivers, beaches, and wetlands—that is accessible to the general public in large metropolitan areas. Specifically, the indicator would report the percentage of metropolitan areas with different amounts of open space per resident.	Heinz Center, 2002; Heinz Center, 2008	
218**	**Ratio of Snow to Precipitation (S/P)**	**Average annual ratio of snowfall (in inches) to total precipitation (in inches). ***	**Lettenmaier et al., 2008.**	**259, 260**
219**	**Ratio of water withdrawals to annual streamflow**	**Ratio of total annual surface and groundwater withdrawal in 1990 (QW) to unregulated mean annual streamflow (Qs). Method of calculation: QW/Qs**	**Hurd et al., 1999.**	
220	Recreation - Outdoor (number of activities)	This indicator reports the number of times Americans over the age of 15 took part in a variety of outdoor recreational activities. (Each time someone took part in an activity is counted: if the activity took place over multiple days, each day counts as a separate event, and if a person took part in several activities on a single day, each activity is counted as a separate event.)	Heinz Center, 2002; Heinz Center, 2008	608
221	Recreation - Participation in freshwater activities (number of days)	This indicator shows the number of days that people took part in a variety of freshwater activities. A "recreation day" for this measure is any day during which a person was engaged in the activity, whether for only a few	Heinz Center, 2002; Heinz Center, 2008	

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		minutes or for many hours.		
222	Recreation in Forests (Number of days of recreational activity per year)	This indicator would report the number of days per year that people engage in a variety of recreational activities in forests. Activities such as walking, hiking and backpacking, fishing and hunting, wildlife viewing, cross-country and downhill skiing, and snowmobiling would be included.	Heinz Center, 2002; Heinz Center, 2008	
223	Recreation on Farmlands (Number of days of engagement in recreational activities)	This indicator would report the number of days spent fishing, hunting, viewing wildlife, or engaged in other recreational activities on farmland.	Heinz Center, 2002; Heinz Center, 2008	
224	Recreation on Grasslands and Shrublands (Number of days of recreational activity per year)	This indicator will report the number of days per year that people engage in a variety of recreational activities on the nation's grasslands and shrublands. Activities will include: hunting; off-road vehicle (ORV) driving, motorsports, mountain biking, and snowmobiling; bird watching and nature study; and hiking and camping.	Heinz Center, 2002; Heinz Center, 2008	
225	Recreational water quality (beach-mile-days affected by Enterococcus)	This indicator will report the percentage of "beach-mile-days" affected by various levels of Enterococcus, a bacterium that indicates contamination with human or animal waste. A "beach-mile-day" is one mile of beach affected for one day—100 miles of beach affected for one day would count the same as 1 mile affected for 100 days.	Heinz Center, 2002; Heinz Center, 2008	
226	Red List Index	Index of threatened/endangered status for birds, based on a 1988 baseline.	MEA, 2005b.	
227	Relative Bed Stability (RBS)	Ratio that compares measures of particle size of observed sediments to the size of sediments that each stream can move or scour during its flood stage (based on measures of the size, slope, and other physical characteristics of the stream channel).	USEPA, 2006b; USEPA, 2008b.	
228[x]	Relative sea level rise (RSLR)	Function of absolute sea level, changes in land level, and sediment delivery	MEA, 2005b.	229, 241, 405, 412

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229	Relative sea level rise (RSLR)	The net change in the relative elevations of the sea surface and coastal lands	Day et al., 2008.	228, 241, 405, 412
230	Riparian Areas (extent, acreage)	For streams and rivers, the indicator reports on the type of land cover on their shorelines and adjacent areas ("riparian" areas): forest; grasslands, shrublands, or wetlands; and urban/suburban or agricultural land.	Heinz Center, 2002; Heinz Center, 2008	
231	**Riparian Condition (Riparian Condition Index)**	**This indicator will describe the condition of riparian (streamside) areas. The condition of these areas will be rated using an index that combines key factors such as water flows, streambed physical condition, riparian vegetation composition and structure, and use by various species. Such a measure should take into account multiple factors, including hydrology (e.g., relationship to natural flow patterns), geomorphology (e.g., stream sediment transport), and biology (e.g., canopy cover) to provide an overall index of condition.**	**Heinz Center, 2002; Heinz Center, 2008**	
232	River channel and geomorphology	N/A	Gleick and Adams, 2000.	
233	River flow and nitrogen loads	Indicator reports total nitrogen arriving in a water body (e.g., from the Mississippi River system to the Gulf of Mexico).	Chesapeake Bay Program, 2008.	
234	Road surface (area)	This indicator would report on the percentage of land area that is road surface (including unpaved roads).	Heinz Center, 2002; Heinz Center, 2008	
235[x]	Runoff	N/A	Twilley et al., 2001.	236
236	Runoff from precipitation and snowmelt (mean annual)	Water-balance model (monthly precipitation and potential evapotranspiration) and output from the two GCMs to estimate the effects of climate change	National Assessment Synthesis Team, 2000a.	235
237	Runoff -large areas	N/A	Gleick and Adams, 2000.	
238	Runoff patterns	N/A	Lettenmaier et al., 2008.	
239	Runoff -regions	N/A	Gleick and Adams, 2000.	
240[x]	Salinity	N/A	USEPA, 2006b.	603, 84

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241[x]	Sea level rise	N/A	Gleick and Adams, 2000.	228, 229, 405, 412
242	Sea surface temperature (difference from average)	Indicator describes whether sea surface temperature (SST) is above or below average. Method used: (1) the seasonal average sea surface temperature (SST) of near-shore water (shoreline out to 25 miles) was calculated for the warmest season in each region (termed the "seasonal mean maximum"), which typically occurred during summer or fall; (2) the long-term mean (during the warmest seasons) for the period of observation (1985–1998) was calculated; and (3) the long-term mean was then subtracted from the seasonal mean maxima. Thus, values greater than zero are positive "anomalies" (i.e., deviations from the long-term average), and those less than zero are negative anomalies.	Heinz Center, 2002; Heinz Center, 2008	243
243[x]	Sea surface temperature (trend)	N/A	Twilley et al., 2001.	242
244	Seagrass cover	N/A	MEA, 2005b.	
245	Seals (number)	Number of seals observed in winter months at two monitoring locations.	Long Island Sound Study, 2008.	
246	Sediment contaminants (chemical levels)	Total organic carbon, metals, polynuclear aromatic hydrocarbons (PAH), PCBs (Polychlorinated Biphenyls), pesticides.	Hayslip et al., 2006.	
247	Sediment Contamination (exceedance of regulatory value)	Using ERM and ERL guidelines. Good: No ERM values are exceeded, and fewer than five ERL values are exceeded. Fair: No ERM values are exceeded, and five or more ERL values are exceeded. Poor: One or more ERM values are exceeded.	USEPA, 2006a.	
248[x]	Sediment delivery	N/A	MEA, 2005b.	249
249	Sediment discharge (river to coast)	Sediment load discharged from riverine systems into estuarine and coastal systems	Day et al., 2008.	248

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250	Sediment Quality Index (3 components)	Based on three sediment quality component indicators: sediment toxicity, sediment contaminants, and sediment TOC. Good: Less than 5% of the NEP estuarine area is in poor condition, and more than 50% of the NEP estuarine area is in good condition. Fair: 5% to 15% of the NEP estuarine area is in poor condition, or more than 50% of the NEP estuarine area is in combined poor and fair condition. Poor: More than 15% of the NEP estuarine area is in poor condition.	USEPA, 2006a.	50
251	Sediment Total Organic Carbon (TOC)	Good: The TOC concentration is less than 2%. Fair: The TOC concentration is between 2% and 5%. Poor: The TOC concentration is greater than 5%.	USEPA, 2006a.	
252	Sediment toxicity	Acute sediment toxicity test.	Hayslip et al., 2006.	
253	Sediment Toxicity (species test)	Using a 10-day static toxicity test with the amphipod Ampelisca abdita. Good: Mortality is less than or equal to 20%. Poor: Mortality is greater than 20%.	USEPA, 2006a.	
254	Shape of "Natural" Patches (Ratio of perimeter to area of patch)	This indicator describes the shape of patches of "natural" lands in the farmland landscape, by reporting on the percentage of patch area that is found in "compact" patches (e.g., like a circle), "elongated" patches (e.g., like a long narrow rectangle), and an intermediate class of patch shape. These classes are defined based on the ratio of the perimeter, or edge, of each patch to its area; these perimeter-to-area ratios will be divided by patch area for the sake of comparison. "Natural" areas include forest, grasslands and shrublands, wetlands, and lands enrolled in the Conservation Reserve Program (CRP).	Heinz Center, 2002; Heinz Center, 2008	
255	Shellfish (acreage, harvest)	Indicators include acreage of shellfish beds and harvests of important commercial mollusks and crustaceans (oyster and lobster).	Long Island Sound Study, 2008.	
256	Shoreline types (miles/category)	Reports the miles of coastline in several categories, including: beach; mud or sand flats; steep sand, rock, or clay cliffs; wetlands; and coastline "armored" with bulkhead or riprap. The coastline includes ocean-front areas and the shoreline of estuaries and bays.	Heinz Center, 2002; Heinz Center, 2008	

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257	Shrubland Patches (Percent of grassland patches that cover a certain area)	This indicator will describe the fraction of grassland area and shrubland area that is in patches of different sizes. The total area occupied by patches of a certain size will be reported as a percentage of the total area of either grasslands or shrublands.	Heinz Center, 2002; Heinz Center, 2008	
258	Silt-Clay content of sediment	The proportion of fine grained materials (silt and clay) in the estuarine sediments.	Hayslip et al., 2006.	
259[X]	Snow influence	Share of average annual precipitation (P) that falls as snow (Ps) (i.e., snow water equivalent).	Hurd et al., 1998.	218, 260
260[X]	Snow Water Equivalent (SWE)	N/A	Lettenmaier et al., 2008.	259, 218
261	Snowmelt event dates	N/A	Lettenmaier et al., 2008.	
262	Snowmelt runoff volume	N/A	Lettenmaier et al., 2008.	
263[X]	Snowpack	N/A	Frumhoff et al., 2006; Frumhoff et al., 2007.	264
264	Snowpack	N/A	Gleick and Adams, 2000.	263
265	Snowpack density	N/A	Lettenmaier et al., 2008.	
266[X]	Snowpack depth	N/A	Lettenmaier et al., 2008.	438, 440
267	Soil Biological Condition (Percentage of croplands with variety of worms)	This indicator reports the percentage of croplands in three different ranges on the Nematode Maturity Index (NMI), an index that measures the types of roundworms, or nematodes, in the soil. Calculation of the NMI is based on the proportion of nematodes with different levels of tolerance for disturbance. A map showing the percentage of cropland in each major cropland region with low index values (indicating disturbed soils) would accompany the nationwide map.	Heinz Center, 2002; Heinz Center, 2008	

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Indicator ID#	Indicator	Definition	Literature Source *[See Appendix A for full citation]*	Duplicate
268	Soil Erosion (Percentage of U.S. farmlands prone to erosion)	This indicator reports the percentage of U.S. farmlands according to their potential for erosion by wind or water. These data are based on an index that combines information on soil characteristics, topography, and management activities such as tillage practices and whether crop residue is left on the field or not. This indicator covers croplands (excluding pastures) and Conservation Reserve Program (CRP) lands.	Heinz Center, 2002; Heinz Center, 2008	
269[x]	Soil moisture	N/A	Twilley et al., 2001.	270
270	Soil moisture	N/A	Gleick and Adams, 2000.	269
271	Soil Organic Matter (Percentage of organic matter by soil weight)	This indicator reports the amount of organic matter — partially decayed plant and animal matter —in the top 4-6 inches of cropland soil. Soil organic matter is usually measured as the percentage of organic matter (by dry weight) in the top 4-6 inches of the soil, where human activities have most influence on soil condition.	Heinz Center, 2002; Heinz Center, 2008	
272	Soil Salinity (Percentage of croplands with high salinity)	This indicator reports the percentage of cropland with different levels of salt content, measured in decisiemens per meter (dS/m). A map showing the percentage of land in each major cropland region with elevated salt levels (i.e., over 4 dS/m), would accompany the nationwide map.	Heinz Center, 2002; Heinz Center, 2008	
273	Species Status (Percent of metropolitan areas with species at risk)	This indicator reports the degree to which "original" plants and animals are either absent entirely or are at risk of being lost from metropolitan areas. Original species are those that, before European settlement, inhabited the lands now occupied by metropolitan areas. Specifically, the indicator will report on the fraction of metropolitan areas where 25% or more, 50% or more, and 75% or more of original species are at risk of being displaced or are absent.	Heinz Center, 2002; Heinz Center, 2008	
274	Spring high water	This indicator is the average high tide during a full or new moon. It approximates the boundary between tidal wetlands and dry land.	U.S. Climate Change Science Program, 2008.	
275[x]	Spring ice-out dates	This indicator reports the date at which lake ice cover ends.	Lettenmaier et al., 2008.	134, 423

Indicator ID#	Indicator	Definition	Literature Source *[See Appendix A for full citation]*	Duplicate
276	**Status of Animal Communities in Urban and Suburban Streams (Percent of urban/suburban sites with undisturbed and disturbed species)**	**This indicator reports on "biological integrity" in urban and suburban streams. Biological integrity is a measure of the degree to which the suite of fish and bottom-dwelling (or benthic) animals (including insects, worms, mollusks, and crustaceans) resemble what one might find in a relatively undisturbed stream in the same region. Tests assess the number of different species, number and condition of individuals, and food chain interactions. High scores indicate close resemblance to "reference" or undisturbed conditions, and low scores indicate significant deviation from them.**	**Heinz Center, 2002; Heinz Center, 2008**	
277	Status of Animal Species in Farmland Areas	This indicator reports the status of wildlife in farmland areas.	Heinz Center, 2002; Heinz Center, 2008	
278	Stream Bank Vegetation	This indicator describes the percentage of miles of stream (stream-miles) in urban and suburban areas that are lined with trees, shrubs, and other plants.	Heinz Center, 2002; Heinz Center, 2008	
279	**Streamflow variability (annual)**	**The coefficient of variation (CV) of unregulated streamflow is an indicator of annual streamflow variability. It is computed as the ratio of the standard deviation of unregulated annual streamflow (oQs) to the unregulated mean annual streamflow (QS)'.**	**Hurd et al., 1999.**	**413, 415**
280[x]	Streamflow variability (daily and weekly)	Trends in streamflow volumes based on daily flow data (same as "Changing Stream Flows" from (2) Heinz Center, 2002) are indicators of daily and weekly streamflow variability.	USEPA, 2008b.	281, 282
281	Streamflow variability (daily and weekly)	This indicator describes changes in the amount and timing of river and streamflow by reporting the percentage of monitored streams or rivers with major, moderate, and minimal changes in low flow, high flow, and the timing of these two extreme events. The indicator also describes the nature of major flow changes. Four subindicators were included in the analysis:	Heinz Center, 2002; Heinz Center, 2008	280, 282
282[x]	Streamflow variability (daily)	N/A	Lettenmaier et al., 2008.	280, 281

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Indicator ID#	Indicator	Definition	Literature Source [See Appendix A for full citation]	Duplicate
283[x]	Stream Habitat Quality - Farmland Streams (Presence of certain attributes compared to undisturbed streams)	This indicator describes the habitat quality of farmland streams by comparing a number of key attributes to those of relatively undisturbed streams in the same general area. The index would incorporate the presence of riffles and pools, the size of streambed sediments and the degree to which larger gravel and cobbles are buried in silt, the presence of branches, tree trunks, and other large woody pieces, and the stability of the bank.	Heinz Center, 2002; Heinz Center, 2008	284
284**	**Stream habitat quality (comparison to baseline)**	**This indicator is represented by the Rapid Bioassessment Protocol score, an index that can be used to assess the condition of underwater and bank habitats. The Rapid Bioassessment Protocol score is used to assess habitat conditions based on field observations of ten variables: epifaunal substrate/ available cover, embeddedness (for riffles) or pool substrate characterization (for pools), velocity and depth regimes (for riffles) or pool variability (for pools), sediment deposition, channel flow status, channel alteration, frequency of riffles or bends (for riffles) or channel sinuosity (for pools), bank stability (condition of banks), bank vegetative protection, and riparian vegetated zone width.***	**Heinz Center, 2002; Heinz Center, 2008**	**283**
285	Streamflow (discharge)	Discharge data from a national network of stream gages	National Assessment Synthesis Team, 2000a.	549
286	Submerged Aquatic Vegetation (SAV)	Rooted aquatic plants that support the health of ecosystems by generating food and habitat for waterfowl, fish, shellfish, and invertebrates.	USEPA, 2008b.	
287	Suburban/Rural Land Use Change	This indicator describes the pattern and intensity, or density, of development, both at the outer edge of suburban development around cities, and in rural areas that, despite the lack of a large town center, are growing rapidly toward suburban densities.	Heinz Center, 2002; Heinz Center, 2008	
288	Suspended solids (total, 4 substances)	Suspended materials include soil particles (clay and silt), algae, plankton, and other substances. Total suspended solids (TSS) refer to the matter that is suspended in water.	Hayslip et al., 2006.	
289	Temperature (average annual)	Mean annual temperature.	Gleick and Adams, 2000.	

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290	Temperature (average daily)	N/A	Kling et al., 2003 using data from Wuebbles and Hayhoe, 2003.	
291	Temperature -streams	N/A	Lettenmaier et al., 2008.	
292	Thermal sensitivity (changes in extremes)	This indicator is based on the sensitivity to changes in extreme temperatures. It combines the vulnerability of two sub-indicators: (1) heat (the average annual number of days with maximum temperatures exceeding 35 degrees C) and (2) cold (the average annual number of days with average temperatures below O degrees C).	Hurd et al., 1999.	
293	Tidal wetlands area	N/A	Chesapeake Bay Program, 2008.	
294	Timber Growth and Harvest - Private (Volume of timber harvested vs. grown over time)	This indicator reports the annual amount of new wood grown and the annual amount of wood harvested on public and private timberlands, by region.	Heinz Center, 2002; Heinz Center, 2008	
295	Timber Harvest - By Region (Volume of timber over time)	This indicator reports trends in timber harvest, by regions East and West, and by primary product category (sawlogs, pulpwood, etc.).	Heinz Center, 2002; Heinz Center, 2008	
296	Timber Harvest - By Use: Fuelwood (Volume of timber over time)	This indicator reports trends in timber harvest, by region and by primary product category (sawlogs, pulpwood, etc.).	Heinz Center, 2002; Heinz Center, 2008	
297	Timber Harvest - By Use: Logging Residues/Other (Volume of timber over time)	This indicator reports trends in timber harvest, by region and by primary product category (sawlogs, pulpwood, etc.).	Heinz Center, 2002; Heinz Center, 2008	
298	Timber Harvest - By Use: Other Products (Volume of timber over time)	This indicator reports trends in timber harvest, by region and by primary product category (sawlogs, pulpwood, etc.).	Heinz Center, 2002; Heinz Center, 2008	

Indicator ID#	Indicator	Definition	Literature Source *[See Appendix A for full citation]*	Duplicate
299	Timber Harvest - By Use: Pulpwood (Volume of timber over time)	This indicator reports trends, by region, in the harvest of pulpwood.	Heinz Center, 2002; Heinz Center, 2008	
300	Timber Harvest - By Use: Sawlogs (Volume of timber over time)	This indicator reports trends, by region, in the harvest of sawlogs.	Heinz Center, 2002; Heinz Center, 2008	
301	Timber Harvest - By Use: Veneer logs (Volume of timber over time)	This indicator reports trends, by region, in the harvest of veneer logs.	Heinz Center, 2002; Heinz Center, 2008	
302	Topography/Elevation (LIDAR)	This indicator includes: (1) Light Detection and Ranging (LIDAR) mapping, and (2) shallow water-penetrating LIDAR.	Coastal States Organization, 2007.	
303	Total Impervious Area (Percent of urban/suburban areas having a certain amount of impervious area)	This indicator classifies urban and suburban areas according to their percentage of impervious surface (e.g., roads, parking lots, driveways, sidewalks, rooftops, etc.). The indicator uses several thresholds: less than 10% impervious surface in the region, at least 10%, at least 20%, and at least 30%.	Heinz Center, 2002; Heinz Center, 2008	
304	Trophic state	This indicator integrates water clarity, phosphorus concentration, and chlorophyll a.	USEPA, 1995.	
305	Trophic state (coastal waters)	This indicator refers to aspects of aquatic systems associated with the growth of algae, decreasing water transparency, and lowering oxygen levels in the lower water column that can harm fish and other aquatic life.	USEPA, 2008b.	
306	Tropical storm frequency	Frequency and intensity of tropical storms (current and predicted with climate change)	Day et al., 2007.	
307	Unusual marine mortalities	Unusual mortality events (UME) are characterized by an abnormal number of dead animals or by the appearance of dead animals in locations or at times of the year that are not typical for that species.	Heinz Center, 2002; Heinz Center, 2008	

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Indicator ID#	Indicator	Definition	Literature Source *[See Appendix A for full citation]*	Duplicate
308	Urban and Suburban Areas (extent/acreage)	This indicator presents the extent/acreage of urban and suburban areas as a percentage of the total U.S. land area, for the most recent 50-year period and compared to pre-settlement estimates. It also reports on a key component of freshwater ecosystems (freshwater wetlands) and will report on the area of brackish water, a key component of coastal and ocean ecosystems when data become available.	Heinz Center, 2002; Heinz Center, 2008	
309	Urban and Suburban Lands - By Region (Area covered by urban/suburban lands by region)	This indicator reports the extent of urban and suburban lands, in acres.	Heinz Center, 2002; Heinz Center, 2008	
310	Urban and Suburban Lands - By Region (Percent area covered by urban/suburban lands by region)	This indicator reports the extent of urban and suburban lands as a percentage of all land area in a region.	Heinz Center, 2002; Heinz Center, 2008	
311	Urban and Suburban Lands - Composition of Undeveloped Urban and Suburban Lands (Percent area of undeveloped lands by region)	This indicator reports on the extent and composition of undeveloped lands, such as wetlands, croplands, forest, or grassland and shrubland, contained within urban and suburban areas.	Heinz Center, 2002; Heinz Center, 2008	
312	Urban Heat Island (Percent of metropolitan areas with having certain differences in air temperature between rural and urban areas)	This indicator describes the difference between urban and rural air temperatures for major U.S. metropolitan areas. Temperatures within urban areas will be compared to those in less-developed surrounding areas.	Heinz Center, 2002; Heinz Center, 2008	
313	Vegetative cover -riparian (area of 3 classes)	This indicator reports the sum of the amount of woody cover provided by three layers of riparian vegetation: the ground layer, woody shrubs, and	USEPA, 2006b.	

Indicator ID#	Indicator	Definition	Literature Source *[See Appendix A for full citation]*	Duplicate
		canopy trees.		
314	Water Availability: Streamflow per Capita (Vulnerability of Domestic Water Uses)	A measure estimating per capita water availability based on per capita average annual streamflow (QS). Method of calculation: 1. QS/pop.	Hurd et al., 1998.	
315	Water Clarity	This indicator reports the percentage of lake and reservoir area with low-, medium-, and high-clarity water. (Ponds are not included because of their shallow depth.)	Heinz Center, 2002; Heinz Center, 2008	316, 317
316[x]	Water Clarity (secci, remote sensing)	This indicator presents correlations between water clarity, as measured by the Secchi disk, and light in the blue and red bands of the spectrum reflected from lake water surfaces and measured as "brightness" by satellite sensors.	Brezonik et al., 2007.	315, 317
317[x]	Water clarity (secci, transmitivity)	Light transmitivity, secci depth.	Hayslip et al., 2006.	315, 316
318	**Water Clarity Index (real vs. reference)**	**Water clarity index (WCI) is calculated by dividing observed clarity at 1 meter by a regional reference clarity at 1 meter. This regional reference is 10% for most of the U.S., 5% for areas with naturally high turbidity, and 20% for areas with significant submersed aquatic vegetation (SAV) beds or active SAV restoration programs. Good: WCI ratio is >2. Fair: WCI ratio is between 1 and 2. Poor: WCI ratio < 1.**	**USEPA, 2006a.**	
319	**Water Quality Index (5 components)**	**This indicator is based on 5 water quality component indicators (DIN, DIP, chlorophyll a, water clarity, and dissolved oxygen).**	**USEPA, 2006a.**	
320	Water use to storage	This indicator is the ratio of total annual average surface and groundwater withdrawals in 1990 (Qw) to total active basin storage (S). Method of calculation: QW/S.	Hurd et al., 1998.	
321	Water withdrawals	This indicator reports the total amount of surface water and groundwater withdrawn for use in the municipal, rural, industrial, thermoelectric, and	Heinz Center, 2002; Heinz Center, 2008	447

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Indicator ID#	Indicator	Definition	Literature Source *[See Appendix A for full citation]*	Duplicate
		irrigation sectors.		
322	**Waterborne human disease outbreaks (events)**	**This indicator reports the number of disease outbreaks (i.e., at least two people getting sick) attributed to drinking water that is untreated or where treatment has failed to remove disease-causing organisms, or to swimming or other recreational contact at lakes, streams, and rivers.**	**Heinz Center, 2002; Heinz Center, 2008**	
323	Watershed forest cover (area)	N/A	Chesapeake Bay Program, 2008.	
324	Wetland Extent, Change, and Sources of Change	N/A	USEPA, 2008b.	
325	**Wetland loss**	**Rate or total extent of wetland loss relative to original extent of wetland.**	**MEA, 2005b.**	
326**	**Wetland species at risk (number of species)**	**Number of wetland and freshwater species at risk, either threatened or endangered. ***	**Hurd et al., 1999.**	
327	Wetlands, Lakes, Reservoirs, and Ponds (extent, acreage)	This indicator reports the area of wetlands and lakes, reservoirs, and ponds and the length of small, medium, and large streams and rivers.	Heinz Center, 2002; Heinz Center, 2008	
328	**Ratio of water use to safe yield**	**Safe yield provides an estimate of the maximum quantity of water that can be withdrawn during an extended dry period without depleting the source beyond its ability to be replenished in naturally 'wet years.' It is measured as the water balance of inflows, usable storage, and evapotranspiration determined between Jun-Oct in a median year, using an 80% likelihood of water level recovery by the following spring. This indicator reports the ratio of water use to safe yield.**	**Schmitt et al., 2008.**	
329	Percent urbanized	N/A	Schmitt et al., 2008.	

Indicator ID#	Indicator	Definition	Literature Source *[See Appendix A for full citation]*	Duplicate
330	Summer retail sales	N/A	Schmitt et al., 2008.	
331	Seasonal housing	N/A	Schmitt et al., 2008.	
332	Peak drinking water use	Peak drinking water use at individual public water systems.	Schmitt et al., 2008.	
333	nitrate in drinking water	Percent of public water systems (PWSs) nationally with at least one compliance monitoring sample detection of nitrate at a concentration greater than one-half the nitrate drinking water standard.	USEPA, 2008d.	
334	select pesticides in drinking water	Percent of PWSs nationally with at least one detection of alachlor, atrazine, carbofuran, endothall, and/or simazine at a concentration greater than one-half the respective drinking water standard.	USEPA, 2008d.	
335	Total Trihalomethanes (TTHMs) in drinking water	Percent of PWSs nationally with at least one compliance monitoring sample detection of Total Trihalomethanes (TTHMs, disinfection byproducts) greater than one-half the TTHM drinking water standard. TTHMs include chloroform, bromodichloromethane, dibromochloromethane, and bromoform.	USEPA, 2008d.	
336	Cyanotoxins (the 3 on the Contaminant Candidate List 3 or CCL3) in drinking water	Percent of PWSs sites with at least one detection of one of the three cyanotoxins.	USEPA, 2008d.	
337[X]	Dissolved oxygen concentration	N/A	Murdoch et al., 2000.	71, 72, 73, 74, 75, 131
338	Lake stratification timing	The occurrence and timing of thermal stratification in lakes.	Murdoch et al., 2000.	
339	Lake volume	N/A	Murdoch et al., 2000.	

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340	Ice cover duration	N/A	Murdoch et al., 2000.	
341	Metabolic rate	Rates of productivity, decomposition, and chemical reactions in surface waters	Murdoch et al., 2000.	
342	Epilimnion volume	Volume of the upper mixed layer in stratified lakes.	Murdoch et al., 2000.	
343	Hypolimnion temperature	Temperature of the bottom water in stratified lakes.	Murdoch et al., 2000.	153
344	Permafrost and glacial extent	N/A	Murdoch et al., 2000.	
345	Solute concentration	Concentrations of dissolved materials in water	Murdoch et al., 2000.	76
346	Surface water extent	Areal extent of surface waters	Murdoch et al., 2000.	
347	Dominant flowpath	Relative importance of various hydrological pathways (i.e., surface runoff, shallow subsurface flow, deep groundwater flow)	Murdoch et al., 2000.	
348**	**Erosion rate**	**Rate of soil erosion from watershed lands**	**Murdoch et al., 2000.**	
349	Water clarity	N/A	Murdoch et al., 2000.	
350	Water residence time	Rate of water inflow to and outflow from a water body	Murdoch et al., 2000.	
351**	**Instream use/total streamflow**	**Ratio of instream use to total streamflow. Method of calculation: (Instream flow requirements to meet the needs of fish and wildlife)/(1975 streamflow + 1975 consumption - 1975 groundwater overdraft)**	**Meyer et al., 1999.**	
352**	**Total use/total streamflow**	**Method of calculation: (Instream flow requirements to meet the needs of fish and wildlife + 1975 consumption)/(1975 streamflow + 1975 consumption - 1975 groundwater overdraft)**	**Meyer et al., 1999.**	
353	Flow regime	This indicator is a composite of several measurable streamflow variables, including magnitude, frequency, duration, seasonal timing, and rate of change of flows	Meyer et al., 1999.	

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Indicator ID#	Indicator	Definition	Literature Source *[See Appendix A for full citation]*	Duplicate
354	Broad geographic region	Regions are Arctic and subarctic North America, Laurentian Great Lakes and Precambrian Shield, Rocky Mountains, Mid Atlantic and New England, Southeastern US, Pacific Coast and Western Great Basin, Great Plains, Arid Southwest	Meyer et al., 1999.	
355	Cyanobacteria abundance	Relative abundance of cyanobacteria in phytoplankton as characterized by photopigments. High performance liquid chromatography (HPLC), coupled to photodiode array spectrophotometry (PDAS).	Paerl et al., 2003.	
356	Enterococci abundance	Number of colony forming units of enterococcal bacteria per volume of water.	Paerl et al., 2003.	
357	Peatland extent	Extent or density of peatland.	Burkett and Kusler, 2000.	
358	Isolated wetland extent	Extent or density of isolated wetlands (alpine wetlands, prairie potholes).	Burkett and Kusler, 2000.	
359	Water quality criteria	Water quality criteria are developed for specific chemicals to evaluate whether a water body is supporting aquatic life uses. Such criteria describe the minimum level of water quality necessary to allow a use to occur. EPA has developed water quality criteria for 157 pollutants to protect a variety of water body uses.	USEPA, 2002.	
360[X]	Vulnerability to floods	Percent of population that lives in floodplains.	Intergovernmental Panel on Climate Change, 2007.	209
361	**Snowmelt reliance**	**Dependence of water uses on seasonal melting of snow and/or glaciers.**	**Intergovernmental Panel on Climate Change, 2007.**	
362	Pesticide concentration	Pesticide concentration in surface water, groundwater, bed sediments, or fish tissue relative to a health benchmark (human or aquatic life). Acute and chronic benchmarks have been determined for most commonly used pesticides.	Gilliom et al., 2006.	
363	Predicted pesticide concentration	Predicted pesticide concentration for selected pesticides (atrazine, dieldrin). The indicator values are predicted by a regression model.	Gilliom et al., 2006.	

Indicator ID#	Indicator	Definition	Literature Source *[See Appendix A for full citation]*	Duplicate
364**	**Pesticide toxicity index**	**The Pesticide Toxicity Index (PTI) accounts for multiple pesticides in a sample, including pesticides without established benchmarks for aquatic life. The PTI combines information on exposure of aquatic biota to pesticides (measured concentrations of pesticides in stream water) with toxicity estimates (results from laboratory toxicity studies) to produce a relative index value for a sample or stream. The PTI value is computed for each sample of stream water by summing the toxicity quotients for all pesticides detected in the sample. The toxicity quotient is the measured concentration of a pesticide divided by its toxicity concentration from bioassays (such as an LC50 or EC50).**	**Gilliom et al., 2006.**	
365	Groundwater contribution to baseflow	Proportion of baseflow in streams that is contributed by groundwater discharge	Hayashi and Rosenberry, 2002.	
366	Phosphorus concentration -streams (total)	Average annual concentration of total phosphorus (in milligrams per liter).	USGS, 1999.	
367**	**Herbicide concentrations in streams (Percent of streams with highest concentration)**	**Average concentrations of herbicides in US streams. ***	**USGS, 1999.**	
368	Herbicides Use (Weight per unit of agricultural land)	Herbicide use in pounds, per acre of agricultural land.	USGS, 1999.	
369**	**Insecticide concentrations in streams (Percent of streams with highest concentration)**	**Average concentrations of insecticides in US streams. ***	**USGS, 1999.**	
370	Insecticide Use (Weight per unit of agricultural land)	Insecticide use in pounds, per acre of agricultural land.	USGS, 1999.	

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Indicator ID#	Indicator	Definition	Literature Source [See Appendix A for full citation]	Duplicate
371**	**Organochlorines in Bed Sediment (Percent of streams with highest concentration)**	**Average concentrations of organochlorines in bed sediments. ***	**USGS, 1999.**	
372	Organochlorines Use (Weight per unit of agricultural land)	Organochlorines use in pounds, per acre of agricultural land.	USGS, 1999.	
373**	**Herbicides in Groundwater (Percent of aquifers with highest concentration)**	**Average concentrations of herbicides in shallow groundwater and aquifers. ***	**USGS, 1999.**	
374**	**Insecticides in Groundwater (Percent of aquifers with highest concentration)**	**Average concentrations of insecticides in shallow groundwater and aquifers. ***	**USGS, 1999.**	
375	Occurrence of One or More VOCs in Aquifers (Concentration detected by aquifer)	Detection of VOCs in aquifer samples demonstrates the vulnerability of many of the Nation's aquifers to VOC contamination.	Zogorski et al., 2006.	
376	Occurrence of One or More VOCs in Aquifers - by Aquifer Study (Percent of aquifer studies with detects)	Percentage of the 98 aquifer studies conducted as part of the Study-Unit investigations that had detections of one or more VOCs at an assessment level of 0.2 µg/L.	Zogorski et al., 2006.	
377	Occurrence of One or More VOCs in Aquifers - by Principal Aquifer (Percent of aquifers with detects)	Detection frequencies, expressed as a percentage, by principal or other aquifer, of one or more VOCs at an assessment level of 0.2 µg/L.	Zogorski et al., 2006.	

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378	Occurrence of One or More VOCs in Aquifers - by Aquifer Lithology (Percent of detects per aquifer type)	Detection frequencies, expressed as a percentage, by aquifer lithology category, of one or more VOCs at an assessment level of 0.2 µg/L.	Zogorski et al., 2006.	
379	Occurrence of VOC Groups in Aquifers (Percent of aquifers with detects)	Detection frequencies, expressed as a percentage, for various VOC groups at assessment levels of 0.2 µg/L and 0.02 µg/L.	Zogorski et al., 2006.	
380	Occurrence of Individual VOCs in Aquifers	Detection frequencies, expressed as a percentage, for various VOCs at assessment levels of 0.2 µg/L and 0.02 µg/L. The 15 most frequently detected VOCs represent most of the use groups and include 7 solvents, 4 THMs, 2 refrigerants, 1 gasoline oxygenate, and 1 gasoline hydrocarbon.	Zogorski et al., 2006.	
381	Population Served by Domestic Wells (Percent of population relying on domestic wells for drinking water)	Domestic wells are privately owned, self-supplied sources for domestic water use.	Zogorski et al., 2006.	
382	Population Served by Public Wells (Percent of population relying on public wells for drinking water)	Public wells are privately or publicly owned and supply ground water for PWSs. As defined by the USEPA, PWSs supply drinking water to at least 15 service connections or regularly serve at least 25 individuals daily at least 60 days a year.	Zogorski et al., 2006.	
383	Pesticide detection frequency	Atrazine, DEA, metolachlor, prometon, and simazine were "were detected with sufficient frequency to perform statistical analysis of temporal changes in both detection frequency and concentration."	Bexfield, 2008.	
384	Playas (shallow ephemeral lakes)	The existence of lakes in these valleys depends on local (watershed) precipitation, playa surface evaporation and, except in endorheic basins (especially prevalent in the Great Basin and north-central Mexico), alluvial hydrological drainage.	Grimm et al., 1997.	

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385	Ecosystem thermal regime (latitude, shift in miles)	N/A	Poff et al., 2002.	
386	Migration corridor restriction	Dams and reservoirs, deforestation, diversion of water for offstream uses such as irrigation and urban development.	Poff et al., 2002.	
387	Thermal - Habitat suitable for trout	N/A	Poff et al., 2002.	
388	Stream baseflow (summer)	Water in stream channel.	Poff et al., 2002.	
389	Wetland hydroperiod	Patterns of water depth, and the duration, frequency, and seasonality of flooding.	Poff et al., 2002.	
390	Fens (area, abundance)	Groundwater-dominated wetlands	Poff et al., 2002.	
391	**Salinity intrusion (coastal wetlands)**	**N/A**	**Poff et al., 2002.**	
392	**Heat-Related Illnesses Incidence**	**N/A**	**Ebi et al., 2007.**	
393	Populations at Increased Risk - Older and Younger Age Groups	Heat-related mortality in individuals over 65 years of age, and in babies and infants.	Ebi et al., 2007.	
394	Populations at Increased Risk - Using of Certain Drugs	Certain drugs (such as stimulants, beta-blockers, anticholinergics, digitalis, and barbiturates) interfere with the body's ability to cope with high temperatures.	Ebi et al., 2007.	
395	Populations at Increased Risk - Dehydrated Individuals	Populations of individuals that have a tendency to consume fewer non-alcoholic fluids.	Ebi et al., 2007.	

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396	Populations at Increased Risk - Individuals with Low Fitness	N/A	Ebi et al., 2007.	
397	Populations at Increased Risk - Individuals Who Engage in Excessive Exertion	Outdoor workers and those who maintain a vigorous exercise regimen during a heat wave are particularly at risk.	Ebi et al., 2007.	
398	Populations at Increased Risk - Individuals Who Are Overweight	N/A	Ebi et al., 2007.	
399	Populations at Increased Risk - Reduced Adjustment to High Outdoor Temperatures	N/A	Ebi et al., 2007.	
400	Populations at Increased Risk - Urban Populations	N/A	Ebi et al., 2007.	
401	Populations at Increased Risk - Individuals with Lower Socio-economic Status	N/A	Ebi et al., 2007.	
402	Populations at Increased Risk - Individuals Living Alone	N/A	Ebi et al., 2007.	
403	Temperature Increases	Impact of increased temperature on hypoxia in wetlands.	Ebi et al., 2007.	
404	Precipitation Increases	Impact of increased precipitation on hypoxia in wetlands.	Ebi et al., 2007.	
405[x]	Sea level rise	Impact of increased sea level rise on hypoxia in wetlands.	Ebi et al., 2007.	228, 229, 241, 412

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Indicator ID#	Indicator	Definition	Literature Source [See Appendix A for full citation]	Duplicate
406	Strength of Summer Wind	Impact of stronger summer winds on hypoxia in wetlands.	Ebi et al., 2007.	
407	Hurricane Intensity	N/A	Ebi et al., 2007.	
408	Hurricane Frequency	N/A	Ebi et al., 2007.	
409	Frequency and Magnitude of El Niño/Southern Oscillation (ENSO)	N/A	Ebi et al., 2007.	
410	Peak Flows	N/A	Ebi et al., 2007.	
411	Intensity of Rainfall	N/A	Ebi et al., 2007.	
412[X]	Sea level rise	N/A	Ebi et al., 2007.	228, 229, 241, 405
413[X]	Streamflow Variability (annual)	Annual minimum, median, and maximum daily streamflow values for 1941-1999 at 400 sites in the coterminous U.S. considered to have natural streamflow.	McCabe and Wolock, 2002.	279, 415
414	Days of 99th Percentile Flow	Number of days per year that meet or exceed 99th percentile streamflow values for 1941-1999 at 400 sites in the coterminous U.S. considered to have natural streamflow. 99th percentile flow value calculated for each site from HCDN streamflow data. 99th percentile value = 0.99 (highest flow value for site during period of record).	McCabe and Wolock, 2002.	
415[X]	Streamflow Variability (annual min, med, max value)	Annual minimum, median, and maximum daily streamflow values from 1940-1999 at 435 sites in the coterminous U.S. and southeastern Alaska considered to have natural streamflow.	Lins and Slack, 2005.	279, 413
416	Seasonal Streamflow Timing (Month of annual min, med, max)	Month of the annual minimum, median, and maximum streamflows for 1940-1999 at 435 sites in the coterminous U.S. and southeastern Alaska considered to have natural streamflow.	Lins and Slack, 2005.	421

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417	Center of Volume Date	Date by which half of the total water volume for a time period has gone by a river gauging station. Time periods were winter/spring (Jan 1 to May 31) and fall (Oct 1 to Dec 31). Analyzed for 27 rural, unregulated river gauging stations in New England with an average of 68 years of record. Winter/spring center of volume date = WSCV.	Hodgkins et al., 2003.	
418	Peak Flow Date	Date of the highest daily mean flow within a season: winter/spring (Jan 1 to May 31) and fall (Oct 1 to Dec 31). Analyzed at 27 rural, unregulated river gauging stations in New England with an average of 68 years of record.	Hodgkins et al., 2003.	
419	Ratio of Seasonal to Annual Flow	N/A	Hodgkins et al., 2003.	
420	Magnitude of Monthly Flows	N/A	Hodgkins et al., 2003.	
421[x]	Timing of Seasonal Peak Flows	N/A	Hodgkins et al., 2003.	416
422	Median Total Seasonal Snowfall	The median accumulation of snow (usually in units of height) over a particular snow season.	Hodgkins et al., 2003.	
423	Lake Ice-Out Date	Lake ice-out dates are the dates of ice break-up, i.e. the annual dates in spring when winter ice cover leaves a lake.	Hodgkins et al., 2003.	134, 275
424	Monthly Average Streamflow	Daily streamflow data averaged into monthly time series data for 37 sites in New England considered to have natural streamflow.	Bradbury et al., 2002.	
425	Winter Average Streamflow	Daily streamflow data averaged into winter seasonal streamflow data for 37 sites in New England considered to have natural streamflow.	Bradbury et al., 2002.	
426	Winter Average Temperature	Monthly divisional temperature averaged into "winter average temperature" values for the period 1895-1999.	Bradbury et al., 2002.	
427	Winter Average Precipitation	Monthly divisional precipitation averaged into "winter average precipitation" values for the period 1895-1999.	Bradbury et al., 2002.	
428	Surface Air Temperature	N/A	Bradbury et al., 2002.	

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429	Storm-Track Patterns	Spatial variations in the paths followed by centers of low atmospheric pressure.	Bradbury et al., 2002.	
430	Snowfall Variability	N/A	Bradbury et al., 2002.	
431	Tree-Ring Chronology	N/A	Bradbury et al., 2002.	
432	Diurnal Range of Surface Air Temperature (DTR)	The difference between the daytime maximum temperature and the nighttime minimum temperature for a 15 km by 15 km site on the Konza Prairie near Manhattan, KS, in 1987-1989.	Dai et al., 1999.	
433	Daily Mean Cloud Cover	The daily average amount of the sky covered by clouds (reported in eighths or oktas of sky covered) for a 15 km by 15 km site on the Konza Prairie near Manhattan, KS, in 1987-1989.	Dai et al., 1999.	
434	Top 5-cm Soil Moisture Content	The moisture content of the top 5 cm of soil for a 15 km by 15 km site on the Konza Prairie near Manhattan, KS, in 1987-1989.	Dai et al., 1999.	
435	Surface Specific Humidity	The ratio of the mass of water vapor within a given mass of air near the Earth's surface (reported in g of water vapor per kg of air at specified temperature) for a 15 km by 15 km site on the Konza Prairie near Manhattan, KS, in 1987-1989.	Dai et al., 1999.	
436	Dew Point	The temperature to which a given unit of air must be cooled (at constant pressure) in order for vapor to condense into water.	Roderick and Farquhar, 2002.	
437**	**Precipitation Elasticity of Streamflow**	**The proportional change in streamflow (Q) divided by the proportional change in precipitation (P) for 1,291 gauged watersheds across the continental US.**	**Sankarasubramanian et al., 2001.**	
438	Snowpack Depth	The regional average snowpack depth, in inches.	Sankarasubramanian et al., 2001.	266, 440
439	Concentration of Particulate and Colored Dissolved Organic Material (CDOM)	Concentration of pigmented compounds, dissolved in a waterbody that derives from organic material.	Warwick and Pienitz, 2006.	

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440[x]	Snowpack Depth (2)	Regional snowpack for the Western United States.	Barnett, et al., 2005.	266, 438
441	Aerosols	The amount of aerosol pollution (particulate matter) in a unit of air.	Barnett, et al., 2005.	
442	Water withdrawals: Public Supply (Volume of water used per day)	Volume of water consumed in the public supply per day. This is different from water withdrawals, as one of the largest uses of water is for cooling of thermoelectric power plants, and much of that water is returned to the streams from which it is withdrawn (use of water for hydroelectric power generation, virtually none of which is consumptively used, is not included in this category). On the other hand, a much higher fraction of the water withdrawn for irrigation is consumptively used.	Lettenmaier et al., 2008.	
443	Water withdrawals: Rural Domestic and Livestock (Volume of water used per day)	Volume of water consumed by rural domestic and livestock per day. This is different from water withdrawals, as one of the largest uses of water is for cooling of thermoelectric power plants, and much of that water is returned to the streams from which it is withdrawn (use of water for hydroelectric power generation, virtually none of which is consumptively used, is not included in this category). On the other hand, a much higher fraction of the water withdrawn for irrigation is consumptively used.	Lettenmaier et al., 2008.	
444	Water withdrawals: Irrigation (Volume of water used per day)	Volume of water consumed for irrigation purposes per day. This is different from water withdrawals, as one of the largest uses of water is for cooling of thermoelectric power plants, and much of that water is returned to the streams from which it is withdrawn (use of water for hydroelectric power generation, virtually none of which is consumptively used, is not included in this category). On the other hand, a much higher fraction of the water withdrawn for irrigation is consumptively used.	Lettenmaier et al., 2008.	150
445	Water withdrawals: Thermoelectric Power (Volume of water used per day)	Volume of water consumed for thermoelectric power generation per day. This is different from water withdrawals, as one of the largest uses of water is for cooling of thermoelectric power plants, and much of that water is returned to the streams from which it is withdrawn (use of water for hydroelectric power generation, virtually none of which is consumptively used, is not included in this category). On the other hand, a much higher fraction of the water withdrawn for irrigation is consumptively used.	Lettenmaier et al., 2008.	

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Indicator ID#	Indicator	Definition	Literature Source [See Appendix A for full citation]	Duplicate
446	Water withdrawals: Other Industrial Uses (Volume of water used per day)	Volume of water consumed for other industrial uses per day. This is different from water withdrawals, as one of the largest uses of water is for cooling of thermoelectric power plants, and much of that water is returned to the streams from which it is withdrawn (use of water for hydroelectric power generation, virtually none of which is consumptively used, is not included in this category). On the other hand, a much higher fraction of the water withdrawn for irrigation is consumptively used.	Lettenmaier et al., 2008.	
447[X]	Water withdrawals: Total (Volume of water used per day)	The data compiled by the USGS are somewhat limited in that they are for water withdrawals, rather than consumptive use. The distinction is important, as one of the largest uses of water is for cooling of thermoelectric power plants, and much of that water is returned to the streams from which it is withdrawn (use of water for hydroelectric power generation, virtually none of which is consumptively used, is not included in this category). On the other hand, a much higher fraction of the water withdrawn for irrigation is consumptively used.	Lettenmaier et al., 2008.	321
448	Extent of reservoir storage (Volume of water stored per area)	N/A	Lettenmaier et al., 2008.	
449**	**Ratio of reservoir storage to mean annual flow (Volume of water stored per unit flow)**	**A small storage-to-runoff ratio usually indicates that the reservoir is primarily used to shape within-year variations in runoff, and a large storage-to-runoff value usually indicates that the reservoir is primarily used to smooth interannual variations in runoff. ***	**Lettenmaier et al., 2008.**	
450	Precipitation (variability)	Variability of mean annual precipitation, expressed as the Coefficient of Variation, C sub v (the standard deviation divided by the mean), for the continental U.S.	Lettenmaier et al., 2008.	
451	Runoff Ratio	Annual mean runoff divided by annual mean precipitation, for the continental U.S. and Alaska.	Lettenmaier et al., 2008.	
452	Snow to runoff ratio	Ratio of maximum mean snow accumulation to mean annual runoff, for the continental U.S. and Alaska.	Lettenmaier et al., 2008.	

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Indicator ID#	Indicator	Definition	Literature Source *[See Appendix A for full citation]*	Duplicate
453**	**Runoff (variability)**	**Variability of annual runoff, expressed as the Coefficient of Variation, C sub v (the standard deviation divided by the mean), for the continental U.S. and Alaska.**	**Lettenmaier et al., 2008.**	
454	Runoff (variability - persistence)	Variability of annual runoff, expressed as the "lag one" correlation coefficient, for the continental U.S. This correlation coefficient reflects the correlation between two values of the same variable (i.e. runoff) at different points in time.	Lettenmaier et al., 2008.	
455	Variability of April-Sept. streamflow	Variability of April-Sept. streamflow at 141 unregulated sites across the Western U.S.	Lettenmaier et al., 2008.	
456	Incidence of "surplus" flow days	Number of days with flows above a station-dependent surplus threshold, for 42 HCDN sites in the central and southern U.S.	Lettenmaier et al., 2008.	
457	Length of snow season	Length of the snow season in the Ohio Valley over the second half of the 20th century.	Lettenmaier et al., 2008.	
458	Warm Season Surface Water Supply	Defined as precipitation minus potential evapotranspiration, for several sites on the Arctic coastal plain over the past 50 years.	Lettenmaier et al., 2008.	
459	Phosphorus and nitrogen concentration	Concentrations of total P and N from 1975 to 1994 at 250 river sites with drainages greater than 1000 square kilometers.	Lettenmaier et al., 2008.	186
460**	**Macroinvertebrate Index of Biotic Condition**	**Total index score is the sum of scores for a variety of individual measures, also called indicators or metrics. The metrics used to develop the Macro-invertebrate Index for the WSA covered six different characteristics of macroinvertebrate assemblages that are commonly used to evaluate biological condition: taxonomic richness, taxonomic composition, taxonomic diversity, feeding groups, habits, and pollution tolerance. Each metric was scored and then combined to create an overall Macroinvertebrate Index for each region, with values ranging from 0 to 100. ***	**USEPA, 2006b.**	

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Indicator ID#	Indicator	Definition	Literature Source [See Appendix A for full citation]	Duplicate
461**	**Macroinvertebrate Observed/Expected (O/E) Ratio of Taxa Loss**	The Macroinvertebrate O/E Ratio of Taxa Loss (henceforth referred to as O/E Taxa Loss) measures a specific aspect of biological health: taxa that have been lost at a site. The taxa expected (E) at individual sites are predicted from a model developed from data collected at least-disturbed reference sites; thus, the model allows a precise matching of sampled taxa with those that should occur under specific, natural environmental conditions. By comparing the list of taxa observed (O) at a site with those expected to occur, the proportion of expected taxa that have been lost can be quantified as the ratio of O/E.	**USEPA, 2006b.**	**569, 32**
462	**Coastal Benthic Communities**	This indicator is based on a multi-metric benthic communities index that reflects overall species diversity in estuarine areas throughout the contiguous United States (adjusted for salinity, if necessary) and, for some regions, the presence of pollution-tolerant and pollution-sensitive species. The benthic community condition at each sample site is given a high score if the index exceeds a particular threshold (e.g., has high diversity or populations of many pollution-sensitive species), a low score if it falls below the threshold conditions, and a moderate score if it falls within the threshold range.	**USEPA, 2008b.**	
463[X]	Alien or Invasive Plant Species	N/A	USEPA, 2008a.	143
464	Native Plant Species & Genera	N/A	USEPA, 2008a.	
465	Plant Species Diversity	N/A	USEPA, 2008a.	
466	Percent Similarity of Plant Species Composition to Reference Standard	N/A	USEPA, 2008a.	
467	**Threatened & Endangered Plant Species**	**N/A**	**USEPA, 2008a.**	**22**
468	Graminoid Taxa	N/A	USEPA, 2008a.	

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469	Dominant Plant Taxa	N/A	USEPA, 2008a.	
470	Dicot and Monocot Species	N/A	USEPA, 2008a.	
471	Woody Species	N/A	USEPA, 2008a.	
472	Seedless Vascular Plants (Ferns & Fern Allies)	N/A	USEPA, 2008a.	
473	Nonvascular Plants/Bryophytes	N/A	USEPA, 2008a.	
474	Overall Floristic Quality - Floristic Quality Assessment Indices (FQAI) and Coefficients of Conservatism (CC)	FQAI use species-specific CCs that reflect the tendency of a species to occur in pristine vs. disturbed habitats. Intact native plant communities in relatively undisturbed sites will have high FQAI scores.	USEPA, 2008a.	
475	**Vegetation Indices of Biotic Integrity (IBI)**	**IBI use relationships of plant species, plant communities, plant guilds, vegetation structure, etc. to anthropogenic disturbance and stress to describe wetland condition. Typically, the highest IBI values represent reference standards or least-disturbed ecological conditions.**	**USEPA, 2008a.**	
476	Other Indices of Vegetation Condition	N/A	USEPA, 2008a.	
477	PFG Composition - Nutrient Functional Groups	Composition of plant functional groups (PFG) based on nutrient properties.	USEPA, 2008a.	
478	PFG Composition - Sediment Functional Groups	Composition of PFG based on sediment properties.	USEPA, 2008a.	
479	PFG Composition - Growth Habit/Canopy Architecture	Composition of PFG based on growth habit (tap-rooted, stoloniferous, rhizomatous, matrix interstitial, etc.).	USEPA, 2008a.	

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Indicator ID#	Indicator	Definition	Literature Source [See Appendix A for full citation]	Duplicate
480	PFG Composition - Sensitive Species	Composition of PFG based on species with high coefficients of conservatism.	USEPA, 2008a.	
481	PFG Composition - Tolerant Species	Composition of PFG based on species with low coefficients of conservatism.	USEPA, 2008a.	
482	PFG Composition - Hydrophyte Status	Composition of PFG based on hydrophyte status.	USEPA, 2008a.	
483	PFG Composition - Life Span	Composition of PFG based on life span (annual, perennial, .etc.).	USEPA, 2008a.	
484	PFG Composition - Aquatic Plant Guilds	Composition of PFG based on aquatic plants.	USEPA, 2008a.	
485	PFG Composition - Pioneer Species or Opportunistic Native or Alien Species	Composition of PFG based on pioneer status or opportunism.	USEPA, 2008a.	
486	PFG Composition - Light Requirements/Shade Tolerance	Composition of PFG based on light requirements or shade tolerance.	USEPA, 2008a.	
487	Community Type	N/A	USEPA, 2008a.	
488	Patchiness (Interspersion) of Vegetation	N/A	USEPA, 2008a.	
489	Distribution of Plant Communities	N/A	USEPA, 2008a.	
490	Zonation or Vegetation Distribution Typical of Wetland Class	N/A	USEPA, 2008a.	
491	Total Absolute Cover	N/A	USEPA, 2008a.	

