Conservation and Maintenance of Soil and Water Resources

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Introduction

FOREST ECOSYSTEM PRODUCTIVITY and functioning depend on soil and water resources. But the reverse is also true—forest and land-use management activities can significantly alter forest soils, water quality, and associated aquatic habitats (Ice and Stednick 2004, Reid 1993, Wigmosta and Burges 2001). Soil and water resources are protected through the allocation of land for that purpose or through appropriate management regimes and best management practices (Blinn and Kilgore 2001, Young 2000). Because the biophysical linkage between soils and hydrological functions is strong, conservation land-use designations and best practices for forest management usually combine soil and water conservation objectives (California Department of Forestry and Fire Protection 2014, Minnesota Forest Resources Council 2013). In the absence of widespread, long-term direct measures of water and soil condition, information on land use, management activity, and application of best practices can serve as useful indicators of efforts to conserve soil and water resources.

Soil

Human society depends on soils for many essential services, which Blum (2005) categorized into six environmental, social, and economic functions: (1) biomass production, (2) protection of humans and the environment, (3) gene reservoir, (4) physical basis for human activities, (5) source of raw materials, and (6) soil and cultural heritage. Of these, the first three are most important from an environmental perspective:

- Biomass production is the aspect of soils that addresses the production of food, fiber, and fodder (Foley et al. 2005, Matson et al. 1997).
- The protection of humans and the environment includes those functions where soils filter, buffer, and transform water and gases among the terrestrial, hydrologic, and atmospheric systems—described narrowly by Gilliam (1994) and more broadly by Lowrance et al. (1984). Not all transformations are positive; for example, soil microbes convert elemental mercury to methyl mercury which bioaccumulates in the food chain (Jeremiason et al. 2006, Mitchell et al. 2008).
- As a gene reservoir, soil biota are critical to nutrient mineralization, which supports plant productivity (Van Der Heijden et al. 2008).

Key Findings

- Forest ecosystem productivity and function depend on soil and water resources. Forest and land-use management activities can significantly alter forest soils, water quality, and associated aquatic habitats.
- Across the Northern States, 76 million people depend on public and private forests for high quality water supplies.
- Thirty-six million acres (21 percent) of northern forest land is under Federal and State management.
- For private forest lands, which account for most of the forest land area in the North, Forest Stewardship Management Plans are of particular value in helping forest owners manage their resources sustainably; excluding land held by the forest products industry, 10 percent of private acreage is managed under such plans, but the covered area for individual States ranges from <5 percent to >30 percent.
- All Northern States except Minnesota have suboptimal conditions for one or more soil attributes on ≥50 percent of their survey plots; Delaware and Maryland have the largest number of plots with soil conditions that limit potential tree growth.
- The 10 States with the highest levels of suboptimal soil conditions are all located in the East.
- Only 2 of 551 northern watersheds have water supplies that currently are inadequate to meet societal demands, a number that is projected to increase substantially by 2060.
- Watersheds with the potential to produce high quality water tend to be found in forested regions of the upper Midwest, New England, and along the Appalachian Mountains; watersheds with relatively low potential to produce high quality water are located in the Midwest.
- State and Federal forest land area is expected to remain relatively constant for the next 50 years; however, expanding human populations are expected to place more pressure on public lands for freshwater supplies and other benefits.
- Under a future of moderately growing population and rapidly growing income, urban areas are projected to increase by 78 percent and forest areas are projected to shrink by 6 percent.
- Although total area of Federal and State forest land in the North is projected to remain stable through 2060, the relative area of 0.29 acres per person is projected to decrease to 0.23 acres per person due to increasing human population.
- On average for all northern watersheds, the amount of water used to meet societal demands is projected to increase under most future scenarios; for most watersheds, supplies would remain adequate, but the number of watersheds with the potential for shortfalls likely would increase.
- By 2060, the potential to supply high quality water is projected to decline for most watersheds in the North.
- At a regional scale, climate projections had more impact on future water supply and stress than did land-use or population projections, but there were some exceptions for individual watersheds.

Because soil is a limited resource, its six functions need to occur in appropriate spatial and temporal combinations to ensure its sustainability (Blum 2005).

Soils are dynamic and are commonly described as the result of five factors: climate, organisms, topographic relief, geologic parent material, and the passage of time (Jenny 1941). Understanding which of these factors are likely to remain stable and which are subject to change is critical to projecting future forest soil resources. Of the five soil-forming factors, global climate change and land-use change—two factors that are highly variable even in the current environment—will most strongly influence climate and organisms. Topographic relief and parent material can both change over geologic time, but they are relatively stable over human time scales, except when altered by direct human activities (such as surface mining or construction). One notable exception is the formation of soil along riparian corridors, where changes in river flow and sediment delivery resulting from land-use or climate change would influence the formation and character of future soils.

Climate influences soil formation and properties in two primary ways: temperature and precipitation. Temperature influences the physical, chemical, and biological processes that first transform raw parent material (such as sand, clay, and rock) into soil and then guide the development of the soil profile. Precipitation, both the total amount and the intensity of individual events, influences the transport of minerals through the soil profile to deeper horizons and eventually to local streams and other surface waters. Also, excessive water can lead to anaerobic conditions that again influence the physical, chemical, and biological processes in soil. Some soil properties change along a continuous temperature and precipitation gradient, but others strongly respond to thresholds, as reported by Dahlgren et al. (1997) in a study that placed the threshold along the effective winter snow line for soils in the California Sierra Nevada, thus reinforcing Jenny's (1941) conclusion that changes in climate can produce changes in soil properties. Such changes in soil properties could result in trees becoming nutrient stressed as changes also occur in the underlying cycles and interactions of essential mineral cycles (St. Clair et al. 2008). Of particular concern is the availability of soil minerals to trees, particularly in landscapes that experience precipitation decreases along with temperature increases. Oren et al. (2001) reported that soil nutrient and water deficits could limit tree growth responses to carbon dioxide enrichment. In addition, Saxe et al. (1998) reported that nutrient uptake by roots occurs primarily in the soil solution, and uptake can be greatly reduced with increasing drought events.

Organisms are important to soils. Not only do animals and plants modify the landscape in which they live, but they are also subject to climate and land-use changes, further exacerbating direct influences of climate and land use on soils. Observing forests developing on similar parent material, Finzi et al. (1998) found that community dynamics significantly influence surface soil acidity and base cation availability, thus altering potential plant productivity.

Another important contributor to forest soils is the glaciation that covered most of the northern landscape; these events essentially restarted the process of soil formation and plant succession.

Many plants and animals can migrate across great distances, an ability that some important soil forming organisms lack. Earthworms, which are nonnative throughout much of the North, are very slow colonizers. But these species have a profound influence on forest soils. Holdsworth et al. (2007) found that one of the best predictors of nonnative earthworm invasion is the distance to nearest road (Wisconsin) or cabin (Minnesota). Humans clearly play a role in the introduction of these nonnative "ecosystem engineers." Hale et al. (2005) found that the introduction of European worms to northern forests greatly reduces forest floor thickness, even to the point of complete removal. The invasion of nonnative earthworms could increase the pressure placed on forests already stressed by changing climates (Bohlen et al. 2004).

