Criterion 4:

CONSERVATION AND MAINTENANCE OF SOIL AND WATER RESOURCES

Montréal Process Criterion 4 (Montréal Process Working Group 2010); Northern Area Forest Sustainability Indicators 8.1-8.5, 9.1-9.2 (USDA FS 2010d)

The importance of conservation and maintenance of soil and water resources

Soils

Soils are the fundamental resource enabling land to provide a wide array of benefits. Both humans and wildlife rely on soils for the production of life-sustaining nourishment and shelter. Soil is important to society because it supports plants that supply food, fibers, drugs, and other essentials and because it filters water and recycles wastes.

Broadly defined, soil is the natural medium for the growth of land plants, regardless of their size structure or species composition. Narrowly defined, soil is a natural body comprised of solids (minerals and organic matter), liquids, and gases that occurs on the land surface, occupies space, and has at least one of the following characteristics: (1) horizons (or

Key Findings for Criterion 4

- **A potentially serious soils-related forest health threat is increasing soil acidity and associated decreasing soil calcium reserves along with increasing potentially toxic levels of exchangeable aluminum. This soil condition is strongly related to atmospheric acid deposition.**
- **Forests protect the soil both directly and indirectly from wind and water erosion. Wind erosion is rare in wooded areas, because they are protected by forest canopy, strong soil tree root anchor support, and forest floor mulch (tree litter).**
- **Soil compaction is not a widespread problem on forested lands and is largely confined to trails (walking, biking, hiking, equestrian, and motorized) and forest harvest operations.**
- **Across the North, 48 percent of the water supply originates on the forest lands that cover 42 percent of the region. About 94 percent of the water that originates from forests comes from State and private forest lands.**
- **Forests in the North have the capacity to supply about 280 billion m^3 (226 million acre-feet) of water annually.**
- **The ability of a watershed to produce clean water increases with increasing proportion of forest cover.**
- **Many northern watersheds have water quality problems, especially near major metropolitan areas. Locations of concern include New Jersey, Delaware, and Ohio; and southern Illinois, Indiana, Michigan, Minnesota, and New Hampshire.**

layers) that are distinguishable from the initial material and form a multiphase matrix resulting from additions, losses, transfers, and transformations of energy and matter; (2) the ability to support rooted plants in a natural environment (USDA NRCS 2010). The relative proportions of minerals, organic matter, water, and air largely determines the ability of the soil to support plant life (O'Neill et al. 2005).

Soil classification is based on soil properties observed in the field, inferred from field observations, or measured in a laboratory (USDA NRCS 2006). The general soil association units that occur in repeatable patterns on the landscape are mapped from broad-based soil inventories (USDA NRCS 2010). Figure 31 shows the distribution of the principal soil kinds in the North and the contiguous United States as classified and developed by the National Cooperative Soil Survey.

FIGURE 31
General soil map for the Northern States and the conterminous United States (USDA NRCS 2011).

Soil quality refers to the capacity of a soil to sustain biological productivity, maintain environmental quality, and promote plant and animal health (Doran and Parkin 1994). Concise definitions for soil quality include "fitness for use" and "the capacity of a soil to function." Combining these, soil quality is the ability of a soil to perform the functions necessary for its intended use. Soil functions include sustaining biological diversity, activity, and productivity; regulating water and solute flow; filtering, buffering, and degrading organic and inorganic materials; storing and cycling nutrients and carbon; and providing physical stability and support (Kuykendall 2008). Soil quality and land management both have a direct influence on water and atmospheric quality and, by extension, human and animal health (Doran and Parkin 1994, Kennedy and Papendick 1995).

Soil quality information helps answer several key questions about: (1) the productivity and sustainability of forest systems, (2) the conservation of soil and water resources, (3) the accumulation of persistent toxic substances, and (4) the contribution of forested systems to the global carbon cycle (O'Neill et al. 2005). For forestry as well as agriculture, maintenance of site productivity is vital to sustainable management.

Water

The factors that affect water quality and supply in forest ecosystems include climate and hydrology, catchment geology, natural disturbances, land management, and actual land-use activities. Water quality in undisturbed forested catchments can provide important baseline references for monitoring physical, chemical, or biological trends in catchments that have varying levels of land use, and can identify management activities that need to be altered to preserve water quality (USDA FS 2009a). The quality and quantity of runoff have long been a focus of forest management, which can have beneficial as well as detrimental effects, depending on the objectives, timing, techniques, and size of operations.

