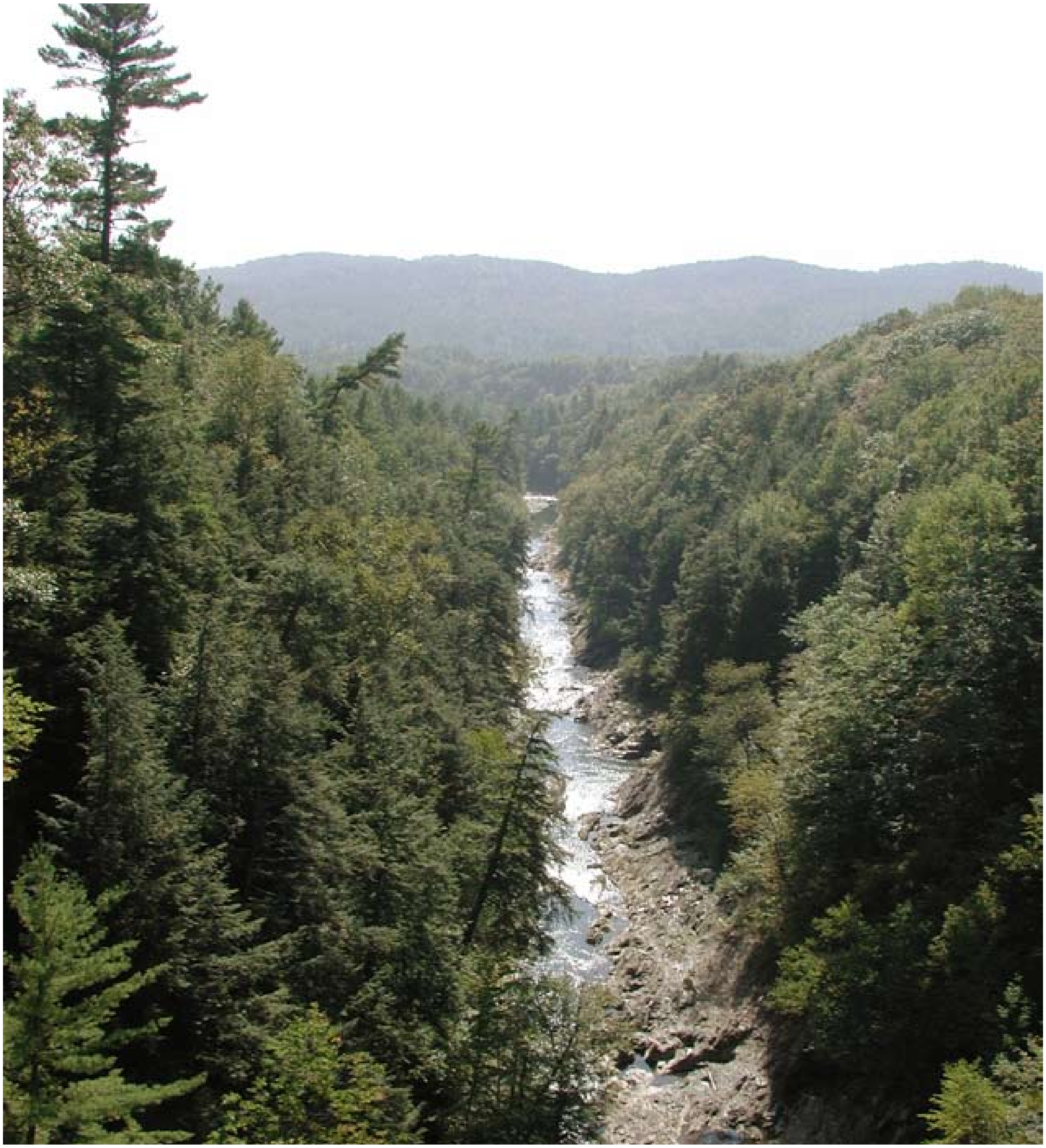


Forests, Water and People:
Drinking water supply and forest lands in the Northeast and Midwest United States

Martina C. Barnes, Albert H. Todd, Rebecca Whitney Lilja, and Paul K. Barten

United States Department of Agriculture
Forest Service
Northeastern Area State and Private Forestry
Newtown Square, PA 19073
NA-FR-01-08
June 2009

ACKNOWLEDGMENTS

The authors give special thanks to Robin Morgan, Northeastern Area State and Private Forestry (now with the Northern Research Station), Forest Service, U.S. Department of Agriculture, for her support and guidance in development of this project; and to Carl Reeverts, U.S. Environmental Protection Agency, for his help in providing critical data sets on drinking water consumers and supplies. Thanks go to Rebecca Whitney Lilja, Office of Knowledge Management, Northeastern Area State and Private Forestry, for producing all of the maps in this report, and for her patience through many rounds of changes. Thanks also go to Russ Lafayette, Eastern Region (R9) of the Forest Service, for his helpful comments on the draft report.

Cover: *The Quechee Gorge in Windsor County, Vermont, is part of the high-ranking Black-Ottauquechee watershed. Photo by Sherri Wormstead.*

Forests, Water and People:
Drinking water supply and forest lands in the Northeast and Midwest United States

Authors

Martina C. Barnes, Regional Planner, Northeastern Area State and Private Forestry, Forest Service, U.S. Department of Agriculture

Albert H. Todd, Watershed Program Leader, Northeastern Area (now Assistant Director, Ecosystem Services and Markets), State and Private Forestry, Forest Service, U.S. Department of Agriculture

Rebecca Whitney Lilja, GIS Analyst, Northeastern Area State and Private Forestry, Forest Service, U.S. Department of Agriculture

Paul K. Barten, Ph.D., Associate Professor, University of Massachusetts, Amherst

United States Department of Agriculture
Forest Service
Northeastern Area State and Private Forestry
11 Campus Boulevard, Suite 200
Newtown Square, PA 19073
NA-FR-01-08
June 2009
www.na.fs.fed.us

CONTENTS

ABSTRACT vi

INTRODUCTION 1

Objectives of This Report 1

Multiple Barrier Approach to Water Protection 1

Source Protection Versus Water Treatment 2

STUDY AREA 4

Land Use 6

Water Consumption 7

Large water supplies 7

Medium-sized water supplies 8

Small water supplies 8

ANALYSIS METHODS 9

Step 1: Calculate Ability to Produce Clean Water (APCW) 10

APCW index by 30-meter pixels 10

Mean APCW for Watersheds 12

Step 2: Add Data on Drinking Water Consumers 12

Step 3: Add Data on Private Forest Land 12

Step 4: Add Data on Change in Housing Density 13

RESULTS AND DISCUSSION 15

Index of a Watershed's Ability to Produce Clean Water (APCW) (Step 1) 15

Importance of Watersheds for Drinking Water Supply (Step 2) 18

Importance of Watersheds With Private Forests for Drinking Water Supply (Step 3) 20

Top-scoring watersheds—Eastern portion of the study area 21

Top-scoring watersheds—Western portion of the study area 22

Development Pressure on Private Forests in Watersheds Important for Drinking Water Supply (Step 4) 26

Top-ranking watersheds—Eastern portion of the study area 28

Top-ranking watersheds—Western portion of the study area 29

SUMMARY OF RESULTS 32

CLOSING COMMENTS 34

APPENDIX A: National Forest Lands Important for Drinking Water Supply 36

APPENDIX B: Technical Information Regarding Analysis and Metadata 42

REFERENCES 69

Text Boxes

Case Study—Low-Scoring Watershed: South Fork Sangamon River, Springfield, IL 17

Case Study—Moderate-Scoring Watershed: James River, Springfield, MO 25

Case Study—High-Ranking Watershed: Merrimack River, Manchester, NH 27

A Watershed Protection Forest Is... 34

Tables

Table 1: Population and forest area in the Northeast and Midwest in 1900 and 2000, by State 6

Table 2: Surface water supply systems in the Northeast and Midwest and population served in 2005, by State 8

Table 3: Data sets used in the watershed analysis, by attribute 10

Table 4: Biophysical characterization for 30-meter pixels, by attribute and ability to produce clean water (APCW). Higher scores indicate greater ability to produce clean water 12

Table 5: Summary of watershed analysis and prioritization, by steps in the GIS overlay process 13

Table 6: Top scoring watersheds for drinking water supply in the Northeast and Midwest, by composite score and Hydrologic Unit Code (HUC) 19

Table 7: Top scoring watersheds in the eastern portion of the study area, in terms of private forests important for drinking water supply, by label in Map 9 and composite score 22

Table 8: Top scoring watersheds in the western portion of the study area, in terms of private forests important for drinking water supply, by abel in Map 10 and composite score 24

Table 9: Watersheds in the eastern portion of the study area with the greatest development pressure on private forests important for drinking water supply, by label in Map 12 and composite score 29

Table 10: Watersheds in the western portion of the study area with the greatest development pressure on private forests important for drinking water supply, by label in Map 13 and composite score 31

Table 11: Forest land ownership in the Northeast and Midwest, by number of surface water consumers 33

Figures

Figure 1: As in the watershed of the Quabbin Reservoir in western Massachusetts, sustainably managed forests provide insurance against pollution from roads, sewers, and urban runoff. 2

Figure 2: New York City's commitment to land management in its source watershed translates directly to abundant quality drinking water for city residents, and annually avoids over $300 million in filtration costs. 3

Figure 3: Nine layers of GIS data (boxes) were combined in stepwise fashion, to produce four indices (ovals) of watershed importance for drinking water supplies and the need for private forest management to protect those supplies. 14

Figure 4: Forest land ownerships in source water watersheds in the Northeast and Midwest 32

Figure 5: Forest shelters this high-quality stream in Maryland. 33

Maps

Map 1: Study area. The study area includes the District of Columbia and 20 States in the Northeast and Midwest United States. 4

Map 2: Private and protected forest land. Most forests in the Northeast and Midwest United States are privately owned. 5

Map 3: Change in housing density, 2000 - 2030. Housing density in the study area is projected to increase from 2000 to 2030. 5

Map 4: Surface water consumers. Most surface drinking water supply systems in the Northeast are small, each serving less than 100,000 people... 7

Map 5: Index of the Ability to Produce Clean Water, 30-meter pixel view. The index of the ability to produce clean water was developed by combining six layers of spatial data: forest and agricultural lands, riparian forest cover, soil erodibility, road density, and housing density. Areas with higher scores have greater ability to produce clean water. 15

Map 6: Index of the Ability to Produce Clean Water, watershed view. The index of the ability to produce clean water indicates the probability of finding surface waters of high quality in a watershed. Higher scores indicate higher probability. 16

Map 7: Importance of watersheds providing drinking water supply, watershed view. Watersheds with the highest scores have the greatest ability to produce high quality water for the largest population 18

Map 8: Importance of watersheds and private forests for drinking water supplies, watershed view. Watersheds that scored high in their ability to produce high quality water for the largest population also scored high in the amount of private forested land they encompassed. 20

Map 9: Importance of watersheds and private forests for drinking water supplies in the eastern portion of the study area, watershed view. Watersheds that scored highest in terms of importance for drinking water and for private forests important for drinking water supply were in the eastern portion of the study area. See table 7 for more information about each watershed. 21

Map 10: Importance of watersheds and private forests for drinking water supplies in the western portion of the study area, watershed view. High-scoring watersheds in terms of importance of watersheds and private forests for drinking water supply in the western portion of the study area did not score as high as watersheds in the eastern portion (Map 9). See Table 8 for more information about each watershed. 23

Map 11: Development pressure on forests and drinking water supplies, watershed view. Watersheds with the highest rank and the highest risk of future development are near major cities and metropolitan areas. 26

Map 12: Development pressure on private forests and drinking water supplies in the eastern portion of the study area, watershed view. In the eastern portion of the study area, forested water supply watersheds subject to the greatest development pressure are along the Interstate Highway 95 corridor. See Table 9 for more information about each watershed. 28

Map 13: Development pressure on private forests and drinking water supplies in the western portion of the study area, watershed view. Less private forest land in the western portion of the study area means there is less development pressure on drinking water supply watersheds than in the eastern portion. See Table 10 for more information about individual watersheds. 30

ABSTRACT

Forests are critically important to the supply of clean drinking water in the Northeast and Midwest portion of the United States. In this part of the country more than 52 million people depend on surface water supplies that are protected in large part by forested lands. The public is generally unaware of the threats to their water supplies or the connection between clean water and the extent and condition of forest lands in source water watersheds. The future security of water supplies will not be ensured by a focus on water treatment alone. Protecting and managing forests in source watersheds is an essential part of future strategies for providing clean, safe drinking water that citizens can afford. This analysis uses a GIS-based process and a series of maps to create a watershed condition index based on physical and biological attributes. Using a multi-step process, this index is then used to compare 540 watersheds across 20 States and the District of Columbia, in terms of their ability to produce clean water. The study also quantifies the magnitude and scope of forest-dependent drinking water supplies, and their dependence on private forests; and it identifies watersheds that are threatened by land use change or are in need of management to sustain and improve forests that protect water supplies. The final maps and data display development pressure on private forests in watersheds important for drinking water.

INTRODUCTION

Forests in the 20 States and Washington, DC, served by the Northeastern Area State and Private Forestry, Forest Service, U.S. Department of Agriculture, help to protect more than 1,600 drinking water supplies that are the source of water for more than 52 million Americans (U.S. Department of Agriculture, Forest Service 2005). More than two-thirds of the population in this region depend on water from streams, lakes, and reservoirs. The quality of this water depends, in part, on the forest lands in their watersheds. Besides providing this valuable public benefit, these forests are also often managed for timber products, wildlife, and recreation that help to conserve them as open space. While many citizens who depend on surface water from municipal sources live very close to their water supply system, the value of forests specifically to water quality and water supply is often overlooked by both the public and policymakers.

Objectives of This Report

This project had two main objectives. The first was to illustrate the direct geographic connection between forests, water, and people—sometimes called the "forest-to-faucet" connection. The maps and data for this objective display a watershed's ability to produce clean water. The second objective was to demonstrate the importance of private forests to protecting surface drinking water quality and the potential threats to those forests. The maps and data for this objective display development pressure on private forests in watersheds important for drinking water. By looking at these relationships on a landscape scale, priorities for management action can be better determined.

The unique results of this analysis can be used in a number of ways: to guide strategies for forest land protection, outreach, and technical assistance to municipal water providers, and to refine and target assistance to individual forest landowners.

Multiple Barrier Approach to Water Protection

The time-tested multiple barrier approach to water protection remains vitally important to protecting drinking water supplies (National Research Council 2000). Multiple barriers to disease agents provide the greatest protection to public health. This approach involves several consecutive and interrelated steps; (1) protecting source areas, (2) treating drinking water, and (3) monitoring the drinking water distribution system to ensure success. The single most important barrier has proven to be source water protection.

Figure 1: *As in the watershed of the Quabbin Reservoir in western Massachusetts, sustainably managed forests provide insurance against pollution from roads, sewers, and urban runoff. Photo by Martina Barnes.*

In the Northeast and Midwest United States and throughout much of the world, forests are the crucial first barrier for source water protection (Dudley and Stolton 2003, National Research Council 2000, Platt and others 2000). Some of the Northeast's biggest cities, such as Boston, Hartford, and New York, took action more than a century ago to protect their water supplies by purchasing land in the watersheds that are the source of their drinking water. Even today, these cities are able to provide clean, safe water to millions of their citizens with minimal need for treatment (Barten and others 1998; Barten 2005). Yet, most people are unaware of the connection between clean water and the extent and condition of forest lands, or of the threats to their water supplies posed by development pressure (Ernst 2004).

Source Protection Versus Water Treatment

The future security of water supplies will not be ensured by a focus on water treatment alone. Protecting and managing forests in source watersheds are essential parts of future strategies for providing clean, safe drinking water that citizens can afford (Barten and Ernst 2004). One of the main reasons suppliers are revisiting the idea of source protection is the growing realization that allowing untreated water quality to degrade, in addition to threatening public health, also increases treatment and capital costs.

Advancements in the science of water treatment (filtration and disinfection) have enabled most cities to effectively treat water to remove known contaminants and provide safe drinking water. However, these same advancements have sometimes led to the false assumption that the quality of untreated water supplies is less critical today (Ernst 2006). Many small and medium-sized municipal water suppliers have been moving away from protecting and managing their source lands in favor of filtration and new treatment technologies. Some municipalities are even selling these lands, as they consider them unnecessary assets.

As the degree of water treatment and disinfection has increased, so has concern over the potential health effects of exposure to the byproducts of extensive disinfection (Ernst 2004). A continually expanding list of diverse contaminants, coupled with greater pollutant loads and fewer natural barriers, has also made water treatment more expensive and increased the risk that contaminants may reach the faucet (Ernst and others 2004). Water suppliers who draw water from intensively used source lands face treatment challenges, such as these:

Figure 2: *New York City's commitment to quality land management in its source watershed translates directly to abundant quality drinking water for city residents, and annually avoids over $300 million in filtration costs. Photo courtesy of George M. Aronson, photographer.*

1. Emergence of new contaminants that suppliers may not be prepared to test for or treat, or that may be in the water long before they are identified as a threat to public health,
2. Spikes in pollutant loads after storms that make treatment more difficult,
3. Increased treatment and capital costs due to higher loads and changing regulations.

Reliance on treatment alone can also be a costly alternative in the long run (National Research Council 2000). By protecting the watershed of the Quabbin Reservoir in western Massachusetts and practicing sustainable forestry since the 1930s, Boston made a cost-effective investment in clean source waters that will never be threatened by pollution from roads, sewers, or urban runoff (Figure 1). Allowing untreated water quality to degrade, in addition to threatening public health, also increases treatment and capital costs. New York City estimated the cost of installing filtration alone to be nearly $7 billion, with over $300 million in annual operating costs. As a result, New York City has chosen to sustain the quality of land management in its source watershed in order to sustain high water quality for a substantially lower investment (Figure 2).

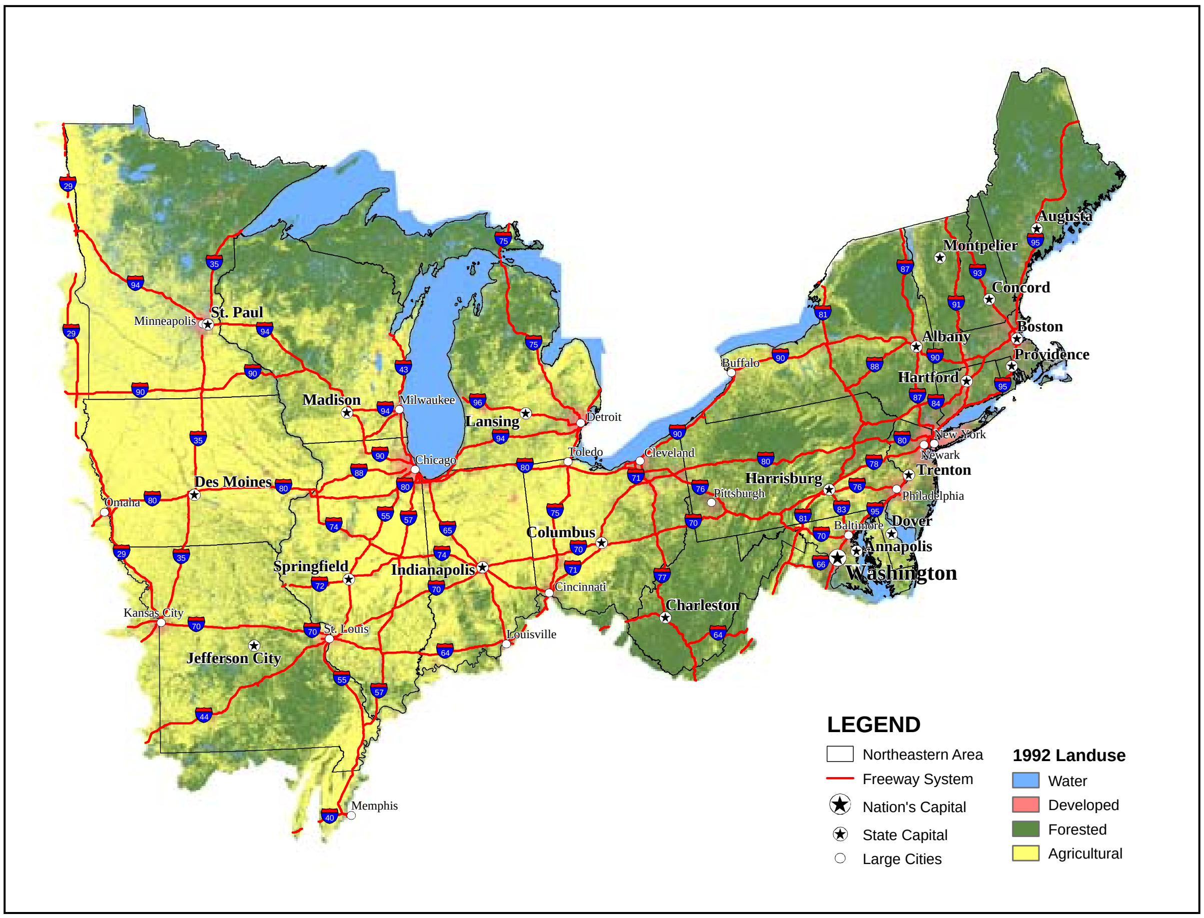
Current research on the public health impacts of urban and agricultural runoff in untreated water sources, and a recognition of the high costs and limitations of technological fixes reinforce two principles that were taken for granted a century ago: (1) the public water supply should be reasonably clean to begin with, and (2) forests and natural lands are critical to the quantity and quality of water supplies.

A recent report from the World Bank, titled *Running Pure*, concluded that protecting forests around water catchment areas is no longer a luxury but a necessity (Dudley and Stolton 2003). Protecting forests—which reduce erosion and sediment, improve water purity, and in some cases capture and store water—is a cost-effective way to provide clean drinking water. When forests are removed, the costs of providing clean and safe drinking water to urban areas increase dramatically (Dudley and Stolton 2003).

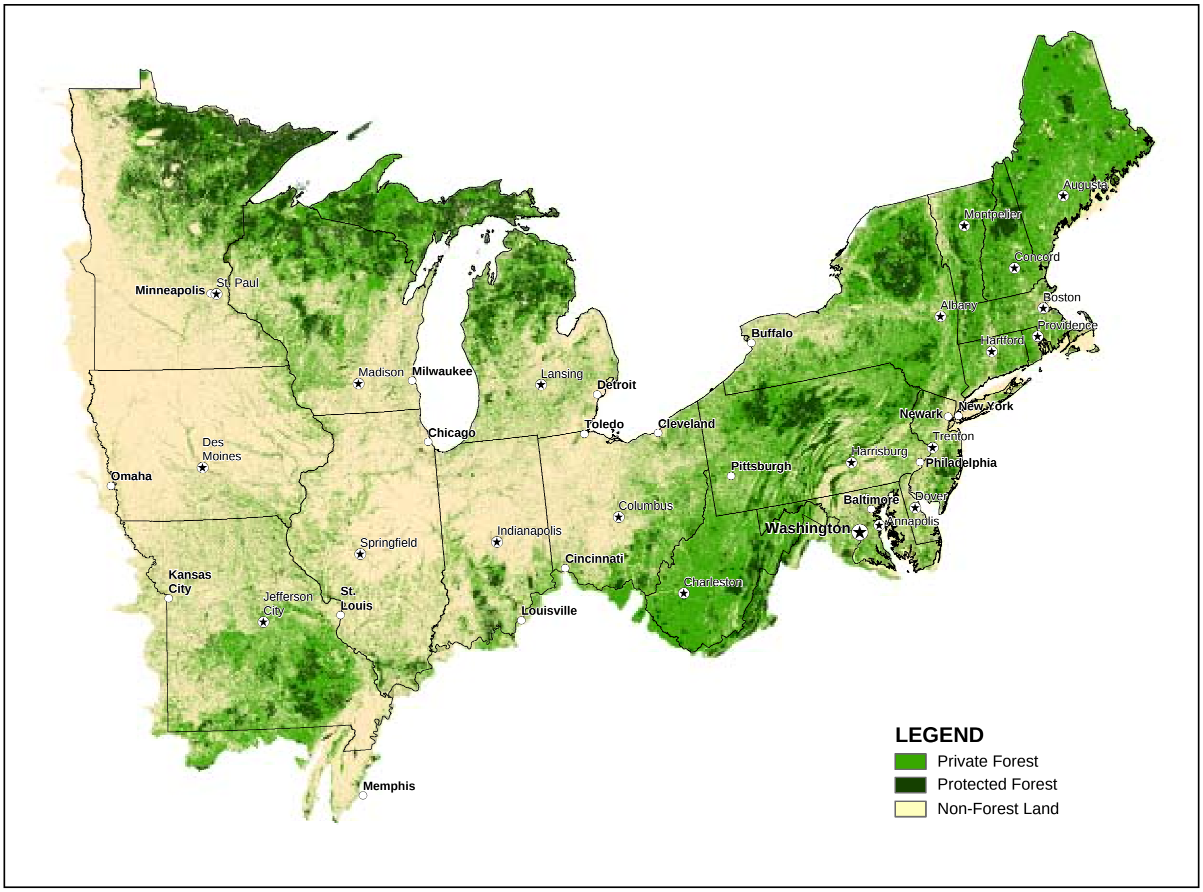
A study of water suppliers conducted by the Trust for Public Land in association with the U.S. Forest Service and the American Water Works Association's Source Water Protection Committee has found that operating treatment costs decrease as forest cover in a source area increases (Ernst and others 2004).

STUDY AREA

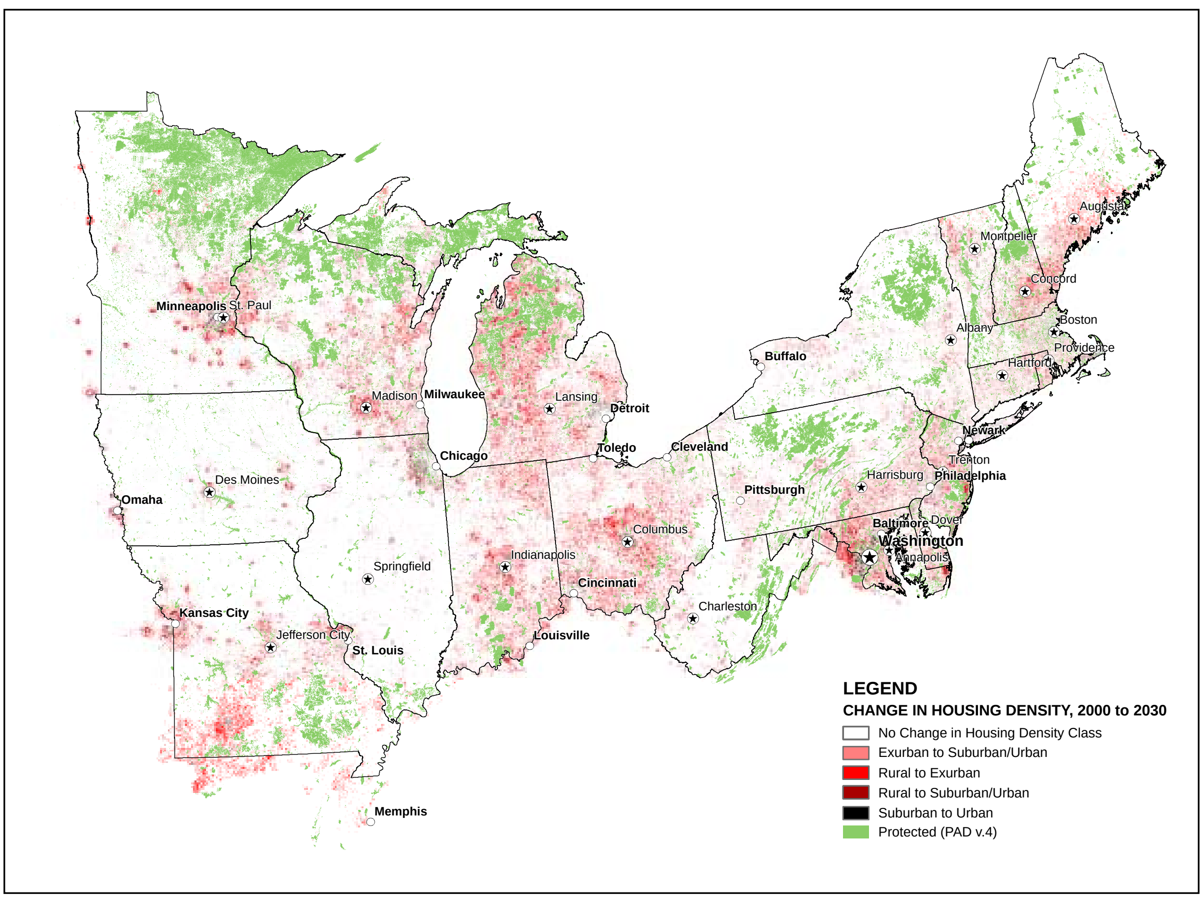
The 20-State study area, including the District of Columbia, stretches from the mountains of northern Maine to the banks of the Mississippi River, and from the hills of Missouri to the Chesapeake Bay (Map 1). The area is both the most populated and the most forested part of the country. While the study area makes up only 18 percent of the land area of the United States (Smith and others 2004), it is home to over 43 percent of its population (U.S. Bureau of the Census 2000). Before European settlement, roughly 300 million acres of forest covered this region (Smith and others 2004). Today, about 4 out of every 10 acres in this region is covered by forest, representing some 170 million acres and 23 percent of the nation's forest land. Of these forests, 92 percent are non-federally owned, with 76 percent owned by private landowners, which includes non-industrial private forest (NIPF) owners (Map 2; Smith and others 2004).



Map 1: Study area. *The study area includes the District of Columbia and 20 States in the Northeast and Midwest United States.*



Map 2: Private and protected forest land.
Most forests in the Northeast and Midwest United States are privately owned.



Map 3: Change in housing density, 2000 – 2030.
Housing density in the study area is projected to increase from 2000 to 2030.

Land Use

Although forest acreage has been increasing for most of the last 100 years, a growing population and increasing consumption of water, wood, and energy have outpaced increases in forest cover. More than 2,000 acres of forest land are cleared for development each day in the United States, and growth projections suggest that as many as 138 million acres of private forest land will be threatened by development between 2005 and 2030 (Stein and others 2005). In the Northeast and Midwest States, nearly 3.8 million acres of forest were lost to development between 1982 and 1997, with another 12 million acres projected to be lost by the year 2030 (Lund 2005; Map 3). Much of this increase in development is occurring outside metropolitan centers and spreading across the landscape in what is often referred to as "sprawl." Because of the need for dispersed transportation and business centers, this pattern of development tends to consume a much greater amount of open space than more compact and historic urban development. As a result, there were more people per square mile of forest in 2000 than in 1900 (Table 1).

Table 1: Population and forest area in the Northeast and Midwest in 1900 and 2000, by State

State	Year	Population*	Forest area (mi²)† ‡	People per square mile of forest	Forest acres per person
Connecticut	1900	910,000	3,305	275	2.3
	2000	3,282,031	6,886	477	1.3
Delaware	1900	180,000	547	329	1.9
	2000	754,000	598	1,261	0.5
Illinois	1900	4,800,000	3,906	1,229	0.5
	2000	12,130,000	6,767	18,953	0.3
Indiana	1990	2,500,000	6,250	400	1.7
	2000	5,940,000	7,033	845	0.8
Iowa	1900	2,200,000	3,906	563	1.1
	2000	2,900,000	3,203	905	0.7
Maine	1900	694,466	23,730	29	21.9
	2000	1,274,923	27,639	46	13.9
Maryland	1900	1,200,000	3,438	349	1.8
	2000	5,200,000	4,009	1,297	0.5
Massachusetts	1900	2,788,000	5,824	479	1.3
	2000	6,175,169	10,545	586	1.1
Michigan	1900	2,400,000	24,218	99	6.5
	2000	9,860,000	30,127	327	1.9
Minnesota	1900	1,700,000	23,492	72	8.8
	2000	4,920,000	26,094	188	3.3
Missouri	1900	3,100,000	28,594	108	5.9
	2000	5,500,000	21,863	252	2.5
New Hampshire	1900	412,000	8,896	46	13.9
	2000	1,201,134	18,240	66	9.7
New Jersey	1900	1,883,669	2,500	754	1.0
	2000	8,414,350	3,672	2,292	0.3
New York	1900	7,283,000	9,445	771	0.8
	2000	18,196,601	28,841	631	1.0
Ohio	1900	4,200,000	7,500	560	1.1
	2000	11,260,000	12,273	918	0.7
Pennsylvania	1900	6,302,115	8,600	740	0.9
	2000	12,281,054	26,562	462	1.4
Rhode Island	1900	430,000	754	570	1.1
	2000	990,819	1,339	740	0.9
Vermont	1900	343,641	3,419	10	6.4
	2000	608,827	7,233	84	7.6
West Virginia	1900	960,000	14,219	68	9.5
	2000	1,800,000	18,919	95	6.7
Wisconsin	1900	2,100,000	25,000	84	7.6
	2000	5,250,000	24,942	210	3.0

* Gibson and Lennon 1999; U.S. Bureau of the Census, Population Division 2000 (2000 population data).