One of the concerns about land-use and climate change impacts on soils is the potential for feedback loops. According to Eswaran et al. (1993), the amount of organic carbon stored in soil is three times larger than what is stored in aboveground biomass, and double what is stored in the atmosphere. Although little is known about the potential complex feedbacks between a changing climate and soil carbon stocks, Davidson and Janssens (2006) reported that wetland, peatland, and permafrost soils are the most vulnerable to changing land-use and climate patterns.

Water

Adequate and reliable water supplies are critical to the proper functioning of social, economic, and ecological systems, all of which depend on forested watersheds for a broad range of aquatic benefits (or ecosystem services): freshwater supplies, stream-flow regulation, water-quality maintenance, and habitat for fish and other organisms. To varying degrees across the North, 76 million people rely on public and private forests for high quality water supplies (USDA FS 2005). Understanding the links among forests, water resources, and people is critical both for developing forest protection and management policies across the United States (Steen 2004). Many forest management policies and practices are designed to reduce negative impacts on water resources or improve conditions in places where disturbances have occurred (Aust and Blinn 2004).

As populations continue to grow in the region (Zarnoch et al. 2010), policy makers and managers need information about the potential effects of changing climate and land-use patterns on the ability of forested watersheds to supply sufficient water to this burgeoning population (Chapter 2).

Changing climate and land-use patterns have direct impacts on the quantity and quality of water resources at multiple scales. As temperatures increase, increasing rates of water loss through evapotranspiration can reduce the surface-water volume levels (Gleick 2000, Levin et al. 2002, National Assessment Synthesis Team 2000). However, volume will also be impacted by changes in the amount, timing, and variability of precipitation in addition to the frequency and intensity of storm events (Gleick 2000, Levin et al. 2002, National Assessment Synthesis Team 2000). Assessments of future water supplies also need to account for changes in land cover and land-use patterns, which have been shown to greatly affect the water balance in long-term watershed studies (Ford et al. 2011, Piao et al. 2007, Swank and Douglass 1974).

Changing land-use patterns can also affect water quality. Land-use conversions can change landscape-level forest composition and structure and can increase loading of sediments and other potential pollutants (Osborne and Kovacic 1993).

In particular, urbanization changes the quantity and character of trees and forests and increases the area of impervious surfaces (such as roads and parking lots). This reduces the ability of precipitation to infiltrate the soil (Sun and Lockaby 2012), resulting in an increase in the amount of surface runoff and, consequently, in the amount of sediment being delivered to streams (Booth and Jackson 1997). Other pollutants could also increase with an increase in urbanization. For example, wastewater and fertilizers increase phosphorous concentrations in urban streams (Paul and Meyer 2001), and in the western Great Lakes, turbidity is correlated with tree canopy disturbances and phosphorus is correlated with the amount of urban acreage in a watershed (Seilheimer et al. 2013).

Forest management practices can affect both the quantity and quality of water (National Research Council 2008), with impacts varying across areas, forest and treatment types, soils, climate, and harvesting intervals. As an example of effects on quantity, canopy removal during harvesting can reduce evapotranspiration levels, increasing water yield. This effect is usually transient, however, as the regrowth of young forest eventually results in a decrease of water yield. With respect to water quality, disturbances to soil during forest management activities could result in greater sediment delivery to surface waters. Recognition of the links between forest management practices and water resources has led to the development of best management practices (page 152) that focus on minimizing or eliminating deleterious effects (Aust and Blinn 2004).

Across the region, providing for future population and economic growth while meeting biodiversity conservation goals will require sufficient quantities of high quality water. Assessments of water quantity and quality under a range of plausible future climate and land-use scenarios answer a range of questions, including how levels of water quantity and quality might change in the future, where these changes might be the greatest, and whether water supplies will be sufficient to meet human demands. Answers to these questions will help inform policy and management decisions that could alter the trajectories of changing climate and land-use patterns.

INDICATORS OF SOIL AND WATER CONSERVATION AND MAINTENANCE

Some indicators of soil and water conservation and maintenance can be addressed using available data, for both current conditions and future projections, but others are much more difficult to project. For example, quantifying current acreage of lands enrolled in conservation easements and incentive programs is feasible, but predicting the future direction of legal, institutional, and policy conditions that affect these programs is much more difficult; so for these and other indicators, future conditions cannot be reliably predicted (Chapter 9).

Where Forest Management Focuses on Soil and Water Protection

The extent to which soil (land) and water resources in forested areas are protected by legislative or administrative designation or where their protection is the primary management focus is one indicator of forest sustainability. Such designations or management protections guard against degradation of soil resources, maintain soil quality, and prevent impairment of water supplies intended for public consumption (USDA FS 2011). A closely related indicator examines the proportion of forest management activities that meet best management practices or other relevant legislation to protect soil and water resources. Chapter 9 provides additional information about voluntary certification programs designed to protect soil and water resources, as well as the legal, institutional, and economic framework for forest conservation and sustainable management.

Because of the strong biophysical link between soils and hydrological functions, conservation land-use designations and best practices for forest management usually combine soil and water conservation objectives. Because data for these indicators was not available, information from State forestry reports of management activity and land-use designations was used.

The lack of consistency among reporting protocols presented considerable challenges in addressing the indicators across an entire region (Carpenter 2007) and complicated efforts to predict public and private forest land-use patterns, practices, laws, and regulations and their associated impacts over the next 50 years. However, this is not to downplay the challenges of expanding human populations with resulting pressures on land and water resources. We simply describe best management practices and stewardship plans. Using a moderate population forecast, we show that increases in the forested land base over the last century are coming to an end, and per capita decreases are projected for the future. The public land ownership footprint is relatively small on the northern landscapes, and the private sector is where most land-use change and forest management will happen. The magnitude of forest area losses can have implications for the natural processes critical to ecosystem health as well as the environmental services that derive from clean air, water quality, and carbon storage (Carpenter 2007).

Stewardship Challenges for Private Forests

The northern forest landscape has been shaped by the stewardship ethic observed by generations of private landowners, local conservation and recreation groups, and public agencies. Lessons were learned from overzealous harvesting at the end of the 19th century. Now the lands and waters that will be needed to meet current and future conservation and recreation demands are under pressures unknown a generation ago.

Private lands that once supported high-quality family farmlands, working forests, and wetlands are now being converted to a variety of other uses (Chapter 10). The rural countryside is being divided into smaller parcels as an increasing number of people can afford a 10-, 20- or 40-acre private getaway. Often, this parcellation (Chapter 3) is self-fulfilling—the more that areas become fragmented, the more pressure there is to subdivide remaining parcels (Wisconsin DNR 2010).

Because most northern forest land is in private ownership (74 percent), private forest lands may well provide the bulk of wood products and other accessible natural resource raw materials like sands, gravels, oil, and gas minerals. Thus, they deserve careful consideration and thoughtful conservation measures to preserve soil and water benefits into the future. Partnerships involving government and nongovernment organizations, companies, and individuals are not only desirable but also necessary for the conservation and maintenance of forest ecosystems and the economic and social benefits that derive from them. Laws, regulations, and voluntary approaches all have a place in efforts to achieve sustainability (Carpenter 2007, Chapter 9).