Much of the North's highest quality water supplies originate in forests (Brown and Binkley 1994). Forested watersheds provide

water purification, mitigation of floods and droughts, soil retention, and habitat maintenance. Surface water runoff in forest environments is rare with most rainfall and snowmelt moving into streams through subsurface flows, accelerating nutrient uptake, cycling, and contaminant absorption processes. The quality and abundance of fresh water in lakes, wetlands, streams, and rivers determine aquatic and terrestrial species biodiversity.

Forests are crucial to the protection of drinking water (Barnes et al. 2009). Managing forests for clean water production will grow in importance as the northern populations and water demand both increase. The water resource is also one of the many attractions for swimming, boating, canoeing, fishing, and other water-based activities. The enjoyment of these activities depends directly on the quality of the water resource. In addition, aquatic as well as terrestrial wildlife species depend on the water resource.

The North is characterized by a cool-moist-temperate climate, associated with the Lake States and higher elevations of the eastern Continental Divide. Although seasonally variable, these conditions produce large volumes of fresh water that support production of forest vegetation, provide water-based recreation opportunities, and supply the region's drinking water. Northern landscapes support the headwaters of most major eastern rivers, including the Mississippi. In the lower 48 States, although highlands and mountains constitute a relatively small land area proportion, they serve as "water towers" with water supplies originating at the tops of watersheds.

Water supplies and their uses are affected by population growth, economic trends, legal decisions, and climatic extremes such as droughts. Water is in effect a finite resource because few approaches for dramatically augmenting current water supplies are ecologically or economically viable (Barnes et al. 2009). While water shortages and restrictions are regular news in the West, they also occur in the North, particularly in urban areas. In addition to drought, the primary threat to water supplies in the North is loss of forest to development, agriculture, or other land uses.

As private lands continue to be developed, public and other protected forest lands will become more important as sources of high quality water.

Indicators of soil and water resource conservation for northern forests

Soil quality

Some disturbances and management practices can degrade forest ecosystem health and productivity by changing soil chemical or physical properties. As part of its Forest Inventory and Analysis plot network the Forest Service implements a national forest-soil monitoring program to address specific questions about the long-term sustainability of the Nation's forest soil resources (USDA FS 2011g). Although many soil and water metrics are available to gauge forest health (O'Neill et al. 2005), the focus here for northern forests is on chemical changes, compaction, and erosion.

Figure 32 shows the spatial distribution of calcium to aluminum (Ca:Al) molar ratios in northern forests. The map serves as a coarse filter for anticipating soils-related threats to forest health, one of which is increasing acidity in association with a decreasing Ca:Al ratio (indicating smaller calcium reserves and potentially toxic levels of exchangeable aluminum). This soil condition is strongly related to atmospheric acid deposition. Nutrient-poor and acidic forest soil conditions are found throughout the United States, but highly acidic soils with low calcium and high aluminum levels are concentrated in the Northeastern States and southward along the Appalachian Mountains. A continued decrease in the Ca:Al ratio could put calcium-sensitive tree species at risk of decline and die-off, with other site-specific factors influencing the outcome at any given location. Forests on soils with a low Ca:Al ratio may be

