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Availability

This report, as well as supporting documentation, data, and analysis tools, can be found on the Bioenergy Knowledge Discovery Framework at bioenergykdf.net. Go to https://bioenergykdf.net/billionton2016/vol2reportinfo for the latest report information and metadata.

Additional Information

The U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy's Bioenergy Technologies Office and Oak Ridge National Laboratory provide access to information and publications on biomass availability and other topics. The following websites are available:

- energy.gov
- eere.energy.gov
- bioenergy.energy.gov
- web.ornl.gov/sci/transportation/research/bioenergy/

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7 | Impacts of Forest Biomass Removal on Water Yield across the United States

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7.1 Introduction

Water is essential to all forms of life on earth and is a powerful, integrated indicator of environmental health and ecosystem sustainability (Asbjornsen et al. 2015). In some areas of the United States, water availability and water quality are declining as a result of urbanization, climate change, and increased water demand for agricultural irrigation, power generation, and domestic water use (Sun et al. 2008). Forest hydrological studies across the United States and around the world in the past century (Vose et al. 2011) show that forests greatly influence water quantity and quality. Forests play an important role in regulating the quantity, quality, and timing of water yield from watersheds—and, thus, in maintaining the ecosystems that depend on water (Edwards, Williard, and Schoonover 2015). It is estimated that over half of the water supply from the United States is provided by domestic forestlands (Brown, Hobbins, and Ramirez 2008; Sun, Caldwell, and McNulty 2015); therefore, forest management—such as reforestation/afforestation, tree harvesting, stand thinning, and other forest management practices—can influence watershed water yield (i.e., outflow from a drainage basin) by altering the terrestrial hydrological cycle. This cycle involves precipitation, evapotranspiration (ET), infiltration, soil moisture dynamics, and streamflow (Sun, Caldwell, and McNulty 2015; Stednick 1996; Christopher, Schoenholtz, and Nettles 2015). For example, deforestation generally elevates total streamflow and peak flow rates due to the reduction of ET caused by the removal of forest canopies (Brown et al. 2013), decrease in soil infiltration capacity as a result of soil compaction (Bruijnzeel 2004), and forest road construction (Edwards and Williard 2010). In contrast, afforestation or reforestation generally decreases watershed water yield because ET increases as a result of increase in water use by trees that have greater biomass both above- and belowground than vegetation in previous land uses (Sun et al. 2010; Brown et al. 2005).

Harvesting biomass from forests is one potential approach to both meeting increasing bioenergy demand and contributing to energy security in the United States (Evans 2016; Caputo et al. 2016; Holland et al. 2015). It is important to evaluate the environmental effects of various biomass harvesting methods and removal fractions to make sure that the harvesting of biomass does not harm aspects of the environment, such as water quality and water supply (King et al. 2013; Bonsch et al. 2016; Caputo et al. 2016; Christopher, Schoenholtz, and Nettles 2015). Supply constraints applied in *BT16* dictate that biomass removal is excluded from environmentally sensitive areas and is limited to a fraction of the total biomass available. Although these constraints are intended to reduce potentially negative environmental impacts, more thorough analyses are required for better planning of harvesting biomass, as well as better understanding of how these effects differ across locations, biomass types, and management practices (Lin, Anar, and Zheng 2015; Christopher, Schoenholtz, and Nettles 2015).

In addition, water quality is intrinsically linked to water quantity. As such, it is important to examine water quantity consequences in addition to impacts on water quality as a result of biomass removal (Binkley, Burnham, and Allen 1999). Changes in water quantity due to forestry activities are likely to affect water quality because water quantity affects both concentrations of stream water nutrients and other chemicals and total loading of chemicals and sediment. For example, forest harvesting may increase streamflow in forested watersheds and, therefore, may increase overland flow, peak flow rates, stormflow volume, which results in stream bank and channel erosion and increased sediment loading (Boggs, Sun, and McNulty 2015; Cristan et al. 2016).

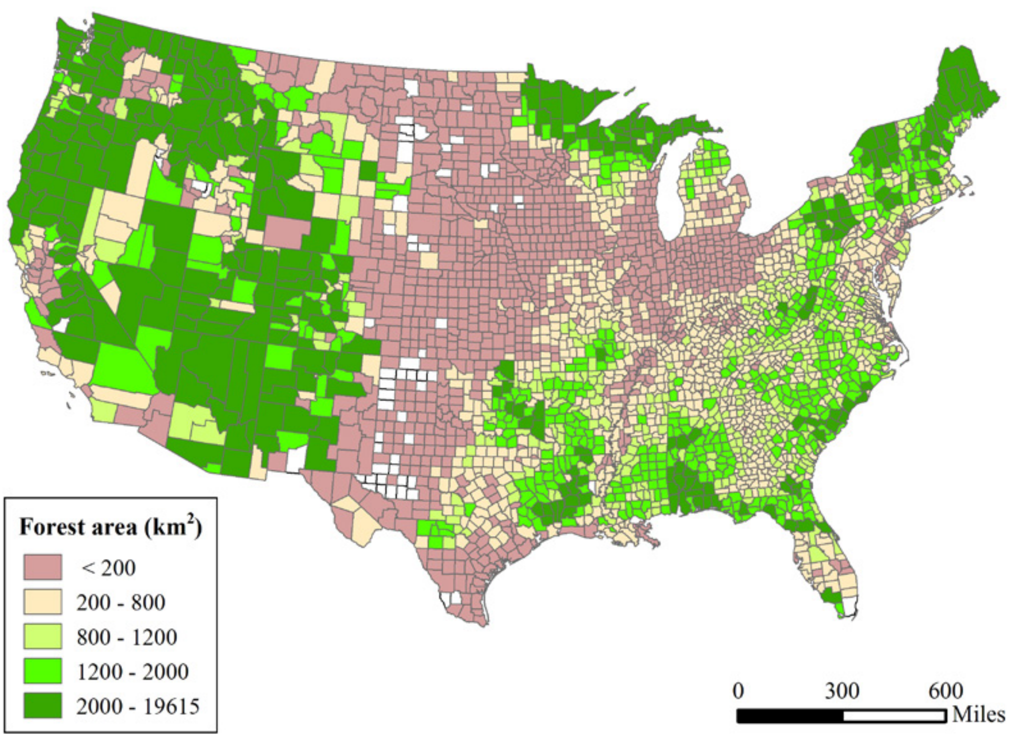
The overall goal of this chapter is to evaluate the potential effects of select *BT16* scenarios of forest-biomass harvesting on water quantity. The specific objective of the study is to quantify the water yield at both watershed (12-digit hydrologic unit code [HUC 12]) and county levels across the lower 48 states. The study focuses on the effects of potential forest removals on the seasonal and annual total water yield at watershed and county scales. Counties that are sensitive to biomass removal are identified to help reduce the risk of environmental degradation and to maximize the positive effects of biomass production on watershed functions.