Unlike governments that manage their forests with specialized staffs and resources, private citizens with small parcels often lack resources for developing their own plans for resource management. State and Federal agencies make an effort to provide technical assistance, help landowners recognize special areas, and support them in managing these areas for special values. In today's environment, progress toward sustainability requires continuous public awareness and discourse.

Based on a review of public programs and options for private forestry, Sampson and DeCoster (1997) concluded that Federal support is not keeping pace with changing demographics. In effect, the mosaic of U.S. forests, including those in the North, is managed by owners who have diverse cultural backgrounds and objectives and who operate within a complex framework of Federal, State, and local laws and regulations, private-property rights, and public land-management policies. Understanding the linkages among these factors and their aggregate impact is critical to understanding future forest sustainability.

Sampson and DeCoster (1997) recommend expanding service to rapidly developing communities and suggest more sophisticated marketing by policy leaders to target the needs of specific audiences. Implementing such a strategy would require more detailed information on forest landowners and the relationship between communities and the forest resource; however, inadequate funding for investments in marketing is cited as the major impediment to adopting these changes (Carpenter 2007).

More detailed information about forest ownership, management, and stewardship can be found in Chapter 9.

Best Management Practices

Best management practices are recommendations for working on the land. Forestry best management practices include a set of preventative measures designed to control or reduce the movement of sediment, nutrients, pesticides, or other pollutants from soils to surface waters (Aust and Blinn 2004). They capture and maintain a collective wisdom about how to protect the environment during operations such as harvesting and road building. They are meant to guide and regulate daily routine activities undertaken in the course of the (often) small projects that, taken together, alter stands, landscapes, and regions. They are designed to avoid excessive loss of productive soils from the landscape and to protect receiving surface waters from the excess sediment loads that result from accelerated erosion.

Best management practice categories include preharvest, stream management, logging roads, stream crossings, site preparation, chemical use, roads-to-bed, and wetlands (USDA FS 2011). All Northern States have some form of best management standards and guidelines across three general areas of management: silviculture, water (wetlands) and soils, and wildlife or biodiversity (Table 6.1). They can be voluntary or mandatory and can take the form of recommendations, guidelines, or standards. Once established, their effectiveness depends on whether they are maintained and whether their use is promoted (USDA FS 2011).

Table 6.1—Forest management standards and guidelines and their monitoring across ownership types for the North (Shifley et al. 2012); whether standards and guides are mandatory or voluntary; and whether the purpose of monitoring is for compliance with the standard or guideline or for effectiveness of the standard or guideline. (Note that information for Connecticut was missing from Shifley et al. [2012], but is included here.)

State	Standard or guideline					
	Silviculture		Water, soils		Wildlife, biodiversity	
	State forests	Private forests	State forests	Private forests	State forests	Private forests
Connecticut	Voluntary; no monitoring	Voluntary; no monitoring	Mandatory; monitor for compliance	Mandatory; monitor for compliance	Voluntary; no monitoring	Voluntary; no monitoring
Delaware	Mandatory; monitor for compliance	None	Mandatory; monitor for compliance	Mandatory; monitor for compliance	None	None
Iowa	Mandatory; monitor for compliance, effectiveness	Voluntary; no monitoring	Mandatory; monitor for compliance, effectiveness	Voluntary; no monitoring	Mandatory; monitor for compliance, effectiveness	Voluntary; no monitoring
Illinois	Monitor for effectiveness	Voluntary; no monitoring	Monitor for effectiveness	Voluntary; no monitoring	None	None
Indiana	Mandatory; no monitoring	Voluntary; no monitoring	Mandatory; monitor for compliance, effectiveness	Voluntary; no monitoring	Mandatory; no monitoring	Voluntary; no monitoring
Massachusetts	Mandatory; monitor for compliance, effectiveness	None	Mandatory; monitor for compliance, effectiveness	None	Mandatory; monitor for compliance, effectiveness	None
Maryland	Voluntary; monitor for compliance, effectiveness	None	Mandatory; monitor for compliance, effectiveness	Mandatory; no monitoring	None	None
Maine	Voluntary; monitor for compliance, effectiveness	None	Voluntary; monitor for compliance, effectiveness	Voluntary; monitor for compliance, effectiveness	Voluntary; monitor for compliance, effectiveness	None
Michigan	Monitor for compliance	None	Mandatory; monitor for compliance	Voluntary; no monitoring	Mandatory; monitor for compliance	None
Minnesota	Voluntary; monitor for compliance	Voluntary; monitor for compliance	Voluntary; monitor for compliance	Voluntary; monitor for compliance	Voluntary; monitor for compliance	Voluntary; monitor for compliance

Table 6.1 continued

State	Standard or guideline					
	Silviculture		Water, soils		Wildlife, biodiversity	
	State forests	Private forests	State forests	Private forests	State forests	Private forests
Missouri	Monitor for compliance, effectiveness	Voluntary; no monitoring	Mandatory; monitor for compliance, effectiveness	Voluntary; no monitoring	Mandatory; monitor for compliance, effectiveness	Voluntary; no monitoring
New Hampshire	Voluntary; no monitoring	Voluntary; no monitoring	Mandatory; monitor for compliance	Mandatory; monitor for compliance	None	None
New Jersey	Monitor for compliance, effectiveness	Voluntary; monitor for compliance	Mandatory; monitor for compliance	Mandatory; monitor for compliance	Monitor for compliance	Voluntary; monitor for compliance
New York	Monitor for compliance	Voluntary; no monitoring	Monitor for compliance	Voluntary; no monitoring	Monitor for compliance	Voluntary; no monitoring
Ohio	Mandatory; monitor for compliance	Mandatory; no monitoring	Mandatory; monitor for compliance	Mandatory; no monitoring	Mandatory; monitor for compliance	Mandatory; no monitoring
Pennsylvania	Mandatory; monitor for compliance	Voluntary; no monitoring	Mandatory; monitor for compliance	Mandatory; monitor for compliance	Mandatory; monitor for compliance, effectiveness	Voluntary; no monitoring
Rhode Island	Mandatory; monitor for compliance, effectiveness	Voluntary; monitor for compliance	Mandatory; monitor for compliance, effectiveness	Voluntary; monitor for compliance	Mandatory; monitor for compliance	Voluntary; no monitoring
Vermont	Voluntary; no monitoring	Voluntary; no monitoring	Mandatory; monitor for compliance	Mandatory; monitor for compliance, effectiveness	Voluntary; no monitoring	Voluntary; no monitoring
Wisconsin	Voluntary; monitor for compliance	Voluntary and mandatory; monitor for compliance	Voluntary and mandatory; monitor for compliance, effectiveness	Voluntary and mandatory; monitor for compliance, effectiveness	Voluntary and mandatory; monitor for compliance	Voluntary and mandatory; monitor for compliance
West Virginia	None	Voluntary; no monitoring	Mandatory; monitor for compliance	Mandatory; monitor for compliance	None	Voluntary; no monitoring

Forest Stewardship Management Plans

Forest stewardship management plans are particularly valuable in helping private forest owners manage their resources sustainably. Consulting foresters or State forestry staffs work with landowners to assess resources, determine management goals that include best management practices, and develop plans for operations and activities (including harvesting, timber stand improvement work, and wildlife habitat protection and maintenance). Ideally, the consulting forester is both a sounding board to help owners clarify their goals and intentions, and a source of expert and practical information about the potential for ensuring sustainability while pursuing other desired outcomes (Shifley et al. 2012). To meet the Federal standards, forest stewardship management plans must include consideration of soil stability and water quality.