† Barten 2007; Smith and others 2001, Table 3 (forest area for all non-New England states served by the Northeastern Area); Foster 1990 (forest area for Connecticut, Massachusetts, Maine, New Hampshire, Rhode Island, Vermont); Kellogg 1909 (1900 forest area data).

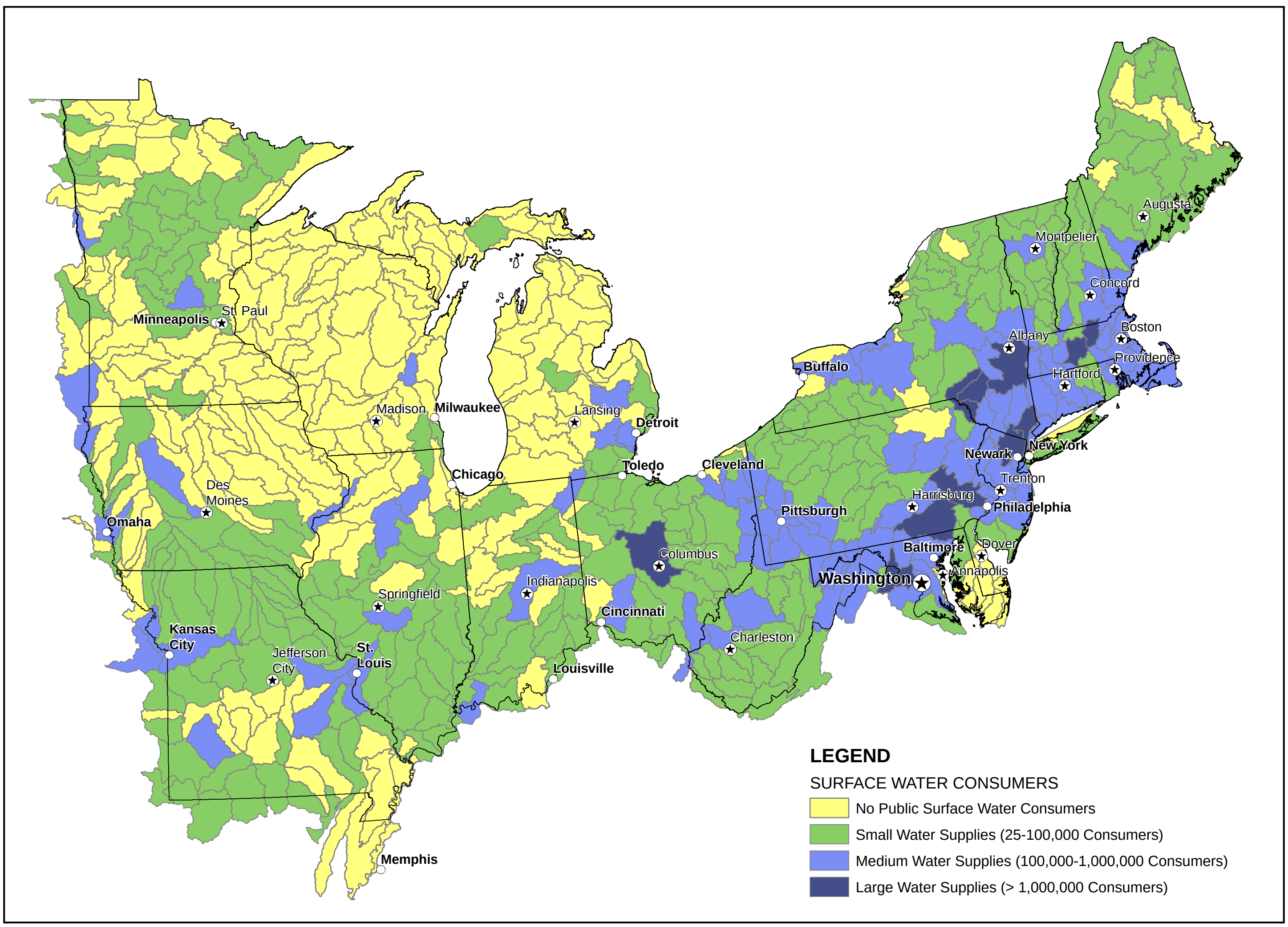
‡ 1 square mile (mi2) = 640 acres.

Water Consumption

Across the study area, daily household water use exceeds 4 trillion gallons. This figure is based on water use of approximately 75 gallons daily per capita (household water use only, not including irrigation or power generation). This amounts to more than 27,000 gallons per person per year or more than three 20-foot diameter swimming pools! By comparison, per capita water use in 1900 was 5 to 10 gallons per day. In the New York City metropolitan area alone, water consumers use nearly 2 billion gallons of water per day (National Research Council 2000). Major cities like New York and Boston have undertaken comprehensive programs to protect large forested watersheds far from these cities. Most small to mid-sized systems, however, are within 10 to 20 miles from the point of use, with limited opportunities for expansion to new forested watersheds (Sedell and Apple 2002).

Large water supplies.

Generally, large water supply systems serve more than 1 million consumers and are owned and operated by public agencies with significant budgets and proactive management programs. The Catskill, Delaware, and Croton watersheds deliver 1.2 billion to 2.3 billion gallons per day to 9 million consumers in the New York metropolitan area. Most forest land in these watersheds is privately owned. The City and the Watershed Agricultural Council have promoted a program of outreach to forest landowners to improve timber management activities in the watershed. The Quabbin, Ware, and Wachusett Rivers serve over 2.2 million people in 47 communities and the City of Boston. This water supply system is predominantly publicly owned, and the Commonwealth of Massachusetts manages more than 100,000 acres of watershed forest. Of this acreage, 75 percent is actively managed, also producing nearly 10 million board feet of timber each year.



Map 4: Surface water consumers. *Most surface drinking water supply systems in the Northeast and Midwest are small, each serving less than 100,000 people.*

Medium-sized water supplies.

Medium-sized surface water supply systems generally serve more than 100,000 people with a mix of public and private lands, and may have moderately funded systems with some ongoing planning, protection, and management.

Small water supplies.

The majority of surface water supply systems are small, serving communities of 25 to less than 100,000 people (Map 4). These watersheds generally have minimal public ownership (except areas buffering small reservoirs), as well as minimal planning, and infrequent forest management. These smaller water supply systems often lack staffing or adequate management expertise and violate drinking water standards almost twice as often as those serving larger communities (Ernst and Hart 2005). The protection and proper management of forest lands for small and large systems alike is a critical and cost-effective approach to ensuring quality drinking water in the future.

Table 2: Surface water supply systems in the Northeast and Midwest and population served in 2005, by State (U.S. Environmental Protection Agency 2005).

State	Public water supplies*	Population served†
Connecticut	36	2,231,610
Delaware	‡	4,510
Illinois	87	1,657,750
Indiana	36	1,710,050
Iowa	29	632,860
Maine	59	393,240
Maryland and District of Columbia	40	4,085,850
Massachusetts	103	4,901,910
Michigan	17	1,295,335
Minnesota	15	973,828
Missouri	84	2,502,640
New Hampshire	40	480,780
New Jersey	30	3,482,340
New York	297	11,555,950
Ohio	126	3,133,310
Pennsylvania	305	7,530,110
Rhode Island	11	566,601
Vermont	63	261,710
West Virginia	139	1,621,140
Wisconsin	5	199,460
System intakes outside the Northeast	84	3,193,294
Total	**1,608**	**52,411,270**

* Public water supplies are community or public drinking water systems as defined by the EPA, www.epa.gov/OGWDW/guide/sen104.html.

† Water consumer data were provided by watershed, and then prorated by watershed area to estimate consumers by State.

‡ Part of Philadelphia's water supply system.

Water supplies in the Northeast are finite and irreplaceable, and—with the exception of large rivers and lakes—most water sources have already been tapped. There are few ecologically or economically viable ways to dramatically augment current supplies. While they have been regular news in the West, water shortages have now taken center stage in the humid East as well. In addition to natural conditions such as drought, the primary threats to water supplies in the Northeast and Midwest are loss of forest to development, agriculture, or other land uses. If these threats are realized, the result is chronic erosion, altered and unstable streams, loss of riparian vegetation, and diminished forest health or watershed condition left by historic land use.

ANALYSIS METHODS

The study used a GIS-based process and a series of maps to create a watershed condition index based on physical and biological attributes. Using a multi-step process, this index was then used to compare watersheds across the 20 States and District of Columbia, in terms of their ability to produce clean water. Through regional maps, this analysis also accomplishes the following: quantifies the magnitude and scope of forest-dependent drinking water supplies and their dependence on private forests; and identifies watersheds that are threatened by land use change or that are in need of forest management to sustain and improve forests that protect water supplies.

To score the importance of watersheds across the 20-State study area, four indices were developed for each watershed:

1. Ability to produce clean drinking water
2. Importance for drinking water supply
3. Dependence on unprotected private forest land for drinking water supply
4. Threat of forest conversion or need for management, to sustain and improve forest conditions to protect drinking water supply

Each index was created by overlaying spatial data in a Geographic Information System (GIS) (Figure 3). Data layers were given equal weight in the overlay process to avoid potential bias; all resources were considered equally important. Each dataset was converted into a 30-meter resolution spatial grid and then summarized by watershed. Watersheds with eight-digit Hydrologic Unit Codes (HUCs) developed by the U.S. Geological Survey were selected as the summary units of the analysis, because they were large enough to ensure consistent data between units of analysis but small enough to identify priorities based on localized variations. The HUCs also facilitate the identification of problems and opportunities by hydrological boundaries rather than political ones. Within the study area are 540 separate HUC-8 watersheds. Where watersheds fell partly outside the political boundary of the study area, however, the entire watershed area was included in the analysis.

To maintain consistency across the 20-state area, nine standard nation-wide datasets were collected, scored, and overlaid to create the indices. While more current data was available for several states, this method used a seamless dataset to avoid dramatic changes from one State to another. A variety of other data sets were evaluated but were not used, due to problems identified with data consistency or appropriate scale. For example, the percent of impaired streams data provided by the U.S. Environmental Protection Agency were considered. Due to wide variations in State reporting of impaired streams, however, the layer was not included in this analysis (Table 3).

Table 3: Data sets used in the watershed analysis, by attribute (Appendix B).

Attribute	Datasets	Source
Forest land	1992 National Landcover Dataset	U.S. Geological Survey 1999
Agricultural land by watershed	1992 National Landcover Dataset	U.S. Geological Survey 1999
Riparian forest cover by watershed	1:100,000-scale National Hydrography Dataset, buffered to 30 meters	Hatfield 2005
Road density	2002 Bureau of Transportation Statistics (BTS) Roads	U.S. Department of Transportation 2002
Soil erodibility	STATSGO Soil Dataset, kffact	Miller and White 1998
Housing density by watershed	Housing density in 2000	Theobald 2004
Surface drinking water consumers per unit area	Public Drinking Water System (PWS) Consumers by eight-digit HUC; City Drinking water consumers for New York City, Philadelphia, St. Louis, St. Paul, and Washington DC	U.S. Environmental Protection Agency 2005
Private forest by watershed	Protected Areas Database, Version 4; Wisconsin Stewardship Data	Conservation Biology Institute 2006; U.S. Geological Survey, Upper Midwest Environmental Sciences Center 2005
Development pressure per unit area	Housing density in 2000 and 2030	Theobald 2004

Step 1: Calculate Ability to Produce Clean Water (APCW)

APCW Index by 30-meter pixels

The APCW Index characterized a variety of biophysical conditions in each watershed known to influence water quality. This index of water quality and watershed integrity uses six attributes: forest land, agricultural land, riparian forest cover, road density, soil erodibility, and housing density. Many other activities such as industrial pollution and mining, and natural variables such as climate change, floods, and fires, can also impact water quality. The evaluation of source water threats beyond traditional land use were not within the scope of this study but would be of value in more detailed source water analyses.

The forest land, agricultural land, and riparian forest buffer data were summarized by watershed and converted to a 30-meter spatial grid. The soil erodibility, road density, and housing density data were kept in their original 30-meter grid format and not summarized by watershed. Each of the six attributes was rated from 1 to 4 (low to very high) based on scientifically accepted standards (Table 4). Where standards or parameters were not available, the data was divided into quartiles for the purpose of analysis.

The six attributes were summed to determine the APCW Index for each 30-meter grid cell:

$$F + A + R + D + S + H = APCW$$

where,

F = Forest land (percent)

A = Agricultural land (percent)

R = Riparian forest cover (percent)

D = Road density (quartiles)

S = Soil erodibility (k factor)

H = Housing density (acres per housing unit, in 2000), and

APCW = Ability to Produce Clean Water

The resulting index has a total potential value of 6 to 24.

The APCW attributes are surrogates for important watershed characteristics that influence water yield and water quality. The goal of this project was not to make deterministic predictions of changes in nutrient, sediment, or other nonpoint source pollutant loading or flow regime, but rather to rank the 540 watersheds in the study area on a common scale. This ranking required the normalization of several attributes to enable objective comparison on a unit area basis (i.e., very large watersheds were not "advantaged" and comparatively small watersheds were not "disadvantaged"). This normalization produced a sufficient range of numerical variation in scores and more clearly identified critical watersheds. Characteristics of critical watersheds are a very high APCW, a large number of water consumers (per unit area), a large proportion of private forest land (that is potentially available for development and conversion to other land uses), and a high rate of forest conversion projected for 2030 (Stein and others 2005).

The scoring (i.e., low, moderate, high, very high) of the APCW layer was derived from a comprehensive review of salient literature (de la Cretaz and Barten 2007, Ice and Stednick 2004; National Research Council 2000 Stein and others 2005) and results of the Northeastern Area State and Private Forestry's Spatial Analysis Project and the Chesapeake Bay Resource Lands Assessment (U.S. Department of Agriculture, Forest Service 2006, U.S. Geological Survey 2000).

The following is an explanation of the basis for the APCW scores.

Forest land: Long-term watershed studies have shown that 20 to 30 percent of the catchment area must be treated (or forest biomass harvested) to produce measurable water yield increases and associated water quality changes. Hence, the "very high" score was defined as 75-100% forested—and the other scores were apportioned equally.

Agricultural land by watershed: Agricultural land use, especially row crops, typically generates more substantial changes in water yield and quality in relation to watershed area (de la Cretaz and Barten 2007, Chapters 7 and 9). The proportional areas reflect these thresholds and were successfully tested during a decade of earlier work in the Chesapeake Bay watershed.

Riparian forest cover by watershed: The area and continuity of riparian forest cover directly influences water quality in ways that parallel the effects of forest cover at the watershed scale (de la Cretaz and Barten 2007, Chapter 5).

Road density: Road density is the surrogate layer for "development" and the addition of impervious surfaces and pollution sources to watersheds. Since there is neither detailed spatial data nor a consistent relationship between development, streamflow, and water quality, a straightforward quartile division was used to score watersheds.

Soil erodibility: The soil erodibility layer uses commonly accepted categories within the USDA Natural Resouces Conservation Service's National Soils Database to represent the likelihood that—other characteristics being equal—the combined effects of soil texture and structure influence surface erosion, sediment transport, and water quality degradation.

Housing density by watershed: The housing density layer used for this analysis was based on past and current statistics on housing density and population, road density, past growth patterns, and locations of urban areas. The same model was used in the Forests on the Edge study (Stein and others 2005), which was based on research published in a peer-reviewed article in Ecology and Society (Theobald 2005). To date, Theobald's housing density research has been used in three research reports published by the Forest Service (Stein and others 2005, 2006, 2007).

Table 4: Biophysical characterization for 30-meter pixels, by attribute and ability to produce clean water (APCW). Higher scores indicate greater ability to produce clean water.

Attribute	**Scoring for 30-meter grid cell**			
	Low (1 point)	**Moderate (2 points)**	**High (3 points)**	**Very high (4 points)**
Percent forest land (F)	0 – 24	25 – 49	50 – 75	>75
Percent agricultural land (A)	>30	21 – 30	10 – 20	<10
Percent riparian forest cover (R)	0 – 29	30 – 50	51 – 70	>70
Road density (D; quartiles)	75 – 100th percentile	50 – 74th percentile	25 – 49th percentile	0 – 24th percentile
Soil erodibility (S; k factor)	>0.34	0.28 – 0.34	0.2 – 0.28	0 – 0.2
Housing density (H; acres per housing unit in 2000)	< 0.6 acre/ unit	0.6 – 5.0 acres/ unit	5.0 – 20.0 acres/unit (east) 5.0 – 40.0 acres/unit (west)	> 20.0 acres/unit (east) > 40.0 acres/unit (west)
Total APCW	Potential value 6 – 24			

Note: Letters in parentheses correspond to the equation in the text. For more detailed information on any of the above data layers, please refer to the technical information in appendix B.

Mean APCW for Watersheds

The APCW values were averaged to create a mean APCW for a watershed. This mean was divided into 10 quantiles, with the 1st quantile receiving a score of 10 (very high) and the 10th quantile receiving a score of 1 (low) (Table 5).

Step 2: Add Data on Drinking Water Consumers

Step 2 combined the results of Step 1, the watershed's mean Ability to Produce Clean Water, with water use data from the U.S. Environmental Protection Agency's (EPA) Surface Drinking Water Information System (SDWIS).

Selecting only surface water consumers (reservoirs and streams), the total number of drinking water consumers was summed for each eight-digit watershed and divided by the watershed area. For cities that use large river or lake intakes, such as Philadelphia, St. Louis, St. Paul, Chicago, and Washington, DC, the number of drinking water consumers was allocated among all upstream watersheds in relation to the drainage area that contributes water to the point of intake or diversion. For cities with municipal systems with multiple reservoirs in different eight-digit watersheds—including the New York City Watershed (Croton and Catskill/Delaware systems), Bridgeport and surrounding communities in southwestern Connecticut (reservoirs managed by Aquarion Water), metropolitan Boston, MA (Quabbin and Wachusett Reservoirs), and Springfield, MO—water consumers were allocated to reservoirs in relation to their storage volume and contribution to the total system capacity. The result for all watersheds and water supply systems was divided into 10 quantiles and combined with the APCW quantiles to yield a potential composite score of 2 to 20 (Figure 3, Table 5).

Step 3: Add Data on Private Forest Land

Step 3 combines the results of Step 2 with the percent of private forests in the watershed to highlight those private forest areas important for surface water drinking supply. The private forest database was derived using a subset of the Conservation Biology Institute's Protected Areas database and an updated Wisconsin dataset (U.S. Geological Survey 2005). Only permanently protected lands (Federal, State, county, local, or permanent conservation easements) were considered "protected;" all other lands were considered unprotected, having the potential to be developed. The percent private forest by watershed was divided into 10 quantiles, and then combined with the results of Step 2 to yield a total potential of 3 to 30 (Figure 3, Table 5).

Step 4: Add Data on Change in Housing Density

Step 4 combines the results of Step 3 with the development pressure of future housing density increase on forests. Development pressure was calculated by subtracting the housing density in 2000 from projections for 2030. If housing density would have increased from rural to exurban, rural to suburban/urban, or exurban to suburban/urban between 2000 and 2030, development pressure was said to occur (Stein and others 2005, Theobald 2004; see Appendix B for detailed definitions). The total acreage of land under development pressure in the watershed was divided by the watershed area, divided into 10 quantiles, and then combined with the results of Step 3 to yield a total potential score of 4 to 40 (Figure 3, Table 5). The use of 10 quantiles to map the four steps in this analysis satisfied the practical need to generate an objective numerical gradient that would describe the many possible combinations of biophysical characteristics, water use, current development, and projected forest conversion to the year 2030.

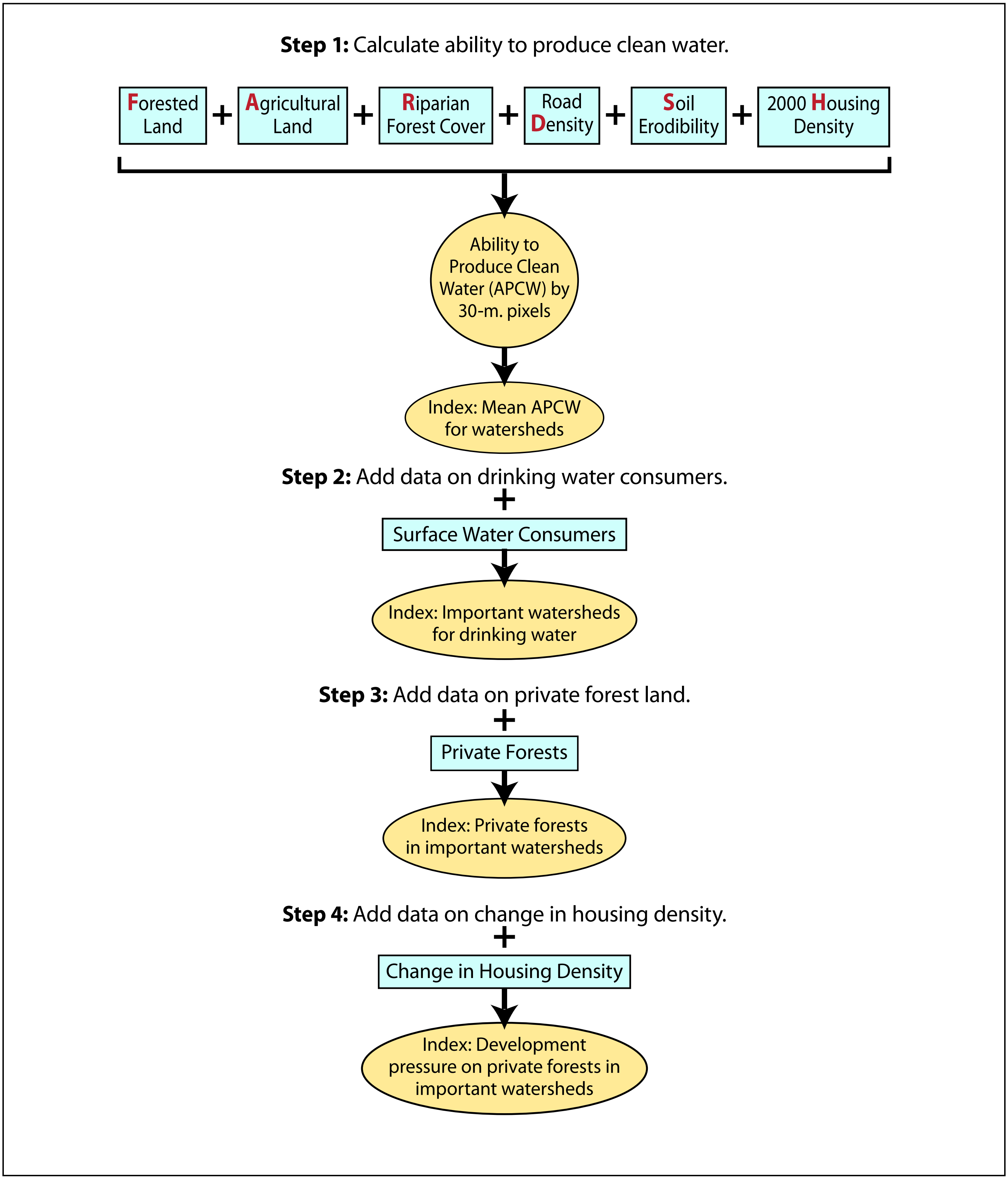
Watersheds with the highest scores have the greatest ability to produce clean water for the greatest number of drinking water consumers. High ranking watersheds also have the largest amount of private forest land that is under the greatest pressure for development and conversion to other uses.

Table 5: Summary of watershed analysis and prioritization, by steps in the GIS overlay process

GIS Overlay	Analysis result	Watershed scoring			
		Low (1 point)	Moderate-high (2-9 points)	Very high (10 points)	Potential composite score (points)
Step 1—Average APCW data for pixels in watershed	Watershed mean APCW	10th quantile	2nd – 9th quantile	1st quantile	1– 10
Step 2—Add data on surface water consumers	Watershed importance to drinking water consumers	10th quantile	2nd – 9th quantile	1st quantile	2 – 20
Step 3—Add data on private forest	Private forest in important watershed	10th quantile	2nd – 9th quantile	1st quantile	3 – 30
Step 4—Add data on change in housing density	Development pressure on private forest in important watershed	10th quantile	2nd – 9th quantile	1st quantile	4 – 40

Note: For more detailed information on any of the above data layers, please refer to the technical information in appendix B.

Figure 3: Nine layers of GIS data (boxes) were combined in stepwise fashion, to produce four indices (ovals) of watershed importance for drinking water supplies and the need for private forest management to protect those supplies.



RESULTS AND DISCUSSION

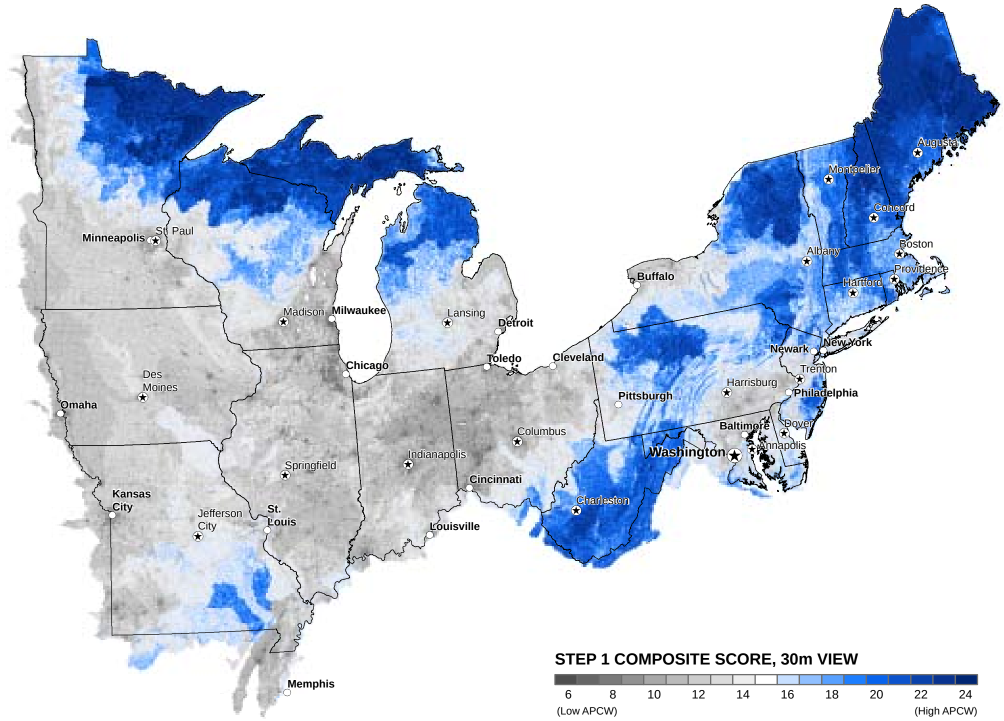
Index of a Watershed's Ability to Produce Clean Water (APCW) (Step 1)

Water quality is a function of biophysical conditions as well as the nature and intensity of land use in a watershed. Watersheds with a large proportion of forest land are more likely to be associated with good water quality. Forests provide the best land cover when it comes to protecting soil, moderating streamflow, supporting healthy aquatic systems, and sustaining good water quality. In the absence of mitigating actions, conversion of forest to other land uses leads to reduced water quality via a net increase in runoff, soil erosion, downstream flooding, and the flow of nutrients and other pollutants into rivers and streams (de la Cretaz and Barten 2007).

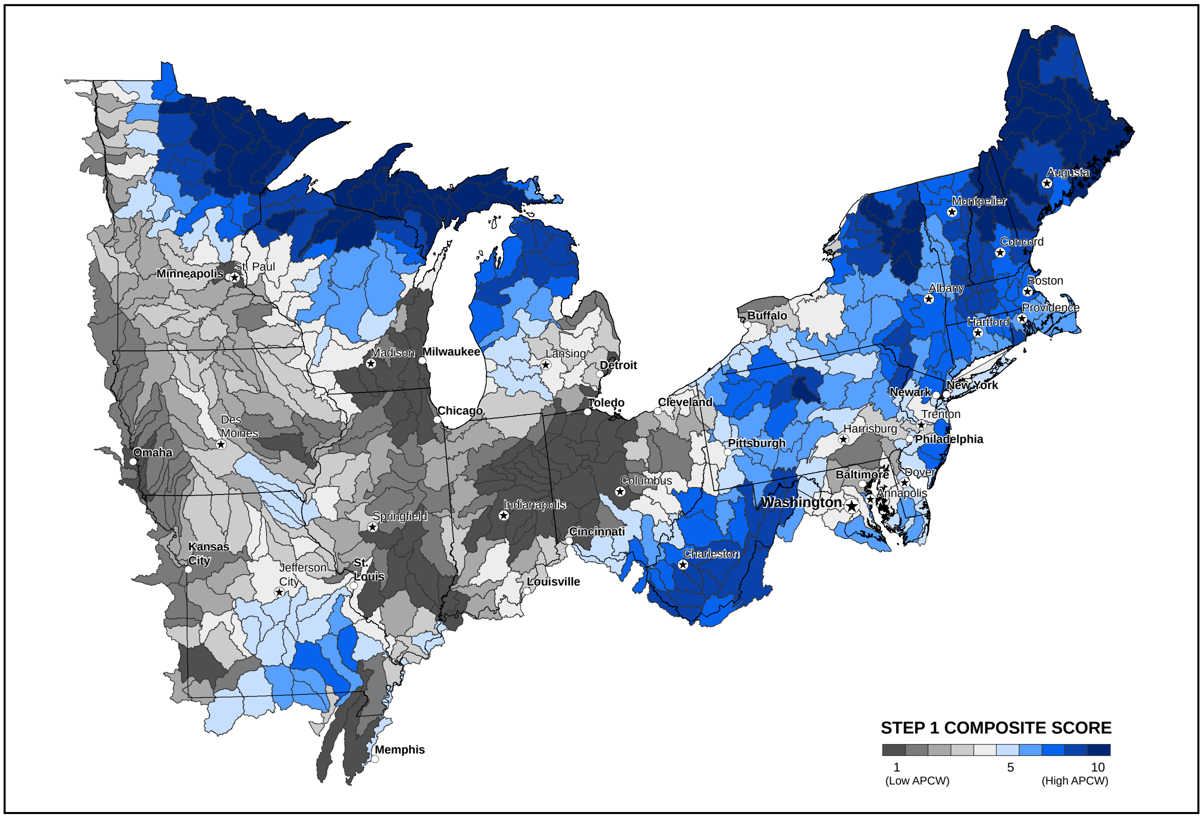
Land uses that tend to dramatically alter natural hydrologic and biological processes also have the greatest potential to negatively influence the flow and quality of water from these watersheds. For example, areas that contain a high percent of forested riparian buffers contribute positively to the ability to produce clean water, while higher amounts of cropland or development are expected to have a negative influence on watershed function and the ability to produce clean water.

Each of the six GIS-based layers that were used to develop the index of APCW (percent forest land by watershed, percent agricultural land by watershed, percent riparian forest cover by watershed, road density, soil erodibility, and 2000 housing density) were ranked from 1 (low APCW) to 4 (very high APCW) according to scientifically accepted breaks or quartiles (Table 4). Map 5 displays the results of the spatial overlay of these six biophysical layers. Map 5 is textured with each 30-meter pixel shown by its composite score.

Map 6 displays an average of these 30-meter pixel scores by eight-digit Hydrologic Unit Code (HUC) watershed, or subbasin, with scores normalized for watershed size on a relative scale of 1 to 10.