The following hypotheses have been used to guide this analysis: (1) forest removals decrease water use by trees and canopy interception of precipitation, and thus cause an increase in water yield and water availability for human and aquatic ecosystems; (2) the magnitude of streamflow increase depends on the level of biomass removal per unit area (e.g., thinning intensity), the total amount of forest removed (e.g., the acreage cut) and the local background climate (i.e., dry or wet environment as indicated by climate dryness index); and (3) effects of biomass removal on water quantity have a large spatial and temporal (i.e., seasonal) variability because of differences in biophysical characteristics.

7.2 Methods

We applied a watershed-scale hydrological modeling approach with biomass harvesting scenarios as the driving forces of hydrologic disturbances under a mean climatic condition (1991–2001). Water-yield responses to complete tree harvesting (100% clear-cutting) or thinning (70% reduction in leaf area index [LAI]) are first examined to quantify the maximum potential impacts per unit of land area at the watershed scale (HUC 12), and then at the county level, by scaling up watershed-scale data. Then, the area of harvesting (clearcutting or thinning) by county from BT16 volume 1 is applied to the complete-harvesting datasets to quantify the projected effects due to potential forest biomass removal at the county level from scenarios in *BT16* volume 1. The forestland area is estimated from the National Land Cover Database 2011 (NLCD 2011) and has a spatial resolution of 30 meters (m) (Homer et al. 2015).

Figure 7.1 | Forestland area by county as determined by the NLCD (2011). The data are from 2006.



7.2.1 Scope of Assessment

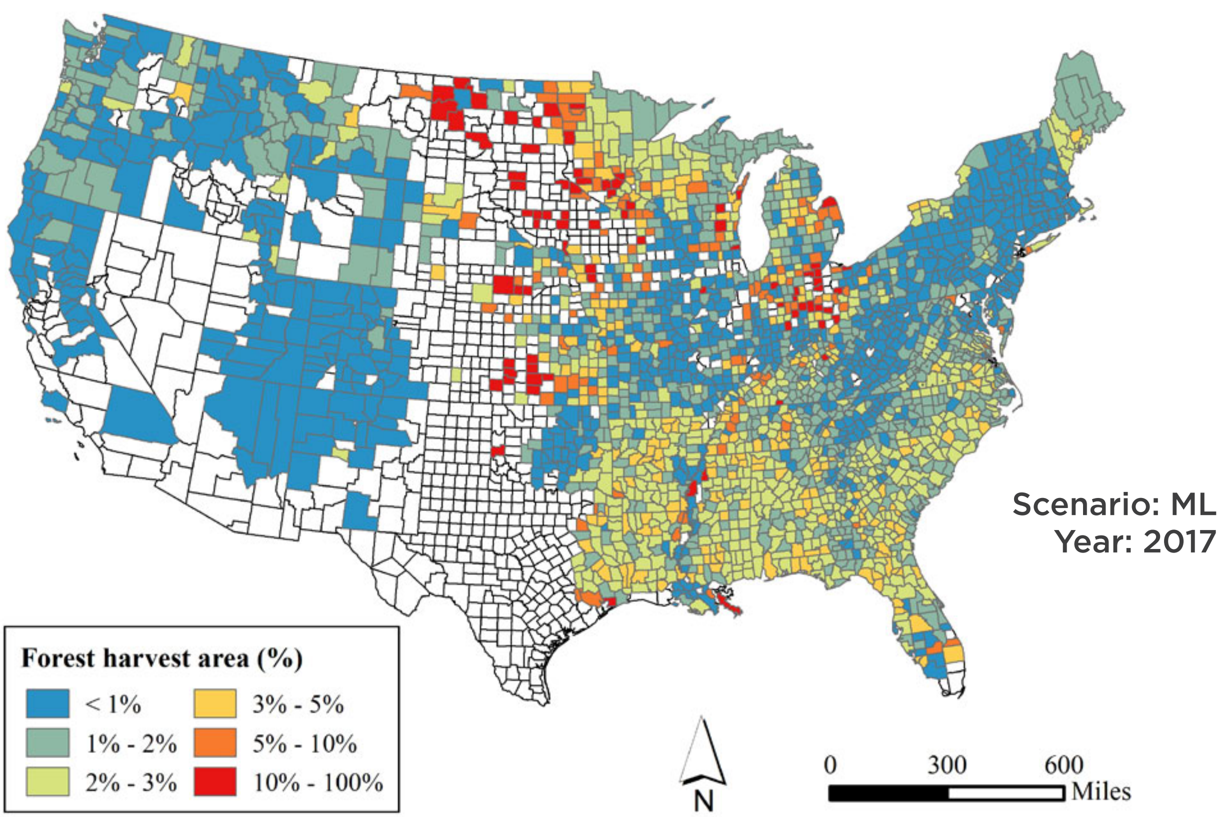
This analysis evaluates water-yield responses to select harvesting scenarios: ML 2017, ML 2040, and HH 2040. These three scenarios represent two levels of biomass demand and two time periods. The ML scenarios represent the baselines while the HH scenario represents the forestry high-housing, high-biomass demand scenario. Areas of harvesting from thinning and clearcutting are compared to total forest areas from NLCD 2011 data (fig. 7.1) in each county to derive harvesting area ratios (percent) for estimating the likely change in water yield from the potential maximum water yield response if the entire forest area in the county were harvested. A majority of counties have a harvesting area, either clearcutting or thinning, that encompasses less than 2% of the land area by county (fig 7.2). In addition, the baseline ML 2017 scenario has the highest potential biomass removal of the three scenarios that were examined. Areas showing high percentage harvesting (>5%) are located at the forest-grassland or forest-cropland transition zones with limited forest biomass potential. Data errors for these areas may exist since the harvesting area data are derived from models and Forestry Inventory Analysis (Nelson and Vissage 2007), but the forestland areas (fig. 7.1) are determined from remote sensing imagery.