Indicator ID#	Indicator	Definition	Literature Source *[See Appendix A for full citation]*	Duplicate
492	Distribution and Cover of Growth Forms	Floating/submerged plants, emergent/terrestrial herbs, shrubs, and trees.	USEPA, 2008a.	
493	Vertical Strata Height and Volume	Herbaceous ground layer, shrub layer(s), tree canopy layer(s).	USEPA, 2008a.	
494	Local Microtopography Generated By Structure of Non-woody Plants	N/A	USEPA, 2008a.	
495	Leaf Area Index	N/A	USEPA, 2008a.	
496	Shrub or Small Tree Stem Density	N/A	USEPA, 2008a.	
497	Evidence or Quantity of Regeneration of Key Plant Species	N/A	USEPA, 2008a.	
498	Litter Cover	N/A	USEPA, 2008a.	
499	Below Ground Biomass	N/A	USEPA, 2008a.	
500	Wrack Extent/Cover	N/A	USEPA, 2008a.	
501	Allochthonous Inputs	N/A	USEPA, 2008a.	
502	Depth of Submerged Plant Cover	N/A	USEPA, 2008a.	
503	Distribution of Woody Debris	N/A	USEPA, 2008a.	
504	Percent Leaf and Root Tissue Carbon/Nitrogen	N/A	USEPA, 2008a.	

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505	Root and Leaf Tissue Carbon/Phosphorus	N/A	USEPA, 2008a.	
506	Photosynthesis/Respiration (P/R) Ratio	N/A	USEPA, 2008a.	
507	Plant Health/Stress/Herbivory	N/A	USEPA, 2008a.	
508	Stable Nitrogen Isotopes in Leaf Tissue	N/A	USEPA, 2008a.	
509	Genetic Diversity	N/A	USEPA, 2008a.	
510	Palynology	N/A	USEPA, 2008a.	
511	Paleoecology	N/A	USEPA, 2008a.	
512	USDA-NRCS Hydric Soil Field Indicators	Presence of hydric soil indicators.	USEPA, 2008a.	
513	Soil Profile Description	N/A	USEPA, 2008a.	
514	Soil Bulk Density	The mass of soil particles divided by the total volume they occupy.	USEPA, 2008a.	
515	Thickness of Organic Soil Layers	N/A	USEPA, 2008a.	
516	Soil Texture	Percent sand, silt, and clay particles.	USEPA, 2008a.	
517	Soil pH	N/A	USEPA, 2008a.	
518	Major Plant Nutrients in Soil	Presence of P, K, Ca, Mg.	USEPA, 2008a.	
519	Soil Organic Matter	Percent organic matter or carbon.	USEPA, 2008a.	
520	Soil Electrical Conductivity	A measure of how well soil units conduct an electric current.	USEPA, 2008a.	
521	Soil Nitrogen	Presence of all N in soil.	USEPA, 2008a.	

Indicator ID#	Indicator	Definition	Literature Source *[See Appendix A for full citation]*	Duplicate
522	Soil Micronutrients	Presence of Cu, Mn, Zn, Fe.	USEPA, 2008a.	
523	Soil Enzyme Analysis	N/A	USEPA, 2008a.	
524	Soil Sulfur	Presence of S.	USEPA, 2008a.	
525	Geomorphic Soil Disturbance	Presence of, e.g., aggregation/degradation.	USEPA, 2008a.	
526	Soil Surface Disturbance	N/A	USEPA, 2008a.	
527	Soil Channels	Presence of incisions, channels, ditches, etc.	USEPA, 2008a.	
528	Sedimentation Rate	Rate of accretion or erosion.	USEPA, 2008a.	
529	Bare Soil	Presence of bare soil features.	USEPA, 2008a.	
530	Presence of Plow Layer	N/A	USEPA, 2008a.	
531	Soil Subsidence	N/A	USEPA, 2008a.	
532[x]	Paleoecology	N/A	USEPA, 2008a.	567
533	Depth Measurements	Surface and groundwater depth (depth of standing water, depth of water in soil excavation pit, etc.).	USEPA, 2008a.	
534	Water Sources	N/A	USEPA, 2008a.	
535	Hydrogeomorphic Unit	N/A	USEPA, 2008a.	
536	Vegetation Hydrologic Guild	N/A	USEPA, 2008a.	
537	Landscape Characteristics	N/A	USEPA, 2008a.	
538	Water Chemistry	N/A	USEPA, 2008a.	
539	Season of Flooding	N/A	USEPA, 2008a.	

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540	Hydrologic Complexity/Microhabitats	N/A	USEPA, 2008a.	
541	Water Velocity	N/A	USEPA, 2008a.	
542	Stream Bedforms	N/A	USEPA, 2008a.	
543	Hydrologic Regimes	N/A	USEPA, 2008a.	
544	COE Primary Indicators of Inundation	N/A	USEPA, 2008a.	
545	COE Secondary Indicators of Inundation	N/A	USEPA, 2008a.	
546	Extent of Inundation	Percent of assessment area inundated, as well as spatial pattern and average depth of inundation.	USEPA, 2008a.	
547	Tidal Range	N/A	USEPA, 2008a.	
548	Spatial Pattern of Flooding	N/A	USEPA, 2008a.	
549[x]	Stream Discharge	N/A	USEPA, 2008a.	285
550	Direct Observation of Streams	Information from landowner interviews.	USEPA, 2008a.	
551	Stream Gauge Data	N/A	USEPA, 2008a.	
552	Ditch Spacing & Depth	N/A	USEPA, 2008a.	
553	Dams or Weirs	Presence of dams or weirs.	USEPA, 2008a.	
554	Levees	Presence of levees.	USEPA, 2008a.	
555	Drain Spacing and Depth	N/A	USEPA, 2008a.	
556	Irrigation	N/A	USEPA, 2008a.	

Indicator ID#	Indicator	Definition	Literature Source *[See Appendix A for full citation]*	Duplicate
557	Sediment Load	N/A	USEPA, 2008a.	
558	Snag Density	Snag density is a sign of impoundment.	USEPA, 2008a.	
559	Fetch	Length of water surface over which wind blows in generating waves.	USEPA, 2008a.	
560	Bird Species Diversity	N/A	USEPA, 2008a.	
561	Sensitive/Tolerant Bird Species	N/A	USEPA, 2008a.	
562	Alien Bird Species	N/A	USEPA, 2008a.	
563	Dominant Bird Species	N/A	USEPA, 2008a.	
564	Bird Guild Composition - Foraging	Composition of bird guild based on foraging technique.	USEPA, 2008a.	
565	Bird Guild Composition - Dietary	Composition of bird guild based on dietary habits (omnivores, granivores, insectivores, etc.).	USEPA, 2008a.	
566	Bird Guild Composition - Nesting Strategy	Composition of bird guild based on nesting strategy (platform, ground, cavity, etc.).	USEPA, 2008a.	
567	Bird Abundance	Number, status, and types of nests.	USEPA, 2008a.	532
568	Bird Habitat Evaluation	N/A	USEPA, 2008a.	
569[x]	Macroinvertebrate Species Diversity	N/A	USEPA, 2008a.	461
570	Sensitive/Tolerant Macroinvertebrate Species	N/A	USEPA, 2008a.	
571	Alien Macroinvertebrate Species	N/A	USEPA, 2008a.	
572	Dominant	N/A	USEPA, 2008a.	

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	Macroinvertebrate Species			
573	Macroinvertebrate Guild Compositions	N/A	USEPA, 2008a.	
574	Macroinvertebrate Habitat Evaluation	N/A	USEPA, 2008a.	
575	Fish Species Diversity	N/A	USEPA, 2008a.	
576	Sensitive/Tolerant Fish Species	N/A	USEPA, 2008a.	
577	Alien Fish Species	N/A	USEPA, 2008a.	
578	Dominant Fish Species	N/A	USEPA, 2008a.	
579[x]	Fish Tissue Contaminants	Presence of toxicants in fish tissue.	USEPA, 2008a.	48, 58, 99
580	Fish Guilds	N/A	USEPA, 2008a.	
581	Fish Habitat Evaluation	N/A	USEPA, 2008a.	
582	Fish Deformities	N/A	USEPA, 2008a.	
583	Algae Species Diversity	N/A	USEPA, 2008a.	
584	Sensitive/Tolerant Algae Species	N/A	USEPA, 2008a.	
585	Alien Algae Species	N/A	USEPA, 2008a.	
586	Dominant Algae Species	N/A	USEPA, 2008a.	
587	Algal Productivity	Measure of algal chlorophyll and biovolume.	USEPA, 2008a.	
588	Algae Habitat Evaluation	N/A	USEPA, 2008a.	

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Indicator ID#	Indicator	Definition	Literature Source *[See Appendix A for full citation]*	Duplicate
589	Hydrologic Modification	N/A	USEPA, 2008a.	
590	Vegetative Alteration	N/A	USEPA, 2008a.	
591	Buffer Alteration/Buffer Characteristics	N/A	USEPA, 2008a.	
592	Onsite Human Disturbance	N/A	USEPA, 2008a.	
593	Invasive Species	N/A	USEPA, 2008a.	
594	Sedimentation	N/A	USEPA, 2008a.	
595	Landscape Composition/Land use/Land cover	N/A	USEPA, 2008a.	
596	Substrate Alterations	N/A	USEPA, 2008a.	
597	Local Surface Disturbance	N/A	USEPA, 2008a.	
598	Point Source Stormwater Input	N/A	USEPA, 2008a.	
599	Eutrophication and Nutrient Enrichment	N/A	USEPA, 2008a.	
600	Water Quality	N/A	USEPA, 2008a.	
601	Trash, Dredge, and Fill	N/A	USEPA, 2008a.	
602	Shoreline Hardening/Barriers to Landward Migration	N/A	USEPA, 2008a.	
603[x]	Salinity and/or	N/A	USEPA, 2008a.	240, 84

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Indicator ID#	Indicator	Definition	Literature Source *[See Appendix A for full citation]*	Duplicate
	Conductivity			
604	Acidity	Change in pH.	USEPA, 2008a.	621, 151
605	Alteration of Natural Disturbance Regime	N/A	USEPA, 2008a.	
606	Toxic Contaminants (Pharmaceuticals)	N/A	USEPA, 2008a.	
607	Habitat Modification	N/A	USEPA, 2008a.	
608[X]	Recreational Use	N/A	USEPA, 2008a.	220
609	Turbidity	N/A	USEPA, 2008a.	
610	Pipelines, Wells, Oil Rigs, Sewer Lines	N/A	USEPA, 2008a.	
611	Contaminants	N/A	USEPA, 2008a.	
612	Thermal Stress	N/A	USEPA, 2008a.	
613	Alteration of Natural Turbidity	N/A	USEPA, 2008a.	
614	Pathogens	N/A	USEPA, 2008a.	
615	Mercury Body Burdens in Sentinel Species	N/A	USEPA, 2008a.	
616	Thermal Alterations	N/A	USEPA, 2008a.	

Indicator ID#	Indicator	Definition	Literature Source *[See Appendix A for full citation]*	Duplicate
617[x]	Carbon Storage	This indicator reports the overall amount of carbon gained or lost over time by major ecosystem types; the change in the amount of carbon stored per unit area of land or water (carbon density), by major ecosystem type; and the recent trends in the concentrations of major carbon-containing gases - carbon dioxide and methane - in the atmosphere compared to average preiundustrial concentrations.	Heinz Center, 2008.	35, 36
618[x]	Established Non-native Species	This indicator reports for plants, animals, and plant and animal pathogens across all ecosystem types: (a) the number of new non-native species that become established over time, by decade; (b) the area with different numbers of established non-native species; (c) the area with different proportions of established non-native species, as a percentage of total species.	Heinz Center, 2008.	144
619	Pattern in Coastal Area	This indicator describes the intermingling of "natural" and "non-natural" landscape (or seascape) features in coastal areas. The interplay between various types of coastal habitats (such as wetlands and open waters), as well as between these habitat types and human development in the coastal zone (such as built structures and dredged areas) provide a general description of the structural pattern of coastal areas. The structural pattern of these areas can be linked to how well they function ecologically and to the amount and type of ecosystem services humans receive from them.	Heinz Center, 2008.	
620	**Instream Connectivity**	**This indicator reports on the proportion of watersheds with different levels of instream connectivity measured as the distance downstream from the "pour point" (where the streams leaves the watershed) to the nearest dam or diversion, such as a pumping station. This indicator also reports on the proportion of watersheds that contain streams with unobstructed flow to their natural endpoint, typically the ocean or a large lake. This indicator focueses on the loss of connectivity over and above any natural discontinuities in aquatic systems.**	**Heinz Center, 2008.**	

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Indicator ID#	Indicator	Definition	Literature Source [See Appendix A for full citation]	Duplicate
621[x]	Freshwater Acidity	This indicator reports: (a) the amount of nitrogen and sulfate deposited from the atmosphere to watersheds each year; (b) the percentage of stream miles and area of lakes and ponds with different levels of acid-neutralizing capacity, a measure of sensitivity of acidification.	Heinz Center, 2008.	604, 151
622	Total withdrawal information by source & type of use	N/A	Miller, personal communication	
623**	**Water Availability: Net Streamflow per Capita (Vulnerability of Domestic Water Uses)**	**A measure estimating per capita water availability using net withdrawals (QW) from streamflow. Method of calculation: (QS-QW)/pop.**	**Hurd et al., 1998**	

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Appendix C. Data Sources, Supporting Information,
and Technical Notes

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The following appendix describes the data sources obtained for 32 of the 53 vulnerability indicators. These data sources were used, when possible, to create one or more maps for each indicator. Supporting information for each data source include: the names of the data sets used; how to obtain the data; website, when available; spatial and temporal resolution; coverage of data set (i.e. national, state, or local); type of data source; format of data relevant to mapping (e.g., ArcGIS, Excel, Access, etc.); and metadata (e.g., definitions of variables in data set, method of data collection, etc.). The Additional Data Characteristics sections for each indicator provide additional detail not captured in the preceding sections.

In addition, this appendix contains technical notes for the 32 vulnerability indicators for which data sources were readily available. The issues presented below may affect the interpretation of an indicator map (if the indicator was mappable) or may provide guidance for future mapping efforts (if the indicator was non-mappable or had an incomplete map).

One indicator (marked with *) had an incomplete map. Five indicators (marked with **) were not mappable given project resources and technical difficulties encountered, as noted in the main report and in the technical notes in this appendix. The remaining 25 indicators were mapped. The mapping methodology for the 25 mapped indicators is presented in Appendix D, and maps for these indicators are presented in Appendix E (displayed using 4-digit hydrologic units) and Appendix F (displayed using ecoregions).

#1 Acid Neutralizing Capacity (ANC)

Literature Source (see Appendix A for full citation):
USEPA, 2006b.

Data Sets Used:
USEPA - Wadeable Streams Assessment (WSA): Water Chemistry Data.

How To Obtain Data:
Download online

URL to Data (if any):
http://www.epa.gov/owow/streamsurvey/web_data.html

Spatial Resolution:
Small streams

Temporal Resolution (period and frequency of collection):
2004-2005; every 5 years (first year of round of data collection was 2004-2005)

Extent/Coverage of Data Set:
National

Type of Data Source:
Survey

Format of Data:
Comma separated

Metadata:
- *Definitions and data descriptions as .txt files.*
  USEPA. 2008. Wadeable Streams Assessment - Definitions of Variables. Available at:
  http://www.epa.gov/owow/streamsurvey/web_data.html. Accessed July 21, 2009.

Additional Data Characteristics:
The WSA Water Chemistry data set contains water chemistry data for small streams, including pH data. Data files are associated with companion text files (using EPA's WSA Definitions of Variables in metadata) that list data set labels and give individual descriptions for each variable. The original literature source, EPA's 2006 WSA report (USEPA, 2006b; see Appendix A for full citation), provides an explanation of how wadeable streams were selected for this study and how data were collected from various sites.

Technical Notes
- *Non-uniform Spatial Distribution of Data:* The ANC sample point data are not distributed homogeneously, which results in dissimilar amounts of ANC data within a HUC-4 boundary. In cases where there are few sample points within a HUC-4 boundary, individual sites may have a large influence on the metric (percentage of "at risk" sites) that is calculated for the reporting unit.

#22 At-Risk Freshwater Plant Communities

Literature Source (see Appendix A for full citation):
Heinz Center, 2008.

Data Sets Used:
NatureServe - Explorer (customized dataset)

How To Obtain Data:
Data were obtained from Jason McNees at NatureServe, 1101 Wilson Blvd., 15th Floor Arlington, VA 22201 via email on July 31, 2009.

URL to Data (if any):
N/A

Spatial Resolution:
State

Temporal Resolution (period and frequency of collection):
2006; not specified

Extent/Coverage of Data Set:
National

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Type of Data Source:
Census

Format of Data:
Excel

Metadata:
- *Details of the National Vegetation Classification System (NVCS).*
  Federal Geographic Data Committee. International Classification of Ecological Communities - Terrestrial Vegetation of the United States. Volume I: The National Vegetation Classification System: Development, Status, and Applications. Available online at: http://www.NatureServe.org/library/vol1.pdf. Accessed July 21, 2009.
- *Explanation of Conservation Status Ranks.*
  NatureServe and Natural Heritage. 2009. Conservation Status Ranks. Available online at: http://www.NatureServe.org/explorer/ranking.htm. Accessed July 21, 2009.
- *Explanation of the Terrestrial Ecological Classification System.*
  NatureServe. 2008. Terrestrial Ecological Classification System. Available online at: http://www.NatureServe.org/publications/usEcologicalsystems.jsp.

Additional Data Characteristics:
NatureServe data, customized for EPA, were used to inform this indicator. Data include the percent of plant species at risk of extinction in each state. In each state, species considered to be at a risk of extinction were ones classified by NatureServe as critically imperiled, imperiled, or vulnerable (using NatureServe and Natural Heritage's Conservation Status Ranks in metadata). In addition, plant species were classified into plant community types based on their physiognomy (using FGDC's NVCS) or based on their landscape settings, biological dynamics, and environmental features (using NatureServe's Terrestrial Ecological Classification System).

Technical Notes
- *State-level Data:* The map for this indicator is based on data calculated on a state-by-state basis. Transforming the data from a state-based representation to a HUC-4 representation requires an assumption that the distribution of at-risk plants is uniform within each state. This assumption allows for area-weighted percentages to be calculated for HUC-4 units that intersect more than one state. Although this is an accepted transformation method because the spatial extent of the HUC-4 units and the state boundaries are identical, the assumption of uniform distribution may result in errors in the metric calculated for each HUC-4 unit.

#24 At-Risk Native Freshwater Species

Literature Source (see Appendix A for full citation):
Heinz Center, 2008.

Data Sets Used:
NatureServe - Explorer (customized dataset).

How To Obtain Data:
Data were obtained from Jason McNees at NatureServe, 1101 Wilson Blvd., 15th Floor
Arlington, VA 22201 via email on July 31, 2009.

URL to Data (if any):
N/A

Spatial Resolution:
State

Temporal Resolution (period and frequency of collection):
2006; not specified

Extent/Coverage of Data Set:
National

Type of Data Source:
Census

Format of Data:
Excel

Metadata:
- *Explanation of Conservation Status Ranks.*
  NatureServe and Natural Heritage. 2009. Conservation Status Ranks. Available online at:
  http://www.NatureServe.org/explorer/ranking.htm. Accessed July 21, 2009.

Additional Data Characteristics:
NatureServe data, customized for EPA, were used to inform this indicator. Data include the
percent of all species at risk of extinction in each state. In each state, species considered to be at
a risk of extinction were ones classified by NatureServe as critically imperiled, imperiled, or
vulnerable (using NatureServe and Natural Heritage's Conservation Status Ranks in metadata).

Note: The data set used to inform this indicator was the same as that used for the indicator #326
(Wetland and Freshwater Species at Risk (number of species)).

Technical Notes
- *State-level Data.* The map for this indicator is based on data calculated on a state-by-state
  basis. Transforming the data from a state-based representation to a HUC-4 representation
  requires an assumption that the percentage of at-risk species is uniform within each state.
  This assumption allows for area-weighted percentages to be calculated for HUC-4 units that
  intersect more than one state. Although this is an accepted transformation method because
  the spatial extent of the HUC-4 units and the state boundaries are identical, the assumption of
  uniform distribution may result in errors in the metric calculated for each HUC-4 unit.

#51 Coastal Vulnerability Index (CVI)

Literature Source (see Appendix A for full citation):
Day et al., 2005.

Data Sets Used:
USGS - A Preliminary Database for the U.S. Atlantic, Pacific and Gulf of Mexico Coasts (U.S. Geological Survey Digital Data Series – 68)

How To Obtain Data:
Download online

URL to Data (if any):
http://pubs.usgs.gov/dds/dds68/htmldocs/data.htm

Spatial Resolution:
1:2,000,000 shoreline at 3-minute resolution

Temporal Resolution (period and frequency of collection):
Time periods vary for the 3 different regions of United States: Atlantic Coast (2000); Pacific Coast (2001); and Gulf Coast (2001). Variable frequency (as data on each of the six variables on which the CVI depends are collected for different time periods and at a different frequencies).

Extent/Coverage of Data Set:
All U.S. coastline.

Type of Data Source:
Database

Format of Data:
ARC/INFO or ASCII

Metadata:
- *Calculation of the CVI.*
  Thieler, R.R., Hammar-Klose, E.S., 2001. National Assessment of Coastal Vulnerability to Sea-Level Rise: Preliminary Results for the U.S. Gulf of Mexico Coast. *U.S. Geological Survey Open-File Report 00-179.* Available online at: http://pubs.usgs.gov/of/2000/of00-179/index.html. Accessed July 21, 2009.

Additional Data Characteristics:
The calculation of the value of this indicator is based on six independent variables (described in Thieler and Hammar-Klose, 2001 in metadata). The original data were housed in the Carbon Dioxide Information Analysis Center's (CDAIC) Coastal Hazards Database(CHD) for 3 geographic regions - East Coast, West Coast, and Gulf Coast. The attributes in this dataset are based on A Coastal Hazards Database for the U.S. Gulf Coast (Gornitz, V. and White, T. W. 1992. ORNL/CDIAC-60, NDP-043B. Oak Ridge National Laboratory, Oak Ridge, Tennessee) updated with data from more recent sources.

Technical Notes
- *Spatial Distribution of Data (special case: coastal indicator):* The spatial extent of the data for this indicator is for coastal and nearshore areas only. This is inherently disconnected from the HUC-4 boundaries, which extend inland and do not consistently include coastal and nearshore regions. This makes aggregation for the purposes of reporting at the HUC-4 scale problematic. To address this issue, a special reporting unit was developed for this indicator. Each unit extends approximately 20 miles inland and includes approximately 150 miles of coastline.
- *Local Variation:* CVI values vary considerably at local scales. By averaging the CVI values within the special coastal reporting units, localized vulnerability is masked.

*#55 Commercially Important Fish Stocks***

Literature Source (see Appendix A for full citation):
Heinz Center, 2008.

Data Sets Used:
NOAA National Marine Fisheries Service (NMFS)

How To Obtain Data:
Request directly from NOAA NMFS Research Centers

URL to Data (if any):
N/A

Spatial Resolution:
Regional (e.g., Pacific Coast, Southeast, Northeast, etc.)

Temporal Resolution (period and frequency of collection):
1981-2005; at least 10 years of annual data per stock

Extent/Coverage of Data Set:
National (coastal)

Type of Data Source:
Census

Format of Data:
Unknown

Metadata:
N/A

Additional Data Characteristics:
The NOAA NMFS data set includes spawning stock biomass and total exploitable stock biomass data on 109 fish stocks over a 10-year period. These data do not include near-shore stocks (i.e.,

those in state waters within 3 miles of the shore), many of which are under state management jurisdiction, and anadromous salmon stocks from the Pacific Northwest. The Heinz Center calculated stock trends for 109 stocks based on the estimated weight or biomass of the entire stock using linear regression analysis to establish which stocks were increasing or decreasing by more than 25%.

Technical Notes
- *Spatial Distribution of Data (special case: marine indicator):* This indicator does not provide vulnerability information for any land or nearshore areas. This is a marine indicator that only evaluates fish stocks located at least 3 miles from the coast and is inherently disconnected from the HUC-4 boundaries which extend inland. No other data source for commercially important fish stocks in inland waters or nearshore areas was identified.
- *Low-Resolution Data:* The data set for this indicator only provides three data values at a very coarse spatial scale: NE Atlantic, SE Atlantic, and Pacific. These three data points do not provide the variation necessary to assess vulnerability.

#95 Fish and Bottom-Dwelling Animals**

Literature Source (see Appendix A for full citation):
Heinz Center, 2008.

Data Sets Used:
(a) USEPA - Wadeable Streams Assessment (WSA)
(b) USEPA - Storage and Retrieval System (STORET)

How To Obtain Data:
(a) Download online
(b) Download online (if file size is large, can get via e-mail).

URL to Data (if any):
(a) http://www.epa.gov/owow/streamsurvey/web_data.html
(b) http://iaspub.epa.gov/storpubl/DW_home

Spatial Resolution:
(a) N/A
(b) HUC-8 watershed level

Temporal Resolution (period and frequency of collection):
(a) 2004-2005, every 5 years (first year of round of data collection was 2004-2005)
(b) 1900-2009; daily

Extent/Coverage of Data Set:
(a) National
(b) National

Type of Data Source:
(a) Survey
(b) Database

Format of Data:
(a) Comma separated
(b) Excel

Metadata:
- *Definitions and data descriptions as txt files.*
  USEPA. 2008a. Wadeable Streams Assessment - Definitions of Variables. Available at:
  http://www.epa.gov/owow/streamsurvey/web_data.html. Accessed July 21, 2009.

Additional Data Characteristics:
To assess the condition of fish and bottom-dwelling animals, the Macroinvertebrate Index of
Biotic Condition was calculated (using methods in EPA's 2006 WSA report; USEPA 2006b).
This index is based on multiple metrics, such as: taxa richness, evenness of species across taxa,
the relative abundance of different taxa, the feeding strategy of taxa, the habitat preference of
taxa, and the tolerance of taxa to stressors. Data on these are available in EPA's WSA data set
and in EPA's STORET data set. Sites with index scores 75-95% lower than the reference streams
were identified as 'moderate,' whereas 'degraded' sites were those with index scores lower than
95% of the reference streams.

Technical Notes
- *Duplicate indicator.* Upon further analysis, this indicator was determined to be a duplicate of
  the indicator Macroinvertebrate Index of Biotic Condition (#460). Although these indicators
  were cited by two distinct literature sources (Heinz Center, 2008 and USEPA, 2006b
  respectively), their underlying data source i.e. EPA's Wadeable Streams Assessment is the
  same and the same calculation is involved in obtaining the value of the indicator.

#125 Groundwater Reliance

Literature Source (see Appendix A for full citation):
Hurd et al., 1998; Hurd et al.,1999.

Data Sets Used:
United States Geological Survey (USGS) - National Water-Use Dataset.

How To Obtain Data:
Download online

URL to Data (if any):
http://water.usgs.gov/watuse/

Spatial Resolution:
HUC-8 watershed

Temporal Resolution (period and frequency of collection):
1985-2000; every 5 years

Extent/Coverage of Data Set:
National

Type of Data Source:
Database

Format of Data:
ASCII

Metadata:
- *Description of water use parameters.*
  USGS. Estimated Use of Water in the United States. Available online at:
  http://water.usgs.gov/watuse/. Accessed December 15, 2010.

Additional Data Characteristics:
The USGS National Water-Use Dataset provides data on the total annual withdrawals from groundwater and surface water and total annual withdrawals from only groundwater for the year 1990.

Technical Notes
There are no technical notes for this indicator.

#165 Meteorological Drought Indices

Literature Source (see Appendix A for full citation):
National Assessment Synthesis Team, 2000a.

Data Sets Used:
NOAA National Climatic Data Center (NCDC) - Divisional Data on the Palmer Drought Severity Index (PSDI).

How To Obtain Data:
Download online

URL to Data (if any):
http://www7.ncdc.noaa.gov/CDO/CDODivisionalSelect.jsp

Spatial Resolution:
344 "climate divisions," with varying number of divisions per state

Temporal Resolution (period and frequency of collection):
1895 to present; monthly

Extent/Coverage of Data Set:
National

Type of Data Source:
Database

Format of Data:
ASCII

Metadata:
- *Description of the PSDI.*
  Karl, T.R., R.W. Knight, D.R. Easterling, and R.G. Quayle. 1996. Indices of climatic change for the United States. *Bulletin of the American Meteorological Society.* 77 (2): 279-292.
- *Data dictionary for PSDI data.*
  National Oceanic and Atmospheric Administration (NOAA). 2007. Time-bias Corrected Divisional Temperature-Precipitation-Drought Index. Prepared by the National Climatic Data Center (NCDC). Available online at: http://www7.ncdc.noaa.gov/CDO/DIV_DESC.txt. Accessed July 21, 2009.
- *Definitions of climate divisions.*
  National Oceanic and Atmospheric Administration (NOAA). 2009. Definitions of Climate Divisions. Prepared by the National Climatic Data Center (NCDC). Available online at: http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?WWDI~getstate~US. Accessed July 21, 2009.

Additional Data Characteristics:
The NOAA NCDC Divisional Data on the PSDI includes the calculated value of the PSDI for each of 344 climate divisions in the U.S. The description of the index (from Karl et al., 1996 in metadata) and other supporting information (from NOAA's data dictionary for PSDI data and definitions of climate divisions in metadata) are also available.

Technical Notes
There are no technical notes for this indicator.

#190 Number of Dry Periods in Grassland/Shrubland Streams and Rivers (Percent of streams with dry periods over time)*

Literature Source (see Appendix A for full citation):
Heinz Center, 2008.

Data Sets Used:
(a) USGS - Hydro Climatic Data Network (HDCN)
(b) USGS - Stream Gauge Data

How To Obtain Data:
Data (integrated data set of (a) and (b) above) were obtained from Anne Marsh, Ph. D., Director of Observation and Understanding Programs, The H. John Heinz III Center for Science, Economics, and the Environment, 900 17th Street, NW, Suite 700, Washington, D. C. 20006 via email on April 28, 2009.

URL to Data (if any):
(a) N/A
(b) N/A

Spatial Resolution:
(a) HUC-8 watershed level
(b) HUC-8 watershed level

Temporal Resolution (period and frequency of collection):
(a) 1874-1988 (inclusive); daily, monthly, and annual
(b) 1899-2007; daily, monthly, annual

Extent/Coverage of Data Set:
(a) National
(b) National

Type of Data Source:
(a) Database
(b) Database

Format of Data:
(a) ASCII;
(b) .rrd or .img or .xml or .sgml

Metadata:
- *Ecoregion definitions.*
  Bailey, R. G. 1995. Description of the Ecoregions of the United States. Available online at: http://www.fs.fed.us/land/ecosysmgmt/. Accessed July 21, 2009.
- *National Land Cover Dataset (NLCD) - Landcover categories.*
  USEPA. Undated. National Land Cover Dataset (NLCD) - Landcover categories. Available online at: http://www.mrlc.gov/index.php. Accessed July 21, 2009.

Additional Data Characteristics:
Data were obtained from the two different datasets: daily streamflow data at study sites from USGS' Stream Gauge Data data set, and daily streamflow data for reference sites in relatively undisturbed locations from USGS' HDCN data set. Data were integrated into a single data set by the Heinz Center; this integrated data set was ultimately used for mapping. In addition, ecoregion definitions (from Bailey, 1995 in metadata) and land cover region definitions (from USEPA's NLCD Landcover Categories in metadata) were used to define watersheds in grasslands and shrublands.

Technical Notes

- *Data Gaps in National Coverage:* This indicator is based on a 2009 study by the H. John Heinz III Center for Science, Economics, and the Environment (Heinz Center) that evaluated the number of "zero-flow" periods in streams that flow through watersheds dominated by grassland and/or shrubland land cover types. The authors of the study delineated watersheds for USGS stream gages, calculated the land use within those watersheds, and then analyzed streamflow records for watersheds dominated by grassland and shrubland cover. They determined the average annual percent of streams in Western ecoregions that experienced dry periods during a rolling 5-year period. The Heinz Center did not conduct this analysis for Eastern ecoregions. Although the reasons for this are unclear, it is likely that this is because few, if any, stream sites in Eastern ecoregions satisfied their definition of a "grassland" or "shrubland" stream.
- *Non-uniform Spatial Distribution of Data:* In the Western ecoregions, the number of grassland sites within each HUC-4 unit varies widely. In cases where there are few grassland sites within a HUC-4 boundary, individual sites may have a large influence on the average number of dry periods that is calculated for that areas. The resulting spatial heterogeneity may be a reflection of this sensitivity to data availability.

#209 Population (human) Susceptible to Flood Risk**

Literature Source (see Appendix A for full citation):
Hurd et al., 1998; Hurd et al.,1999.

Data Sets Used:
(a) FEMA Q3 Flood Data
(b) ESRI ArcUSA - US Census tract data.

How To Obtain Data:
(a) 26 CDs (for all USA) available for a fee, online or on phone.
(b) Available on ArcGIS.

URL to Data (if any):
(a) http://www.fema.gov/hazard/map/q3.shtm#0
(b) N/A

Spatial Resolution:
(a) Individual street addresses
(b) 2 scales - 1:2,000,000 and 1:25,000,000

Temporal Resolution (period and frequency of collection):
(a) N/A
(b) N/A

Extent/Coverage of Data Set:
(a) National
(b) National

Type of Data Source:
(a) Collection of flood maps
(b) Census

Format of Data:
(a) Digital Line Graph (DLG), ARC/INFO, MapInfo
(b) ARC/INFO (ArcView and ArcGIS compatible)

Metadata:
N/A

Additional Data Characteristics:
500-year floodplain data from FEMA's Q3 Digital Flood Data were overlaid with U.S. Census Tract Data from ArcGIS.

Technical Notes

- *Data Gaps in National Coverage:* This indicator evaluates the human population currently residing within the 500-year floodplain. This would be calculated by overlaying estimates of the 500-year floodplain from the Federal Emergency Management Agency (FEMA) with population data from the U.S. Census Bureau. According to FEMA's Map Service Center, GIS-compatible digital flood plain data are only available for certain parts of the country, as shown in the map below. Without the digital flood plain data, significant effort is required to create a national map for this indicator.
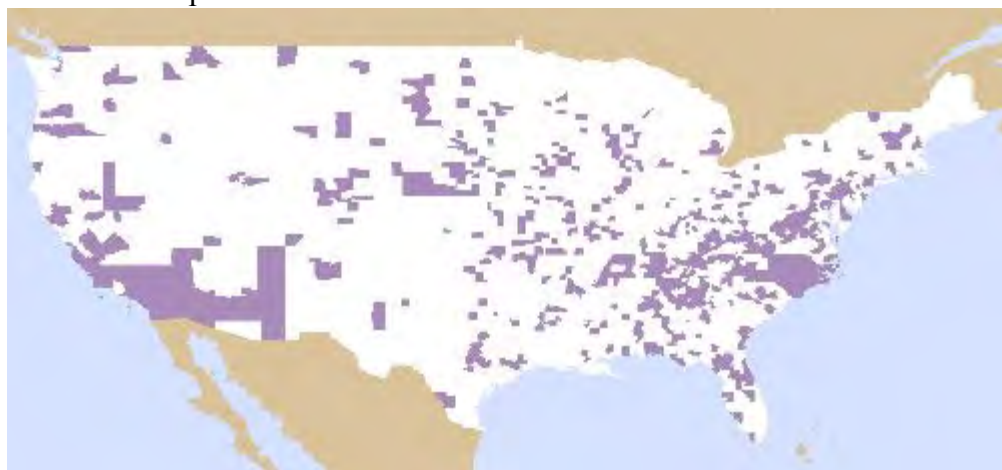
Availability of Digital Flood Insurance Rate Maps (DFIRMs). The Federal Emergency Management Agency provides GIS-compatible flood plain maps for all areas in purple. *Source: Federal Emergency Management Agency*

#218 Ratio of Snow to Total Precipitation

Literature Source (see Appendix A for full citation):
Lettenmaier et al., 2008.

Data Sets Used:
Monthly Climate Data and Observation Station Locations from National Climatic Data Center.

How To Obtain Data:
Download online (free for .gov and .edu domains).

URL to Data (if any):
http://gis.ncdc.noaa.gov/snowfallmo/

Spatial Resolution:
18,116 stations

Temporal Resolution (period and frequency of collection):
1867 to present; annual

Extent/Coverage of Data Set:
National

Type of Data Source:
Database

Format of Data:
Tabular, Delimited, Time Series, NWS Condensed B (suitable for SWMM), Worksheet, dBase, Binary, NCDC

Metadata:
N/A

Additional Data Characteristics:
NOAA's Monthyl Climate Data and Observation Locations data set contains climate data (rain, snow, evaporation, temperature, degree days). Based on available station-level time-series data, the unweighted numeric average for each HUC-4 can be calculated using stations within that HUC watershed.

Technical Notes
There are no technical notes for this indicator.

#219 Ratio of Withdrawals to Streamflow

Literature Source (see Appendix A for full citation):
Hurd et al.,1999.

Data Sets Used:
(a) Oregon State University - PRISM Climate Modeling System: Mean Annual Precipitation data
(b) Oregon State University - PRISM Climate Modeling System: Mean Daily Maximum Temperature data
(c) USGS - National Water-Use Dataset.

How To Obtain Data:
Download online

URL to Data (if any):
(a) http://www.prism.oregonstate.edu/products/matrix.phtml
(b) http://www.prism.oregonstate.edu/products/matrix.phtml
(c) http://water.usgs.gov/watuse/

Spatial Resolution:
(a) 30 arc-second (800 meters)
(b) 30 arc-second (800 meters)
(c) HUC-8 watershed

Temporal Resolution (period and frequency of collection):
(a) 1971 – 2000; monthly
(b) 1971 – 2000; monthly
(c) 1985 – 2000; every 5 years

Extent/Coverage of Data Set:
(a) National
(b) National

Type of Data Source:
(a) Interpolated grid
(b) Interpolated grid
(c) Database

Format of Data:
ASCII

Metadata:
- *Calculation of streamflow.*
  Vogel, R.M., I. Wilson, and C. Daly. 1999. Regional Regression Models of Annual Streamflow for the United States." *Journal of Irrigation and Drainage Engineering.* 125 (3): 148-157.
- *Metadata for PRISM U.S. average monthly or annual precipitation data.*
  http://www.prism.oregonstate.edu/docs/meta/ppt_30s_meta.htm
- *Metadata for PRISM U.S. average monthly temperature data.*
  http://www.climatesource.com/us/fact_sheets/meta_tmin_us_71b.html

- *Description of water use parameters.*
  USGS. Estimated Use of Water in the United States. Available online at:
  http://water.usgs.gov/watuse/. Accessed December 15, 2010.

Additional Data Characteristics:
As described in the metadata for (b), mean annual temperature was calculated as the average of
the mean maximum and mean minum temperature for a given location.

Technical Notes
There are no technical notes for this indicator.

#284 Stream Habitat Quality

Literature Source (see Appendix A for full citation):
Heinz Center, 2008.

Data Sets Used:
USEPA - Wadeable Streams Assessment (WSA).

How To Obtain Data:
Download online

URL to Data (if any):
http://www.epa.gov/owow/streamsurvey/web_data.html

Spatial Resolution:
Small streams

Temporal Resolution (period and frequency of collection):
2004-2005; every 5 years (first year of round of data collection was 2004-2005)

Extent/Coverage of Data Set:
National

Type of Data Source:
Survey

Format of Data:
Comma separated

Metadata:
- *Definitions and data descriptions as .txt files.*
  USEPA. 2008. Wadeable Streams Assessment - Definitions of Variables. Available at:
  http://www.epa.gov/owow/streamsurvey/web_data.html. Accessed July 21, 2009.

Additional Data Characteristics:
Data on the biological condition of small streams, water quality, and biological data on various stream types were used to inform this indicator.

Technical Notes
- *Non-uniform Spatial Distribution of Data:* The sampling effort for EPA's Wadeable Streams Assessment (WSA) varies across HUC-4 units. In cases where there are few sample points within a HUC-4 boundary, individual sites may have a large influence on the average rapid assessment score that is calculated for that area. The map for this indicator shows a heterogeneous distribution of vulnerability, which may be a reflection of this sensitivity to sampling effort.
- *Local Variation:* Habitat quality varies at local scales and is affected by local factors. By calculating an average assessment score for each HUC-4 unit, localized vulnerability within the HUC-4 unit is masked.

#322 Waterborne Human Disease Outbreaks (events)**

Literature Source (see Appendix A for full citation):
Heinz Center, 2008.

Data Sets Used:
Centers for Disease Control and Prevention (CDC) - Waterborne Disease and Outbreak Surveillance System (WBDOSS).

How To Obtain Data:
Download online

URL to Data (if any):
http://www.cdc.gov/healthywater/statistics/wbdoss/surveillance.html

Spatial Resolution:
State

Temporal Resolution (period and frequency of collection):
1985-2004, yearly or every 2 to 3 years

Extent/Coverage of Data Set:
National

Type of Data Source:
Data summaries

Format of Data:
PDF and web page

Metadata:
N/A

Additional Data Characteristics:
Data from the CDC's WBDOSS on the number of waterborne human disease outbreaks in both drinking and recreational water, listed by state, by etiologic agent and type of water system, by deficiency/type of exposure and type of water system, are used to inform this indicator.

Technical Notes
- *Data Collection and Reporting Discontinued:* The most recent data from the Waterborne Disease and Outbreak Surveillance System (WBDOSS) appear to be from 2006. According to the Heinz Center (2008), data are no longer reported.
- *Quality of Source Data:* The WBDOSS relies on voluntary reporting from public health departments within the Unites States. The data collection methods used for the WBDOSS raise data quality concerns due to:
  o *Variable Resources for Reporting:* Some states, territories, or local public health departments may have more available resources for reporting WBDOs and may be more able or inclined to report such cases than other states. Therefore, a map of nationwide WBDOs reported may represent the distribution of actual outbreaks.
  o *Voluntary Data Reporting:* The Heinz Center (2008) study, which defined this indicator, states that inconsistencies in reporting or an altogether lack of reporting may occur as it is not mandatory for states, territories, and local public health departments to report WBDOs.
  o *Skewed Representation of Large vs. Small Public Water Supplies:* There may be under-reporting of WBDOs from public water supplies serving small communities and over-reporting due to larger outbreaks from larger PWSs as the latter is more likely to receive widespread attention from authorities and the media.

#325 Wetland Loss**

Literature Source (see Appendix A for full citation):
MEA, 2005b.

Data Sets Used:
(a) USFWS - National Wetlands Inventory (NWI)
(b) NatureServe Explorer

How To Obtain Data:
(a) Download online
(b) Download online

URL to Data (if any):
(a) http://www.fws.gov/wetlands/Data/DataDownload.html
(b) http://www.NatureServe.org/explorer/

Aquatic Ecosystems, Water Quality, and Global Change:
Challenges of Conducting Multi-Stressor Global Change Vulnerability Assessments

Final Report
August 2011

Spatial Resolution:
(a) Lower 48 states (USGS 1:24,000 or 1:100,000 topographic quadrangle), Alaska (USGS 1:63,000 topographic quadrangle), Hawaii (County and USGS topographic quadrangle), Puerto Rico and USVI (County and USGS topographic quadrangle), Pacific Trust Territories (County/Island), Data are in decimal degrees on the North American Datum of 1983
(b) State or by NLCD 2001 map-zones

Temporal Resolution (period and frequency of collection):
(a) N/A
(b) N/A

Extent/Coverage of Data Set:
(a) National
(b) National

Type of Data Source:
(a) Database
(b) Census

Format of Data:
(a) NWI - digital wetlands polygon, .sgml and .xml
(b) .xls or .xml

Metadata:
- *National Vegetation Classification System (NVCS).*
  Federal Geographic Data Committee. 2009. National Vegetation Classification System. Available online at: http://biology.usgs.gov/npsveg/nvcs.html. Accessed on November 19, 2009.
- *Terrestrial Ecological Classification System.*
  NatureServe/Natural Heritage. 2009. Terrestrial Ecological Classification System. Available online at: http://www.natureserve.org/explorer/classeco.htm. Accessed on November 19, 2009.

Additional Data Characteristics:
Data from two datasets were used to inform this indicator: data on wetland vegetation and hydrologic properties of wetlands from NWI, and plant species vulnerability rankings and data on their abundance in U.S. states from NatureServe Explorer. Vulnerability rankings (from Natural Heritage) were used to estimate relative susceptibility to extinction. In addition, plant species were classified into plant community types based on their physiognomy (using NVCS) or based on their landscape settings, biological dynamics, and environmental features (using Terrestrial Ecological Classification System).

Technical Notes
- *Significant Data Processing Required:* National Wetlands Inventory (NWI) data can only be downloaded at the 7.5 minute (1:24K) or 15 minute (1:100K) scales. In the lower 48 states, the USGS has designated approximately 56,500 1:24K-scale quadrangles. It would require substantial effort to download data for each of these quadrangles and assemble them into a

national dataset. It may be possible to acquire a national wetlands dataset from the U. S. Fish & Wildlife Service, although the FWS web site currently states that "Due to limited resources, custom wetland data extractions by the Wetlands Team are no longer available."

- *Data Gaps in National Coverage:* There are data gaps in the national coverage that would diminish the usefulness of this national map. According to the FWS, the wetlands in 13 states are either unmapped or are recorded on hardcopy maps only.

- *Inadequate Historical Data:* The indicator describes wetland loss, which suggests that a second data source must be used to calculate a change in the area of wetlands over time. A data source that delineates historical wetland extent at the national scale has not been identified.

#326 Wetland and Freshwater Species at Risk (number of species)

Literature Source (see Appendix A for full citation):
Hurd et al., 1998.

Data Sets Used:
NatureServe - Explorer (customized dataset).

How To Obtain Data:
Data were obtained from Jason McNees at NatureServe, 1101 Wilson Blvd., 15th Floor Arlington, VA 22201 via email on July 31, 2009.

URL to Data (if any):
N/A

Spatial Resolution:
State

Temporal Resolution (period and frequency of collection):
2006; not specified

Extent/Coverage of Data Set:
National

Type of Data Source:
Census

Format of Data:
Excel

Metadata:
- *Explanation of Conservation Status Ranks.*
  NatureServe and Natural Heritage. 2009. Conservation Status Ranks. Available online at: http://www.NatureServe.org/explorer/ranking.htm. Accessed July 21, 2009.

Additional Data Characteristics:
Data on the number of at-risk water-dependent species were originally compiled by the Natural Heritage Data Centers and The Nature Conservancy for the EPA's Index of Watershed Indicators (IWI), a study published in 1997. The IWI project was discontinued due to lack of adequate funding. Therefore, NatureServe data, customized for EPA, were used to inform this indicator. Data include the percent of all species at risk of extinction in each state. In each state, species considered to be at a risk of extinction were ones classified by NatureServe as critically imperiled, imperiled, or vulnerable (using NatureServe and Natural Heritage's Conservation Status Ranks in metadata).

Note: The data set used to inform this indicator was identical to that used for the indicator #24 (At-Risk Native Freshwater Species).

Technical Notes
- *State-level Data:* The map for this indicator is based on data calculated on a state-by-state basis. Transforming the data from a state-based representation to a HUC-4 representation requires an assumption that the distribution of at-risk species is uniform within each state. This assumption allows for area-weighted totals to be calculated for HUC-4 units that intersect more than one state. Although this is an accepted transformation method because the spatial extent of the HUC-4 units and the state boundaries are identical, the assumption of uniform distribution may result in errors in the metric calculated for each HUC-4 unit.

#348 Erosion Rate

Literature Source (see Appendix A for full citation):
Murdoch et al., 2000.
Data Sets Used:
Soil erosion rates estimated with the Revised Universal Soil Loss Equation (RUSLE)

How To Obtain Data:
Request directly from:
Dawen Yang, PhD, Professor
Department of Hydraulic Engineering
Tsinghua University
Beijing 100084, China
Tel: +86-10-62796976
Fax: +86-10-62796971
E-mail: yangdw@tsinghua.edu.cn

URL to Data (if any):
N/A

Spatial Resolution:
0.5 degree grid

Temporal Resolution (period and frequency of collection):
1980; not applicable (modeled data)

Extent/Coverage of Data Set:
Global

Type of Data Source:
Model output

Format of Data:
ASCII grid

Metadata:

- *Description of dataset development.*
  Yang, D. W., S. Kanae, T. Oki, T. Koike, and K. Musiake. 2003. Global potential soil erosion with reference to land use and climate changes. *Hydrological Processes.* 17:2913-2928.

Additional Data Characteristics:
Erosion Rate was estimated with the Revised Universal Soil Loss Equation (RUSLE). RUSLE does not account for deposition of eroded soil, so this indicator is more precisely defined as soil movement. The literature source also describes variations of this dataset that incorporate simulations of future climatic conditions (see Yang et al. (2003) for details). The study also includes future soil erosion predictions based on changes in precipitation, temperature, and land cover.

Technical Notes

- *Limited Temporal Resolution of Source Data:* The source data for this map are based on land cover patterns in 1980. Changes in land cover since then may affect the spatial distribution of soil erosion.

#351 Instream Use/Total Streamflow

Literature Source (see Appendix A for full citation):
Meyer et al.,1999.

Data Sets Used:
(a) USGS - National Water-Use Dataset
(b) USGS - Mean annual runoff data
(c) WRC (U.S. Water Resources Council) - Groundwater Recharge. From: WRC. 1978. The Nation's Water Resources: 1975-2000 (Vol. 2). U.S. Government Printing Office, Washington D.C.

How To Obtain Data:
(a) Download online
(b) Download online
(c) Hardcopy book (obtained from library).

URL to Data (if any):
(a) http://water.usgs.gov/watuse/
(b) http://water.usgs.gov/GIS/metadata/usgswrd/XML/runoff.xml
(c) N/A

Spatial Resolution:
(a) HUC-8 watershed
(b) 1:5,000,000 (runoff of tributary streams)
(c) HUC-2 regions

Temporal Resolution (period and frequency of collection):
(a) 1985-2000; every 5 years
(b) 1951-1980; one-time effort
(c) 1975; one-time effort

Extent/Coverage of Data Set:
(a) National
(b) National
(c) National

Type of Data Source:
(a) Database
(b) Modeled dataset
(c) Published report

Format of Data:
(a) ASCII
(b) ArcGIS file (.e00)
(c) Tabular (hard copy)

Metadata:
- *Description of water use parameters.*
  USGS. Estimated Use of Water in the United States. Available online at:
  http://water.usgs.gov/watuse/. Accessed December 15, 2010.

Additional Data Characteristics:
Data for this indicator were derived from three sources: data on total groundwater withdrawals for the year 1995 from USGS' National Water-Use Dataset, modeled mean annual runoff estimates based on annual streamflow data from USGS' mean annual runoff dataset, and groundwater recharge estimates from WRC, 1978. The ratio of instream use to total streamflow was then calculated as described in the WRC report (1978).

Technical Notes

- *Missing Data for Input Variables:* Estimates of runoff (streamflow) and groundwater overdraft (the amount of groundwater withdrawals that exceeds the long-term average annual recharge rate) are used to calculate this indicator. For some regions, groundwater recharge estimates were not available from the original source based on 1975 data. In these areas, withdrawal (as measured in 1975) was assumed to equal recharge. These recharge estimates were then compared to 1995 groundwater withdrawals to calculate updated estimates of groundwater overdraft.

#352 Total Use/Total Streamflow

Literature Source (see Appendix A for full citation):
Meyer et al., 1999.

Data Sets Used:
(a) USGS - National Water-Use Dataset
(b) USGS - Mean annual runoff data
(c) WRC (U.S. Water Resources Council) - Groundwater Recharge. From: WRC. 1978. The Nation's Water Resources: 1975-2000 (Vol. 2). U.S. Government Printing Office, Washington D.C.

How To Obtain Data:
(a) Download online
(b) Download online
(c) Hardcopy book (obtained from library).

URL to Data (if any):
(a) http://water.usgs.gov/watuse/
(b) http://water.usgs.gov/GIS/metadata/usgswrd/XML/runoff.xml
(c) N/A

Spatial Resolution:
(a) HUC-8 watershed
(b) 1:5,000,000 (runoff of tributary streams)
(c) HUC-2 regions

Temporal Resolution (period and frequency of collection):
(a) 1985-2000; every 5 years
(b) 1951-1980; 1 time effort
(c) 1975; one-time effort

Extent/Coverage of Data Set:
(a) National
(b) National
(c) National

Type of Data Source:
(a) Database
(b) Modeled dataset
(c) Published report

Format of Data:
(a) ASCII
(b) ArcGIS file (.e00)
(c) Tabular (hard copy)

Metadata:
- *Description of water use parameters.*
  USGS. Estimated Use of Water in the United States. Available online at:
  http://water.usgs.gov/watuse/. Accessed December 15, 2010.

Additional Data Characteristics:
Data for this indicator were derived from three sources: data on total groundwater withdrawals and consumptive use for the year 1995 from USGS' National Water-Use Dataset, modeled mean annual runoff estimates based on annual streamflow data from USGS' mean annual runoff dataset, and groundwater recharge estimates from WRC, 1978. The ratio of total use to total streamflow was then calculated as described in the WRC report (1978).

Technical Notes
- *Missing Data for Input Variables:* Estimates of runoff (streamflow) and groundwater overdraft (the amount of groundwater withdrawals that exceeds the long-term average annual recharge rate) are used to calculate this indicator. For some regions, groundwater recharge estimates were not available from the original source based on 1975 data. In these areas, withdrawal (as measured in 1975) was assumed to equal recharge. These recharge estimates were then compared to 1995 groundwater withdrawals to calculate updated estimates of groundwater overdraft. In addition, this indicator assesses water consumption as a component of total use. The consumptive use data from USGS does not distinguish between water consumed from groundwater and surface water sources, and it is unclear in the original data source whether this distinction is relevant. Additional investigation into the role of consumptive use in this indicator and the original source of water consumed is recommended.
- *Low-Resolution Data:* Estimates of groundwater recharge were developed at the 2-digit HUC scale and applied evenly to all sub-regions (4-digit HUCs) within the region.

#364 Pesticide Toxicity Index (PTI)

Literature Source (see Appendix A for full citation):
Gilliom et al., 2006.

Data Sets Used:
USGS - NAWQA.

How To Obtain Data:
Download online

URL to Data (if any):
http://water.usgs.gov/nawqa/pnsp/pubs/circ1291/appendix6/

Spatial Resolution:
51 study units

Temporal Resolution (period and frequency of collection):
1991 (20 study units); 1994 (16 study units); 1997 (15 study units); Variable frequency (from one-time collection to daily depending on purpose and collection site)

Extent/Coverage of Data Set:
National

Type of Data Source:
Database

Format of Data:
Comma separated or Excel

Metadata:
- *NAWQA Study Description.*
  USGS. 2006. About NAWQA Study Units. Available online at:
  http://water.usgs.gov/nawqa/studies/study_units.html. Accessed July 21, 2009.
- *Daphnia EC50 Values.*
  USEPA. 2009. ECOTOX Database. Available online at: http://cfpub.epa.gov/ecotox/.
  Accessed September 11, 2009.

Additional Data Characteristics:
The USGS NAWQA data set, which contained data on the occurrence of 76 pesticides (including herbicides and insecticides) and 7 pesticide by-products in streams and shallow groundwater (100ft or less below ground level) at 20 USGS study sites in 1991, 1994, and 1997, was used to inform this indicator. Descriptions of study sites and their year of assessment were also available (from USGS's About NAWQA webpage in metadata). The Pesticide Toxicity Index (PTI) accounts for multiple pesticides in a sample, including pesticides without established benchmarks for aquatic life. The PTI combines information on measured concentrations of pesticides in stream water with toxicity estimates (i.e. toxicity quotients calculated based on laboratory toxicity studies, e.g. EC50 values for *Daphnia* from EPA's ECOTOX database) to produce a relative index value for a sample or stream. The PTI value is computed for each sample of stream water by summing the toxicity quotients for all pesticides detected in the sample.