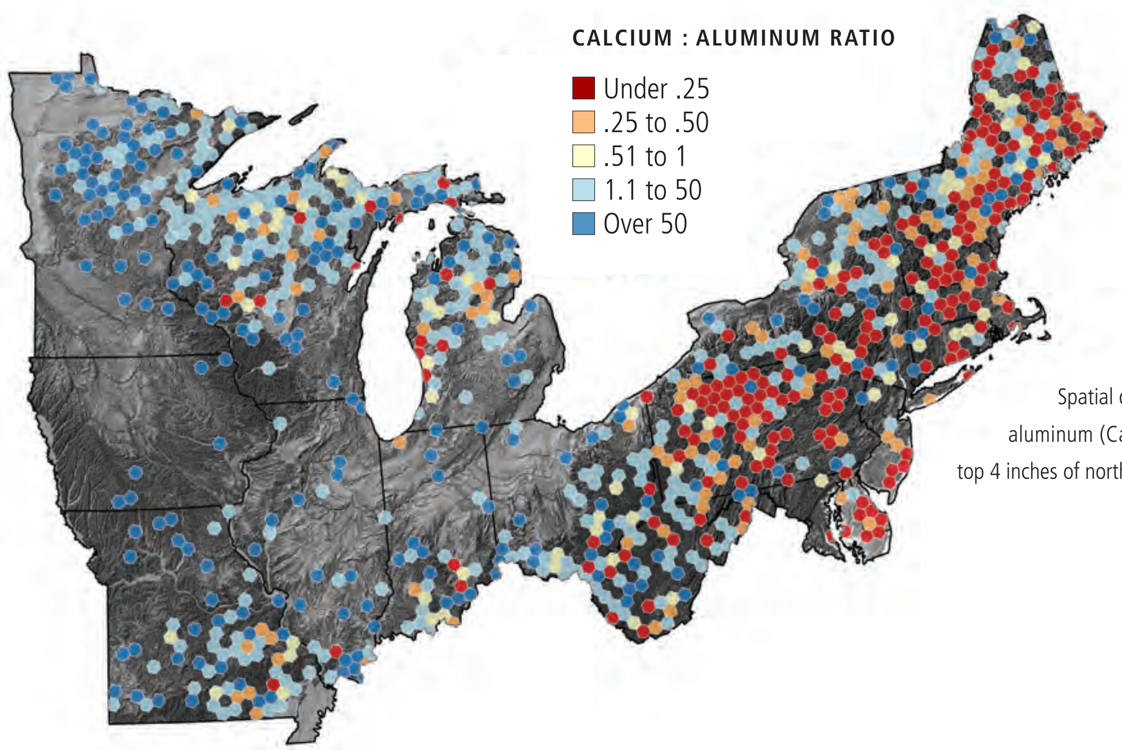


FIGURE 32

Spatial distribution of calcium to aluminum (Ca:Al) molar ratios in the top 4 inches of northern forest soils, 2000 to 2004 (USDA FS 2011g).

more susceptible to damage from additional stressors such as industrial inputs, drought, insects, and diseases (Cronan and Grigal 1995).

Forests protect the soil both directly and indirectly from wind and water erosion. Sites with exposed soil are at highest risk of accelerated soil erosion, but they represent only a small fraction of all forested lands. Although most forest inventory plots have at least some bare soil, few (0.4 to 5.5 percent) have more than 50-percent bare soil. Estimates of bare soil as a percentage of the forest floor provide an indirect measure of potential soil erosion, which reduces soil fertility, has offsite impacts, and decreases land values. Wind-caused erosion is rare in wooded areas, which are protected by forest canopy, strong soil tree root anchor support, and forest floor mulch (tree litter).

Soil compaction reduces pore space and decreases the volume of air in the soil. Compaction occurs when the mineral portion of the soil becomes compressed by heavy equipment or by repeated passes of light equipment, people, or animals. Only 0.3 to 4.7 percent of observed forest monitoring plots show evidence of compaction on more than half the plot area (Fig. 33). Thus, soil compaction is not so much a widespread problem on forested lands as it is a seemingly localized phenomenon that is largely confined to trails (walking, biking, hiking, equestrian, and motorized) and forest harvest operations (USDA FS 2011g).