As a case in point, many different methods are available for harvesting and removing trees from forest areas, and the way they are applied affects the kinds and degrees of impacts on ecosystems. For example, timber harvesting is known to remove soil nutrients—especially the base cations calcium, magnesium, and potassium—as part of the fiber removed from the site, and to increase the exposure of soil and residues to light, heat, and moisture. This results in accelerated decomposition of organic matter and some small acceleration of chemical weathering of inorganic minerals in soils and rocks, increasing the availability of nutrients for transport. Nitrogen, which normally would be taken up by living trees in the form of ammonium, is converted by soil microbes to nitrate, a form of nitrogen easily transported in water. This conversion results in a temporary flush of hydrogen atoms that replace base cations on soil particles and cause nutrients to move into the soil solution where they become susceptible to leaching. Stewardship plans that target soil organic matter content and nutrient stores would address issues related to timber harvesting (timing and intensity), land-use history, and the effects of potential nutrient losses resulting from soil erosion (Carpenter 2007).

Variations in the number of forest stewardship plans among States largely reflect differences in the amount of forest acreage and the number of owners, but States also differ in the degree of emphasis they place on stewardship planning in relation to other priorities. Because technical assistance from professional foresters is central to plan development, the number of plans and the number of acres covered are both sensitive to changes in the Federal and State funding that determines their availability (Shifley et al. 2012). An increasing number of landowners (with increasingly smaller landholdings) is also a critical challenge for those providing the needed technical assistance. About 10 percent of all northern nonindustrial private forest acreage (acreage not owned by forest products companies) is managed under stewardship plans, but the covered area for individual States ranges from <5 percent to >30 percent (Table 6.2).

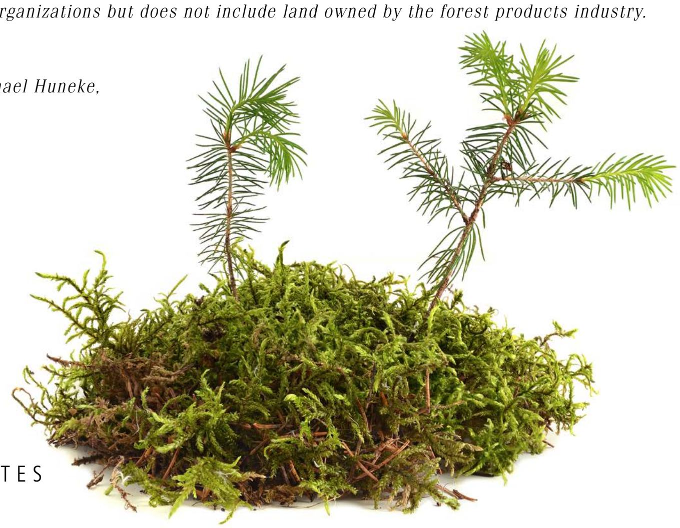
Table 6.2—Cumulative area of private forest land in the North that is covered by active forest stewardship plans, 2010 (Shifley et al. 2012).

State	Area		
	Total forest area[ab]	Cumulative area under forest stewardship plans[c]	
	(thousand acres)	(thousand acres)	(percent)
Wisconsin	9,674	2,985	31
New Hampshire	2,844	634	22
Maryland	1,462	324	22
Illinois	3,509	628	18
Delaware	244	39	16
Minnesota	5,921	860	15
New Jersey	805	115	14
Massachusetts	1,998	276	14
Indiana	3,588	463	13
Iowa	2,511	295	12
Ohio	6,064	520	9
New York	12,190	975	8
Pennsylvania	9,603	531	6
West Virginia	7,174	270	4
Vermont	3,109	110	4
Connecticut	1,148	39	3
Maine	6,261	210	3
Missouri	11,755	343	3
Rhode Island	251	7	3
Michigan	9,458	203	2
Northern U.S. total	99,569	9,828	10

[a]*Includes family farms, real estate investment trusts, and timber investment management organizations but does not include land owned by the forest products industry.*

[b]*From Smith et al. (2009).*

[c]*From State data in the Performance Measurement Accountability System, provided by Michael Huneke, U.S. Forest Service.*



Other Conservation Efforts

Many Federal, State, and local laws are in place to conserve and protect special environmental, cultural, social, or scientific values. Agencies regulate against harm to special resources like soil, fisheries, water quality, watershed protection, air quality, and species at risk. They acquire or administer lands for special purposes, or provide technical assistance on how to mitigate the adverse impacts of forest management on special resources. For example, maintenance of soil and site quality is written into the management plan of every national forest, with monitoring protocols designed to detect forest-productivity losses that are ≥15 percent (Powers et al. 1990).

FOREST LAND WITH SIGNIFICANT SOIL DEGRADATION

Trees grow in response to available light, water, and nutrients. Tree stress increases when nutrient levels are suboptimal. Cronan and Grigal (1995) demonstrated that calcium/aluminum ratios measured in soil solution are useful indicators of tree stress, and Page-Dumroese et al. (2010) summarized the science of soil monitoring for managers of national forests and rangelands. In this analysis of suboptimal soil conditions, indicators of soil quality developed by Amacher et al. (2007) were applied to survey plots maintained by Forest Inventory and Analysis (Table 6.3).

Table 6.3—Percentage of forest inventory plots, 2000-2005, in the North that were reported to have suboptimal soil conditions (FIA data).

Soil Quality Indicator	Connecticut	Delaware	Illinois	Indiana	Iowa	Maine	Maryland	Massachusetts	Michigan
				At 0- to 10-cm depth (percent)					
Phosphorus[a] < 15 mg/kg	62	84	70	91	64	78	100	73	73
Phosphorus[b] < 10 mg/kg	NA[c]	NA	60	75	25	NA	NA	NA	33
Exchange aluminum > 100 mg/kg	92	83	14	35	0	81	88	81	27
Exchange calcium < 100 mg/kg	46	66	7	4	0	37	75	50	17
Exchange potassium < 100 mg/kg	69	76	41	65	19	79	88	69	81
Exchange magnesium < 50 mg/kg	54	62	10	17	0	60	75	69	45
Organic carbon < 1 percent	0	0	0	6	0	1	0	0	6
Total nitrogen < 0.1 percent	8	14	7	11	5	4	25	13	23
Water pH less than 4.0	0	59	0	0	0	25	25	31	8
				At 10- to 20-cm depth (percent)					
Phosphorus[a] < 15 mg/kg	69	90	75	91	53	84	83	82	70
Phosphorus[c] < 10 mg/kg	NA	NA	60	75	40	100	NA	NA	77
Exchange aluminum > 100 mg/kg	85	83	37	54	5	74	88	81	22
Exchange calcium < 100 mg/kg	77	90	11	24	0	61	75	81	40
Exchange potassium < 100 mg/kg	100	97	63	85	32	95	100	94	95
Exchange magnesium < 50 mg/kg	85	90	11	39	3	81	100	88	65
Organic carbon < 1 percent	23	10	26	20	11	5	0	0	34
Total nitrogen < 0.1 percent	46	55	49	44	22	14	88	19	57
Water pH < 4.0	0	28	0	0	0	7	0	6	2