Technical Notes

- *Non-uniform Spatial Distribution of Data:* The sampling effort for the USGS National Water Quality Assessment (NAWQA) Program varies across HUC-4 units. In cases where there are few sample points within a HUC-4 boundary, individual sites may have a large influence on the average pesticide concentration that is calculated for that area. The map for this indicator shows a heterogeneous distribution of vulnerability, which may be a reflection of this sensitivity to sampling effort. In addition, there are numerous HUC-4 units where no data are available.

- *Local Variation:* Pesticide concentrations in streams vary at local scales and are affected by local factors. By calculating an average concentration for each HUC-4 unit, localized vulnerability within the HUC-4 unit is masked.

- *Relative Rather than Absolute Toxicity:* The Pesticide Toxicity Index (PTI) accounts for multiple pesticides in a sample, including pesticides without established benchmarks for aquatic life. The PTI combines information on exposure of aquatic biota to pesticides (measured concentrations of pesticides in stream water) with toxicity estimates (results from laboratory toxicity studies) to produce a relative index value for a sample or stream. The PTI value is computed for each sample of stream water by summing the toxicity quotients for all pesticides detected in the sample. The toxicity quotient is the measured concentration of a pesticide divided by its toxicity concentration from bioassays (such as an LC50 or EC50). This approach follows the Concentration Addition Model of toxicity. Although simple addition is unlikely to strictly apply for complex mixtures of pesticides from different classes and with different effects and modes of action, the PTI is still useful as a relative index. While the PTI does not indicate whether water in a sample is toxic, its value can be used to rank or compare the relative potential toxicity of different samples or different streams.

#367 Herbicide Concentrations in Streams

Literature Source (see Appendix A for full citation):
USGS, 1999.

Data Sets Used:
USGS - NAWQA.

How To Obtain Data:
Download online

URL to Data (if any):
http://water.usgs.gov/nawqa/pnsp/pubs/circ1291/appendix6/

Spatial Resolution:
51 study units

Temporal Resolution (period and frequency of collection):
1991 (20 study units); 1994 (16 study units); 1997 (15 study units); Variable frequency (from one-time collection to daily depending on purpose and collection site)

Extent/Coverage of Data Set:
National

Type of Data Source:
Database

Format of Data:
Comma separated or Excel

Metadata:
- *NAWQA Study Description.*
  USGS. 2006. About NAWQA Study Units. Available online at:
  http://water.usgs.gov/nawqa/studies/study_units.html. Accessed July 21, 2009.

Additional Data Characteristics:
The USGS NAWQA data set, which contained data on the occurrence of 76 pesticides (including herbicides and insecticides) and 7 pesticide by-products in streams and shallow groundwater (100ft or less below ground level) at 20 USGS study sites in 1991, 1994, and 1997, was used to inform this indicator. Descriptions of study sites and their year of assessment were also available (from USGS's About NAWQA webpage in metadata).

Technical Notes
- *Non-uniform Spatial Distribution of Data:* The sampling effort for the USGS National Water Quality Assessment (NAWQA) Program varies across HUC-4 units. In cases where there are few sample points within a HUC-4 boundary, individual sites may have a large influence on the average herbicide concentration that is calculated for that area. The map for this indicator shows a heterogeneous distribution of vulnerability, which may be a reflection of this sensitivity to sampling effort. In addition, there are numerous HUC-4 units where no data are available.
- *Local Variation:* Herbicide concentrations in streams vary at local scales and are affected by local factors. By calculating an average concentration for each HUC-4 unit, localized vulnerability within the HUC-4 unit is masked.

#369 Insecticide Concentrations in Streams

Literature Source (see Appendix A for full citation):
USGS, 1999.

Data Sets Used:
USGS - NAWQA.

How To Obtain Data:
Download online

URL to Data (if any):
http://water.usgs.gov/nawqa/pnsp/pubs/circ1291/appendix6/

Spatial Resolution:
51 study units

Temporal Resolution (period and frequency of collection):
1991 (20 study units); 1994 (16 study units); 1997 (15 study units); Variable frequency (from one-time collection to daily depending on purpose and collection site)

Extent/Coverage of Data Set:
National

Type of Data Source:
Database

Format of Data:
Comma separated or Excel

Metadata:
- *NAWQA Study Description.*
  USGS. 2006. About NAWQA Study Units. Available online at:
  http://water.usgs.gov/nawqa/studies/study_units.html. Accessed July 21, 2009.

Additional Data Characteristics:
The USGS NAWQA data set, which contained data on the occurrence of 76 pesticides (including herbicides and insecticides) and 7 pesticide by-products in streams and shallow groundwater (100ft or less below ground level) at 20 USGS study sites in 1991, 1994, and 1997, was used to inform this indicator. Descriptions of study sites and their year of assessment were also available (from USGS's About NAWQA webpage in metadata).

Technical Notes
- *Non-uniform Spatial Distribution of Data:* The sampling effort for the USGS National Water Quality Assessment (NAWQA) Program varies across HUC-4 units. In cases where there are few sample points within a HUC-4 boundary, individual sites may have a large influence on the average insecticide concentration that is calculated for that area. The map for this indicator shows a heterogeneous distribution of vulnerability, which may be a reflection of this sensitivity to sampling effort. In addition, there are numerous HUC-4 units where no data are available.
- *Local Variation:* Insecticide concentrations vary at local scales and are affected by local factors. By calculating an average concentration for each HUC-4 unit, localized vulnerability within the HUC-4 unit is masked.

#371 Organochlorines in Bed Sediment

Literature Source (see Appendix A for full citation):
USGS, 1999.

Data Sets Used:
USGS - National Water-Quality Assessment (NAWQA).

How To Obtain Data:
Download online

URL to Data (if any):
http://water.usgs.gov/nawqa/pnsp/pubs/circ1291/appendix6/

Spatial Resolution:
51 study units

Temporal Resolution (period and frequency of collection):
1991 (20 study units); 1994 (16 study units); 1997 (15 study units); Variable frequency (from one-time collection to daily depending on purpose and collection site)

Extent/Coverage of Data Set:
National

Type of Data Source:
Database

Format of Data:
Comma separated or Excel

Metadata:
- *NAWQA Study Description.*
  USGS. 2006. About NAWQA Study Units. Available online at:
  http://water.usgs.gov/nawqa/studies/study_units.html. Accessed July 21, 2009.

Additional Data Characteristics:
The USGS NAWQA data set, which contained data on the occurrence of 32 compounds (8 individual parent compounds, 1 individual breakdown product, and 7 groups of parent compounds, plus related breakdown products or chemical impurities in the manufactured product) in bed sediment at 20 USGS study sites in 1991, 1994, and 1997, was used to inform this indicator. Descriptions of study sites and their year of assessment were also available (from USGS's About NAWQA webpage in metadata).

Technical Notes
- *Non-uniform Spatial Distribution of Data:* The sampling effort for the USGS National Water Quality Assessment (NAWQA) Program varies across HUC-4 units. In cases where there are few sample points within a HUC-4 boundary, individual sites may have a large influence

on the average concentration that is calculated for that area. The map for this indicator shows a heterogeneous distribution of vulnerability, which may be a reflection of this sensitivity to sampling effort. In addition, there are numerous HUC-4 units where no data are available.

- *Local Variation:* Organochlorine concentrations vary at local scales and are affected by local factors. By calculating an average concentration for each HUC-4 unit, localized vulnerability within the HUC-4 unit is masked.

#373 Herbicides in Groundwater

Literature Source (see Appendix A for full citation):
USGS, 1999.

Data Sets Used:
USGS - NAWQA.

How To Obtain Data:
Download online

URL to Data (if any):
http://water.usgs.gov/nawqa/pnsp/pubs/circ1291/appendix6/

Spatial Resolution:
51 study units

Temporal Resolution (period and frequency of collection):
1991 (20 study units); 1994 (16 study units); 1997 (15 study units); Variable frequency (from one-time collection to daily depending on purpose and collection site)

Extent/Coverage of Data Set:
National

Type of Data Source:
Database

Format of Data:
Comma separated or Excel

Metadata:
- *NAWQA Study Description.*
  USGS. 2006. About NAWQA Study Units. Available online at:
  http://water.usgs.gov/nawqa/studies/study_units.html. Accessed July 21, 2009.

Additional Data Characteristics:
The USGS NAWQA data set, which contained data on the occurrence of 76 pesticides (including herbicides and insecticides) and 7 pesticide by-products in streams and shallow groundwater

(100ft or less below ground level) at 20 USGS study sites in 1991, 1994, and 1997, was used to inform this indicator. Descriptions of study sites and their year of assessment were also available (from USGS's About NAWQA webpage in metadata).

Technical Notes
- *Non-uniform Spatial Distribution of Data:* The sampling effort for the USGS National Water Quality Assessment (NAWQA) Program varies across HUC-4 units. In cases where there are few sample points within a HUC-4 boundary, individual sites may have a large influence on the average concentration that is calculated for that area. The map for this indicator shows a heterogeneous distribution of vulnerability, which may be a reflection of this sensitivity to sampling effort. In addition, there are numerous HUC-4 units where no data are available.
- *Local Variation:* Herbicide concentrations vary at local scales and are affected by local factors. By calculating an average concentration for each HUC-4 unit, localized vulnerability within the HUC-4 unit is masked.

#374 Insecticides in Groundwater

Literature Source (see Appendix A for full citation):
USGS, 1999.

Data Sets Used:
USGS - NAWQA.

How To Obtain Data:
Download online

URL to Data (if any):
http://water.usgs.gov/nawqa/pnsp/pubs/circ1291/appendix6/

Spatial Resolution:
51 study units

Temporal Resolution (period and frequency of collection):
1991 (20 study units); 1994 (16 study units); 1997 (15 study units); Variable frequency (from one-time collection to daily depending on purpose and collection site)

Extent/Coverage of Data Set:
National

Type of Data Source:
Database

Format of Data:
Comma separated or Excel

Metadata:
- *NAWQA Study Description.*
  USGS. 2006. About NAWQA Study Units. Available online at:
  http://water.usgs.gov/nawqa/studies/study_units.html. Accessed July 21, 2009.

Additional Data Characteristics:
The USGS NAWQA data set, which contained data on the occurrence of 76 pesticides (including herbicides and insecticides) and 7 pesticide by-products in streams and shallow groundwater (100ft or less below ground level) at 20 USGS study sites in 1991, 1994, and 1997, was used to inform this indicator. Descriptions of study sites and their year of assessment were also available (from USGS's About NAWQA webpage in metadata).

Technical Notes
- *Non-uniform Spatial Distribution of Data:* The sampling effort for EPA's Wadeable Streams Assessment (WSA) varies across HUC-4 units. In cases where there are few sample points within a HUC-4 boundary, individual sites may have a large influence on the average concentration that is calculated for that area. The map for this indicator shows a heterogeneous distribution of vulnerability, which may be a reflection of this sensitivity to sampling effort. In addition, there are numerous HUC-4 units where no data are available.
- *Local Variation:* Insecticide concentrations vary at local scales and are affected by local factors. By calculating an average concentration for each HUC-4 unit, localized vulnerability within the HUC-4 unit is masked.

#437 Precipitation Elasticity of Streamflow

Literature Source (see Appendix A for full citation):
Sankarasubramanian et al., 2001.

Data Sets Used:
(a) USGS - Hydroclimatic Data Network (HDCN): Streamflow data
(b) Oregon State University - PRISM Climate Modeling System: Mean Annual Precipitation data

How To Obtain Data:
(a) Download online
(b) Download online

URL to Data (if any):
(a) http://pubs.usgs.gov/of/1992/ofr92-129/hcdn92/hcdn/ascii/
(b) http://www.prism.oregonstate.edu/

Spatial Resolution:
(a) HUC-8
(b) 2.5 arc-min

Temporal Resolution (period and frequency of collection):
(a) 1874 - 1988; annual
(b) 1990 - present; monthly

Extent/Coverage of Data Set:
(a) National
(b) National

Type of Data Source:
(a) Database
(b) Database

Format of Data:
(a) ASCII
(b) ASCII

Metadata:
- *Description of HDCN data.*
  Landwehr, J. M., and J. R. Slack, 1992. Hydro-Climatic Data Network: A U.S. Geological Survey Streamflow Data Set for the United States for the Study of Climate Variations, 1874-1988. U.S. Geological Survey Open-File Report 92-129. Available online at: http://pubs.er.usgs.gov/usgspubs/ofr/ofr92129. Accessed July 21, 2009.
- *Description of PRISM modeling.*
  Daly, C., R. P. Neilson, and D. L. Phillips. 1994. "A Statistical-Topographic Model for Mapping Climatological Precipitation over Mountainous Terrain." *Journal of Applied Meterology.* 33: 140-158.
- *Calculation of precipitation elasticity of streamflow.*
  Sankarasubramanian, A., R. M. Vogel, and J. F. Limbrunner. 2001. Climate Elasticity of Streamflow in the United States. Water Resources Research. 37 (6): 1771-1781.

Additional Data Characteristics:
Data on streamflow were obtained from USGS's HDCN data set. Data on precipitation were obtained from Oregon State University's PRISM data set. Explanations for how data in HDCN and PRISM were collected and/or modeled are also available (from Landwehr and Slack, 1992 and Daly et al., 1994 in metadata). For the purposes of mapping this indicator with relative ease, Figure 4 in the original literature source, Sankarasubramanian et al., 2001 (see Appendix A for full reference) was used. However, the complete original data set could also be recalculated for mapping purposes using the data sources listed here.

Technical Notes
- *Map Derived from Figure in Source Literature:* The original data used to calculate this indicator were not available and suitable alternatives would require significant effort to assemble. Therefore, the map for this indicator was derived from isopleths that are presented in the source literature (Figure 4 in Sankarasubramanian et al. 2001). The original map was based on data collected from 1951-1988. Streamflow and precipitation data available from the U.S. Geological Survey and Oregon State University's PRISM Group, respectively, could be used to reproduce an updated version of this map.

#449 Ratio of Reservoir Storage to Mean Annual Runoff

Literature Source (see Appendix A for full citation):
Lettenmaier et al., 2008.

Data Sets Used:
(a) US Army Corps of Engineers (USACE) - National Inventory of Dams (NID)
(b) USGS - Mean annual runoff data

How To Obtain Data:
(a) Download online (need to register for free)
(b) Download online

URL to Data (if any):
(a) https://nid.usace.army.mil (Note: You must accept the security certificate in order to view database) OR http://www.nationalatlas.gov/mld/dams00x.html
(b) http://water.usgs.gov/GIS/metadata/usgswrd/XML/runoff.xml

Spatial Resolution:
(a) 80,000 dams (latitude and longitude specifications included only major dams available at National Atlas site)
(b) 1:5,000,000 (runoff of tributary streams)

Temporal Resolution (period and frequency of collection):
(a) 1972-2006; unclear how often it is updated
(b) 1951-1980; 1 time effort

Extent/Coverage of Data Set:
(a) National
(b) National

Type of Data Source:
(a) Database
(b) Modeled dataset

Format of Data:
(a) Tabular (need to copy-paste into Excel)
(b) ArcGIS file (.e00)

Metadata:
- *Calculation of ratio of reservoir storage to mean annual runoff.*
  Graf, W.L., 1999: Dam nation: A geographic census of American dams and their large-scale hydrologic impacts, Water Resources Research, 35 (4): 1305-1311.

Additional Data Characteristics:
Data for this indicator were derived from two sources: dam reservoir storage data from the USACE's NID data set and modeled mean annual runoff estimates based on annual streamflow

data from USGS' mean annual runoff dataset. The storage to runoff ratio can then be calculated (as specified in Graf, 1999 in metadata).

Technical Notes
- *Quality of Source Data:* This indicator uses the National Inventory of Dams to evaluate reservoir storage. This database contains a wide variety of water control structures, some of which may not be relevant for this indicator. An effort to remove irrelevant water control structures (e.g. coastal flood gates, navigational locks) was made, although the accuracy of the dam record attributes used to apply these filters is unclear.

#453 Runoff Variability

Literature Source (see Appendix A for full citation):
Lettenmaier et al., 2008.

Data Sets Used:
University of Washington (Land Surface Hydrology Research Group) - Variable Infiltration Capacity (VIC) Land Surface Data Set.

How To Obtain Data:
Download online (need to register for free).

URL to Data (if any):
http://www.hydro.washington.edu/SurfaceWaterGroup/Data/VIC_retrospective/index.html (file is:
ftp://ftp.hydro.washington.edu/pub/CE/HYDRO/nijssen/vic_global/calibrated/runoff.calibrated.monthly.1980_1993.nc.gz)

Spatial Resolution:
2 degrees

Temporal Resolution (period and frequency of collection):
1950-2000; 3-hourly

Extent/Coverage of Data Set:
National

Type of Data Source:
Modeled dataset

Format of Data:
NetCDF

Metadata:
- *Explanation of VIC model.*

Maurer, E.P., A.W. Wood, J.C. Adam, D.P. Lettenmaier, and B. Nijssen, 2002. A long-term hydrologically-based data set of land surface fluxes and states for the conterminous United States, Journal of Climate, 15: 3237-3251.

- *VIC Global Hydrologic Simulations – Variable descriptions.*
University of Washington (Land Surface Hydrology Research Group). Undated. VIC Global Hydrologic Simulations. Available online at:
http://www.hydro.washington.edu/SurfaceWaterGroup/Data/vic_global.html. Accessed July 21, 2009.

Additional Data Characteristics:
Data on runoff are available from the output of the University of Washington's VIC model which simulates the global land surface hydrological cycle. The model outputs include five model-derived variables: evapotranspiration, snow-water equivalent, soil moisture storage, total storage, and runoff (which is the variable of interest). Detailed descriptions of input variables and output parameters of this model are also availabled (from Maurer et al., 2002 in metadata).

Technical Notes
- *Low-Resolution Data:* This indicator uses simulations of the global land surface hydrological cycle from the Variable Infiltration Capacity (VIC) Model to predict runoff. The native spatial resolution of the model output is a 2° x 2° grid and the model output is stored in NetCDF format. A more recent series of VIC model predictions at a finer spatial resolution may be available from the same source, but the NetCDF file available online appears to be corrupt.

#460 Macroinvertebrate Index of Biotic Condition

Literature Source (see Appendix A for full citation):
USEPA, 2006b.

Data Sets Used:
USEPA - Wadeable Streams Assesment (WSA) (Stream Water Benthic Macroinvertebrate Metrics).

How To Obtain Data:
Download online

URL to Data (if any):
http://www.epa.gov/owow/streamsurvey/web_data.html (file is: wsa_benmet300_ts_final.csv)

Spatial Resolution:
Small streams

Temporal Resolution (period and frequency of collection):
2004-2005; every 5 years (first year of round of data collection was 2004-2005)

Extent/Coverage of Data Set:
National

Type of Data Source:
Survey

Format of Data:
Comma separated

Metadata:
- *Definitions and data descriptions as .txt files.*
  USEPA. 2008. Wadeable Streams Assessment - Definitions of Variables. Available at: http://www.epa.gov/owow/streamsurvey/web_data.html. Accessed July 21, 2009.
- *Site information for WSA sites.*
  USEPA 2008. Wadeable Streams Assessment - Post-Sampling Site Info and Survey Design. Available at: http://www.epa.gov/owow/streamsurvey/web_data.html. Accessed July 21, 2009. (file is: wsa_siteinfo_ts_final.csv).

Additional Data Characteristics:
Data on counts of individual benthic macroinvertebrates at various stages of their life cycle were obtained from EPA's WSA Benthic Macroinvertebrate Metrics data set. Data files are associated with companion text files (using EPA's WSA Definitions of Variables in metadata) that list data set labels and give individual descriptions for each variable. The original literature source, EPA's 2006 WSA report (USEPA, 2006b; see Appendix A for full citation), provides an explanation of how wadeable streams were selected for this study and how data were collected from various sites.

Technical Notes
- *Non-uniform Spatial Distribution of Data:* The sampling effort for EPA's Wadeable Streams Assessment (WSA) varies across HUC-4 units. In cases where there are few sample points within a HUC-4 boundary, individual sites may have a large influence on the average Macroinvertebrate Index of Biotic Condition value that is calculated for that area. The map for this indicator shows a heterogeneous distribution of vulnerability, which may be a reflection of this sensitivity to sampling effort.
- *Local Variation:* Macroinvertebrate community condition varies at local scales and is affected by local factors. By calculating an average value for the Macroinvertebrate Index of Biotic Condition for each HUC-4 unit, localized vulnerability within the HUC-4 unit is masked.

#461 Macroinvertebrate Observed/Expected (O/E) Ratio of Taxa Loss

Literature Source (see Appendix A for full citation):
USEPA, 2006b.

Data Sets Used:
USEPA - Wadeable Streams Assessment (Stream Water Benthic Macroinvertebrate Metrics).

How To Obtain Data:
Download online

URL to Data (if any):
http://www.epa.gov/owow/streamsurvey/web_data.html (file is: wsa_benmet300_ts_final.csv)

Spatial Resolution:
Small streams

Temporal Resolution (period and frequency of collection):
2004-2005; every 5 years (first year of round of data collection was 2004-2005)

Extent/Coverage of Data Set:
National

Type of Data Source:
Survey

Format of Data:
Comma separated

Metadata:
- *Definitions and data descriptions as .txt files.*
  USEPA. 2008. Wadeable Streams Assessment - Definitions of Variables. Available at:
  http://www.epa.gov/owow/streamsurvey/web_data.html. Accessed July 21, 2009.

Additional Data Characteristics:
Data on percent diversity of benthic macroinvertebrates were obtained from EPA's WSA
Benthic Macroinvertebrate Metrics data set. Data files are associated with companion text files
(using EPA's WSA Definitions of Variables in metadata) that list data set labels and give
individual descriptions for each variable. The original literature source, EPA's 2006 WSA report
(USEPA, 2006b; see Appendix A for full citation), provides an explanation of how wadeable
streams were selected for this study and how data were collected from various sites.

Technical Notes
- *Non-uniform Spatial Distribution of Data:* The sampling effort for EPA's Wadeable Streams
  Assessment (WSA) varies across HUC-4 units. In cases where there are few sample points
  within a HUC-4 boundary, individual sites may have a large influence on the average
  Macroinvertebrate O/E value that is calculated for that area. The map for this indicator
  shows a heterogeneous distribution of vulnerability, which may be a reflection of this
  sensitivity to sampling effort.
- *Local Variation:* Macroinvertebrate community condition varies at local scales and is
  affected by local factors. By calculating an average value for the Macroinvertebrate O/E
  Ratio, localized vulnerability is masked.

#462 Coastal Benthic Communities**

Literature Source (see Appendix A for full citation):
USEPA, 2008b.

Data Sets Used:
Underlying sampling data in USEPA's National Coastal Assessment (NCA) database.

How To Obtain Data:
Download online

URL to Data (if any):
http://www.epa.gov/emap/nca/html/data/index.html

Spatial Resolution:
Not clear (EPA's website states that there are "thousands" of sampling sites, but no specific number; data contains latitude/longitude specs.)

Temporal Resolution (period and frequency of collection):
1990-2002; no defined frequency (1 datum/site for only year listed)

Extent/Coverage of Data Set:
National

Type of Data Source:
Database

Format of Data:
Excel

Metadata:
- *Definition and calculation of benthic index.*
  USEPA. 2005. National Coastal Condition Report (NCCR). EPA-620/R-03/002. Available online at: http://www.epa.gov/owow/oceans/nccr/2005/index.html. Accessed July 21, 2009.

Additional Data Characteristics:
The coastal benthic communities index used in this indicator is based on multiple independent variables (described in EPA's NCCR in metadata). Data for these independent variables, (including total count of taxa, total abundance, mean abundance, mean biomass, total biomass, and diversity index) can be obtained from the underlying sampling data in EPA's NCA dataset.

Technical Notes
- *Inconsistencies in Reporting Data:* Data provided on the National Coastal Assessment (NCA) web site were collected by multiple agencies. The methods used to calculate an index to describe the status of benthic communities vary between agencies. These differences make comparisons between states and regions problematic.

- *Data Gaps in National Coverage:* Data are not currently available for many of the nation's coastal areas.

#623 Water Availability: Net Streamflow per Capita

Literature Source (see Appendix A for full citation):
Hurd et al.,1999.

Data Sets Used:
(a) Oregon State University - PRISM Climate Modeling System: Mean Annual Precipitation data
(b) Oregon State University - PRISM Climate Modeling System: Mean Daily Maximum Temperature data
(c) USGS - National Water-Use Dataset.

How To Obtain Data:
Download online

URL to Data (if any):
(a) http://www.prism.oregonstate.edu/products/matrix.phtml
(b) http://www.prism.oregonstate.edu/products/matrix.phtml
(c) http://water.usgs.gov/watuse/

Spatial Resolution:
(a) 30 arc-second (800 meters)
(b) 30 arc-second (800 meters)
(c) HUC-8 watershed

Temporal Resolution (period and frequency of collection):
(a) 1971 – 2000; monthly
(b) 1971 – 2000; monthly
(c) 1985 – 2000; every 5 years

Extent/Coverage of Data Set:
(a) National
(b) National
(c) National

Type of Data Source:
(a) Interpolated grid
(b) Interpolated grid
(c) Database

Format of Data:
ASCII

Metadata:

- *Calculation of streamflow.*
  Vogel, R.M., I. Wilson, and C. Daly. 1999. "Regional Regression Models of Annual Streamflow for the United States." *Journal of Irrigation and Drainage Engineering.* 125(3): 148-157.
- *Metadata for PRISM U.S. average monthly or annual precipitation data.*
  http://www.prism.oregonstate.edu/docs/meta/ppt_30s_meta.htm
- *Metadata for PRISM U.S. average monthly temperature data.*
  http://www.climatesource.com/us/fact_sheets/meta_tmin_us_71b.html
- *Description of water use parameters.*
  USGS. Estimated Use of Water in the United States. Available online at: http://water.usgs.gov/watuse/. Accessed December 15, 2010.

Additional Data Characteristics:
As described in the metadata for (b), mean annual temperature was calculated as the average of the mean maximum and mean minum temperature for a given location.

Technical Notes
There are no technical notes for this indicator.

Appendix D. Mapping Methodology

Aquatic Ecosystems, Water Quality, and Global Change:
Challenges of Conducting Multi-Stressor Global Change Vulnerability Assessments

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Aquatic Ecosystems, Water Quality, and Global Change:
Challenges of Conducting Multi-Stressor Global Change Vulnerability Assessments

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This appendix provides details of the procedures used for mapping each of 26 indicators (including the indicator marked with a * that had an incomplete map.) Maps were created using ArcMap 9.2. Prior to mapping, data were prepared (including aggregation to the appropriate scale, when necessary) using Microsoft Excel or Microsoft Access.

Data sources listed in this appendix and their technical notes are described in greater detail in Appendix C, as are technical issues related to creating or interpreting maps for these indicators. Maps of the 25 indicators are presented in Appendix E (displayed using 4-digit hydrologic units) and in Appendix F (displayed using ecoregions).

#1 Acid Neutralizing Capacity (ANC)

Data Sources (see Appendix C for more details):
- Stream Water Chemistry (Filename: waterchemistry.csv): EPA Wadeable Streams Assessment. Available online at: http://www.epa.gov/owow/streamsurvey/web_data.html
- Stream Site Info: EPA Wadeable Streams Assessment (Filename: wsa_siteinfo_ts_final.csv). Available online at: http://www.epa.gov/owow/streamsurvey/web_data.html
- Hydrologic Units - http://water.usgs.gov/GIS/metadata/usgswrd/XML/huc250k.xml

Processing Steps:
(1) Water chemistry data were downloaded and opened as a comma-delimited text file in Microsoft Excel. The columns containing "SiteID" and "ANC" were saved as a new .dbf file.
(2) The .dbf file with water chemistry data, the hydrologic units, and Site Info were opened in ArcMap 9.2. The water chemistry table was joined to the Site Info table using the SiteID field.
(3) An event theme was mapped for all sites with corresponding water chemistry data, using the LON_DD and LAT_DD fields (North American Datum of 1983).This event theme was exported as a shapefile.
(4) The "AtRisk" field was added to the exported shapefile. If the value in the "ANC" field was < 100, then the AtRisk field value was calculated as 1. All other records were assigned a value of 0.
(5) The sites were aggregated with the 4-digit HUCs using a spatial join. If a HUC contained more than one site, the total (sum) for the numeric fields was calculated. As a result of the spatial join, a new shapefile was created. The "Pct_AtRisk" field was added to the new shapefile, and field values were calculated by using:

$$\text{Percent at Risk} = \frac{\text{At Risk Sites within HUC}}{\text{Total Sites within HUC}}$$

(6) Data were mapped using the Pct_AtRisk field to indicate low, medium, and high vulnerability categories.

#22 Percent of At-Risk Freshwater Plant Communities

Data Sources (see Appendix C for more details):
- Freshwater Plants Status: The H. John Heinz III Center for Science, Economics, and the Environment (Heinz Center). 2009. Email message to Cadmus. April 17, 2009. (Filename: G1-G5 wetlands by state.xls).
- State Boundaries: Environmental Systems Research Institute (ESRI) Data & Maps. – Projected to Albers map projection)
- Hydrologic Units - http://water.usgs.gov/GIS/metadata/usgswrd/XML/huc250k.xml

Processing Steps:
- (1) The Microsoft Excel spreadsheet containing the percentages of at-risk plants was opened in ArcMap. These percentages were reported by state.
- (2) State boundaries and hydrologic units were also opened in ArcMap.
- (3) The percentages were joined to the state boundaries shapefile using a table join and the State Name attribute. The resulting shapefile was intersected with the 4-digit hydrologic units.
- (4) Using the area of each hydrologic unit, the area of the intersected shapes, and the percentage of at-risk plant species, an area-weighted percentage value was calculated for each intersected area.
- (5) The shapefile was dissolved by the 4-digit HUC code to re-aggregate the 4-digit HUCs. The area-weighted percentages were summed.
- (6) The final map was created using the summed area-weighted percentages in the HUC4_AtRiskFWPlants.shp shapefile to indicate low, medium, and high vulnerability categories.

#24 Percent of At-Risk Freshwater Species

Data Sources (see Appendix C for more details):
- Freshwater Species Status: The H. John Heinz III Center for Science, Economics, and the Environment (Heinz Center). 2009. Email message to Cadmus. April 17, 2009. (Filename: AtRiskFWanimalSPby state.xls)
- State Boundaries: Environmental Systems Research Institute (ESRI) Data & Maps. – Projected to Albers map projection)
- Hydrologic Units - http://water.usgs.gov/GIS/metadata/usgswrd/XML/huc250k.xml

Processing Steps:
- (1) The Microsoft Excel spreadsheet containing the percentages of at-risk species was opened in ArcMap. These percentages were reported by state.
- (2) State boundaries and hydrologic units were also opened in ArcMap.
- (3) The percentages were joined to the state boundaries shapefile using a table join and the State Name attribute. The resulting shapefile was intersected with the 4-digit hydrologic units.
- (4) Using the area of each hydrologic unit, the area of the intersected shapes, and the percentage of at-risk species, an area-weighted percentage value was calculated for each intersected area.

(5) The shapefile was dissolved by the 4-digit HUC code to reaggregate the 4-digit HUCs. The area-weighted percentages were summed.

(6) The final map was created using the summed area-weighted percentages in the HUC4_AtRiskFWSpecies.shp shapefile to indicate low, medium, and high vulnerability categories.

#51 Coastal Vulnerability Index

Data Sources (see Appendix C for more details):

- USGS - A Preliminary Database for the U.S. Atlantic, Pacific and Gulf of Mexico Coasts (U.S. Geological Survey Digital Data Series – 68; Three data sets: Gulf Coast, East Coast, and West Coast).) Available online at: http://pubs.usgs.gov/dds/dds68/htmldocs/data.htm

Processing Steps:

(1) ArcGIS shapefiles, containing attributes for the raw CVI variables, CVI, and risk categories associated with CVI values, were opened in ArcMap 9.2.

(2) The Coastal Vulnerability Index (CVI) uses 6 variables, which appear as attributes in the shapefiles:

- Mean Wave Height - - mean elevation of all nonnegative 5' by 5' grid cells within a given 0.25˚ grid cell; values in meters. WIS hindcast nearshore mean wave height 1976-1995.
- Mean Tide Range - average of the mean tide range for all the gauge stations that occur within a given 0.25˚ grid cell (mean tide range is the difference in height between mean high water and mean low water in 1988); values in meters.
- Regional Coastal Slope (%) – Acquired from ETOPO5 and NGDC elevation data.
- Erosion and Accretion rates (m/yr) - the local subsidence trend.
- Relative Sea-Level Rise (mm/yr) – Acquired from NOS tide stations.
- Geomorphology Risk - ordinal value indicative of the type and susceptibility of the landforms within a given 0.25˚ grid cell to inundation and erosion.

(3) The values for each variables are grouped into risk categories, and these risk categories are used to calculate the CVI value using the following formula:

$$CVI = (a*b*c*d*e*f*g)/6] \wedge \tfrac{1}{2}$$

The calculated CVI values are then grouped into risk categories (4 = very high risk, 3 = high risk, 2 = medium risk, 1 = low risk).

(4) Hydrologic units are not a suitable reporting unit for this indicator, so a new coastal unit was produced by creating a 20 mile inland buffer of the shoreline. The buffer was divided into 150-mile long segments to show variation along the coast.

(5) The vertices within the linear geometry of each shapefile feature were converted to points. Each point inherited the attributes, including the CVI risk categories (4 = very high risk, 3 = high risk, 2 = medium risk, 1 = low risk), of the original linear feature. All points within the new coastal units were averaged using a spatial join.

(6) The final map of coastal units was created using the average CVI risk values to indicate low, medium, and high vulnerability categories.

#125 Groundwater Reliance

Data Sources (see Appendix C for more details):
- United States Geological Survey (USGS). Water Usage, 1995
  http://water.usgs.gov/watuse/spread95/ush895.txt
- Hydrologic Units - http://water.usgs.gov/GIS/metadata/usgswrd/XML/huc250k.xml

Processing Steps:
(1) Data from USGS were downloaded and imported into ArcMap 9.2.
(2) The water usage data table was joined to the attribute table for the hydrologic units shapefile, using the "HUC_CODE" and "HUC8Code" fields.
(3) The 8-digit HUC regions were aggregated into 4-digit HUCs with the 'dissolve' function in ArcMap. The "SUB" attribute was used as the basis for the dissolve process. During the dissolve operation, summary statistics were calculated for Total Groundwater Withdrawals (TO_WGWTo) and Total Withdrawals (TO_WTotl) attributes.
(4) After the 4-digit HUC shapefile was produced with the dissolve operation, a new field for Groundwater Reliance (GWRel_95) was added to store groundwater reliance values.
(5) Next, the indicator values were calculated using:

$$\text{Groundwater Reliance (GWRel\_95)} = \frac{\text{Total Groundwater Withdrawals (TO\_WGWTo)}}{\text{Total Withdrawals (TO\_WTotl)}}$$

(6) Finally, the Groundwater Reliance data were displayed on the map with symbology to indicate low, medium, and high vulnerability categories.

#165 Meteorological Drought Indices

Data Sources (see Appendix C for more details):
- Palmer Drought Severity Index: National Climatic Data Center. Available online at: http://www7.ncdc.noaa.gov/CDO/CDODivisionalSelect.jsp#
- NCDC Climate Division Boundaries. Available online at: ftp://ftp.ncdc.noaa.gov/pub/data/divboundaries/gis/
- Hydrologic Units - http://water.usgs.gov/GIS/metadata/usgswrd/XML/huc250k.xml

Processing Steps:
(1) The drought index data were downloaded for the climate divisions within each of the continental U.S. states as comma-delimited text for the years 2003-2007. The data for each state were imported into a Microsoft Access database and compiled into a single table.
(2) A select query was used to compute average Palmer Drought Severity Index values for each climate division over the 2003-2007 time period using values in the PDSI column. The query results were exported as a .dbf.
(3) The NCDC Climate Division Boundaries shapefile was opened in ArcMap 9.2, along with the hydrologic units and the .dbf containing drought severity values.
(4) The DIVISION_ID attribute was used to join the climate boundaries to the drought index data.
(5) The joined shapefile was intersected with the hydrologic units.

(6) Using the area of the original climate boundaries, the area of the intersected shapes, and the PDSI values, an area-weighted Palmer Drought Severity Index value was calculated for each intersected area.
(7) The shapefile was dissolved by the 4-digit HUC code to reaggregate the 4-digit HUCs. The area-weighted percentages were summed during the 'dissolve' operation.
(8) The final map was created using summed area-weighted percentages in the dissolved shapefile to indicate low, medium, and high vulnerability categories.

#190 Number of Dry Periods in Grassland/Shrubland Streams and Rivers*

Data Sources (see Appendix C for more details):
- Grassland Stream Sites and Flow Data, 2002-2006: The H. John Heinz III Center for Science, Economics, and the Environment (Heinz Center). 2009. Email message to Cadmus. April 28, 2009. (Filename: GSdry periods_Cadmus.xls).
- Hydrologic Units - http://water.usgs.gov/GIS/metadata/usgswrd/XML/huc250k.xml

Processing Steps:
(1) The Microsoft Excel spreadsheet containing site and zero-flow data from the Heinz Center was opened in ArcMap, along with the hydrologic units, and Site data.
(2) Grassland sites within the zero-flow table were joined to the site information table using the Site Number field.
(3) An event theme was created for the joined records, using the LON_DD and LAT_DD fields (North American Datum 1983). The event theme was exported as a shapefile.
(4) The sites were aggregated within the 4-digit HUCs using a spatial join. If a HUC contained more than one site, the numeric attributes within the site data were summarized with the "SUM" option. As a result of the spatial join, a new shapefile was created (Ind190_HUC4_Sites.shp).
(5) To determine the average annual percentage of streams with zero-flow period, the proportion of streams with zero flow within each 4-digit HUC was computed for each year, and then the mean of five years (2002-2006) was computed for each HUC.
(6) The final map was created using the Mean_Pct attribute to indicate low, medium, and high vulnerability categories. In 4-digit HUCs where no site data were available, the HUC was assigned to a 'No Data' category.

#218 Ratio of Snow to Total Precipitation

Data Sources (see Appendix C for more details):
- Monthly Climate Data and Observation Station Locations from National Climatic Data Center. Available online at: http://gis.ncdc.noaa.gov/snowfallmo/ (The web site provides access to multiple parameters, including snowfall totals. Data can be downloaded for free from .edu and .gov domains.)
- Hydrologic Units - http://water.usgs.gov/GIS/metadata/usgswrd/XML/huc250k.xml

Processing Steps:

(1) Climate data for all U.S. observation stations were downloaded and imported into Microsoft Access. (Data were downloaded in two batches due to NCDC file size limits).

(2) The ratio of average annual snowfall (Element Code = 'TSNW') to average annual precipitation (Element Code = 'TPCP') was calculated using a series of queries that summed the monthly snow and precipitation totals for each year, calculated an annual ratio, then averaged the annual ratios across the 1998-2007 time period. The output of the queries was saved as a .dbf and imported into ArcMap 9.2.

(3) Observation station site data were also downloaded and opened as a fixed-width file in Excel. Within this file, latitude and longitude coordinates for the observation stations were in the format of Degrees: Minutes. These values were converted in Microsoft Excel to Decimal Degrees using the formula:

$$Decimal\ Degrees = Degrees + (Minutes/60)$$

(4) An event theme was created in ArcMap for the Observation Stations using the adjusted Lat/Long coordinates. This theme was joined to the .dbf containing heat sensitivity data using the "COOPID" attribute. Not all Observation Stations had corresponding heat sensitivity data; sites with heat sensitivity data were exported to shapefile and mapped.

(5) The stations (points) were aggregated within each 4-digit HUC (polygon) using a spatial join. If a HUC contained more than one site, the average value across sites was calculated.

(6) The final map was produced using the Avg_RATIO field to indicate low, medium, and high vulnerability categories.

#219 Ratio of Withdrawals to Streamflow

Data Sources (see Appendix C for more details):

- Mean Annual Precipitation 1971-2000: PRISM Climate Group (Oregon State University). Available online at: http://www.prism.oregonstate.edu/products/matrix.phtml

- Mean Daily Maximum Temperature 1971-2000: PRISM Climate Group (Oregon State University). Available online at: http://www.prism.oregonstate.edu/products/matrix.phtml

- United States Geological Survey (USGS). Water Usage, 1995 http://water.usgs.gov/watuse/spread95/ush895.txt

- Hydrologic Units - http://water.usgs.gov/GIS/metadata/usgswrd/XML/huc250k.xml

Processing Steps:

(1) PRISM data were downloaded and converted to ESRI© GRID format using the ASCII Text to Grid tool in ArcMap 9.2.

(2) Mean daily temperature was calculated with the raster calculator using the following formula as described by Vogel, 1999: (Max Temp + Min Temp) / 2.

(3) Mean precipitation and mean daily temperature within each 4-digit HUC were calculated using the Zonal Statistics function.

(4) A new attribute for mean annual streamflow was calculated with the field calculator in ArcMap for each HUC-4 unit using the regression equations in Vogel, 1999 (Table 2). The HUC-2 code was used to associate each HUC-4 with the appropriate regional regression equation.
(5) The water usage data table was joined to the attribute table for the hydrologic units shapefile, using the "HUC_CODE" and "HUC8Code" fields.
(6) The 8-digit HUC regions were aggregated into 4-digit HUCs with the 'dissolve' function in ArcMap. The "SUB" attribute was used as the basis for the dissolve process. During the dissolve operation, summary statistics were calculated for Total Withdrawals.
(7) Streamflow and withdrawals were adjusted for some HUC-4 units to account for withdrawals and streamflow that occur upstream.
(8) A new attribute for the ratio of withdrawals to streamflow was calculated with the field calculator. The units for streamflow and withdrawals were converted as needed.
(9) The final map was produced indicating low, medium, and high vulnerability categories.

#284 Stream Habitat Quality

Data Sources (see Appendix C for more details):
- Stream Rapid Assessment Metrics: EPA Wadeable Streams Assessment. (Filename: rapidhabmetrics.csv). Available online at: http://www.epa.gov/owow/streamsurvey/web_data.html
- Stream Site Info: EPA Wadeable Streams Assessment. (Filename: wsa_siteinfo_ts_final.csv). Available online at: http://www.epa.gov/owow/streamsurvey/web_data.html
- Hydrologic Units - http://water.usgs.gov/GIS/metadata/usgswrd/XML/huc250k.xml

Processing Steps:
(1) The rapid assessment data were downloaded and opened as a comma-delimited text file in ArcMap, along with the stream site data, and the hydrologic units.
(2) This Rapid Assessment and Site Info tables were joined using the SiteID field.
(3) An event theme was mapped for the joined records, using the LON_DD and LAT_DD fields (North American Datum 1983). Only sites with corresponding Rapid Assessment scores were mapped. This event theme was exported to shapefile.
(4) The sites were aggregated within the 4-digit HUCs using a spatial join. If a HUC contained more than one site, the average value for the Rapid Assessment score (RH_SUM) was calculated. As a result of the spatial join, a new shapefile was created (HUC4_RapidAssessment.shp).
(5) The final map was created using the Avg_RH_SUM field to indicate low, medium, and high vulnerability categories. In 4-digit HUCs where no sampling occurred, the HUC was assigned a 'No Data' category.

#348 Erosion Rate

Data Sources (see Appendix C for more details):

- Revised Universal Soil Loss Equation (RUSLE): RUSLE_1980.asc grid file of soil erosion rates estimated for entire globe at 0.5 deg resolution with the RUSLE. Data were obtained from: Dawen YANG, PhD, Professor, Department of Hydraulic Engineering Tsinghua University, Beijing 100084, China; Tel: +86-10-62796976; Fax: +86-10-62796971; E-mail: yangdw@tsinghua.edu.cn
- State Boundaries: Environmental Systems Research Institute (ESRI) Data & Maps. – Projected to Albers map projection)
- Hydrologic Units - http://water.usgs.gov/GIS/metadata/usgswrd/XML/huc250k.xml

Processing Steps:

(1) The ASCII file containing RUSLE data was converted to raster grid using ASCII to Raster tool in ArcMap.
(2) Using the raster calculator, the grid values were multiplied by 1,000,000 to facilitate conversion to polygons. The raster type was changed to integer.
(3) The raster was converted to a polygon layer using the Raster to Polygon tool in ArcMap.
(4) A new field called RUSLE = grid/1,000,000 was created in the polygon layer.
(5) The Intersect tool was used to combine the HUC4 layer with the RUSLE polygon layer to create a new layer called HUC4_RUSLE_Intersect.
(6) A new field called AREAXRUSLE = AREA · RUSLE was created.
(7) Summarized HUC4_RUSLE_Intersect layer on the HUC ID field (SUB), and calculating the sum of AREAXRUSLE
(8) The summarized data table was joined to the HUC4 polygon layer and exported as a new layer called HUC4_RUSLE.
(9) In HUC4_RUSLE, a new field RUSLE = AREAXRUSLE / AREA was created.
(10) The final map was created using the "RUSLE" attribute in the HUC4_RUSLE.shp shapefile to indicate low, medium, and high vulnerability categories.

#351 Instream Use / Total Streamflow

Data Sources (see Appendix C for more details):

- United States Geological Survey (USGS). Water Usage, 1995 http://water.usgs.gov/watuse/spread95/ush895.txt
- Hydrologic Units - http://water.usgs.gov/GIS/metadata/usgswrd/XML/huc250k.xml
- Mean Annual Runoff: U.S. Geological Survey. Available online at: http://water.usgs.gov/GIS/metadata/usgswrd/XML/runoff.xml
- Groundwater Recharge - WRC (U.S. Water Resources Council), 1978. The Nation's Water Resources: 1975-2000 (Vol. 2). U.S. Government Printing Office, Washington D.C.

Processing Steps:

(1) The water usage data table was joined to the attribute table for the hydrologic units shapefile, using the "HUC_CODE" and "HUC8Code" fields.
(2) The 8-digit HUC regions were aggregated into 4-digit HUCs with the 'dissolve' function in ArcMap. The "SUB" attribute was used as the basis for the dissolve process. During

the dissolve operation, summary statistics were calculated for the Total Groundwater Withdrawals attribute.

(3) After the 4-digit HUC shapefile was produced with the dissolve operation, surface water withdrawal values were converted from megagallons per day to gallons per year.

(4) The isopleths in the mean annual runoff dataset were opened in ArcMap. The Spatial Analyst extension was used to interpolate continuous runoff values across the country.

(5) Mean runoff values within each 4-digit HUC were calculated using the Zonal Statistics function.

(6) An attribute for groundwater recharge rates was added and groundwater overdraft values were calculated based on the definition in the WRC (1978) report: (Groundwater Recharge – Groundwater Withdrawals)

(7) An attribute for instream use was added and calculated based on the definition in the WRC (1978) report: (Streamflow * 0.6)

(8) Indicator values were calculated using the formula described in WRC (1978). Streamflow is assumed to be equal to runoff:

Instream use / (Streamflow – Groundwater overdraft)

(9) Finally, the indicator values were displayed on the map with symbology to indicate low, medium, and high vulnerability categories.

#352 Total Use / Total Streamflow

Data Sources (see Appendix C for more details):

- United States Geological Survey (USGS). Water Usage, 1995
  http://water.usgs.gov/watuse/spread95/ush895.txt
- Hydrologic Units - http://water.usgs.gov/GIS/metadata/usgswrd/XML/huc250k.xml
- Mean Annual Runoff: U.S. Geological Survey. Available online at:
  http://water.usgs.gov/GIS/metadata/usgswrd/XML/runoff.xml
- Groundwater Recharge - WRC (U.S. Water Resources Council), 1978. The Nation's Water Resources: 1975-2000 (Vol. 2). U.S. Government Printing Office, Washington D.C.

Processing Steps:

(1) The water usage data table was joined to the attribute table for the hydrologic units shapefile, using the "HUC_CODE" and "HUC8Code" fields.

(2) The 8-digit HUC regions were aggregated into 4-digit HUCs with the 'dissolve' function in ArcMap. The "SUB" attribute was used as the basis for the dissolve process. During the dissolve operation, summary statistics were calculated for the Total Consumptive Use and Total Groundwater Withdrawals attributes.

(3) After the 4-digit HUC shapefile was produced with the dissolve operation, surface water withdrawal values were converted from megagallons per day to gallons per year.

(4) The isopleths in the mean annual runoff dataset were opened in ArcMap. The Spatial Analyst extension was used to interpolate continuous runoff values across the country.

(5) Mean runoff values within each 4-digit HUC were calculated using the Zonal Statistics function.

(6) An attribute for groundwater recharge rates was added and groundwater overdraft values were calculated based on the definition in the WRC (1978) report: (Groundwater Recharge – Groundwater Withdrawals)

(7) An attribute for instream use was added and calculated based on the definition in the WRC (1978) report: (Streamflow * 0.6)

(8) Indicator values were calculated using the formula described in WRC (1978). Streamflow is assumed to be equal to runoff:

        (Instream use + Total Consumptive Use) / (Streamflow – Groundwater overdraft)

(9) Finally, the indicator values were displayed on the map with symbology to indicate low, medium, and high vulnerability categories.

#364 Pesticide Toxicity Index (PTI)

Data Sources (see Appendix C for more details):

- Pesticide (herbicides and insecticide) Concentrations: USGS NAWQA Program. "The Quality of Our Nation's Waters Pesticides in the Nation's Streams and Ground Water, 1992-2001" (USGS Circular 1291). Available online at: http://water.usgs.gov/nawqa/pnsp/pubs/circ1291/appendix6/appendix6a.txt
- USEPA. 2009. ECOTOX Database. Available online at: http://cfpub.epa.gov/ecotox/. Accessed September 11, 2009.
- NAWQA Sites: USGS. NAWQA Data Warehouse: SiteFile Master. shttp://infotrek.er.usgs.gov/nawqa_queries/sitemaster/index.jsp
- Hydrologic Units: http://water.usgs.gov/GIS/metadata/usgswrd/XML/huc250k.xml

Processing Steps:

(1) EC50 values for all *Daphnia* species for pesticides measured by NAWQA were downloaded from EPA's ECOTOX database. For each pesticide, the mean *Daphnia* EC50 value was calculated.

(2) Pesticide concentration data were downloaded and imported into Microsoft Excel.

(3) In Excel, the concentration of each pesticide at each sample event was divided by its mean Daphnia EC50 value to calculate its toxicity quotient.

(4) The toxicity quotients for all pesticides were summed for each sampling event to calculate that event's PTI. The toxicity quotients for constituents that were not measured or were below detection levels were assumed to be zero.

(5) The PTIs for all sampling events at each site were summed to calculate a site PTI. This table was imported into ArcMap.

(6) The PTI table was joined to the NAWQA Sites using the "STAID" attribute. In some cases, the STAID value required minor edits to correctly join the tables. A total of 187 sites with pesticide concentration data were successfully joined to the NAWQA spatial data.

(7) NAWQA spatial data were displayed as an event theme, using the Latitude and Longitude variables (North American Datum of 1983).

(8) Next, the hydrologic units (4-digit HUCs) were added to the ArcMap project and joined using a spatial join to the NAWQA points. If more than one site with pesticide data was located within a 4-digit HUC, the PTI values were averaged across sites. In some cases, there were no sites with pesticide data within a 4-digit HUC.

(9) The final map was created using symbology to indicate low, medium, and high vulnerability categories for each 4-digit HUC. In 4-digit HUCs where no sampling occurred, the HUC was assigned a 'No Data' category.

Note: Pesticide concentrations in agricultural areas, urban areas, and mixed land use areas were combined for this indicator, although the USGS reports these land use types separately.

#367 Herbicide Concentrations in Streams

Data Sources (see Appendix C for more details):
- Herbicide Concentrations: USGS NAWQA Program. "The Quality of Our Nation's Waters Pesticides in the Nation's Streams and Ground Water, 1992-2001" (USGS Circular 1291). Available online at: http://water.usgs.gov/nawqa/pnsp/pubs/circ1291/appendix6/appendix6a.txt
- NAWQA Sites: USGS. NAWQA Data Warehouse: SiteFile Master. shttp://infotrek.er.usgs.gov/nawqa_queries/sitemaster/index.jsp
- Hydrologic Units: http://water.usgs.gov/GIS/metadata/usgswrd/XML/huc250k.xml

Processing Steps:
(1) Herbicide data were downloaded and imported into Microsoft Excel.
(2) In Excel, measured values for herbicides, herbicide degradates, and fungicides were identified and summed for each sampling event. Constituents that were not measured or were below detection levels were assumed to be zero.
(3) The herbicide concentration table was imported into ArcMap. For each sampling site, the average of these total concentrations was calculated for all sampling events that occurred at that site using the "Summarize" function.
(4) The summarized herbicide table and was joined to the NAWQA Sites using the "STAID" attribute. In some cases, the STAID value required minor edits to correctly join the tables. A total of 182 sites with herbicide concentration data were successfully joined to the NAWQA spatial data.
(5) NAWQA spatial data were displayed as an event theme, using the Latitude and Longitude variables (North American Datum of 1983).
(6) Next, the hydrologic units (4-digit HUCs) were added to the ArcMap project and joined using a spatial join to the NAWQA points. If more than one site with herbicide data was located within a 4-digitt HUC, the concentration values were averaged across sites. In some cases, there were no sites with herbicide data within a 4-digit HUC.
(7) The final map was created using symbology to indicate low, medium, and high vulnerability categories for each 4-digit HUC. In 4-digit HUCs where no sampling occurred, the HUC was assigned a 'No Data' category.

Note: Herbicide concentrations in agricultural areas, urban areas, and mixed land use areas were combined for this indicator, although the USGS reports these land use types separately.

#369 Insecticide Concentrations in Streams

Data Sources (see Appendix C for more details):
- Insecticide Concentrations: USGS NAWQA Program. "The Quality of Our Nation's Waters Pesticides in the Nation's Streams and Ground Water, 1992-2001" (USGS Circular 1291). Available online at:
  http://water.usgs.gov/nawqa/pnsp/pubs/circ1291/appendix6/appendix6a.txt
- NAWQA Sites: USGS. NAWQA Data Warehouse: SiteFile Master. Available online at:
  shttp://infotrek.er.usgs.gov/nawqa_queries/sitemaster/index.jsp
- Hydrologic Units: http://water.usgs.gov/GIS/metadata/usgswrd/XML/huc250k.xml

Processing Steps:
(1) Data were downloaded (see data sources) and imported into Microsoft Excel.
(2) In Excel, measured values for insecticides, insecticide degradates, and acaricides were identified and summed for each sampling event. Constituents that were not measured or were below detection levels were assumed to be zero.
(3) The insecticide concentration table was imported into ArcMap. For each sampling site, the average of these total concentrations was calculated for all sampling events that occurred at that site using the "Summarize" function.
(4) The summarized insecticide table and was joined to the NAWQA Sites using the "STAID" attribute. In some cases, the STAID value required minor edits to correctly join the tables. A total of 182 sites with insecticide concentration data were successfully joined to the NAWQA spatial data.
(5) NAWQA spatial data were displayed as an event theme, using the Latitude and Longitude variables (North American Datum of 1983).
(6) Next, the hydrologic units (4-digit HUCs) were added to the ArcMap project and joined using a spatial join to the NAWQA points. If more than one site with insecticide data was located within a 4-digitt HUC, the concentration values were averaged across sites. In some cases, there were no sites with insecticide data within a 4-digit HUC.
(7) The final map was created using symbology to indicate low, medium, and high vulnerability categories for each 4-digit HUC. In 4-digit HUCs where no sampling occurred, the HUC was assigned a 'No Data' category.

Note: Insecticide concentrations in agricultural areas, urban areas, and mixed land use areas were combined for this indicator, although the USGS reports these land use types separately.