The projected hydrological response to forest harvesting is estimated based on the maximum potential response in each county if the entire forest were harvested, with an assumption that the response is proportional to forest removal:

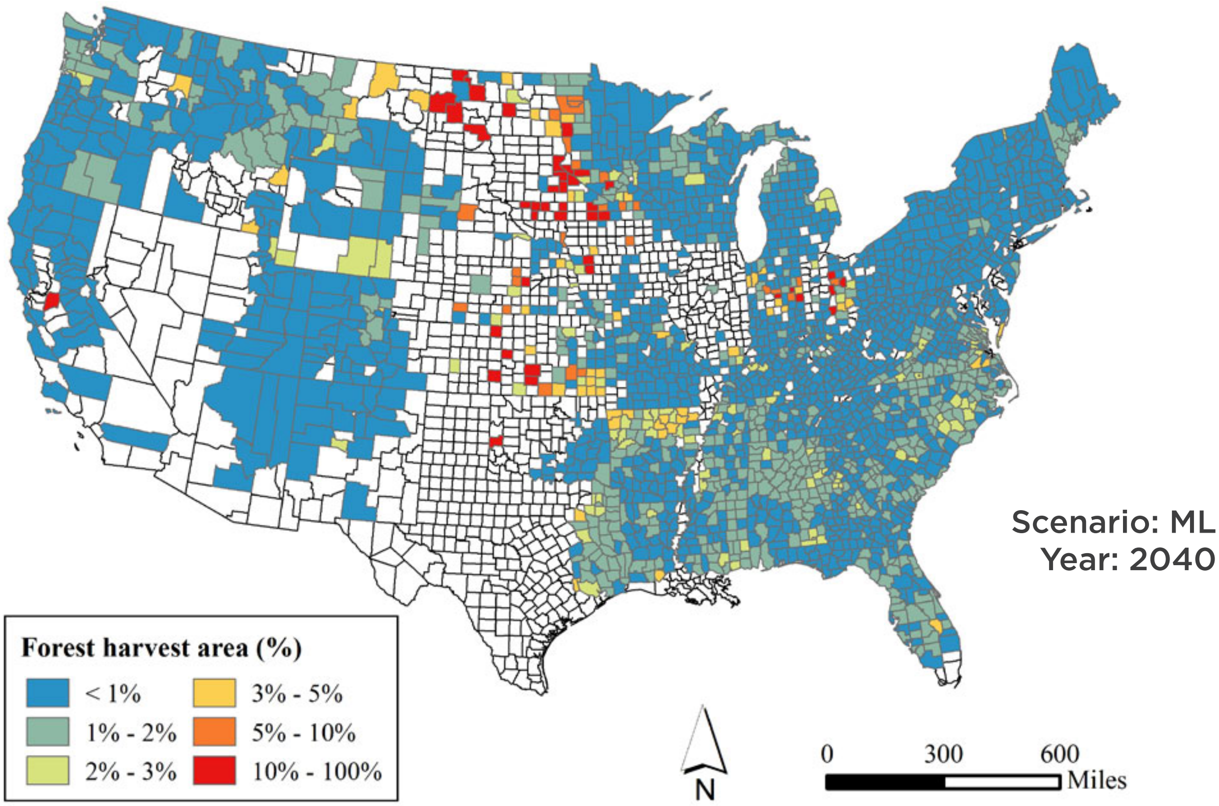
Projected hydrological response = maximum potential hydrological response × percentage of forest harvest area