Map 5: ***Index of the Ability to Produce Clean Water, 30-meter pixel view.*** *The index of the ability to produce clean water was developed by combining six layers of spatial data: forest and agricultural lands, riparian forest cover, soil erodibility, road density, and housing density. Areas with higher scores have greater ability to produce clean water.*



Map 6: *Index of the Ability to Produce Clean Water, watershed view.* *The index of the ability to produce clean water indicates the probability of finding surface waters of high quality in a watershed. Higher scores indicate higher probability***.**

Maps 5 and 6 highlight the differences across the Northeast and Midwest United States in terms of land-use characteristics. Watersheds in a darker shade of blue show where forest land is likely to have a positive influence on surface water supply. On the other hand, shades of gray indicate that intensive agriculture and imperviousness are likely to degrade water quality. Analysis at the eight-digit HUC scale does mask some of these influences. Within a single large watershed, water quality and land use may vary widely and be distributed in broadly disparate patterns. Averaging conditions across a large watershed area gives a general probability of finding good or poor conditions but not a true spatial representation of the precise on-the-ground conditions at any given point. Therefore, a high score in this index does not imply that no water quality problems exist in a given watershed, but rather that the probability of finding surface waters of high quality is greater than in a lower-ranked watershed.

Areas that ranked highest for their ability to produce clean water are northern Minnesota and Wisconsin, Michigan's Upper Peninsula, the Adirondack region of northern New York, central Pennsylvania, most of Maine, and northern New Hampshire. Other high scoring areas include upper Michigan, southern West Virginia, north-central Pennsylvania near the Allegheny National Forest, eastern Vermont and western New Hampshire, western Massachusetts, and northeastern New York.

In contrast, forest and grassland ecosystems that have been converted to intensive agriculture ranked lowest in APCW. Across large areas of the Midwest, where groundwater systems are the primary supply for rural communities, the influence of agriculture on nutrient cycling, soil erosion, pesticide residues, and other contaminants dwarfs the influence of forests (which comprise a small proportion of the landscape) (de la Cretaz and Barten 2007).

Not all areas scoring low in the APCW have poor surface water quality; however, the likelihood of finding clean drinking water requiring less chemical treatment is greater in higher scoring areas. High density population centers, especially around St. Paul – Minneapolis, Chicago, Indianapolis, Cincinnati, and Columbus, ranked lowest due to their high level of development combined with low percent forest, high soil erodibility, and high percent agriculture.

The APCW index may have its greatest utility in characterizing the areas where a focus on protection or restoration or a combination of these strategies may be most appropriate. In addition, scoring of individual watersheds can be repeated at intervals to show trends in watershed condition in the broadest sense over time. Where finer scale watershed delineation and hydrography exist, these same data layers could be used to produce a more accurate local depiction of the index.

Case Study—Low-Scoring Watershed

South Fork Sangamon River, Springfield, IL

Watershed Score for Step 1: 1 out of 10

Watershed Rank: 487 of 540

The 784-square-mile South Fork Sangamon River Watershed supplies over 22 million gallons per day (MGD) of water to over 150,000 people in the Springfield, IL, area. The local utility owns Lake Springfield, which serves as the primary storage and source of drinking water. Constructed in 1935, this 4,200-acre reservoir is the largest municipally owned lake in Illinois. Besides water supply, the lake is a major central Illinois recreation center, as well as the source of condenser cooling water for the utility's lakeshore power plant complex. The lake, shoreline, and lake-area parks host some 600,000 recreational visitors each year.

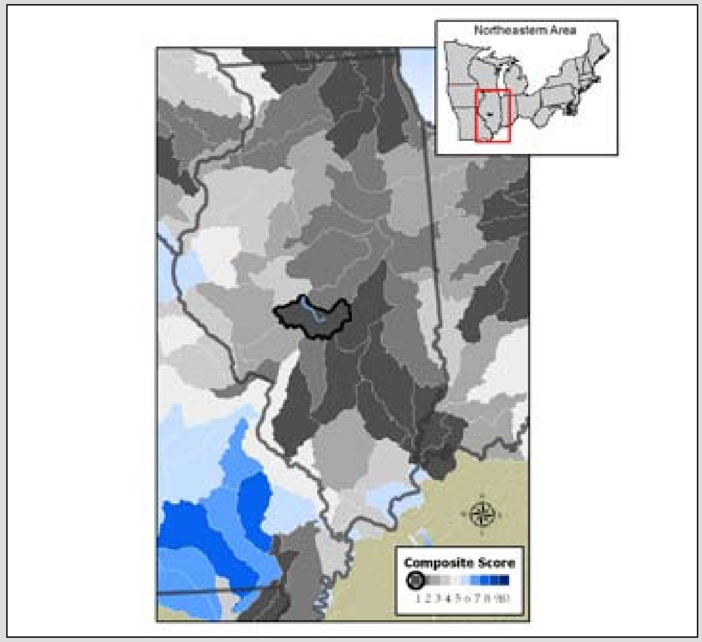
Land use in the watershed is primarily agricultural, with only 4 percent forest cover overall. Corn and soybeans are primary crops. Riparian buffers are also dominated by agricultural lands with less than 20 percent in forests.

This watershed ranked low in Step 1 of the analysis. This score means that in comparison to other watersheds in the study area, it has a lower ability to produce clean water because it has a high percent of agriculture and a low percent of forested land.

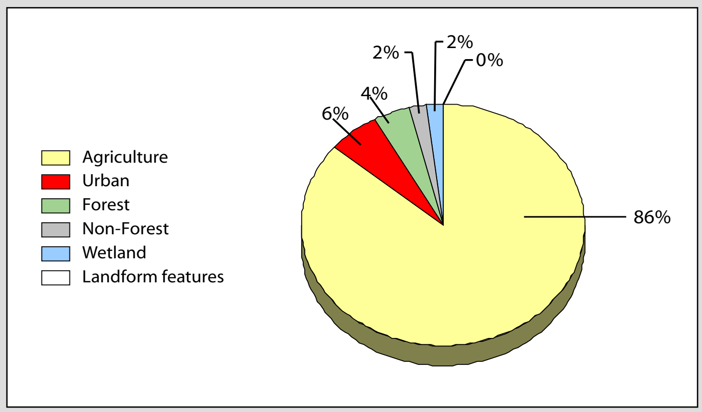
Water undergoes a rigorous purification and testing process, to ensure it is free of harmful bacteria and particulate matter. Untreated water quality is lower than average with average turbidity of 9.3 nephelometric turbidity units (NTUs). Turbidity is a water quality measure that reflects the level of fine suspended particles of clay, silt, organic and inorganic matter, plankton, and other microscopic organisms that are in the water. Water designated for drinking must have turbidities consistently below 1 NTU. The watershed may also have untreated water quality higher than typical agricultural watersheds, because the upper arms of Lake Springfield trap more than 50% of the sediment that enters the reservoir.

Generally, this water supply system has higher-than-average chemical treatment costs of $96.50/MGD on average. Plant operators noted that water quality has been stable or improving and that cooperation with agricultural partners was a reason for improvement. Farmers have reduced atrazine applications and planted 600 acres of filter strips. Restoring lakeside prairie grass may also have contributed to improved water quality.

www.cwlp.com/lake_springfield/lake.htm



Step 1 results show where the ability to produce clean water is greatest in the South Fork Sangamon River Watershed, a low-scoring watershed.

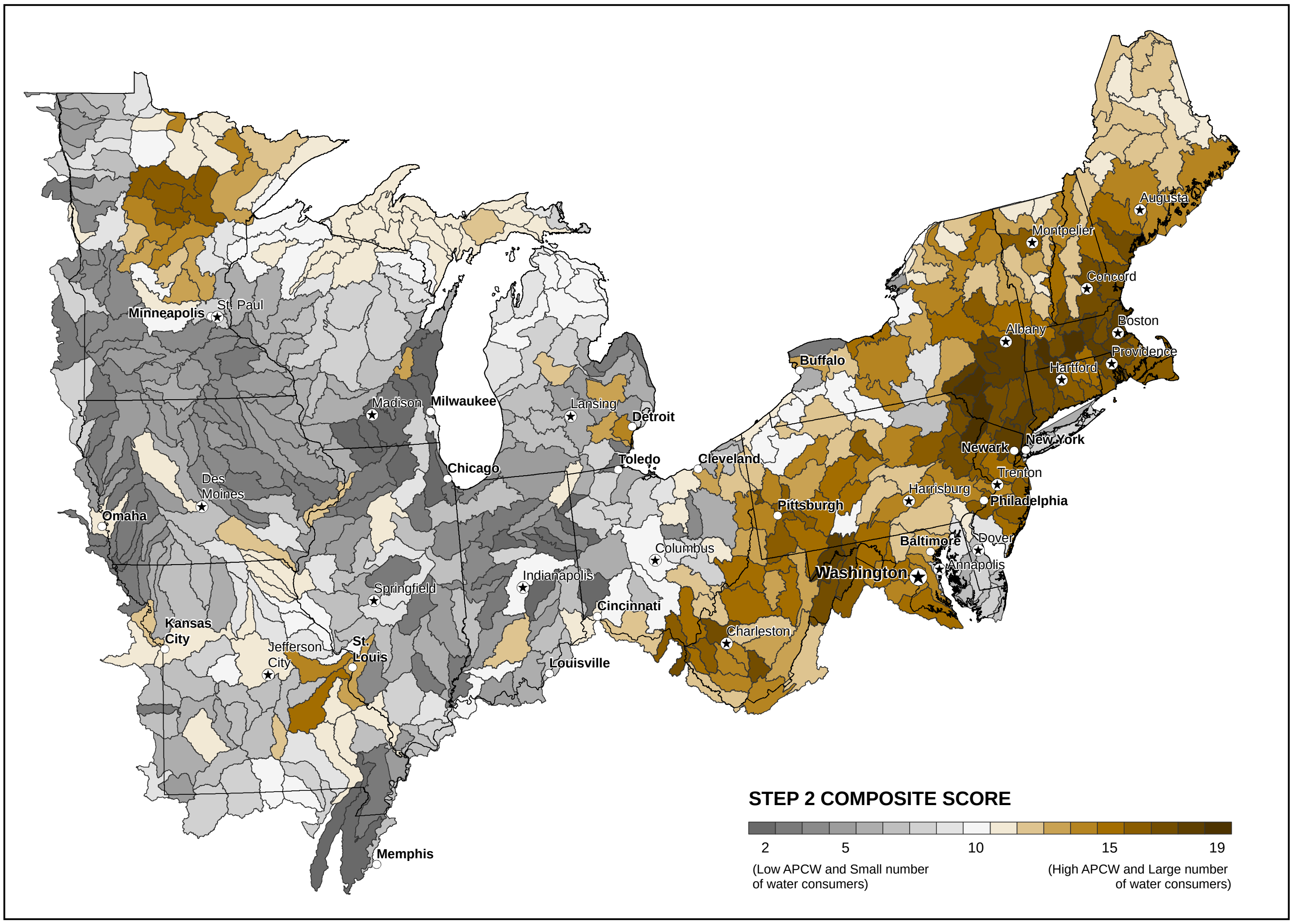


Land use in the low-scoring South Fork Sangamon River Watershed is primarily agricultural.

Lake Springfied dam gates. Lake Springfield is the largest municipally owned lake in Illinois and is the primary storage reservoir for the South Fork Sangamon River Watershed. Photo by Ted Meckes, City, Water, Light and Power Co., Springfield, IL.

Importance of Watersheds for Drinking Water Supply (Step 2)

Map 7 combines the index of Ability to Produce Clean Water with the total number of drinking water consumers served by that watershed to highlight those areas that provide high quality water to the largest population. Watersheds scoring high on this map are important forested watersheds and highlight the location of leading municipal water providers, both public and private. This region-wide map displays the eight-digit HUC watershed scores on a relative scale of 2 to 20.



Map 7: ***Importance of watersheds providing drinking water supply, watershed view.*** *Watersheds with the highest scores have the greatest ability to produce high quality water for the largest population***.**

Table 6: Top scoring watersheds for drinking water supply in the Northeast and Midwest, by composite score and Hydrologic Unit Code (HUC)

Composite score	HUC	Watershed	States
19	01080204	Chicopee	MA
19	01080206	Westfield	CT MA
19	02040102	East Branch Delaware	NY
19	02040104	Middle Delaware-Mongaup-Brodhead	NJ NY PA
18	01070004	Nashua	MA NH
18	01080207	Farmington	CT MA
18	01090001	Charles	MA
18	01090003	Blackstone	MA RI
18	02020005	Schoharie	NY
18	02020006	Middle Hudson	CT MA NY
18	02030101	Lower Hudson	CT NJ NY
18	02030103	Hackensack-Passaic	NJ NY
18	02040101	Upper Delaware	NY PA
18	02070002	North Branch Potomac	MD PA WV

Areas scoring highest are likely to be forested watersheds near large population centers. Many of these watersheds with a high APCW are the same watersheds that serve drinking water consumers in the eastern United States. The top scoring watersheds include southeastern New York (the New York City watersheds), northeastern Pennsylvania (the Pocono Mountains), central and western Massachusetts (Quabbin Reservoir and Berkshire Mountains), northern Connecticut (Hartford), and the Highlands of New Jersey. Other high scoring areas reflect the large amount of forest cover in the Northeast, and include portions of New England—including coastal Maine, Massachusetts, Connecticut, and Rhode Island—and large portions of Pennsylvania, western Maryland, and West Virginia. Relatively high scoring watersheds were also located in northern Minnesota (around St. Paul – Minneapolis) and eastern Missouri (west of St. Louis).

In general, States including and to the west of Ohio ranked lower than the New England and Mid-Atlantic States. The reasons for these results include (1) the smaller numbers of surface water consumers in States west of and including Ohio, since groundwater supplies are more common there; (2) the lower overall forest cover and higher percentage of agricultural lands in much of the region west of Ohio; and (3) the number of drinking water consumers is allocated among all upstream watersheds that rely on large intakes (such as the Upper Mississippi River or Lake Michigan) and systems where a large watershed contributes to the point of diversion.

Watersheds with a high score in Map 7 should be recognized as critically important to the health and welfare of a large percentage of the population in the Northeast and Midwest. These are the workhorses of water supply in the region.

Importance of Watersheds With Private Forests for Drinking Water Supply (Step 3)

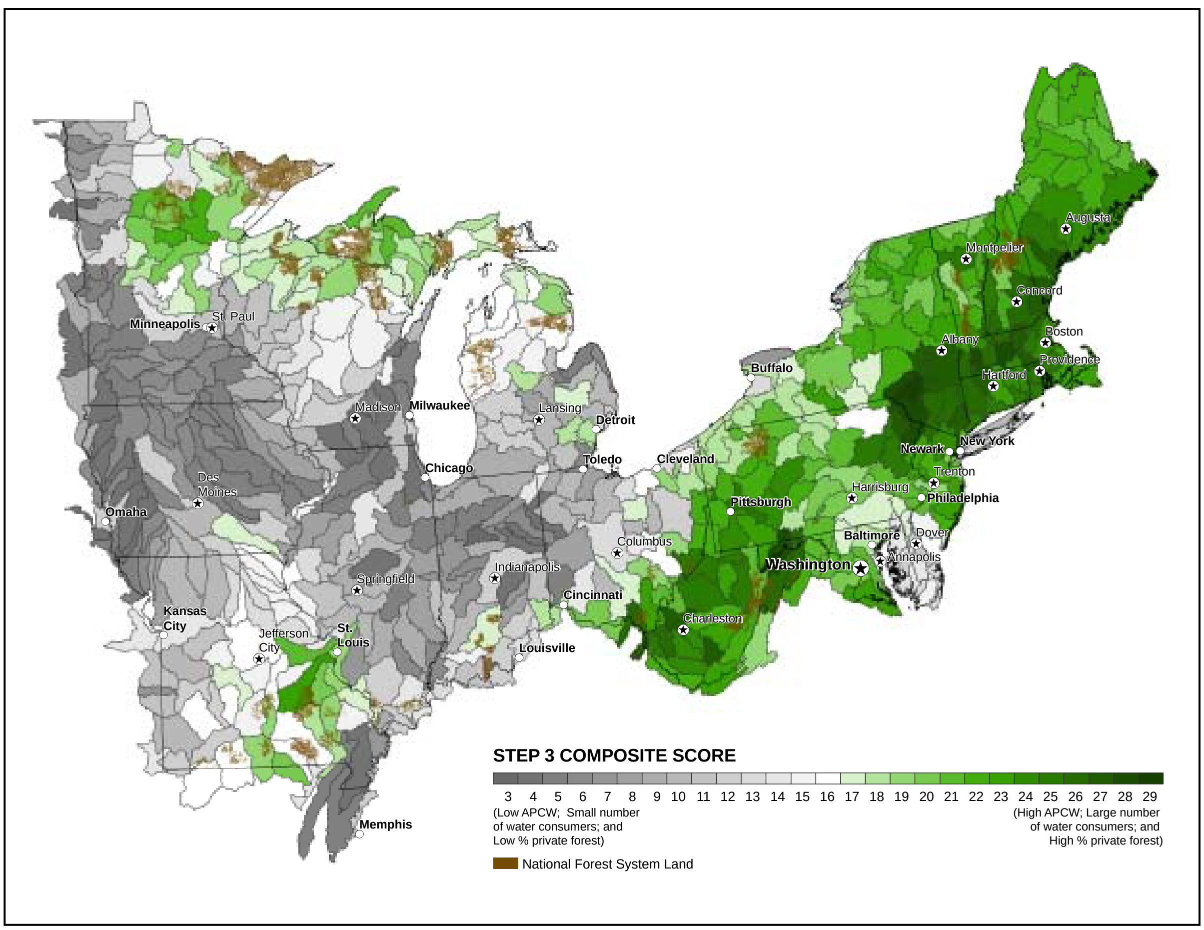
It is a common misconception that all or most lands that supply public drinking water are publicly owned or otherwise protected. Some highly valued drinking water supplies do come from public or other lands that are protected from future development or land-use impacts. Other water supply system lands have limited protection zones, often surrounding reservoirs, lakes, or intakes, while the remainder of the watershed is vulnerable to land-use change. Many small watershed supplies, however, contain only private lands with little or no protective agreements or special land-use provisions.

Map 8 combines the results of the Ability to Produce Clean Water, number of surface drinking water consumers served, and the percent private forest land, to illustrate the important role that private forest lands play in protecting water supplies. As described under Analysis Methods, each of the three data layers was ranked from 1 to 4 in quartiles (very high = 4 points, high = 3 points, intermediate = 2 points, and low = 1 point), and then summed for each eight-digit HUC watershed, resulting in composite scores ranging from 3 to 30.

Map 8 shows that most of the watersheds that ranked highest for their ability to produce clean water for large numbers of water consumers are also characterized by a high percent of private forest land. In general, areas scoring highest (dark green) as private forested watersheds with surface drinking water supply areas are east of Ohio. The highest scoring watersheds in this part of the analysis were in southern Maine, eastern New Hampshire, central and western Massachusetts, western Connecticut, southeastern New York, northeastern Pennsylvania, western Maryland, and southern West Virginia.

Map 8 illustrates those important water supplies where current protection relies primarily on the decisions made by hundreds or even thousands of private forest landowners. In other words, watersheds that score high on this map contain very little protected land and are highly dependent on the management of forests by private landowners in order to protect water quality.

Map 8 also illustrates the importance of the 1911 Weeks Act in establishing National Forests, by authorizing the Federal purchase of forest lands in and around the headwaters and watersheds of navigable streams. By 1980, more than 12.1 million acres of land had been



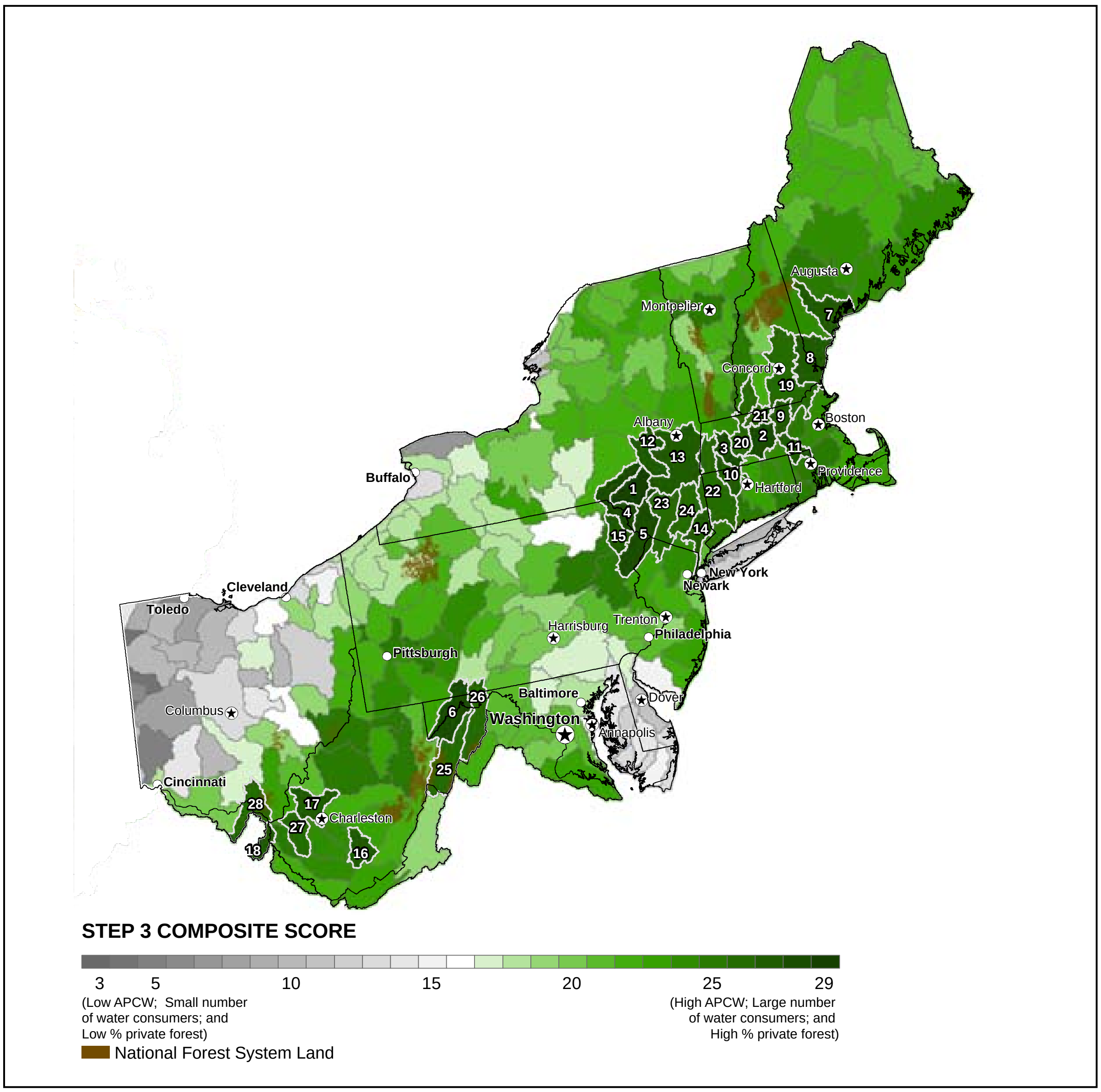
Map 8: ***Importance of watersheds and private forests for drinking water supplies, watershed view.*** *Watersheds that scored high in their ability to produce high quality water for the largest population also scored high in the amount of private forested land they encompassed.*

added, through purchase, to the National Forest system within the study area boundary. Maps A-1, A-2, and A3 show the National Forest System lands relative to the high scoring watersheds for drinking water. Although most of the forest land in the region is privately owned, passage of the Weeks Act helped to emphasize the importance of protecting lands near water supply watershed areas (Buie 1979, p. 3).

Top scoring watersheds—Eastern portion of the study area

The study area was divided into eastern and western components for ease of discussion and to more easily view the geographic distribution of priority watersheds.

Most states in the eastern portion of the study area (Map 9, Table 7) scored high because approximately 75 percent of the privately owned forested lands in the study area are found here.



Map 9: ***Importance of watersheds and private forests for drinking water supplies in the eastern portion of the study area, watershed view.*** *Watersheds that scored highest in terms of importance for drinking water and for private forests important for drinking water supply were in the eastern portion of the study area. See Table 7 for more information about each watershed.*

Table 7: Top-scoring watersheds in the eastern portion of the study area in terms of private forests important for drinking water supply, by label in Map 9 and composite score.

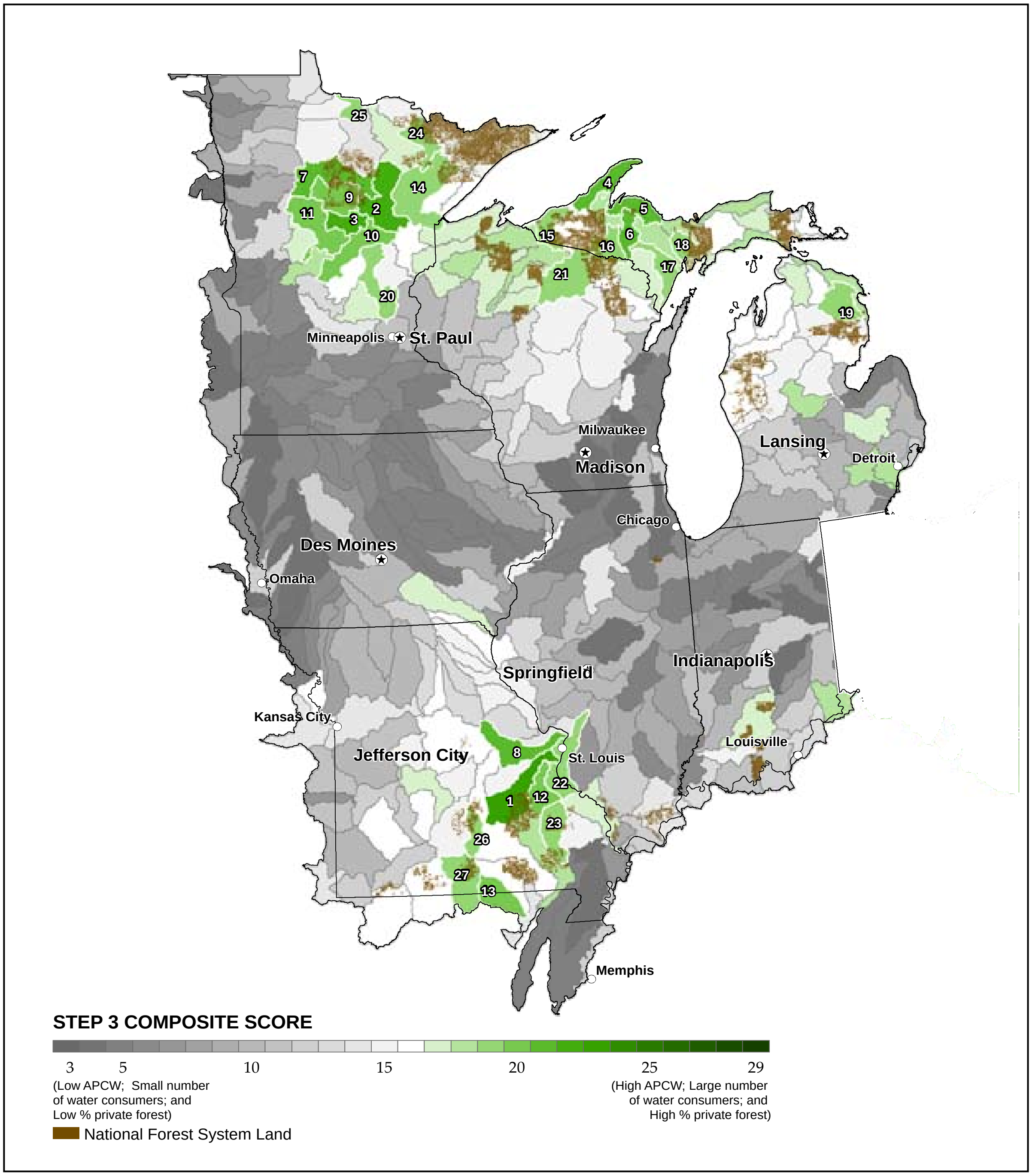
Label in map 9	Composite score	Watershed	HUC	State
1	29	East Branch Delaware	02040102	NY
2	28	Chicopee	01080204	MA
3	28	Westfield	01080206	CT MA
4	28	Upper Delaware	02040101	NY PA
5	28	Middle Delaware-Mongaup-Brodhead	02040104	NY PA NJ
6	28	North Branch Potomac	02070002	MD PA WV
7	27	Presumpscot	01060001	ME
8	27	Piscataqua-Salmon Falls	01060003	ME NH MA
9	27	Nashua	01070004	MA NH
10	27	Farmington	01080207	CT MA
11	27	Blackstone	01090003	MA RI
12	27	Schoharie	02020005	NY
13	27	Middle Hudson	02020006	CT MA NY
14	27	Lower Hudson	02030101	CT NY NJ
15	27	Lackawaxen	02040103	PA
16	27	Lower New	05050004	WV
17	27	Lower Kanawha	05050008	WV
18	27	Big Sandy	05070204	KY WV
19	26	Merrimack	01070002	MA NH
20	26	Middle Connecticut	01080201	MA NH VT
21	26	Miller	01080202	MA NH
22	26	Housatonic	01100005	CT MA NY
23	26	Rondout	02020007	NJ NY
24	26	Hudson-Wappinger	02020008	NY
25	26	South Branch Potomac	02070001	MD VA WV
26	26	Cacapon-Town	02070003	MD PA VA WV
27	26	Lower Guyandotte	05070102	WV
28	26	Little Scioto-Tygarts	05090103	KY OH WV

Top scoring watersheds—Western portion of the study area

Overall, watersheds in the western portion of the study area (Map 10, Table 8) scored lower than watersheds in the eastern portion. This result is not unexpected.

The highest scores were in northern Minnesota, western Missouri, and Michigan's Upper Peninsula. Much like the results of Step 2, these results are likely due to the fact that this part of the country is less forested overall and relies much less on small surface water supplies for drinking water sources. In the western half of the region, the areas that scored highest are aligned more closely with the watersheds in and around National Forest boundaries. For more information on National Forest System lands important for drinking water, see Appendix A. The protection of water quality is a high priority for management of these public lands; results of the analysis show that high priority watersheds are near public lands.

Soils, geology, geography, and land use have led to a greater dependence on large surface water supply systems such as the Great Lakes, or rivers such as the Mississippi or Ohio. These large lake or run-of-the-river systems mean that the analysis spreads water demand across a large landscape, reducing the watershed scores. In addition, states west of Ohio depend to a much greater degree on groundwater sources for drinking water, both as a factor of geology and because ambient water quality problems in many tributaries are brought on by intensive agriculture as a dominant land use. Since this study focuses on surface water supply systems, watersheds that depend on groundwater scored lower and are inherently more difficult to link directly to the influence of forest cover.



Map 10: ***Importance of watersheds and private forests for drinking water supplies in the western portion of the study area, watershed view.*** *High scoring watersheds in terms of importance of watersheds and private forests for drinking water supply in the western portion of the study area did not score as high as watersheds in the eastern portion (Map 9). See Table 8 for more information about each watershed.*

Table 8: Top-scoring watersheds in the western portion of the study area, in terms of private forests important for drinking water supply, by label in map 10 and composite score.

Label in map 10	Composite score	Watershed	HUC	State
1	23	Meramec	07140102	MO
2	22	Prairie-Willow	07010103	MN
3	22	Pine	07010105	MN
4	21	Keweenaw Peninsula	04020103	MI
5	21	Dead-Kelsey	04020105	MI
6	21	Michigamme	04030107	MI
7	21	Mississippi Headwaters	07010101	MN
8	21	Lower Missouri	10300200	MO
9	20	Leach Lake	07010102	MN
10	20	Elk-Nokasippi	07010104	MN
11	20	Crow Wing	07010106	MN
12	20	Big	07140104	MO
13	20	Spring	11010010	AR MO
14	19	St. Louis	04010201	MN WI
15	19	Black-Presque Isle	04020101	MI WI
16	19	Brule	04030106	MI WI
17	19	Cedar-Ford	04030109	MI
18	19	Tacoosh-Whitefish	04030111	MI
19	19	Thunder Bay	04070006	MI
20	19	Rum	07010207	MN
21	19	Upper Wisconsin	07070001	MI WI
22	19	Cahokia-Joachim	07140101	IL MO
23	19	Upper St. Francis	08020202	MO
24	19	Vermilion	09030002	MN
25	19	Upper Rainy	09030004	MN
26	19	Big Piney	10290202	MO
27	19	North Fork White	11010006	AR MO

Case Study—Moderate-Scoring Watershed

James River, Springfield, MO

Watershed Score for Step 3: 12 out of 30

Watershed Rank: 330 of 540

The nearly 1,400-square-mile James River watershed in southwestern Missouri is on the Ozark plateau and contains the city of Springfield, MO. Land use is roughly split between forest (31%), agricultural cover (grazing land, 37%), and other land uses. Riparian buffers are about 50 percent forested with over one-third containing agricultural land. The watershed is characterized by grazing lands and residential development dominated by large lots of 5 – 10 acres.