#371 Organochlorines in Bed Sediment

Data Sources (see Appendix C for more details):
- Organochlorine Concentrations: USGS NAWQA Program. "The Quality of Our Nation's Waters Pesticides in the Nation's Streams and Ground Water, 1992-2001" (USGS Circular 1291). Available online at:
  http://water.usgs.gov/nawqa/pnsp/pubs/circ1291/appendix6/appendix6c.txt
- NAWQA Sites: USGS. NAWQA Data Warehouse: SiteFile Master. Available online at:
  shttp://infotrek.er.usgs.gov/nawqa_queries/sitemaster/index.jsp
- Hydrologic Units: http://water.usgs.gov/GIS/metadata/usgswrd/XML/huc250k.xml

Processing Steps:
  (1) Organochlorine concentration data were downloaded and imported into Microsoft Excel.
  (2) In Excel, measured values for all parameters except P49271 (organic carbon in sediment) were summed for each site. Only one sampling event occurred at each site, so aggregation at the site level was not conducted. Constituents that were not measured or were below detection levels were assumed to be zero.
  (3) The organochlorine occurrence data were imported into ArcMap, and joined to the NAWQA Sites using the "STAID" attribute. A total of 1,015 sites with organochlorine concentration data were successfully joined to the NAWQA spatial data.
  (4) NAWQA spatial data were displayed as an event theme, using the Latitude and Longitude variables (North American Datum of 1983).
  (5) The hydrologic units (4-digit HUCs) were opened in ArcMap and joined to the NAWQA points using a spatial join. If more than one site with organochlorine data was located within a 4-digit HUC, the total concentration values were averaged across sites. In some cases, there were no sites with organochlorine data within a 4-digit HUC.
  (6) The final map was created using symbology to indicate low, medium, and high vulnerability categories for each 4-digit HUC. In 4-digit HUCs where no sampling occurred, the HUC was assigned a 'No Data' category.

Note: Organochlorine concentrations in agricultural areas, urban areas, and mixed land use areas were combined for this indicator, although the USGS reports these land use types separately.

#373 Herbicide Concentrations in Groundwater

Data Sources (see Appendix C for more details):
  - Herbicide Concentrations: USGS NAWQA Program. "The Quality of Our Nation's Waters Pesticides in the Nation's Streams and Ground Water, 1992-2001" (USGS Circular 1291). Available online at: http://water.usgs.gov/nawqa/pnsp/pubs/circ1291/appendix6/appendix6b.txt
  - Hydrologic Units: http://water.usgs.gov/GIS/metadata/usgswrd/XML/huc250k.xml

Processing Steps:
  (1) Herbicide concentration data were downloaded and imported into Microsoft Excel.
  (2) In Excel, measured values for herbicides, herbicide degradates, and acaricides were identified and summed for each sampling event. Constituents that were not measured or were below detection levels were assumed to be zero.
  (3) These herbicide occurrence data were imported into ArcMap and displayed as an event theme, using the Latitude and Longitude variables (North American Datum of 1983).
  (4) Next, the hydrologic units (4-digit HUCs) were added to the ArcMap project and joined using a spatial join to the sampling event points. If more than one sampling event with herbicide data occurred within a 4-digit HUC, the concentration values were averaged across events. In some cases, no herbicide collection events occurred within a 4-digit HUC.

(5) The final map was created using symbology to indicate low, medium, and high vulnerability categories for each 4-digit HUC. In 4-digit HUCs where no sampling occurred, the HUC was assigned a 'No Data' category.

Note: Herbicide concentrations in agricultural and urban areas were combined for this indicator, although the USGS reports these land use types separately.

#374 Insecticide Concentrations in Groundwater

Data Sources (see Appendix C for more details):
- Insecticide Concentrations: USGS NAWQA Program. "The Quality of Our Nation's Waters Pesticides in the Nation's Streams and Ground Water, 1992-2001" (USGS Circular 1291). Available online at: http://water.usgs.gov/nawqa/pnsp/pubs/circ1291/appendix6/appendix6b.txt
- Hydrologic Units: http://water.usgs.gov/GIS/metadata/usgswrd/XML/huc250k.xml

Processing Steps:
(1) Insecticide concentration data were downloaded and imported into Microsoft Excel.
(2) In Excel, measured values for insecticides, insecticide degradates, and acaricides were identified and summed for each sampling event. Constituents that were not measured or were below detection levels were assumed to be zero.
(3) These insecticide concentration data were imported into ArcMap and displayed as an event theme, using the Latitude and Longitude variables (North American Datum of 1983).
(4) Next, the hydrologic units (4-digit HUCs) were added to the ArcMap project and joined using a spatial join to the sampling event points. If more than one sampling event with insecticide data occurred within a 4-digit HUC, the concentration values were averaged across events. In some cases, no insecticide collection events occurred within a 4-digit HUC.
(5) The final map was created using symbology to indicate low, medium, and high vulnerability categories for each 4-digit HUC. In 4-digit HUCs where no sampling occurred, the HUC was assigned a 'No Data' category.

Note: Insecticide concentrations in agricultural and urban areas were combined for this indicator, although the USGS reports these land use types separately.

#437 Precipitation Elasticity of Streamflow

Data Sources (see Appendix C for more details):
- Precipitation Elasticity of Streamflow: Adapted from Figure 4 *in* Sankarasubramanian et al. (2001). Water Resources Research 37(6).
- Hydrologic Units - http://water.usgs.gov/GIS/metadata/usgswrd/XML/huc250k.xml

Processing Steps:
(1) An image of Figure 4 was imported into ArcMap and georeferenced.

(2) Using the Spatial Analyst extension, the isopleths in Figure 4 were digitized and used to interpolate continuous elasticity values across the country.
(3) Mean elasticity values within each 4-digit HUC were calculated using the Zonal Statistics function.
(4) The final map was created using symbology to indicate low, medium, and high vulnerability categories for each 4-digit HUC.

Note: For the purposes of mapping this indicator with relative ease, Figure 4 in the original literature source, Sankarasubramanian et al., 2001 (see Appendix A for full reference) was used. However, the complete original data set could also be recalculated for mapping purposes using the data sources listed in Appendix C.

#449 Ratio of Storage to Runoff
Data Sources (see Appendix C for more details):
- Reservoir Storage: National Inventory of Dams (from the National Atlas). Available online at: http://www.nationalatlas.gov/mld/dams00x.html
- Mean Annual Runoff: U.S. Geological Survey. Available online at: http://water.usgs.gov/GIS/metadata/usgswrd/XML/runoff.xml
- Hydrologic Units - http://water.usgs.gov/GIS/metadata/usgswrd/XML/huc250k.xml

Processing Steps:
(1) The isopleths in the mean annual runoff dataset were opened in ArcMap. The Spatial Analyst extension was used to interpolate continuous runoff values across the country.
(2) Mean runoff values within each 4-digit HUC were calculated using the Zonal Statistics function.
(3) The shapefile containing data for dams was opened in ArcMap. The total maximum reservoir storage capacity was calculated by joining the 4-digit HUCs to the dam data using a spatial join. If more than one reservoir occurred within a 4-digit HUC, the storage capacity was summed.
(4) The ratio of storage capacity to mean annual runoff was calculated within each 4-digit HUC and saved within a new attribute.
(5) The final map was created using symbology to indicate low, medium, and high vulnerability categories for each 4-digit HUC.

#453 Runoff Variability
Data Sources (see Appendix C for more details):
- Global Runoff, 1980-1993. Available online at: http://www.hydro.washington.edu/SurfaceWaterGroup/Data/vic_global.html
  Specific data file:
  ftp://ftp.hydro.washington.edu/pub/CE/HYDRO/nijssen/vic_global/calibrated/runoff.calibrated.monthly.1980_1993.nc.gz
- Hydrologic Units - http://water.usgs.gov/GIS/metadata/usgswrd/XML/huc250k.xml

Processing Steps:
    (1) The modeled runoff data were downloaded and decompressed.
    (2) The NetCDF file, containing monthly runoff data, was imported into ArcMap. Monthly grids were exported from the NetCDF format for all months during the 1984-1993 time period (120 months).
    (3) Annual runoff was calculated by aggregating the monthly values for each year.
    (4) The mean and standard deviation of the annual runoff within each 2˚ x 2˚ grid cell was calculated using the 10 annual values.
    (5) The coefficient of variation was calculated by dividing mean annual runoff by the standard deviation for each grid cell.
    (6) The mean coefficient of variation within the 4-digit HUCs was calculated using the Zonal Statistics function.
    (7) The final map was created using symbology to indicate low, medium, and high vulnerability categories for each 4-digit HUC.

#460 Macroinvertebrate Index of Biotic Condition

Data Sources (see Appendix C for more details):
- Stream Water Benthic Macroinvertebrate Metrics: EPA Wadeable Streams Assessment. (Filename: wsa_benmet300_ts_final.csv). Available online at: http://www.epa.gov/owow/streamsurvey/web_data.html
- Stream Site Info: EPA Wadeable Streams Assessment (Filename: wsa_siteinfo_ts_final.csv). Available online at: http://www.epa.gov/owow/streamsurvey/web_data.html
- Hydrologic Units - http://water.usgs.gov/GIS/metadata/usgswrd/XML/huc250k.xml

Processing Steps:
    (1) Benthic macroinvertebrate data were downloaded and opened as a comma-delimited text file in Microsoft Excel. The columns containing the SiteID and Macroinvertebrate Index (MMI_WSA) attributes were saved as a new comma-delimited text file.
    (2) The text file with macroinvertebrate data, the hydrologic units, and Site Info were opened in ArcMap 9.2. The macroinvertebrate and Site Info tables were joined using the SiteID attribute.
    (3) An event theme was mapped for the joined records with corresponding macroinvertebrate data, using the LON_DD and LAT_DD fields (North American Datum 1983). This event theme was exported as a shapefile.
    (4) The sites were aggregated within the 4-digit HUCs using a spatial join. If a HUC contained more than one site, the average value for the Macroinvertebrate Index was calculated.
    (5) The final map was created using the Avg_MMI_WS field to indicate low, medium, and high vulnerability categories. In 4-digit HUCs where no sampling occurred, the HUC was mapped assigned a 'No Data' category.

#461 Macroinvertebrate Observed / Expected Ratio of Taxa Loss

Data Sources (see Appendix C for more details):

- Stream Water Benthic Macroinvertebrate Metrics: EPA Wadeable Streams Assessment. (Filename: wsa_benmet300_ts_final.csv). Available online at: http://www.epa.gov/owow/streamsurvey/web_data.html
- Stream Site Info: EPA Wadeable Streams Assessment. (Filename: wsa_siteinfo_ts_final.csv). Available online at: http://www.epa.gov/owow/streamsurvey/web_data.html
- Hydrologic Units - http://water.usgs.gov/GIS/metadata/usgswrd/XML/huc250k.xml

Processing Steps:

(1) Benthic macroinvertebrate data were downloaded and opened as a comma-delimited text file in Microsoft Excel. The columns containing the SiteID and Macroinvertebrate O/E Ratio (OE_5_3REG) attributes were saved as a new comma-delimited text file.
(2) The text file with macroinvertebrate data, the hydrologic units, and Site Info were opened in ArcMap 9.2. The macroinvertebrate and Site Info tables were joined using the SiteID attribute.
(3) An event theme was mapped for the joined records with corresponding macroinvertebrate data, using the LON_DD and LAT_DD fields (North American Datum 1983). This event theme was exported as a shapefile.
(4) The sites were aggregated within the 4-digit HUCs using a spatial join. If a HUC contained more than one site, the average value for the O/E Ratio was calculated.
(5) The final map was created using the Avg_OE_5_3 field to indicate low, medium, and high vulnerability categories. In 4-digit HUCs where no sampling occurred, the HUC was mapped assigned a 'No Data' category.

#623 Water Availability: Net Streamflow per Capita

Data Sources (see Appendix C for more details):

- Mean Annual Precipitation 1971-2000: PRISM Climate Group (Oregon State University). Available online at: http://www.prism.oregonstate.edu/products/matrix.phtml
- Mean Daily Maximum Temperature 1971-2000: PRISM Climate Group (Oregon State University). Available online at: http://www.prism.oregonstate.edu/products/matrix.phtml
- United States Geological Survey (USGS). Water Usage, 1995 http://water.usgs.gov/watuse/spread95/ush895.txt This data set includes population within each HUC-8 unit.
- Hydrologic Units - http://water.usgs.gov/GIS/metadata/usgswrd/XML/huc250k.xml

Processing Steps:

(1) PRISM data were downloaded and converted to ESRI© GRID format using the ASCII Text to Grid tool in ArcMap 9.2.
(2) Mean daily temperature was calculated with the raster calculator using the following formula as described by Vogel, 1999: (Max Temp + Min Temp) / 2.

(3) Mean precipitation and mean daily temperature within each 4-digit HUC were calculated using the Zonal Statistics function.

(4) A new attribute for mean annual streamflow was calculated with the field calculator in ArcMap for each HUC-4 unit using the regression equations in Vogel, 1999 (Table 2). The HUC-2 code was used to associate each HUC-4 with the appropriate regional regression equation.

(5) The water usage data table was joined to the attribute table for the hydrologic units shapefile, using the "HUC_CODE" and "HUC8Code" fields.

(6) The 8-digit HUC regions were aggregated into 4-digit HUCs with the 'dissolve' function in ArcMap. The "SUB" attribute was used as the basis for the dissolve process. During the dissolve operation, summary statistics were calculated for total population and total withdrawals.

(7) Streamflow and withdrawals were adjusted for some HUC-4 units to account for streamflow and withdrawals upstream of the HUC-4 unit.

(8) A new attribute for net per capita streamflow was calculated with the field calculator, using the following equation:

$$(\text{Streamflow} - \text{Withdrawals}) / \text{Population}$$

The units for streamflow and population were converted as needed.

(9) The final map was produced indicating low, medium, and high vulnerability categories.

Appendix E. Example Maps for Indicators of Water Quality and Aquatic Ecosystem Vulnerability, Displayed Using 4-digit Hydrologic Units

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This appendix contains example maps (and map descriptions) for 25 vulnerability indicators displayed using 4-digit hydrologic units. These maps are intended to illustrate the methodological challenges of creating indicator maps, and rely on simplifying assumptions (such as the use of quantiles instead of thresholds). Therefore, they are not appropriate for drawing conclusions regarding the vulnerability of water quality and aquatic ecosystems in any particular state or region. Descriptions of U.S. geographic regions are based on definitions provided by the U.S. Census Bureau. Subregion descriptions were based on U.S. Census definitions, but modified slightly for clarity.

1. **Northeast**
   a. New England
   i. Connecticut
   ii. Maine
   iii. Massachussetts
   iv. New Hampshire
   v. Rhode Island
   vi. Vermont
   b. Middle Atlantic
   i. New Jersey
   ii. New York
   iii. Pennsylvania
2. **Midwest**
   a. Great Lakes
   i. Indiana
   ii. Illinois
   iii. Michigan
   iv. Ohio
   v. Wisconsin
   b. Western Midwest
   i. Iowa
   ii. Kansas
   iii. Minnesota
   iv. Missouri
   v. Nebraska
   vi. North Dakota

   vii. South Dakota
3. **South**
   a. South Atlantic
   i. Delaware
   ii. District of Columbia
   iii. Maryland
   iv. North Carolina
   v. South Carolina
   vi. Virginia
   vii. West Virginia
   b. Southeast
   i. Florida
   ii. Georgia
   iii. Kentucky
   iv. Alabama
   v. Mississippi
   vi. Tennessee
   c. Central South
   i. Texas
   ii. Oklahoma
   iii. Arkansas
   iv. Louisiana
4. **West**
   a. Mountain West
   i. Arizona
   ii. Colorado

   iii. Idaho
   iv. New Mexico
   v. Montana
   vi. Utah
   vii. Nevada
   viii. Wyoming
   b. Pacific West
   i. California
   ii. Oregon
   iii. Washington

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#1 Acid Neutralizing Capacity, 2000-2004

Percent of Sites with ANC < 100 millieq/L

- 0%
- 0.0001% - 10.00%
- 10.01% - 17.39%
- 17.40% - 25.00%
- 25.01% - 100.0%
- No Data
- States

0 100 200 300 400 500 Miles

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#1 Acid Neutralizing Capacity

This continental U.S. indicator map shows the percentage of sites with Acid Neutralizing Capacity (ANC) less than 100 millieq/L in each HUC-4 area. Data were available for the vast majority of lower-48 watersheds. The majority of watersheds are at 0%. Most of the watersheds with less ANC are a narrow band which spans from the Southeast to the Northeast. Only six watersheds are in the lowest category of ANC (25.01 - 100% of sites <100 millieq/L).
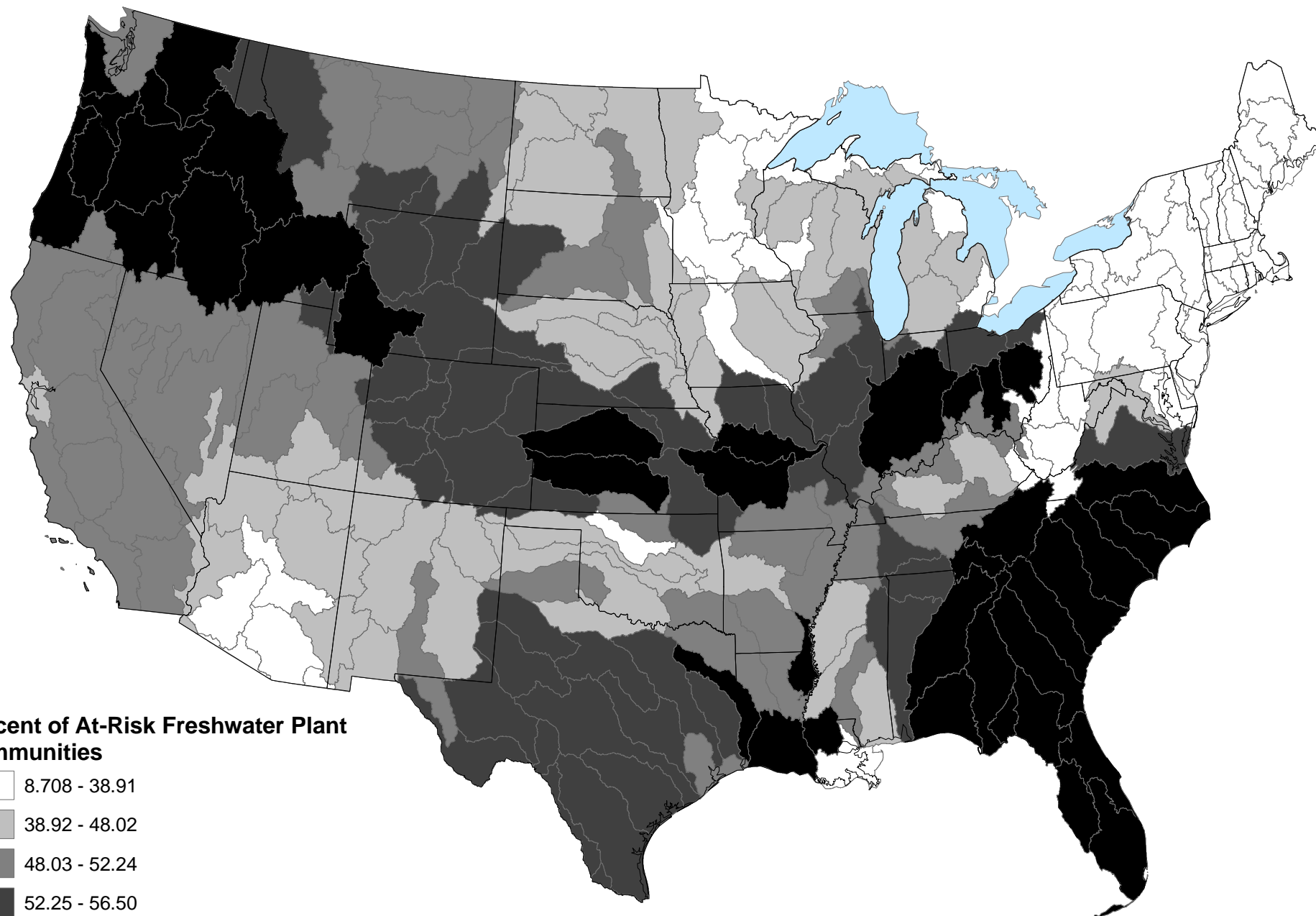
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#22 At-Risk Freshwater Plant Communities, 2006

Percent of At-Risk Freshwater Plant Communities

- 8.708 - 38.91
- 38.92 - 48.02
- 48.03 - 52.24
- 52.25 - 56.50
- 56.51 - 100.0
- States
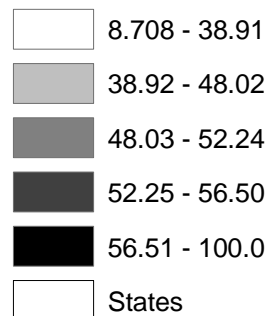
0 100 200 300 400 500 Miles

#22 At-Risk Freshwater Plant Communities

The continental U.S. map for this indicator shows the percentage of freshwater plant communities that are considered at-risk in each HUC-4 area. Data were available for all lower-48 watersheds. The regions with the highest percentages of freshwater plant communities at risk (56.51 - 100.0% at risk) for this indicator occur in the South Atlantic, Southeast, Northwest, large parts of Kansas, Missouri, Indiana, Ohio, and Louisiana. Relatively high percentages of plant communities at risk (52.25 - 56.50%) occur in Texas and in parts of the Mountain West and Midwest, extending eastward from Wyoming to Ohio.

Moderate percentages of plant communities at risk (48.03 - 52.24%) occur in a contiguous band in the Southwest, and in large parts of Montana, South Dakota, and Arkansas. Relatively lower percentages of communities at risk (38.92 - 48.02%) occur in two vertical bands in the northern Midwest region, and a horizontal band in the Southwest, including parts of Arizona, New Mexico, and small parts of Texas and Oklahoma. The Northeast and parts of Minnesota, Iowa, and Arizona have the lowest percentages (8.708 - 38.91%) of at-risk freshwater plant communities.

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#24 At-Risk Native Freshwater Species, 2009
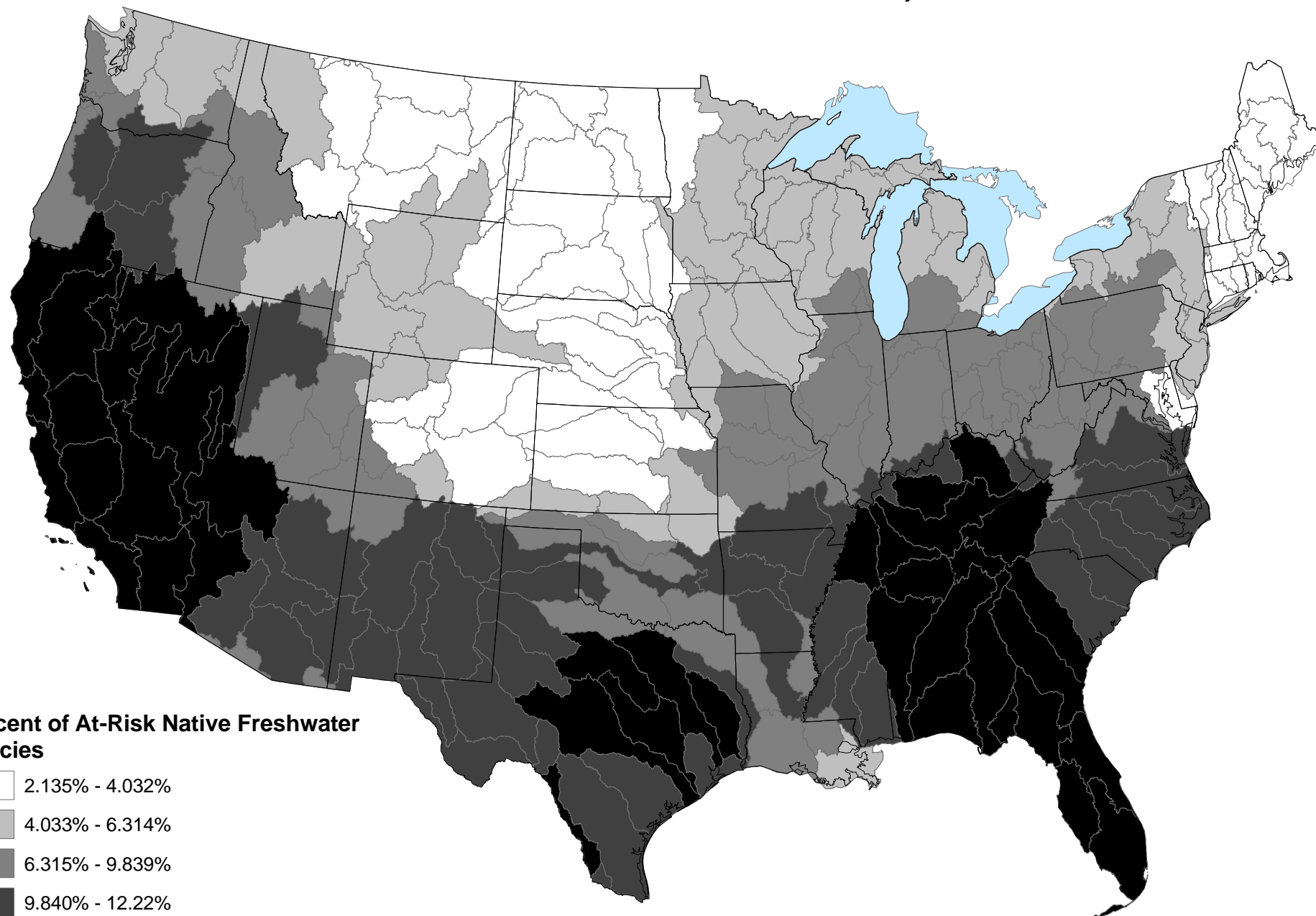
Percent of At-Risk Native Freshwater Species

- 2.135% - 4.032%
- 4.033% - 6.314%
- 6.315% - 9.839%
- 9.840% - 12.22%
- 12.23% - 25.25%
- States
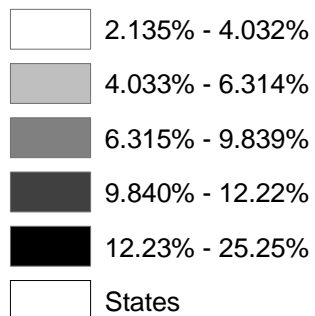
0 100 200 300 400 500 Miles

#24 At-Risk Native Freshwater Species

This continental U.S. indicator map shows the percentage of at-risk native freshwater species in each HUC-4 area. Data were available for all lower-48 watersheds. This map displays a very clear pattern. Homogenous blocks of high percentages of risk (12.23 - 25.25%) are found in the Southwest, East Texas, and the Southeast. With very few exceptions, risk is a steady gradation from these areas to New England and the central U.S., which are at very low percentages of risk (2.135 - 4.032%). The Chesapeake Bay is also an area with low percentage of species at risk.

#51 Coastal Vulnerability Index, 2001

Coastal Vulnerability Index

☐	1.00 - 1.77
▨	1.78 - 2.41
▨	2.42 - 2.83
▨	2.84 - 3.18
■	3.19 - 3.97
☐	States

0　100　200　300　400　500 Miles

#51 Coastal Vulnerability Index– CVI

This continental U.S. indicator map shows the Coastal Vulnerability Index (CVI) for coastline areas. Data were available for all lower-48 coastlines. Areas of high vulnerability (3.19 - 3.97) include parts of the California, Texas, and North Carolina, as well as the entire Mississippi Delta coastline and the Chesapeake Bay. Areas of moderate (2.84 - 3.18), medium (2.42 - 2.83), and low (1.78 - 2.41) vulnerability are interspersed along the coastline. Very low (1.00 - 1.77) vulnerability occurs mostly on the Northeast coastline.

#125 Groundwater Reliance, 1995
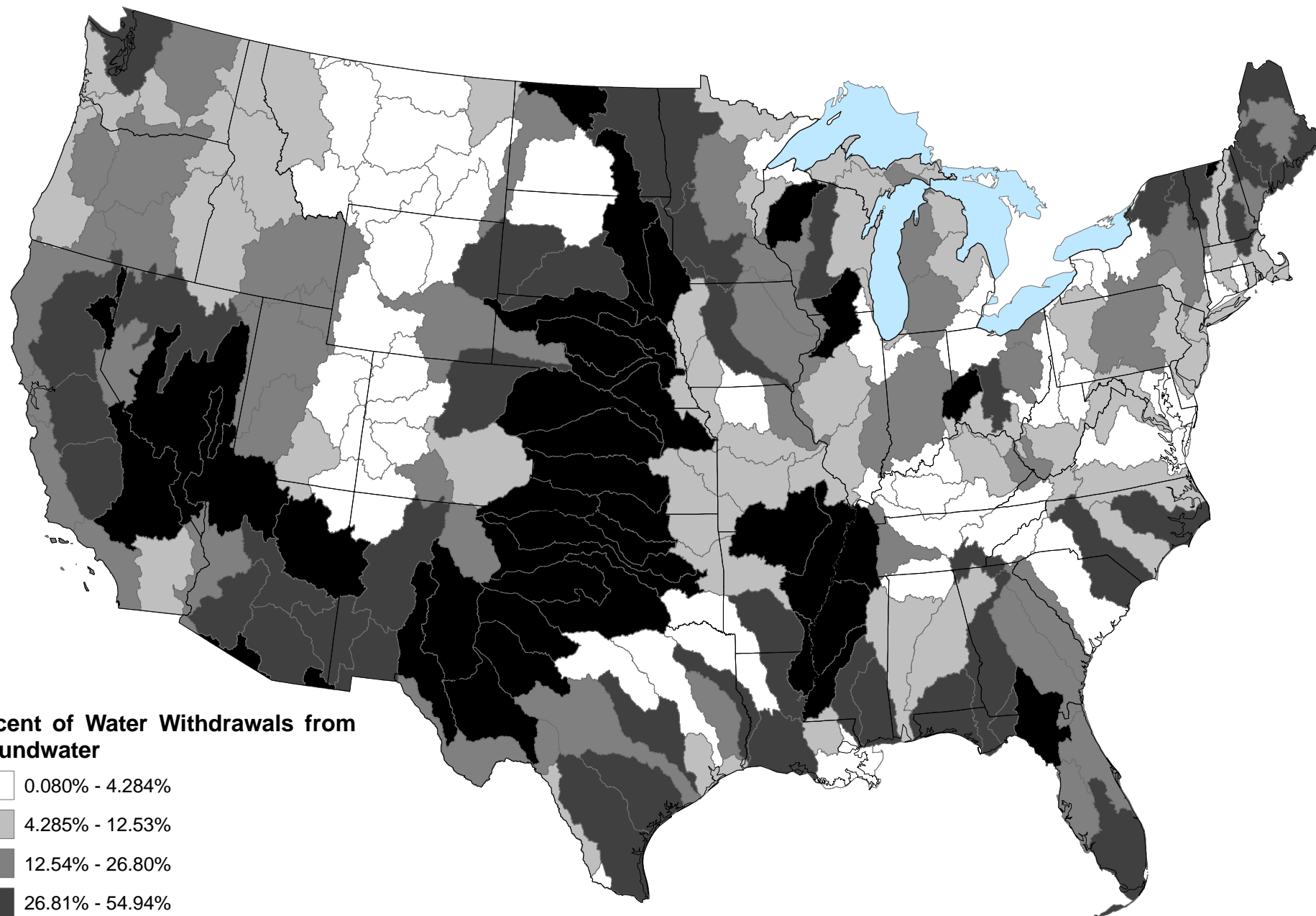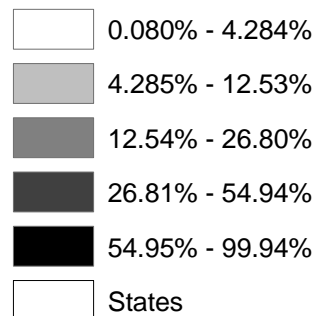
Percent of Water Withdrawals from Groundwater

- 0.080% - 4.284%
- 4.285% - 12.53%
- 12.54% - 26.80%
- 26.81% - 54.94%
- 54.95% - 99.94%
- States

0   100   200   300   400   500 Miles

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#125 Groundwater Reliance

This continental U.S. indicator map shows the percentage of groundwater reliance in each HUC-4 area. Data were available for all lower-48 watersheds. A high level (54.95 - 99.94%) of groundwater reliance is mainly observed in a vertical band in the Midwest, stretching from parts of North Dakota to much of West Texas, as well as in two clusters in the Southwest and along the Mississippi River. Moderate to low (4.285 - 54.94%) groundwater reliance is observed scattered across the nation. The main area with almost no groundwater reliance (0.080 - 4.284%) is in the Mountain West, and stretches from Montana to the Four Corners. Other watersheds with almost no groundwater reliance are scattered across the nation, most notably in central Texas; which is in direct contrast with adjacent watersheds with high groundwater reliance.
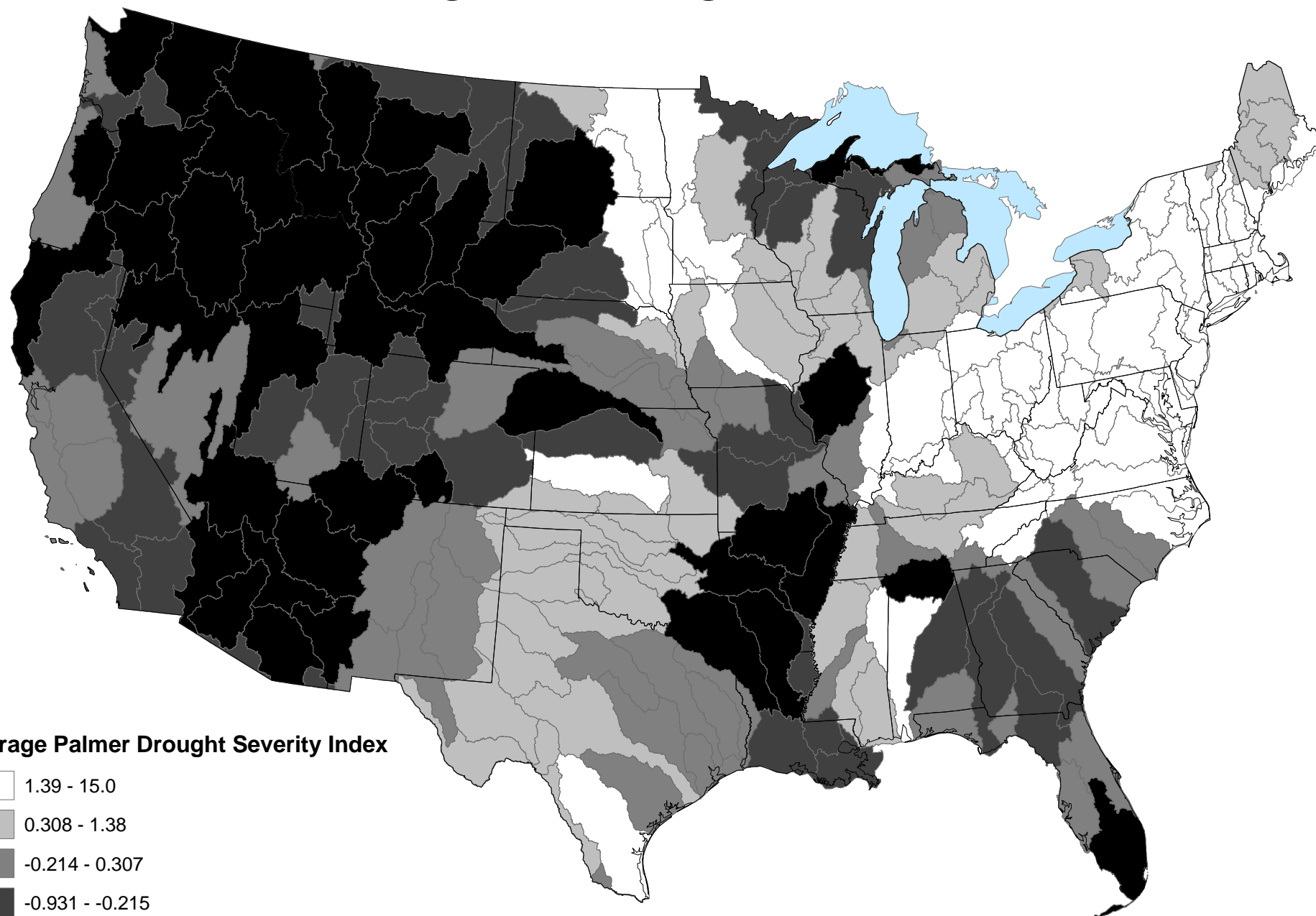
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#165 Meteorological Drought Indices, 2003-2007

Average Palmer Drought Severity Index

- 1.39 - 15.0
- 0.308 - 1.38
- -0.214 - 0.307
- -0.931 - -0.215
- -7.33 - -0.932
- States

0   100   200   300   400   500 Miles
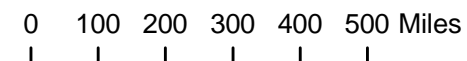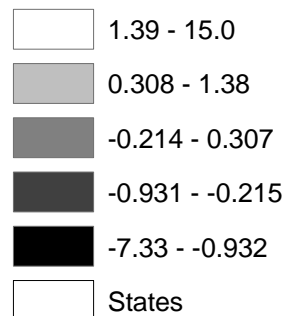
#165 Meteorological Drought Indices

This continental U.S. indicator map shows the average Palmer Drought Severity Index (PDSI) in each HUC-4 area. Data were available for all lower-48 watersheds. A high PDSI values (1.39 to 15) are observed mainly in the Northeast. Moderate and low PDSI values (0.308 to 1.38, and -0.214 to 0.307) are observed in the central Midwestern states. Very low and extremely low PDSI values (-0.931 to -0.215, and -7.33 to -0.932) are observed mainly in the Northwest, southern Mountain West, Central South, and the Southeast.
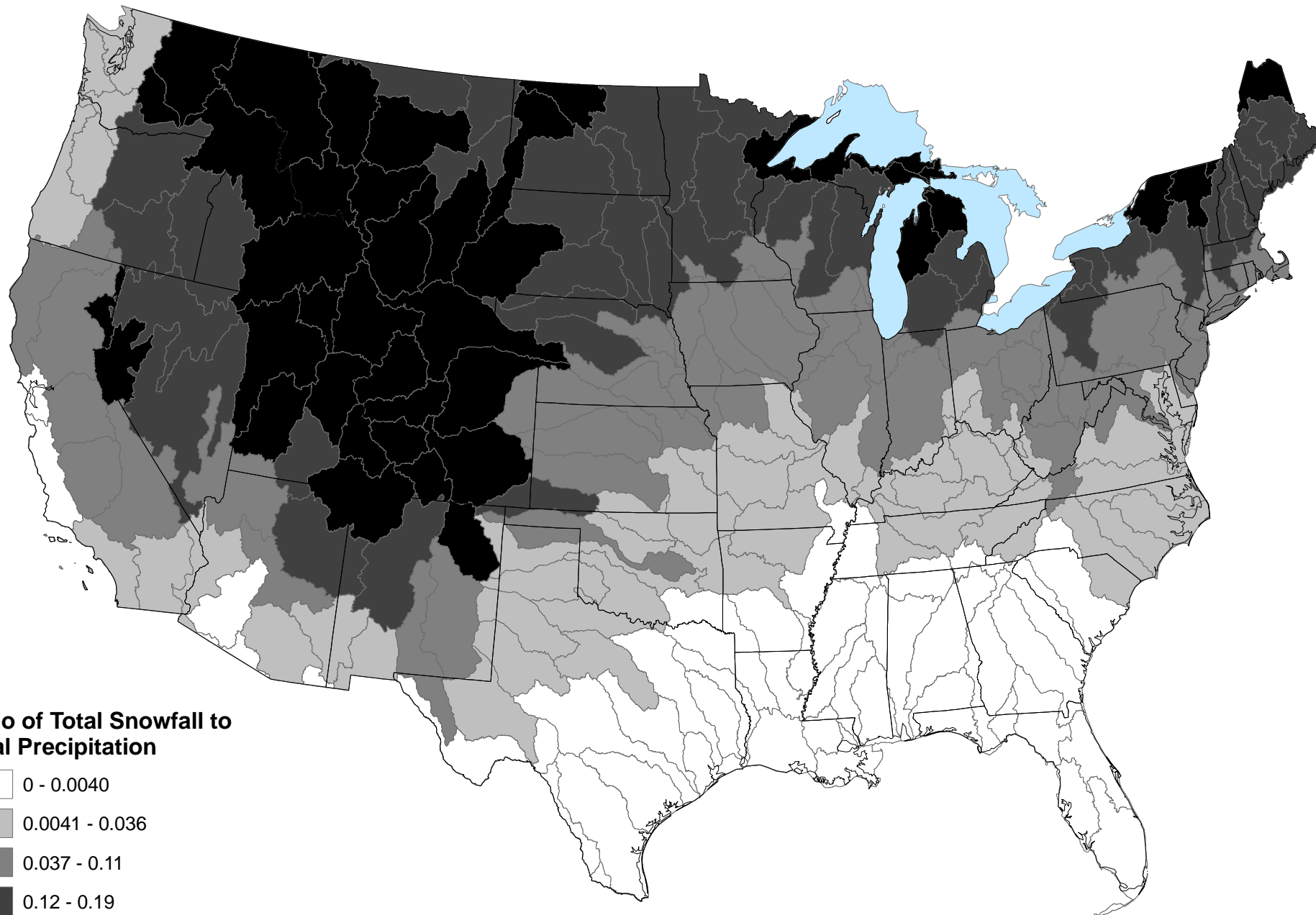
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#218 Ratio of Snow to Total Precipitation, 1998-2007

Ratio of Total Snowfall to Total Precipitation

- 0 - 0.0040
- 0.0041 - 0.036
- 0.037 - 0.11
- 0.12 - 0.19
- 0.20 - 0.47
- States

0 100 200 300 400 500 Miles
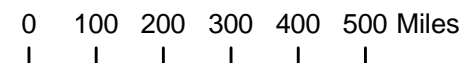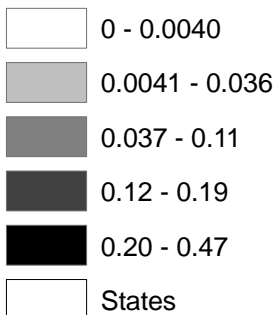
#218 Ratio of Snow to Total Precipitation

This continental U.S. indicator map shows the ratio of total snowfall to total precipitation in each HUC-4 area. Data were available for all lower-48 watersheds. Unsurprisingly, this map shows a strong north-south trend, with the highest ratios (0.20 - 0.47) in the northen and mountainous regions, including the West, Great Lakes region, and parts of New England. These high ratios are surrounded by graded bands of moderate (0.12 - 0.19), low (0.037 - 0.11), and very low (0.0041 - 0.036) snowfall to total precipitation ratios. Parts of California and Arizona have a ratio of zero, as does the Gulf Region.

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#219 Ratio of Water Withdrawls to Annual Streamflow, 1995

Total Withdrawls / Annual Streamflow

- 0.00068 - 0.055
- 0.056 - 0.16
- 0.17 - 0.53
- 0.54 - 1.5
- 1.6 - 59
- States
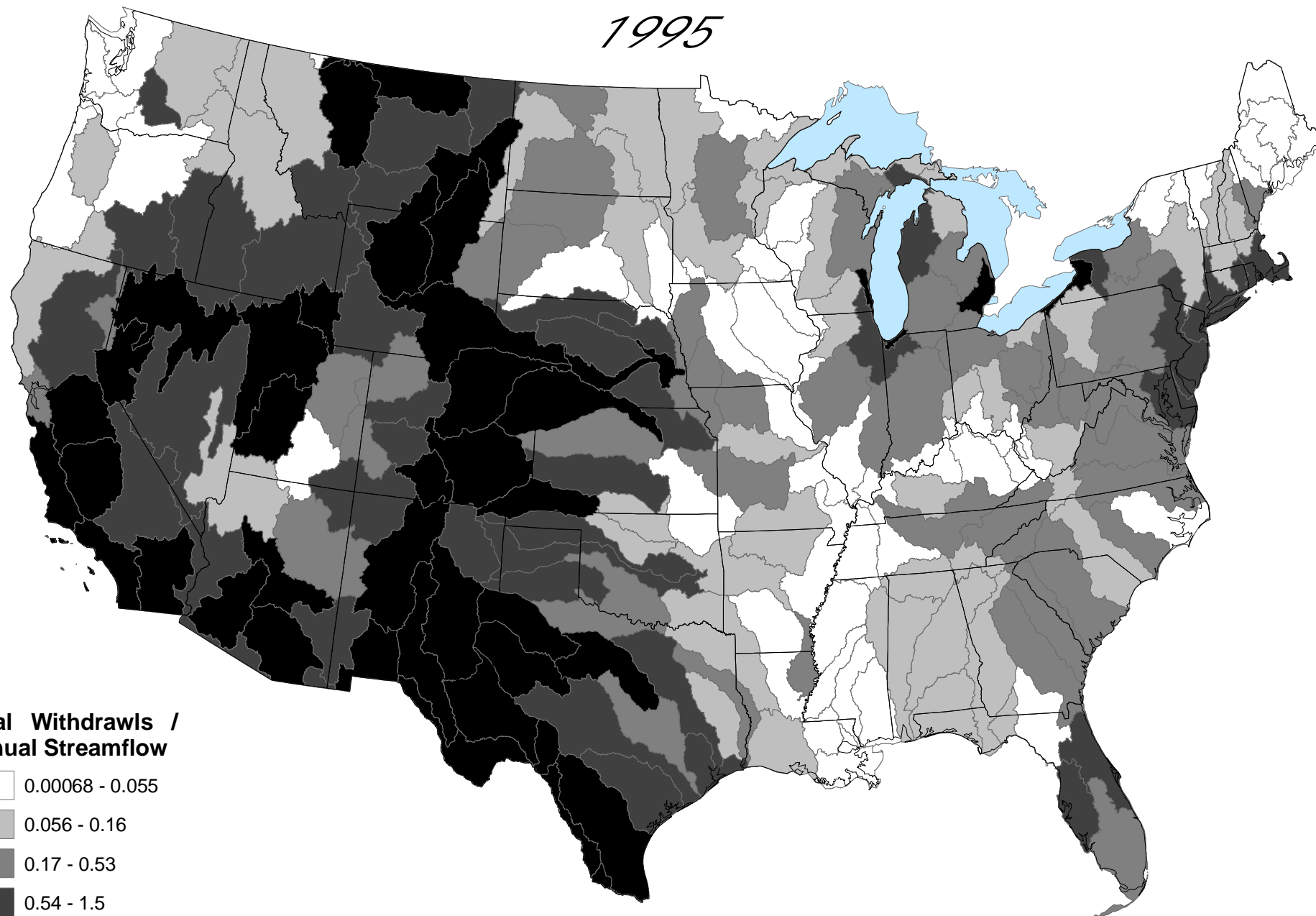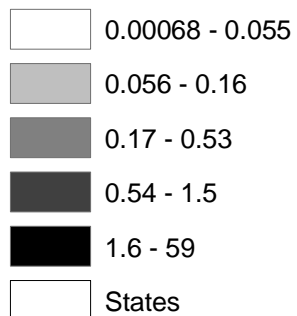
0   100   200   300   400   500 Miles

#219 Ratio of Water Withdrawals to Annual Streamflow

This continental U.S. indicator map shows the ratio of water withdrawals to annual streamflow in each HUC-4 area. Data were available for all lower-48 watersheds. High ratios (1.6 - 59) are almost exclusively found in the West (with small exceptions in the Lower Peninsula of Michigan and the Buffalo region). Moderate ratios (0.54 - 1.5) are found largely in the West, along the Middle Atlantic Corridor, in Florida, and in the Great Lakes region. Low (0.17 - 0.53) and very low (0.056 - 0.16) ratios are scattered throughout the country, but with higher prevalence in the East. Ratios of almost zero (0.00068 - 0.055) are found largely near the Mississippi River or tributaries, in the Pacific Northwest, and in New England.

#284 Stream Habitat Quality, 2000-2004
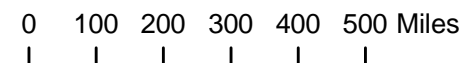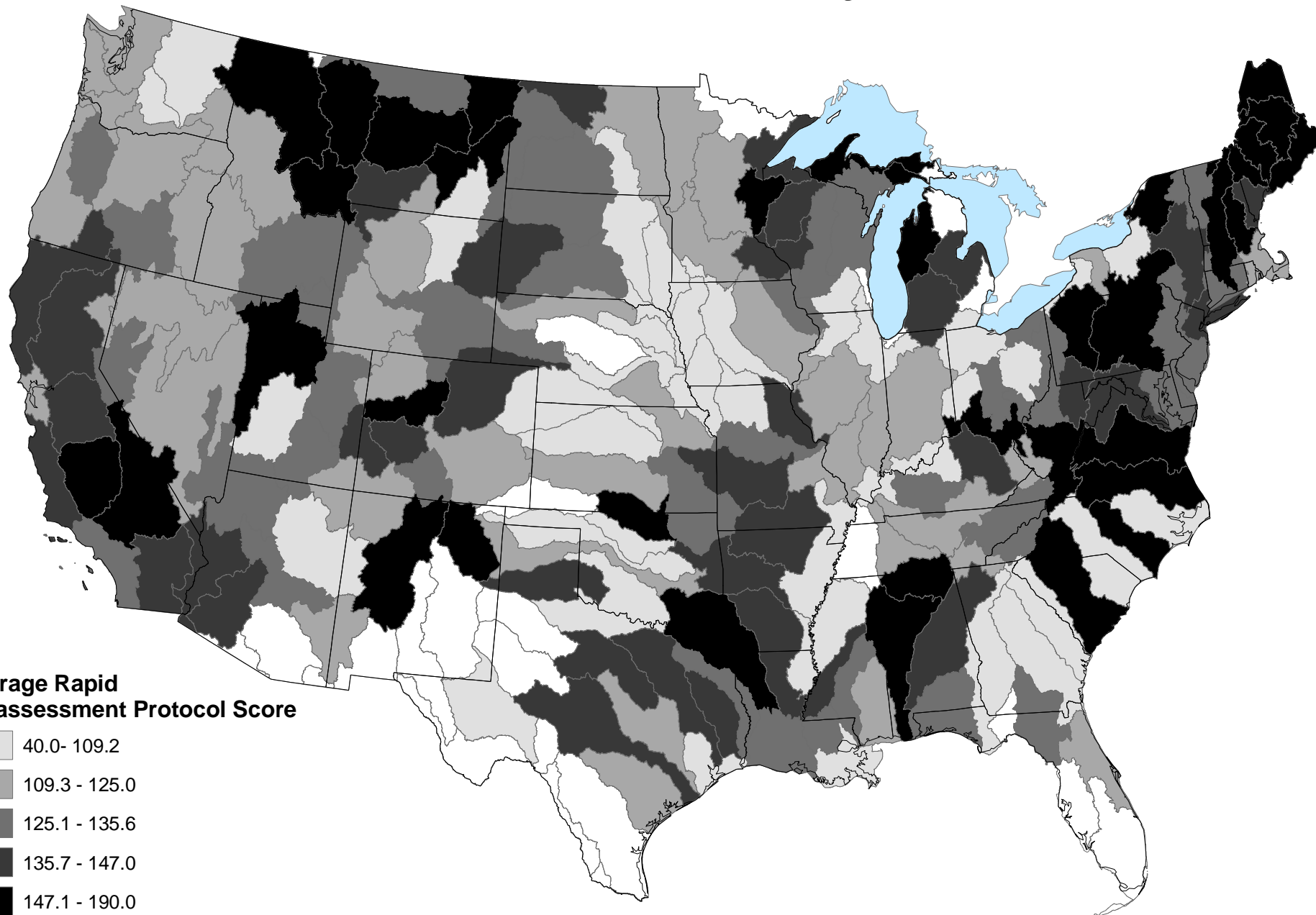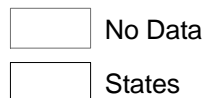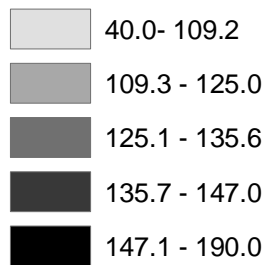
**Average Rapid
Bioassessment Protocol Score**

- 40.0- 109.2
- 109.3 - 125.0
- 125.1 - 135.6
- 135.7 - 147.0
- 147.1 - 190.0
- No Data
- States

0   100   200   300   400   500 Miles

#284 Stream Habitat Quality

This continental U.S. indicator map shows stream habitat quality, as defined by the average rapid bioassessment protocol score, in each HUC-4 area. Data were available for the vast majority of lower-48 watersheds. The highest scores (147.1 - 190.0 and 135-.7 - 147.0) are scattered throughout the country, with clusters found in the South Atlantic and Northeast, the northern Mountain West, and the Pacific Northwest. Moderate scores (125.1 - 135.6 and 109.3 - 125.0) are also found throughout the country, with clusters in the Northwest and Great Lakes Region. The lowest scores (40.0 - 109.2) are found in Georgia and a vertical band in the Midwest.