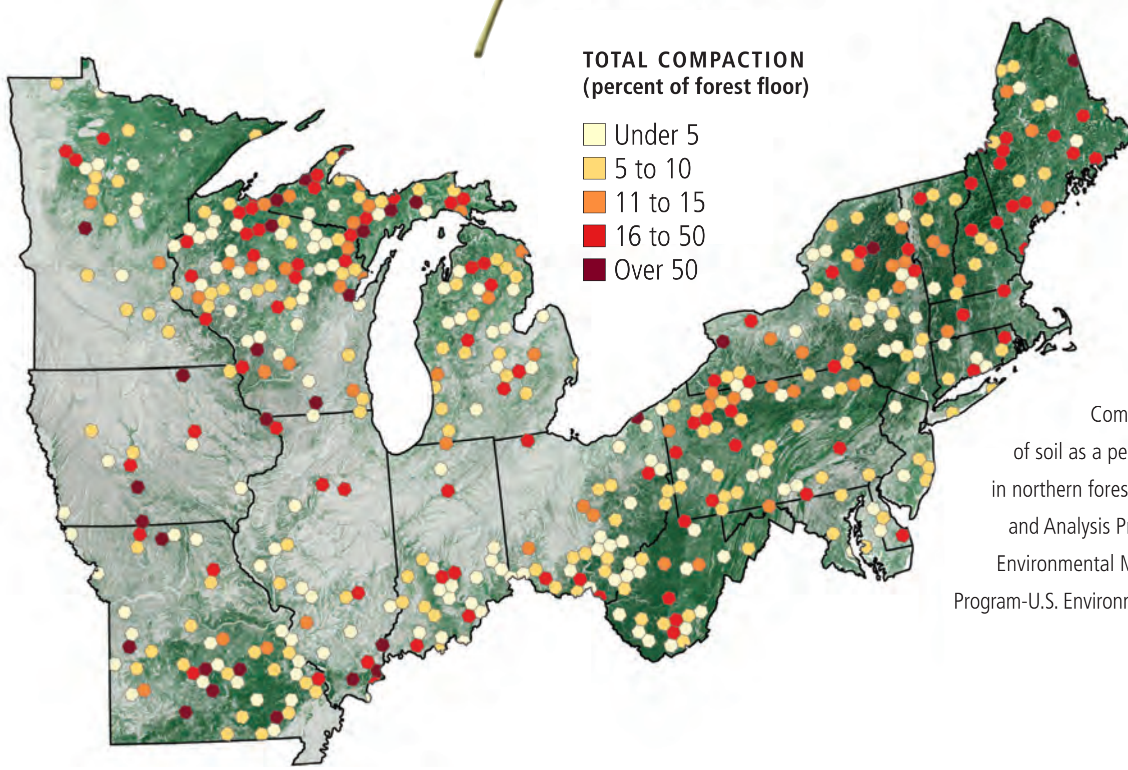


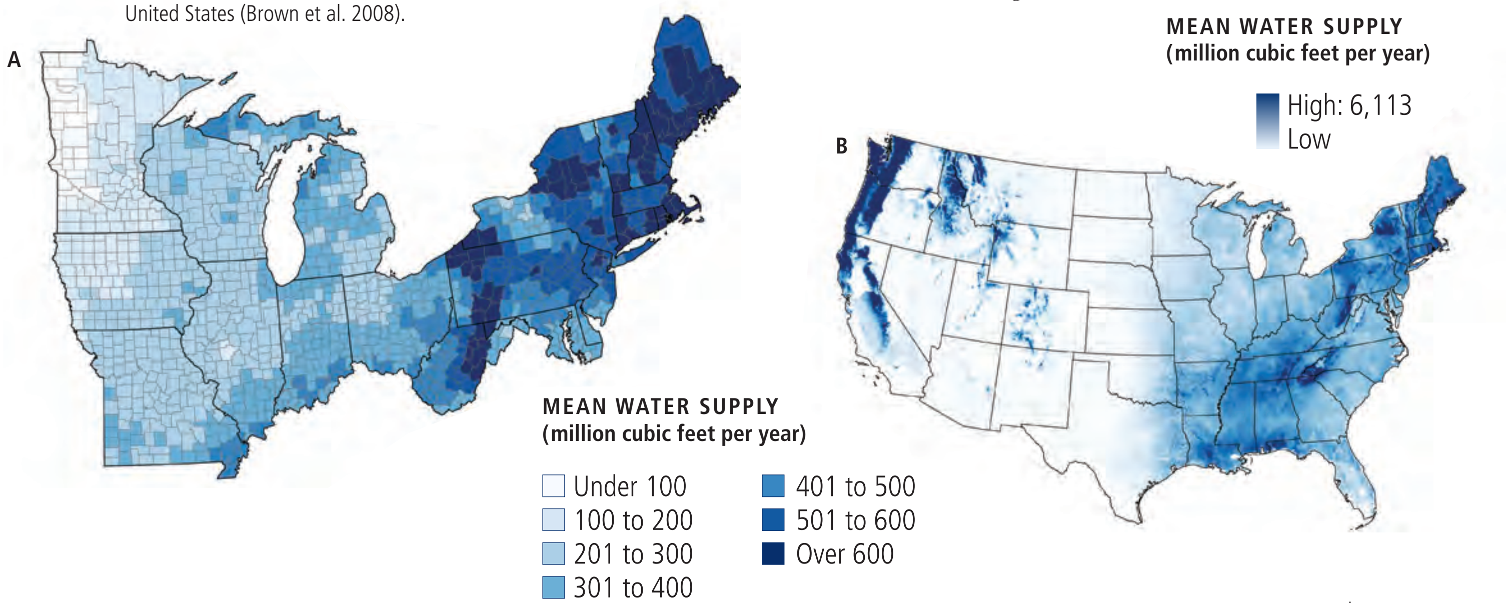
FIGURE 33
Compaction in the top 4 inches of soil as a percentage of the forest floor in northern forests (source: Forest Inventory and Analysis Program, U.S. Forest Service; Environmental Monitoring and Assessment Program-U.S. Environmental Protection Program).

Autumn colors surround
the Glade Creek Grist Mill in West Virginia

Compaction can have a variety of negative effects on soil fertility. Reduction in pore space makes the soil more dense and difficult to penetrate, and can constrain the size, reach, and extent of root systems; this can lead to structural failure of plants and destabilization of entire trees. Reduction in soil aeration and movement of fluids can reduce the ability of roots to absorb water, nutrients, and oxygen, thus resulting in shallow rooting and stunted tree forms. At the landscape scale, destruction of soil structure can limit water infiltration, resulting in increased runoff and of soil loss from erosion. In addition to changes in soil physical properties, compaction can also significantly impact biological and chemical processes occurring in the soil. For example, by reducing the oxygen content below what is required for adequate respiration, severe compaction can disrupt root metabolism and move the soil toward an anaerobic condition (O'Neill et al. 2005).