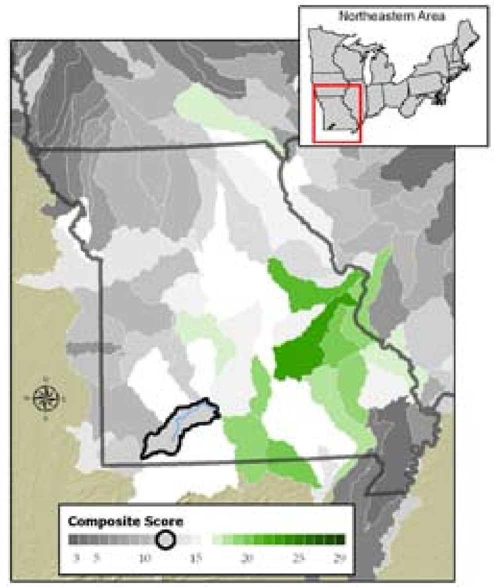
Approximately 80 percent of Springfield's drinking water comes from surface waters (lakes, rivers) and the rest from ground water (wells, springs). The Blackman Water Treatment Plant in the southeastern corner of the city receives water from Fellows Lake, Stockton Lake, and the James River. Water from a tributary of the James River fills Stockton Lake—a primary reservoir for the water supply system. Water from this lake is then pumped uphill about 460 feet into Fellows Lake. Lake water makes up two-thirds or more of the plant's intake water. At times, the plant also draws up to a third of its supply directly from the James River.

This watershed scored in the moderate importance range in the analysis. This means that in comparison to other watersheds in the study area, it has a good ability to produce clean surface water because one-third of its land base is forested. Many people rely on the surface drinking water supplies, and the water supplies are located near forest lands that are privately owned and subject to a medium level of development pressure.

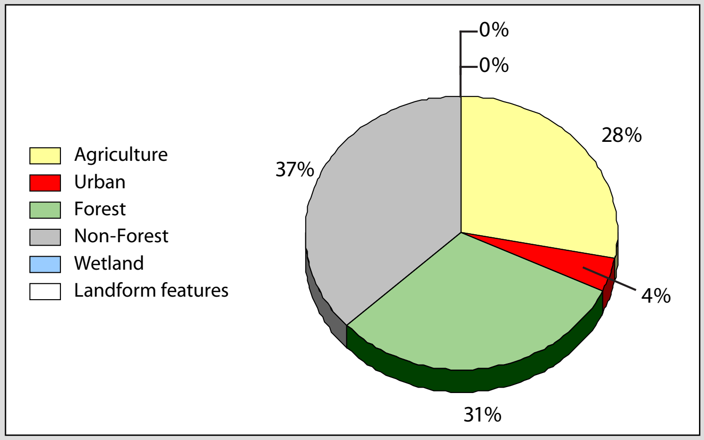
The Blackman Water Treatment Plant provides about 18 million gallons per day (MGD) of treated water to its customers with per unit chemical treatment costs of $62.20/MGD. Although water supply reservoirs have improved dramatically since the 1930s, plant operators have reported a decline in untreated water quality in recent years attributed to eutrophication from increased turbidity in the James River, sedimentation of reservoirs, and increased development of the source watershed. Failing septic systems are also seen as one of the top issues in the watershed.

County planning and zoning laws have been improved to address better watershed protection. The Watershed Committee of the Ozarks, a nonprofit that has been partnering with local stakeholders, is working to protect some property in the source watershed and to educate the public.

www.watershedcommittee.org/



Step 3 results show where the role of private forests in protecting water supplies is greatest in the James River Watershed, a moderate-scoring watershed.



Land use is divided roughly among grazing, forest, and other land uses in the James River Watershed, a moderate-scoring watershed.

Springfield, MO, receives most of its water supply from areas outside the James River basin, but some of its water comes from James River intakes. Photo by Dave Ballou, City of Springfield, MO.

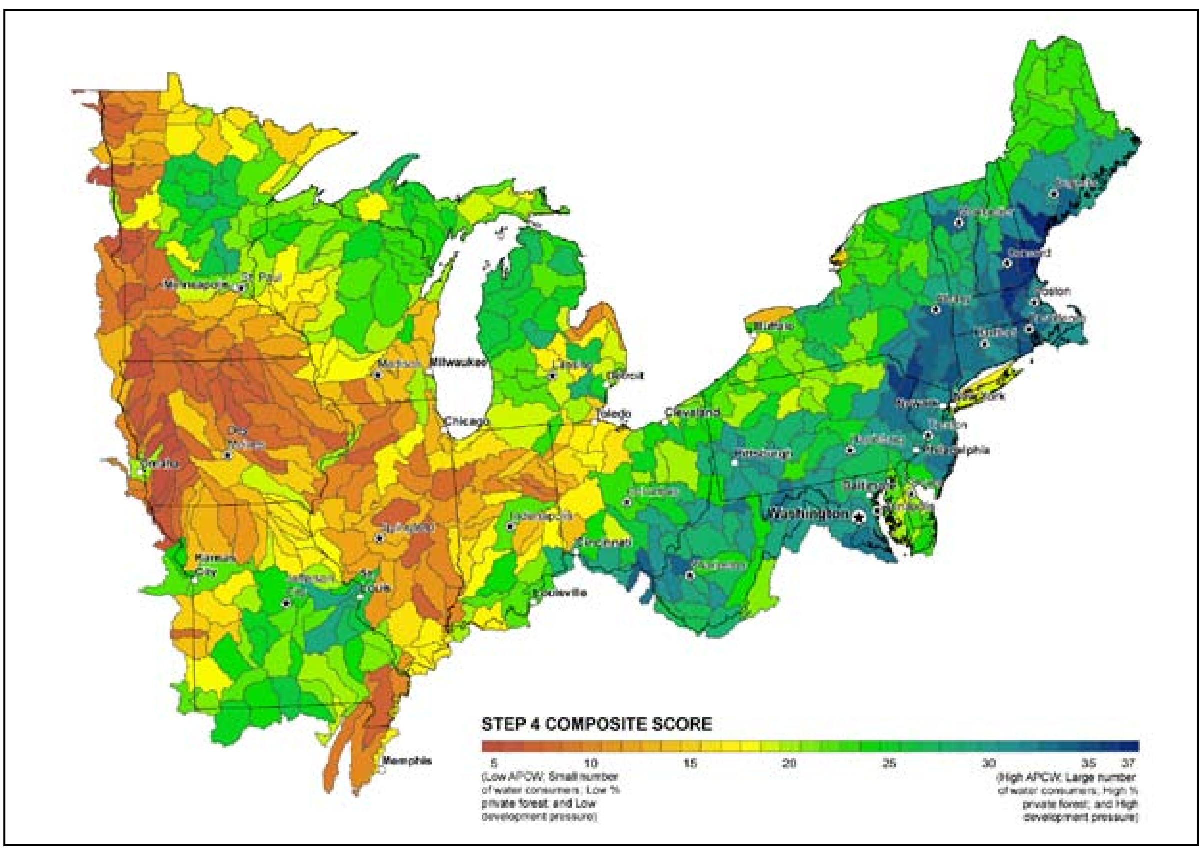
Development Pressure on Private Forests in Watersheds Important for Drinking Water Supply (Step 4)

The fact that watersheds are protected predominantly by private forest lands means that those watersheds are vulnerable to land-use change if they fall within areas of projected future growth. According to the EPA, more than 60 percent of U.S. water pollution comes from runoff from lawns, farms, cities, and highways, as well as leachate from septic systems (U.S. EPA 2007). The loss of forest lands to development affects not only the quality of drinking water, and therefore the cost of treating it, but the quantity as well. While it increases demand and water use, development also reduces the ability of water to infiltrate and recharge water supplies, and reduces supply as well.

In this analysis, housing density data, derived from U.S. Census (2000) block data, served as an indicator of development pressure. Projections of housing density change from 2000 to 2030 (Theobold 2005) that were developed as part of the Forests on the Edge project (Stein and others 2005) were combined with private land to illustrate those unprotected forest areas where housing density is likely to increase. Areas where housing density increased were extracted and reclassified as "development pressure." The acreage subject to development pressure was then calculated for each watershed and divided by the acreage of the watershed. This "development pressure per unit area" was then used to assign a value from low to high.

Map 11 combines the results of the index of Ability to Produce Clean Water, surface drinking water consumers served, percent private forest land, and housing conversion pressure to highlight environmentally important water supply protection areas that are at the highest risk for future development. Areas that ranked high are near the major cities in the Northeastern United States. Many local water supplies were established "just outside of town," and now development is encroaching upon them. In general the highest ranking watersheds in the western half of the study area fell well below those in the eastern half, with the highest ranked watersheds in northern Minnesota, northern Wisconsin, northern Michigan and the Upper Peninsula, and southern and eastern Missouri. The high scoring watersheds in the western half are near major cities or metropolitan areas, including Minneapolis – St. Paul, Lansing, Jefferson City, and St. Louis.

In general, areas scoring highest for risk of future development pressure ran along the eastern seaboard, from eastern Pennsylvania to southern Maine. Watersheds that scored highest are in southern Maine, eastern New Hampshire, central Massachusetts, and northeastern Pennsylvania. High-scoring watersheds were also found in southern Ohio, western West Virginia, northern New Jersey, southeastern New York, Rhode Island, central Massachusetts, and northern Vermont.



Map 11: *Development pressure on forests and drinking water supplies, watershed view.* *Watersheds with the highest scores and the highest risk of future development are near major cities and metropolitan areas.*

Case Study—High-Scoring Watershed

Merrimack River, Manchester, NH

Watershed Score for Step 4: 36 out of 40

Watershed Rank: 4 of 540

The 43-square-mile Merrimack River watershed provides the drinking water supply for a number of small communities as well as the residents of the city of Manchester, NH. The watershed is primarily forested (about 70%) and typical of southern New England forest, with pine, hemlock, and northern hardwoods as dominant vegetation. Most streams are well buffered by forest and wetland.

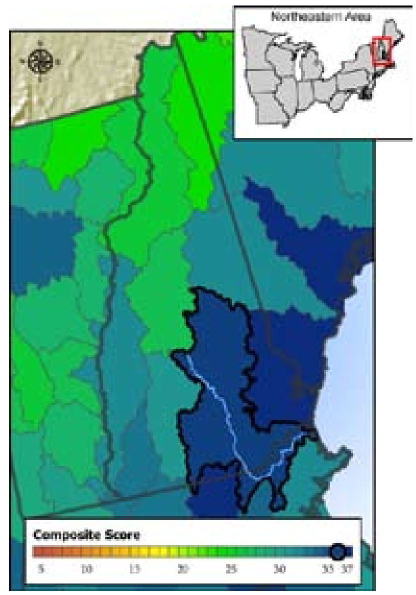
The Manchester Water Works, the State of New Hampshire's largest water utility, manages the Merrimack River intake and is responsible for providing drinking water to the City of Manchester and portions of Auburn, Bedford, Derry, Goffstown, Hooksett, and Londonderry. Located adjacent to Lake Massabesic, the Manchester Water Treatment Plant treats the water before it is distributed to homes and industries. The plant presently delivers in excess of 17.75 million gallons per day (MGD) to approximately 159,000 consumers in the greater Manchester area.

This watershed was one of the highest scoring watersheds in steps 3 and 4 of the analysis. Compared with other watersheds in the study area, this watershed had a very high ability to produce clean water because it is has such a high percent of forest; and the forests around the drinking water supplies are mainly privately owned and at great risk of development pressure.

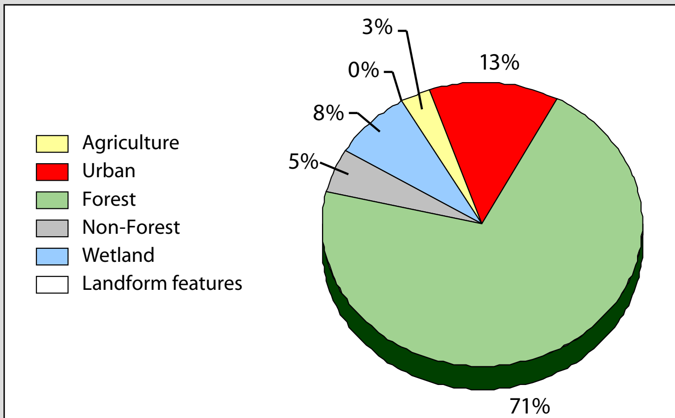
Watershed management in the source water watershed includes an active forestry program. Under the direction of a professional forester, the Manchester Water Works annually harvests about 500,000 board feet of timber. The purpose of this program is to develop the best tree cover for the forest environment and promote controlled water retention and runoff.

The Manchester area is growing substantially. The Manchester Water Treatment Plant purchased 8,000 acres, or about 3 percent of the watershed, to protect source water quality; however, the remainder of watershed forests remain privately owned. Although better-than-average water would be expected, the Manchester water plant has reported declining water quality. In recent years, the per unit water treatment cost increased from $53.26/MGD to $82.50/MGD.

www.manchesternh.gov/website/Departments/WaterWorks/WaterSupply/tabid/419/Default.aspx



Step 4 results show where development pressure on important private forest is greatest in the Merrimack River watershed, a high-scoring watershed.



Land use is primarily forest in the Merrimack River Watershed, a high-scoring watershed.

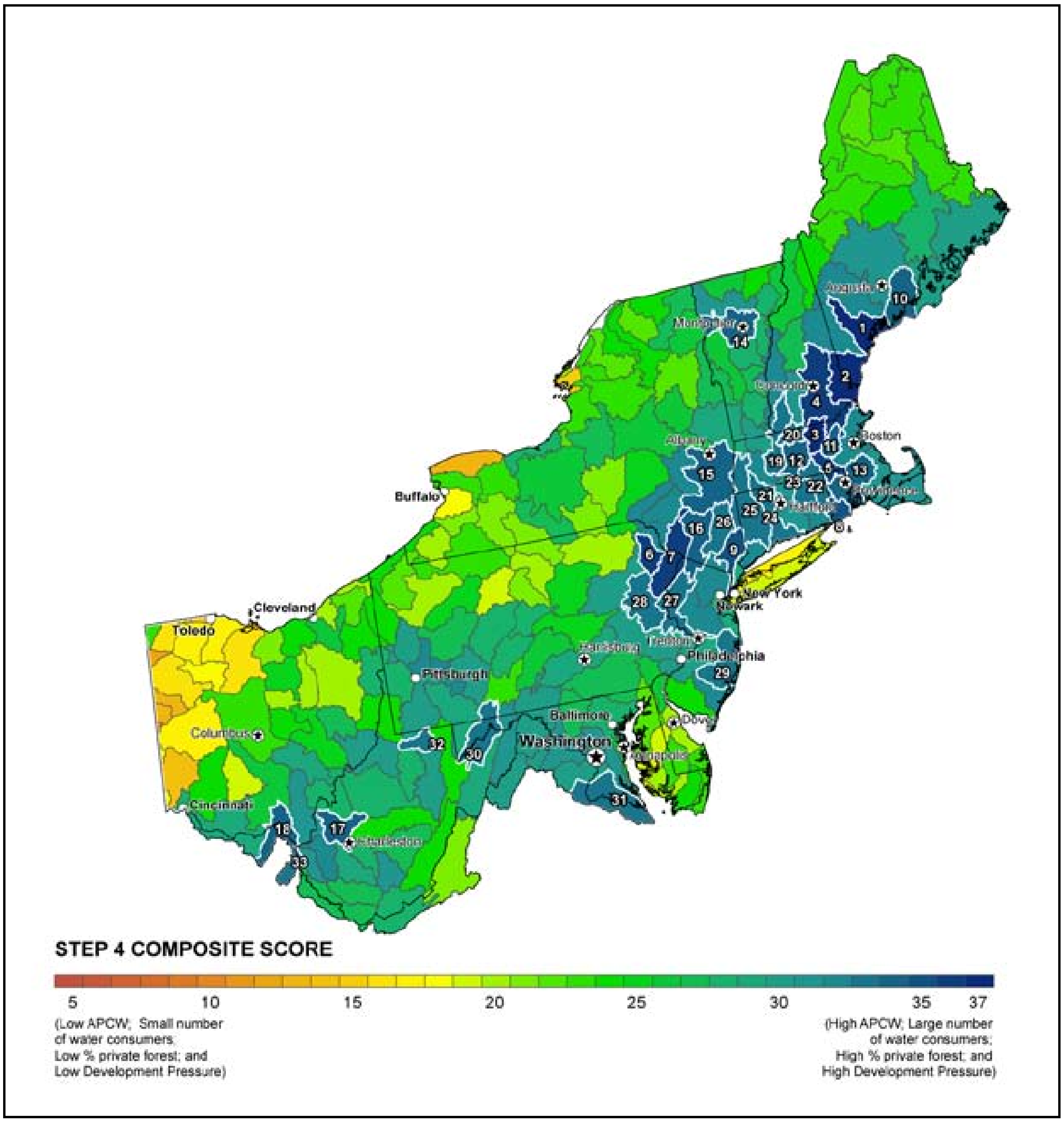
At 110 miles in length, the Merrimack River is an important regional focus in New Hampshire and Massachusetts. It flows through Manchester, the largest city in New Hampshire, and provides drinking water to the city of Nashua and surrounding towns. Photo by William Frament, U.S. Forest Service.

Top ranking watersheds—Eastern portion of the study area

The study area was divided into an eastern and western component for ease of discussion and to more easily view the geographic distribution of priority watersheds.

In the Northeast, many city water supplies were established "just outside of town," and new development is encroaching upon them. A recent study in New Hampshire showed that lands contributing to water supply made up approximately 10 percent of the State, while 75 percent of the population and most major communities relied on these lands for drinking water. The study also found, however, that these lands were four times more likely to be developed than other forest land in the State as a whole, and only 12 percent of these critical areas were permanently protected (Society for the Protection of New Hampshire Forests 1998).

Not surprisingly, those watersheds containing substantial existing forest lands and rapidly expanding towns and cities received the highest ranking. For example, the Presumpscot watershed includes the rapidly growing city of Portland, ME, while the Nashua and Merrimack watersheds are rapidly developing for commuters to Boston, MA. It is in the eastern portion of the study area along the Interstate Highway 95 corridor, where drinking water watersheds are subject to the greatest pressure.



Map 12: *Development pressure on private forests and drinking water supplies in the eastern portion of the study area, watershed view.* *In the eastern portion of the study area, forested water supply watersheds subject to the greatest development pressure are along the Interstate Highway 95 corridor. See Table 9 for more information about each watershed*

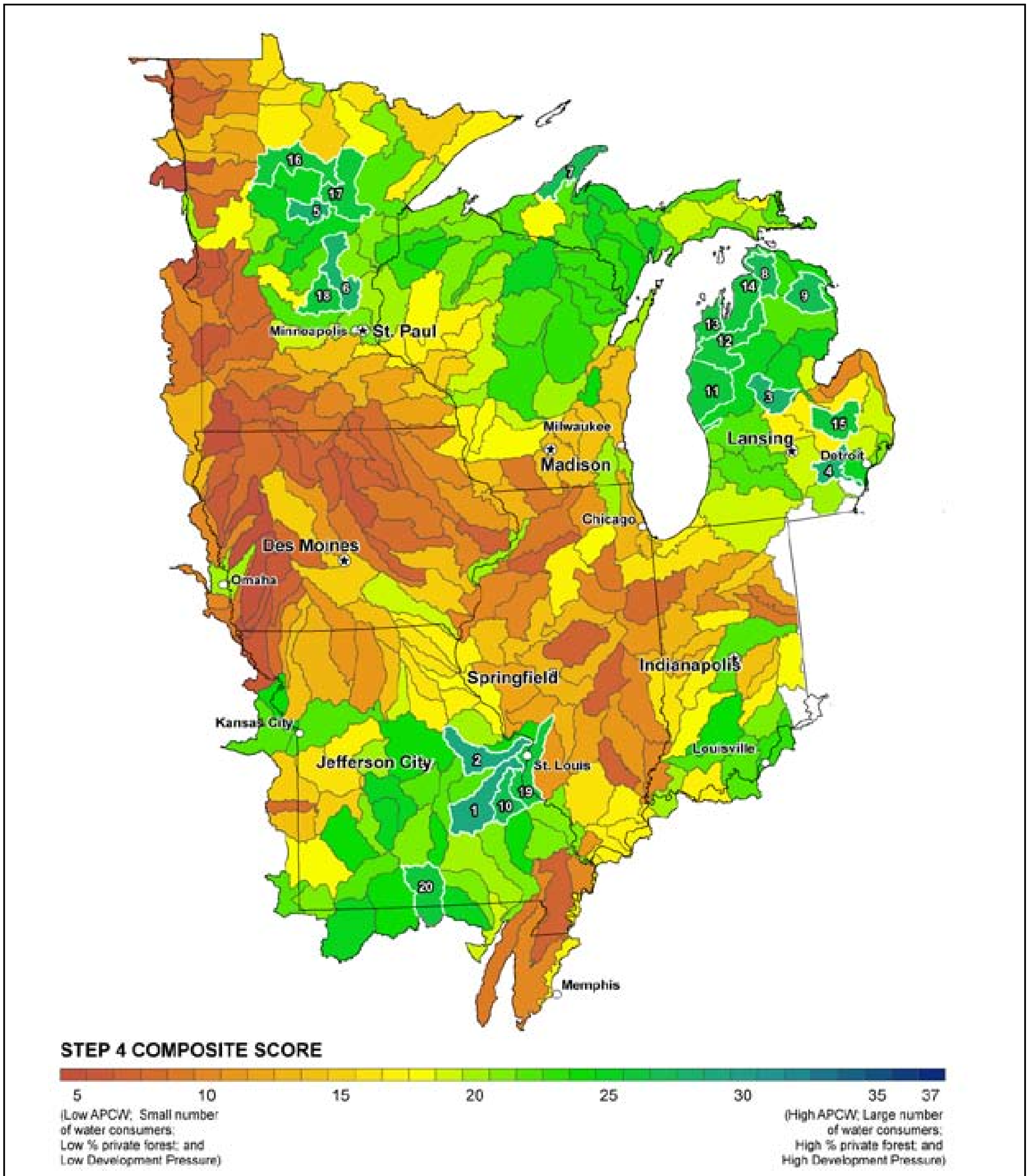
Table 9: Watersheds in the eastern portion of the study area with the greatest development pressure on private forests important for drinking water supply, by label in map 12 and composite score.

Label in map 12	Composite score	Watershed	HUC	State
1	37	Presumpscot	01060001	ME
2	37	Piscataqua-Salmon Falls	01060003	ME NH MA
3	37	Nashua	01070004	MA NH
4	36	Merrimack	01070002	MA NH
5	36	Blackstone	01090003	MA RI
6	36	Lackawaxen	02040103	PA
7	36	Middle Delaware-Mongaup-Brodhead	02040104	NJ NY PA
8	35	Pawcatuck-Wood	01090005	RI CT
9	35	Lower Hudson	02030101	CT NJ NY
10	34	St. George-Sheepscot	01050003	ME
11	34	Concord	01070005	MA
12	34	Chicopee	01080204	MA
13	34	Narragansett	01090004	MA RI
14	34	Winooski	02010003	VT NY
15	34	Middle Hudson	02020006	CT MA NY
16	34	Rondout	02020007	NJ NY
17	34	Lower Kanawha	05050008	WV
18	34	Little Scioto-Tygarts	05090103	KY OH WV
19	33	Middle Connecticut	01080201	MA NH VT
20	33	Miller	01080202	MA NH
21	33	Farmington	01080207	CT MA
22	33	Quinebaug	01100001	CT MA RI
23	33	Shetucket	01100002	CT MA
24	33	Quinnipiac	01100004	CT
25	33	Housatonic	01100005	CT MA NY
26	33	Hudson-Wappinger	02020008	NY
27	33	Middle Delaware-Musconetcong	02040105	NJ PA
28	33	Lehigh	02040106	PA
29	33	Mullica-Toms	02040301	NJ
30	33	North Branch Potomac	02070002	MD PA WV
31	33	Lower Potomac	02070011	MD VA
32	33	Upper Monongahela	05020003	PA WV
33	33	Big Sandy	05070204	KY WV

Top ranking watersheds—Western portion of the study area

Like the Step 3 analysis results, watersheds in the western portion of the study area rank lower overall than watersheds in the eastern portion, and for many of the same reasons. However, another factor in these lower rankings is the presence of less private forest land and less potential for development and impact on watersheds.

Conversely, these same conditions make it easier to identify and target those areas that are high priority in the western part of the study area. Three distinct regions stand out: the watersheds in Missouri between the growth centers of St. Louis and Jefferson City, the growing retirement and recreation-based communities along the upper portion of Lake Michigan and the suburbs of Detroit, and the "white collar" communities north of Minneapolis – St. Paul. All three regions provide challenges for future protection of water supplies. Although not ranked in the top 20, northeastern Wisconsin stands out clearly as a regional priority as well.



Map 13: ***Development pressure on private forests and drinking water supplies in the western portion of the study area, watershed view.*** *Less private forest land in the western portion of the study area means there is less development pressure on drinking water supply watersheds than in the eastern portion. See Table 10 for more information about individual watersheds.*

Table 10: Watersheds in the western portion of the study area with the greatest development pressure on private forests important for drinking water supply, by label in map 13 and composite score.

Label in map 13	Composite score	Watershed	HUC	State
1	29	Meramec	07140102	MO
2	29	Lower Missouri	10300200	MO
3	28	Pine	04080202	MI
4	28	Huron	04090005	MI
5	28	Pine	07010105	MN
6	28	Rum	07010207	MN
7	27	Keweenaw Peninsula	04020103	MI
8	27	Cheboygan	04070004	MI
9	27	Thunder Bay	04070006	MI
10	27	Big	07140104	MO
11	26	Pere Marquette-White	04060101	MI
12	26	Manistee	04060103	MI
13	26	Betsie-Platte	04060104	MI
14	26	Boardman-Charlevoix	04060105	MI
15	26	Flint	04080204	MI
16	26	Mississippi Headwaters	07010101	MN
17	26	Prairie-Willow	07010103	MN
18	26	Clearwater-Elk	07010203	MN
19	26	Cahokia-Joachim	07140101	IL MO
20	26	North Fork White	11010006	AR MO

SUMMARY OF RESULTS

Water, in all its uses and permutations, is by far the most valuable commodity that comes from the forest land that we manage, assist others to manage, and/or regulate.

–National Association of State Foresters Policy Statement, 2004

The results of this analysis confirm that forests are critically important to the supply of clean drinking water in the Northeast and Midwest. Forests protect the reservoirs and water supplies for more than 52 million people in over 1,600 drinking water supplies (U.S. Department of Agriculture, Forest Service 2005). The results provide a foundation on which protection and management strategies for water supply systems can be built.

Specifically, the results describe the magnitude and scope of forest-dependent drinking water supplies and quantify the dependence of the population on forests in these watersheds. The maps identify large-scale watersheds where strategic action and partnerships are likely needed to reduce the threat of land use change and to increase forest protection. The maps also show areas where forest management strategies aimed specifically at maintaining or enhancing the quality, quantity, and timing of water flow may be beneficial.

Of the 540 eight-digit watersheds in the Northeast and Midwest, 329 of them are surface water watersheds. Just 78 of these watersheds supply the drinking water for nearly 38 million people. The forests in these drinking water supply watersheds are overwhelmingly in private ownership and are being converted to other uses at an estimated rate of 350 acres per day. This rate of loss could increase to as much as 900 acres per day by 2030. Growth projections suggest that as many as 12 million acres of private forest land in these States may be converted to other uses by 2030.

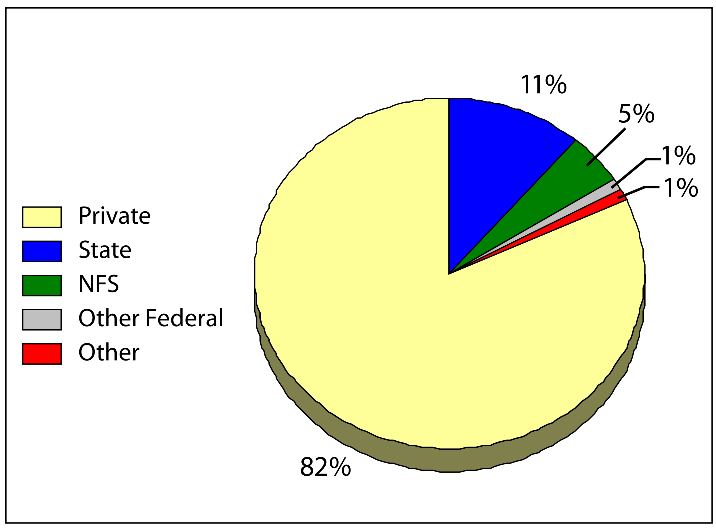


Figure 4: *Forest land ownerships in source water watersheds in the Northeast and Midwest.*

Table 11. Forest land ownership in the Northeast and Midwest, by number of surface water consumers.

Type and number of surface water consumers in the watershed	Type of land ownership (percent)				
	Private	State	National Forest System	Other Federal	Other*
No public surface water consumers	70	16	9	1	4
Small water supply systems (25 – 100,000 consumers)	80	12	6	1	1
Medium-sized water supply systems (100,001 – 1,000,000 consumers)	87	9	2	1	1
Large water supply systems (>1,000,000 consumers)	87	11	0	1	2

* Other ownerships include tribal, local, county, private-protected, joint, and unknown.

This analysis also shows significant differences between watersheds that supply drinking water. Water supply systems in the eastern half of the study area are more likely to be dominated by a dependence on surface water of high existing quality, using limited chemical treatment, and located in smaller forested watersheds—often with more numerous intakes. Water supply systems in the western half of the study area are more likely to use groundwater or be of lower existing water quality due to intense agricultural land use. These water supplies are also much more likely to draw from large rivers or lakes and rely upon extensive treatment to meet drinking water standards.

For every water supply system, there is someone who oversees it and a managing or governing entity who makes the decisions that affect its operation and its future. Throughout the study area, there is great diversity in the amount of oversight and available expertise. Many water supply systems are very small—serving only 500–3,500 people with few or no dedicated technical staff. Larger systems serving 50,000 or more may have engineers, foresters, consultants, and work crews on staff. In each case, however, the protection and management of forests play a role in the central mission—to provide reliable safe drinking water.

This analysis highlights the need to address a number of issues that water suppliers face related to protection and management of water supply systems. The issues include—

- Conservation of forest land
- Sustainable management of forests
- Understanding the forest-to-faucet connection by consumers and decisionmakers
- Appreciation of the actual cost of clean drinking water
- Communication between water providers and water consumers
- Availability of forest information and data to water providers

Figure 5: *Forest shelters this high-quality stream in Maryland. Photo by Al Todd.*

CLOSING COMMENTS

The forest is connected to the faucet: the cleanest water flows from healthy forested watersheds (Dissmeyer 2000). A watershed protection forest provides services like filtering air and water, reducing floods and erosion, sustaining stream flows and aquatic species, ensuring watershed stability and resilience, and absorbing rain and refilling groundwater aquifers. Maintaining these watershed services is essential.

Aside from the economic value of forest products like wood and paper, if forests fall into poor health or are converted to other uses, society has to invest billions in technological alternatives to replace the natural ecosystem services that the forests provided essentially for free.