Figure 7.2 | Forest harvesting percentage (clearcutting plus thinning) under three biomass scenarios in 2017 and 2040

A.



B.


Scenario: ML
Year: 2040
Forest harvest area (%)
< 1%
1% - 2%
2% - 3%
3% - 5%
5% - 10%
10% - 100%
N
0
300
600
Miles

C.

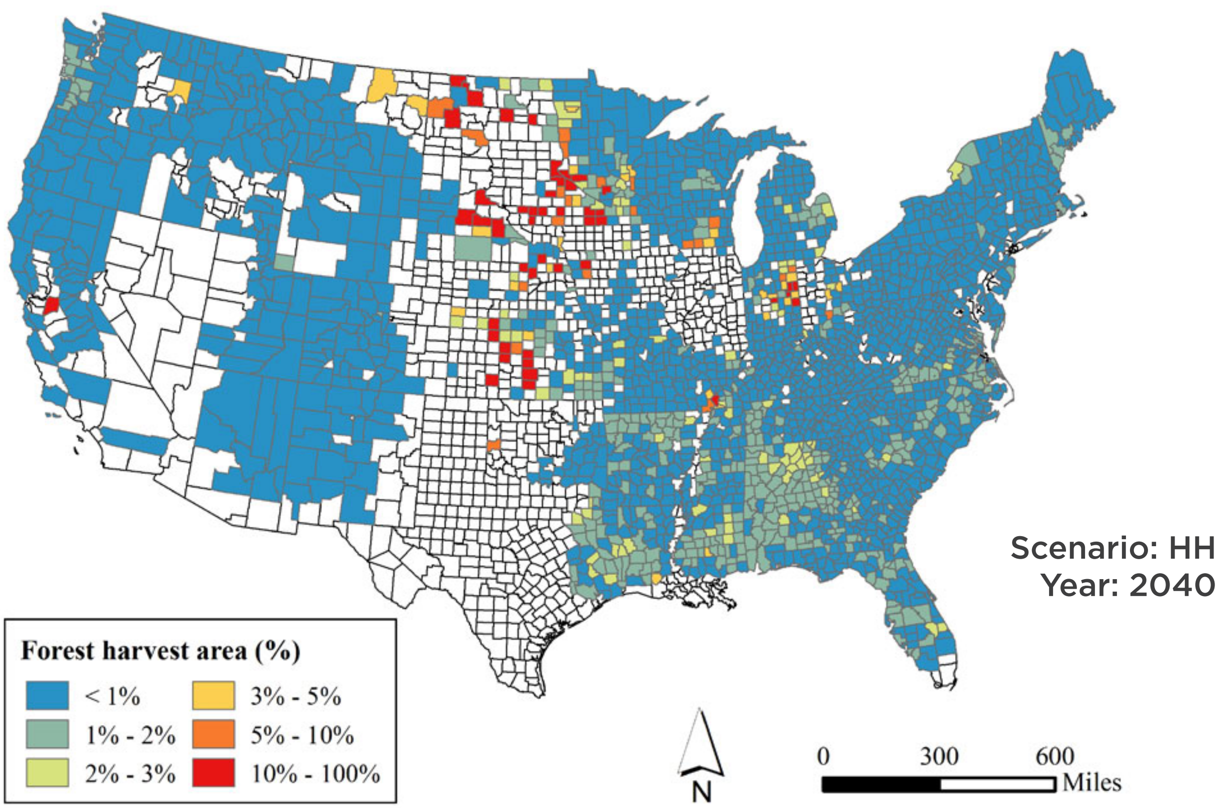
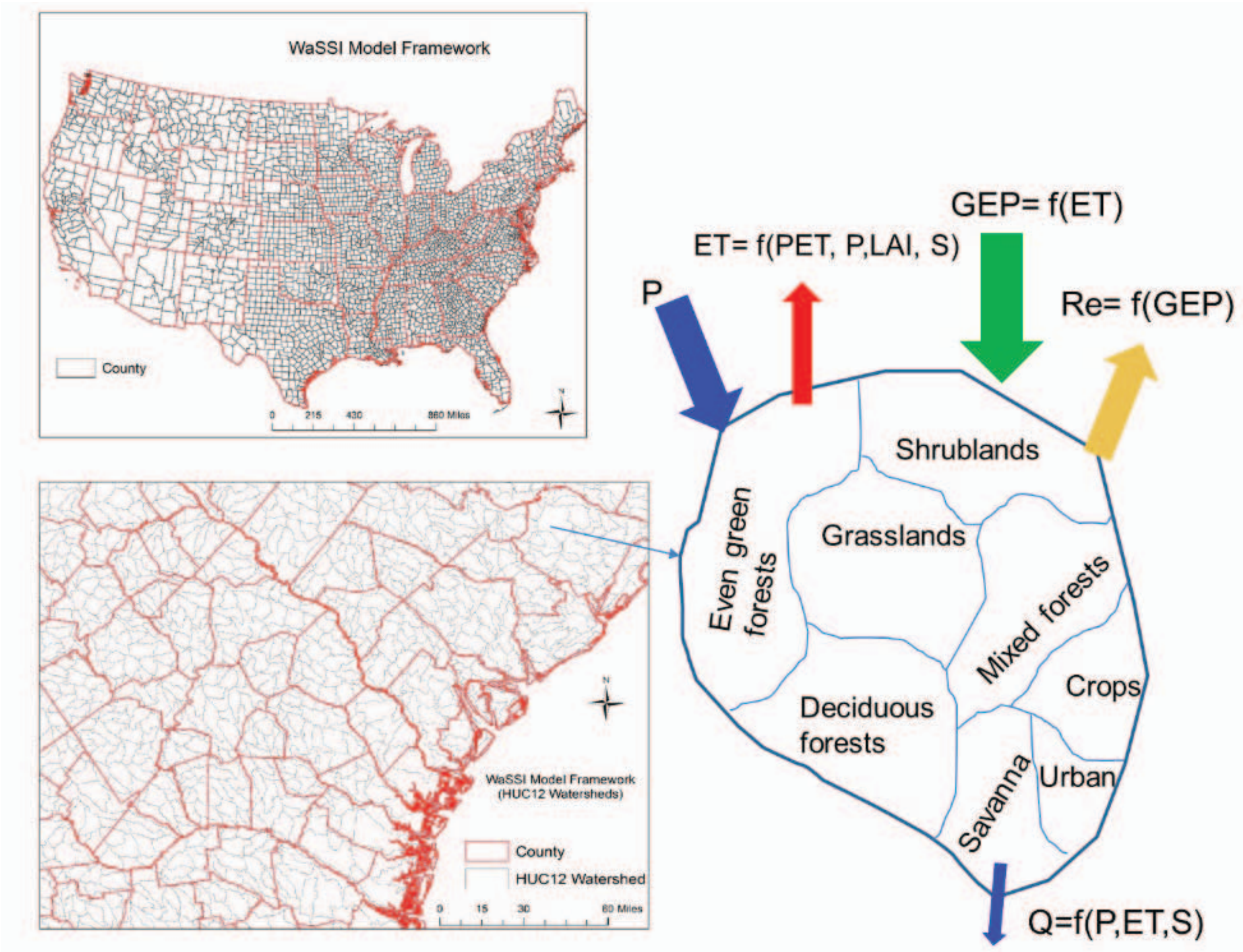