[a]*Test performed according to Bray and Kurtz (1945).*

[b]*Test performed according to Olsen et al. (1954).*

[c]*NA = no data available.*

Table 6.3 continued

Soil Quality Indicator	Minnesota	Missouri	New Hampshire	New Jersey	New York	Ohio	Pennsylvania	Rhode Island	Vermont	West Virginia	Wisconsin
At 0- to 10-cm depth (percent)											
Phosphorus[a] < 15 mg/kg	44	88	77	100	76	88	80	50	89	96	49
Phosphorus[b] < 10 mg/kg	13	88	NA[c]	NA	50	100	NA	NA	NA	NA	22
Exchange aluminum > 100 mg/kg	24	20	85	50	67	35	85	100	63	58	32
Exchange calcium < 100 mg/kg	1	9	35	63	20	5	43	0	40	14	8
Exchange potassium < 100 mg/kg	48	49	74	88	64	49	72	0	90	54	74
Exchange magnesium < 50 mg/kg	11	14	65	88	42	19	70	0	63	31	26
Organic carbon < 1 percent	3	4	0	0	1	0	5	0	3	0	4
Total nitrogen < 0.1 percent	13	11	3	50	4	2	4	0	10	17	21
Water pH less than 4.0	2	0	18	50	33	2	30	0	23	10	5
At 10- to 20-cm depth (percent)											
Phosphorus[a] < 15 mg/kg	52	90	86	80	83	90	81	100	86	90	56
Phosphorus[c] < 10 mg/kg	64	80	NA	NA	0	100	100	NA	NA	NA	71
Exchange aluminum > 100 mg/kg	28	28	67	38	64	49	89	100	67	65	36
Exchange calcium < 100 mg/kg	3	24	70	88	42	28	61	50	50	29	17
Exchange potassium < 100 mg/kg	77	74	100	88	86	78	93	100	100	67	90
Exchange magnesium < 50 mg/kg	31	22	94	88	59	39	84	50	83	47	48
Organic carbon < 1 percent	31	40	3	13	4	38	22	0	0	10	27
Total nitrogen < 0.1 percent	54	55	21	88	13	47	35	0	17	53	55
Water pH < 4.0	2	0	6	25	13	0	8	0	10	2	1

Federal and State Land

A number of programs and legal instruments focus on preserving specific forest-soil-water interactions and conditions at State and Federal levels. An example is the 1891 Forest Reserve Act, which established the first forest reserves (designated as national forests in 1907). Its original purpose was to preserve water resources—that is, to protect watersheds from erosion and flooding—and to protect timber supplies from overexploitation; but it later became the basis for a growing conservation movement to preserve natural resources for future generations by applying multiple-use and sustained-yield principles to forest management. These principles stress the need to balance the uses of the major resources and benefits of forests—timber and soil productivity, water supplies, recreation, livestock forage, wildlife and fish, and minerals—in the best public interest.

To forecast changes in amount of Federal and State land area per person, it is assumed that State and Federal land area will remain relatively constant for the next 50 years, but projected increases in human populations will likely place more pressure on public land and water resources.

An examination of Federal and State forest land area illustrates differences in rankings among U.S. regions (Table 6.4). Thirty-six million acres (or 21 percent) of northern forest land is managed by Federal and State agencies. Federal and State forest land was 0.29 acres per person in 2007 and is expected to decrease to 0.23 acres per person by 2060 under an assumption of increasing urbanization (moderate population and high economic growth) and relatively stable to slightly decreasing forest area.

Table 6.4—Combined area of all Federal and State forest land in the United States, 2007, and projected change in acres per capita, 2007 to 2060, assuming constant forest area in these ownerships, with increasing population (Cordell et al. 2012, Smith et al. 2009).

Region	Federal and State forested area			
	2007			2060
	(thousands of acres)	(percent of total)	(acres per capita)	(acres per capita)
North	36,345	21	0.29	0.23
South	26,541	12	0.25	0.16
Rocky Mountains	112,597	75	3.99	2.27
Pacific Coast	141,762	66	2.87	1.86
U.S. total	317,244	42	1.03	0.71

Private Forest Land

Private forests are expected to continue being converted to developed uses. Smith et al. (2009) reported that the bulk of northern forest land (58 percent) is in private ownership (defined here as all private owners, excluding forest products companies); the remainder is held by the Federal government (8 percent), State and local governments (17 percent), and corporate forest ownership (17 percent).

Although lands in public ownership are expected to form the base for most "legislatively" protected or reserved forest, management and land-use change will have the biggest impacts on private lands. The increase in number of humans in the next 50 years could bring different demands on forest resources and other natural resources, particularly on private lands near the urban fringe. A variety of programs and legal instruments are in place to preserve specific forest-soil-water interactions and conditions regardless of ownership. These include establishing conservation easements, placing lands in private and public land trusts, and marketing rights that are traditionally associated with property.

PROJECTIONS OF WATER SUPPLY AND QUALITY

Water Quantity

Baseline conditions from 2010 and projected climate, land-use, and human population change were used to assess the ability of water supplies to meet societal demands from 2010 to 2060. Projections were based on unique combinations of IPCC (2007) storylines and general circulation models (Table 6.5). The projections used greenhouse gas emissions storylines developed by the Intergovernmental Panel on Climate Change (IPCC 2007, Chapter 2): A1B assumes moderate greenhouse gas emissions associated with moderate gains in population growth and large gains in income and energy consumption—but with a balanced renewable/fossil fuel portfolio, A2 assumes relatively high greenhouse gas emissions associated with large gains in population growth and energy consumption with moderate gains in income, and B2 assumes relatively low greenhouse gas emissions associated with moderate gains in population growth, income, and energy consumption. Storylines A1B and A2 storylines were used for our water resource assessments; storyline B2 was omitted because projected emissions under the B2 storyline may underestimate actual greenhouse gas emissions (Raupach et al. 2007). See Tavernia et al. (2013) for detailed description and assumptions.

Table 6.5—Water supply and stress index (WaSSI) in the 551 watersheds of the North, estimated for 2010 and projected for 2060, under two IPCC (2007) greenhouse gas emissions storylines—A1B assumes moderate greenhouse gas emissions associated with large urbanization gains and moderate population growth and rapid income growth, and A2 assumes moderate greenhouse gas emissions associated with moderate urbanization gains, rapid population growth, and moderate income growth—combined with three general circulation models, CGCM-3.1MR, CSIRO-Mk 3.5, and MIROC3.2MR.