The degradation of water supplies and widespread flooding and erosion, in large degree, inspired the creation of the Forest Service a century ago, along with the birth of the conservation era. When President Theodore Roosevelt and Gifford Pinchot, the first Chief of the Forest Service, set up a system of National Forests, it was primarily for "securing favorable conditions of water flows." Pinchot and Federal policymakers of the time were most concerned about preserving the forests that sustained the function of watersheds. In his Primer on Forestry, Pinchot (1903) wrote,

> *A forest, large or small, may render its service in many ways. It may reach its highest usefulness by standing as a safeguard against floods, winds, snow slides, or especially against the need of water in the streams.*

Abundant, clean drinking water is a precious resource for which there is no substitute. People can look for alternatives sources of energy, or change their diets to adjust to new sources of food. Without enough water, however, people must reduce their water use, find more water, or move. The United States has enjoyed an abundance of clean water, accessible to all of its citizens; however, drinking water scarcity is a growing concern. With projections of increasing U.S. population, competition for water is expected to grow. Water shortages, worsened by increasing demand, are becoming

A Watershed Protection Forest Is …

Based on a centuries-old concept in European and North American forestry

A living filter that protects aquatic ecosystems, drinking water supplies, and human health

Comprised of layers (overstory, midstory, and regeneration) with diverse species and ages

Growing vigorously and assimilating nutrients and sequestering carbon

Critical in protecting areas, such as riparian zones and steep slopes

Deliberately patterned across the landscape to be resistant to and resilient after natural disturbances (wildfire, storms, insects, and diseases)

Monitored to inform adaptive management

commonplace even in the humid eastern states. Climate change and its potential effects on water quantity, quality, and timing add a serious and complicated challenge to already perplexing water issues.

For natural resource agencies, a renewed focus on forests and their connection to clean and abundant water will be critical. The Forest Service—in partnership with State and local governments, nonprofits, and private landowners—has a shared responsibility to care not just for the land but for the nation's liquid assets as well.

Forested watersheds in the study area provide clean water that fills rivers, streams, lakes, and wetlands, sustains fisheries, and flows from faucets of homes and businesses. Water may be the most valuable product produced by public and private forest lands.

For more information on watershed forestry, including projects and tools linking forestry and clean drinking water, go to these Web sites:

- Northeastern Area State and Private Forestry's watershed Web site: www.na.fs.fed.us/watershed/
- Forest-to-Faucet Partnership's Web site: www.wetpartnership.org/

APPENDIX A: National Forest Lands Important for Drinking Water Supply

Contents

Tables

Table A-1: Forest land ownerships in the 65 source water watersheds containing National Forest System (NFS) land in the Northeast and Midwest, by number of surface water consumers..... 38

Table A-2: National Forests and the top 50 percent of watersheds important for drinking water supply in the eastern portion of the study area, by label in map A-2 and composite score 39

Table A-3: National Forests and the top 50 percent of watersheds important for drinking water supply in the western portion of the study area, by label in map A-3 and composite score 41

Figure

Figure A-1: Overall percentage of all forest land ownerships in the 65 source water watersheds that contain National Forest System (NFS) lands in the Northeast and Midwest 38

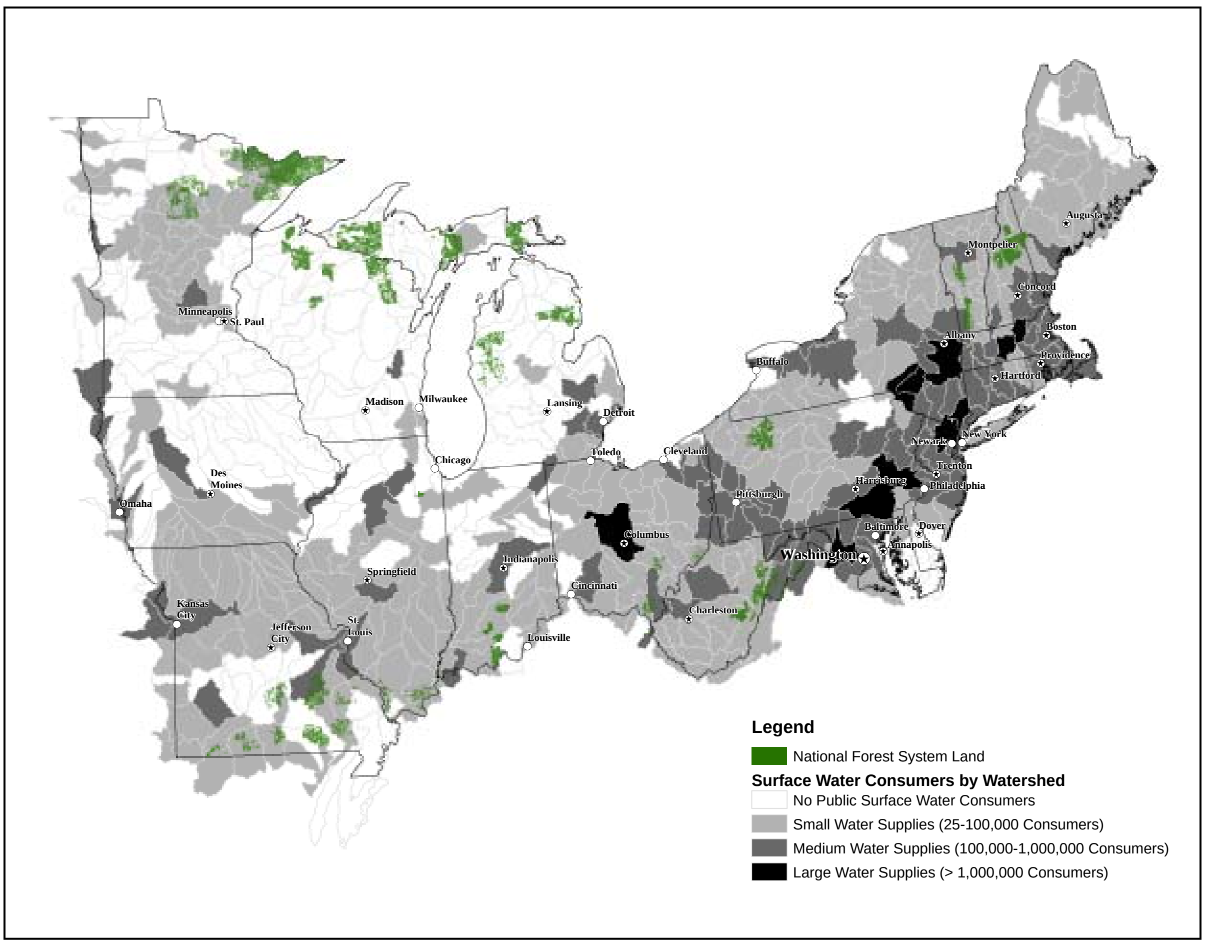
Maps

Map A-1: National Forests and important watersheds. National Forest System lands are near water supply systems that serve large numbers of consumers in the Northeast and Midwest..........37

Map A-2: National Forests and watersheds important for drinking water supply, eastern portion of the study area, watershed view. In the eastern portion of the study area, watersheds in National Forests scored moderate to high in their importance for drinking water supply. See Table A-2 for more information about individual watersheds. 39

Map A-3: National Forests and watersheds important for drinking water supply, western portion of the study area, watershed view. In the western portion of the study area, all watersheds that scored high in importance for drinking water supply contain some National Forest lands. See Table A-3 for more information about individual watersheds. 40

The 1897 Organic Administrative Act, which authorized the establishment of much of the National Forest System, said that the forest reserves were to protect and enhance water supplies, reduce flooding, secure favorable conditions of water flow, protect the forest from fires and other depredations, and provide a continuous supply of timber. By 1915, National Forests in the West had been established in much the form they retain today. At the time, few Federal forests were designated in the East because of the lack of public domain. Demand for eastern National Forests resulted in the passage of the 1911 Weeks Act, authorizing the acquisition of Federal lands to protect the watersheds of navigable streams. From 1911 to 1945, about 24 million acres of depleted farms, stumpfields, and burned woodlands were incorporated into the National Forest System. Map A-1 shows the National Forest System lands in the Northeast and Midwest in relation to source water watersheds and water consumers served.



Map A-1: *National Forests and important watersheds.* *National Forest System lands are near water supply systems that serve large numbers of consumers in the Northeast and Midwest.*

Maintaining supplies of clean drinking water and protecting watersheds from degradation are major reasons for management of the National Forests. Another notable issue regarding management is whether municipal watersheds should be placed under active or passive management in order to sustain supplies of high quality water. While natural resource professionals agree that active management can be compatible with or even desirable in sustaining water supplies, many people also believe that, in the interest of water quality, forests in watersheds should not be altered in any way.

Another issue is development and loss of open space. Although the vast majority of National Forest lands are unlikely to be converted to any form of developed uses, these scenic protected lands also attract development to their borders. In the Northeast and Midwest, for example, as shown in Figure A-1, the majority of forest land ownerships in the 65 source water watersheds that contain National Forest System lands are privately owned and subject to land use conversion. Moreover, the vast majority of drinking water consumers are supplied by privately owned lands, in comparison to the small percentage supplied by State and Federal lands (Table A-1). However, development adjacent to National Forest boundaries is still a serious concern in many parts of the country, including the northeast. These more intensive land uses on the fringe of public lands increase the risks for wildlife, contribute to the spread of invasive plants and pests, reduce access to recreation, fragment habitat, and impact water quality.

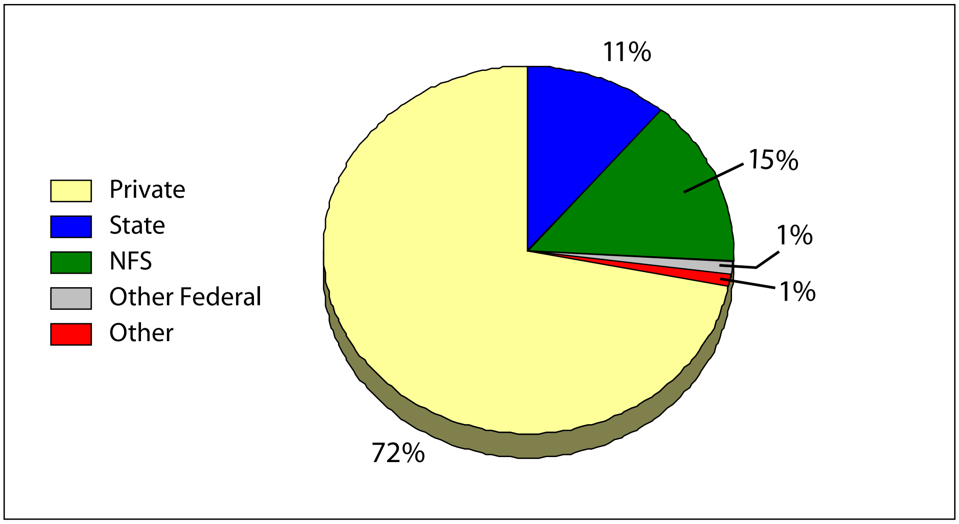


***Figure A-1**: Overall percentage of all forest land ownerships in the 65 source water watersheds that contain National Forest System (NFS) lands in the Northeast and Midwest.*

Table A-1. Forest land ownerships in the 65 source water watersheds containing National Forest System (NFS) land in the Northeast and Midwest, by number of surface water consumers (percent)

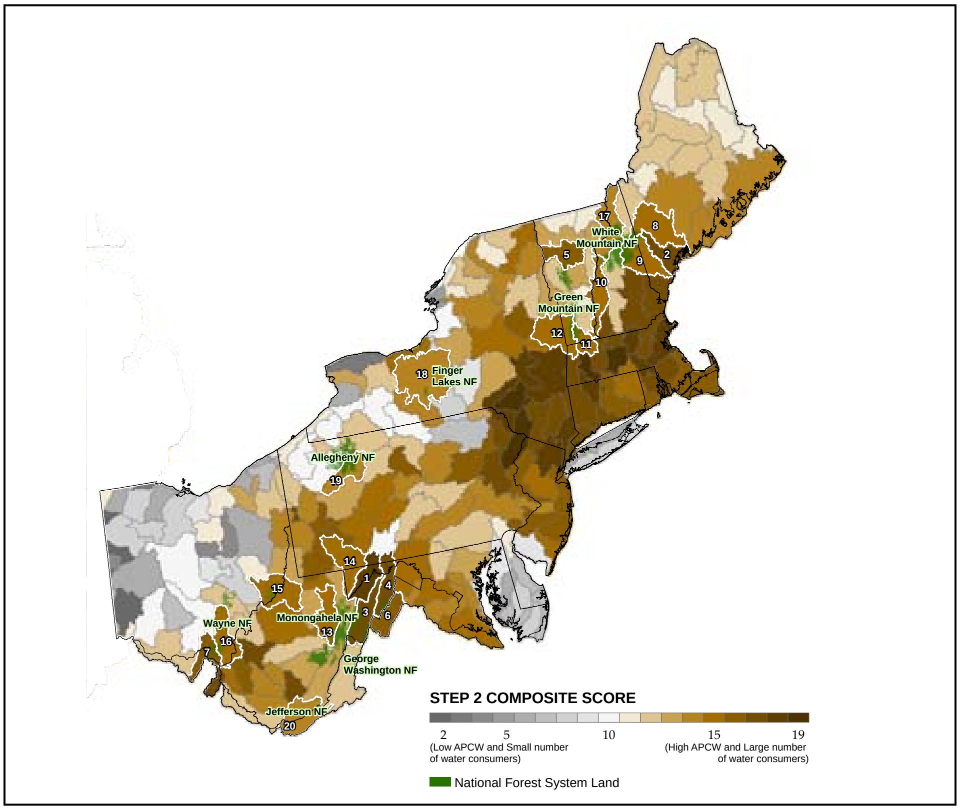
Number of surface water consumers in the watershed	Private	State	NFS	Other Federal	Other*
Small water supplies (25 –100,000 consumers)	84%	8%	7%	0%	1%
Medium-sized water supplies (100,000 – 1,000,000 consumers)	70%	12%	17%	1%	1%
Large water supplies (>1,000,000 consumers)	*There are no large water supply systems in watersheds that contain National Forest land.*				

*Other ownerships include tribal, local, county, private-protected, joint, and unknown.

Maps A-2 and A-3 show that the study area was split into eastern and western halves, displaying the National Forest boundaries overlaid on Step 2 analysis maps. In other words, these maps illustrate the relationship of National Forest lands and the relative importance of water supplies in terms of the ability to produce clean water for the greatest number of water consumers.

Overall, in the eastern portion of the study area, National Forests fall within the moderate- to high-scoring watersheds (Map A-2). In the western portion of the study area, the Chippewa and Mark Twain National Forests coincide with the highest scoring watersheds, and in general, all of the highest scoring watershed areas contain some National Forest lands (Map A-3).

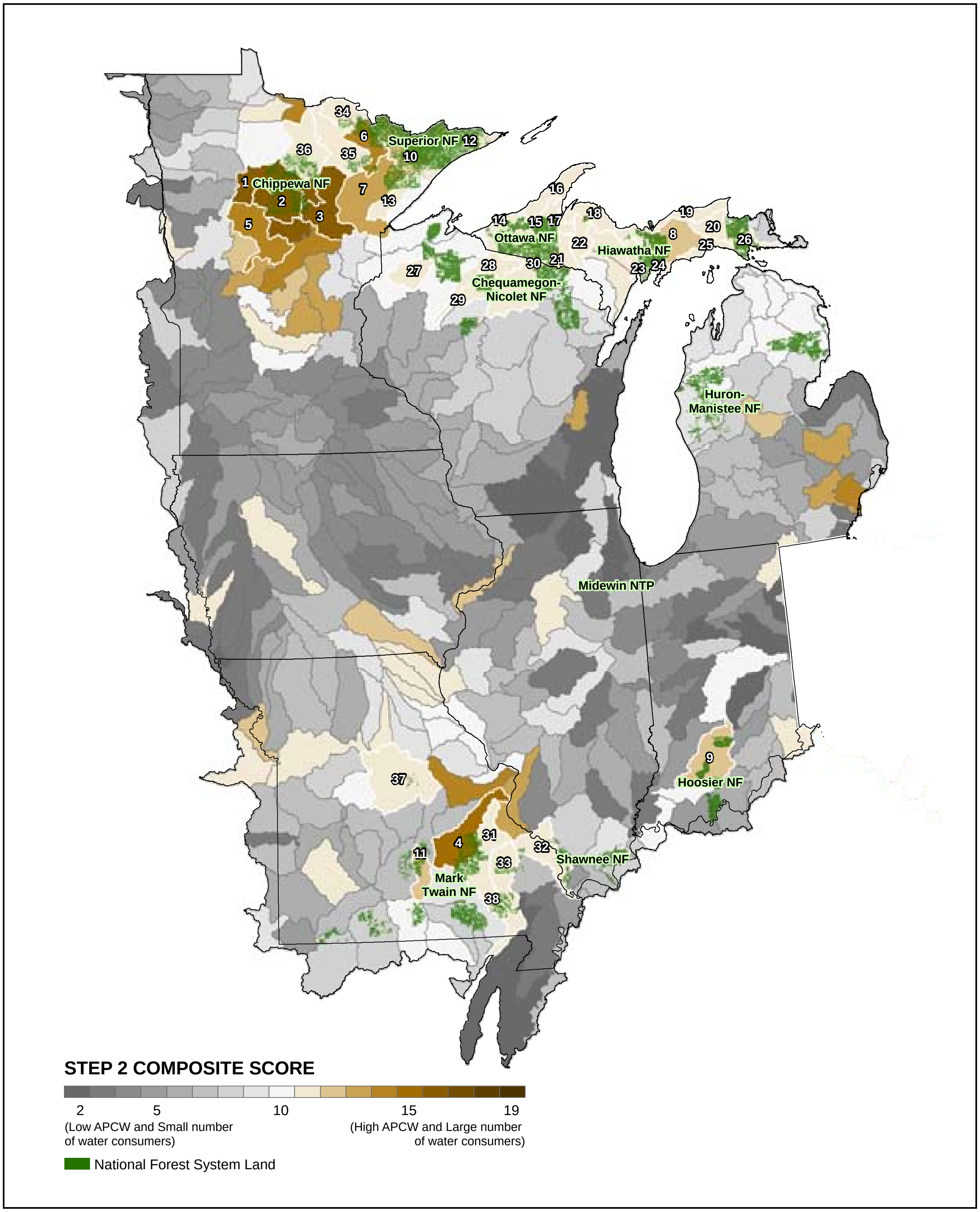
These maps help to highlight areas where National Forests are important in surface drinking water supplies and areas where this relationship is reinforced by currently unprotected forested areas. These maps also highlight areas where the collaborative management of public and private lands may benefit water consumers.



Map A-2: ***National Forests and watersheds important for drinking water supply, eastern portion of the study area, watershed view.*** *In the eastern portion of the study area, watersheds in National Forests scored moderate to high in their importance for drinking water supply. See Table A-2 for information about individual watersheds.*

Table A-2: National Forests and the top 50 percent of watersheds important for drinking water supply in the eastern portion of the study area, by label in map A-2 and composite score.

Label in Map A-3	Step 2 Composite Score	Hydrologic Unit Code	Watershed	Land Acreage	National Forest Acreage	Percent of watershed in National Forest	NFS	State(s)
1	18	02070002	North Branch Potomac	853,706	3	<1.0	Monongahela	MD PA WV
2	17	01060001	Presumpscot	635,384	8,578	1.4	White Mountain	ME
3	17	02070001	South Branch Potomac	946,664	152,164	16.1	George Washington/ Monongahela	MD VA WV
4	17	02070003	Cacapon-Town	766,584	51,778	6.8	George Washington	MD PA VA WV
5	16	02010003	Winooski	737,226	12,783	1.7	Green Mountain	VT NY
6	16	02070006	North Fork Shenandoah	655,235	3,068	<1.0	George Washington	VA WV
7	16	05090103	Little Scioto-Tygarts	637,369	54,370	8.5	Daniel Boone/Wayne	KY OH WV
8	15	01040002	Lower Androscoggin	1,264,856	60,660	4.8	White Mountain	ME NH
9	15	01060002	Saco	1,055,962	244,824	23.2	White Mountain	ME NH
10	15	01080104	Upper Connecticut-Mascoma	921,973	13,472	1.5	White Mountain	NH VT
11	15	01080203	Deerfield	416,335	67,705	16.3	Green Mountain	MA VT
12	15	02020003	Hudson-Hoosic	1,190,337	78,768	6.6	Green Mountain	MA NY VT
13	15	05020001	Tygart Valley	874,687	28,475	3.3	Monongahela	WV
14	15	05020006	Youghiogheny	1,121,664	6	<1.0	Monongahela	MD PA WV
15	15	05030201	Little Musringum-Middle Island	1,152,085	63,998	5.6	Wayne	OH WV
16	15	05090101	Raccoon-Symmes	920,885	54,337	5.9	Wayne	OH WV
17	14	01080101	Upper Connecticut	1,250,729	190,772	15.3	White Mountain	ME NH VT
18	14	04140201	Seneca	2,072,942	15,234	<1.0	Finger Lakes	NY
19	14	05010005	Clarion	797,893	132,875	16.7	Allegheny	PA
20	14	05050002	Middle New	1,067,967	1,366	<1.0	Jefferson	VA WV



Map A-3: *National Forests and watersheds important for drinking water supply, western portion of the study area, watershed view.* *In the western portion of the study area, all watersheds that scored high in importance for drinking water supply contain some National Forest lands. See Table A-3 for information about individual watersheds.*

Table A-3: National Forests and the top 50 percent of watersheds important for drinking water supply in the western portion of the study area, by label in map A-3 and composite score.

Label in Map A-3	Step 2 Composite Score	Hydrologic Unit Code	Watershed	Land Acreage	National Forest Acreage	Percent of watershed in National Forest	NFS	State(s)
1	16	07010101	Mississippi Headwaters	1,087,518	239,048	22	Chippewa	MN
2	16	07010102	Leach Lake	707,800	199,108	28	Chippewa	MN
3	16	07010103	Prairie-Willow	1,241,431	44,988	4	Chippewa	MN
4	15	07140102	Meramec	1,365,884	174,876	13	Mark Twain	MO
5	14	07010106	Crow Wing	1,179,214	590	0.1	Chippewa	MN
6	14	09030002	Vermilion	585,030	183,885	31	Superior	MN
7	13	04010201	St. Louis	1,830,340	139,480	8	Superior	MN WI
8	12	04060106	Manistique	882,840	190,471	22	Hiawatha	MI
9	12	05120208	Lower East Fork White	1,276,450	189,773	15	Hoosier	IN
10	12	09030001	Rainy Headwaters	1,386,415	1,175,226	85	Superior	MN
11	12	10290202	Big Piney	481,091	89,001	18	Mark Twain	MO
12	11	04010101	Baptism-Brule	952,729	579,097	61	Superior	MN
13	11	04010202	Cloquet	486,460	65,275	13	Superior	MN
14	11	04020101	Black-Presque Isle	632,267	182,131	29	Ottawa	MI WI
15	11	04020102	Ontonagan	851,254	491,647	58	Ottawa	MI WI
16	11	04020103	Keweenaw Peninsula	683,841	7,126	1	Ottawa	MI
17	11	04020104	Sturgeon	452,263	120,164	27	Ottawa	MI
18	11	04020105	Dead-Kelsey	575,108	12,963	2	Ottawa	MI
19	11	04020201	Betsy-Chocolay	717,211	50,801	7	Hiawatha	MI
20	11	04020202	Tahquamenon	517,930	67,121	13	Hiawatha	MI
21	11	04030106	Brule	657,974	216,652	33	Chequamegon-Nicolet/Ottawa	MI WI
22	11	04030107	Michigamme	438,641	4,170	1	Ottawa	MI
23	11	04030111	Tacoosh-Whitefish	401,708	86,219	21	Hiawatha	MI
24	11	04030112	Fishdam-Sturgeon	349,846	160,860	46	Hiawatha	MI
25	11	04060107	Brevoort-Millecoquins	341,555	27,373	8	Hiawatha	MI
26	11	04070002	Carp-Pine	406,330	216,357	53	Hiawatha	MI
27	11	07030002	Namekagon	599,774	31,231	5	Chequamegon-Nicolet	WI
28	11	07050002	Flambeau	678,200	9,734	1	Chequamegon-Nicolet	MI WI
29	11	07050003	South Fork Flambeau	467,663	134,914	29	Chequamegon-Nicolet	WI
30	11	07070001	Upper Wisconsin	1,276,907	127,740	10	Chequamegon-Nicolet/Ottawa	MI WI
31	11	07140104	Big	616,759	33,751	5	Mark Twain	MO
32	11	07140105	Upper Mississippi-Cape Girardeau	1,026,466	56,516	6	Mark Twain/ Shawnee	IL MO
33	11	08020202	Upper St. Francis	820,394	110,996	14	Mark Twain	MO
34	11	09030003	Rainy Lake	477,779	48,796	10	Superior	MN
35	11	09030005	Little Fork	1,140,280	80,769	7	Superior	MN
36	11	09030006	Big Fork	1,234,864	181,169	15	Chippewa	MN
37	11	10300102	Lower Missouri-Moreau	2,136,106	15,352	1	Mark Twain	MO
38	11	11010007	Upper Black	1,214,146	225,267	19	Mark Twain	AR MO

APPENDIX B: Technical Information Regarding Analysis and Metadata

Contents

Introduction 44

Definitions 44

Analysis Area 45

Step 1: Calculate Ability to Produce Clean Water 46

- Forested land 47
- Agricultural land 49
- Riparian forest cover 50
- Road density 52
- Soil erodibility 53
- Housing density 54
- Ability to produce clean water (APCW) index by 30-m pixels 56
- Step 1 composite score: Mean APCW for watersheds 57

Step 2: Add Data on Drinking Water Consumers 58

- Step 1 composite score 58
- Surface drinking water consumers per unit area 59
- Step 2 composite score: Importance of watersheds for drinking water supply 61

Step 3: Add Data on Private Forest Land 62

- Step 2 composite score 62
- Private forest 62
- Step 3 composite score: Importance of watersheds with private forests for drinking water supply 65

Step 4: Add Data on Change in Housing Density 66

- Step 3 composite score 66
- Development pressure per unit area 66
- Step 4 composite score: Development pressure on private forests in watersheds important for drinking water supply 68

Tables

Table B-1: GIS overlay process to estimate Ability to Produce Clean Water (APCW) for eight-digit HUC watersheds in the 20-State study area........46

Table B-2: Prioritization method for Step 2 for eight-digit HUC watersheds in the 20-State study area........58

Table B-3: Prioritization method for Step 3 for eight-digit HUC watersheds in the 20-State study area........62

Table B-4: Prioritization method for Step 4 for eight-digit HUC watersheds in the 20-State study area........6

Introduction

The goal of the Forests, Water, and People analysis is to evaluate current and projected future conditions across the Northeast and Midwest in order to maximize the protection and enhancement of forests, drinking water supplies, public health, and aquatic ecosystems. The project involves compiling a GIS database using existing and available data to quantify the key connections between forests, land use, water, and people in the Northeastern United States. The database will permit evaluation and ranking of these connections and characteristics, to identify priority areas for forest conservation and restoration. Results are intended to help managers determine where their investments will have the greatest benefits.

This appendix is intended to serve as a technical guide to the Forests, Water, and People analysis for GIS professionals and researchers.

Definitions

Proclamation boundaries are identified in the proclamation that establishes the outer boundary within which a national forest or grassland could be established.

Administrative boundaries identify the specific lands actually owned by the Federal Government and managed by the national forest. Proclamation boundaries were used for this study because these are the only Forest Service boundary data available in a national-level database.

Private land was defined to include tribal, forest industry, and non-industrial private ownerships, excluding public lands and other private lands identified as protected through conservation easements.

Housing density is defined as the number of acres per housing unit.

Increased housing density was defined to mean shifts from rural to exurban or from rural or exurban to urban.

Rural is defined for this project as private land with greater than 20 acres per housing unit in the east (the 12 states in the study area that are east of but do not include Ohio, and including the Big Sandy watershed) and greater than 40 acres per housing unit in the west (the 8 states in the study area that are west of and include Ohio). Forest lands in this housing density can support timber, most wildlife, and water quality.

Exurban is defined for this project as private land with 5 – 20 acres per housing unit in the east (the 12 states in the study area that are east of but do not include Ohio, and including the Big Sandy watershed) and land with 5 – 40 acres per housing unit in the west (the 8 states in the study area that are west of and include Ohio) . Forest lands in this level of housing density can support many types of wildlife; however, commercial timber management is less likely.

Suburban is defined for this project as private land with 0.6 – 5 acres per housing unit. These lands are less likely to contribute to timber production, wildlife habitat, or water quality because of increased road density, infrastructure, and human population levels. Forest patches, however, are valued for their aesthetics, and noise abatement properties.

Urban is defined for this project as private land with less than 0.6 acre per housing unit. These lands are not likely to contribute to timber production, wildlife habitat, or water quality because of high road density, infrastructure, and human population levels.

Analysis Area

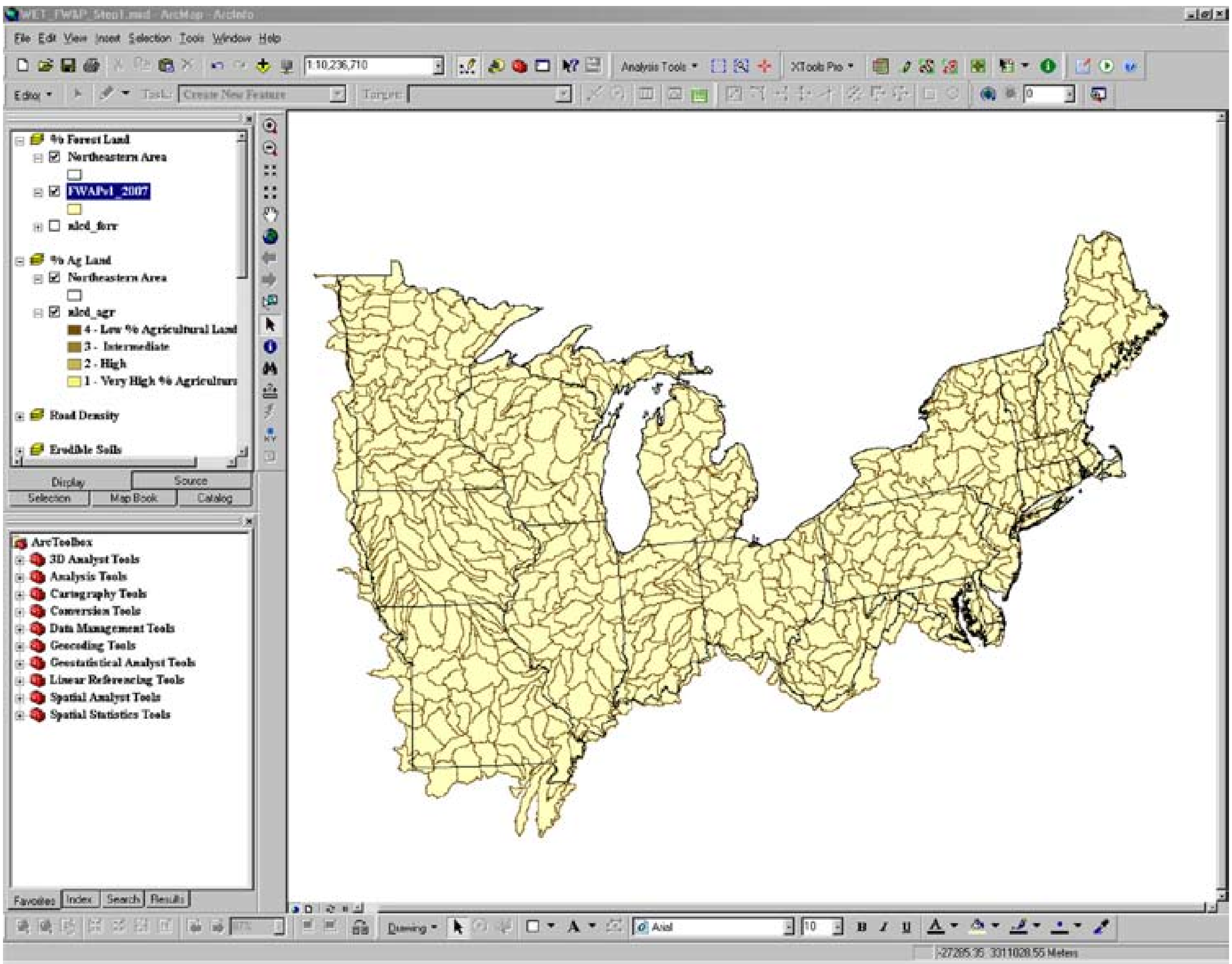
Data Source: U.S. Geological Survey. 1994. 1:250,000-scale hydrologic units of the United States. Open-File Report 94-0236. Reston, VA. http://water.usgs.gov/GIS/metadata/usgswrd/XML/huc250k.xml (August 10, 2007)

Description: This data set is based on the Hydrologic Unit Maps published by the U.S. Geological Survey Office of Water Data Coordination, together with the list descriptions and name of region, subregion, accounting units, and cataloging unit. The hydrologic units are encoded with an eight-digit number that indicates the hydrologic region (first two digits), hydrologic subregion (second two digits), accounting unit (third two digits), and cataloging unit (fourth two digits).