Scenario: HH
Year: 2040
Forest harvest area (%)
< 1%
1% - 2%
2% - 3%
3% - 5%
5% - 10%
10% - 100%
N
0
300
600
Miles

Figure 7.3 | Structure of the ecohydrological model (WaSSI) that simulates the full water and carbon balances at the HUC 12 watershed scale



7.2.2 Description of the Ecohydrological Model (WaSSI)

The WaSSI (Water Supply Stress Index) ecohydrological model (Sun et al. 2011b; Sun et al. 2008; Caldwell et al. 2012) was developed to examine the broad impacts of climate change, land cover/land use change, and population growth on water and carbon budgets and on water stresses at monthly and watershed scales (see fig. 7.3). WaSSI has been tested, validated, and applied at the 8-digit HUC (HUC 8) and HUC 12 watershed scales across the conterminous United States (Caldwell et al. 2015; Caldwell et al. 2012; Sun et al. 2015b; Sun et al. 2015a). The model simulates all monthly water fluxes (i.e., ET, infiltration, soil water storage, snow accumulation and melt, surface runoff, and base flow) for each of the land cover categories in a watershed with mixed land uses, as well as aggregates to the entire basin using an area weighted averaging method. Infiltration, soil storage, and runoff were estimated based on the algorithms from the Sacramento Soil Moisture Accounting Model and the 11 soil parameters derived from State Soil Geographic Data Base (STATSGO). The monthly ET model embedded in WaSSI was derived empirically using eddy flux and sap flow measurements at multiple sites from grassland to subtropical conifer forests (Sun et al. 2011a). ET was calculated as a function of potential ET (PET), which is calculated by a temperature-based PET equation, LAI, precipitation, and soil water content. Forest LAI data are derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) product at a 1 kilometer (km) resolution. The WaSSI model has been applied to quantify the effects of introducing exotic tree species (e.g., Eucalyptus) on regional water budgets in the United States (Vose et al. 2015). Details of the WaSSI model can be found in the program's user guide: http://www.forestthreats.org/research/tools/WaSSI/WaSSIUserGuide_english_v1.1.pdfforestthreats.org/research/tools/WaSSI/WaSSIUserGuide_english_v1.1.pdf.

In this study, it is assumed that the magnitude of biomass removals corresponds to change in LAI, the key parameter in the WaSSI model linking vegetation dynamics, water use (ET), and water yield (table 7.1). The total water yield response is the sum of the response to thinning and clearcutting activities. Water yield is modeled first at the HUC 12 scale and then is scaled to the county level using a weighted average approach. Water yield is expressed in both depth in millimeters (mm) and volume units (million cubic meters or million gallons).

Input data to the WaSSI model mainly include soil properties, land covers, LAI, precipitation, and air temperature. Monthly mean (2000–2006) LAI data were used in this modeling study that focus on sensitivity to LAI change. The 1 km STATSGO soil data were used to derive the 11 soil parameters. The watershed-level land cover compositions were scaled from 30 m using NLDC 2011 data for the year 2006 for the conterminous United States. The mean monthly 1 km LAI over 2000–2011 was derived from MODIS LAI products. The multi-year mean monthly LAI by land-cover type was computed by overlaying the land-cover data with MODIS LAI products. The monthly 4 km-scale precipitation and temperature data over the 1991–2001 averaging period were obtained from PRISM Climate Group data.