#326 Wetland and Freshwater Species At-Risk, 2006
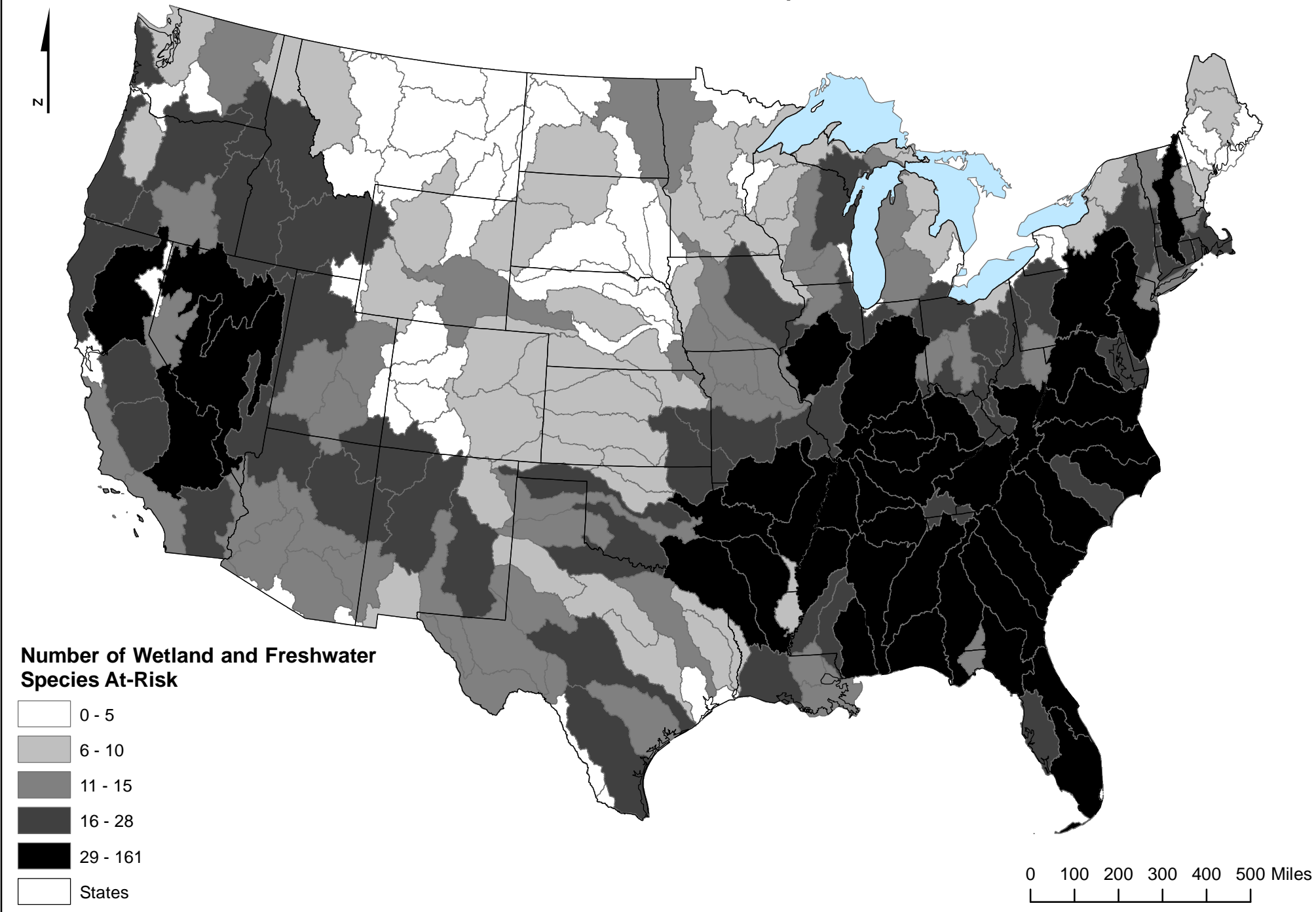
Number of Wetland and Freshwater Species At-Risk

- 0 - 5
- 6 - 10
- 11 - 15
- 16 - 28
- 29 - 161
- States

0 100 200 300 400 500 Miles

#326 Wetland and Freshwater Species at Risk

This continental U.S. indicator map shows the number of wetland and freshwater species that are at risk in each HUC-4 area. Data were available for all lower-48 watersheds. A large number (29 - 161) of species are at risk in most of the watersheds in the Southeast, and in a few watersheds in the Northeast and West. Watersheds with a moderate (16 - 28) number of species at risk are largely found near watersheds with a high number of species at risk. Watersheds with a low (11 - 15) and very low (6 - 10) number of species at risk are found everywhere but the Southeast. Watersheds with almost no (0 - 5) species at risk are mostly found in the northern Mountain West and Western Midwest

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#348 Erosion Rate, 1980

Soil Loss (tons/ha/year)

- 0.5391 - 2.888
- 2.889 - 4.205
- 4.206 - 5.861
- 5.862 - 9.594
- 9.595 - 25.57
- States

0   100   200   300   400   500 Miles

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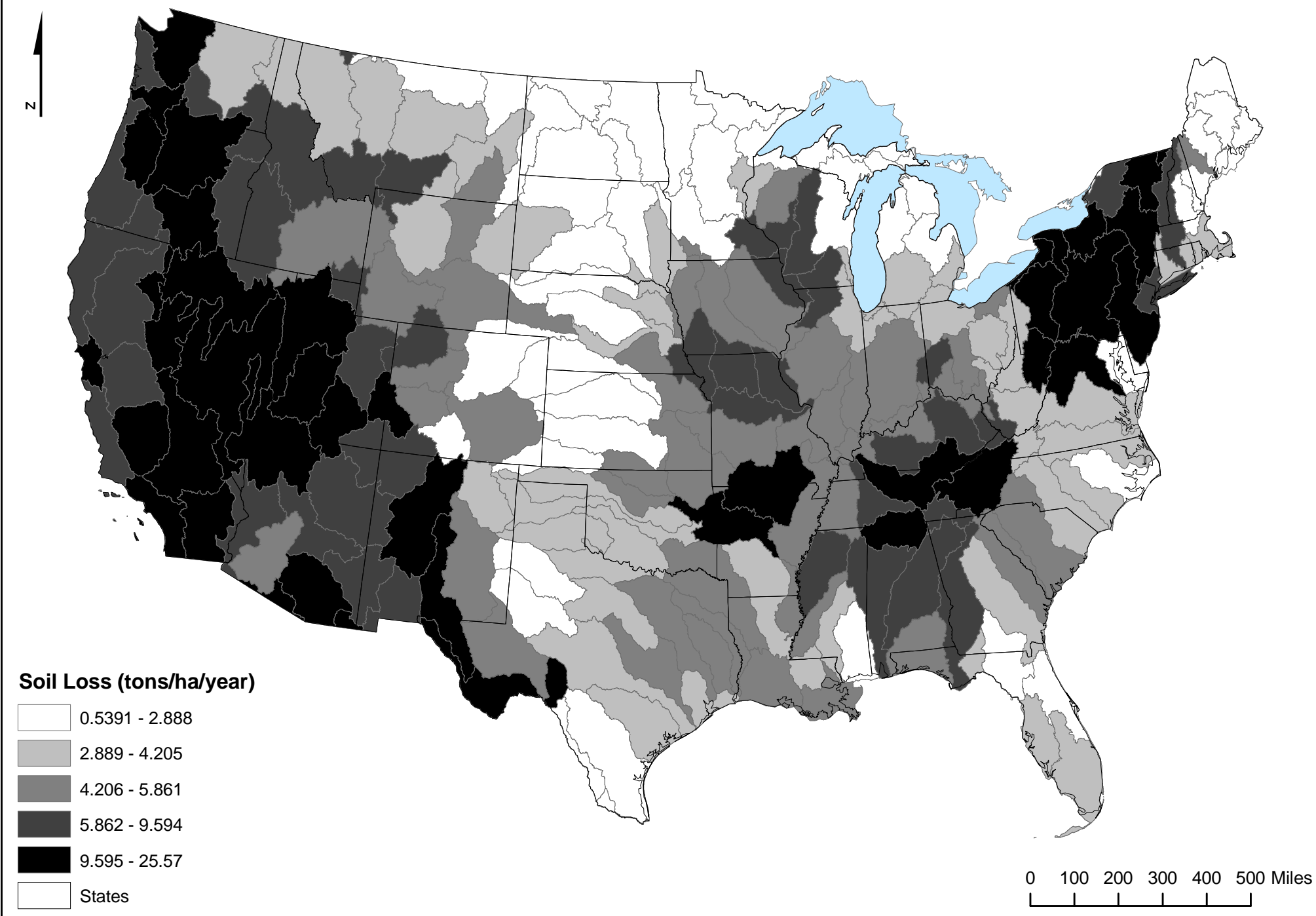
#348 Erosion Rate

This continental U.S. indicator map shows the average erosion rate in each HUC-4 area. Data were available for all lower-48 watersheds. High (9.595 - 25.57 tons/ha/year) and moderate (5.862 - 9.594 tons/ha/year) soil loss is found principally in the West, Middle Atlantic, and parts of the Southeast. Lower (0.5391 - 5.861 tons/ha/year) soil loss rates are found scattered about the country and in a vertical band from Montana to Texas.

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#351 In-Stream Use / Total Streamflow

In-Stream Use / Total Streamflow

▢	0.60 - 1.00
▪	1.01 - 1.09
▢	States

0   100   200   300   400   500 Miles

#351 Instream Use/Total Streamflow

This continental U.S. indicator map shows the ratio of in stream use to total streamflow in each HUC-4 area. Data were available for all lower-48 watersheds. All watersheds but one fall in the 0.60 to 1.00 category, with one watershed in Oklahoma and Kansas in the 1.01 to 1.09 category.

#352 Total Use / Total Streamflow
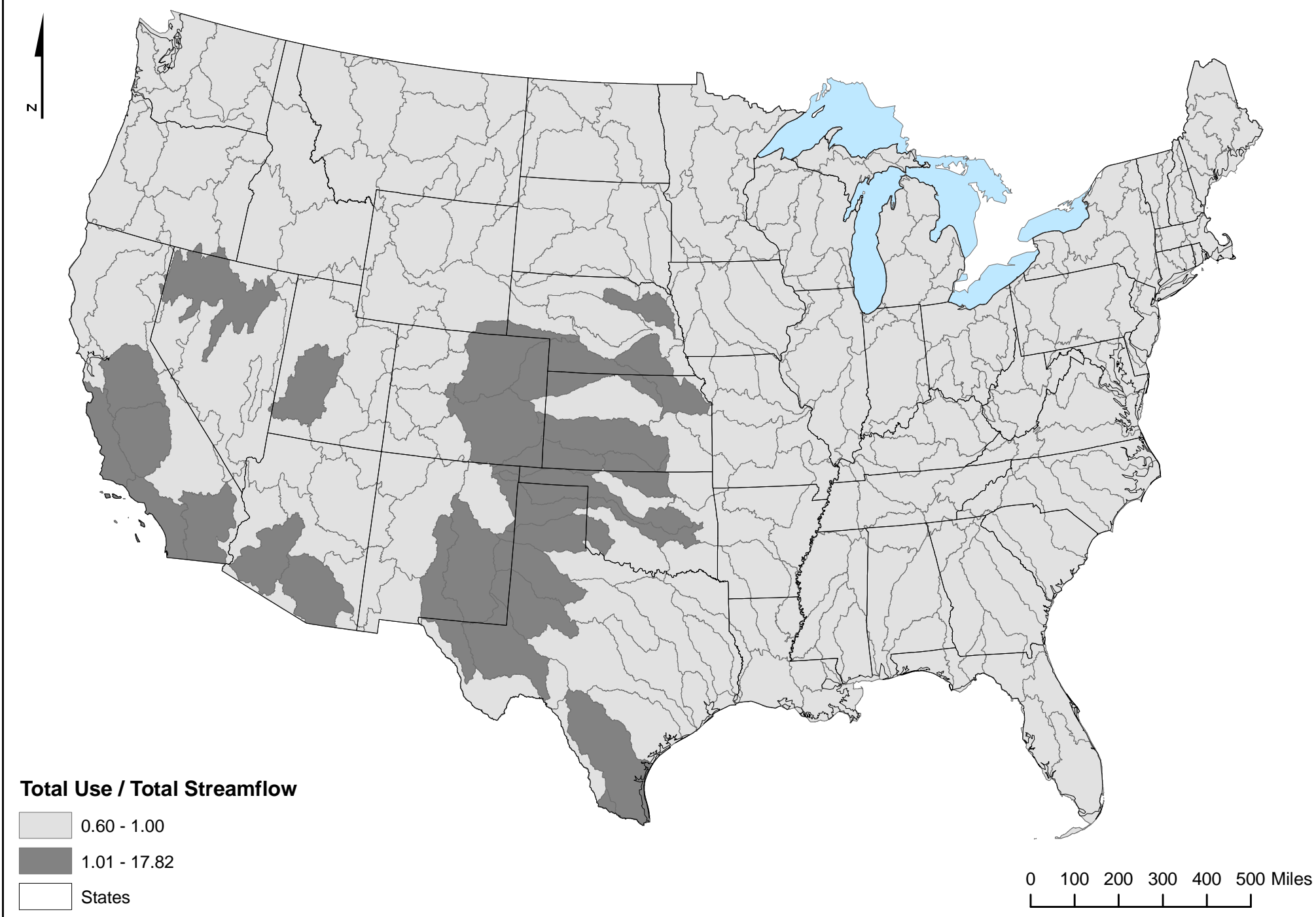
Total Use / Total Streamflow

0.60 - 1.00

1.01 - 17.82

States

0   100   200   300   400   500 Miles

#352 Total Use / Total Streamflow

This continental U.S. indicator map shows the ratio of total use to total streamflow in each HUC-4 area. Data were available for all lower-48 watersheds. Most watersheds fall in the 0.60 to 1.00 category. However there are a few in the Southwest and southern Midwest in the 1.01 to 17.82 category.

#364 Pesticide Toxicity Index, 1992-2001

Pesticide Toxicity Index for Daphnia species

	0.0000020 - 0.00028
	0.00029 - 0.0017
	0.0018 - 0.0072
	0.0073 - 0.017
	0.018 - 0.16
	No Data
	States

0   100   200   300   400   500 Miles
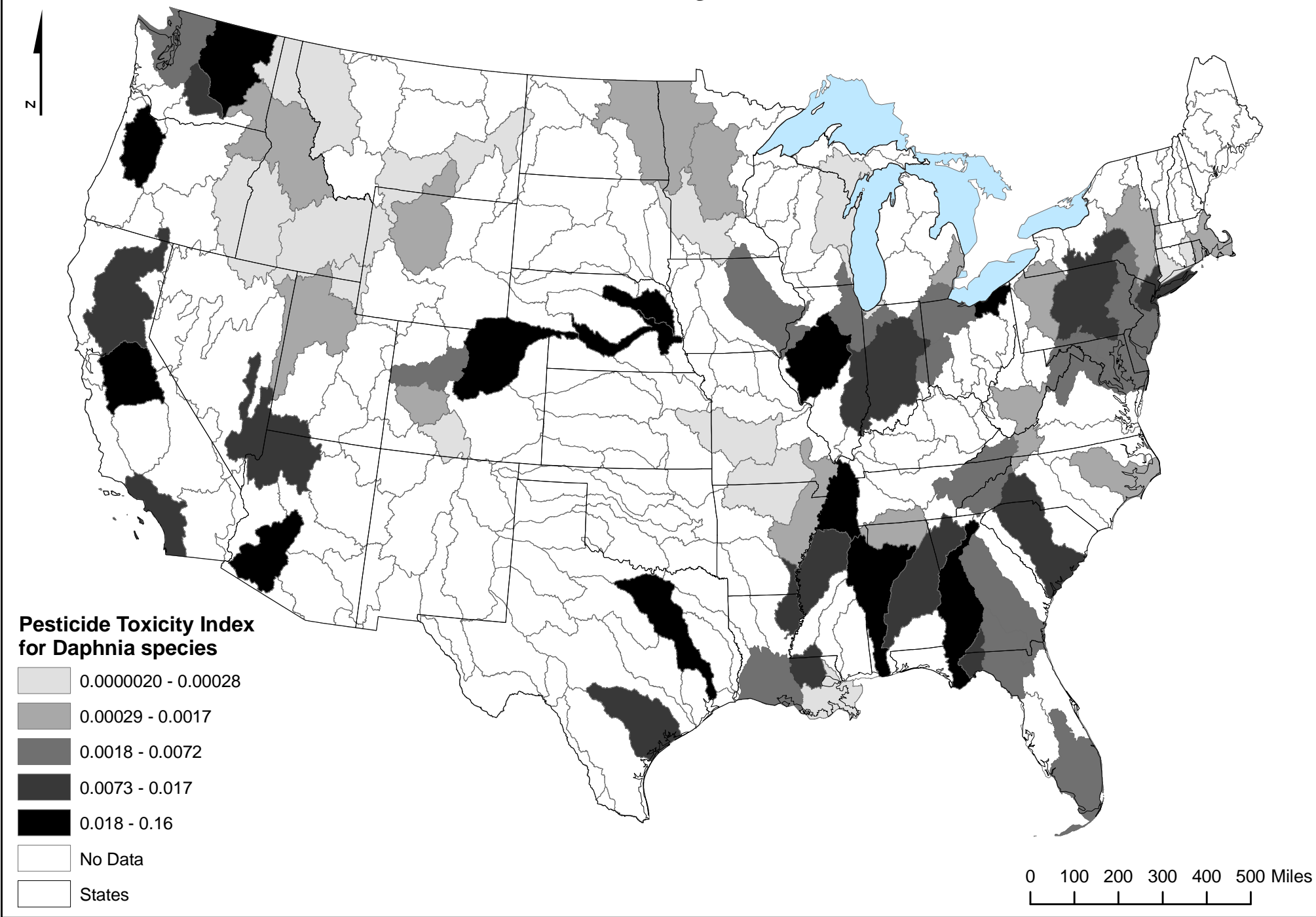
#364 Pesticide Toxicity Index

This continental U.S. indicator map shows the Daphnia species pesticide toxicity index in each HUC-4 area. Data were not available for many of the lower-48 watersheds. Available data is insufficient to infer geographic patterns.

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#367 Herbicide Concentrations in Streams, 1993-2001

Herbicide Concentrations (ug/L)

- 0.00975 - 0.0837
- 0.0838 - 0.243
- 0.244 - 0.857
- 0.858 - 2.66
- 2.67 - 18.4
- No Data
- States

0   100   200   300   400   500 Miles
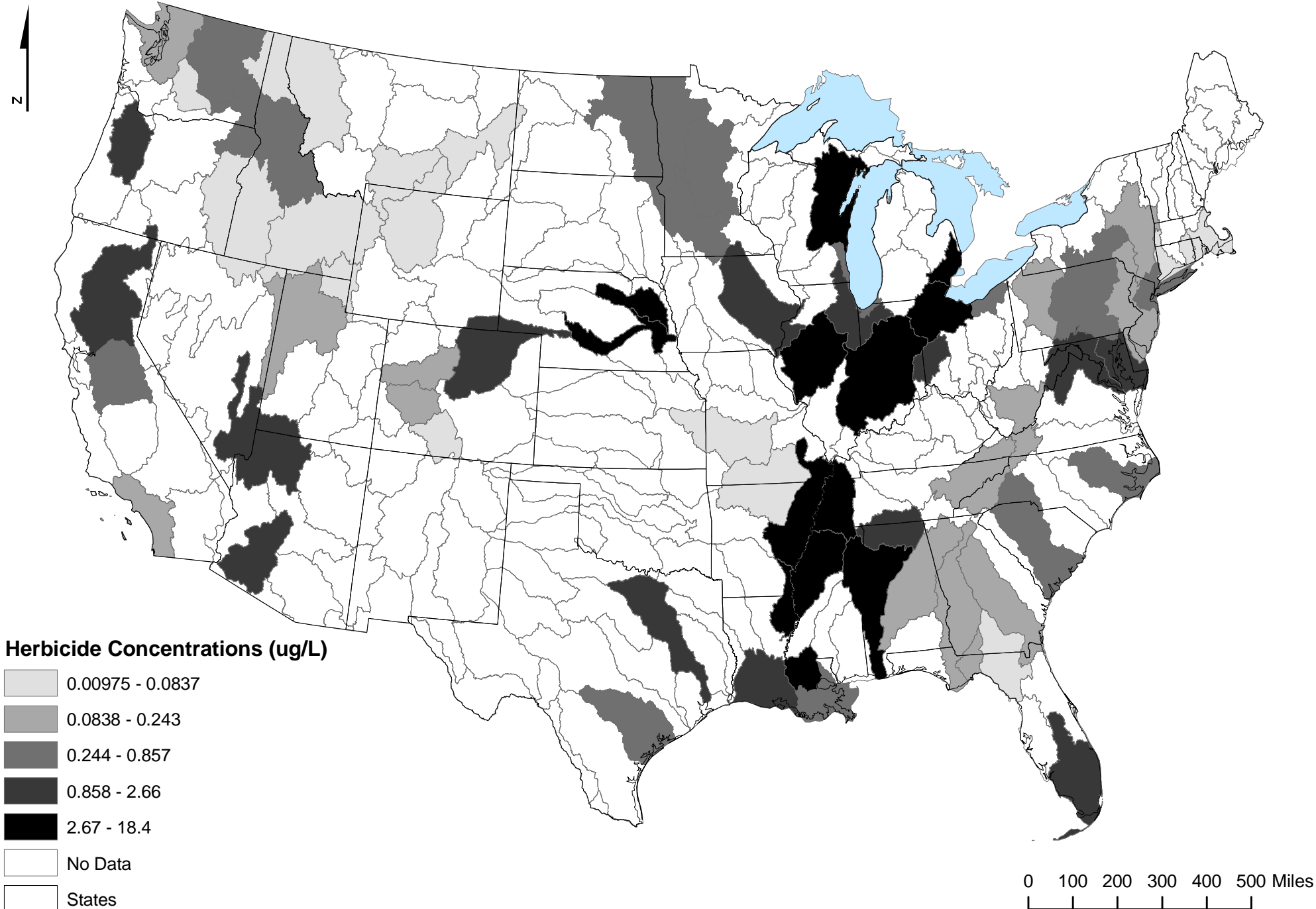
#367 Herbicide Concentrations in Streams

This continental U.S. indicator map shows herbicide concentrations in streams in each HUC-4 area. Data were not available for many of the lower-48 watersheds. Available data is insufficient to infer geographic patterns.

#369 Insecticide Concentrations in Streams, 1993-2001
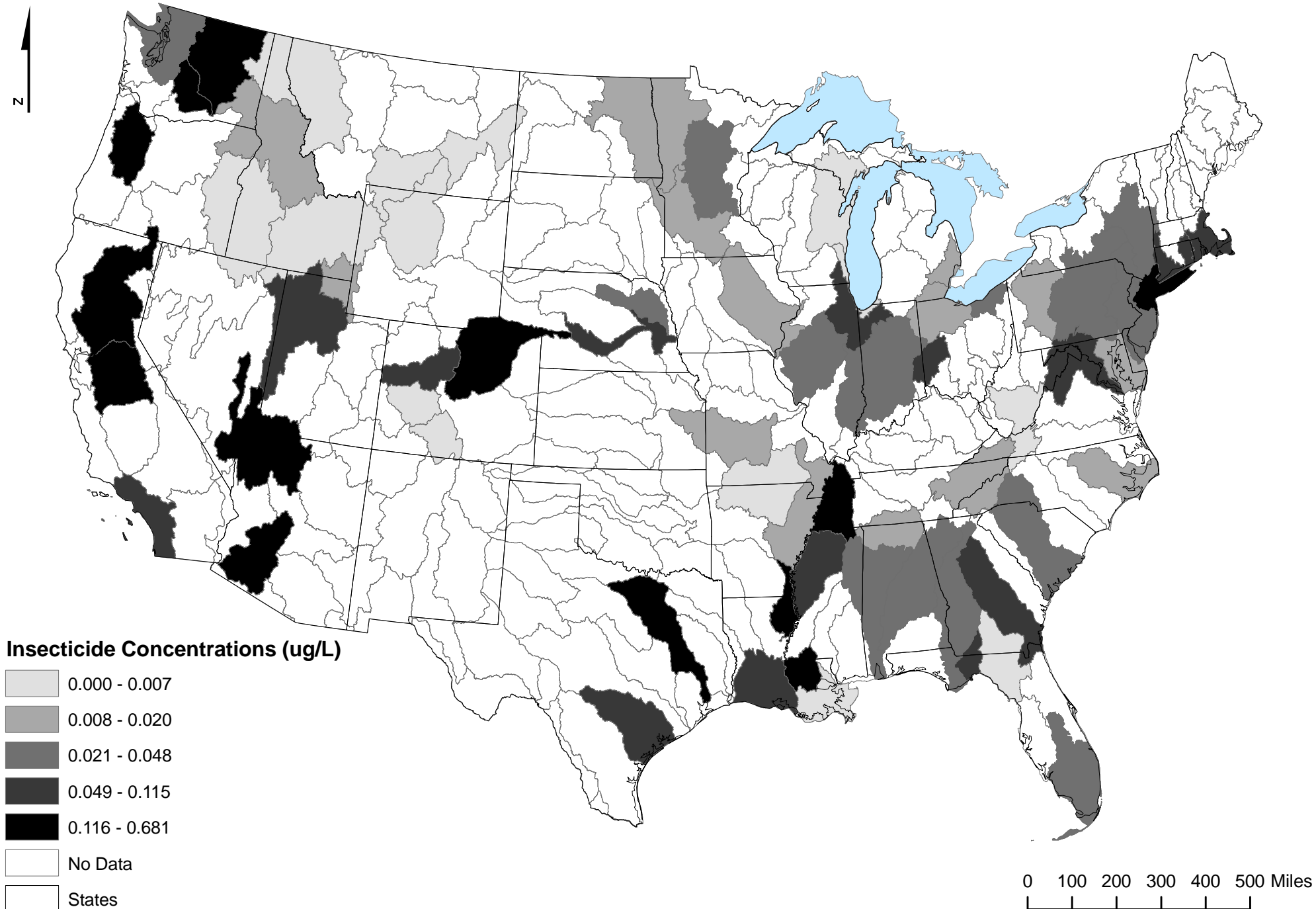
Insecticide Concentrations (ug/L)

- 0.000 - 0.007
- 0.008 - 0.020
- 0.021 - 0.048
- 0.049 - 0.115
- 0.116 - 0.681
- No Data
- States

0   100   200   300   400   500 Miles

#369 Insecticide Concentrations in Streams

This continental U.S. indicator map shows insecticide concentrations in streams in each HUC-4 area. Data were not available for many of the lower-48 watersheds. Available data is insufficient to infer geographic patterns.

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#371 Organochlorines in Bed Sediment, 1991-1997

Organochlorines in Streambed Sediment (ug/kg dry weight)

- 0.000- 7.834
- 7.835 - 32.00
- 32.01 - 75.82
- 75.83 - 175.2
- 175.3 - 453.0
- No Data
- States

0   100   200   300   400   500 Miles
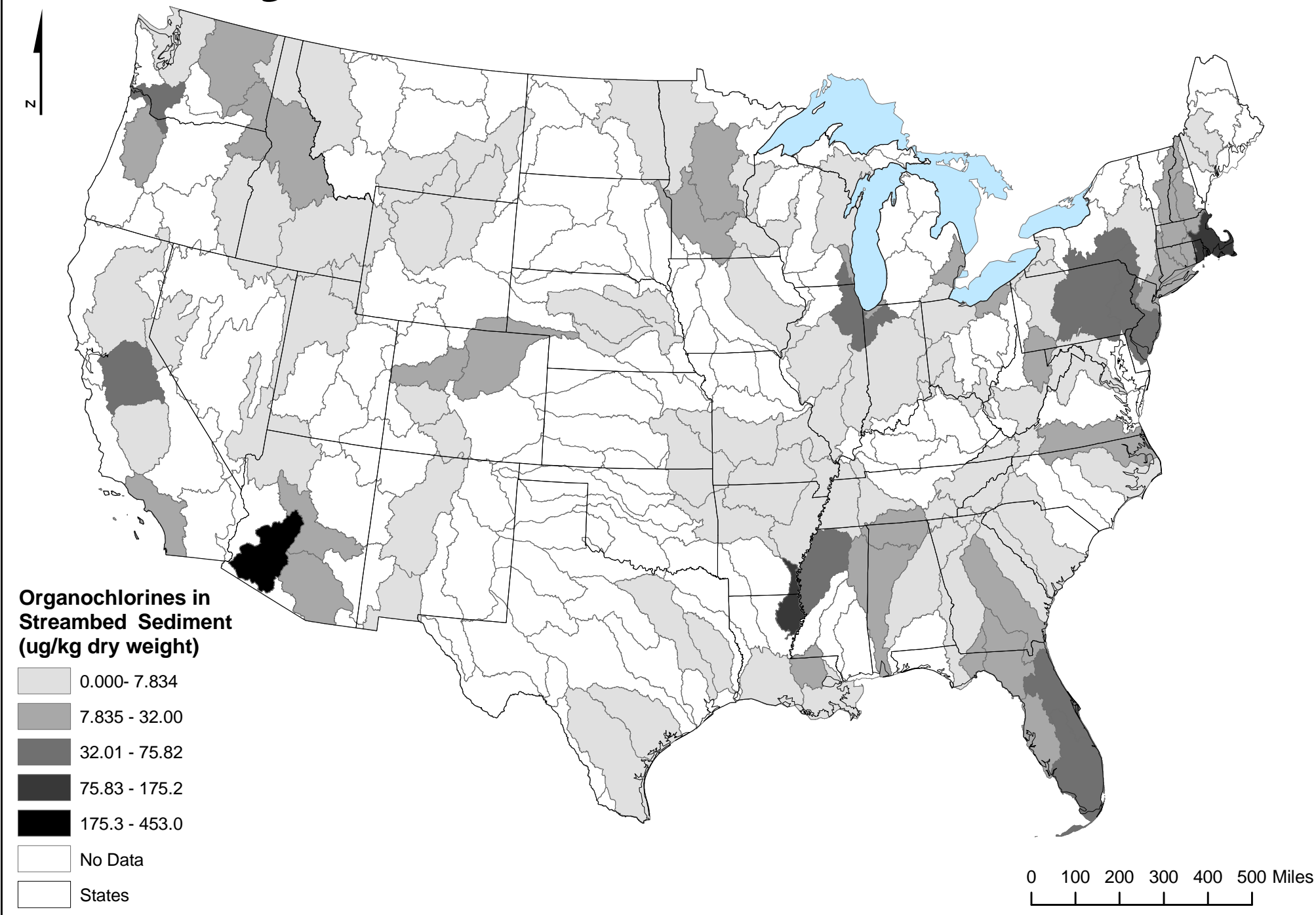
#371 Organochlorines in Bed Sediment

This continental U.S. indicator map shows organochlorine concentrations in streambed sediment in each HUC-4 area. Data were not available for many of the lower-48 watersheds. Available data is insufficient to infer geographic patterns.

#373 Herbicides in Groundwater, 1992-2003
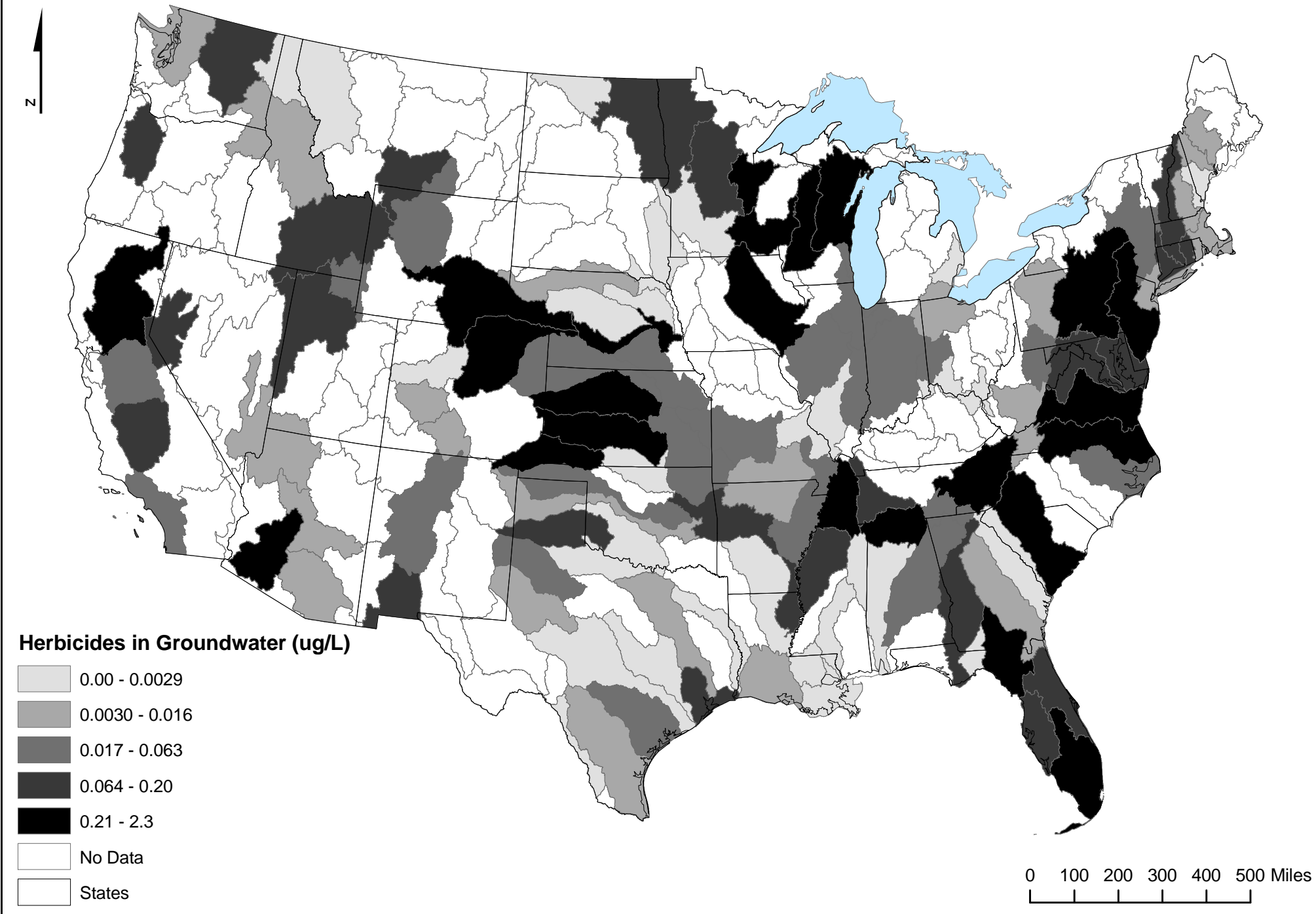
Herbicides in Groundwater (ug/L)

- 0.00 - 0.0029
- 0.0030 - 0.016
- 0.017 - 0.063
- 0.064 - 0.20
- 0.21 - 2.3
- No Data
- States

0   100   200   300   400   500 Miles

#373 Herbicides in Groundwater

This continental U.S. indicator map shows herbicide concentrations in groundwater in each HUC-4 area. Data were available for many of the lower-48 watersheds. Available data is insufficient to infer geographic patterns.

#374 Insecticides in Groundwater, 1992-2003
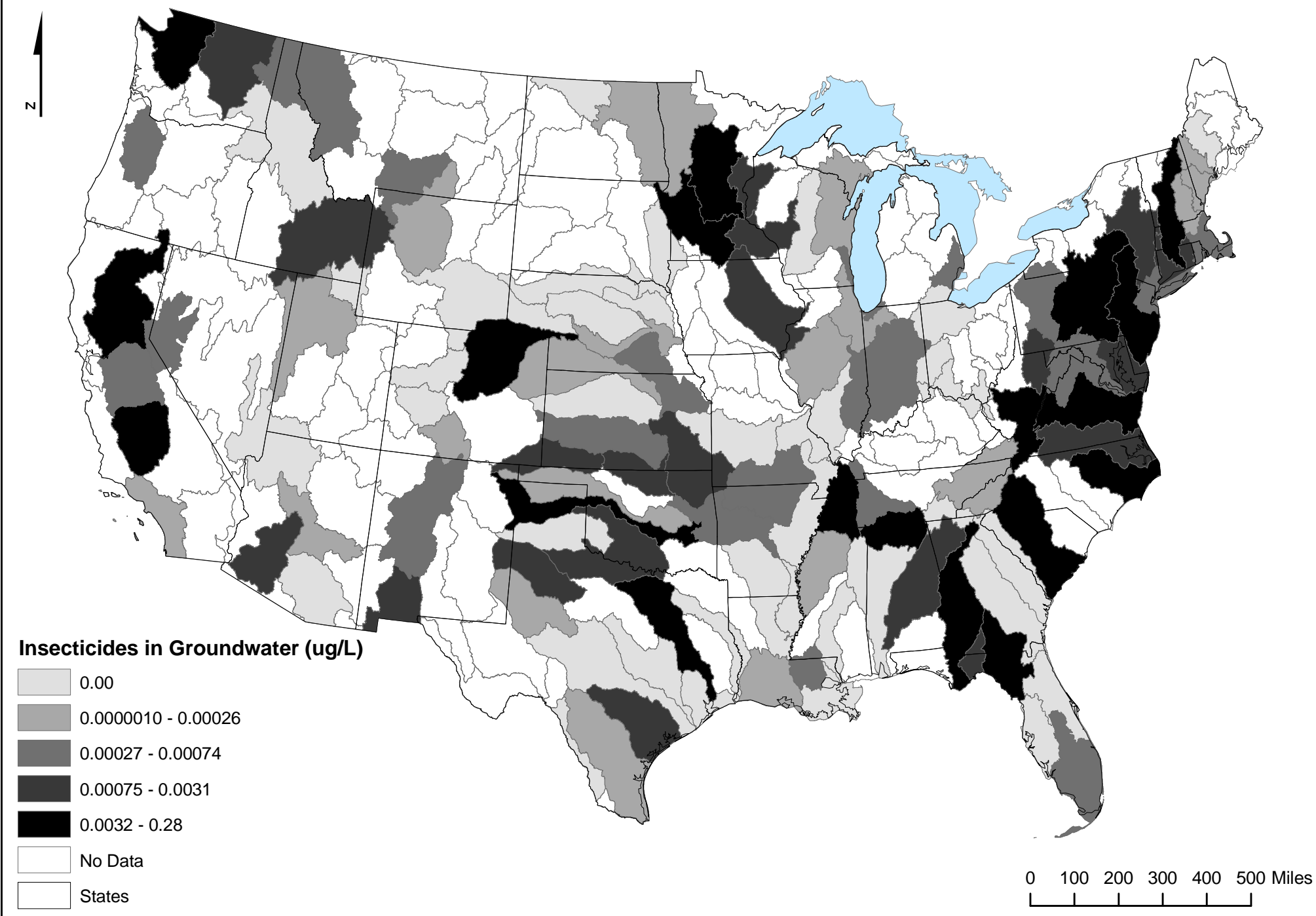
Insecticides in Groundwater (ug/L)

- 0.00
- 0.0000010 - 0.00026
- 0.00027 - 0.00074
- 0.00075 - 0.0031
- 0.0032 - 0.28
- No Data
- States

0　100　200　300　400　500 Miles

#374 Insecticides in Groundwater

This continental U.S. indicator map shows insecticide concentrations in groundwater in each HUC-4 area. Data were not available for many of the lower-48 watersheds. Available data is insufficient to infer geographic patterns, but does indicate the possibility of higher concentrations in the Middle Atlantic Corridor.

#437 Precipitation Elasticity of Streamflow, 1951-1988
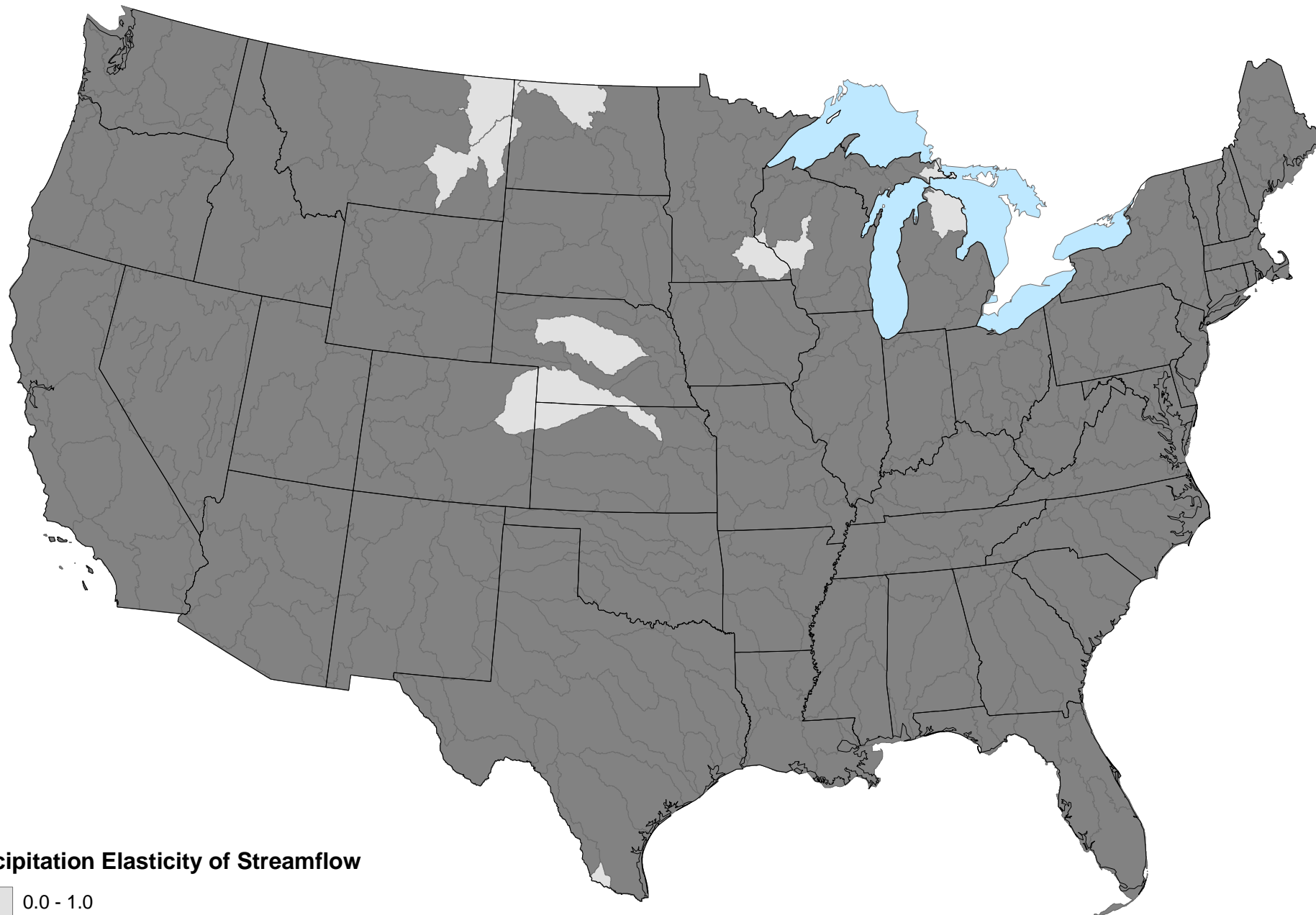
Precipitation Elasticity of Streamflow

	0.0 - 1.0
	1.1 - 3.0
	States

0   100   200   300   400   500 Miles

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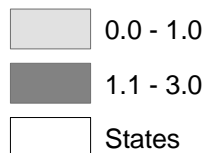
#437 Precipitation Elasticity of Streamflow

This continental U.S. indicator map shows the precipitation elasticity of streamflow in each HUC-4 area. Data were available for all lower-48 watersheds. Every watershed has elasticity in the higher range (1.1 - 3.0) except for a few scattered throughout the Midwest and one in Texas, which have elasticity in the lower range (0.0 - 1.0).

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#449 Ratio of Reservoir Storage to Mean Annual Runoff
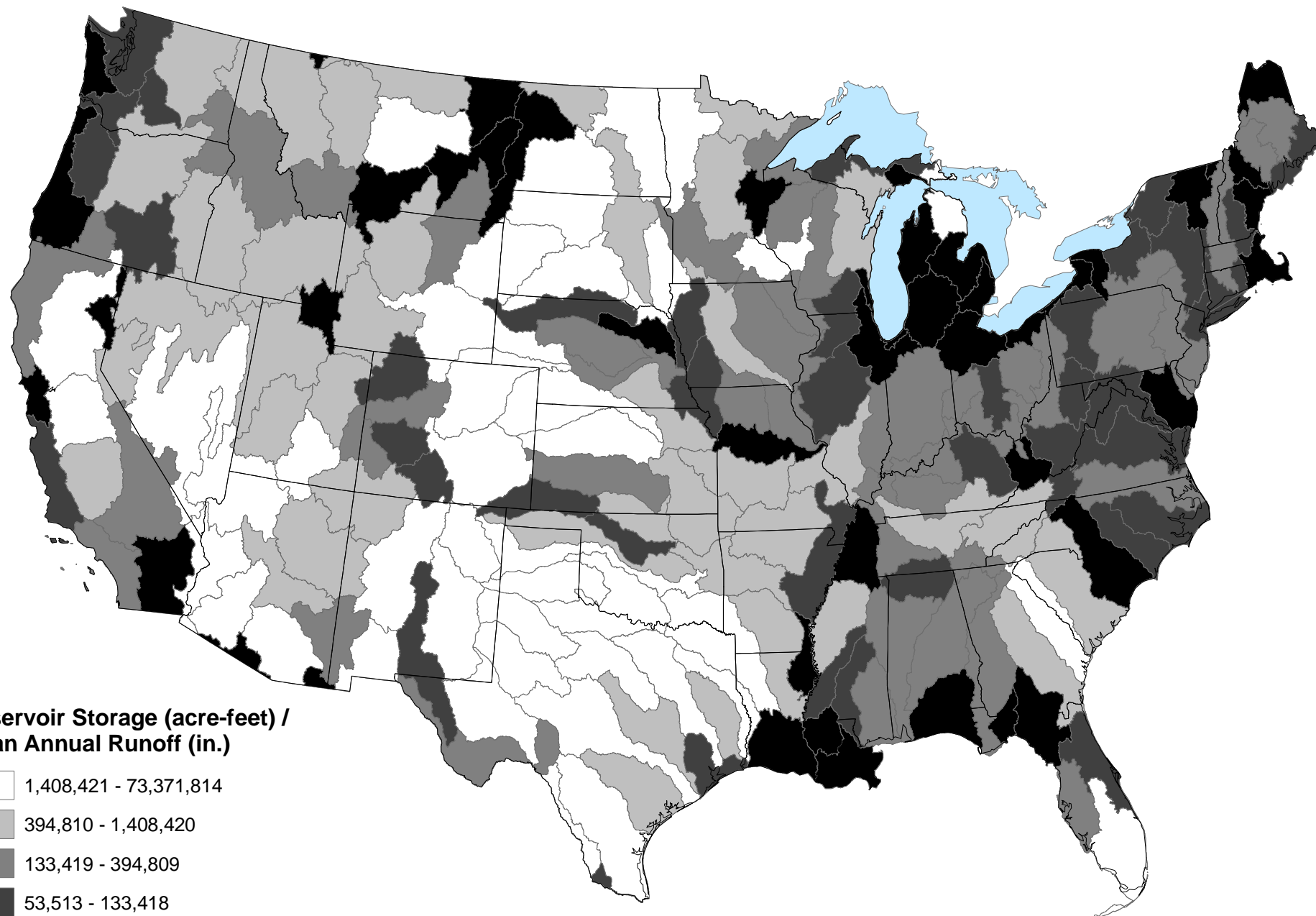
**Reservoir Storage (acre-feet) /
Mean Annual Runoff (in.)**

- 1,408,421 - 73,371,814
- 394,810 - 1,408,420
- 133,419 - 394,809
- 53,513 - 133,418
- 0 - 53,512
- States

0   100   200   300   400   500 Miles

#449 Ratio of Reservoir Storage to Mean Annual Runoff

This continental U.S. indicator map shows the ratio of reservoir storage to mean annual runoff in each HUC-4 area. Data were available for all lower-48 watersheds. High (1,408,421 - 73,371,814 acre-feet/inch) ratios are largely found in the vertical band between North Dakota and Texas. Moderate ratios (394,810 - 1,408,420 acre-feet/inch) are largely found in the Midwest and the West. Low (133,419 - 394,809 acre-feet/inch), very low (53,513 - 133,418 acre-feet/inch), and extremely low (0 - 53,512 acre-feet/inch) ratios are largely found in coastal and Great Lakes watersheds.
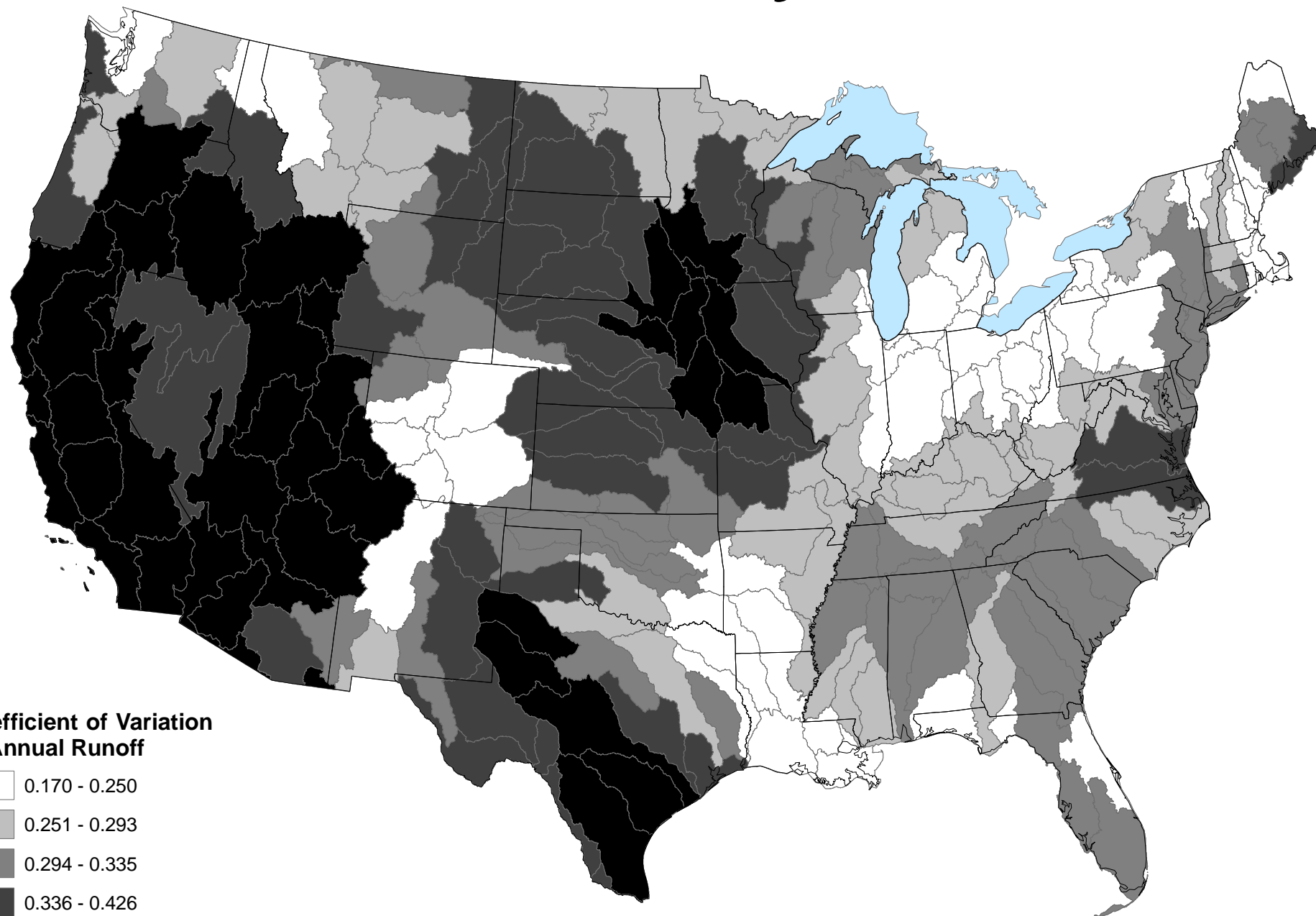
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#453 Runoff Variability, 1984-1993

**Coefficient of Variation
of Annual Runoff**

- 0.170 - 0.250
- 0.251 - 0.293
- 0.294 - 0.335
- 0.336 - 0.426
- 0.427 - 1.111
- States
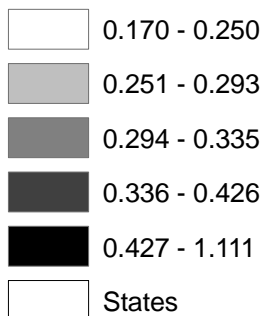
0   100   200   300   400   500 Miles

#453 Runoff Variability

This continental U.S. indicator map shows the coefficient of variation of annual runoff in each HUC-4 area. Data were available for all lower-48 watersheds. A high (0.427 - 1.111) coefficient is observed in clusters covering much of the West, an area in the Midwest centered on Iowa, and part of Texas. Watersheds with a moderate (0.336 - 0.426) ratio are observed adjacent to those clusters as well as in Maine and the Chesapeake region. Watersheds with a low (0.294 - 0.335) and very low (0.251 - 0.293) ratio are observed across the country. The watersheds with the lowest ratio (0.170 - 0.250) are south of the Great Lakes, in New England, and the lower Mississippi Basin.

#460 Macroinvertebrate Index of Biotic Condition, 2000-2004
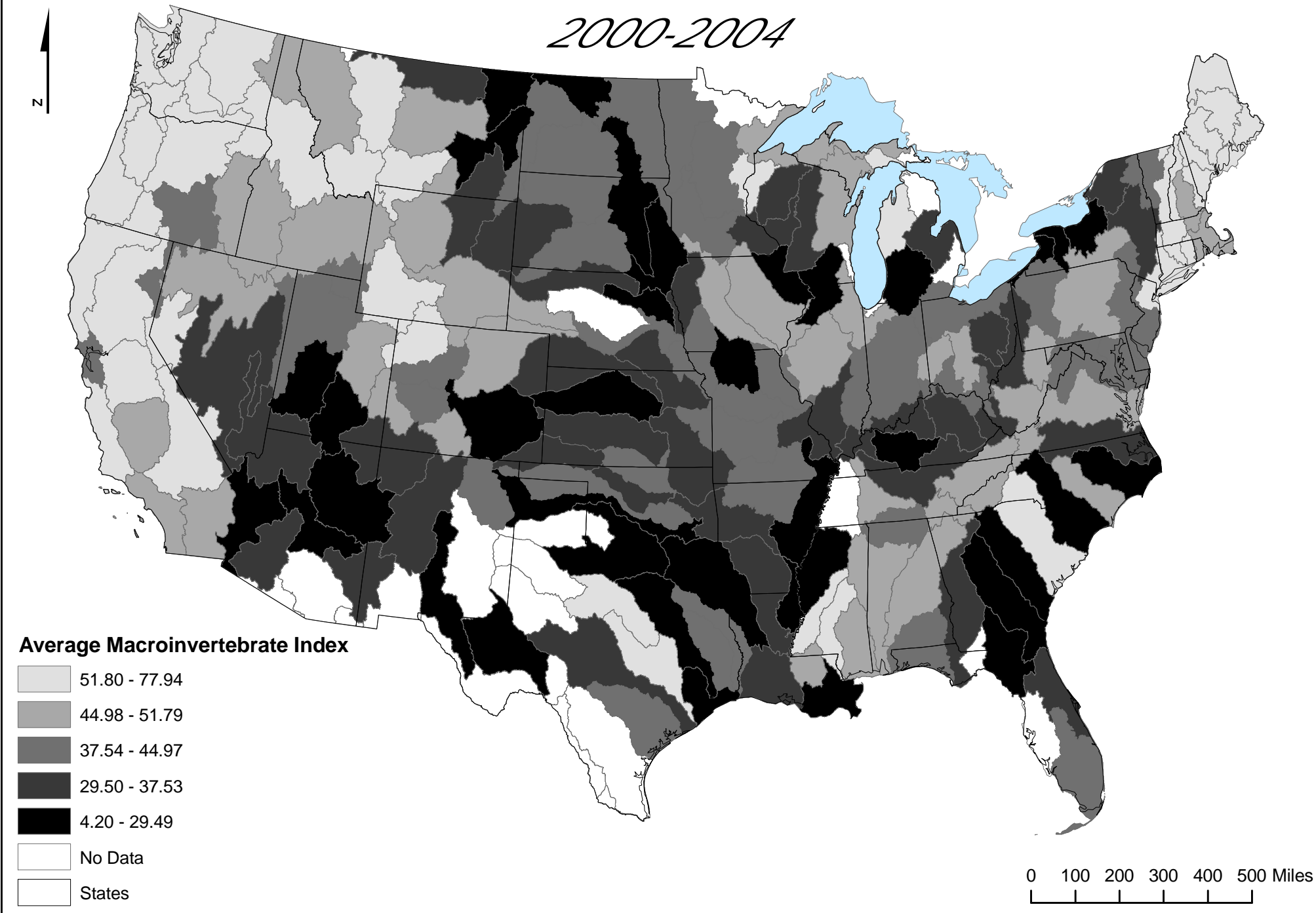
Average Macroinvertebrate Index

- 51.80 - 77.94
- 44.98 - 51.79
- 37.54 - 44.97
- 29.50 - 37.53
- 4.20 - 29.49
- No Data
- States

0   100   200   300   400   500 Miles

#460 Macroinvertebrate Index of Biotic Condition

This continental U.S. indicator map shows the macroinvertebrate index of biotic condition in each HUC-4 area. Data were available for the vast majority of lower-48 watersheds. There is no discernable geographic pattern to the distribution of categories of watersheds.