GIS Process:

1. All watersheds (HUCs) that touched the 20 states in the Northeastern United States were selected and a new polygon data layer, HUC_NA, was created. Note: Some of the HUCs only partially fall within the study area, however, for the purpose of this project, the hydrologic boundary was used rather than the administrative one. Watersheds that are considered water bodies (i.e., Great Lakes, Chesapeake Bay, and Delaware Bay) were eliminated from the final HUC data layer. A total of 540 eight-digit HUC watersheds resulted in the Analysis Area for this project.

Result: See following map.



Data projection

All data was projected into the following coordinate system prior to each of the four steps to maintain the best possible accuracy.

Projection: Albers Conical Equal Area
Standard Parallel: 29.500000
Standard Parallel: 45.500000
Longitude of Central Meridian: –96.000000
Latitude of Projection Origin: 23.000000
False Easting: 0.000000
False Northing: 0.000000
Horizontal Datum Name: North American Datum of 1983
Ellipsoid Name: Geodetic Reference System 80
Semi-major Axis: 6378137.000000
Denominator of Flattening Ratio: 298.257222

Step 1: Calculate Ability to Produce Clean Water

Step 1 characterized the biophysical conditions in each watershed. This characterization, the ability to produce clean water (APCW), is an index of water quality and watershed integrity based on six attributes: forest land, agricultural land, riparian forest cover, road density, soil erodibility, and housing density. The forest land, agricultural land, and riparian forest buffer data was summarized by watershed and converted to a 30-meter (30-m) spatial grid. The road density, soil erodibility, and housing density data were kept in their original 30-m grid format and not summarized by watershed. Each of the six attributes was scored from 1 to 4 (see Table 4 of the main report for more detail on the attribute scoring) based on scientifically accepted standards. Where standards or parameters were not available, the data was divided into quartiles.

The six attributes in step 1 were then summed, resulting in a value of 6 to 24 for each 30-m grid cell. To summarize the data by watershed, the values for all 30-m pixels in each watershed were averaged to produce a single score, with a minimum score of 6 and a maximum score of 24.

The APCW values were averaged to create a mean APCW for a watershed. This mean was divided into 10 quantiles, with the 1st quantile receiving a score of 10 (very high) and the 10th quantile receiving a score of 1 (low).

This step will generate a defensible and understandable analysis of current conditions. It also will highlight the watershed management challenges and opportunities on each site and across the entire region.

Table B-1: GIS overlay process to estimate ability to produce clean water (APCW) for eight-digit HUC watersheds in the 20-State study area.

Attribute	**Scoring for 30-meter grid cell**			
	Low (1 point)	**Moderate (2 points)**	**High (3 points)**	**Very High (4 points)**
Percent forest land (F)	0 – 24	25 – 49	50 – 75	>75
Percent agricultural land (A)	>30	21 – 30	10 – 20	<10
Percent riparian forest cover (R)	0 – 29	30 – 50	51 – 70	>70
Road density (D, quartiles)	75 – 100th percentile	50 – 74th percentile	25 – 49th percentile	0 – 24th percentile
Soil erodibility (S, k factor)	>0.34	0.28 – 0.34	0.2 – 0.28	0 – 0.2
Housing density (H, acres per housing unit in 2000)	< 0.6 acre/unit	0.6 – 5.0 acres/unit	5.0 – 20.0 acres/unit (east) 5.0 – 40.0 acres/unit (west)	> 20.0 acres/unit (east) > 40.0 acres/unit (west)
Total APCW	**F + A + R + D + S + H = APCW** Potential score 6 – 24			
Attribute	**Watershed Scoring**			
	Low (1 point)	**High/moderate (2-9 points)**		**High (10 points)**
Step 1 = Mean APCW for Watersheds	10th quantile	2nd – 9th quantile		1st quantile

Forested land

Data Source: U.S. Geological Survey (USGS). 1999. 1992 *National Land Cover Data*. Sioux Falls, SD.

http://eros.usgs.gov/products/landcover/nlcd.html. (August 10, 2007)

Description: Forested land data was extracted from the National Land Cover Data (NLCD,1992) with a spatial resolution of 30 meters. The NLCD is compiled from Landsat satellite TM imagery and supplemented by various ancillary data (where available). The analysis and interpretation of the satellite imagery was conducted using very large, sometimes multi-State image mosaics (i.e., up to 18 Landsat scenes). Using a relatively small number of aerial photographs for "ground truth," the thematic interpretations were necessarily conducted from a spatially broad perspective. Furthermore, the accuracy assessments (see below) correspond to "Federal regions" which are groupings of contiguous States. Thus, the reliability of the data is greatest at the State or multi-State level. The statistical accuracy of the data is known only for the region. The land cover data files are provided as a "Geo-TIFF" for each State.

GIS Process:

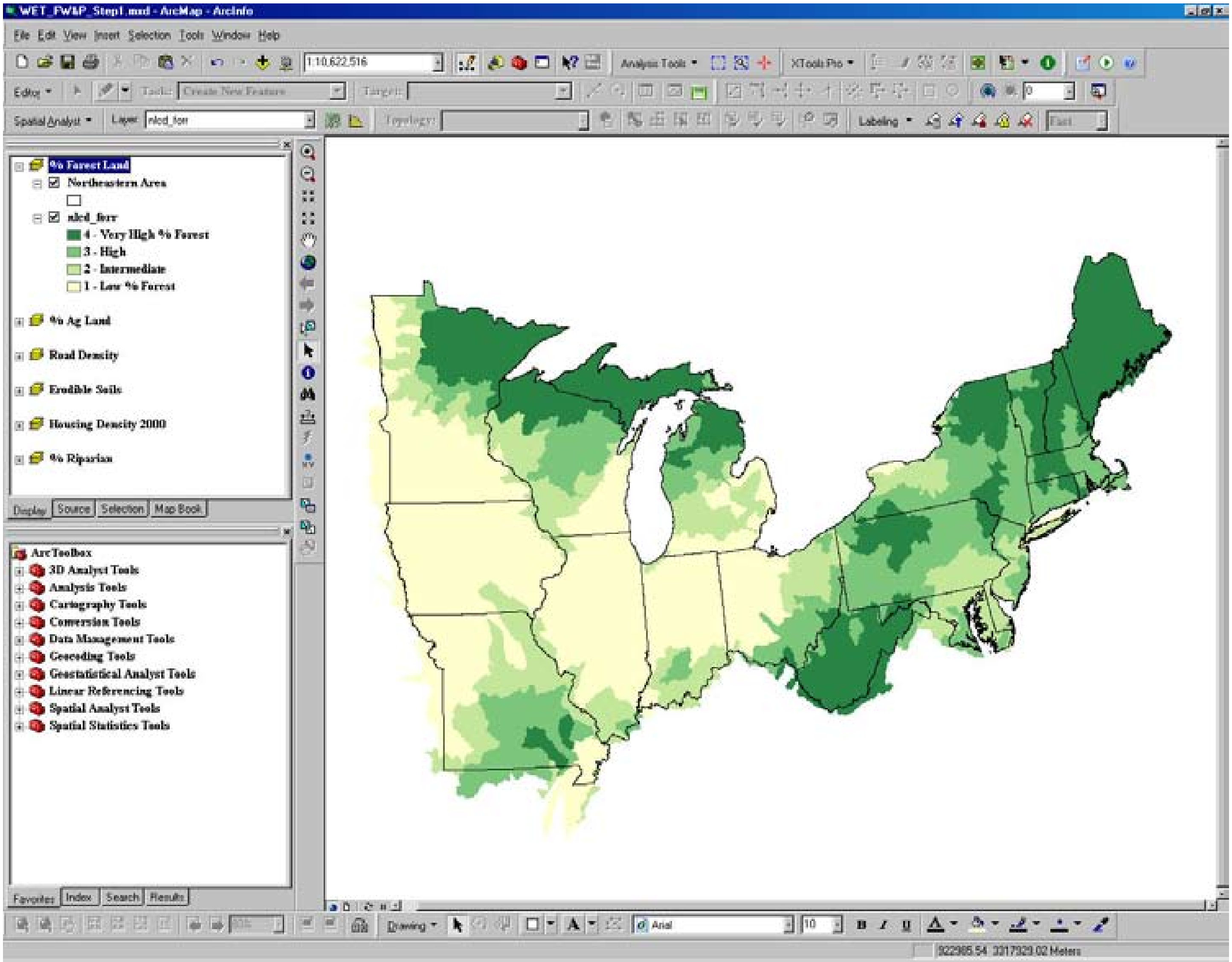
1. The raw, downloaded NLCD GeoTiffs were converted to GRID using ArcInfo workstation.
2. Once each state file was a GRID, all the GRIDs were merged to create a single GRID, nlcd92_huc.
3. Forested land was summarized using NLCD grid values 33 Transitional, 41 Deciduous Forest, 42 Evergreen Forest, 43 Mixed Forest, 51 Shrubland, 91 Woody Wetlands. The GRID was reclassified so all forested grid codes equaled "1" and all other grid codes equaled "0," nlcd_for.
4. Using the "Tabulate Areas" function, the acreage of forested land in each watershed was computed. The resulting table was then joined to the HUC_NA shapefile.
5. The percent of the watershed that is forested was calculated by dividing the acreage of forested land by the total watershed land acreage. The results were saved in the attribute field Per_FOR.
6. The percent forest was reclassified into the four categories summarized in Table B-1. The results were saved in the attribute field Per_FOR_R.

Excerpt 1 from Table B-1

Attribute	Scoring for 30-meter grid cell			
	Low (1 point)	Moderate (2 points)	High (3 points)	Very High (4 points)
Percent forest land (F)	0 – 24	25 – 49	50 – 75	>75

7. The HUC_NA shapefile was converted to a raster data set with a pixel size of 30 m and the value field set to the attribute Per_FOR_R.

Result: See following map.


WET_FW&P_Step1.mxd - ArcMap - ArcInfo
File Edit View Insert Selection Tools Window Help
1:10,622,516
Analysis Tools
XTools Pro
Editor
Task: Create New Feature
Target:
Spatial Analyst
Layer: nlcd_forr
Topology:
Labeling
% Forest Land
Northeastern Area
nlcd_forr
4 - Very High % Forest
3 - High
2 - Intermediate
1 - Low % Forest
% Ag Land
Road Density
Erodible Soils
Housing Density 2000
% Riparian
Display Source Selection Map Book
ArcToolbox
3D Analyst Tools
Analysis Tools
Cartography Tools
Conversion Tools
Data Management Tools
Geocoding Tools
Geostatistical Analyst Tools
Linear Referencing Tools
Spatial Analyst Tools
Spatial Statistics Tools
Favorites Index Search Results
Drawing
Arial
10
922985.54 3317929.02 Meters

Agricultural land

Data Source: Same as for percent forested land.

Description: Same as for percent forested land.

GIS Process:

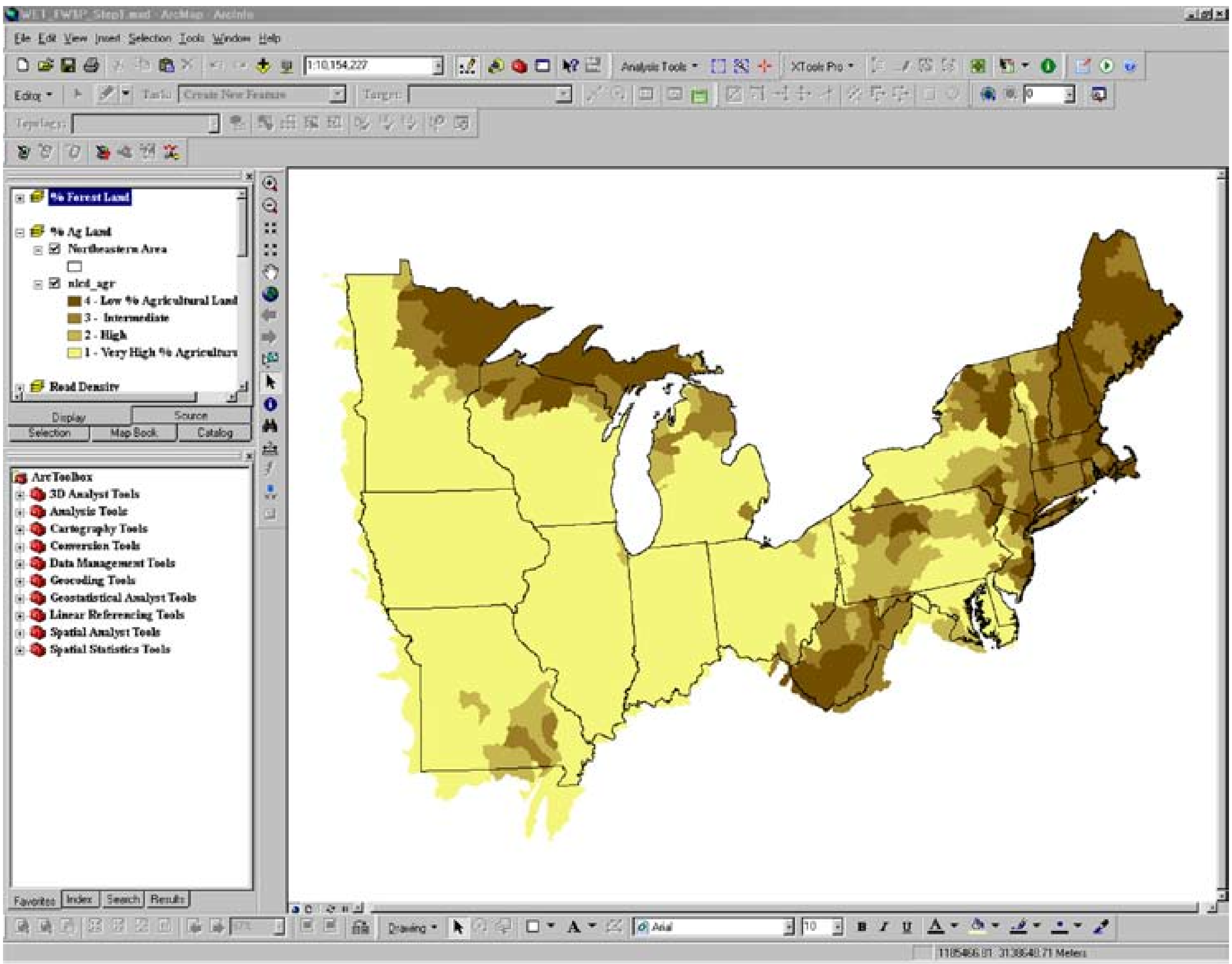
1. The raw, downloaded NLCD GeoTiffs were converted to GRID using ArcInfo workstation.
2. Once each state file was a GRID, all the GRIDs were merged to create a single GRID, nlcd92_huc.
3. Agricultural Land was summarized using grid values 61 Orchard/Vineyard; 71 Grasslands/Herbaceous; 81 Pasture/Hay; 82 Row Crops; 83 Small Grains; 84 Fallow; 85 Urban/Recreational Grasses. The GRID was reclassified so all agricultural land grid codes equaled "1" and all other grid codes equaled "0," nlcd_ag.
4. Using the "Tabulate Areas" function, the acreage of agricultural land in each watershed was computed. The resulting table was then joined to the HUC_NA shapefile.
5. The percent of the watershed that is agricultural land was calculated by dividing the acreage of agricultural land by the total watershed land acreage. The results were saved in the attribute field Per_AG.
6. The percent agricultural land was reclassified into the four categories summarized in Table 1. The results were saved in the attribute field Per_A

Excerpt 2 from Table B-1

Attribute	Scoring for 30-meter grid cell			
	Low (1 point)	Moderate (2 points)	High (3 points)	Very High (4 points)
Percent agricultural land (A)	>30	21 – 30	10 – 20	<10

7. The HUC_NA shapefile was converted to a raster data set with a pixel size of 30 m, and the value field was set to the attribute Per_AG_R.

Result: See following map.



Riparian forest cover

Data Source: Hatfield, Mark. 2005. 30m Buffer of the 1999 National Hydrography Data set (NHD). St. Paul, MN: U.S. Department of Agriculture, Forest Service, Northern Research Station. [unpublished digital data]

Description: The National Hydrography Data set (NHD; USGS) comes with several different layers. Three are of interest to this project: the waterbodies, areas, and flowlines. The waterbodies layer depicts any water that has area, such as lakes, swamps, and ocean. The area layer shows features, such as rivers, that become too large to represent with only a line. The flowline layer shows all linear features, and includes information about the direction of flow through its topology. All three layers include an FCode for each feature, to describe what the feature is. Flowline features coded as "Pipeline" were deleted because they were determined to be irrelevant to the project. Using the buffer tool, a 30-m buffer was created around each feature in the Flowline and Waterbody/Area layers.

Data Source: Same as for percent forested land.

GIS Process:

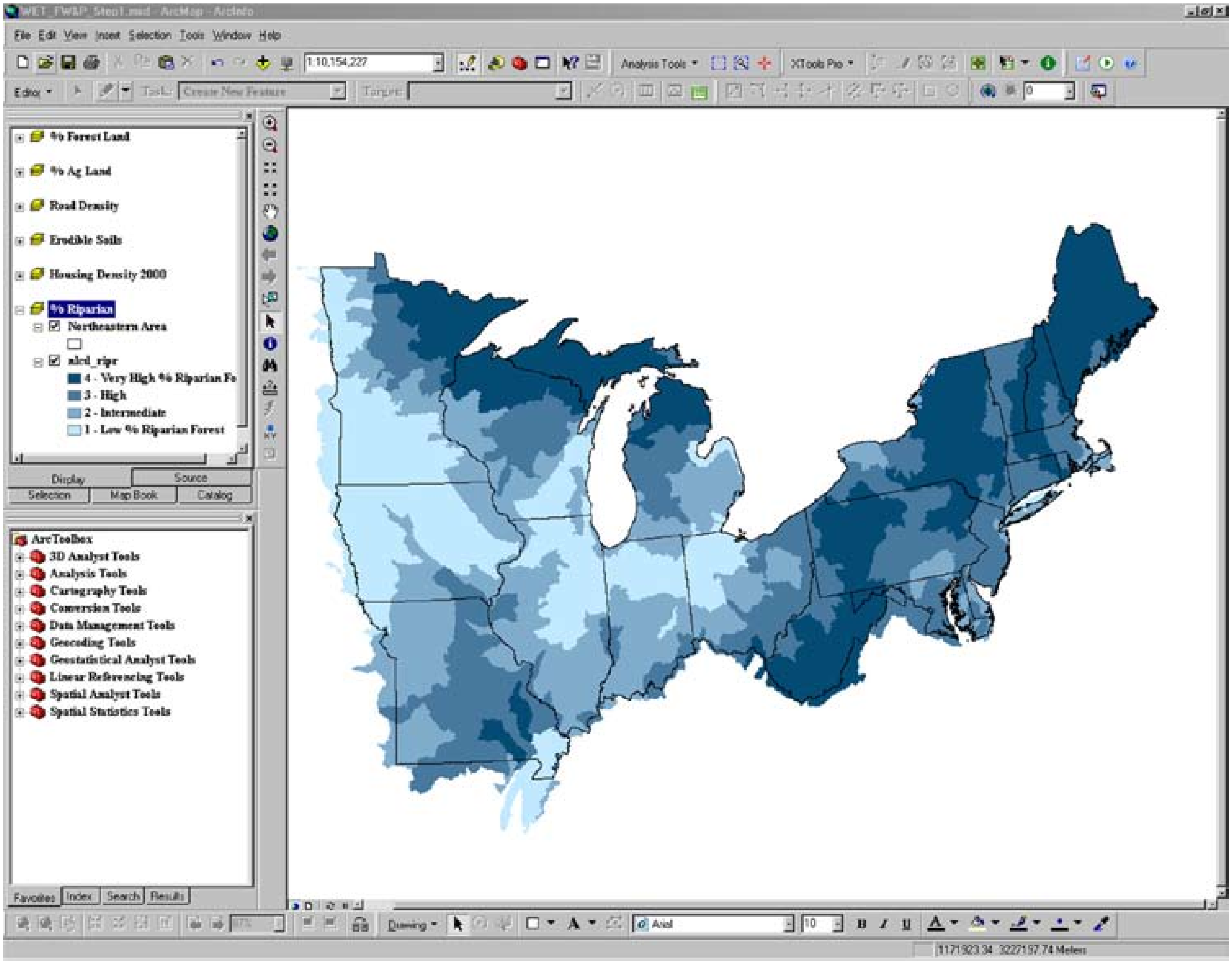
1. The raw, downloaded NLCD GeoTiffs were converted to GRID using ArcInfo workstation.
2. Once each state file was a GRID, all the GRIDs were merged to create a single GRID, nlcd92_huc.
3. Forested Land was summarized using NLCD grid values 33 Transitional; 41 Deciduous Forest; 42 Evergreen Forest; 43 Mixed Forest; 51 Shrubland; 91 Woody Wetlands. The GRID was reclassified so all forested grid codes equaled "1" and all other grid codes equaled "0," nlcd_for.
4. Using the "Extract by Mask" command in ArcInfo, the nlcd_for GRID was clipped to the 30-m NHD buffer nlcd_rip30.
5. Using the "Tabulate Areas" function, the acreage of forested land within the riparian buffer for each watershed was computed using the nlcd_rip30 GRID and HUC_NA polygon shapefile. The acreage of forested land was divided by the total acreage of riparian buffer in the watershed. The resulting table was then joined to the HUC_NA shapefile. The results were saved in the attribute field Per_RIP.
6. The percent riparian forest cover was reclassified into the four categories summarized in Table 1. The results were saved in the attribute field Per_RIP_R. See step 7.

Excerpt 3 from Table B-1

Attribute	**Scoring for 30-meter grid cell**			
	Low (1 point)	Moderate (2 points)	High (3 points)	Very High (4 points)
Percent riparian forest cover (R)	0 – 29	30 – 50	51 – 70	>70

7. The HUC_NA shapefile was converted to a raster data set with a pixel size of 30 m and the value field set to the attribute Per_RIP_R. See step 6.

Result: See following map.


File Edit View Insert Selection Tools Window Help
Analysis Tools
XTools Pro
Editor
Task: Create New Feature
Target:
% Forest Land
% Ag Land
Road Density
Erodible Soils
Housing Density 2000
% Riparian
Northeastern Area
nlcd_ripr
4 - Very High % Riparian Fo
3 - High
2 - Intermediate
1 - Low % Riparian Forest
Display
Source
Selection
Map Book
Catalog
ArcToolbox
3D Analyst Tools
Analysis Tools
Cartography Tools
Conversion Tools
Data Management Tools
Geocoding Tools
Geostatistical Analyst Tools
Linear Referencing Tools
Spatial Analyst Tools
Spatial Statistics Tools
Favorites
Index
Search
Results
Drawing
Arial
10
1171923.34 3227197.74 Meters

Road density

Data Source: U.S. Department of Transportation. 2002. Bureau of Transportation Statistics (BTS): Roads. http://seamless.usgs.gov/ (December 1, 2006)

Description: This data set portrays a Bureau of Transportation Statistics overview of the road networks for all 50 States, the District of Columbia, and Puerto Rico.

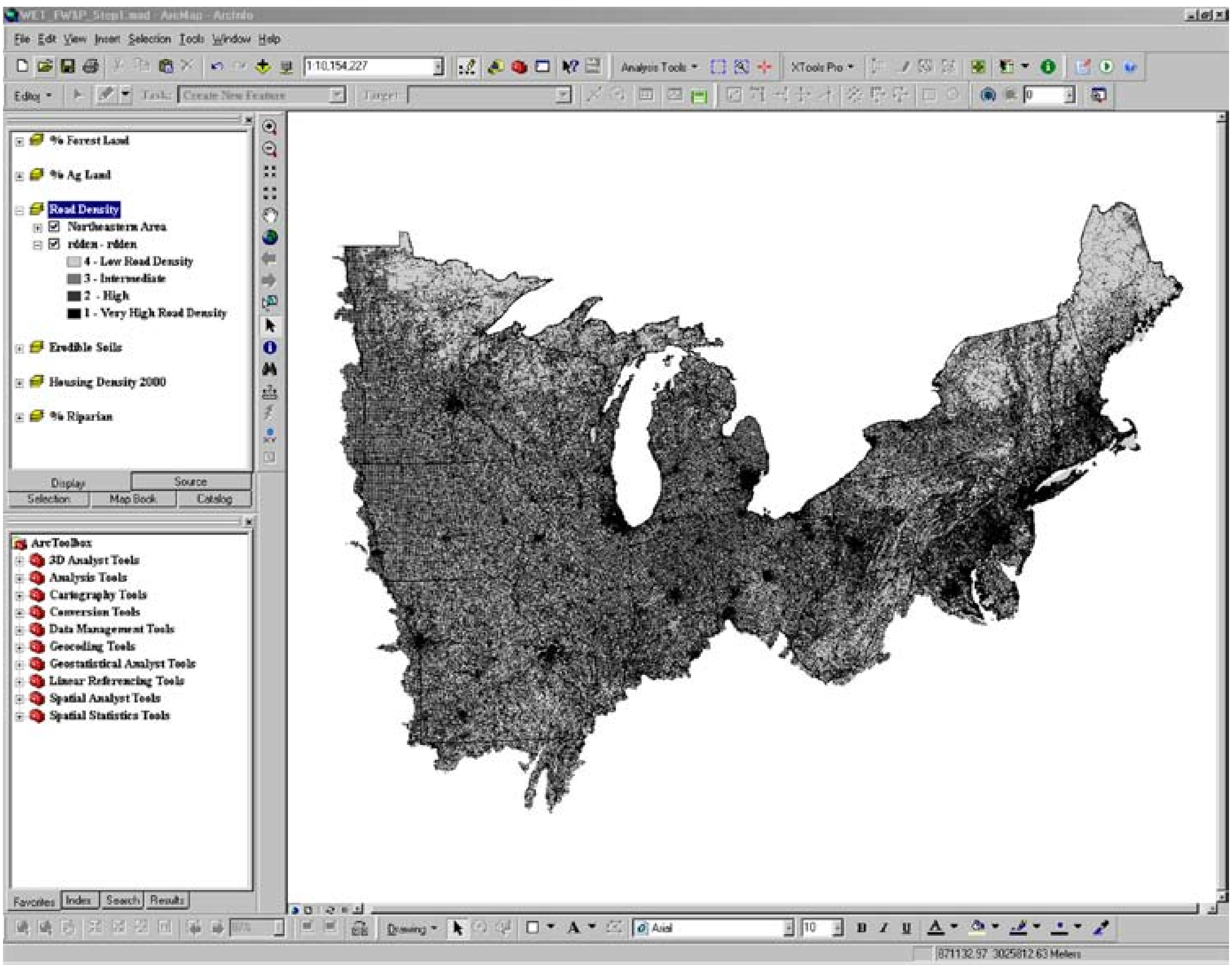
GIS Process:

1. Removed ferry routes from road layer Feature Class Code (FCC) A65, A66, A68, and A69.
2. Ran "Line Density" function in ArcInfo. Parameters were set as follows:
   Cell size = 30 m
   Search radius = 564.3326 m (to equal a search area of 1 km^2)
   Units = square kilometer
3. The line density function had to be run in sections due to file size; therefore, each final line density grid had to be merged together. Where two grids overlapped, the average line density was computed.
4. The results were sorted into four quartiles, and reclassified with values 1-4.

Excerpt 4 from Table B-1

Attribute	Scoring for 30-meter grid cell			
	Low (1 point)	Moderate (2 points)	High (3 points)	Very High (4 points)
Road density (D, quartiles)	75 – 100th percentile	50 – 74th percentile	25 – 49th percentile	0 – 24th percentile

Result: See following map.



Soil erodibility

Data Source: Miller, Douglas A.; White, Richard A. (NRCS) 1998. STATSGO: A conterminous United States multi-layer soil characteristics data set for regional climate and hydrology modeling. www.soilinfo.psu.edu/index.cgi?soil_data&conus (December 1, 2006)

GIS Process:

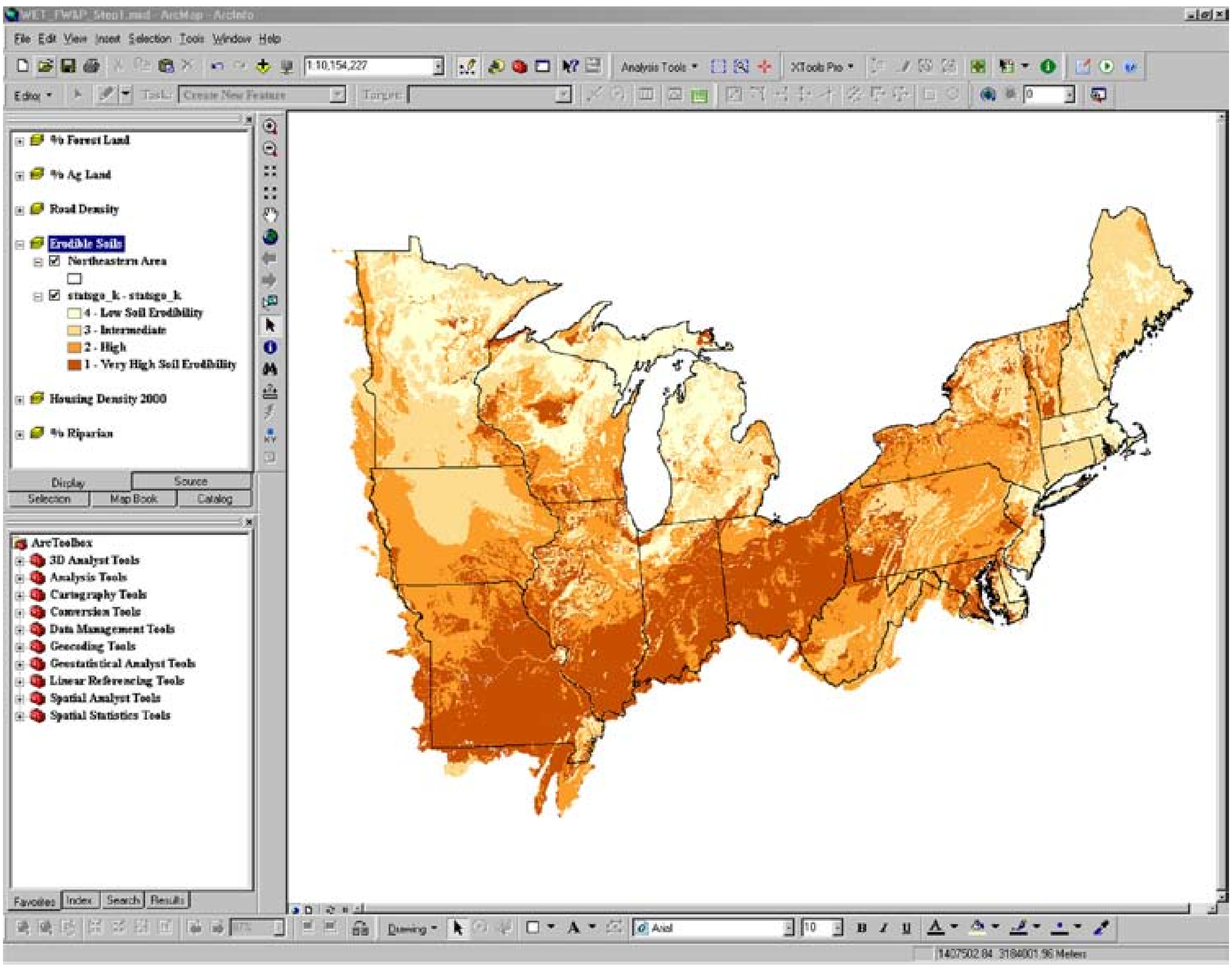
1. Clipped the STATSGO mapunit coverage to the HUC_NA boundary
2. Joined the mu_kfact table to the clipped STATSGO shapefile.
3. Converted shape to raster using the kffact field as the grid value.
4. Reclassified the grid, where

   Kffact =
   a. 0-0.2 = 4
   b. 0.2-0.28 = 3
   c. 0.28-0.34 = 2
   d. >0.34 = 1

Excerpt 5 from Table B-1

Attribute	Scoring for 30-meter grid cell			
	Low (1 point)	Moderate (2 points)	High (3 points)	Very High (4 points)
Soil erodibility (S, k factor)	>0.34	0.28 – 0.34	0.2 – 0.28	0 – 0.2

Result: See following map.