Estimate/scenario	Overall WaSSI[a]	Watersheds and populations in each category of water stress[b]					
		Low WaSSI		Moderate WaSSI		High WaSSI	
	Stress index	Number of watersheds (percent)	Million persons (percent)	Number of watersheds (percent)	Million persons (percent)	Number of watersheds (percent)	Million persons (percent)
Estimate, 2010	0.07	538 (98)	121.3 (98)	11 (2)	2.1 (2)	2 (0)	0.2 (0)
A1B+CGCM3.1[c]	0.08	536 (97)	150.6 (96)	13 (2)	6.0 (4)	2 (0)	0.2 (0)
A1B+CSIROMk3.5[c]	0.13	521 (95)	142.9 (91)	21 (4)	12.5 (8)	9 (2)	1.4 (1)
A1B+MIROC3.2[c]	0.19	504 (92)	135.5 (86)	29 (5)	18.1 (12)	18 (3)	3.2 (2)
A2+CGCM3.1	0.18	505 (92)	151.5 (86)	31 (6)	20.6 (12)	15 (3)	5.1 (3)
A2+CSIROMk3.5	0.09	532 (97)	155.5 (88)	15 (3)	19.5 (11)	4 (1)	2.2 (1)
A2+MIROC3.2	0.14	516 (94)	156.5 (88)	24 (4)	18.3 (10)	11 (2)	2.4 (1)

[a] *The proportion of the water supply that is used to meet societal demands; values represent an average of annual values for watersheds across the region.*

[b] *Watersheds are classified into three categories based on their WaSSI values: low (<0.50), moderate (0.50 to 1), and high (>1).*

[c] *Sources of models: CGCM3.1 = Canadian Centre for Climate Modeling and Analysis Third Generation Coupled Global Climate Model (T47 medium resolution version) (http://www.ec.gc.ca/ccmac-cccma); MIROC3.2 = University of Tokyo Center for Climate System Research, National Institute for Environmental Studies, and Frontier Research Center for Global Change, Japan, Model for Interdisciplinary Research on Climate version 3.2 (medium resolution) (http://www-pcmdi.llnl.gov/ipcc/model_documentation/MIROC3.2_hires.htm); CSIRO-Mk3.5 = Commonwealth Scientific and Industrial Research Organization, Australia, Mark 3.5 Global Climate Model (http://www.cawcr.gov.au/publications/technicalreports/CTR_021.pdf).*

For these assessments, we used a water supply and stress index (WaSSI), defined by Sun et al. (2008) as the proportion of a watershed's water supply that is used to meet societal demands. When WaSSI values are >1, water supplies are insufficient and external sources could be needed to meet the deficit. Watersheds were classified into three categories based on their WaSSI values:

- <0.50—low stress
- 0.50 to 1—moderate stress
- >1—high stress

The working scale for WaSSI is the U.S. Geologic Survey 8-digit Hydrologic Unit Code, which describes approximately 2100 watersheds in the lower 48 States (USDA NRCS 2009). See Tavernia et al. (2013) for a detailed description of methods.

The 551 watersheds in the North currently experience little water stress (Fig. 6.1, Table 6.5). Across watersheds, the average annual WaSSI value was 0.07, and only two watersheds had high WaSSI values, indicating high stress. About 121 million people reside in watersheds with low stress values, 2 million in watersheds with moderate stress, and 200,000 people in two watersheds with high stress, one located in western Iowa, the other in central Illinois.

By 2060, changes in climate, land-use patterns, and human populations could individually and collectively alter water stress levels. Temperature levels across the region are expected to increase under all scenarios considered, although the magnitude of projected increase varies (Chapter 2). An increase in temperature could lead to increased evaporative loss and decreased water availability, thus increasing water stress. However, water abundance is primarily driven by precipitation (McCabe and Wolock 2011). Scenarios differ with respect to precipitation, with some suggesting that regional precipitation will increase and others suggesting that it will decrease (Chapter 2). For a specific location, projected changes in precipitation also vary in magnitude and direction. Urban land use is projected to increase across the region with variations in magnitude across scenarios and locations (Chapter 10). Because urban areas are less vegetated, are less permeable, and have lower evapotranspiration rates than other land-use types, water surface abundance would increase in some areas, but at a cost to water quality (Lull and Sopper 1966, 1969; Sun and Lockaby 2012). Although projections indicate that the overall human population in the region would increase under all scenarios considered, the rate of growth would vary among scenarios (see Chapter 2) and across the region, with some locations expected to have smaller populations by 2060. Increases in human populations can be expected to increase water demand and place an additional burden on water supplies.