FIGURE 34

Yearly average water supply (precipitation minus evapotranspiration) by counties in the (A) Northern States and (B) conterminous United States (Brown et al. 2008).



Water supply and quality

Brown et al. (2008) have estimated annual water supply (precipitation minus evapotranspiration) for the conterminous United States (Fig. 34). The areas of largest water supply in the North are associated with dense forest cover (compare Fig. 34 with Figs. 1 and 4), particularly in the highlands and mountains that serve as natural water towers

An estimated 48 percent of the northern water supply originates on forest lands (Table 7), which cover 42 percent of the region's surface area, Approximately 6 percent of the northern water supply originates on Federal forest land, including 5 percent on national forests and national grasslands. The remaining 94 percent of the water supply from northern forests originates on from State and private lands (Table 8), compared to 65 percent for western forests. Public forest lands dominate in the West, where 66 percent of forests are in Federal ownership and 51 percent are national forests and national grasslands.

Table 7—Annual water supply in the conterminous United States by land cover class, region, and State (Brown et al. 2008). Proportions by column are given for regions and U.S. totals. Note that 1 million cubic meters of water is equivalent to approximately 811 acre-feet or 264 million gallons.

State and region	Forest	Rangeland	Agriculture	Water-wetland	Other	Total
	(million cubic meters)					
Connecticut	4,466	0	766	771	1,691	7,694
District of Columbia	18	0	0	0	63	81
Delaware	529	0	976	377	106	1,988
Iowa	2,393	1,772	25,327	863	945	31,300
Illinois	5,691	326	29,864	2,005	2,184	40,070
Indiana	6,442	135	22,887	999	1,273	31,736
Massachusetts	7,375	16	643	1,508	2,546	12,088
Maryland	4,087	0	3,732	971	829	9,619
Maine	40,569	291	2,411	5,318	2,281	50,870
Michigan	19,776	1,004	14,723	9,701	1,681	46,885
Minnesota	6,346	203	12,477	7,995	805	27,826
Missouri	14,842	209	31,852	2,274	1,542	50,719
New Hampshire	12,072	0	768	1,107	735	14,682
New Jersey	4,214	0	1,852	1,383	2,226	9,675
New York	43,133	0	14,240	3,944	3,754	65,071
Ohio	12,748	8	20,691	1,082	2,214	36,743
Pennsylvania	41,310	0	15,707	1,107	3,237	61,361
Rhode Island	1,198	0	53	242	345	1,838
Vermont	10,203	13	1,799	773	374	13,162
Wisconsin	14,760	155	15,944	4,659	889	36,407
West Virginia	26,548	0	3,639	195	700	31,082
North total	278,720	4,132	220,351	47,274	30,420	580,897
Proportion of North (percent)	48	1	38	8	5	100
Alabama	47,321	0	14,545	5,538	3,010	70,414
Arkansas	27,245	69	24,148	6,119	1,303	58,884
Florida	15,094	3,947	7,124	12,822	5,481	44,468
Georgia	35,955	116	13,252	6,133	4,472	59,928
Kentucky	29,720	0	16,728	1,613	1,323	49,384
Louisiana	18,217	278	17,182	17,506	2,434	55,617

Table 7 continued

State and region	Forest	Rangeland	Agriculture	Water-wetland	Other	Total
	(million cubic meters)					
Mississippi	32,512	10	21,885	8,506	2,320	65,233
North Carolina	34,087	0	11,540	6,122	2,580	54,329
Oklahoma	6,388	5,887	9,429	1,361	704	23,769
South Carolina	15,671	0	6,336	4,275	2,041	28,323
Tennessee	38,059	0	18,392	2,663	2,695	61,809
Texas	13,023	8,945	24,202	6,101	3,758	56,029
Virginia	25,743	0	8,817	1,876	1,719	38,155
South total	339,035	19,252	193,580	80,635	33,840	666,342
Proportion of South (percent)	51	3	29	12	5	100
East total (North and South)	617,755	23,384	413,931	127,909	64,260	1,247,239
Proportion of East (percent)	50	2	33	10	5	100
California	53,574	28,587	6,664	784	3,438	93,047
Oregon	78,293	7,899	6,679	977	3,931	97,779
Washington	87,885	7,695	3,032	2,898	11,641	113,151
Pacific Coast total	219,752	44,181	16,375	4,659	19,010	303,977
Proportion of Pacific Coast (percent)	72	15	5	2	6	100
Arizona	1,927	2,734	5	5	37	4,708
Colorado	9,453	11,301	508	224	1,073	22,559
Idaho	38,182	15,756	3,506	863	2,758	61,065
Kansas	378	5,283	9,834	579	390	16,464
Montana	27,805	15,167	2,509	546	2,593	48,620
North Dakota	9	951	2,899	200	30	4,089
Nebraska	16	3,769	7,178	366	171	11,500
New Mexico	2,537	2,826	74	11	38	5,486
Nevada	998	4,582	34	35	149	5,798
South Dakota	51	923	3,736	266	40	5,016
Utah	4,261	5,061	178	111	325	9,936
Wyoming	8,077	10,009	391	730	2,017	21,224
Interior West total	93,694	78,362	30,852	3,936	9,621	216,465
Proportion of Interior West (percent)	43	36	14	2	4	100
West total (Pacific and Interior)	313,446	122,543	47,227	8,595	28,631	520,442
Proportion of West (percent)	60	24	9	2	5	100
Conterminous U.S. total	931,201	145,927	461,158	136,504	92,891	1,767,681
Proportion of Conterminous U.S. (percent)	53	8	26	8	5	100