Housing density

Data Source: Theobald, David M. 2004. Housing density in 2000 and 2030. [Digital Data]. Fort Collins, CO: Colorado State University, Natural Resource Ecology Lab.

Description: This raster data set shows housing density in 2000, based on 2000 U.S. Census Bureau block (SF1) data sets developed by the Natural Resource Ecology Lab.

To reduce the overall file size, the continuous values (in units per hectare * 1,000) were reclassified into the following: Code: Units per hectare

1: ≤1
2: 2 – 8
3: 9 – 15
4: 16 – 31
5: 32 – 49
6: 50 – 62
7: 63 – 82
8: 83 – 124
9: 125 – 247
10: 248 – 494
11: 495 – 1,454
12: 1,455 – 4,118
13: 4,119 – 9,884
14: 9,885 – 24,711
15: 24,712 – 9,999,999

GIS Process:

1. The raw 2000 housing density data was clipped to the analysis area and resampled from a 100-m grid to a 30-m grid.
2. The raw grid values in units per hectare were converted to acres/unit using the following formula:

   ((units/ha)/1,000) * 1 ha/2.47 acres = units/acre (invert) = acres/unit, so the 15 classes equaled:

15 classes (acres/unit)

1: < 2,470
2: 309 – 1,235
3: 165 – 274
4: 80 – 154
5: 50 – 77
6: 40 – 50
7: 30 – 40
8: 20 – 30
9: 10 – 20
10: 5 – 10
11: 1.7 – 5
12: 0.6 – 1.7
13: 0.25 – 0.6
14: 0.1 – 0.25
15: > 0.10

3. The 15 value classes were reclassified into four housing density classes: rural, exurban, suburban, and urban, where:

West (eight States, west of and including Ohio)

Rural:	1 – 6	= 4
Exurban:	7 – 10	= 3
Suburban:	11 – 12	= 2
Urban:	13 – 15	= 1

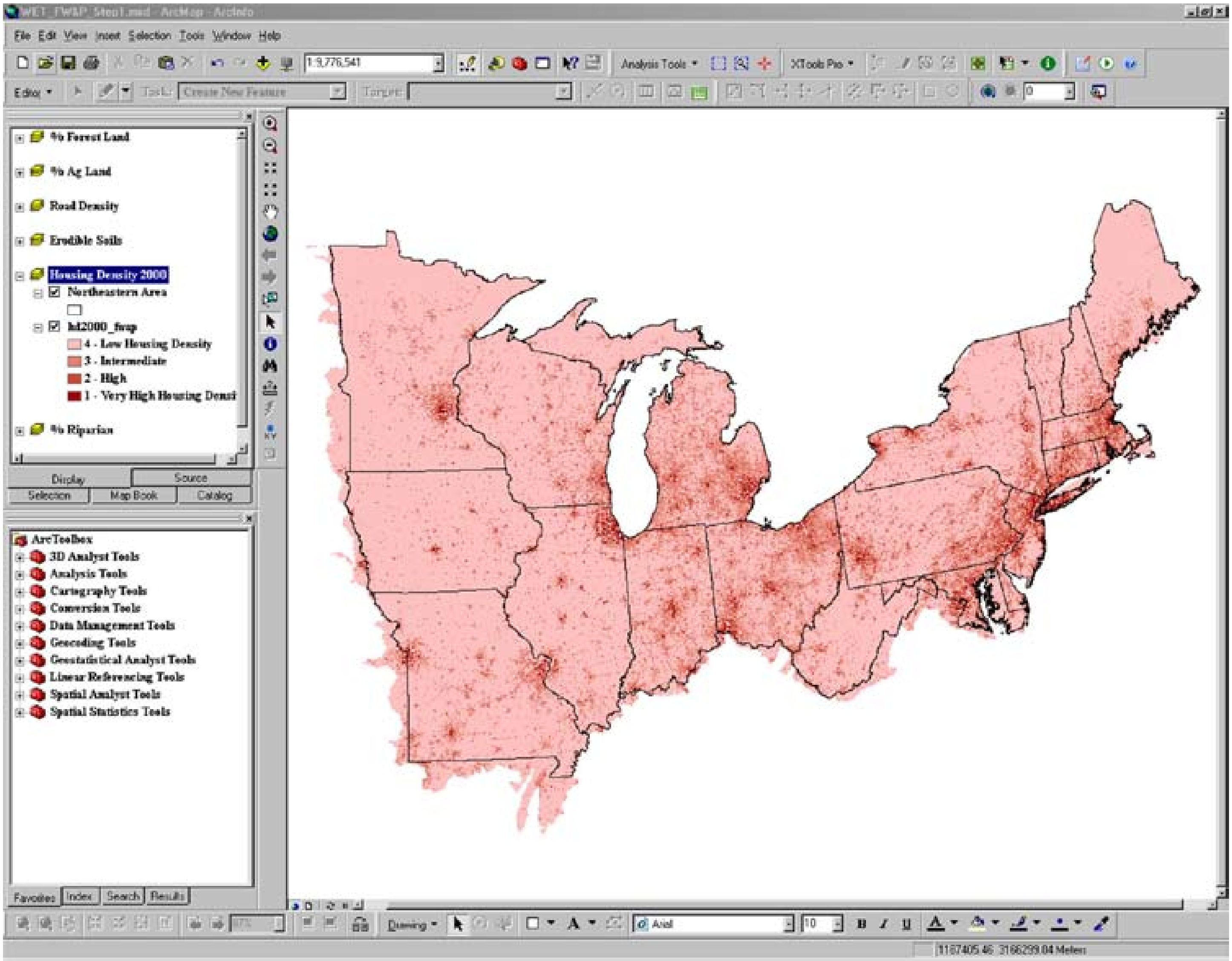
East (12 States, east of, but not including Ohio (does include the Big Sandy Watershed)

Rural:	1 – 8	= 4
Exurban:	9 – 10	= 3
Suburban:	11 – 12	= 2
Urban:	13 – 15	= 1

Excerpt 6 from Table B-1

Attribute	**Scoring for 30-meter grid cell**			
	Low (1 point)	Moderate (2 points)	High (3 points)	Very High (4 points)
Housing density (H, acres per housing unit in 2000)	< 0.6 acre/unit	0.6 – 5.0 acres/unit	5.0 – 20.0 acres/unit (east) 5.0 – 40.0 acres/unit (west)	> 20.0 acres/unit (east) > 40.0 acres/unit (west)

Result: See following map.


WET_FWAP_Step1.mxd - ArcMap - ArcInfo
File Edit View Insert Selection Tools Window Help
1:9,776,541
Analysis Tools
XTools Pro
Editor
Task: Create New Feature
Target:
% Forest Land
% Ag Land
Road Density
Erodible Soils
Housing Density 2000
Northeastern Area
hd2000_fwp
4 - Low Housing Density
3 - Intermediate
2 - High
1 - Very High Housing Densi
% Riparian
Display
Source
Selection
Map Book
Catalog
ArcToolbox
3D Analyst Tools
Analysis Tools
Cartography Tools
Conversion Tools
Data Management Tools
Geocoding Tools
Geostatistical Analyst Tools
Linear Referencing Tools
Spatial Analyst Tools
Spatial Statistics Tools
Favorites
Index
Search
Results
Drawing
Arial
10
1167405.46 3166299.84 Meters

Ability to produce clean water (APCW) index by 30-m pixels

The six attributes in step 1 were summed, resulting in a value of 6 – 24 for each 30-m grid cell.

F + A + R + D + S + H = APCW

where,

F = forest land (percent)

A = agricultural land (percent)

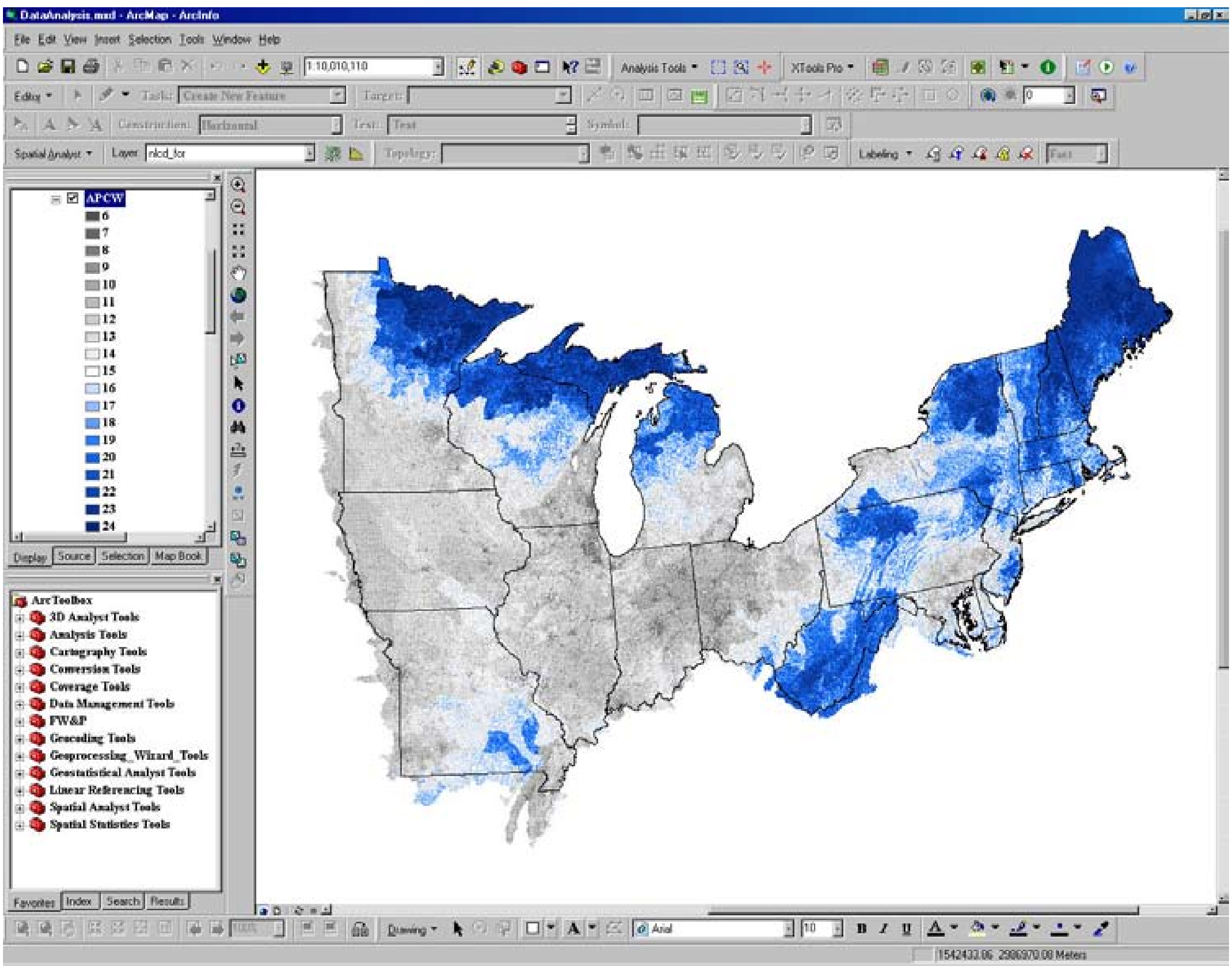
R = riparian forest cover (percent)

D = road density (quartiles)

S = soil erodibility (k factor)

H = housing density (acres per housing unit in 2000)

Result: See following map.



Step 1 composite score: Mean APCW for watersheds

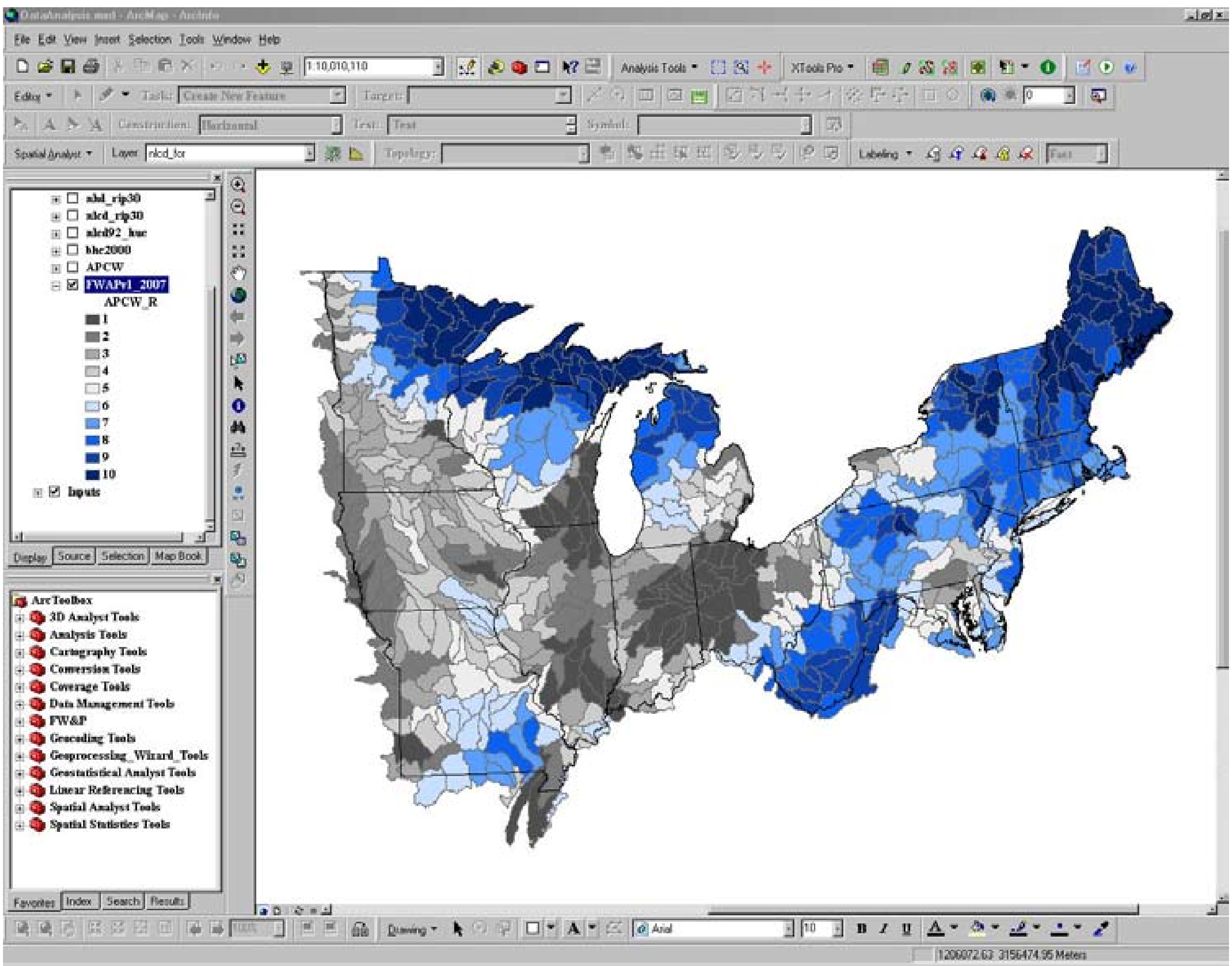
Data Source: Ability to Produce Clean Water (APCW) Index by 30-m pixels

Description: See previous step.

GIS Process

1. Using the "zonal statistics as table" function in ArcInfo, the average APCW score was computed for each watershed.
2. The average scores were split into 10 quantiles and reclassified with a value of 1 – 10, with 1 being the lowest APCW and 10 the highest (See Table B-2.)

Result: See following map.



Step 2: Add Data on Drinking Water Consumers

(See Analysis Methods section of main report)

Step 2 combined the results of Step 1, the Ability to Produce Clean Water, with water use data from the U.S. Environmental Protection Agency's (EPA) Surface Drinking Water Information System (SDWIS). The ability to produce clean water was divided into 10 quantiles, with the 1st quantile receiving a score of 10 and the 10th quantile receiving a score of 1.

Selecting only surface water consumers (reservoirs and streams), the total drinking water consumers was summed for each eight-digit watershed and divided by the watershed area. For large city watersheds that use river intakes, including Philadelphia, St. Louis, St. Paul, and Washington, DC, the drinking water consumers were redistributed among the upstream watersheds. The New York City Watershed was individually calculated using the latest drinking water consumer data from the water utility. The total number of drinking water consumers for each watershed was then divided by the watershed area. This result was divided into 10 quantiles and combined with the APCW to yield a total score ranging from 2 to 20.

Table B-2: Prioritization method for Step 2 for eight-digit HUC watersheds in the 20-State study area.

Attribute	Scoring for 30-meter grid cell		
	Low (1 point)	**Moderate/High (2-9 points)**	**Very High (10 points)**
Step 1 = Mean APCW for Watersheds	10th quantile	2nd – 9th quantile	1st quantile
DW = surface drinking water consumers per unit area	10th quantile	2nd – 9th quantile	1st quantile

(90th percentile and higher = 1st quantile = 10; 80th to 89th percentile = 2nd quantile = 9; 70th to 79th percentile = 3rd quantile = 8 …)

Step 1 composite score

See result from Step 1.

Surface drinking water consumers per unit area

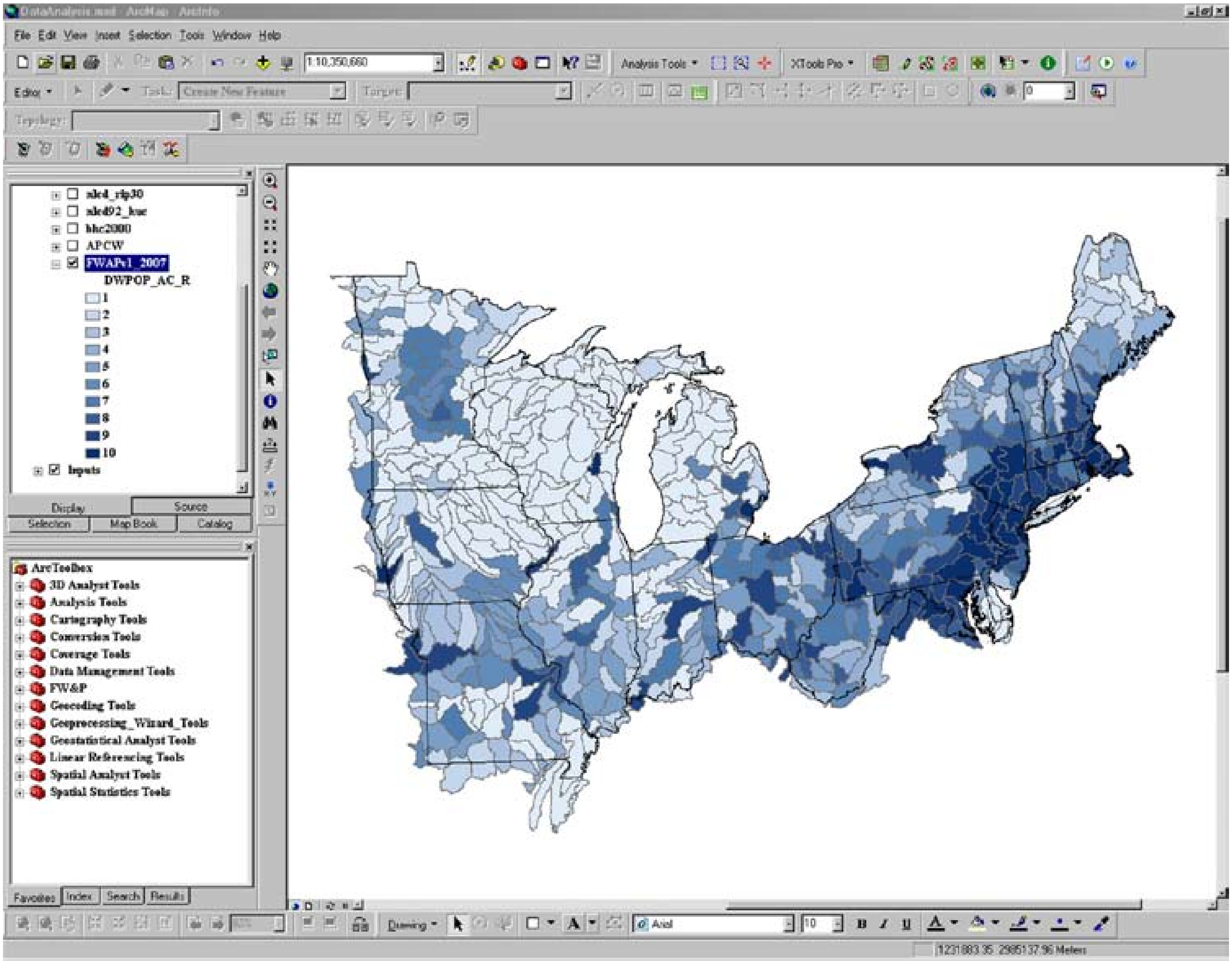
Data Source: U.S. Environmental Protection Agency. 2005. Public drinking water system (PWS) consumers by 8-digit HUC (data extracted from Safe Drinking Water Information System (SDWIS) in the 4th quarter of 2004). http://www.epa.gov/enviro/html/sdwis/sdwis_ov.html (August 10, 2007) This information is proprietary. To request access and permission to this spatial dataset, contact the U.S. EPA Office of Wetlands, Oceans and Watersheds (OWOW) at 202-566-1300.

Description: The public drinking water supply systems regulated by the EPA, and delegated states and tribes, provide drinking water to 90 percent of Americans. These public drinking water supply systems, which may be publicly or privately owned, serve at least 25 people or 15 service connections for at least 60 days per year.

GIS Process:

1. The Public Drinking Water System (PWS) data from the Safe Drinking Water Information System (SDWIS) database catalogs all drinking water intakes, including groundwater wells. Only surface water intakes (code = SW) were considered.
2. Overlaying the 540 watershed boundaries over the drinking water intakes, each intake was attributed with the proper eight-digit watershed code, in which it resides. Intakes that fell within a watershed boundary but obtain their water from the one of the five Great Lakes or the St. Lawrence River were not included.
3. The remaining intakes were evaluated by public water supply system. If a public water supply system spanned two watersheds, the total number of consumers was divided by 2 and half put in each watershed.
4. For the major cities with river intakes (Philadelphia, St. Louis, Cincinnati, St. Paul, Minneapolis, Washington, DC), their consumers were assigned to the eight-digit watershed immediately upstream, not the entire Delaware, Mississippi and Missouri, Ohio, Mississippi, or Potomac watershed above their respective intakes. In other words, it overstates the importance of the nearby watersheds while failing to "credit" the other (nested) upstream watersheds. Each city was evaluated separately:
    a. Cincinnati—The water consumers were prorated over the subwatersheds along the main stem Ohio River.
    b. St. Louis—same rationale, except the distribution of water users was limited to the Mississippi tributaries that are largely in Missouri and the Missouri River "corridor."
    c. Philadelphia and Washington, DC, were distributed on the basis of subwatershed area.
5. New York City watersheds were corrected using current NYCDEP daily drinking water supply estimates.
6. The water consumers were summed by HUC and divided by watershed land acreage.
7. The watershed results were split into 10 quantiles and given a value 1 through 10 (table B-2).

Result: See following map.


File Edit View Insert Selection Tools Window Help
Analysis Tools
XTools Pro
Editor
Task: Create New Feature
Target:
Topology:
nlcd_rip30
nlcd92_lue
hhc2000
APCW
FWAPv1_2007
DWPOP_AC_R
1
2
3
4
5
6
7
8
9
10
Inputs
Display
Source
Selection
Map Book
Catalog
ArcToolbox
3D Analyst Tools
Analysis Tools
Cartography Tools
Conversion Tools
Coverage Tools
Data Management Tools
FW&P
Geocoding Tools
Geoprocessing_Wizard_Tools
Geostatistical Analyst Tools
Linear Referencing Tools
Spatial Analyst Tools
Spatial Statistics Tools
Favorites
Index
Search
Results
Drawing
Arial
10
1231883.35 2985137.96 Meters

***Step 2 composite score:** Importance of watersheds for drinking water supply*

The two attributes in step 2 were summed, resulting in values of 2 to 20 for each watershed.

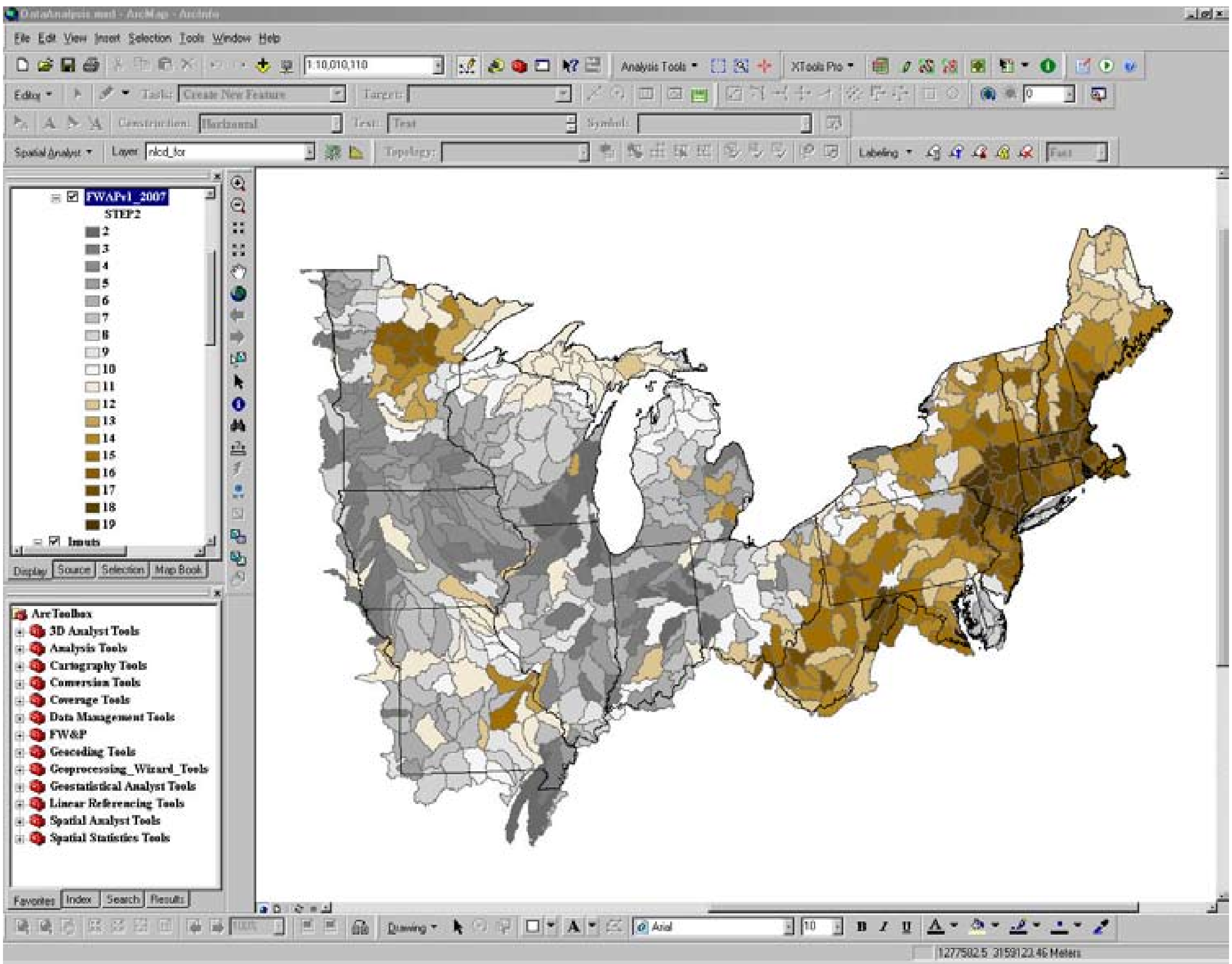
Mean APCW + DW = STEP 2

where,

Mean APCW = Ability to Produce Clean Water

DW = Surface Drinking Water consumers per unit area

Result: See following map.



Step 3: Add Data on Private Forest Land

Step 3 combines the results of Step 2 with the watershed's percent private forest to highlight those areas important for surface water drinking supply that contain private forest lands. The private forest database was derived using a subset of the Conservation Biology Institute's Protected Areas database and an updated Wisconsin data set. Only permanently protected lands (Federal, State, county, local, or permanent conservation easements) were considered "protected," all other lands were considered unprotected, having the potential to be developed. The percent private forest by watershed was divided into 10 quantiles and then combined with the results of Step 2 to yield a total score of 3 – 30.

Table B-3: Prioritization method for Step 3 for eight-digit HUC watersheds in the 20-State study area.

Attribute	Scoring for 30-meter grid cell		
	Low (1 point)	**High/moderate (2-9 points)**	**High (10 points)**
Step 2 = Importance of watersheds for drinking water supply	See results from Step 2		
PF = Private Forest (%)	10th quantile	2nd – 9th quantile	1st quantile

(For example, 90th percentile and higher = 1st quantile = 10; 80th to 89th percentile = 2nd quantile = 9; 70th to 79th percentile = 3rd quantile = 8; …)

Step 2 Composite Score

See results from Step 2.

Private forest

Data Source: Conservation Biology Institute. 2006. CBI Protected Areas Database, Version 4. [CD-ROM] Corvallis, OR. http://www.consbio.org (August 10, 2007).

U.S. Geological Survey, Upper Midwest Environmental Sciences Center. 2005. Gap Analysis Program—Wisconsin Stewardship Data. [Digital Data] La Crosse, WI.

Description: The original CBI Protected Areas Database (PAD) was the product of a collaborative effort between the Conservation Biology Institute and World Wildlife Fund, USA. The second and third versions of the PAD represent updates of the first database. This fourth version of the PAD specifically includes a complete update of 20 eastern and 5 western U.S. States. Polygons are assigned with a GAP Analysis Program (GAP) code of 1, 2, 3, or 4 and IUCN category of I through VI, N/A or Unknown. We added an additional GAP code of 5 to designate bodies of water. MN GAP has assigned some additional GAP codes, which are described in their metadata file. Additionally, the database contains information about parcel type, ownership, size, and protection level.

GAP Code 1: An area having permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a natural state within which disturbance events (of natural type, frequency, intensity, and legacy) are allowed to proceed without interference or are mimicked through management. Examples: national parks, nature preserves, wilderness areas.

GAP Code 2: An area having permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a primarily natural state, but which may receive uses or management practices that degrade the quality of existing natural communities, including suppression of natural disturbance. Examples: State parks, national wildlife refuges, national recreation areas.

GAP Code 3: An area having permanent protection from conversion of natural land cover for the majority of the area, but subject to extractive uses of either a broad, low-intensity type (e.g., logging) or localized intense type (e.g., mining). It also confers protection to federally listed endangered and threatened species throughout the area. Examples: national forests, most Bureau of Land Management land, wildlife management areas.

GAP Code 4: There are no known public or private institutional mandates or legally recognized easements or deed restrictions held by the managing entity to prevent conversion of natural habitat types to anthropogenic habitat types. The area generally allows conversion to unnatural land cover throughout.

Data Source: U.S. Geological Survey (USGS). 1999. 1992 National land cover data set. Sioux Falls, SD. http://edcwww.cr.usgs.gov/programs/lccp/nationallandcover.html (August 10, 2007)

Description: The National Land Cover Data set was compiled from Landsat satellite TM imagery (circa 1992) with a spatial resolution of 30 meters and supplemented by various ancillary data (where available). The analysis and interpretation of the satellite imagery was conducted using large, sometimes multi-State image mosaics (i.e., up to 18 Landsat scenes). Using a relatively small number of aerial photographs for "ground truth," the thematic interpretations were necessarily conducted from a spatially broad perspective. Furthermore, the accuracy assessments (see below) correspond to "Federal regions," which are groupings of contiguous States. Thus, the reliability of the data is greatest at the State or multi-State level. The statistical accuracy of the data is known only for the region. The land cover data files are provided as a "Geo-TIFF" for each State.

GIS Process:

1. The Protected Areas Database (PAD) contains properties that are not permanently protected; therefore, several polygons were removed before percent private forest was calculated.