Model outputs from WaSSI include monthly and annual ET, water yield, and gross primary productivity by watershed. These variables at the watershed level are scaled to the county level using a weighted average approach. Water yield in a unit per land area (mm) is recalculated to convert to quantity in a volume unit (million cubic meters or gallons of water) at the county level by multiplying county land area with water yield in depth (mm).

Table 7.1 | Modeling Experiment Design That Includes Two Types of Biomass Removals (Thinning and Clearcutting) for 2 Years (2017, 2040) as Simulated by ForSEAM

Forest Biomass Harvesting	Effects on LAI
Reference	Mean LAI with land use in 2006; mean climate (1991–2001)
Thinning Three Harvesting Scenarios	Forest LAI decreased by 70%; mean climate
Clearcutting Three Harvesting Scenarios	Forest LAI decreased to 0.5; mean climate

7.3 Results

7.3.1 Potential Maximum Impacts of Forest Removal on Water Yield by County

Mean long-term annual water yield for each county (i.e., for the 1991-2001 reference period) varies greatly from less than 100 mm per year to as high as 2,012 mm because of the large differences in climate (e.g., precipitation and air temperature) across the United States (fig. 7.4). Water yield at the watershed and county level is also influenced by vegetation composition, soil characteristics, and precipitation forms (e.g., snow or rain). For example, forests have higher ET than non-irrigated croplands or grasslands and thus have lower water yield under the same climatic regime. High-elevation watersheds generally receive high precipitation and have low PET, and therefore produce high water yield.

Clearcutting forests can increase county-scale water yield from less than 10 mm per year in the dry areas to as high as 151 mm per year in the wet areas in coastal counties in the Pacific Northwest and the Appalachian region of the eastern United States (fig. 7.5A). These values represent the maximum hydrological response to clearing all forests in a county when comparing to current reference water yield. Thinning forests (reducing 70% of forest LAI) results in relatively lower impacts when compared to the clearcutting options (fig. 7.5B).

Figure 7.4 | WaSSI modeled reference long-term mean annual water yield by county across the United States

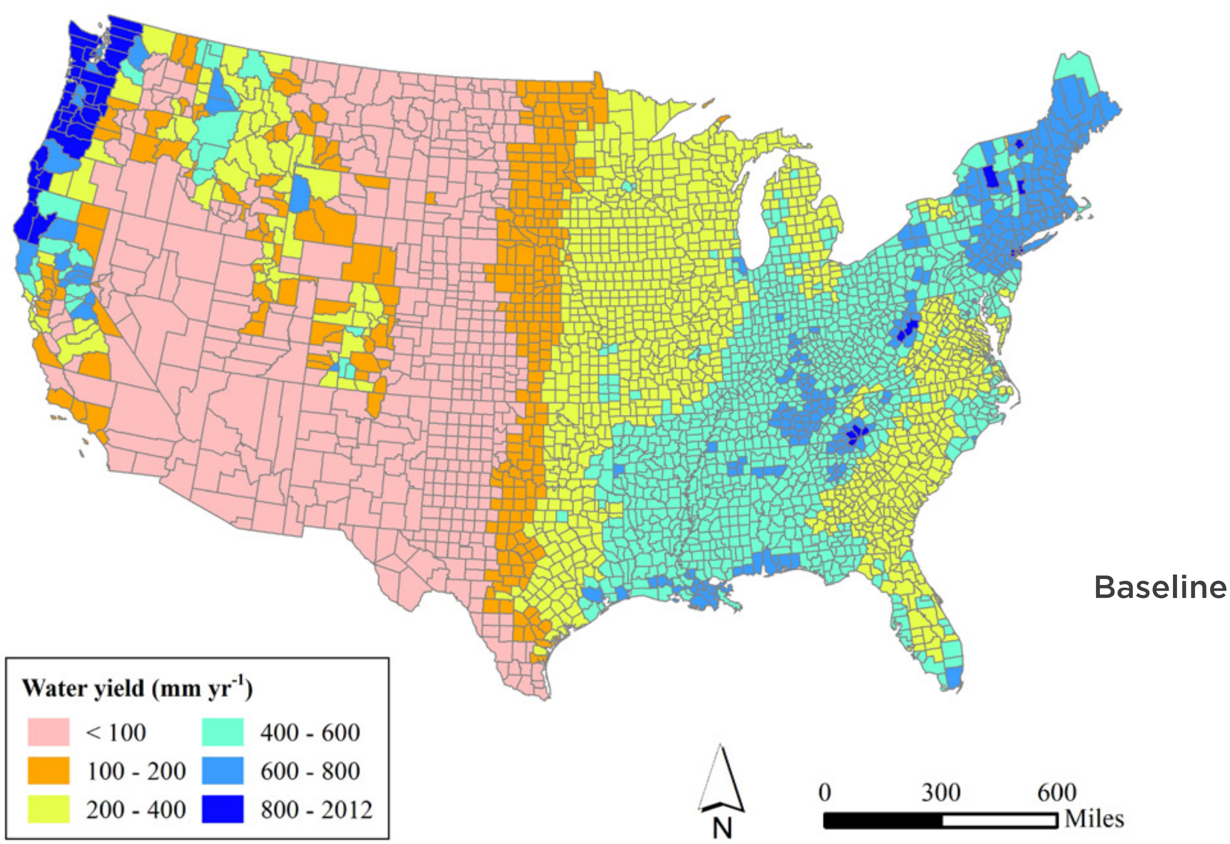
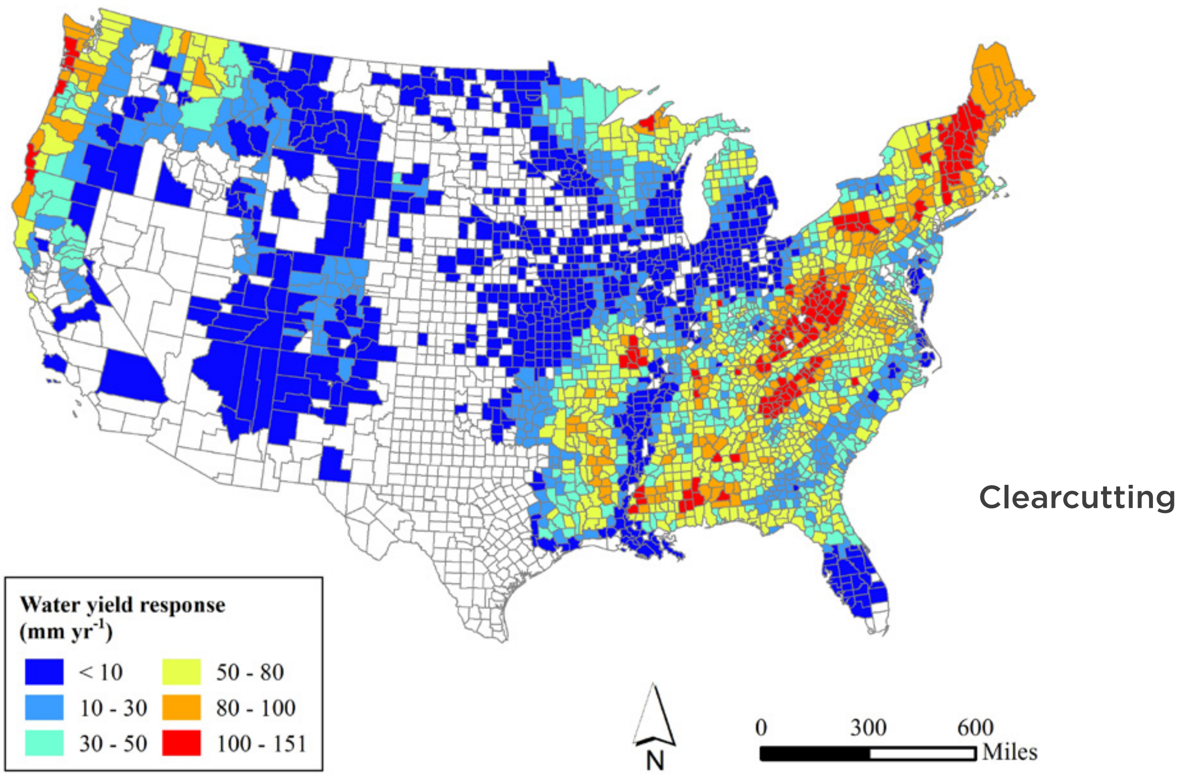