Table 8—Annual water supply in the conterminous United States by ownership, region, and State (Brown et al 2008). Proportions by column are given for regions and U.S. totals. Note that 1 million cubic meters of water is equivalent to approximately 811 acre feet or 264 million gallons.

State and Region	National Forest System	Bureau of Land Manage-ment	National Park Service	Bureau of Indian Affairs	Other Federal	State and Private	Total
	(million cubic meters)						
Connecticut	0	0	0	0	10	7,683	7,694
District of Columbia	0	0	6	0	3	72	81
Delaware	0	0	0	0	39	1,950	1,989
Iowa	0	0	1	4	153	31,141	31,299
Illinois	1,451	0	0	0	272	38,347	40,070
Indiana	1,005	0	9	0	378	30,345	31,737
Massachusetts	2	0	22	0	142	11,922	12,088
Maryland	0	0	80	0	146	9,393	9,619
Maine	199	0	65	79	184	50,343	50,870
Michigan	6,569	0	76	289	392	39,560	46,886
Minnesota	2,505	0	173	1,145	164	23,839	27,826
Missouri	3,490	0	130	0	458	46,642	50,720
New Hampshire	2,715	0	0	0	35	11,932	14,682
New Jersey	0	0	93	0	240	9,343	9,676
New York	30	0	15	164	420	64,441	65,070
Ohio	1,432	0	50	0	132	35,130	36,744
Pennsylvania	1,783	0	84	0	245	59,249	61,361
Rhode Island	0	0	0	0	10	1,828	1,838
Vermont	1,915	0	0	0	97	11,150	13,162
Wisconsin	2,177	0	85	668	220	33,257	36,407
West Virginia	4,990	0	132	0	136	25,824	31,082
North total	30,263	0	1,021	2,349	3,876	543,391	580,900
Proportion of North (percent)	5	0	0	0	1	94	100
Alabama	2,852	0	45	0	902	66,615	70,414
Arkansas	6,170	0	128	0	1,263	51,323	58,884
Florida	2,149	0	303	103	1,982	39,930	44,467
Georgia	5,329	0	53	0	1,676	52,870	59,928
Kentucky	4,183	0	204	0	874	44,123	49,384
Louisiana	1,713	0	38	1	1,379	52,485	55,616
Mississippi	5,303	0	7	35	828	59,060	65,233
North Carolina	8,825	0	1,031	170	1,180	43,123	54,329