    Properties retained:

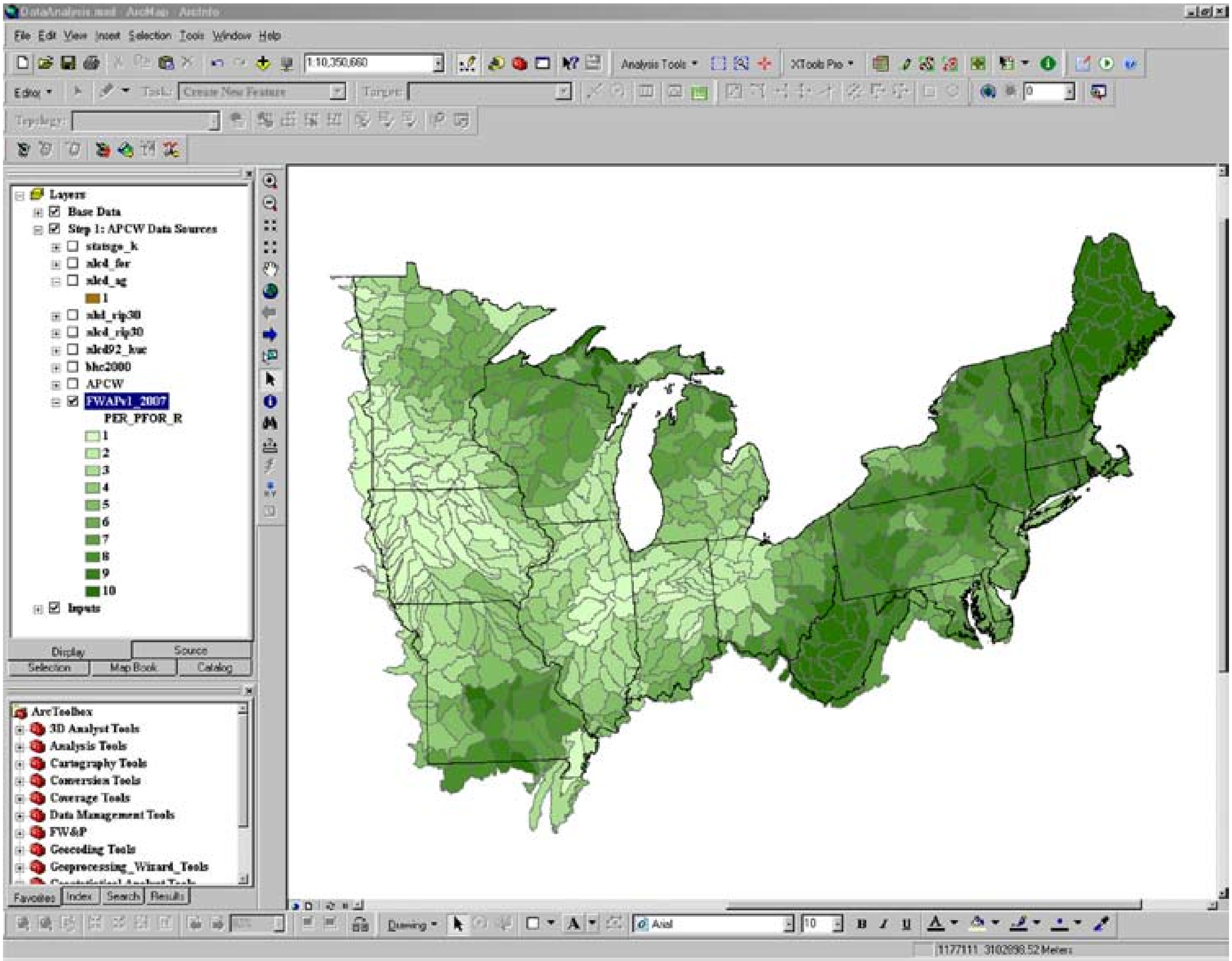
    All State, Federal, local, and county lands were considered permanently protected regardless of gap code (State and county parks and wildlife management areas are GAP code 4).

    Properties removed:

    Ownerships with a GAP code of 4 or above were removed, as were Gap codes of 3 that were designated as private industrial or private non-industrial forest.

2. Using the final edited PAD shapefile as the ERASE template, all the protected areas were erased from the analysis area resulting in a layer of private land.
3. The private land shapefile was used as a mask to clip the nlcd_for GRID (1992 forest land), to achieve a grid of private forest, pri_for.
4. To determine the acreage of private forest land in each watershed, the "tabulated areas" function was run using the pri_for GRID and HUC_NA polygon shapefile.
5. The acreage of private forest was then divided by the total land acreage of the watershed to get the percent private forest by watershed.
6. The results were split into 10 quantiles and given values of 1 through 10 (see Table B-3).

Result: See following map.


Layers
Base Data
Step 1: APCW Data Sources
APCW
FWAPv1_2007
PER_PFOR_R
Inputs
ArcToolbox
3D Analyst Tools
Analysis Tools
Cartography Tools
Conversion Tools
Coverage Tools
Data Management Tools
FW&P
Geocoding Tools
Geoprocessing_Wizard_Tools

***Step 3 composite score:** Importance of watersheds with private forests for drinking water supply*

The two attributes in Step 3 were summed, resulting in a potential composite score of 3 to 30 for each watershed.

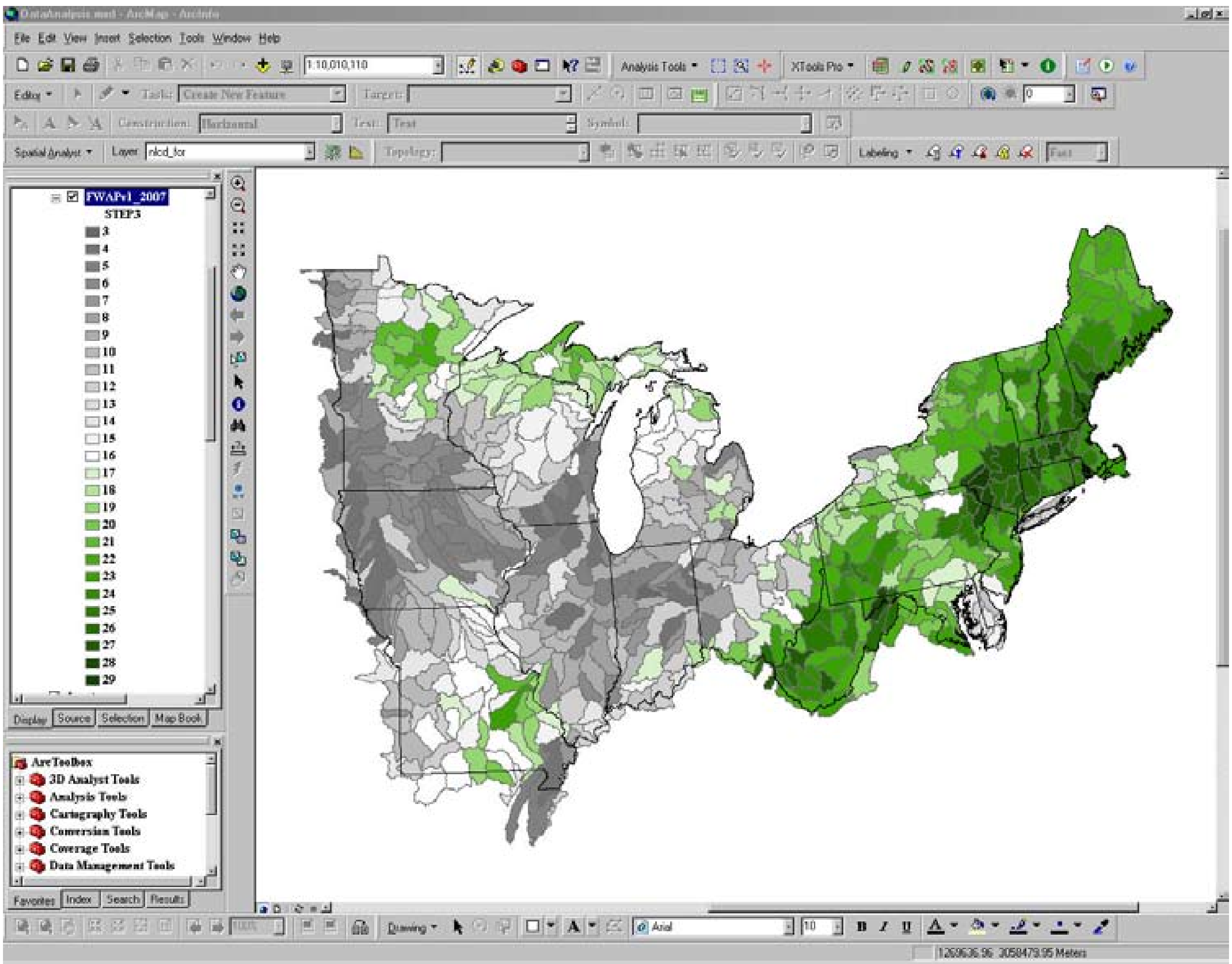
STEP 2 + PF = STEP 3

where,

Step 2 = Importance of watersheds for drinking water supply

PF = percent private forest

Result: See following map.



Step 4: Add Data on Change in Housing Density

Step 4 combines the results of Step 3 with the development pressure of future housing density change on forests. Development pressure was calculated by subtracting the housing density in 2000 from the housing density in 2030. If housing density increased between 2000 and 2030, then development pressure was said to occur. The total acreage of land under development pressure in the watershed was divided by watershed area, divided into 10 quantiles, and then combined with the results of Step 3 to yield a total score ranging from 4 to 40.

Table B-4: Prioritization method for Step 4 for eight-digit HUC watersheds in the 20-State study area.

Attribute	**Score for 30-meter grid cell**		
	Low (1 point)	**High/moderate (2-9 points)**	**High (10 points)**
Step 3 = Importance of watersheds and private forest for drinking water supply	See results from Step 3		
DP = Development pressure per unit area	10th quantile	2nd – 9th quantile	1st quantile

(90th percentile and higher = 1st quantile = 10; 80th to 89th percentile = 2nd quantile = 9; 70th to 79th percentile = 3rd quantile = 8; …)

Step 3 Composite Score

See the results from Step 3.

Development pressure per unit area

Data Source: Theobald, David M. 2004. Housing density in 2000 and 2030 [Digital Data]. Fort Collins, CO: Colorado State University, Natural Resource Ecology Lab.

Description: This raster data set shows housing density in 2000, based on 2000 U.S. Census Bureau block (SF1) data sets developed by the Natural Resource Ecology Lab. Housing Density in 2030 was forecasted using the Spatially Explicit Regional Growth Model (SERGoM v2).

To reduce the overall file size, the continuous values (in units per hectare * 1,000) were reclassified into the following: Code: Units per hectare

1: ≤1
2: 2 – 8
3: 9 – 15
4: 16 – 31
5: 32 – 49
6: 50 – 62
7: 63 – 82
8: 83 – 124
9: 125 – 247
10: 248 – 494
11: 495 – 1,454
12: 1,455 – 4,118
13: 4,119 – 9,884
14: 9,885 – 24,711
15: 24,712 – 9,999,999

GIS Process:

1. The raw 2000 housing density data was clipped to the analysis area and resampled from a 100 m grid to a 30 m grid.
2. The raw grid values in units per hectare were converted to acres/unit using the following formula:

((units/ha)/1,000) * 1 ha/2.47 acres = units/acre (invert) = acres/unit, so the 15 classes equaled:

15 classes (acres/unit)

1: < 2,470
2: 309 – 1,235
3: 165 – 274
4: 80 – 154
5: 50 – 77
6: 40 – 50
7: 30 – 40
8: 20 – 30
9: 10 – 20
10: 5 – 10
11: 1.7 – 5
12: 0.6 – 1.7
13: 0.25 – 0.6
14: 0.1 – 0.25
15: > 0.10

3. The 15 value classes were reclassified into four housing density classes: rural, exurban, suburban, and urban, where:

   West (eight States, west of and including Ohio)

Rural:	1 – 6	= 4
Exurban:	7 – 10	= 3
Suburban:	11 – 12	= 2
Urban:	13 – 15	= 1

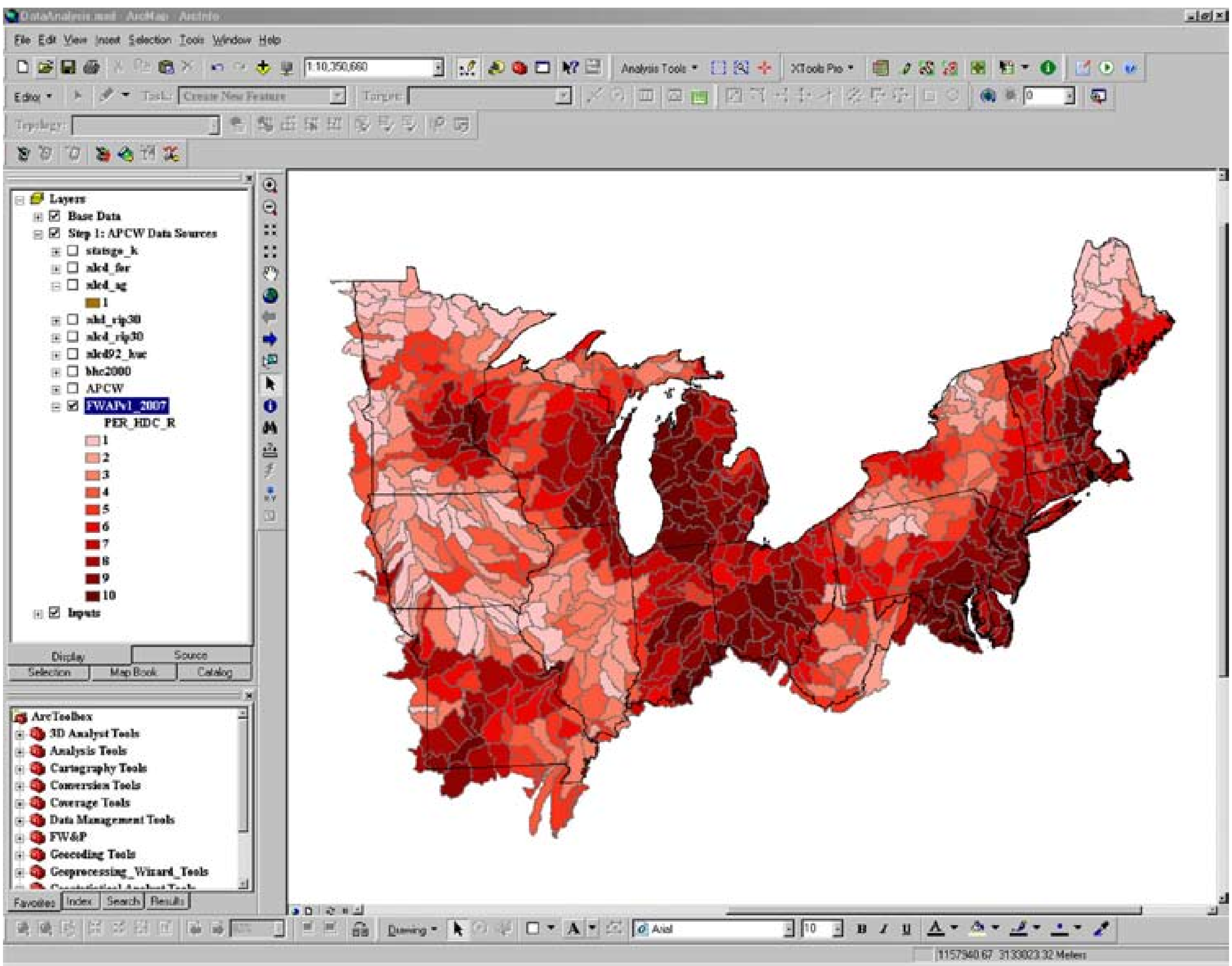
   East (12 States, east of, but not including Ohio (does include the Big Sandy Watershed))

Rural:	1 – 8	= 4
Exurban:	9 – 10	= 3
Suburban:	11 – 12	= 2
Urban:	13 – 15	= 1

4. Using the "Combine" function in ArcInfo, the values of the 2000 Housing density data set were combined with the 2030 housing density data set. Look at the output data set, areas that increased in housing density were extracted and reclassified as "development pressure." Note: Areas that increased from suburban to urban and areas where housing density was not predicted to change were not included in the final data set.

5. The acreage of areas experiencing "development pressure" was calculated for each watershed and divided the land acreage of the watershed. This "development pressure per unit area" fraction was split into 10 quantiles and given a value of 1 (low development pressure) through 10 (very high development pressure; see Table B-4)

Result: See following map.



Step 4 composite score: *Development pressure on private forests in watersheds important for drinking water supply*

Values for the two attributes in step 4 were summed, resulting in a potential composite score of 4 to 40 for each watershed.

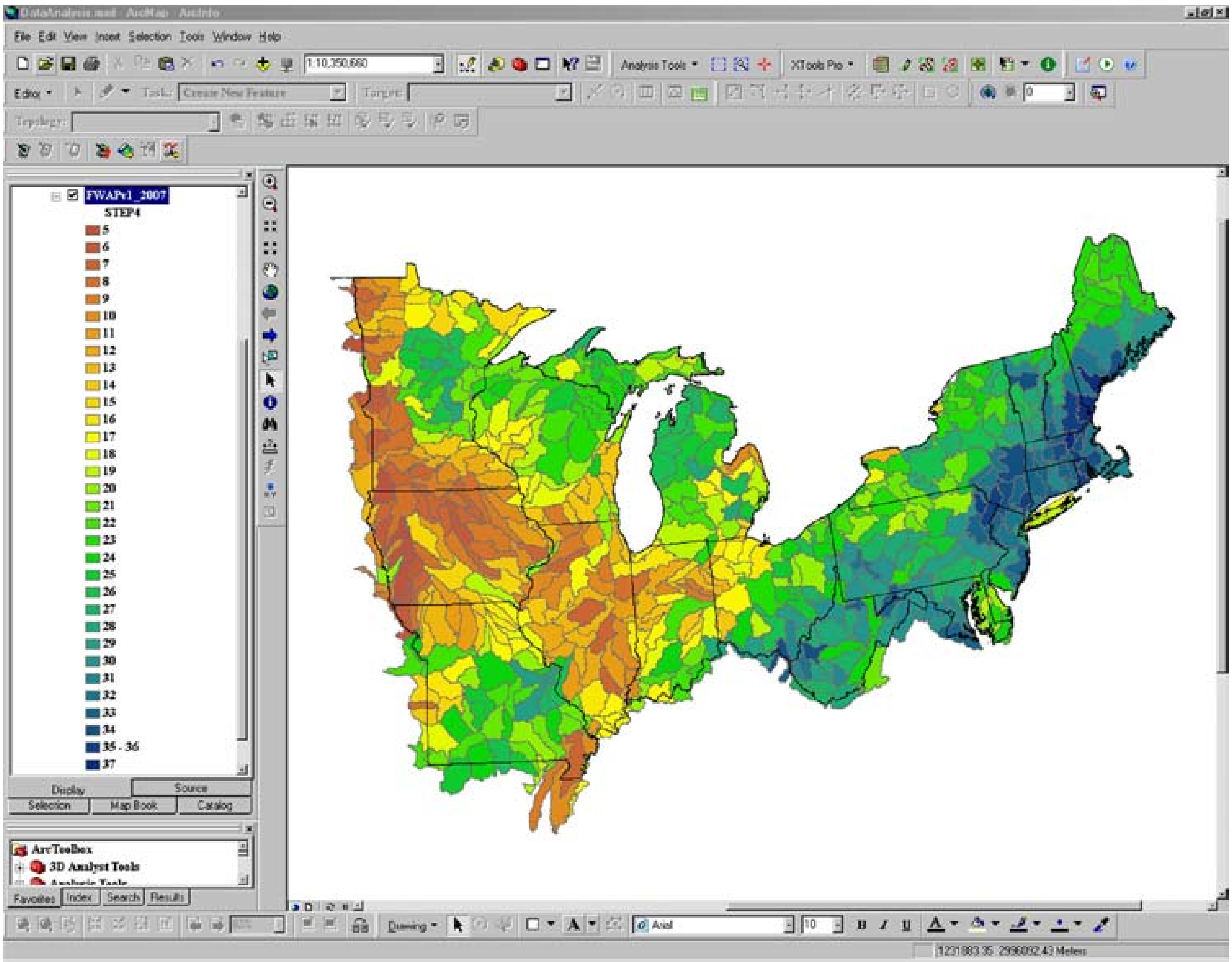
STEP 3 + DP = STEP 4

where,

Step 3 = Importance of watersheds and private forest for drinking water supply

DP = Development Pressure per unit area

Result: See following map.



For more information about the technical process, contact:

Office of Knowledge Management
Northeastern Area State and Private Forestry
USDA Forest Service
11 Campus Boulevard, Suite 200
Newtown Square, PA 19073

REFERENCES

Barten, Paul K. 2005. Conserving the Common Wealth—The forests of Massachusetts in the 21st Century. Barten, Paul K. 2005. Conserving the Common Wealth—The forests of Massachusetts in the 21st Century. Amherst, MA: University of Massachusetts. 7 p.

Barten, Paul K. 2007. The conservation of forests and water in New England … again. New England Forests (Spring): 1-4.

Barten, Paul K.; Ernst, Caryn. 2004. Land conservation and watershed management for source protection. Journal of the American Water Works Association 96(4): 121-135.

Barten, Paul K.; Kyker-Snowman, Tom; Lyons, Paul J.; Mahlstedt, Thomas; O'Connor, Robert; Spencer, Bruce A. 1998. Managing a watershed protection forest. Journal of Forestry 96(8): 10-15.

Buie, Eugene C. 1979. A history of water resource activities of the U.S. Department of Agriculture. Washington, DC: Soil Conservation Service. 28 p.

Carpenter, Constance A.; Giffen, Casey; Miller-Weeks, Margaret. 2003. Sustainability assessment highlights for the Northern United States. NA-TP-05-03. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Area State and Private Forestry. 99 p.

Conservation Biology Institute. 2006. CBI Protected Areas Database, Version 4. [CD-ROM] Corvallis, OR. www.consbio.org (August 10, 2007).

de la Cŕetaz, Avril L.; Barten, Paul K. 2007. Land use effects on streamflow and water quality in the Northeastern United States. Boca Raton, FL: CRC Press—Taylor & Francis Group. 319 p.

Dissmeyer, George E., editor. 2000. Drinking water from forests and grasslands: A synthesis of the scientific literature. General Technical Report SR-39. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 246 p.

Dudley, Nigel; Stolton, Sue. 2003. Running pure: the importance of forest protected areas to drinking water, a research report for the World Bank/WWF Alliance for Forest Conservation and Sustainable Use. Gland, Switzerland: World Bank. 114 p.

Ernst, Caryn. 2004. Protecting the source: land conservation and the future of America's drinking water. San Francisco, CA: Trust for Public Land, Water Protection Series. 56 p.

Ernst, Caryn. 2006. Land conservation: a permanent solution for drinking water source protection. On Tap. Spring 2006. 18-40.

Ernst, Caryn; Hart, Kelley. 2005. Path to protection: ten strategies for successful source water protection. San Francisco, CA: Trust for Public Land, Water Protection Series. 28 p.

Ernst, Caryn; Gullick, Richard; Nixon, K. 2004. Protecting the source: land conservation as a drinking water protection tool. OpFlow (American Water Works Association). 30(5): 1-7.

Foster, David. 1990. Harvard Forest, Long Term Ecological Research Site, Harvard University. http://harvardforest.fas.harvard.edu/data_archive_tmp.903374.txt (May 19, 2008). [New users must establish a free account at http://harvardforest.fas.harvard.edu/data/p01/hf013/HF013-data.html before accessing the data.]

Gibson, Campbell J.; Lennon, Emily, eds. 1999. Historical census statistics on the foreign-born population of the United States: 1850-1990. Working Paper No. 29. Washington, DC: U.S. Bureau of the Census, Population Division. 15 p.

Hatfield, Mark. 2005. 30m Buffer of the 1999 National Hydrography Dataset (NHD). St. Paul, MN: U.S. Department of Agriculture, Forest Service, Northern Research Station. [unpublished digital data]

Hopper, Kim; Ernst, Caryn. 2004. Source protection handbook: using land conservation to protect drinking water supplies. Denver, CO: American Water Works Association. 88 p.

Kellogg, R.S. 1909. The timber supply of the United States. Forest Resource Circular 166. Washington, DC: U.S. Department of Agriculture, Forest Service. 24 p. www.fia.fs.fed.us/library/briefings-summaries-overviews/docs/ForestFactsMetric.pdf (March 1, 2008)

Lund, Daryl. National Resources Inventory. [Unpublished data received 10/6/2005]. Washington, DC: U.S. Department of Agriculture, Natural Resources Conservation Service, Resources Inventory and Assessment Division, George Washington Carver Center.

Miller, Douglas A.; White, Richard A., eds. 1998. STATSGO: A conterminous United States multi-layer soil characteristics data set for regional climate and hydrology modeling. www.soilinfo.psu.edu/index.cgi?soil_data&conus (December 1, 2006)

National Association of State Foresters. 2004. The connection between forests and clean and abundant water: policy statement of the National Association of State Foresters. www.stateforesters.org/positions/2004.water.html. (October 16, 2007)

National Research Council. 2000. *Watershed management for potable water supply: assessing New York City's approach.* Washington, DC: The National Academies Press. 549 p. www.nap.edu (August 10, 2007)

Northeastern Area State and Private Forestry. 2007. Strategic plan, FY 2008 to FY 2012. NA-FR-02-07. Newtown Square, PA: U.S. Department of Agriculture, Forest Service. 62 p.

Pinchot, Gifford. 1903. A primer of forestry: Part 1 – The forest. Bulletin 24. Washington, DC: U.S. Department of Agriculture, Division of Forestry. [Unpaginated] (Original edition September 22, 1899; second edition October 24, 1900.)

Platt, Rutherford H.; Barten, Paul K.; Pfeffer, Max J. 2000. A full, clean glass? Managing New York City's watersheds. *Environment* 42(5): 8-20.

Sedell, James; Apple, Daina D. 2002. Good to the last drop: our municipal water supplies and our forests. Wildland Waters FS-736. Washington, DC: U.S. Department of Agriculture, Forest Service. 16 p.

Sedell, James; Sharpe, Maitland; Apple, Daina D.; Copenhagen, Max; Furniss, Mike. 2000. Water and the Forest Service. FS-660. Washington, DC: U.S. Department of Agriculture, Forest Service. 40 p. www.fs.fed.us/publications/policy-analysis/water.pdf (October 31, 2007)

Smith, W. Brad; Vissage, John S.; Darr, David R.; Sheffield, Raymond M. 2001. Forest resources of the United States, 1997. General Technical Report NC-219. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station. 190 p. www.ncrs.fs.fed.us/pubs/gtr/gtr_nc219.pdf (May 19, 2008)

Smith, W. Brad; Miles, P.D.; Vissage, J.S.; Pugh, S.A. 2004. Forest resources of the United States. 2002. A technical document supporting the USDA Forest Service 2005 update of the RPA Assessment. Gen. Tech. Rep. NC-241. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station. 137 p.

Society for the Protection of New Hampshire Forests. 1998. Our drinking water supply lands in New Hampshire: How secure are they? Research highlights from the New Hampshire Water Supply Land Conservation Project. Concord, NH. www.spnhf.org/pdf/drinkingwater.pdf (April 1, 2008)

Stein, Susan M.; McRoberts, Ronald E.; Alig, Ralph J.; Nelson, Mark D.; Theobald, David M.; Eley, Mike; Dechter, Mike; Carr, Mary. 2005. Forests on the edge: housing development on America's private forests. General Technical Report PNW-GTR-636. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 16 p. www.fs.fed.us/openspace/fote/national_forests_on_the_edge.html (May 2, 2008)

Stein, Susan; McRoberts, Ron; Nelson, Mark; Theobald, David; Eley, Mike; Dechter, Mike 2006. Forests on the Edge: A GIS-based Approach to Projecting Housing Development on Private Forests. In: Aguirre-Bravo, C.; Pellicane, Patrick J.; Burns, Denver P.; Draggan, Sidney, eds. 2006. Monitoring Science and Technology Symposium: Unifying Knowledge for Sustainability in the Western Hemisphere; 2004 Sept. 20-24; Denver, CO. Proceedings RMRS-P-42CD. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station; 736-743.

Stein, Susan M.; Alig, Ralph J.; White, Eric M.; Comas, Sara J.; Carr, Mary; Eley, Mike; Elverum, Kelly; O'Donnell, Mike; Theobald, David M.; Cordell, Ken; Haber, Jonathan; Beauvais, Theodore W. 2007. National forests on the edge: development pressures on America's national forests and grasslands. Gen. Tech. Rep. PNW-GTR-728. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 26 p.

Theobald, David M. 2004. Housing density in 2000 and 2030 [Digital data]. Fort Collins, CO: Colorado State University, Natural Resource Ecology Lab.

Theobald, David M. 2005. Landscape patterns of exurban growth in the USA from 1980 to 2020. Ecology and Society 10(1): 32. www.ecologyandsociety.org/vol10/iss1/art32/ (August 10, 2007)

U.S. Bureau of the Census, Population Division. 2000. Statistical abstract of the United States—the national data book, 1878-2007. www.census.gov/prod/www/abs/statab.html (August 10, 2007)

U.S. Department of Agriculture, Forest Service. 2005. A snapshot of the northeastern forests. NA-IN-01-06. Newtown Square, PA: Northeastern Area State and Private Forestry. 24 p. www.na.fs.fed.us/pubs/misc/snap_shot/ss.pdf#xml=http://www.na.fs.fed.us/cgi-bin/texis.exe/Webinator/search/xml.txt?query=snapshot&pr=default&prox=page&rorder=500&rprox=500&rdfreq=500&rwfreq=500&rlead=500&sufs=0&order=r&cq=&id=46b68eb7b (September 18, 2008)

U.S. Department of Agriculture, Forest Service. 2006. Forest Stewardship Program Spatial Analysis Project. 2 p. www.fs.fed.us/na/sap/ [Date accessed: October 15, 2008]

U.S. Department of Transportation. 2002. Bureau of Transportation statistics (BTS) Roads. http://seamless.usgs.gov (December 1, 2006)

U.S. Environmental Protection Agency. 1997. 1995 Community water system survey. Report 815–R97–001a. Washington, DC: U.S. Environmental Protection Agency. 40 p.U.S. Environmental Protection Agency. 2005. Public drinking water system (PWS) consumers by 8-digit HUC. www.epa.gov/safewater/pws/index.html (August 10, 2007) This information is proprietary. To request access and permission to this dataset, contact the U.S. EPA Office of Wetlands, Oceans and Watersheds (OWOW) at 202-566-1300.

U.S. Environmental Protection Agency. 2007. National water quality inventory: Report to Congress, 2002 Reporting cycle. EPA 841-R-07-001. Washington, DC: Office of Water. www.epa.gov/305b (March 2008)

U.S. Geological Survey. 2000. Chesapeake Bay Resource Lands Assessment. 4 p. www.chesapeakebay.net/resourcelandsassessment.aspx?menuitem=19096 [Date accessed: October 15, 2008]

U.S. Geological Survey. 1994. 1:250,000-Scale hydrologic units of the United States. Open-File Report 94-0236. Reston, VA. http://water.usgs.gov/GIS/metadata/usgswrd/XML/huc250k.xml (August 10, 2007)

U.S. Geological Survey. 1999. 1992 National land cover dataset. Sioux Falls, SD. http://edcwww.cr.usgs.gov/programs/lccp/nationallandcover.htm (August 10, 2007)

U.S. Geological Survey, Upper Midwest Environmental Sciences Center. 2005. Gap Analysis Program—Wisconsin Stewardship Data. [Digital data] La Crosse, WI.

The U.S. Department of Agriculture (USDA) prohibits discrimination in all its programs and activities on the basis of race, color, national origin, age, disability, and where applicable, sex, marital status, familial status, parental status, religion, sexual orientation, genetic information, political beliefs, reprisal, or because all or part of an individual's income is derived from any public assistance program. (Not all prohibited bases apply to all programs.) Persons with disabilities who require alternative means for communication of program information (Braille, large print, audiotape, etc.) should contact USDA's TARGET Center at (202) 720-2600 (voice and TDD). To file a complaint of discrimination, write to USDA, Director, Office of Civil Rights, 1400 Independence Avenue, S.W., Washington, D.C. 20250-9410, or call (800) 795-3272 (voice) or (202) 720-6382 (TDD). USDA is an equal opportunity provider and employer.