Figure 7.5 | WaSSI modeled maximum response of mean annual water yield to A, clearcutting and B, thinning by county across the United States

A.



B.

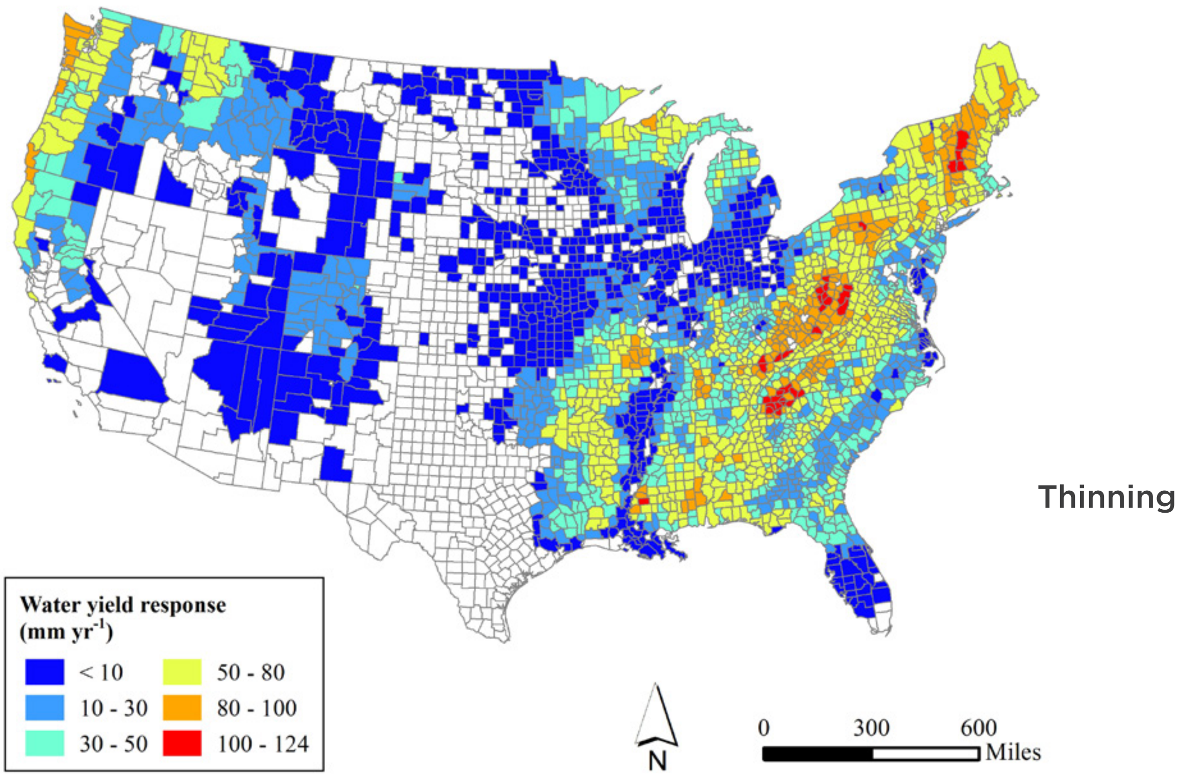
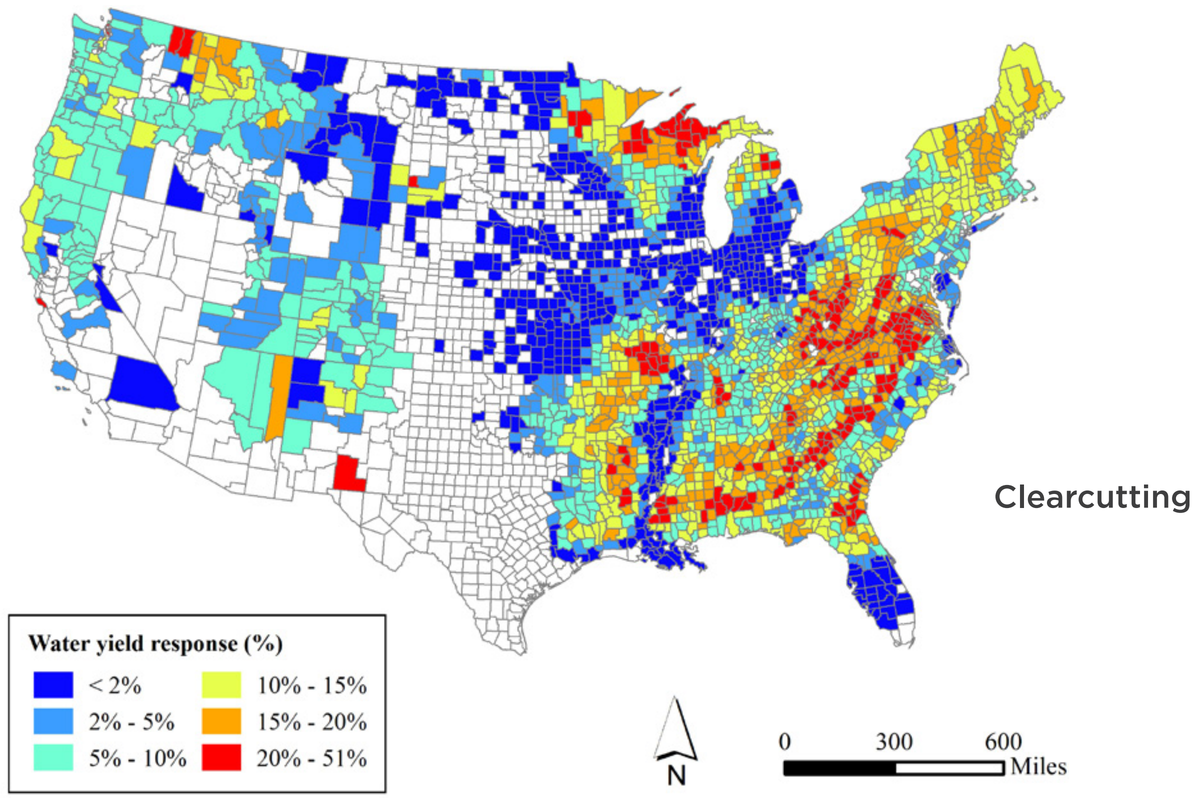
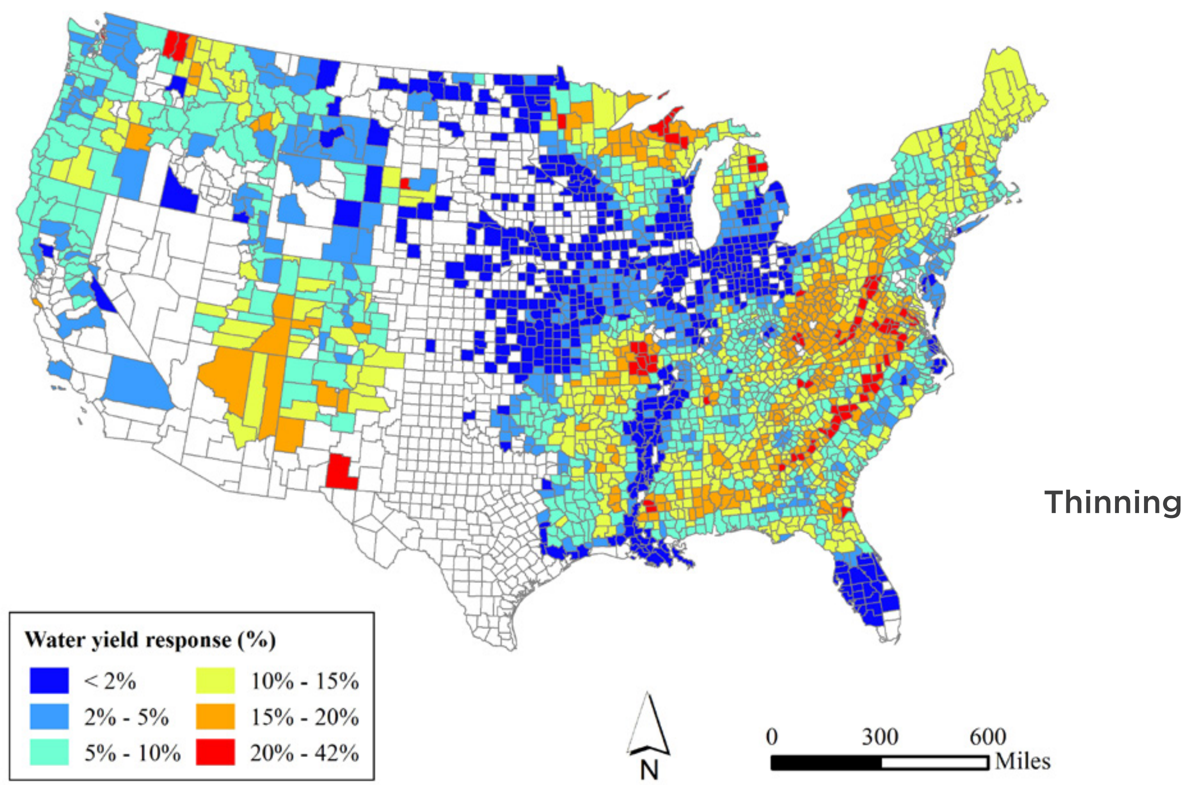