Table 8 continued

State and Region	National Forest System	Bureau of Land Manage-ment	National Park Service	Bureau of Indian Affairs	Other Federal	State and Private	Total
	(million cubic meters)						
Oklahoma	714	0	7	864	866	21,318	23,769
South Carolina	2,034	0	34	0	621	25,634	28,323
Tennessee	2,949	0	1,036	0	1,864	55,960	61,809
Texas	2,373	0	157	3	1,000	52,496	56,029
Virginia	5,398	0	517	0	567	31,673	38,155
South total	49,992	0	3,560	1,176	15,002	596,610	666,340
Proportion of South (percent)	8	0	1	0	2	90	100
East total (North and South)	80,255	0	4,581	3,525	18,878	1,140,001	1,247,240
Proportion of East (percent)	6	0	1	0	2	91	100
California	43,317	5,096	5,878	978	1,568	36,210	93,047
Oregon	43,016	9,212	474	1,049	302	43,727	97,780
Washington	46,950	42	15,963	2,891	2,227	45,080	113,153
Pacific Coast total	133,283	14,350	22,315	4,918	4,097	125,017	303,980
Proportion of Pacific Coast (percent)	44	5	7	2	1	41	1.00
Arizona	2,517	213	93	949	35	902	4,709
Colorado	15,384	1,509	478	107	75	5,006	22,559
Idaho	41,372	3,498	131	1,755	297	14,011	61,064
Kansas	0	0	7	92	218	16,147	16,464
Montana	29,805	1,084	4,057	2,855	234	10,584	48,619
North Dakota	84	1	3	78	51	3,871	4,088
Nebraska	47	0	8	155	51	11,239	11,500
New Mexico	2,468	286	11	365	70	2,287	5,487
Nevada	2,159	2,698	71	46	243	581	5,798
South Dakota	146	2	12	502	26	4,328	5,016
Utah	6,903	801	34	133	27	2,040	9,938
Wyoming	11,270	1,578	4,542	539	127	3,168	21,224
Interior West total	112,155	11,670	9,447	7,576	1,454	74,164	216,466
Proportion of Interior West (percent)	52	5	4	3	2	34	100
West total (Pacific and Interior)	245,438	26,020	31,762	12,494	5,551	199,181	520,446
Proportion of West (percent)	47	5	6	2	1	38	100
Conterminous U.S. total	325,693	26,020	36,343	16,019	24,429	1,339,182	1,767,686
Proportion of conterminous U.S. (percent)	18	1	2	1	1	76	100

More than 52 million people and nearly 1,600 community water systems utilize surface water for municipal drinking water (Barnes et al. 2009). These water supplies are protected largely by private forest lands. Figure 35 illustrates the relative capacity of northern watersheds to produce clean water in juxtaposition to locations of private and public forests.

Many people are unaware of the threats and vulnerabilities to their water, or the connection between clean water and the extent and condition of the forests at the source of their water supplies (Barnes et al. 2009). Figure 36 displays an index of watershed indicators (US EPA 1996b, 2002) that characterizes the condition, vulnerability, and data sufficiency of the aquatic systems in each of 2,111 watersheds in the lower 48 United States. It provides a summary measure of overall watershed health based on 18 indicator variables (US EPA 2010), with three watershed condition scores (better water quality, water quality with less serious problems, and water quality with more serious problems), and two vulnerability scores (high and low).

About 23 percent of the 540 northern watersheds experienced more serious water quality problems with low vulnerability, 35 percent experienced less serious water quality problems with low vulnerability, and