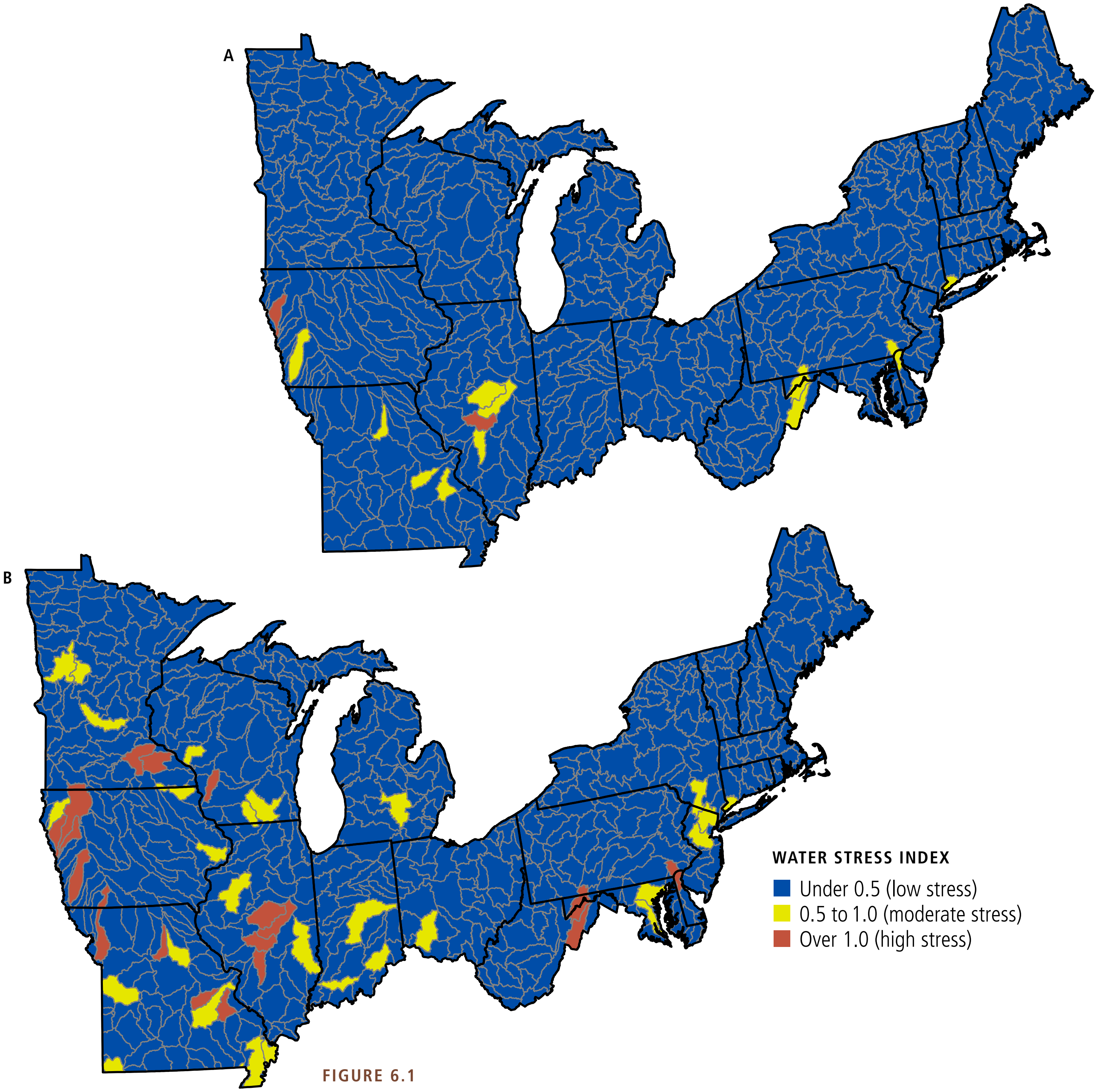


FIGURE 6.1

Average annual water supply and stress index values—the proportion of the water supply being used to meet societal demands—for watersheds in the North (A) in 2010 and (B) projected for 2060 under the MIROC3.2MR general circulation model from the Japanese National Institute for Environmental Studies combined with a greenhouse gas emissions storyline A1B (IPCC 2007) that predicts moderate greenhouse gas emissions, large urbanization gains, moderate population growth and rapid income growth. Maps for five additional projections (storyline-GCM combinations) can be viewed in Tavernia et al. (2013).

Regionally, assessments using the WaSSI model (Caldwell et al. 2012) suggest that WaSSI values would increase under most future scenarios (Fig. 6.1, Table 6.5). Although average annual WaSSI values would remain low under all scenarios, the number of watersheds classified as having moderate or high WaSSI values would increase. Increases in the average annual WaSSI value and the number of watersheds with moderate or high WaSSI values would be highest for storyline A1B with climate projected by the MIROC 3.2MR general circulation model (Table 6.5, Chapter 2). Under this scenario by 2060, approximately 136 million people are expected to live in watersheds with low water stress, 18 million in watersheds with moderate stress, and 3 million in watersheds with high stress. At a regional scale, climate projections had more impact than land-use or population projections, but there were some exceptions for individual watersheds. The results of WaSSI assessments could differ if conducted for localized areas within a watershed or at finer temporal scales, such as monthly (Tavernia et al. 2013).

Other researchers have used lower WaSSI thresholds for labelling watersheds as stressed. Ultimately, local water management strategies affect the level at which a watershed becomes stressed. See Tavernia et al. (2013) for additional discussion.

Water Quality

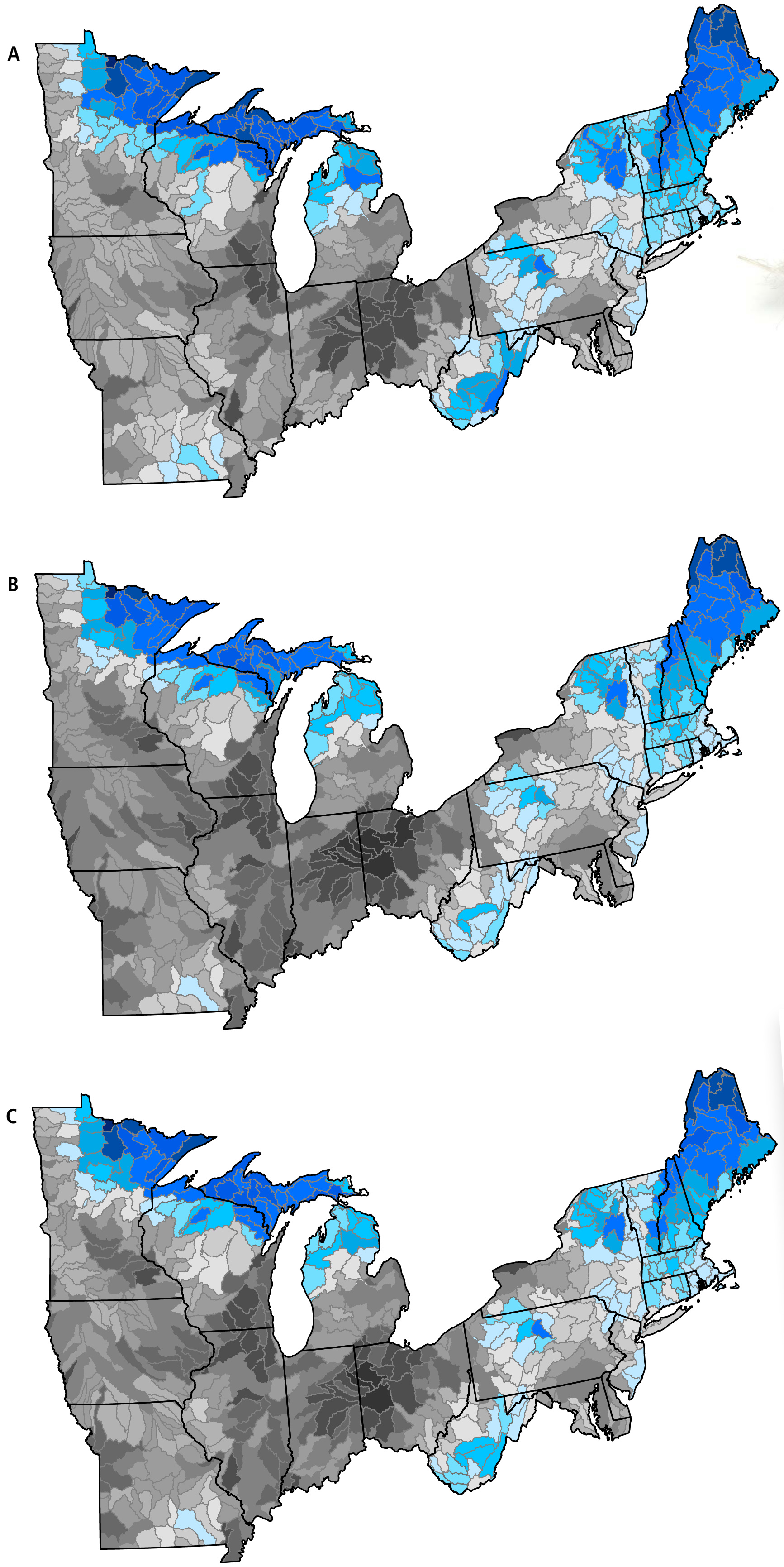
The suitability of water for a given use (such as drinking, industrial processes, or recreation) depends on its quality; for this reason, assessments of future water supplies need to account for the effect of changing land use on water quality. Projections for 2060 suggest that urban areas will increase at the expense of forest and agricultural land (Chapters 2, 10). Projected increases are expected to be highest under storyline A1B (resulting from moderate population growth and high economic growth). Under A1B, urban areas are projected to grow from 37 to 66 million acres (78-percent increase) whereas forest areas are projected to shrink from 174 to 163 million acres (6-percent decrease).