#461 Macroinvertebrate O/E Ratio of Taxa Loss, 2000-2004
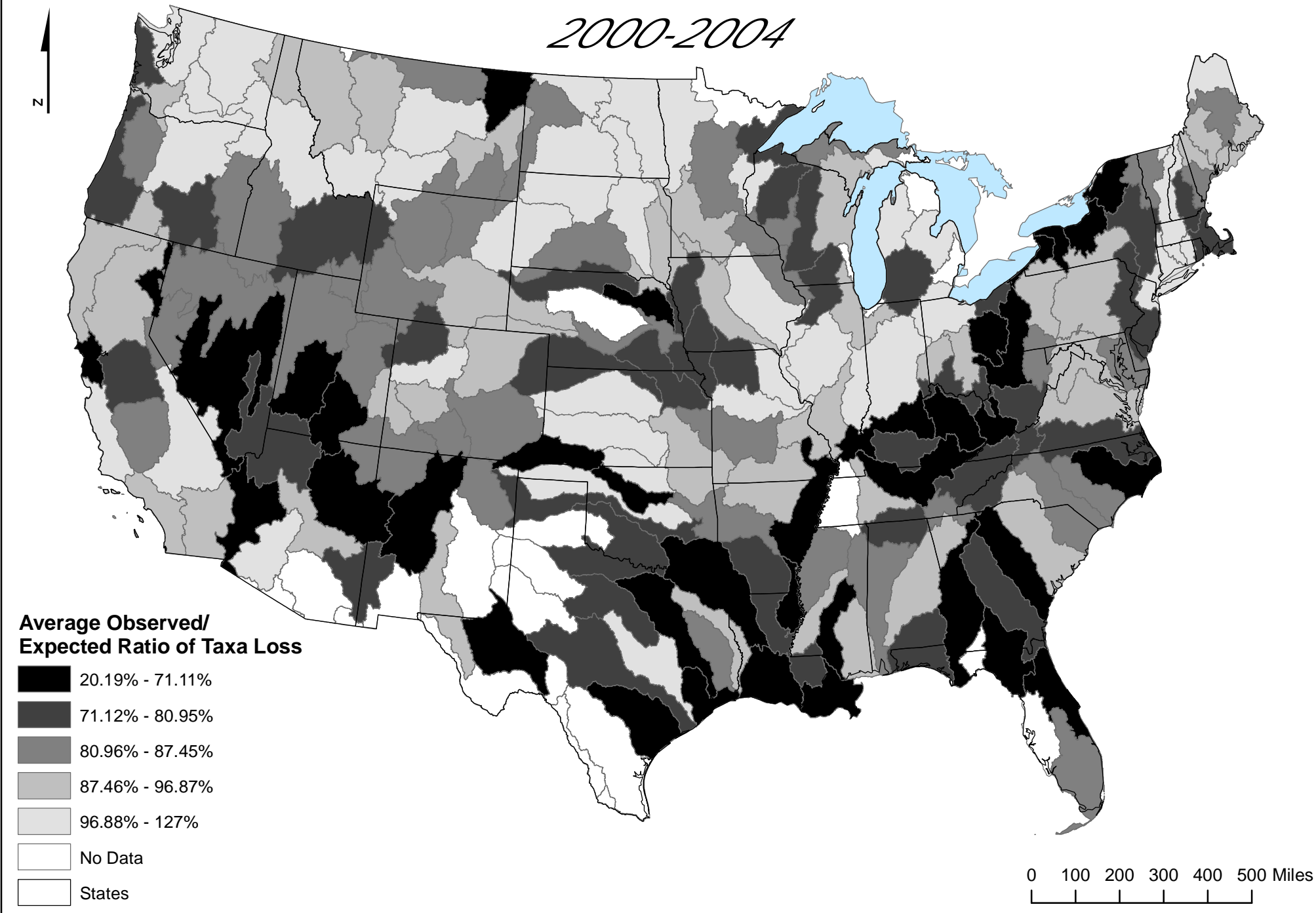
Average Observed/ Expected Ratio of Taxa Loss

- 20.19% - 71.11%
- 71.12% - 80.95%
- 80.96% - 87.45%
- 87.46% - 96.87%
- 96.88% - 127%
- No Data
- States

0 100 200 300 400 500 Miles

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#461 Macroinvertebrate Observed/Expected (O/E) Ratio of Taxa Loss

This continental U.S. indicator map shows the observed taxa as a percentage of the expected macroinvertebrate taxa in each HUC-4 area. Data were available for the vast majority of lower-48 watersheds. This map shows a certain amount of spatial heterogeneity. The highest ratios (96.88% - 127%) occur mostly along the West Coast, in the Pacific Northwest, the Midwest, and New England. Moderate ratios (87.46% - 96.87%) are found in large parts of California, parts of the Northwest, Great Lakes, and South and Middle Atlantic regions. The remaining ratio categories (20.19% - 71.11%, 71.12% - 80.95%, and 80.96% - 87.45%) have no discernable geographic distribution.

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#623 Water Availability: Net Streamflow per Capita, 1995
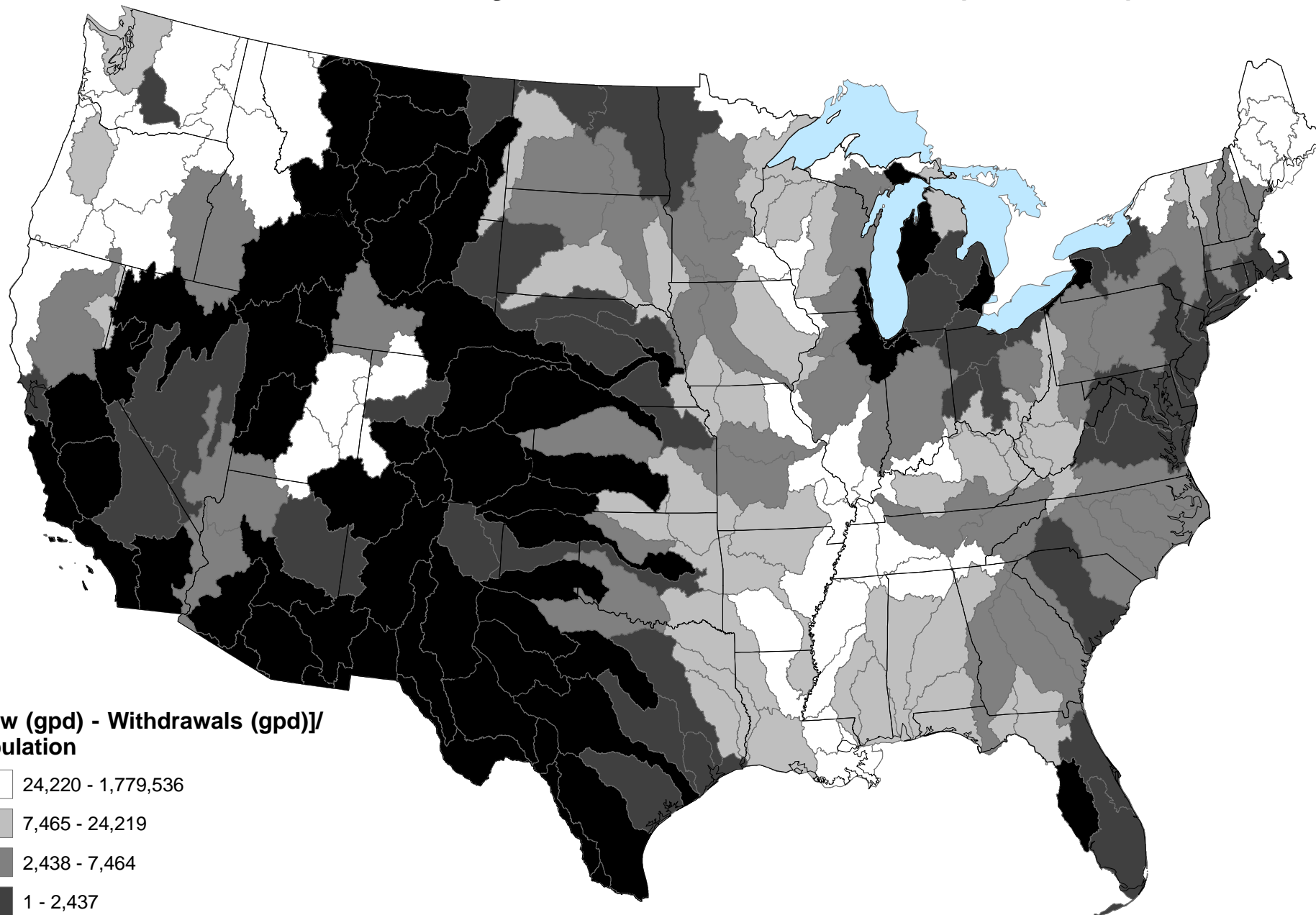
[Flow (gpd) - Withdrawals (gpd)]/ Population

- 24,220 - 1,779,536
- 7,465 - 24,219
- 2,438 - 7,464
- 1 - 2,437
- 0
- States

0 100 200 300 400 500 Miles

#623 Water Availability: Net Streamflow per Capita

This continental U.S. indicator map shows the net streamflow per capita in each HUC-4 area. Data were available for all lower-48 watersheds. High flow per capita (24,220 - 1,779,536 gpd/capita) watersheds are found in the Pacific Northwest, Colorado and Utah, the Mississippi Basin, and Maine. Moderate streamflow per capita (2,438 - 7,464 gpd/capita) watersheds are found mostly around high streamflow per capita watersheds. Very low streamflow per capita (1 - 2,437 gpd/capita) watersheds are found in the Great Lakes region, the Middle Atlantic Corridor, Florida, and the West. Zero net streamflow per capita watersheds are found in the Great Lakes Region, and throughout the West.

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Appendix F. Example Maps for Indicators of Water Quality and Aquatic Ecosystem Vulnerability, Displayed Using Ecoregions

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This appendix contains example maps (and map descriptions) for the 25 vulnerability indicators displayed using Omernik's Level 3 ecoregions (Omernik, 1987[1]). As with the maps in the previous appendix, these maps are intended to illustrate the methodological challenges of creating indicator maps, and rely on simplifying assumptions (such as the use of quantiles instead of thresholds). Therefore, they are not appropriate for drawing conclusions regarding the vulnerability of water quality and aquatic ecosystems in any particular state or region. Descriptions of U.S. geographic regions are based on definitions provided by the U.S. Census Bureau. Subregion descriptions were based on U.S. Census definitions, but modified slightly for clarity.

1. **Northeast**
   a. New England
      i. Connecticut
      ii. Maine
      iii. Massachussetts
      iv. New Hampshire
      v. Rhode Island
      vi. Vermont
   b. Middle Atlantic
      i. New Jersey
      ii. New York
      iii. Pennsylvania
2. **Midwest**
   a. Great Lakes
      i. Indiana
      ii. Illinois
      iii. Michigan
      iv. Ohio
      v. Wisconsin
   b. Western Midwest
      i. Iowa
      ii. Kansas
      iii. Minnesota
      iv. Missouri
      v. Nebraska
      vi. North Dakota
      vii. South Dakota
3. **South**
   a. South Atlantic
      i. Delaware
      ii. District of Columbia
      iii. Maryland
      iv. North Carolina
      v. South Carolina
      vi. Virginia
      vii. West Virginia
   b. Southeast
      i. Florida
      ii. Georgia
      iii. Kentucky
      iv. Alabama
      v. Mississippi
      vi. Tennessee
   c. Central South
      i. Texas
      ii. Oklahoma
      iii. Arkansas
      iv. Louisiana
4. **West**
   a. Mountain West
      i. Arizona
      ii. Colorado
      iii. Idaho
      iv. New Mexico
      v. Montana
      vi. Utah
      vii. Nevada
      viii. Wyoming
   b. Pacific West
      i. California
      ii. Oregon
      iii. Washington

[1]Omernik, J.M. 1987. Ecoregions of the conterminous United States. Map (scale 1:7,500,000). *Annals of the Association of American Geographers.* 77 (1): 118-125.

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#1 Acid Neutralizing Capacity, 2000-2004

Percent of Sites with ANC < 100 millieq/L

- 0%
- 0.01% - 4.17%
- 4.18% - 11.11%
- 11.12% - 27.27%
- 27.28% - 66.67%
- No Data
- States

0   100   200   300   400   500 Miles
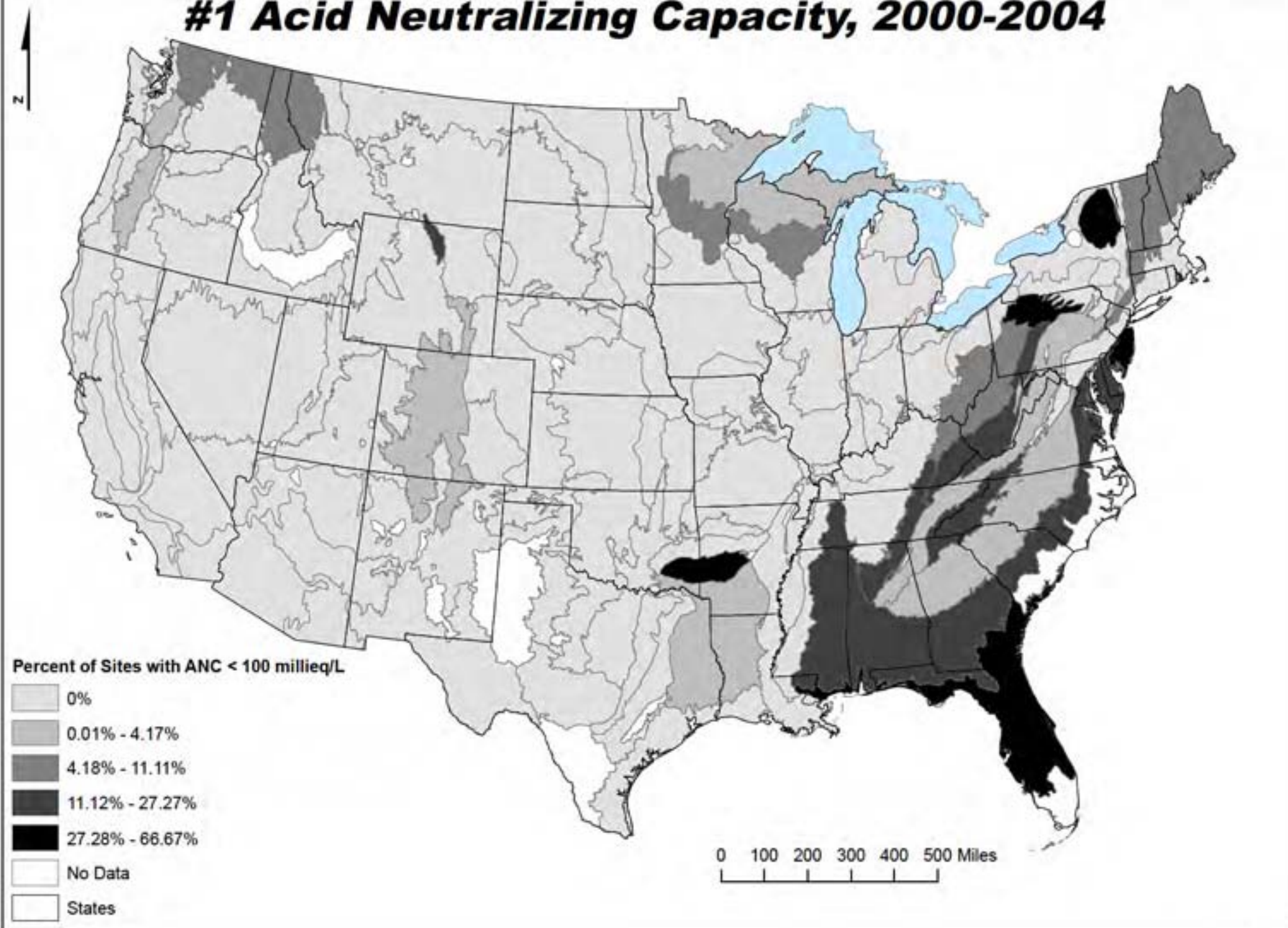
#1 Acid Neutralizing Capacity

This continental U.S. indicator map shows the percentage of sites with Acid Neutralizing Capacity (ANC) less than 100 millieq/L in each ecoregion. Data were available for the vast majority of lower-48 ecoregions. The greater part of ecoregions in the West, Midwest, and Central South have 0% of sites with ANC less than 100 millieq/L. Several ecoregions in the South East and South Atlantic have a moderate (4.18 - 11.11%) or high (11.12 - 27.27%) percentage of sites with ANC less than 100 millieq/L. Ecoregions with the highest percentage of sites (27.28 - 66.67%) with ANC less than 100 millieq/L cover a majority of Florida, parts of the Northeast, and a smaller ecoregion spanning parts of Arkansas and Oklahoma.

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#22 At-Risk Freshwater Plant Communities, 2006

Percent of At-Risk Freshwater Plant Communities

- 0.0% - 31.3%
- 31.4% - 45.7%
- 45.8% - 51.8%
- 51.9% - 55.5%
- 55.6% - 71.1%
- States

0   100   200   300   400   500 Miles
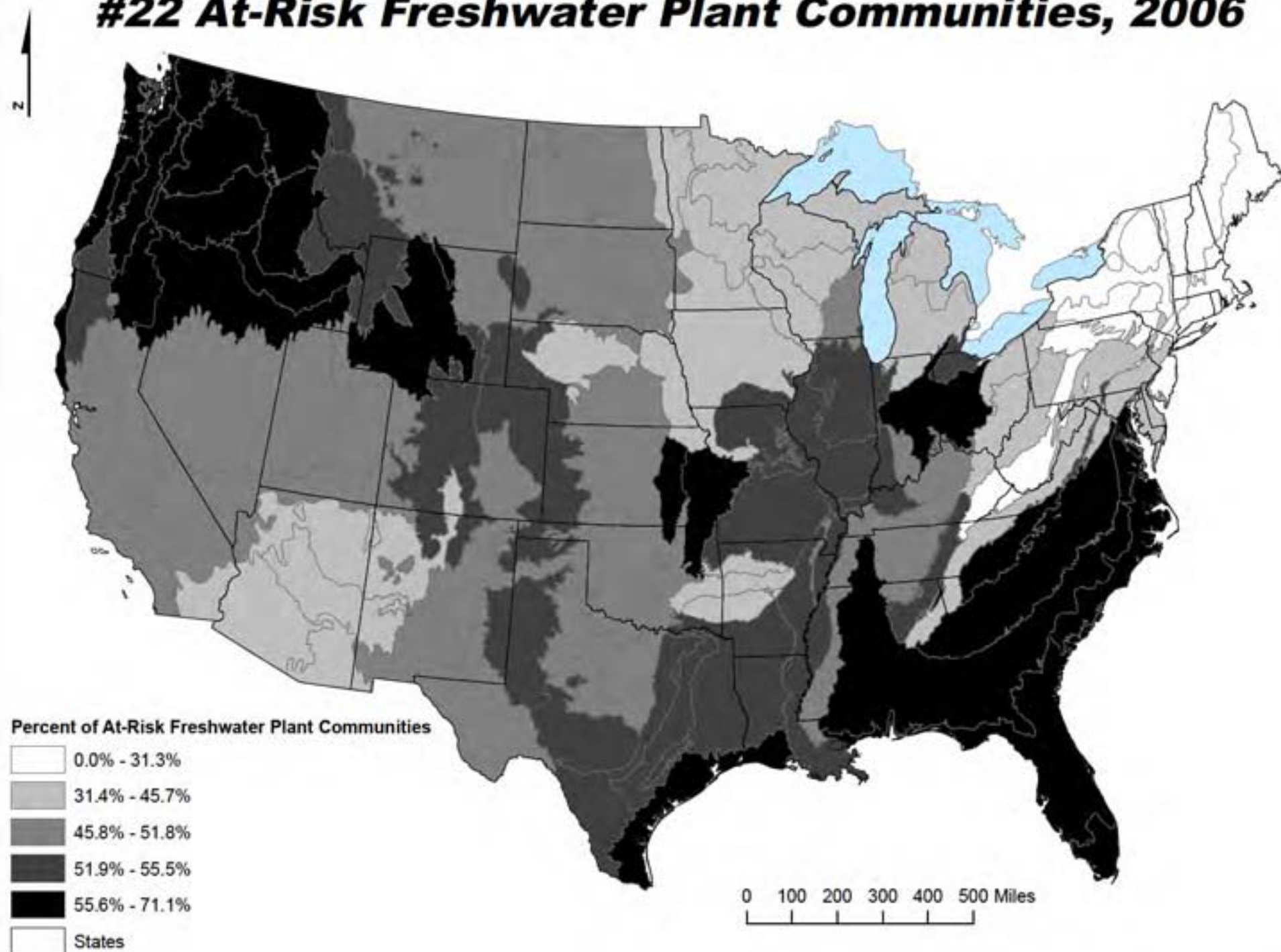
#22 At-Risk Freshwater Plant Communities

This continental U.S. indicator map shows the percentage of freshwater plant communities that are considered at-risk in each ecoregion. Data were available for all lower-48 ecoregions. The ecoregions with the highest percentages of freshwater plant communities at risk (55.6 - 71.1%) for this indicator occur largely in the Southeast and the Pacific Northwest. Relatively high percentages of plant communities at risk (51.9 - 55.5%) occur in ecoregions extending northward from Texas to the Midwest, as well as in ecoregions scattered in the Mountain West.

Moderate percentages of plant communities at risk (45.8 - 51.8%) occur predominantly in the Southwest and Western Midwest regions. Relatively lower percentages of communities at risk (31.4 - 45.7%) occur in New Mexico, the Great Lakes region, and parts of the Middle-Atlantic. The northern Middle Atlantic and Northeast ecoregions have the lowest percentages (0 - 31.3%) of at-risk freshwater plant communities.
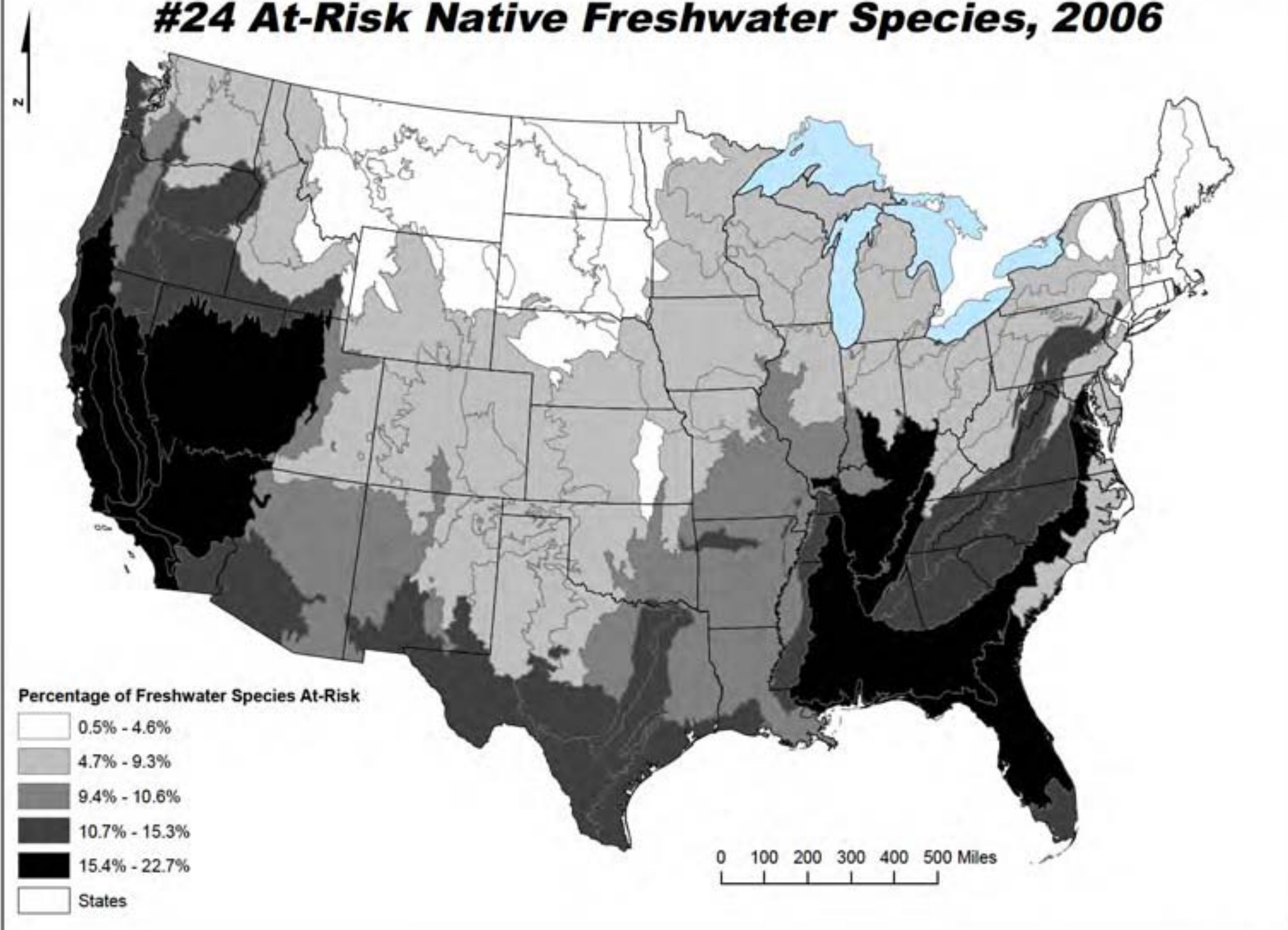
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#24 At-Risk Native Freshwater Species, 2006

Percentage of Freshwater Species At-Risk

- 0.5% - 4.6%
- 4.7% - 9.3%
- 9.4% - 10.6%
- 10.7% - 15.3%
- 15.4% - 22.7%
- States

0 100 200 300 400 500 Miles

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#24 At-Risk Native Freshwater Species

This continental U.S. indicator map shows the percentage of at-risk native freshwater species in each ecoregion. Data were available for all lower-48 ecoregions. Ecoregions with high percentages of freshwater species at risk (15.4 - 22.7%) are found in the Southwest and in the Southeast. These high risk areas are surrounded by bands of moderate (10.7 - 15.3%) percentages of freshwater species at risk. With very few exceptions, risk is a steady gradation from high risk areas in the southern U.S. to low risk areas (0.5 - 4.6%) in New England and the north-central U.S.
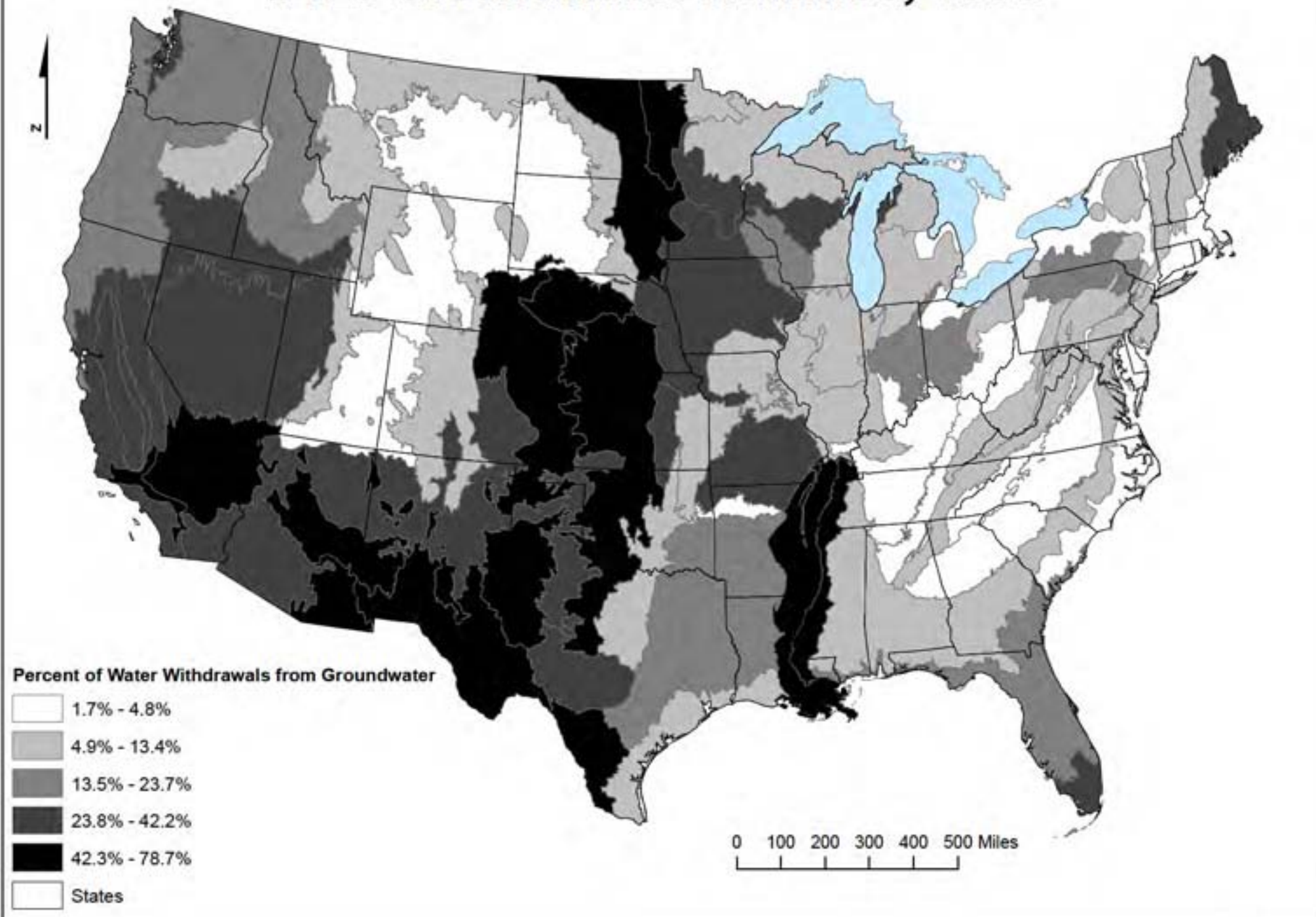
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#125 Groundwater Reliance, 1995

Percent of Water Withdrawals from Groundwater

- 1.7% - 4.8%
- 4.9% - 13.4%
- 13.5% - 23.7%
- 23.8% - 42.2%
- 42.3% - 78.7%
- States

0   100   200   300   400   500 Miles

#125 Groundwater Reliance

This continental U.S. indicator map shows the percentage of groundwater reliance in each ecoregion. Data were available for all lower-48 ecoregions. A high level (42.3 - 78.7%) of groundwater reliance is mainly observed in the ecoregions that stretch from parts of North Dakota through parts of the western Midwest and Mountain West to western Texas. Other areas with high groundwater reliance are found in the ecoregions along the U.S.-Mexico border, in ecoregions along the lower Mississippi River, and in parts of California and Nevada. Moderate to low (4.9 - 42.2%) groundwater reliance is observed scattered across the nation. The main ecoregions with almost no groundwater reliance (1.7 - 4.8%) stretch from Montana to the Four Corners and also occur in parts of the Southeast, South, and Middle Atlantic regions.

#165 Meteorological Drought Indices, 2003-2007
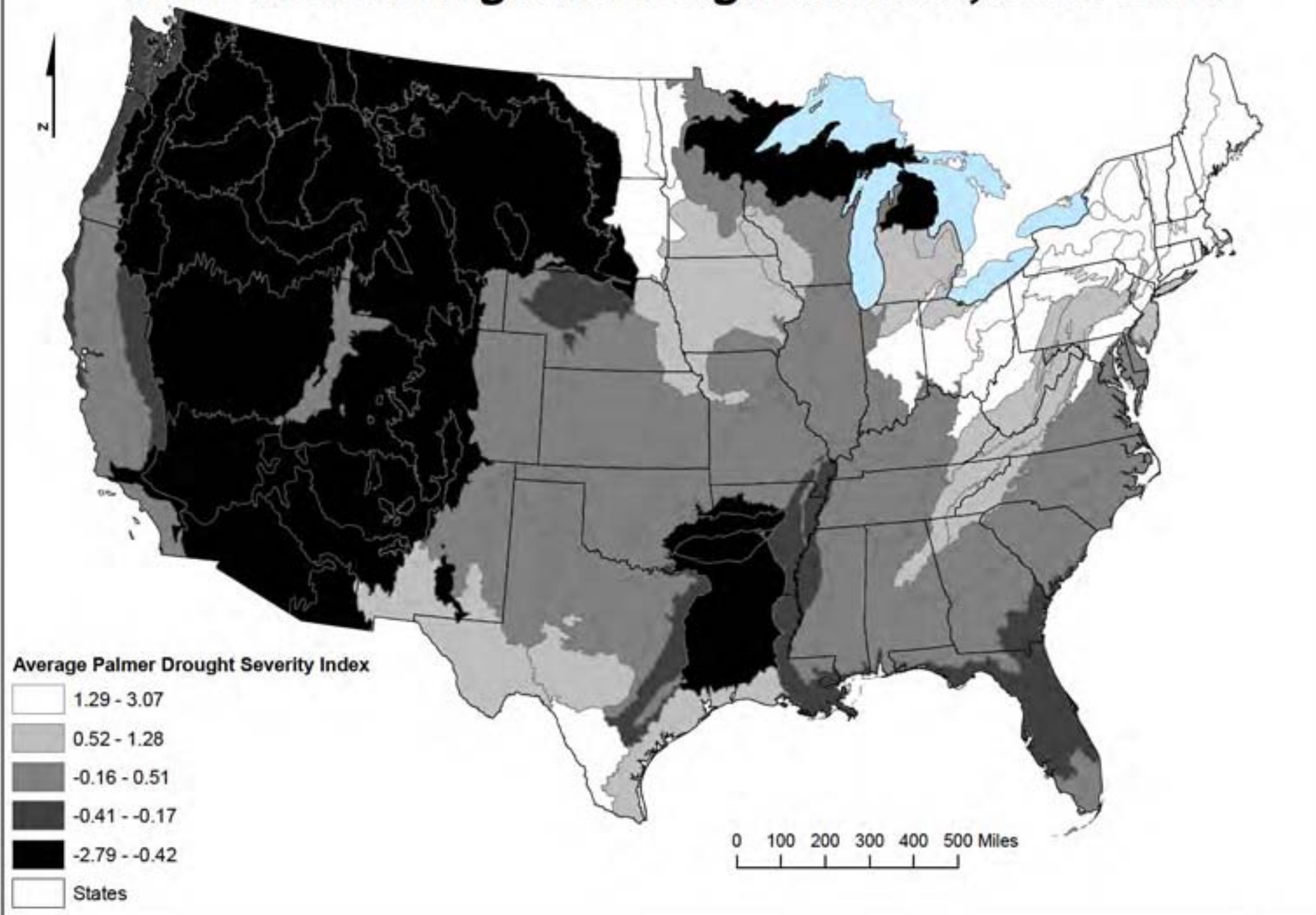
Average Palmer Drought Severity Index

- 1.29 - 3.07
- 0.52 - 1.28
- -0.16 - 0.51
- -0.41 - -0.17
- -2.79 - -0.42
- States

0   100   200   300   400   500 Miles

#165 Meteorological Drought Indices

This continental U.S. indicator map shows the average Palmer Drought Severity Index (PDSI) in each ecoregion. Data were available for all lower-48 ecoregions. Negative values of the PDSI indicate drought, positive values indicate excess rainfall, while 0 represents normal conditions for a given region. A very distinctive pattern emerges on this map. Ecoregions having the lowest PDSI values (-2.79 to -0.42) occur predominantly in the West, but also in along the Great Lakes, and parts of the Central South. Low (-0.41 to -0.17) and moderate (-0.16 to 0.51) PDSI values are observed in the central states. High (0.52 to 1.28) and very high (1.29 to 3.07) PDSI values observed mainly in parts of the Western Midwest, Great Lakes, South Atlantic, and Northeast.

#218 Ratio of Snow to Total Precipitation, 1998-2007
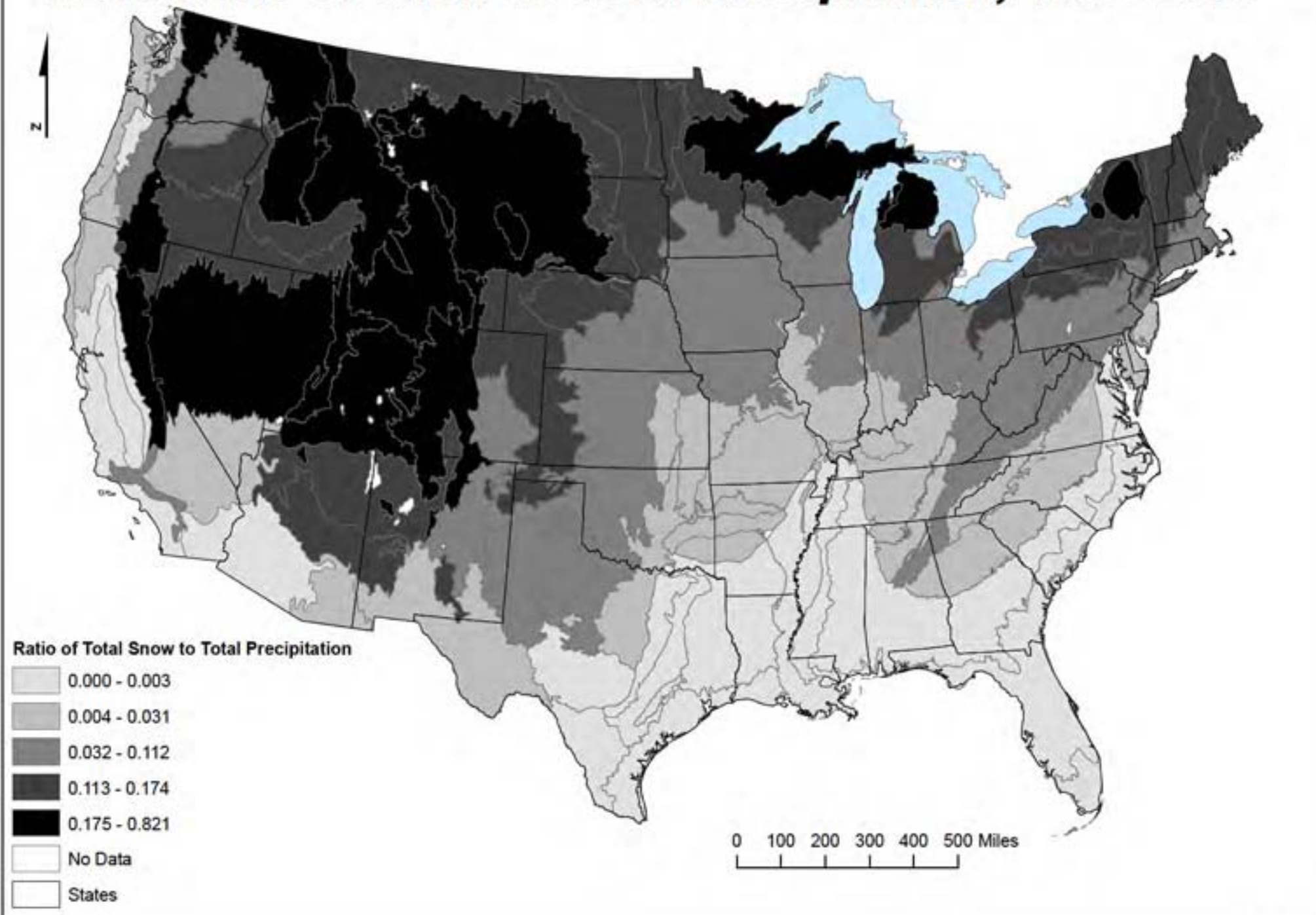
Ratio of Total Snow to Total Precipitation

- 0.000 - 0.003
- 0.004 - 0.031
- 0.032 - 0.112
- 0.113 - 0.174
- 0.175 - 0.821
- No Data
- States

0   100   200   300   400   500 Miles

#218 Ratio of Snow to Total Precipitation

This continental U.S. indicator map shows the ratio of total snowfall to total precipitation in each ecoregion. Data were available for all lower-48 ecoregions. Unsurprisingly, this map shows a strong north-south trend, with the ecoregions with the highest ratios (0.175 - 0.821) occurring in the northern and mountainous regions including the northern West, Great Lakes, and parts of the Northeast. These high ratios are surrounded by graded bands of moderate (0.113 - 0.174), low (0.032 - 0.112) and very low (0.004 - 0.031) snowfall to total precipitation ratios. Parts of California, Arizona, the Central South, and the Southeast have a ratio of zero, indicating no snowfall.

#219 Ratio of Water Withdrawals to Annual Streamflow, 1995
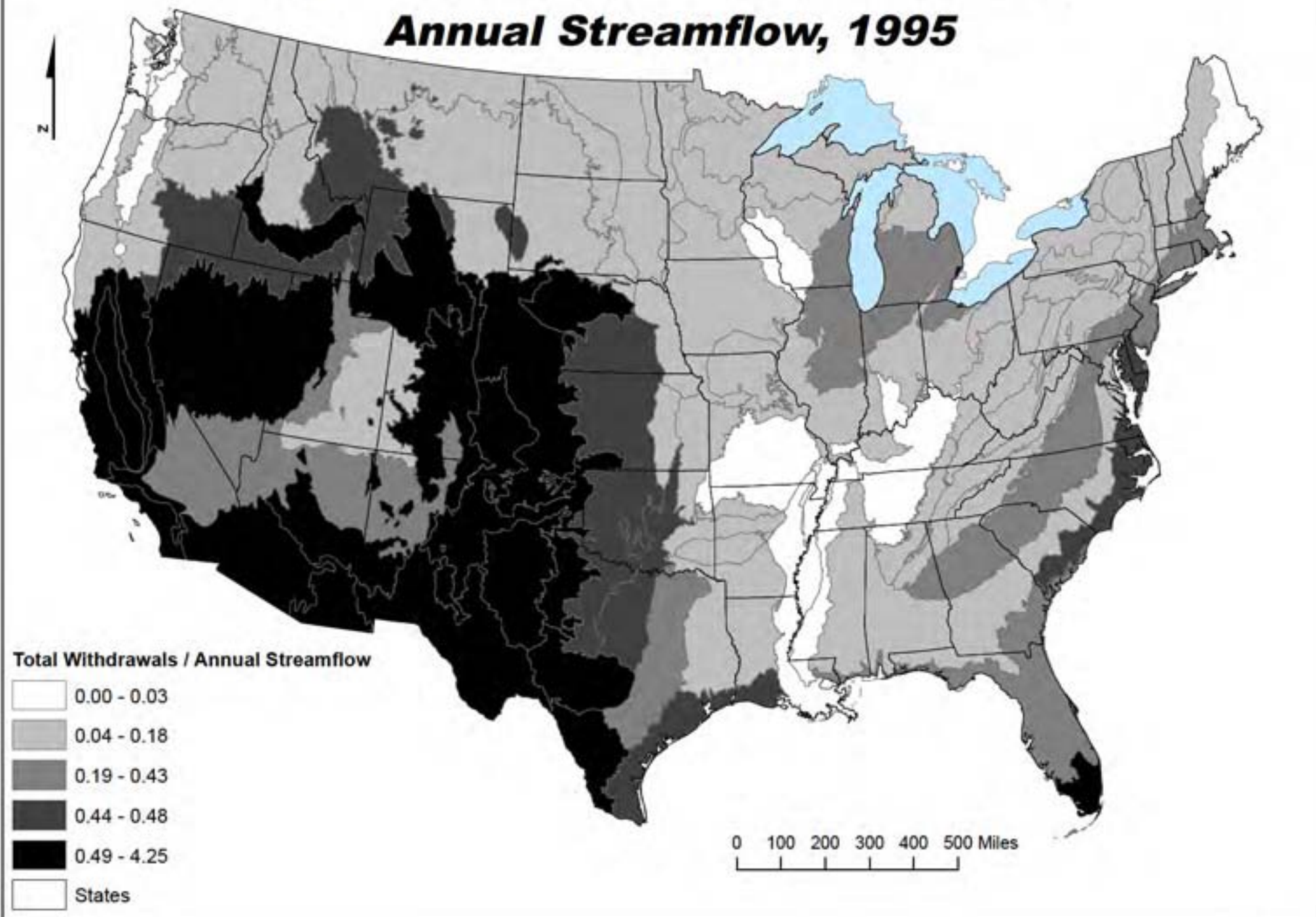
Total Withdrawals / Annual Streamflow

- 0.00 – 0.03
- 0.04 – 0.18
- 0.19 – 0.43
- 0.44 – 0.48
- 0.49 – 4.25
- States

0   100   200   300   400   500 Miles

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#219 Ratio of Water Withdrawals to Annual Streamflow

This continental U.S. indicator map shows the ratio of water withdrawals to annual streamflow in each ecoregion. Data were available for all lower-48 ecoregions. High ratios (0.49 - 4.25) are almost exclusively found in the West. Ecoregions with moderate ratios (0.44 - 0.48) cover parts of Oregon, Nevada, Idaho, Montana, Wyoming, Nebraska, Kansas, Oklahoma, and Texas. Low (0.19 - 0.43) and very low (0.04 - 0.18) ratios are scattered throughout the country, but with higher prevalence in the Midwest and the East. Ratios near zero (0.00 - 0.03) are found largely near the Mississippi River or tributaries, in the Pacific Northwest, southern Wisconsin, and Maine.

#284 Stream Habitat Quality, 2000-2004
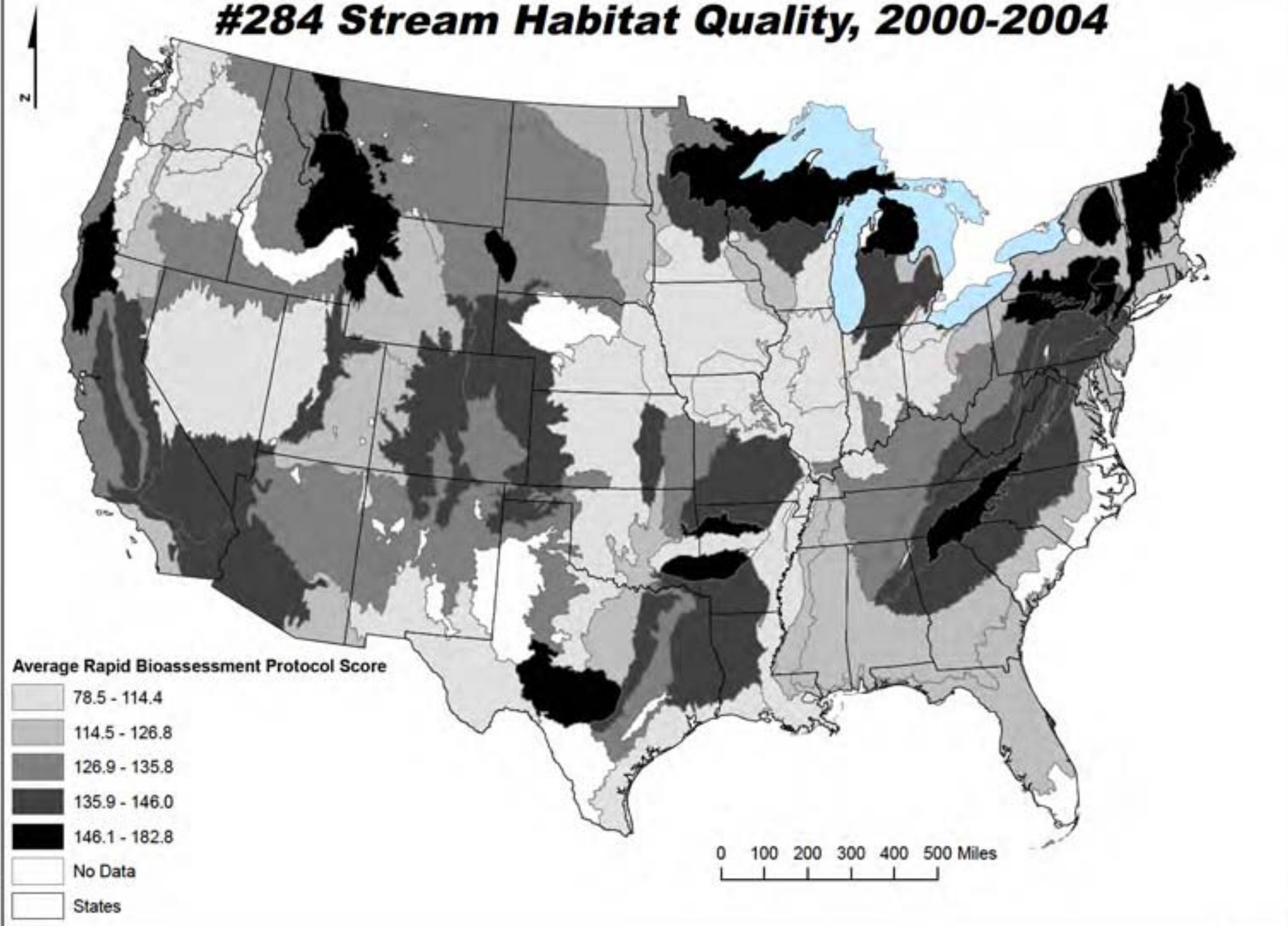
Average Rapid Bioassessment Protocol Score

- 78.5 - 114.4
- 114.5 - 126.8
- 126.9 - 135.8
- 135.9 - 146.0
- 146.1 - 182.8
- No Data
- States

0   100   200   300   400   500 Miles

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#284 Stream Habitat Quality

This continental U.S. indicator map shows stream habitat quality based on the rapid bioassessment protocol score in each ecoregion. Data were available for the vast majority of lower-48 ecoregions. The ecoregions with the highest bioassessment protocol scores (146.1 -182.8 and 135.9 - 146.0) include the northern Great Lakes region, an area which extends from parts of the Southeast to the Northeast and other areas scattered throughout the country. Moderate scores (126.9 - 135.8) are found primarily in the upper Midwest and Mountain West. The lowest scores (114.5 - 126.8 and 78.5 - 114.4) are found scattered in parts of the Southeast, Midwest, Mountain West, and Pacific Northwest.

#326 Wetland and Freshwater Species At-Risk, 2006
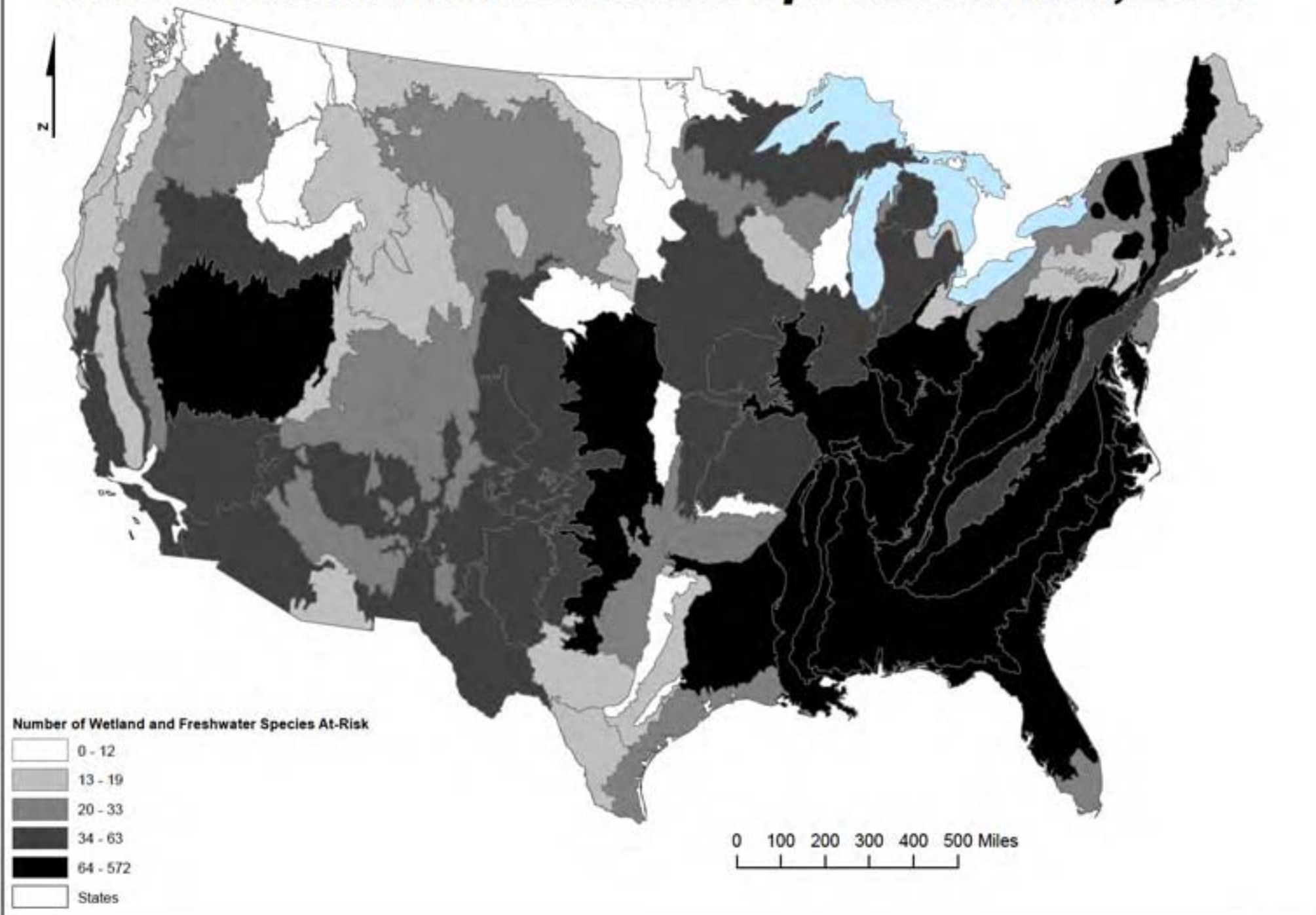
Number of Wetland and Freshwater Species At-Risk

- 0 - 12
- 13 - 19
- 20 - 33
- 34 - 63
- 64 - 572
- States

0   100   200   300   400   500 Miles

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#326 Wetland and Freshwater Species at Risk

This continental U.S. indicator map shows the number of wetland and freshwater species that are at risk in each ecoregion. Data were available for all lower-48 ecoregions. Ecoregions with the largest number (64 - 572) of species at risk are found primarily in the Southeast and South Atlantic regions. Ecoregions with a moderate (34 - 63) number of species at risk are largely found near ecoregions with a high number of species at risk in the Southeast, as well in ecoregions in the West and Midwest. Ecoregions with a low (20 - 33) and very low (13 - 19) number of species at risk are found everywhere but the Southeast. Ecoregions with almost no (0 - 12) species at risk are mostly found primarily in the northern Midwest and Mountain West.