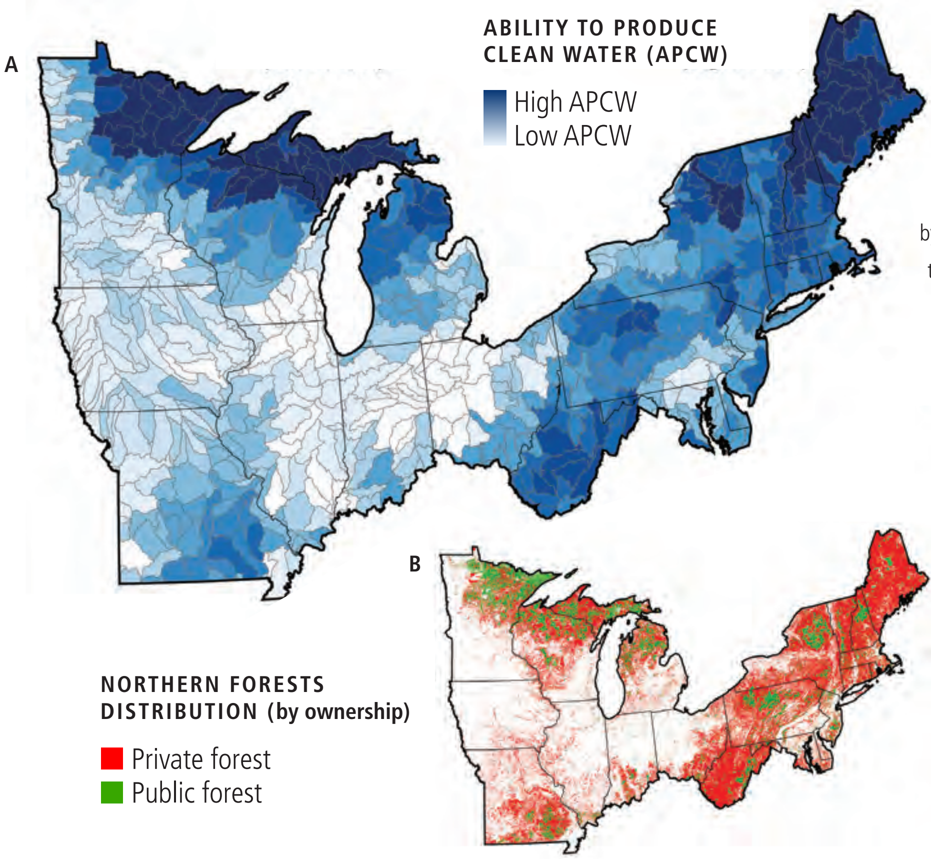


FIGURE 35

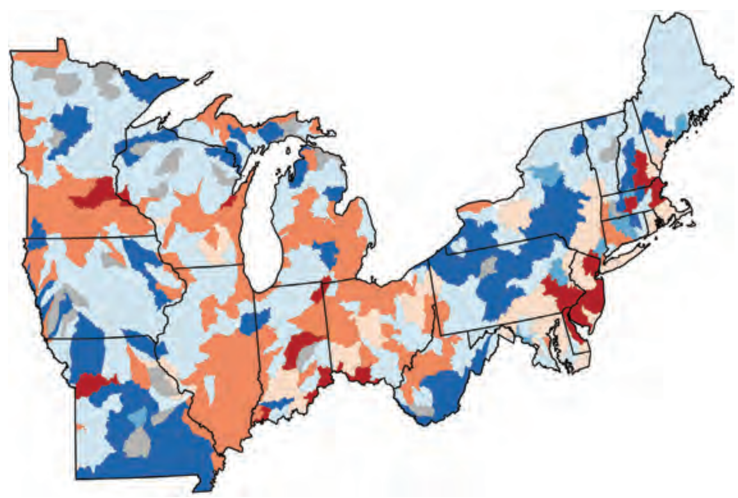
(A) Relative ability of 540 northern watersheds to produce clean water, represented by an index of water quality and watershed integrity that characterizes the biophysical condition of each watershed (Barnes et al. 2009, Homer et al. 2004, Protected Areas Center 2010); and (B) forest cover and ownership.

15 percent experienced better water quality with low vulnerability. Only 1.5 percent of the watersheds experienced better water conditions with high vulnerability. About 3 percent experienced less serious water quality problems with high vulnerability, and about 2 percent experienced more serious water quality problems with high vulnerability. Therefore, as the map illustrates, large areas of the northern watersheds may have potential water quality (as well as supply) problems. Some potential problem areas are in southern Illinois, Michigan, Minnesota, Indiana, New Hampshire; and Delaware, New Jersey, and Ohio.

One in 15 U.S. watersheds is highly vulnerable to further degradation (US EPA 2002). The following national indicators are similar to those of northern watersheds:

- Fifteen percent have relatively good water quality
- Thirty-six percent have moderate water quality problems
- Twenty-two percent have more serious water quality problems
- Twenty-seven percent do not have enough information to be characterized

The future abundance and quality of water supplies will not be ensured by a focus on water treatment alone. Protecting and managing forests in source watersheds is essential for providing clean, safe water (Barnes et al. 2009).



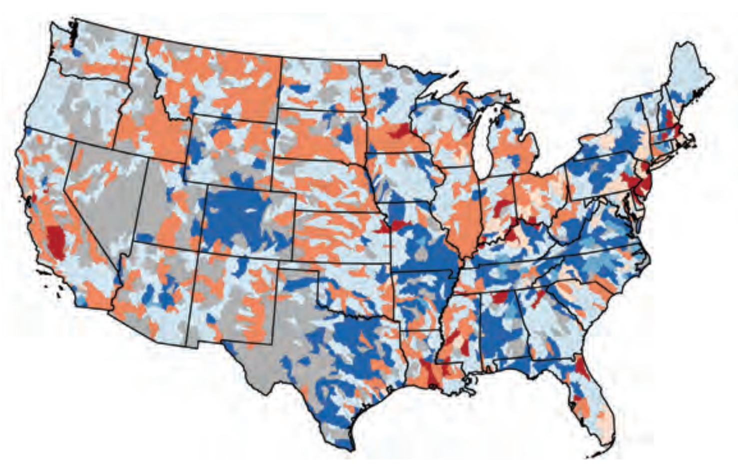


FIGURE 36

Watershed characterization—condition, vulnerability, and data sufficiency—in 1999 for (A) Northern States and (B) conterminous United States. Note that the strength of monitoring programs vary—areas with strong monitoring programs may show more problems than those with weaker programs (US EPA 2011).

NATIONAL WATERSHED CHARACTERIZATION - 1999

- More serious water quality problems - high vulnerability
- More serious water quality problems - low vulnerability
- Less serious water quality problems - high vulnerability
- Less serious water quality problems - low vulnerability
- Better water quality problems - high vulnerability
- Better water quality problems - low vulnerability
- Insufficient data