Conversion of forests to urban areas would negatively impact water quality in a variety of ways, including changing stream temperatures and increasing the load and concentration of sediments, nutrients, pesticides, and other pollutants (Paul and Meyer 2001, Sun and Lockaby 2012).

The potential for the biophysical and land-use characteristics of a watershed to support production of high quality water resources under the 2010 baseline and the land-use conditions projected for 2060, was assessed using a Clean Water Potential Index (CWPI), based on an index developed by Barnes et al. (2009) but modified to substitute some attributes for which future projections are unavailable. Watersheds were assigned individual values based on soil erodibility and the percentage cover of forest, riparian-forest, agricultural, and urban areas. We computed CWPI by combining these values into a composite value that ranged from 5 (low potential for clean water) to 20 (high potential for clean water), assuming constant percentage cover of riparian forest and constant soil erodibility over time. CWPI values are useful for ranking the ability of watersheds to support the production of high quality water resources based on landscape conditions, but realized water quality also depends on additional factors, such as water treatment capacity, that are beyond the scope of this assessment.

Currently, watersheds with relatively high CWPI values tend to be found in forested areas of the upper Midwest, New England, and along the Appalachian Mountains. Relatively low CWPI is found in midwestern watersheds that have low forest use, high agricultural use, and sometimes high urban use (Fig. 6.2). By 2060, land-use changes, predominantly by increases in urban land use, are projected to decrease CWPI values for the majority of watersheds in the region. Under storyline A1B, 362 of 551 (66 percent) watersheds would have lower CWPI values compared to 293 (53 percent) under A2 (Fig. 6.2). Agreement between storylines A1B and A2 was high (Fig. 6.3) with both storylines predicting losses for 288 watersheds and only a few watersheds predicted to experience losses under one or the other alone—74 watersheds under A1B and 5 watersheds under A2. Declines in CWPI values are expected to occur for watersheds scattered throughout the region, suggesting that landscapes within these watersheds will be less able to produce high quality water.

For the vast majority of watersheds, projections indicate that the amount of high-quality water available for human use will be adequate, but some could face shortages, leading to water stress or increasing water treatment costs. Policies including zoning regulations and financial incentives such as conservation easements could help safeguard the role of forests in providing high quality water to human populations.



CLEAN WATER POTENTIAL

5 10 15 20

Low High

FIGURE 6.2

Clean water potential index values for watersheds in the North (A) in 2010; (B) projected for 2060 under storyline A1B that predicts moderate greenhouse gas emissions, large urbanization gains, moderate population growth and rapid income growth; and (C) projected for 2060 under storyline A2 that predicts high greenhouse gas emissions, moderate urbanization gains, rapid population growth, and moderate income growth. Index values are a composite of soil erodibility and percentage cover of forest, riparian-forest, agricultural, and urban areas.

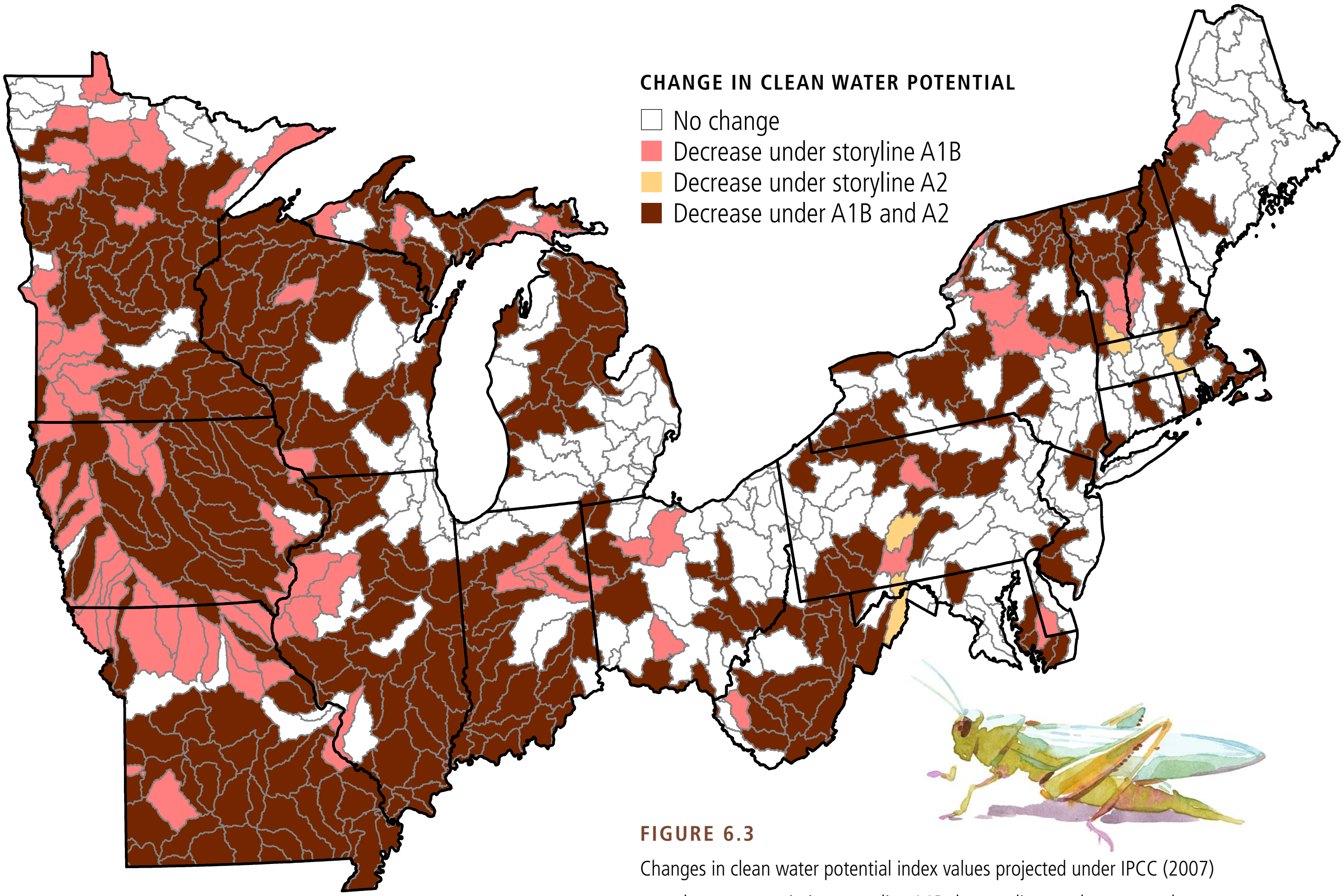


FIGURE 6.3

Changes in clean water potential index values projected under IPCC (2007) greenhouse gas emissions storyline A1B that predicts moderate greenhouse gas emissions, large urbanization gains, moderate population growth, and rapid income growth; and under storyline A2 that predicts high greenhouse gas emissions, moderate urbanization gains, rapid population growth, and moderate income growth. Index values are a composite of soil erodibility and percentage cover of forest, riparian-forest, agricultural, and urban areas.

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