#348 Erosion Rate, 1980

Soil Loss (tons/ha/year)

- 0.00 - 2.02
- 2.03 - 3.18
- 3.19 - 5.44
- 5.45 - 9.38
- 9.39 - 38.41
- States

0   100   200   300   400   500 Miles

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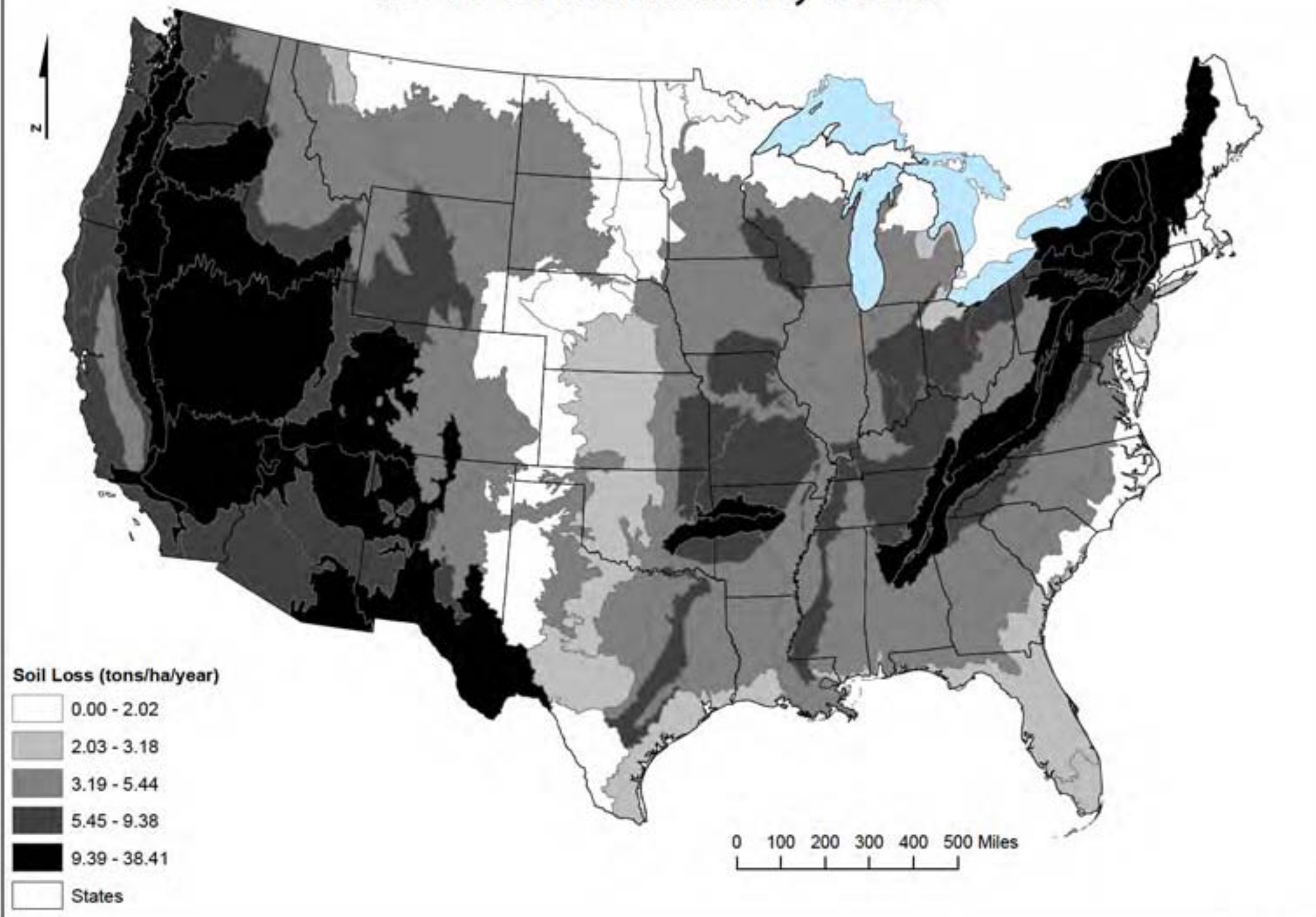
#348 Erosion Rate

This continental U.S. indicator map shows the average erosion rate in each ecoregion. Data were available for all lower-48 ecoregions. Ecoregions with high (9.39 - 38.41 tons/ha/year) and moderate (5.45 - 9.38 tons/ha/year) soil loss are found principally in the West but also in the central Midwest and an area extending from parts of the Southeast to the Northeast. Lower (0.00 - 2.02 tons/ha/year) soil loss rates are found scattered throughout the country, including in a vertical band from North Dakota to Texas, the Great Lakes region, and the Eastern seaboard.
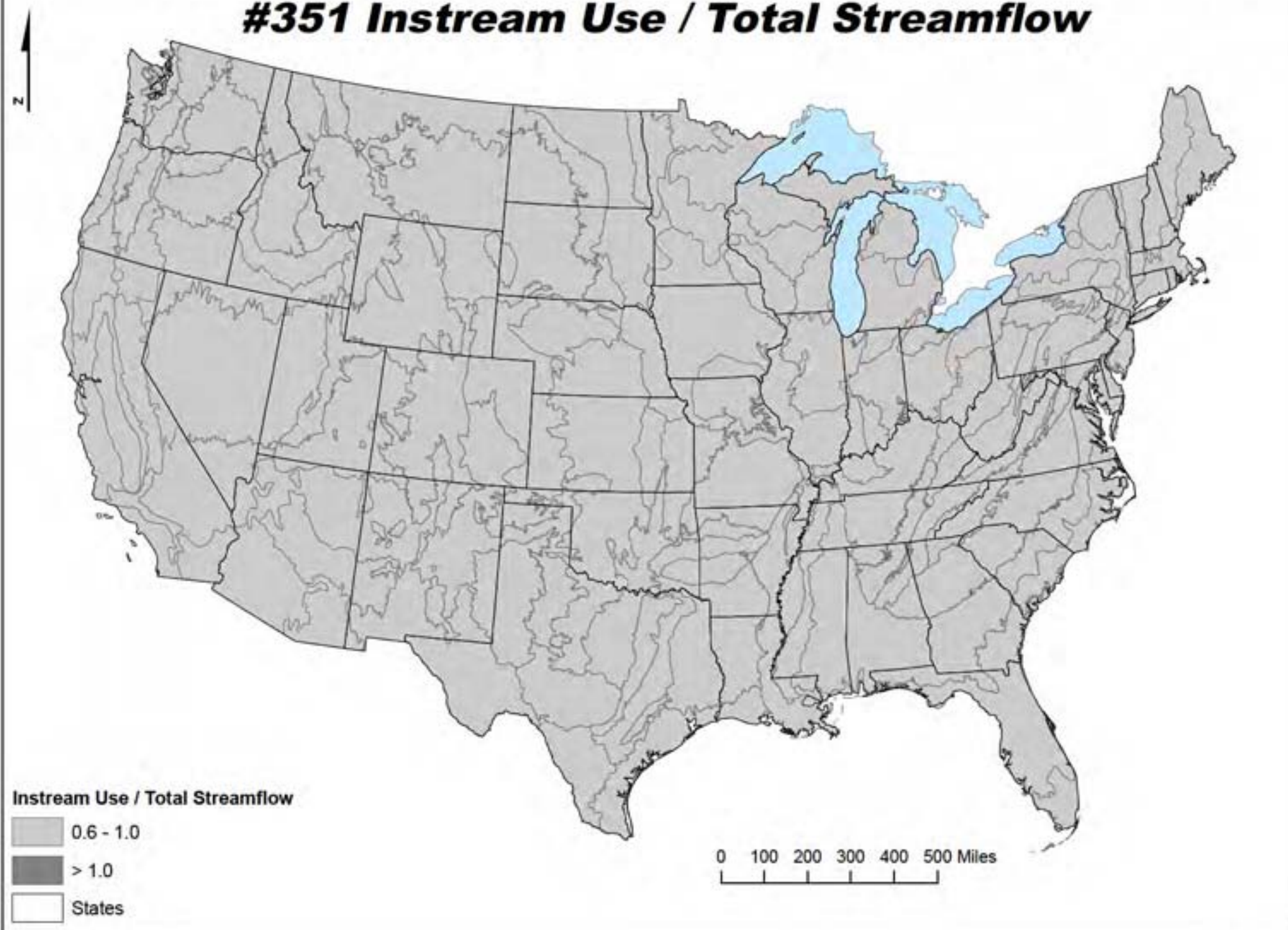
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#351 Instream Use / Total Streamflow

Instream Use / Total Streamflow

- 0.6 - 1.0
- > 1.0
- States

0 100 200 300 400 500 Miles

#351 Instream Use/Total Streamflow

This continental U.S. indicator map shows the ratio of instream use to total streamflow in each ecoregion. Data were available for all lower-48 ecoregions. All ecoregions have values within the range of 0.6 - 1.0.
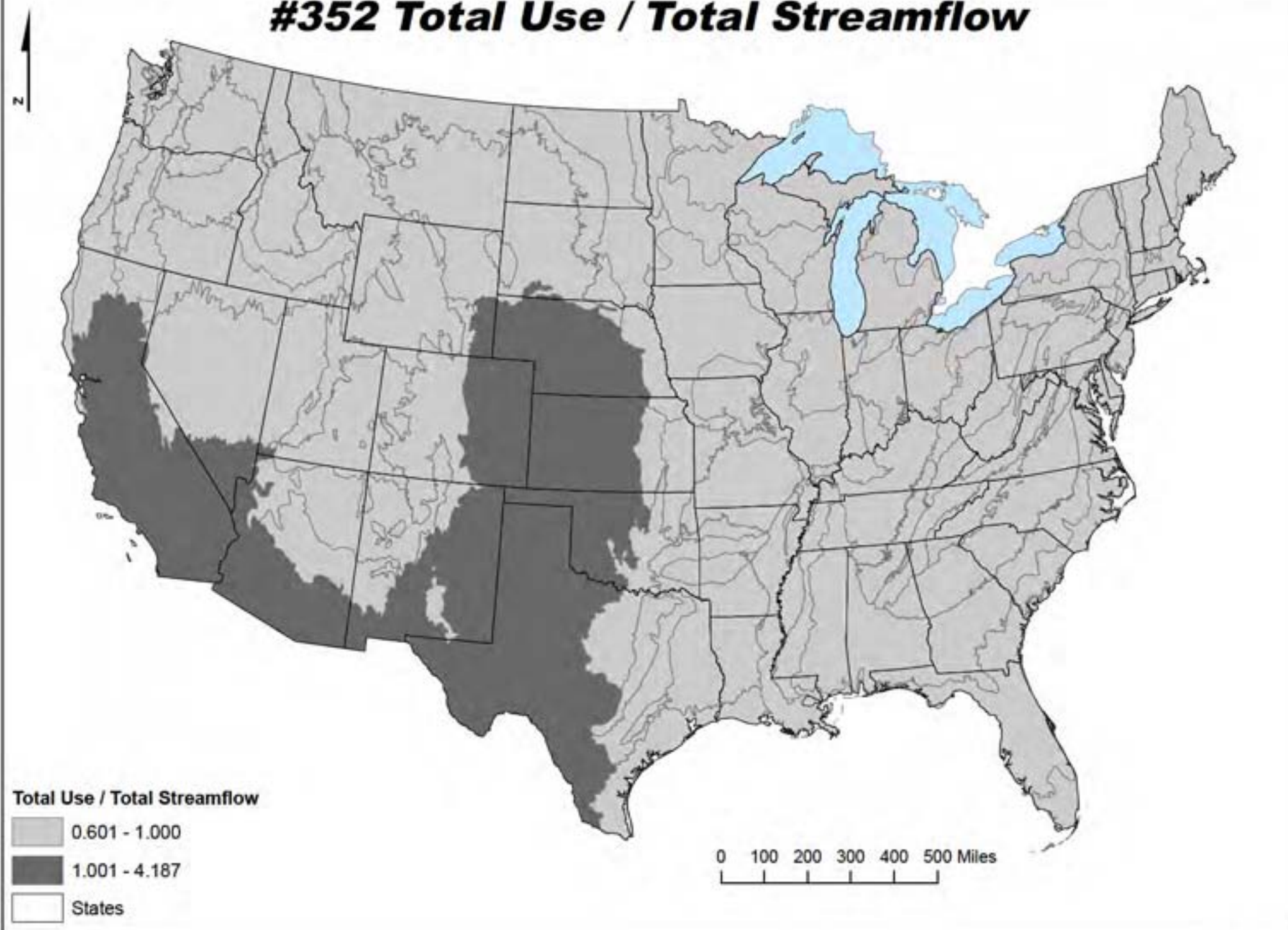
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#352 Total Use / Total Streamflow

Total Use / Total Streamflow

0.601 - 1.000

1.001 - 4.187

States

0   100   200   300   400   500 Miles

#352 Total Use / Total Streamflow

This continental U.S. indicator map shows the ratio of total use to total streamflow in each ecoregion. Data were available for all lower-48 ecoregions. Most ecoregions have values within the 0.601 - 1.000 range. However, there are a few ecoregions in the West and in an area extending from Texas into the Central Midwest, that fall in the 1.001 to 4.187 category.

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#364 Pesticide Toxicity Index, 1992-2001

Pesticide Toxicity Index for Daphnia Species

- 0.0000 - 0.0001
- 0.0002 - 0.0022
- 0.0023 - 0.0078
- 0.0079 - 0.0142
- 0.0143 - 0.0926
- No Data
- States

0   100   200   300   400   500 Miles
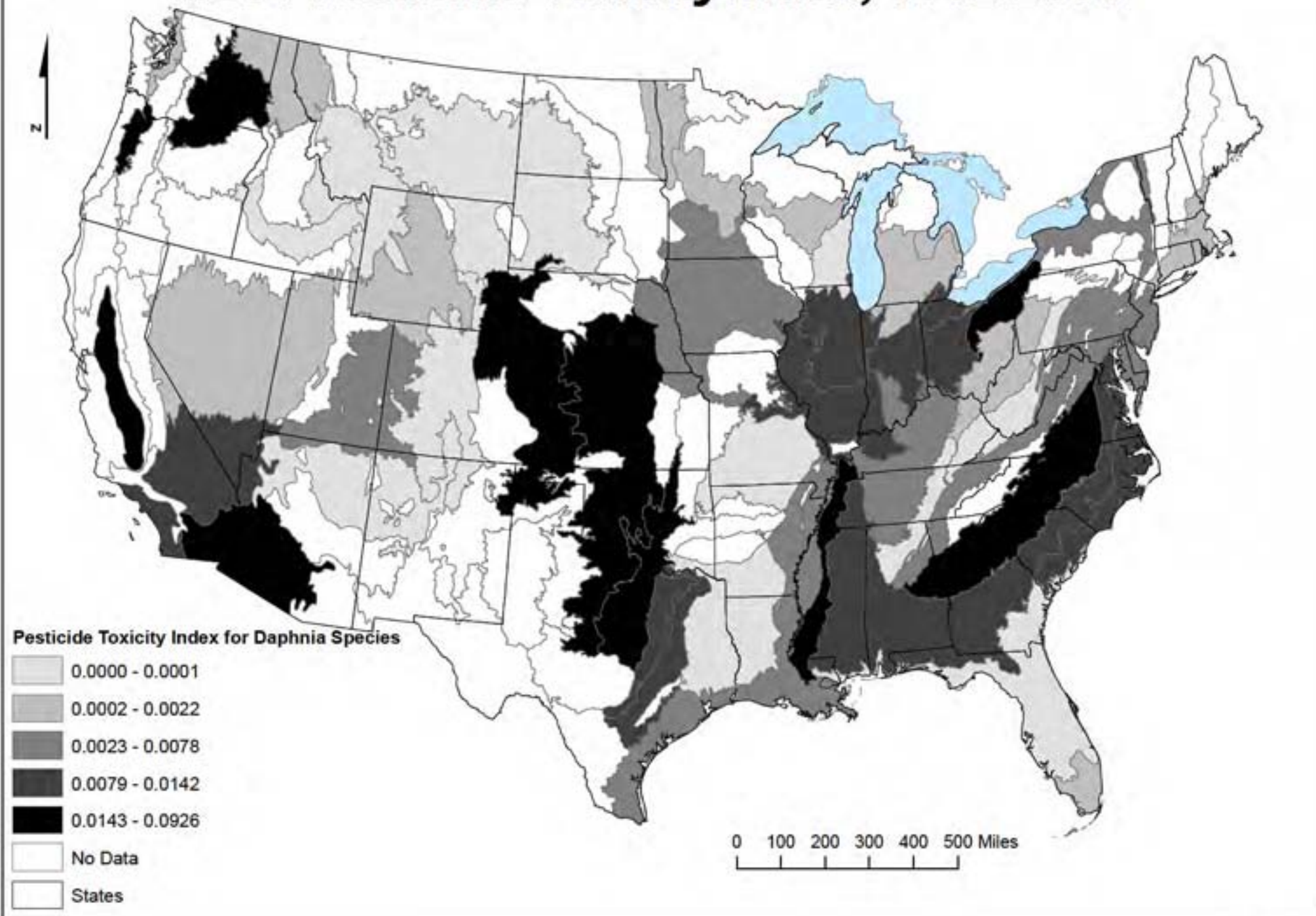
#364 Pesticide Toxicity Index

This continental U.S. indicator map shows the Pesticide Toxicity Index (PTI) for Daphnia species in each ecoregion. Data were not available for many of the lower-48 ecoregions. Available data is insufficient to infer geographic patterns, but does indicate the possibility of higher pesticide toxicity index values in the central states, Southwest, and Southeast.
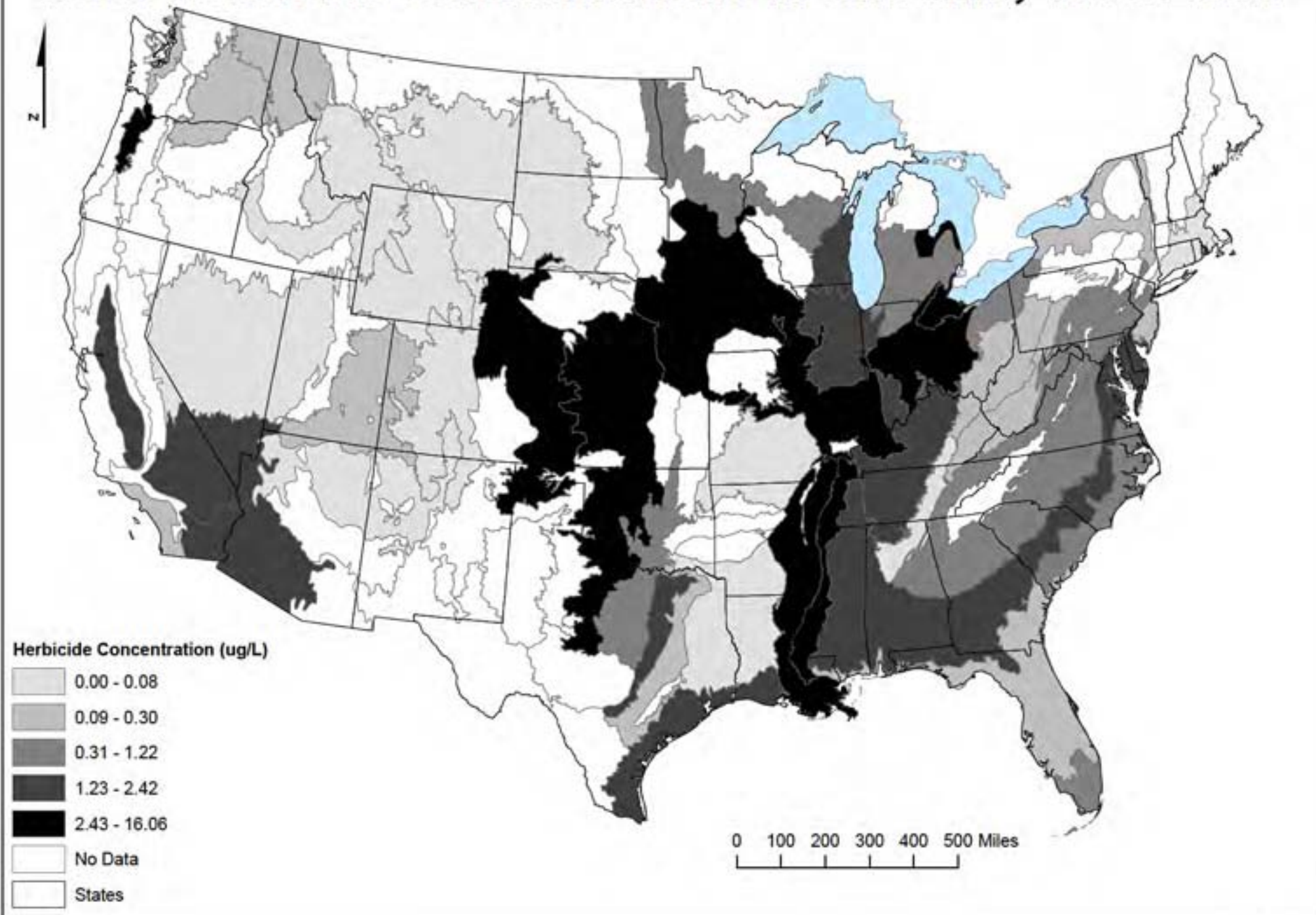
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#367 Herbicide Concentrations in Streams, 1993-2001

Herbicide Concentration (ug/L)

- 0.00 - 0.08
- 0.09 - 0.30
- 0.31 - 1.22
- 1.23 - 2.42
- 2.43 - 16.06
- No Data
- States

0   100   200   300   400   500 Miles

#367 Herbicide Concentrations in Streams

This continental U.S. indicator map shows herbicide concentrations in streams in each ecoregion. Data were not available for many of the lower-48 ecoregions. Ecoregions with the highest (2.43 - 16.06 µg/L) herbicide concentrations in streams occur predominantly in the Midwest and the lower Mississippi Basin. Ecoregions with high (1.23 - 2.42 µg/L) and moderate (0.31 - 1.22 µg/L) herbicide concentrations in streams are scattered in the East, while ecoregions with low (0.09 - 0.30 µg/L) and very low (0.00 - 0.08 µg/L) herbicide concentrations in streams cover most of the Mountain West and parts of the Northeast.

#369 Insecticide Concentrations in Streams, 1993-2001
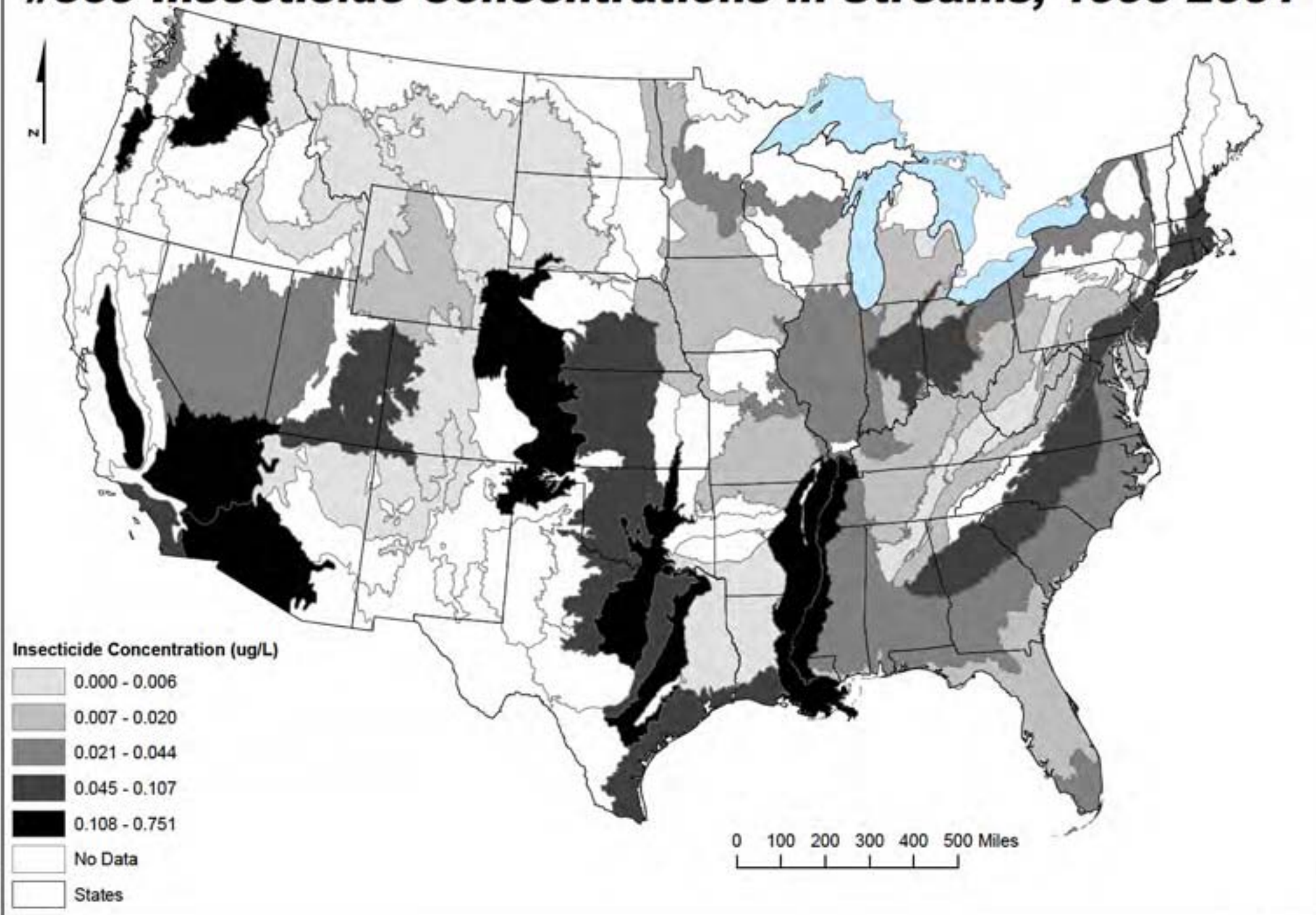
Insecticide Concentration (ug/L)

- 0.000 - 0.006
- 0.007 - 0.020
- 0.021 - 0.044
- 0.045 - 0.107
- 0.108 - 0.751
- No Data
- States

0   100   200   300   400   500 Miles

#369 Insecticide Concentrations in Streams

This continental U.S. indicator map shows insecticide concentrations in streams in each ecoregion. Data were not available for many of the lower-48 ecoregions. Available data is insufficient to infer geographic patterns, but does indicate the possibility of higher concentrations of insecticides in streams in the central states, Southwest, and the lower Mississippi basin.

#371 Organochlorines in Streambed Sediment, 1991-1997
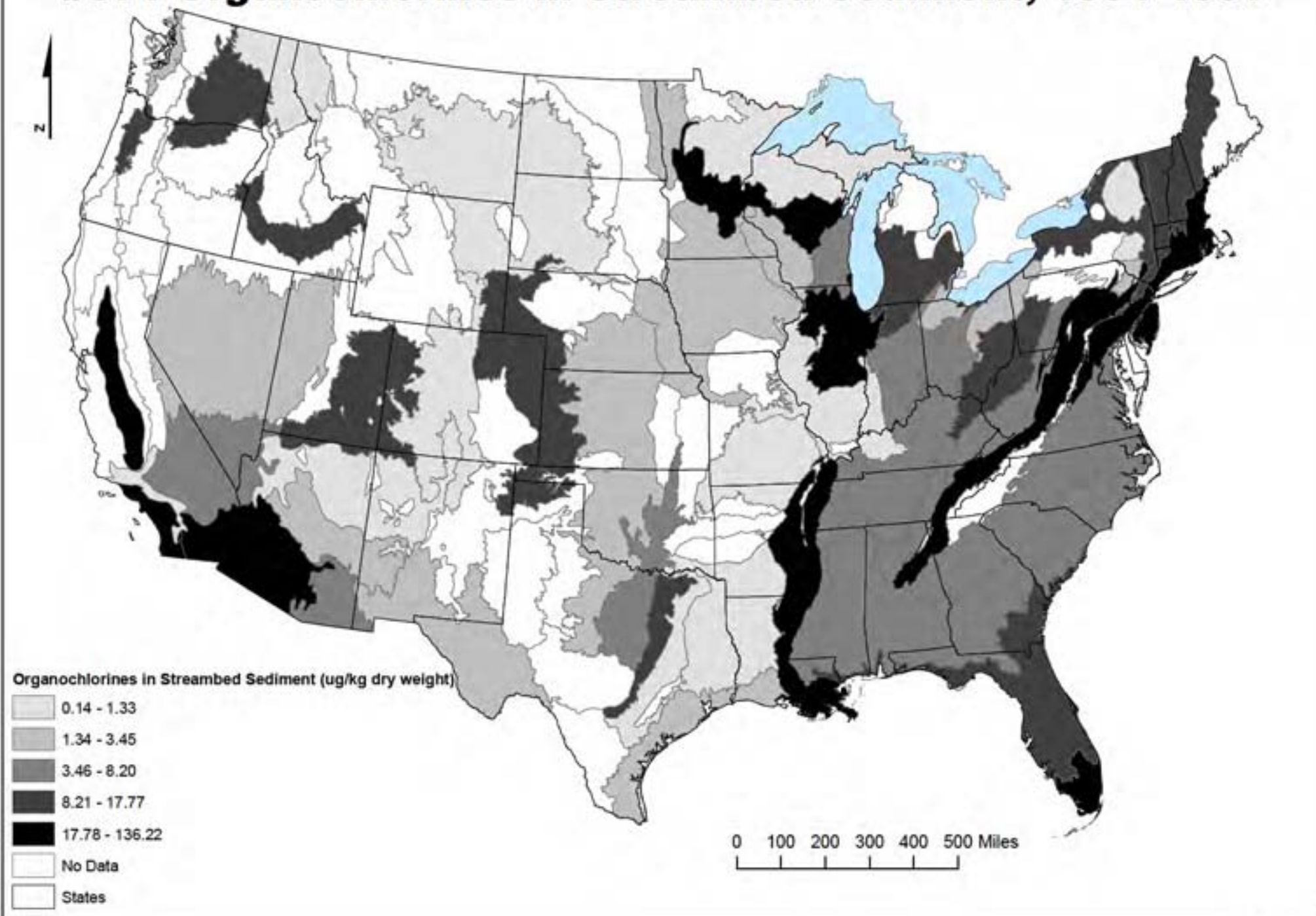
Organochlorines in Streambed Sediment (ug/kg dry weight)

- 0.14 - 1.33
- 1.34 - 3.45
- 3.46 - 8.20
- 8.21 - 17.77
- 17.78 - 136.22
- No Data
- States

0   100   200   300   400   500 Miles

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#371 Organochlorines in Bed Sediment

This continental U.S. indicator map shows organochlorine concentrations in streambed sediment in each ecoregion. Data were not available for many of the lower-48 ecoregions. Available data is insufficient to infer geographic patterns, but does indicate the possibility of higher concentrations of organochlorines in streams in the East and the Southwest.

#373 Herbicides in Groundwater, 1992-2003
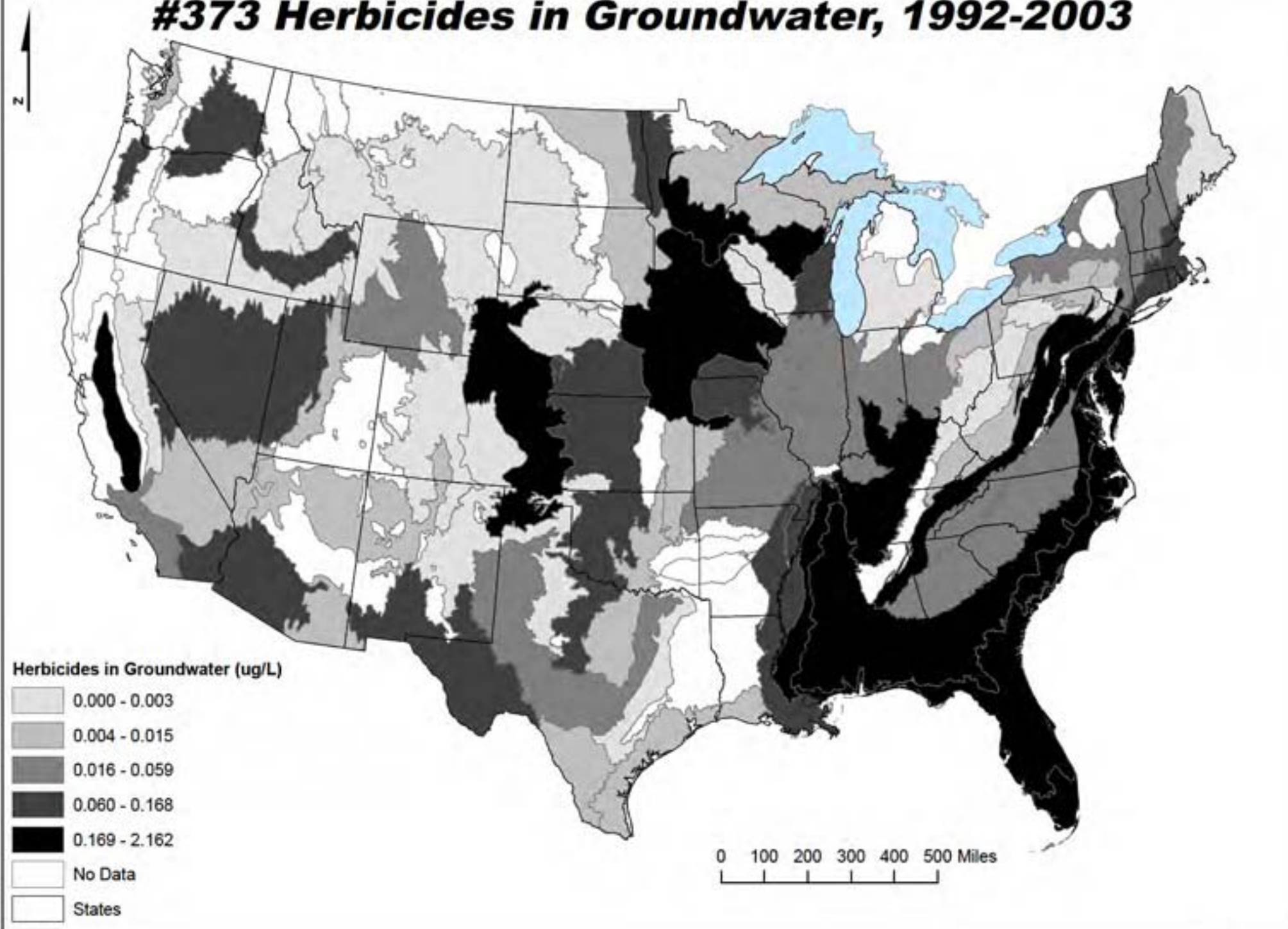
Herbicides in Groundwater (ug/L)

- 0.000 - 0.003
- 0.004 - 0.015
- 0.016 - 0.059
- 0.060 - 0.168
- 0.169 - 2.162
- No Data
- States

0　100　200　300　400　500 Miles

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#373 Herbicides in Groundwater

This continental U.S. indicator map shows herbicide concentrations in groundwater in each ecoregion. Data were not available for many of the lower-48 ecoregions. Ecoregions with the highest (0.169 - 2.162 µg/L and 0.060 - 0.168 µg/L) concentrations of herbicides occur predominantly in the Southeast and in the central Midwestern states. Ecoregions with moderate (0.016 - 0.059 µg/L) and low (0.004 - 0.015 µg/L) concentrations of herbicides in groundwater are scattered throughout the country, while ecoregions with the lowest (0.000 - 0.003 µg/L) concentrations occur primarily in the Northwest.

#374 Insecticides in Groundwater, 1992-2003
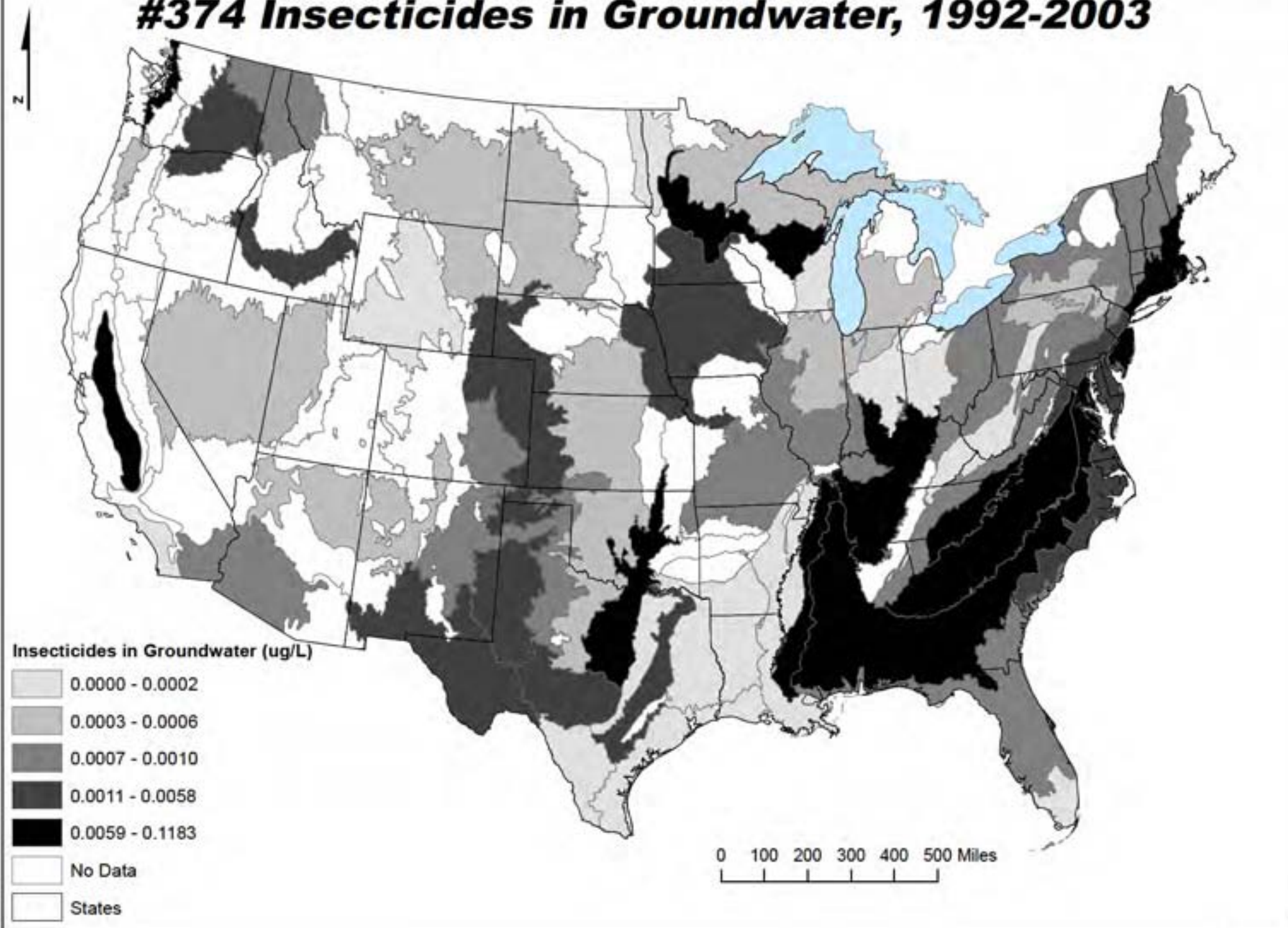
Insecticides in Groundwater (ug/L)

- 0.0000 - 0.0002
- 0.0003 - 0.0006
- 0.0007 - 0.0010
- 0.0011 - 0.0058
- 0.0059 - 0.1183
- No Data
- States

0   100   200   300   400   500 Miles

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#374 Insecticides in Groundwater

This continental U.S. indicator map shows insecticide concentrations in groundwater in each ecoregion. Data were available for only a fraction of lower-48 ecoregions. Ecoregions with the highest (0.0059 - 0.1183 µg/L and 0.0011 - 0.0058 µg/L) concentrations of insecticides in groundwater occur predominantly in the Southeast and South Atlantic regions. Ecoregions with moderate (0.0007 - 0.0010 µg/L) and low (0.0003 - 0.0006 µg/L) concentrations of insecticides in groundwater are scattered throughout the country, while ecoregions with the lowest (0.0000 - 0.0002 µg/L) concentrations occur mostly in the West.

#437 Precipitation Elasticity of Streamflow, 1951-1988
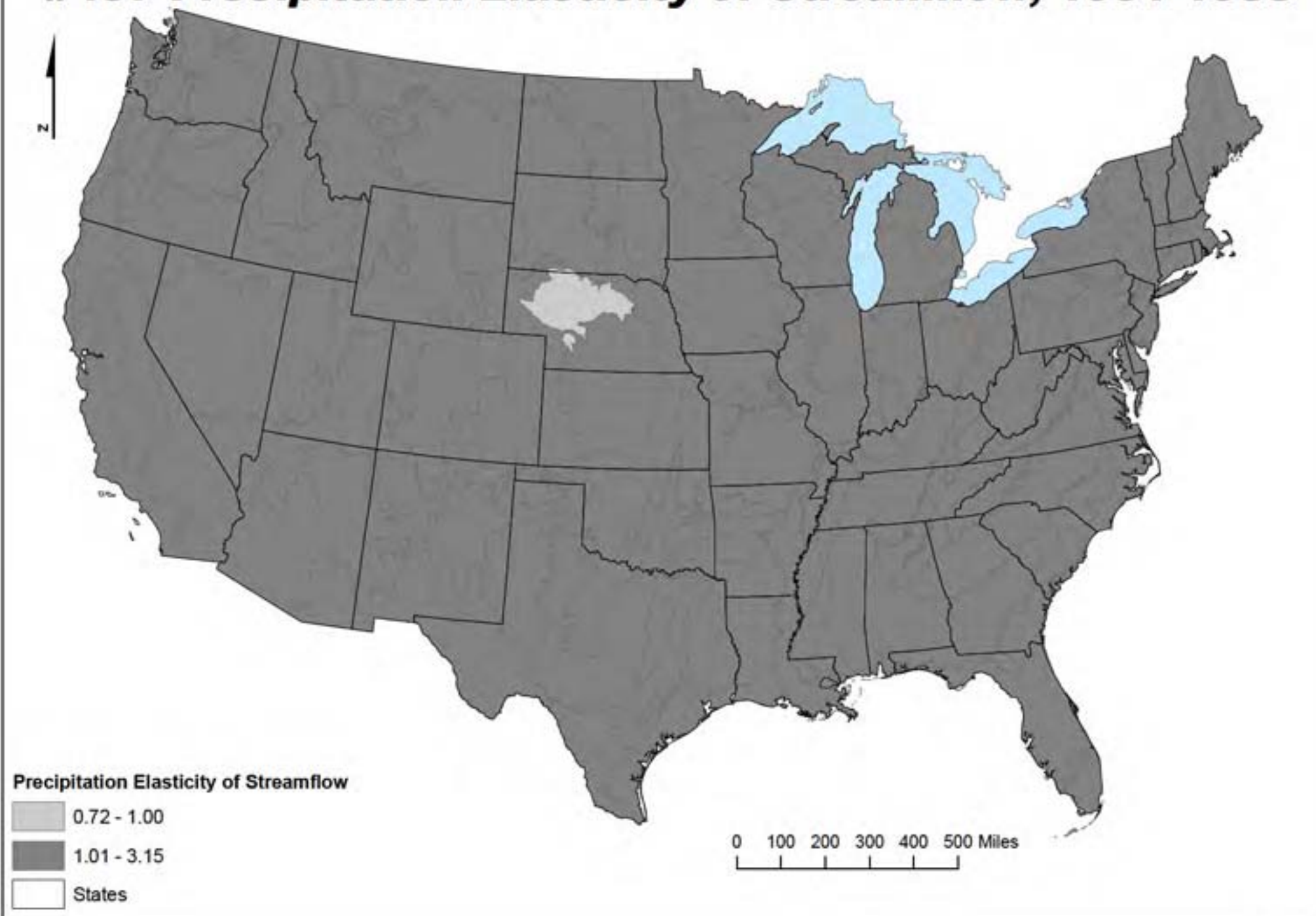
Precipitation Elasticity of Streamflow

	0.72 - 1.00
	1.01 - 3.15
	States

0   100   200   300   400   500 Miles

#437 Precipitation Elasticity of Streamflow

This continental U.S. indicator map shows the precipitation elasticity of streamflow in each ecoregion. Data were available for all lower-48 ecoregions. Every ecoregion has elasticity in the higher range (1.01 - 3.15) except for one ecoregion in Nebraska, which has elasticity in the 0.72 - 1.00 range.

#449 Ratio of Reservoir Storage to Mean Annual Runoff
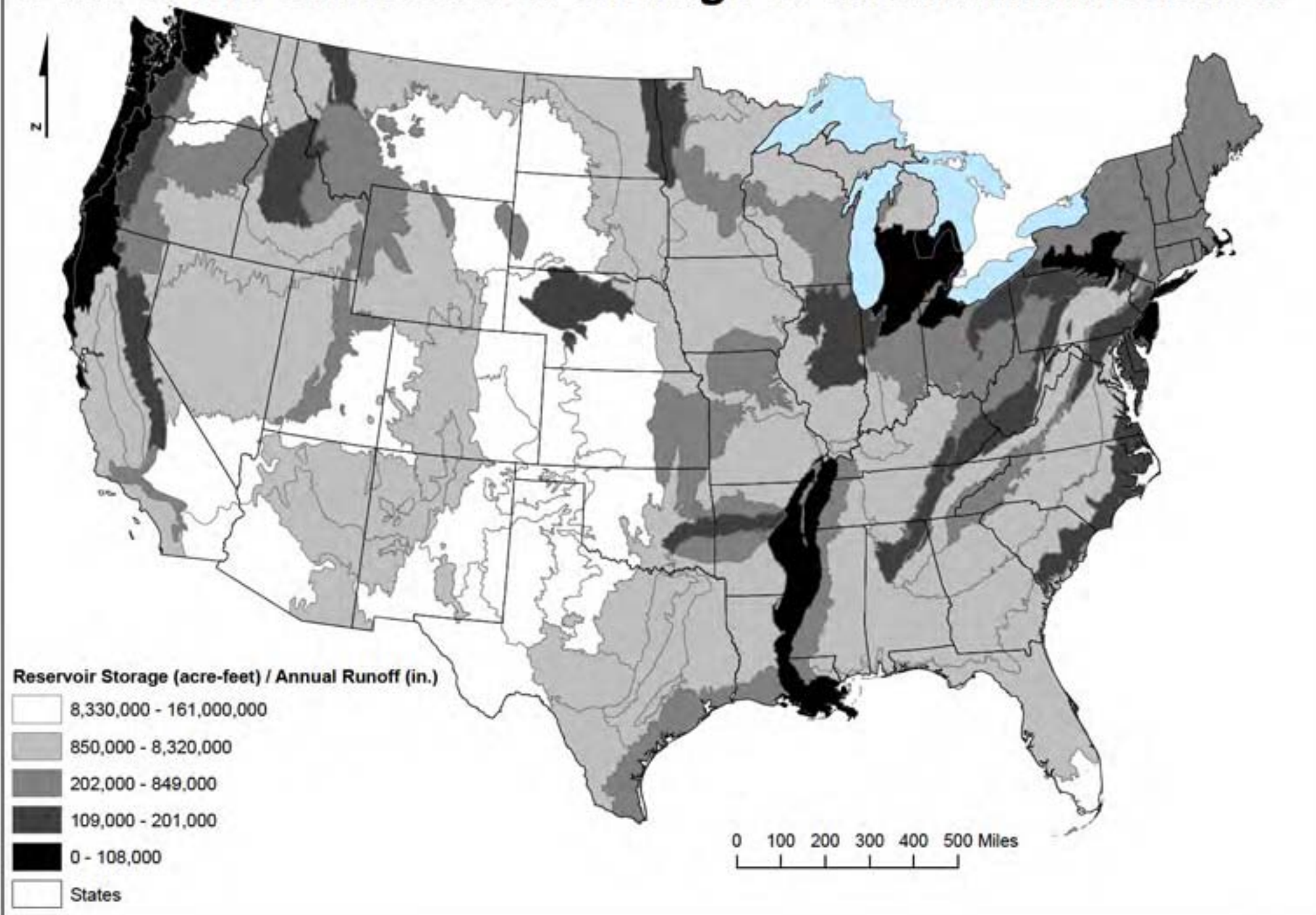
Reservoir Storage (acre-feet) / Annual Runoff (in.)

- 8,330,000 - 161,000,000
- 850,000 - 8,320,000
- 202,000 - 849,000
- 109,000 - 201,000
- 0 - 108,000
- States

0　100　200　300　400　500 Miles

#449 Ratio of Reservoir Storage to Mean Annual Runoff

This continental U.S. indicator map shows the ratio of reservoir storage to mean annual runoff in each ecoregion. Data were available for all lower-48 ecoregions. Ecoregions with the lowest (0 – 108,000 acre-feet/inch) ratios occur in the Pacific Northwest, the lower Mississippi basin, and in Michigan. Ecoregions with low (109,000 - 201,000 acre-feet/inch) and moderate ratios (202,000 – 849,000 acre-feet/inch) are found primarily in the Northeast, but are also scattered throughout the country. Ecoregions with high (850,000 - 8,320,000 acre-feet/inch) and very high (8,330,000 - 161,000,000 acre-feet/inch) ratios cover most of the country with the highest ratios occurring in Western Midwest and Mountain West regions.

#453 Runoff Variability, 1984-1993
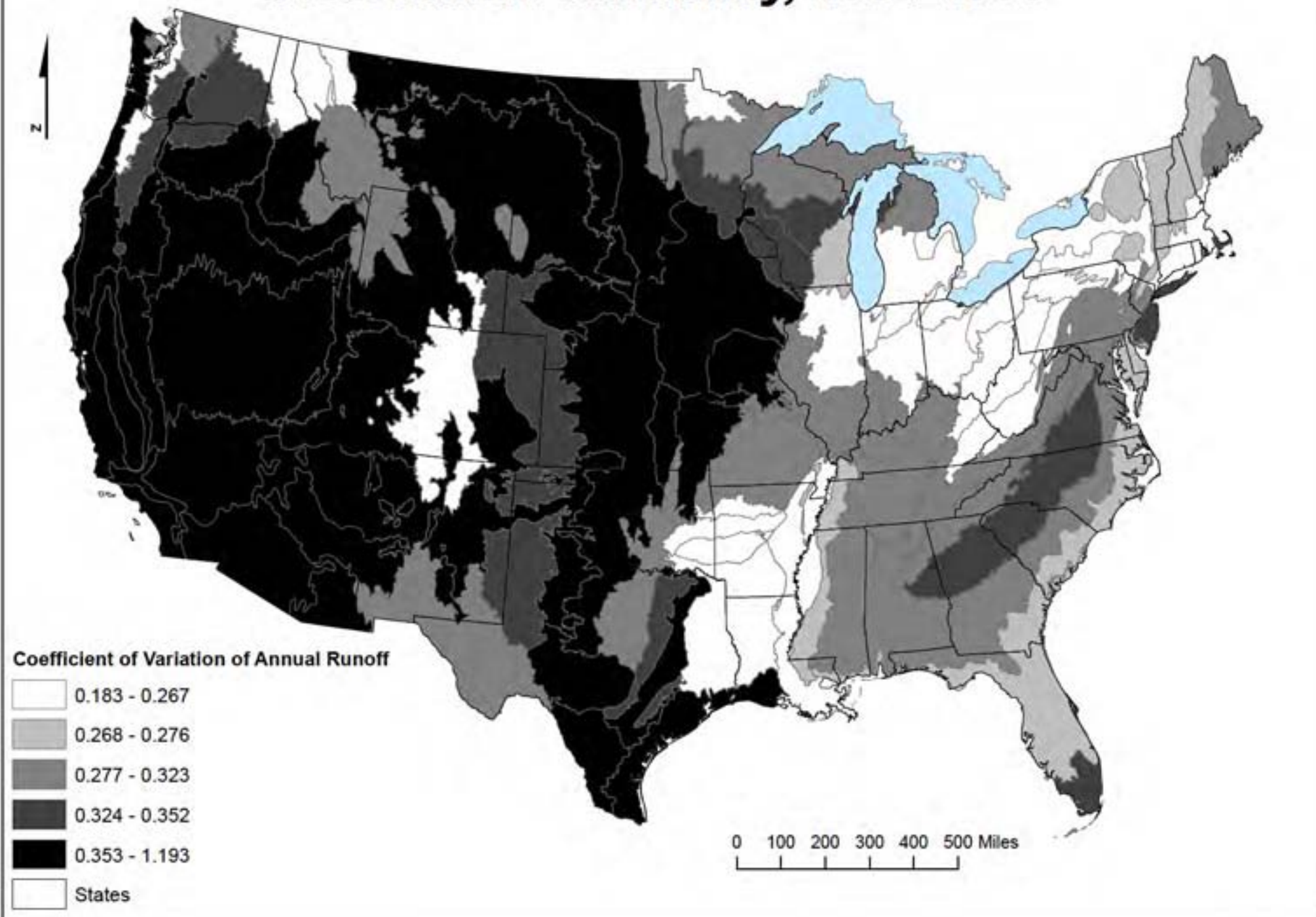
Coefficient of Variation of Annual Runoff

- 0.183 - 0.267
- 0.268 - 0.276
- 0.277 - 0.323
- 0.324 - 0.352
- 0.353 - 1.193
- States

0   100   200   300   400   500 Miles

#453 Runoff Variability

This continental U.S. indicator map shows the coefficient of variation of annual runoff in each ecoregion. Data were available for all lower-48 ecoregions. A very distinctive pattern emerges on this map, with ecoregions with the highest (0.353 - 1.193 and 0.324 - 0.352) coefficients covering almost the entire western half of the country. Ecoregions with moderate (0.277 - 0.323) ratios are observed largely in the Southeast, while ecoregions with low (0.268 - 0.276) and very low (0.183 - 0.267) ratios are observed in the lower Mississippi basin, parts of the Great Lakes region, the Northeast, and Florida.

#460 Macroinvertebrate Index of Biotic Condition, 2000-2004
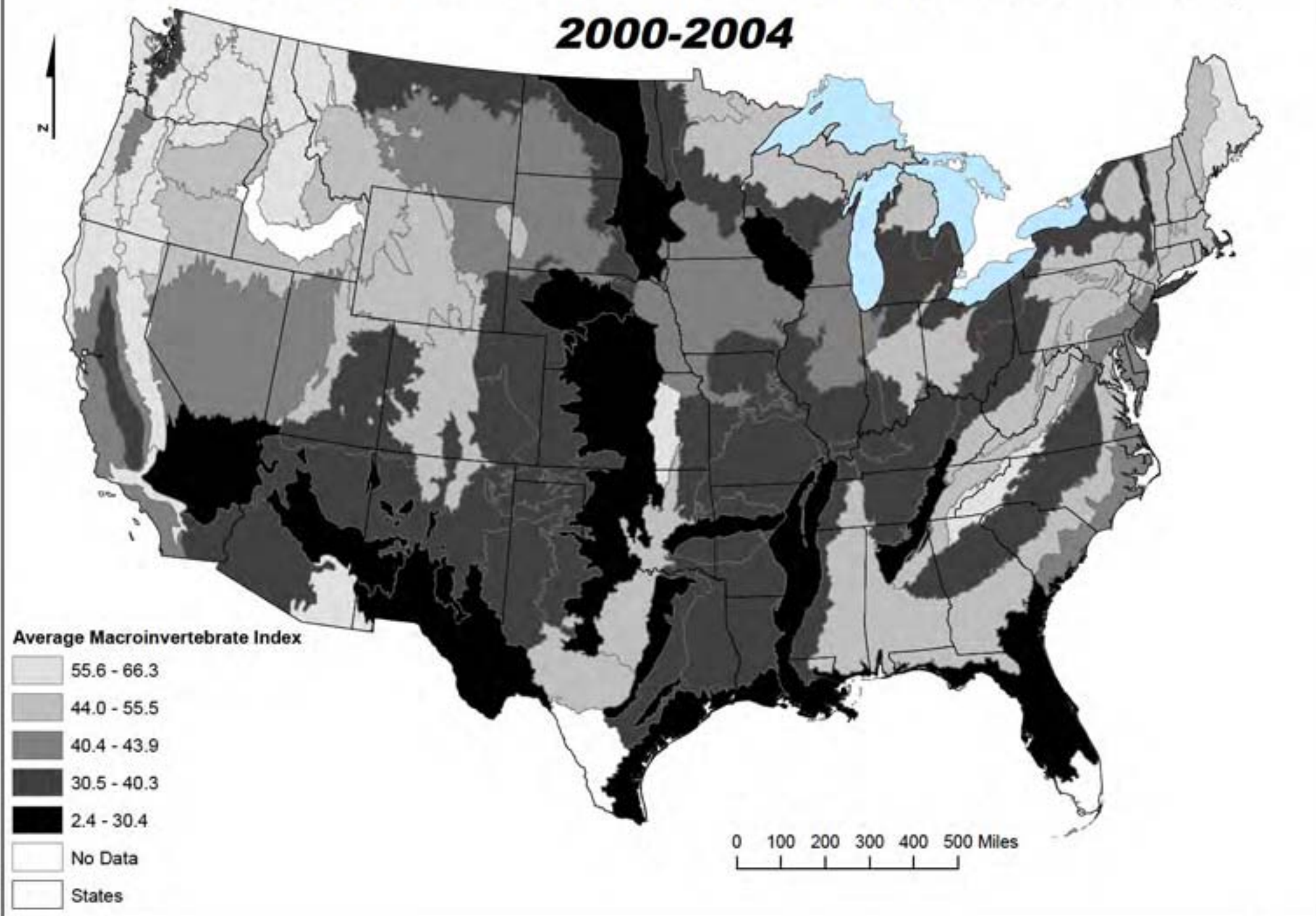
Average Macroinvertebrate Index

- 55.6 - 66.3
- 44.0 - 55.5
- 40.4 - 43.9
- 30.5 - 40.3
- 2.4 - 30.4
- No Data
- States

0   100   200   300   400   500 Miles

#460 Macroinvertebrate Index of Biotic Condition

This continental U.S. indicator map shows the macroinvertebrate index of biotic condition in each ecoregion. Data were available for the vast majority of lower-48 ecoregions. Ecoregions with the lowest (2.4 - 30.4) macroinvertebrate index values occur in the central Midwest and along the Gulf Coast, while ecoregions with the highest (44.0 - 55.5 and 55.6 - 66.3) index values occur primarily in the Northwest. The remaining ecoregions with macroinvertebrate index values in the moderate range (30.5 - 40.3 and 40.4 - 43.9) are scattered throughout the country.

#461 Macroinvertebrate O/E Ratio of Taxa Loss, 2000-2004
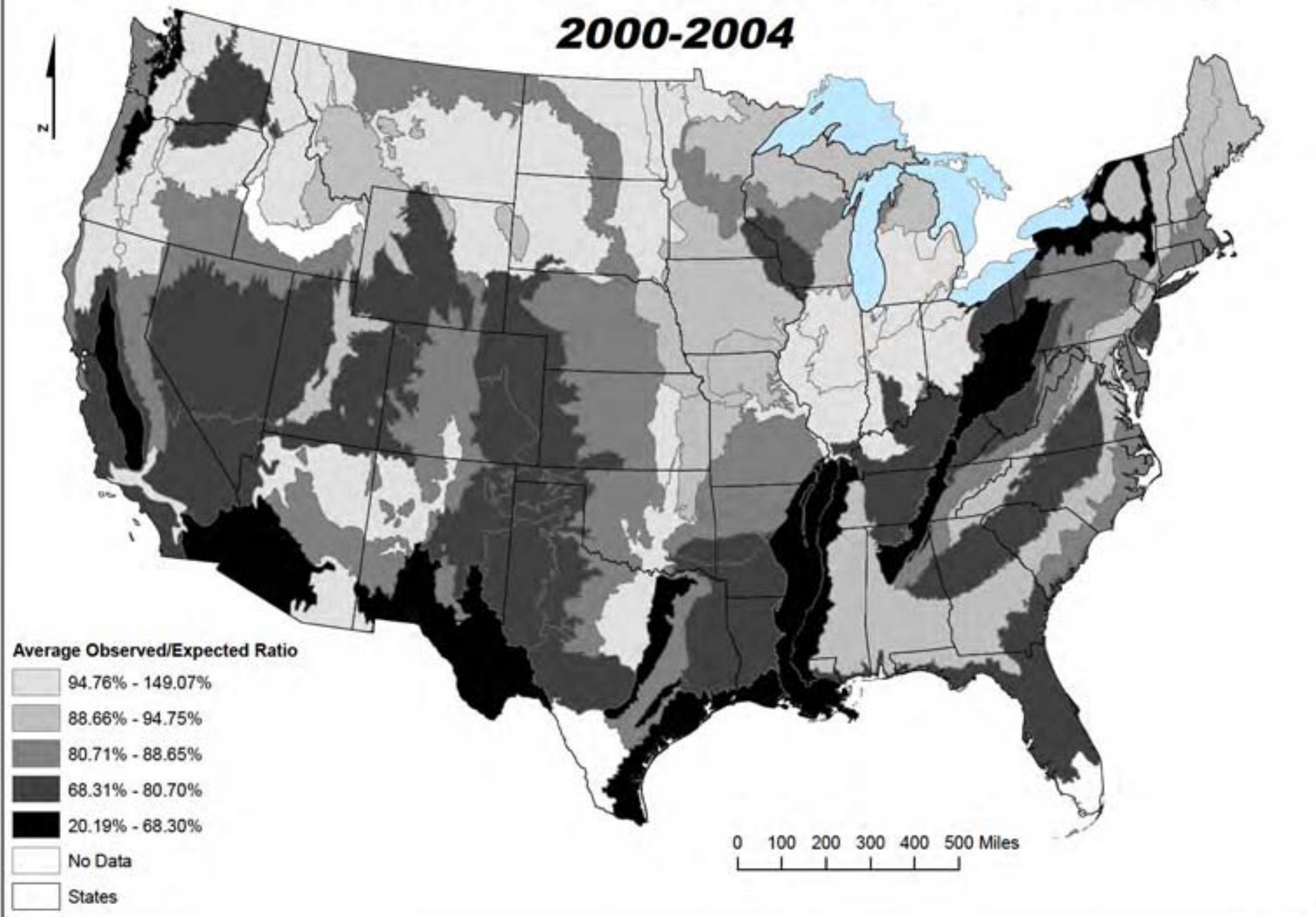
Average Observed/Expected Ratio

- 94.76% - 149.07%
- 88.66% - 94.75%
- 80.71% - 88.65%
- 68.31% - 80.70%
- 20.19% - 68.30%
- No Data
- States

0   100   200   300   400   500 Miles

#461 Macroinvertebrate Observed/Expected (O/E) Ratio of Taxa Loss

This continental U.S. indicator map shows the observed taxa as a percentage of the expected macroinvertebrate taxa in each ecoregion. Data were available for the vast majority of lower-48 ecoregions. This map shows no discernable pattern, but does indicate the possibility of higher ratio of taxa loss in the lower Mississippi basin and parts of the Southwest.
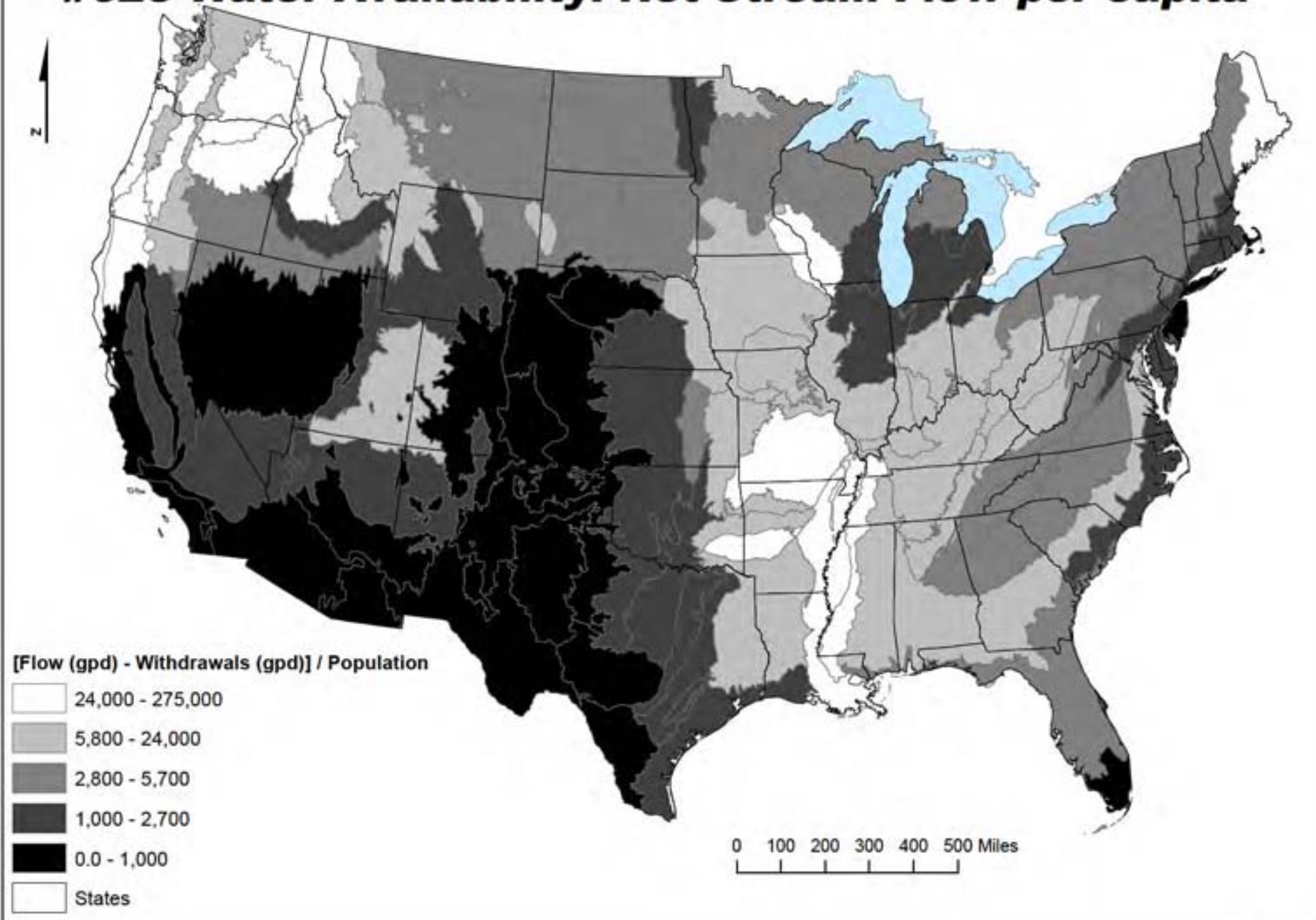
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#623 Water Availability: Net Stream Flow per capita

[Flow (gpd) - Withdrawals (gpd)] / Population

- 24,000 - 275,000
- 5,800 - 24,000
- 2,800 - 5,700
- 1,000 - 2,700
- 0.0 - 1,000
- States

0 100 200 300 400 500 Miles

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#623 Water Availability: Net Streamflow per Capita

This continental U.S. indicator map shows the net streamflow per capita in each ecoregion. Data were available for all lower-48 ecoregions. Ecoregions with the lowest (0.0 – 1,000 gallons/day/capita and 1,000 – 2,700 gallons/day/capita) water availability occur predominantly in the Southwest and parts of the central Mountain West and Midwest. Ecoregions with moderate (2,800-5,700) water availability occur in the northern Mountain West, the Northeast, and in Florida. Ecoregions with the highest (5,800 – 24,000 gallons/day/capita and 24,000 – 275,000 gallons/day/capita) water availability occur in parts of the Midwest, Southeast, the Northwest, and Main

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Appendix G. Vulnerability Category Matrix

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The following matrix displays the data for 25 mapped indicators for each of the 204 HUC-4 watersheds in the continental United States. (Note that one mapped indicator, the Coastal Vulnerability Index (#51), is not included here because a different spatial unit was used to map it). Values for each indicator are represented both by colors and numbers: No data (white, 0); Lowest (light gray, 1); Low (medium gray, 2); Medium (dark gray, 3); High (darker gray, 4), and Highest (black, 5). The shades of black, white, and gray in this matrix match those on the maps in Appendix E and Appendix F.

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SUB	Acid Neutralizing Capacity [#1]	At-Risk Freshwater Plant Communities [#22]	At-Risk Native Freshwater Species [#24]	Groundwater Reliance [#125]	Meteorological Drought Indices [#165]	Ratio of Snow to Precipitation [#218]	Stream Habitat Quality [#284]	Wetland and Freshwater Species at Risk [#326]	Herbicide Concentrations in Streams [#367]	Insecticide Concentrations in Streams [#369]	Organochlorines in Bed Sediment [#371]	Herbicides in Groundwater [#373]	Insecticides in Groundwater [#374]	Precipitation Elasticity of Streamflow [#437]	Ratio of Reservoir Storage to Mean Annual Runoff [#449]	Runoff Variability [#453]	Macroinvertebrate Index of Biotic Condition [#460]	Macroinvertebrate Observed/Expected (O/E) Ratio of Taxa Loss [#461]	Ratio of Water Withdrawals to Annual Streamflow [#219]	Erosion Rate [#348]	Instream Use/ Total Streamflow [#351]	Total Use/ Total Streamflow [#352]	Pesticide Toxicity Index [#364]	Water Availability: Net Streamflow per Capita [#623]
0101	1	1	1	4	2	5	5	2	0	0	0	0	0	5	5	1	1	5	1	1	1	1	0	1
0102	4	1	1	3	2	4	5	2	0	0	0	0	0	5	3	3	1	3	1	1	1	1	0	1
0103	1	1	1	4	2	4	5	1	0	0	1	2	1	5	3	3	1	4	1	1	1	1	0	1
0104	5	1	1	4	2	4	5	1	0	0	1	2	2	5	5	1	1	4	1	3	1	1	0	1
0105	1	1	1	4	1	4	5	1	0	0	0	0	0	5	4	4	1	4	1	1	1	1	0	1
0106	1	1	1	3	1	4	4	2	0	0	0	1	2	5	5	1	1	3	3	1	1	1	0	3
0107	5	1	1	4	1	4	5	3	0	0	2	2	2	5	4	1	2	2	2	1	1	1	0	3
0108	1	1	1	2	1	4	5	5	0	0	2	5	5	5	3	2	1	5	2	4	1	1	0	3
0109	1	1	1	2	1	3	2	4	1	4	4	2	3	5	5	1	2	2	4	2	1	1	2	4
0110	1	1	1	1	1	3	3	4	1	5	2	4	4	5	4	3	1	5	4	2	1	1	1	4
0111	1	1	1	5	2	5	5	1	0	0	0	0	0	5	5	1	1	5	1	5	1	1	0	1
0201	1	1	1	4	1	5	3	3	0	0	0	0	0	5	5	1	3	3	1	5	1	1	0	2
0202	4	1	2	3	1	4	4	4	2	3	2	3	4	5	4	3	4	2	2	5	1	1	2	3
0203	1	1	2	2	1	3	4	3	3	5	2	2	3	5	4	3	1	5	4	4	1	1	4	4
0204	2	1	2	2	1	3	3	5	2	3	3	5	5	5	3	3	3	2	4	5	1	1	3	4
0205	2	1	3	3	1	3	5	5	4	3	3	5	5	5	3	1	2	4	3	5	1	1	4	3
0206	3	1	1	1	1	2	3	4	4	2	0	4	4	5	5	3	3	3	4	2	1	1	3	4
0207	1	2	3	2	1	3	4	5	4	4	1	4	3	5	4	2	3	4	3	5	1	1	3	4
0208	1	4	4	1	1	2	5	5	0	0	0	5	5	5	3	4	2	4	4	2	1	1	0	4
0301	1	5	4	2	1	2	5	5	0	0	2	5	4	5	3	4	4	2	3	2	1	1	0	3
0302	1	5	4	4	1	2	1	5	3	2	1	3	5	5	4	2	5	1	1	1	1	1	2	3
0303	1	5	4	2	3	2	5	4	0	0	0	0	0	5	4	2	2	3	3	2	1	1	0	3
0304	1	5	4	4	3	2	1	5	0	0	0	0	0	5	5	3	5	3	2	2	1	1	0	3
0305	4	5	4	1	4	2	5	5	3	3	1	5	5	5	2	3	1	4	3	3	1	1	4	4
0306	1	5	5	3	3	1	1	5	0	0	1	1	1	5	1	3	5	1	3	3	1	1	0	3
0307	1	5	5	3	4	1	1	5	2	4	2	2	1	5	2	3	5	2	3	2	1	1	3	3

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0308	1	5	5	3	3	1	2	5	0	0	3	4	1	5	4	1	4	1	4	1	1	1	0	4
0309	0	5	5	4	5	1	0	5	4	3	3	5	3	5	1	3	3	3	4	2	1	1	3	4
0310	0	5	5	3	3	1	0	4	0	0	2	4	1	5	3	3	0	0	4	2	1	1	0	5
0311	1	5	5	5	4	1	3	5	1	1	2	5	5	5	5	3	5	1	1	1	1	1	3	2
0312	0	5	5	4	3	1	0	3	2	4	2	1	4	5	5	1	0	0	2	2	1	1	4	2
0313	1	5	5	4	4	1	1	5	2	3	1	4	5	5	3	2	4	1	2	4	1	1	5	3
0314	5	5	5	4	3	1	3	5	0	0	0	0	0	5	5	1	3	2	2	3	1	1	0	2
0315	2	5	5	2	4	1	4	5	2	3	1	3	4	5	3	3	2	4	2	4	1	1	4	2
0316	1	4	5	2	1	1	5	5	5	3	2	1	1	5	3	3	2	3	2	4	1	1	5	2
0317	4	2	4	4	2	1	2	5	0	0	0	0	0	5	3	2	2	4	1	1	1	1	0	2
0318	5	3	4	4	2	1	3	4	0	0	0	1	1	5	4	2	1	1	1	2	1	1	0	2
0401	1	1	2	1	4	5	4	2	0	0	0	0	0	5	3	2	2	2	2	1	1	1	0	2
0402	1	1	2	2	5	5	5	2	0	0	0	0	0	5	4	3	2	3	2	1	1	1	0	1
0403	1	2	2	2	4	4	3	4	5	1	1	5	3	5	2	3	2	4	3	1	1	1	1	3
0404	0	3	3	2	3	3	0	1	3	1	2	3	3	5	5	1	0	0	5	2	1	1	1	5
0405	1	2	3	3	2	4	4	3	0	0	0	0	0	5	5	1	5	2	3	2	1	1	0	4
0406	3	1	2	3	3	5	5	3	0	0	0	0	0	5	5	2	1	5	4	1	1	1	0	5
0407	0	1	2	2	3	5	0	2	0	0	0	0	0	1	1	2	0	0	2	1	1	1	0	2
0408	1	1	2	2	2	4	4	2	0	0	0	0	0	5	5	1	4	5	3	1	1	1	0	4
0409	0	1	2	1	2	4	0	1	5	2	2	1	3	5	5	1	0	0	5	2	1	1	2	5
0410	1	4	3	1	1	3	1	4	5	2	1	2	1	5	5	1	3	5	3	2	1	1	3	4
0411	1	4	3	3	1	3	3	2	3	4	2	0	0	5	5	1	3	2	2	3	1	1	5	4
0412	1	1	2	1	2	4	1	1	0	0	1	0	0	5	5	1	5	1	5	5	1	1	0	5
0413	1	1	2	1	2	4	2	1	0	0	0	0	0	5	4	1	5	1	4	5	1	1	0	4
0414	1	1	2	1	1	4	1	2	0	0	0	0	0	5	4	2	5	1	3	5	1	1	0	4
0415	4	1	2	4	1	5	5	2	0	0	0	0	0	5	4	2	4	1	1	4	1	1	0	1

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0501	4	1	3	2	1	4	5	4	2	2	1	2	3	5	4	1	3	4	2	5	1	1	2	3
0502	3	1	3	1	1	3	4	3	0	0	2	3	4	5	4	2	2	3	3	5	1	1	0	3
0503	1	1	3	1	1	3	3	4	0	0	0	0	0	5	3	1	4	1	3	2	1	1	0	2
0504	1	5	3	3	1	3	1	4	0	0	0	0	0	5	3	1	4	2	3	2	1	1	0	3
0505	4	1	3	2	1	3	5	5	2	1	1	2	5	5	4	2	2	2	2	2	1	1	2	2
0506	1	5	3	4	1	3	3	3	0	0	0	0	0	5	4	1	2	4	2	3	1	1	0	4
0507	1	1	4	3	1	2	2	4	0	0	0	0	0	5	5	2	4	1	1	4	1	1	0	2
0508	1	5	3	5	1	2	1	3	4	4	1	3	1	5	3	1	2	4	2	4	1	1	3	4
0509	4	3	3	2	1	2	5	4	0	0	1	2	1	5	3	2	3	2	1	3	1	1	0	2
0510	1	2	5	2	2	2	4	5	0	0	0	0	0	5	4	2	4	1	1	4	1	1	0	2
0511	1	2	5	1	2	3	3	5	0	0	0	0	0	5	3	2	5	2	2	4	1	1	0	2
0512	1	5	3	3	1	3	2	5	5	3	1	3	3	5	3	1	3	5	3	3	1	1	4	3
0513	3	3	5	1	2	2	2	5	0	0	0	0	0	5	2	2	4	1	3	5	1	1	0	3
0514	1	3	4	1	1	2	1	5	0	0	0	0	0	5	3	2	4	1	1	3	1	1	0	1
0601	4	5	5	1	1	2	3	5	2	2	1	5	2	5	2	3	2	2	3	5	1	1	3	3
0602	5	5	5	4	3	1	2	4	0	0	1	3	1	5	3	3	2	3	2	4	1	1	0	1
0603	5	4	5	1	4	1	5	5	4	2	2	5	5	5	4	3	3	2	2	5	1	1	2	1
0604	1	4	5	4	3	2	2	5	0	0	1	4	3	5	3	3	2	4	1	4	1	1	0	1
0701	1	1	2	3	2	4	2	2	3	3	2	4	5	5	2	4	3	3	3	1	1	1	2	3
0702	1	1	2	4	1	4	2	2	3	2	2	1	5	5	3	4	3	5	2	1	1	1	1	3
0703	1	1	2	2	4	4	5	2	0	0	1	5	4	5	5	4	1	5	2	2	1	1	0	2
0704	4	1	2	3	2	3	4	2	0	0	1	5	4	1	1	4	4	3	1	4	1	1	0	1
0705	1	2	2	5	4	4	4	2	0	0	0	0	0	5	3	3	4	2	1	3	1	1	0	2
0706	1	2	2	3	2	3	3	2	0	0	0	0	0	5	3	4	5	3	1	4	1	1	0	1
0707	1	2	2	4	2	4	3	3	0	0	0	5	1	5	3	3	4	2	2	4	1	1	0	2
0708	1	2	2	3	2	3	2	4	4	2	1	5	4	5	3	4	2	5	1	3	1	1	3	2

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0709	1	3	3	5	2	3	1	3	0	0	0	0	0	5	4	2	5	2	2	4	1	1	0	3
0710	1	1	2	4	1	3	1	3	0	0	0	0	0	5	2	5	2	4	1	3	1	1	0	3
0711	1	5	3	3	4	2	4	3	0	0	0	0	0	5	3	4	3	5	1	4	1	1	0	1
0712	1	4	3	1	2	3	1	4	4	4	3	3	2	5	5	1	2	4	4	2	1	1	3	5
0713	1	4	3	2	5	3	2	5	5	3	1	3	2	5	4	2	2	5	3	3	1	1	5	3
0714	1	4	3	2	3	2	2	4	0	0	1	1	1	5	2	2	4	4	1	3	1	1	0	1
0801	0	4	5	5	2	1	0	5	5	5	1	5	5	5	5	3	0	0	1	3	1	1	5	1
0802	1	3	4	5	5	1	1	5	5	2	1	3	1	5	4	2	5	1	1	3	1	1	2	1
0803	1	2	4	5	2	1	1	5	5	4	3	4	2	5	2	3	5	3	1	4	1	1	4	1
0804	3	3	4	4	5	1	4	5	0	0	0	1	1	5	2	1	3	2	1	2	1	1	0	1
0805	1	5	3	5	4	1	1	2	5	5	4	5	1	5	5	2	5	1	3	3	1	1	4	2
0806	1	3	4	5	2	1	4	4	0	0	0	0	0	5	4	2	1	4	1	3	1	1	0	1
0807	1	5	3	2	4	1	3	3	5	5	2	1	3	5	5	1	2	2	1	2	1	1	4	1
0808	2	5	3	4	4	1	3	4	4	4	1	2	2	5	5	1	4	1	2	3	1	1	3	2
0809	5	1	2	1	4	1	1	3	3	1	1	1	1	5	5	1	5	1	1	3	1	1	1	1
0901	1	2	1	5	2	5	4	1	0	0	0	1	1	1	2	2	5	5	3	1	1	1	0	4
0902	1	1	1	4	1	4	2	3	3	2	1	4	2	5	1	2	3	5	2	1	1	1	2	4
0903	0	1	2	2	4	4	0	1	0	0	0	0	0	5	2	2	0	0	1	1	1	1	0	1
1001	0	3	1	1	3	5	0	1	0	0	0	0	0	5	5	2	0	0	1	4	1	1	0	1
1002	1	3	1	1	5	5	5	1	0	0	0	0	0	5	3	2	1	5	4	4	1	1	0	5
1003	1	3	1	1	5	5	5	1	0	0	0	0	0	5	2	2	1	4	5	2	1	1	0	5
1004	1	3	1	1	5	4	5	1	0	0	0	0	0	5	1	2	2	5	5	2	1	1	0	5
1005	1	3	1	1	4	4	3	1	0	0	0	0	0	5	2	3	4	3	5	1	1	1	0	5
1006	1	3	1	2	4	4	5	1	0	0	0	0	0	1	5	4	5	1	4	1	1	1	0	4
1007	1	4	1	1	5	5	4	1	1	1	1	4	3	5	5	2	1	5	4	4	1	1	1	5
1008	2	4	2	1	5	5	2	2	1	1	1	3	2	5	2	3	2	3	5	2	1	1	2	5

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1009	1	4	2	1	5	5	2	1	0	0	1	0	0	5	3	4	4	3	5	3	1	1	0	5
1010	1	3	1	1	4	4	5	1	1	1	1	0	0	1	5	4	5	4	5	2	1	1	1	5
1011	1	2	1	3	4	5	3	1	0	0	0	0	0	5	5	4	3	3	2	1	1	1	0	2
1012	1	4	1	4	5	5	4	2	0	0	0	0	0	5	1	4	4	5	3	2	1	1	0	4
1013	1	2	1	1	5	4	3	2	0	0	0	0	0	5	1	4	3	5	3	1	1	1	0	3
1014	1	3	1	4	4	4	3	1	0	0	0	0	0	5	1	4	3	3	1	1	1	1	0	2
1015	1	2	1	5	4	4	2	1	0	0	0	2	1	5	4	4	4	2	4	1	1	1	0	4
1016	1	3	1	5	1	4	1	1	0	0	0	0	0	5	2	4	5	5	2	1	1	1	0	3
1017	1	2	1	5	1	4	1	1	0	0	0	1	1	5	1	5	5	4	1	2	1	1	0	2
1018	1	4	2	3	5	5	3	3	0	0	0	5	1	5	1	3	2	4	5	3	1	1	0	5
1019	2	4	1	4	3	5	4	2	5	5	2	5	5	5	1	1	2	4	5	1	1	5	5	5
1020	1	2	1	5	3	3	1	1	5	4	1	5	2	5	3	4	3	3	5	2	1	1	5	5
1021	0	2	1	5	3	4	0	2	0	0	1	1	1	1	3	4	0	0	4	1	1	1	0	4
1022	1	2	1	5	2	3	1	1	5	2	1	1	1	5	5	5	5	1	4	2	1	5	5	4
1023	1	1	2	2	2	3	1	2	0	0	0	0	0	5	4	5	4	2	3	3	1	1	0	3
1024	1	2	2	2	3	3	1	3	0	0	0	0	0	5	4	5	3	2	3	4	1	1	0	2
1025	1	4	1	5	5	3	1	2	0	0	0	3	2	1	1	4	4	2	5	1	1	5	0	5
1026	1	5	1	5	4	3	1	2	0	0	0	5	1	5	1	4	5	5	3	1	1	1	0	3
1027	1	4	1	5	3	3	2	2	0	0	0	3	3	5	2	4	4	2	4	3	1	5	0	4
1028	1	4	3	1	3	3	1	3	0	0	0	0	0	5	3	5	5	2	3	4	1	1	0	2
1029	1	5	3	2	4	2	4	4	1	2	1	3	1	5	2	4	3	3	3	3	1	1	1	3
1030	1	5	3	2	4	2	3	3	0	0	0	0	0	5	5	4	3	5	2	4	1	1	0	3
1101	1	3	4	5	5	2	4	5	1	1	1	2	3	5	2	2	3	4	2	5	1	1	1	2
1102	1	4	1	2	4	5	3	2	0	0	0	0	0	5	1	1	5	3	5	3	1	5	0	5
1103	1	5	2	5	1	3	2	2	0	0	0	5	3	5	3	4	4	5	4	1	1	5	0	5
1104	0	4	2	5	2	4	0	2	0	0	0	5	4	5	4	3	4	1	5	1	1	5	0	5

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1105	1	1	3	5	2	2	1	2	0	0	0	0	0	5	4	3	4	1	2	3	1	1	0	3
1106	1	3	2	5	2	2	5	2	0	0	0	1	4	5	2	3	3	5	2	3	5	5	0	2
1107	1	4	2	2	2	2	3	4	0	0	1	3	4	5	2	3	4	4	1	3	1	1	0	2
1108	1	2	4	3	3	5	5	2	0	0	0	0	0	5	1	4	3	3	4	2	1	1	0	4
1109	1	2	4	5	2	2	2	3	0	0	0	2	5	5	1	3	5	2	4	2	1	5	0	4
1110	1	2	3	5	2	3	1	4	0	0	0	3	2	5	2	3	2	5	5	2	1	5	0	5
1111	1	2	4	2	5	2	3	5	0	0	1	4	3	5	2	1	4	3	2	5	1	1	0	2
1112	1	3	4	5	2	2	4	3	0	0	0	4	1	5	1	4	0	0	5	2	1	5	0	5
1113	1	2	3	5	2	2	1	4	0	0	0	1	4	5	1	2	5	2	3	2	1	1	0	3
1114	2	3	3	1	5	1	5	5	0	0	0	0	0	5	1	1	5	1	2	3	1	1	0	2
1201	1	5	4	4	3	1	3	2	0	0	0	1	1	5	1	1	3	4	3	3	1	1	0	2
1202	1	4	5	3	3	1	4	2	0	0	1	0	0	5	2	3	3	3	2	3	1	1	0	2
1203	1	4	5	1	3	1	4	3	4	5	1	2	5	5	1	2	5	1	4	3	1	1	5	4
1204	1	3	4	3	3	1	1	1	0	0	0	4	1	5	4	4	5	1	4	2	1	1	0	4
1205	0	4	4	5	2	2	0	2	0	0	0	3	4	5	1	5	0	0	5	1	1	5	0	5
1206	1	4	5	1	3	2	4	3	0	0	0	0	0	5	1	3	1	2	5	2	1	1	0	5
1207	1	4	5	4	3	1	2	2	0	0	0	1	1	5	2	4	1	5	3	3	1	1	0	4
1208	0	4	4	5	2	2	0	3	0	0	0	2	2	5	1	5	0	0	5	1	1	5	0	5
1209	1	4	5	3	2	1	5	4	0	0	0	1	1	5	1	5	4	2	4	2	1	1	0	5
1210	1	4	4	4	3	1	2	3	3	4	1	3	4	5	2	5	3	1	4	2	1	1	4	4
1211	0	4	4	4	1	1	0	4	0	0	1	2	2	5	1	5	0	0	5	1	1	5	0	5
1301	1	4	2	3	5	5	3	1	1	1	1	2	2	5	4	1	2	3	5	1	1	1	1	5
1302	1	2	4	4	3	4	5	4	0	0	0	3	3	5	1	1	4	1	5	5	1	1	0	5
1303	0	2	4	4	3	2	0	2	0	0	1	4	4	5	1	2	0	0	5	4	1	1	0	5
1304	0	4	4	3	2	1	0	3	0	0	0	0	0	5	3	4	0	0	5	5	1	1	0	5
1305	0	3	4	5	3	3	0	3	0	0	0	0	0	5	4	3	5	4	5	5	1	5	0	5

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1306	0	2	4	5	3	3	0	4	0	0	0	0	0	5	1	4	0	0	5	3	1	5	0	5
1307	1	4	4	5	2	2	1	3	0	0	0	0	0	5	1	4	5	1	5	3	1	5	0	5
1308	0	4	5	2	2	1	0	1	0	0	0	1	1	5	1	4	0	0	5	1	1	1	0	5
1309	0	4	4	1	3	1	0	1	0	0	0	0	0	1	4	4	0	0	5	1	1	5	0	5
1401	1	4	1	1	4	5	5	1	2	4	2	1	1	5	3	1	3	5	4	3	1	1	3	4
1402	1	4	1	1	4	5	4	1	2	1	1	2	1	5	4	1	3	4	4	3	1	1	2	5
1403	1	3	3	1	4	5	4	1	0	0	0	0	0	5	3	5	2	4	3	5	1	1	0	1
1404	1	5	2	1	5	5	2	2	0	0	0	0	0	5	2	4	1	3	4	3	1	1	0	3
1405	1	4	2	1	4	5	2	1	0	0	0	0	0	5	4	3	1	2	3	4	1	1	0	1
1406	1	3	3	1	4	5	3	3	0	0	0	0	0	5	2	5	2	3	3	4	1	1	0	1
1407	1	2	3	2	3	4	3	3	0	0	0	0	0	5	1	5	5	1	1	5	1	1	0	1
1408	1	2	3	1	5	5	2	4	0	0	0	0	0	5	2	5	4	3	4	4	1	1	0	5
1501	1	2	5	5	5	3	3	5	4	5	1	2	1	5	1	5	4	2	2	5	1	1	4	3
1502	1	2	4	5	5	4	1	4	0	0	0	0	0	5	2	5	5	1	3	4	1	1	0	4
1503	1	2	5	3	5	2	3	3	0	0	0	0	0	5	1	5	5	1	4	4	1	1	0	3
1504	1	2	4	5	5	2	2	3	0	0	0	0	0	5	2	3	4	2	4	4	1	1	0	5
1505	0	1	4	4	5	2	0	3	0	0	2	2	1	5	1	4	0	0	5	5	1	5	0	5
1506	1	1	4	4	5	3	3	3	0	0	3	2	2	5	2	5	5	4	5	4	1	1	0	5
1507	1	1	4	4	5	1	4	3	4	5	5	5	4	5	1	5	4	5	5	3	1	5	5	5
1508	0	1	3	5	4	1	0	1	0	0	0	0	0	5	5	4	0	0	4	5	1	1	0	5
1601	1	4	3	3	4	5	3	1	1	2	1	3	1	5	5	5	3	3	5	4	1	1	1	5
1602	1	3	4	3	5	5	5	4	2	4	1	4	2	5	2	5	3	3	5	5	1	1	2	5
1603	1	3	3	3	4	5	1	3	0	0	0	0	0	5	2	5	4	1	5	5	1	5	0	5
1604	1	3	5	4	5	4	2	5	0	0	0	0	0	5	2	4	2	3	5	5	1	5	0	5
1605	1	3	5	3	4	5	3	4	0	0	1	4	3	5	2	5	1	3	5	5	1	1	0	5
1606	1	3	5	5	3	4	2	5	0	0	0	0	0	5	1	4	4	1	4	5	1	1	0	4

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	INDICATOR																							
SUB	Acid Neutralizing Capacity [#1]	At-Risk Freshwater Plant Communities [#22]	At-Risk Native Freshwater Species [#24]	Groundwater Reliance [#125]	Meteorological Drought Indices [#165]	Ratio of Snow to Precipitation [#218]	Stream Habitat Quality [#284]	Wetland and Freshwater Species at Risk [#326]	Herbicide Concentrations in Streams [#367]	Insecticide Concentrations in Streams [#369]	Organochlorines in Bed Sediment [#371]	Herbicides in Groundwater [#373]	Insecticides in Groundwater [#374]	Precipitation Elasticity of Streamflow [#437]	Ratio of Reservoir Storage to Mean Annual Runoff [#449]	Runoff Variability [#453]	Macroinvertebrate Index of Biotic Condition [#460]	Macroinvertebrate Observed/Expected (O/E) Ratio of Taxa Loss [#461]	Ratio of Water Withdrawals to Annual Streamflow [#219]	Erosion Rate [#348]	Instream Use/ Total Streamflow [#351]	Total Use/ Total Streamflow [#352]	Pesticide Toxicity Index [#364]	Water Availability: Net Streamflow per Capita [#623]
1701	2	4	2	2	5	5	5	2	1	1	1	1	3	5	2	1	2	4	2	2	1	1	1	1
1702	2	5	2	3	5	5	1	3	3	5	2	4	5	5	2	2	1	5	2	2	1	1	5	1
1703	1	5	2	2	4	4	1	1	1	5	0	0	0	5	4	3	1	5	4	4	1	1	4	4
1704	1	5	2	3	5	5	3	4	1	1	1	4	4	5	2	5	2	2	4	4	1	1	1	5
1705	1	5	3	2	5	4	2	4	1	1	1	0	0	5	2	5	2	3	4	4	1	1	1	3
1706	1	5	3	2	5	5	2	4	3	2	2	2	1	5	3	4	1	5	2	4	1	1	2	1
1707	1	5	4	3	5	4	2	4	0	0	0	0	0	5	2	5	1	5	1	5	1	1	0	1
1708	3	5	3	2	4	2	2	1	0	0	3	0	0	5	4	2	1	4	1	5	1	1	0	1
1709	1	5	4	3	5	2	3	2	4	5	2	4	3	5	4	2	1	4	2	5	1	1	5	2
1710	1	5	3	2	3	2	2	4	0	0	0	0	0	5	5	4	1	2	1	4	1	1	0	1
1711	3	3	2	4	5	2	2	2	2	3	1	2	5	5	4	1	1	5	1	5	1	1	3	2
1712	1	5	4	3	5	4	3	3	0	0	0	0	0	5	4	5	3	2	4	5	1	1	0	1
1801	1	3	5	3	5	3	4	4	0	0	0	0	0	5	3	5	1	4	2	4	1	1	0	1
1802	1	3	5	4	4	3	4	5	4	5	1	5	5	5	1	5	1	4	4	4	1	1	4	3
1803	1	3	5	4	3	3	5	4	0	0	1	4	5	5	2	5	2	3	5	5	1	5	0	5
1804	1	3	5	4	3	3	4	4	3	5	3	3	3	5	1	5	1	2	5	4	1	5	5	5
1805	1	2	5	3	3	1	2	1	0	0	0	0	0	5	5	5	3	1	3	5	1	1	0	4
1806	1	3	5	3	3	1	4	3	0	0	0	0	0	5	4	5	1	5	5	4	1	5	0	5
1807	1	3	5	3	4	2	3	3	2	4	2	3	2	5	3	5	2	4	5	5	1	5	4	5
1808	1	3	5	5	4	5	2	1	0	0	0	0	0	5	5	5	3	1	3	5	1	1	0	2
1809	1	3	5	5	4	3	5	5	0	0	0	0	0	5	3	5	1	5	4	5	1	1	0	4
1810	1	3	5	2	4	2	4	4	0	0	0	0	0	5	5	5	2	4	5	5	1	5	0	5

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Appendix H. Evaluation and Potential Modification of Vulnerability Indicators

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This appendix provides an evaluation of each of the 25 mappable indicators within the framework of the five questions presented in the flowchart in Figure 13 (Indicator Evaluation Process) of the report. Each indicator is evaluated to determine how well it represents vulnerability of water quality or aquatic ecosystems, and, when appropriate, how it might be modified to improve its representation of vulnerability (Table 1). In addition, the indicators are also evaluated to examine the extent to which objective functional thresholds may apply to them.

Table 1. Indicator Selection

Indicators are evaluated for the extent to which they represent vulnerability. The indicators can be further evaluated to determine how to modify them to improve their representation of vulnerability. An indicator that accounts for or could account for is then sifted through the Indicator Display (Table 2). An indicator that neither accounts for vulnerability nor can be modified to represent vulnerability is considered inappropriate for mapping with objective breakpoints.

Indicator ID#	Indicator	Does the indicator describe vulnerability?	Can the indicator be modified to describe vulnerability?
1	Acid Neutralizing Capacity (ANC)	Does not directly account for exposure to acidification.	If possible, develop model to predict changes in acidity of precipitation, and the resulting change in stream pH, given ANC.
22	At-Risk Freshwater Plant Communities	Does not directly account for exposure to additional stress from climate change.	Identify plant communities that would be most susceptible to changes in temperature or precipitation. Overlay with predicted climate changes.
24	At-Risk Native Freshwater Species	Does not directly account for exposure to additional stress from climate change.	Identify species that would be most susceptible to changes in temperature or precipitation. Overlay with predicted climate changes.
51	Coastal Vulnerability Index (CVI)	Yes	N/A
125	Groundwater Reliance	Does not put groundwater reliance into context of groundwater availability or availability of other water sources.	Changes in groundwater availability per capita could be simulated by coupling population projections with a groundwater model. However, these estimates would be more meaningful if they were integrated into a model of overall water availability that also included surface water.

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Indicator ID#	Indicator	Does the indicator describe vulnerability?	Can the indicator be modified to describe vulnerability?
165	Meteorological Drought Indices	Does not directly account for exposure to additional stress from climate change.	A stochastic climate model could be used to predict change in drought frequency.
218	Ratio of Snow to Total Precipitation (S/P)	Does not directly account for exposure to additional stress from climate change.	This indicator could be improved by identifying areas where the ratio of snow to precipitation is most sensitive to a unit change in temperature. It could also be improved by accounting for the reliance of streamflow and human water use on snowmelt.
219	Ratio of Withdrawals to Streamflow	Does not account for water shortage risk associated with temporal variability in streamflow and does not directly account for exposure to additional stress from climate change or growth in water demand.	This indicator could be considered one factor in an integrated climatic-hydrologic model (e.g., Wilby, R. L., P. G. Whitehead, A. J. Wade, D. Butterfield, R. J. Davis, and G. Watts. 2006. Integrated modelling of climate change impacts on water resources and quality in a lowland catchment: River Kennet, UK. Journal of Hydrology 330:204-220.)
284	Stream Habitat Quality	Does not directly account for exposure to additional stress from climate change.	Predictions from a climate model could be used to forecast changes in streamflow, which could be linked to stream channel stability (one component of habitat quality) with a hydraulic model.
326	Wetland and Freshwater Species At Risk	Does not directly account for exposure to additional stress from climate change.	Identify species that would be most susceptible to changes in temperature or precipitation. Overlay with predicted climate changes.
348	Erosion Rate	Does not account for exposure to precipitation changes.	Yang et al. (2003) provide projections of the change in erosion rate that would result from climate change. These projections would account for both sensitivity and exposure. However, the model for this indicator does not account for deposition of eroded sediment and therefore cannot be solely relied upon to estimate sediment delivery to aquatic ecosystems.
351	Instream Use/Total Streamflow	Does not directly account for exposure to additional stress from climate change.	The USGS used the information in this indicator and other information to calculate the ratio of consumptive use to renewable water supply. This indicator is a more holistic view of water sustainability. Forecasts of the effects of climate change and population growth on this indicator would integrate sensitivity and exposure.

Indicator ID#	Indicator	Does the indicator describe vulnerability?	Can the indicator be modified to describe vulnerability?
352	Total Use/Total Streamflow	Does not directly account for exposure to additional stress from climate change.	The USGS used the information in this indicator and other information to calculate the ratio of consumptive use to renewable water supply. This indicator is a more holistic view of water sustainability. Forecasts of the effects of climate change and population growth on this indicator would integrate sensitivity and exposure.
364	Pesticide Toxicity Index (PTI)	Does not directly account for exposure to additional stress from climate change.	USGS is developing predictive models for individual pesticides (e.g., atrazine; http://infotrek.er.usgs.gov/warp/). Some of these models contain precipitation variables whose values could be adjusted to simulate the effect of climate change on pesticide concentrations. These individual predictions could be combined to calculate the change in PTI that would be caused by climate change.
367	Herbicide Concentrations in Streams	Does not directly account for exposure to additional stress from climate change.	The pesticide indicators could be improved by: 1. comparing the concentration of an individual pesticide to its health-based regulatory threshold (e.g., atrazine), or 2. calculating the pesticide toxicity index.
369	Insecticide Concentrations in Streams	Does not directly account for exposure to additional stress from climate change.	The pesticide indicators could be improved by: 1. comparing the concentration of an individual pesticide to its health-based regulatory threshold (e.g., atrazine), or 2. calculating the pesticide toxicity index.
371	Organochlorines in Bed Sediment	Does not directly account for exposure to additional stress from climate change.	EPA's National Sediment Quality Survey reports and maps human health and aquatic life risk due to contaminated sediment (http://www.epa.gov/waterscience/cs/report/1997/). Risk is based on all sediment contaminants, so this would be a different indicator.
373	Herbicides in Groundwater	Does not directly account for exposure to additional stress from climate change.	The pesticide indicators could be improved by: 1. comparing the concentration of an individual pesticide to its health-based regulatory threshold (e.g., atrazine), or 2. calculating the pesticide toxicity index.

Indicator ID#	Indicator	Does the indicator describe vulnerability?	Can the indicator be modified to describe vulnerability?
374	Insecticides in Groundwater	Does not directly account for exposure to additional stress from climate change.	The pesticide indicators could be improved by: 1. comparing the concentration of an individual pesticide to its health-based regulatory threshold (e.g., atrazine), or 2. calculating the pesticide toxicity index.
437	Precipitation Elasticity of Streamflow	Does not account for exposure to precipitation changes.	This indicator could be combined with predicted changes in precipitation to predict changes in streamflow.
449	Ratio of Reservoir Storage to Mean Annual Runoff	Does not directly account for exposure to additional stress from climate change.	This indicator could be considered one factor in an integrated climatic-hydrologic model (e.g., Wilby, R. L., P. G. Whitehead, A. J. Wade, D. Butterfield, R. J. Davis, and G. Watts. 2006. Integrated modelling of climate change impacts on water resources and quality in a lowland catchment: River Kennet, UK. Journal of Hydrology 330:204-220.)
453	Runoff Variability	Does not directly account for exposure to additional stress from climate change.	This indicator could be considered one factor in an integrated climatic-hydrologic model (e.g., Wilby, R. L., P. G. Whitehead, A. J. Wade, D. Butterfield, R. J. Davis, and G. Watts. 2006. Integrated modelling of climate change impacts on water resources and quality in a lowland catchment: River Kennet, UK. Journal of Hydrology 330:204-220.)
460	Macroinvertebrate Index of Biotic Condition	The stress-response curve may be improperly characterized, and spatial variation in exposure to future stress is not accounted for.	Indexes of biotic condition respond linearly to stress, so vulnerability to further degradation should be relatively constant.
461	Macroinvertebrate Observed/Expected (O/E) Ratio of Taxa Loss	The stress-response curve may be improperly characterized, and spatial variation in exposure to future stress is not accounted for.	The scale of vulnerability for this indicator should be reversed. The first taxa that are lost are sensitive to small amounts of stress.

Indicator ID#	Indicator	Does the indicator describe vulnerability?	Can the indicator be modified to describe vulnerability?
623	Water Availability: Net Streamflow per Capita	Does not account for water shortage risk associated with temporal variability in streamflow and does not directly account for exposure to additional stress from climate change or growth in water demand.	It may be more appropriate to consider net streamflow in the context of instream flow requirements. This indicator could be considered one factor in an integrated climatic-hydrologic model (e.g., Wilby, R. L., P. G. Whitehead, A. J. Wade, D. Butterfield, R. J. Davis, and G. Watts. 2006. Integrated modelling of climate change impacts on water resources and quality in a lowland catchment: River Kennet, UK. Journal of Hydrology 330:204-220.)

Table 2. Indicator Display

The numerical thresholds used for indicator example maps were determined based on the information available in the literature or by using a continuous grayscale color ramp. Indicators that already reflect vulnerability or could be modified to do so (based on Table 1) can be further evaluated to determine whether objective, functional breakpoints can be used in displaying their values. If so, attributes necessary for determining such functional breakpoints can be identified through a review of relevant literature or through new data collection and analysis efforts. Finally, the validity of the breakpoints when data are aggregated to the appropriate spatial unit can be analyzed to assess the accuracy of the resultant map.

An indicator for which objective breakpoints exist, or for which objective breakpoints can be identified, and for which breakpoints remain valid even when data are aggregated, is considered mappable with objective thresholds. An indicator for which objective breakpoints cannot be identified or for which breakpoints are not valid after data are aggregated is considered mappable along a continuous gradient.

Indicator ID#	Indicator	Are objective breakpoints in the range of vulnerability documented?	Can objective breakpoints be identified?	Are the breakpoints valid when the data are aggregated?
1	Acid Neutralizing Capacity (ANC)	Yes; when ANC values fall below zero, the water is considered acidic and can be either directly or indirectly toxic to biota (i.e., by mobilizing toxic metals, such as aluminum). When ANC is between 0 and 25 milliequilivents, the water is considered sensitive to episodic acidification during rainfall events. These threshold values were determined based on values derived from the National Acid Precipitation Assessment Program (USEPA 2006).	N/A	No; indicator mapped as percentage of sites.
22	At-Risk Freshwater Plant Communities	Yes; risk levels for individual communities are semi-quantitatively defined.	N/A	No; indicator mapped as percentage of sites.
24	At-Risk Native Freshwater Species	Yes; risk levels for individual species are semi-quantitatively defined.	N/A	No; indicator mapped as percentage of sites.

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Indicator ID#	Indicator	Are objective breakpoints in the range of vulnerability documented?	Can objective breakpoints be identified?	Are the breakpoints valid when the data are aggregated?
51	Coastal Vulnerability Index (CVI)	No; it indicates relative risk.	Ideally, the CVI would be calibrated to the occurrence of actual physical effects. This stress response relationship could then be divided into vulnerability categories with natural breaks, or with subjective evaluations of acceptable risk.	Yes
125	Groundwater Reliance	No, because this indicator is not a good measure of vulnerability.	The ratio of per capita water availability to water use has a natural threshold: 1. Other thresholds would be somewhat arbitrary.	Yes, but only with suggested modifications.
165	Meteorological Drought Indices	The thresholds that were used are somewhat objective because a PDSI of 0 indicates neutral conditions, and negative numbers indicate drought. Because the medium category is centered around zero, it appropriately separates areas that have experienced recent drought from those that have not.	While there is an objective breakpoint for separating drought from non-drought, an objective measure of what constitutes a critical drought frequency was not identified.	Yes
218	Ratio of Snow to Total Precipitation (S/P)	No	A general model of water availability that included snowmelt could be used to simulate changes in water availability relative to water demand. A ratio of 1 would be an objective threshold.	Yes, but only with suggested modifications.
219	Ratio of Withdrawals to Annual StreamFlow	Yes, a value of 1 indicates that there is no room for further water withdrawals.	N/A	Yes
284	Stream Habitat Quality	No, breakpoints are arbitrary.	No	N/A

Indicator ID#	Indicator	Are objective breakpoints in the range of vulnerability documented?	Can objective breakpoints be identified?	Are the breakpoints valid when the data are aggregated?
326	Wetland and Freshwater Species At Risk	Yes; risk levels for individual species are semi-quantitatively defined.	N/A	No; indicator mapped as percentage of sites.
348	Erosion Rate	No, tolerable erosion rates vary among ecosystems and are not documented at the national scale.	With the suggested modification, three objective categories of vulnerability would be less erosion, no change, and more erosion with predicted climate change.	Yes, but only with suggested modifications.
351	Instream Use/Total Streamflow	Yes, a value of 1 indicates that there is no room for further water withdrawals, assuming that there is no consumptive use.	The same breakpoint also applies to the suggested modification of the indicator.	Yes, because the HUC is the original scale of measurement.
352	Total Use/Total Streamflow	Yes, a value of 1 indicates that there is no room for further water withdrawals.	The same breakpoint also applies to the suggested modification of the indicator.	Yes, because the HUC is the original scale of measurement.
364	Pesticide Toxicity Index (PTI)	Pesticide toxicity index values have a built-in threshold (1) that indicates probable cumulative effects equivalent to an LC50 or EC50 assuming that the additive toxicity model is appropriate. However, even these standard measures of toxicity are based on a somewhat arbitrary standard of what constitutes a serious health effect (affects 50% of test organisms).	What constitutes a critical level of risk is a subjective choice.	There is no basis for identifying a critical value for the average PTI in a HUC. Averages also obscure variance among the values at individual sites.

Indicator ID#	Indicator	Are objective breakpoints in the range of vulnerability documented?	Can objective breakpoints be identified?	Are the breakpoints valid when the data are aggregated?
367	Herbicide Concentrations in Streams	No, not for mixtures of pesticides.	What constitutes a critical level of risk is a subjective choice. Pesticide toxicity index values have a built-in threshold that indicates probable cumulative effects equivalent to an LC50 or EC50 assuming that the additive toxicity model is appropriate. However, even these standard measures of toxicity are based on a somewhat arbitrary standard of what constitutes a serious health effect (affects 50% of test organisms).	There is no basis for identifying a critical value for the average probability of exceeding a health-based threshold or the average PTI in a HUC. Averages also obscure variance among the values at individual sites.
369	Insecticide Concentrations in Streams	No, not for mixtures of pesticides.	What constitutes a critical level of risk is a subjective choice. Pesticide toxicity index values have a built-in threshold that indicates probable cumulative effects equivalent to an LC50 or EC50 assuming that the additive toxicity model is appropriate. However, even these standard measures of toxicity are based on a somewhat arbitrary standard of what constitutes a serious health effect (affects 50% of test organisms).	There is no basis for identifying a critical value for the average probability of exceeding a health-based threshold or the average PTI in a HUC. Averages also obscure variance among the values at individual sites.
371	Organochlorines in Bed Sediment	Yes, but only with the suggested modification.	N/A	No, data would have to be mapped as percentages for which thresholds are arbitrary, or averages, which obscure variance.

Indicator ID#	Indicator	Are objective breakpoints in the range of vulnerability documented?	Can objective breakpoints be identified?	Are the breakpoints valid when the data are aggregated?
373	Herbicides in Groundwater	No, not for mixtures of pesticides.	What constitutes a critical level of risk is a subjective choice. Pesticide toxicity index values have a built-in threshold that indicates probable cumulative effects equivalent to an LC50 or EC50 assuming that the additive toxicity model is appropriate. However, even these standard measures of toxicity are based on a somewhat arbitrary standard of what constitutes a serious health effect (affects 50% of test organisms).	There is no basis for identifying a critical value for the average probability of exceeding a health-based threshold or the average PTI in a HUC. Averages also obscure variance among the values at individual sites.
374	Insecticides in Groundwater	No, not for mixtures of pesticides.	What constitutes a critical level of risk is a subjective choice. Pesticide toxicity index values have a built-in threshold that indicates probable cumulative effects equivalent to an LC50 or EC50 assuming that the additive toxicity model is appropriate. However, even these standard measures of toxicity are based on a somewhat arbitrary standard of what constitutes a serious health effect (affects 50% of test organisms).	There is no basis for identifying a critical value for the average probability of exceeding a health-based threshold or the average PTI in a HUC. Averages also obscure variance among the values at individual sites.
437	Precipitation Elasticity of Streamflow	The thresholds that were used are somewhat objective because a value of 1 separates areas where a given percentage change in precipitation results in a lower percentage change in streamflow from areas where a that same percentage change in precipitation results in a higher percentage change in streamflow.	Changes in streamflow could be evaluated against instream flow requirements for aquatic life.	Instream flow requirements tend to stream-specific, and therefore, cannot be generalized to all streams in a HUC.

Indicator ID#	Indicator	Are objective breakpoints in the range of vulnerability documented?	Can objective breakpoints be identified?	Are the breakpoints valid when the data are aggregated?
449	Ratio of Reservoir Storage to Mean Annual Runoff	No	Stochastic model output from an integrated climatic-hydrologic model could be evaluated to identify areas where reservoir storage is expected to drop to zero more often than a specified frequency.	Yes, but only with suggested modifications.
453	Runoff Variability	No	Stochastic model output from an integrated climatic-hydrologic model could be evaluated to identify areas where reservoir storage is expected to drop to zero more often than a specified frequency.	Yes, but only with suggested modifications.
460	Macroinvertebrate Index of Biotic Condition	No, breakpoints are arbitrary.	No	N/A
461	Macroinvertebrate Observed/Expected (O/E) Ratio of Taxa Loss	No, breakpoints are arbitrary.	No	N/A
623	Water Availability: Net Streamflow per Capita	Regional differences in water-using activities mean that the sufficiency of available water supplies varies geographically. No documented thresholds were found.	Possibly, although Indicator #351 (Instream Use/Total Streamflow) describes the same concept and has an objective threshold (1).	Yes

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