Figure 7.6 | WaSSI modeled maximum relative response of mean annual water yield to A, clearcutting and B, thinning by county across the United States

A.



B.



To normalize the hydrological response to forest removal, the water yield response can also be expressed as relative change by the following formula. The long-term mean water yield is the reference condition:

(water yield under harvesting – long-term mean water yield)/long-term mean water yield

Relative changes in water yield compared to the reference condition (fig. 7.6) show different spatial patterns from those for the absolute water yield response. For example, areas that have low absolute water yield response in the arid Midwest or the Lower Coastal Plains in the humid Southeast show a relatively large change in water yield, while the regions with high absolute water yield, such as the wet Pacific Northwest (<10%) and the Northeast (<20%), have low relative response. The Piedmont region in the Southeast also shows high relative hydrological response to forest harvesting compared to the reference condition, as high as 50% greater water yield.

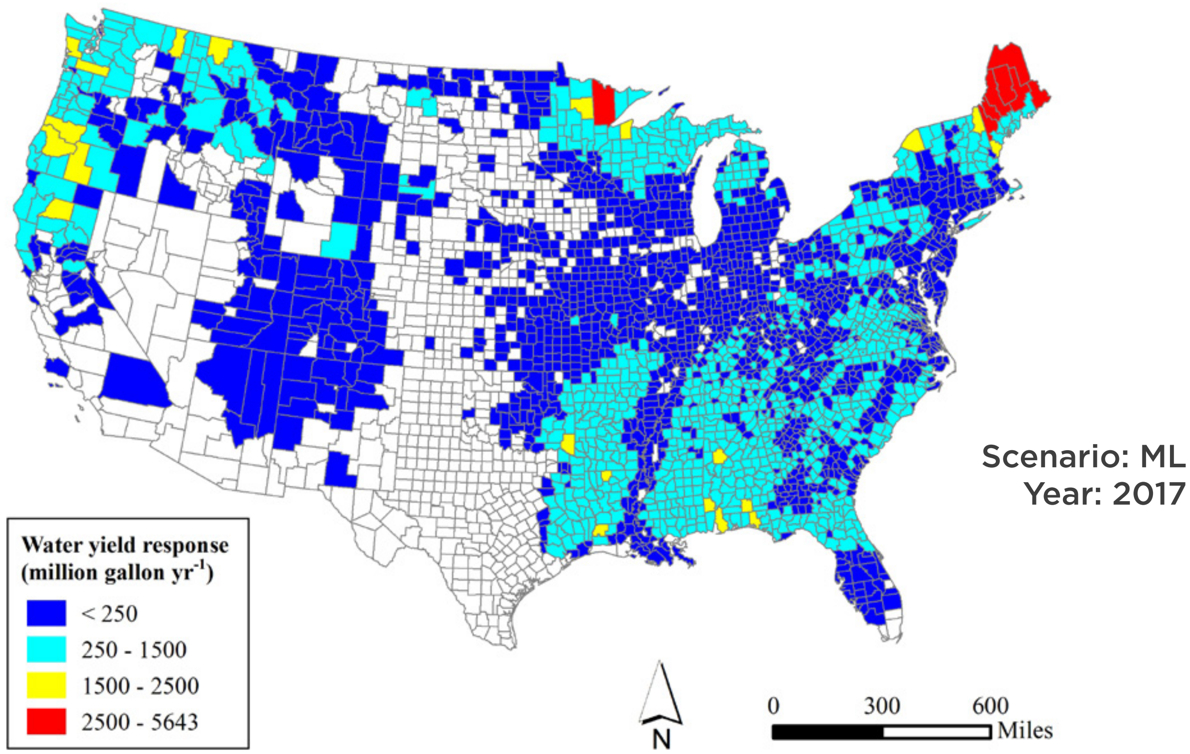
7.3.2 Impacts of Forest Removal on Water Yield by County under Three Scenarios

7.3.2.1 Baseline Case ML 2017

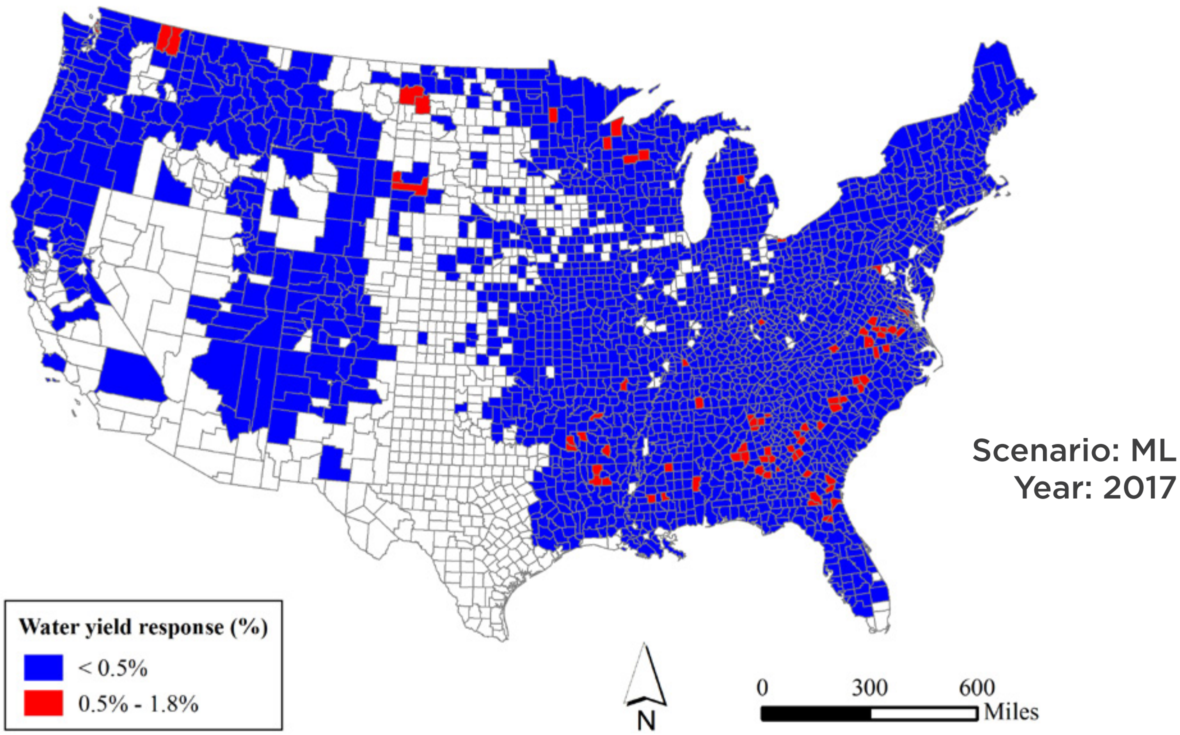
The projected water yield response to harvesting at the county level in the BT16 scenarios was presented as absolute changes in million gallons (fig. 7.7A) and relative changes in percentages (fig. 7.7B). Counties with highest responses (>2,500 million gallons) were found in the high water yield regions in Maine, Minnesota, and Oregon. The relative responses at the county level were rather small (<1.8%) when compared to total water yield of the reference. As discussed earlier, the projected water yield response in the scenarios is controlled by the amount of forest removal, the local hydrological regimes, and the maximum potential water yield response presented in figure 7.5. A majority of the counties had water yield responses of less than 1,500 million gallons per year, or 0.5% of annual water yield.

Figure 7.7 | WaSSI modeled projected response of mean annual water yield to reference under the ML 2017 harvesting scenario across the United States showing A, absolute response in million gallons per year and B, relative response by percentage

A.



B.



This analysis identified 10 counties that show the highest percentage increases in water yield under the ML 2017 scenario (table 7.2). The maximum relative responses of these counties if the entire forest area in the county were harvested vary from 9% to 153%. These counties are located in Maine, Minnesota, Oregon, and Oklahoma in areas that are heavily forested with high runoff (>450 mm per year). St. Louis County in Minnesota is the exception, as runoff is lower (266 mm per year)r and there is extensive biomass removal (1%–2.6%). The largest absolute water yield response was found in Aroostook County in Maine. Nonetheless, the county's 5,643 million gallons per year increase in water yield was considered rather small, representing only 0.2% of the water yield.

The 10 counties that are projected to have the highest relative water yield response (0.8%–1.7%) to biomass harvesting in ML 2017 are listed in table 7.3. These counties are found in both dry (e.g., North Dakota) and wet areas (e.g., North Carolina). The hydrological response was considered to be rather small as a relative water yield, compared to the reference. The maximum relative responses of these counties if the entire forest area in the county were harvested are also presented.

Table 7.2 | The 10 Counties That Have the Highest Water Yield Response (Million Gallons per Year) to Forest Biomass Removals under the Baseline ML 2017 Scenario

County	State	Projected Water Yield Response		Precip-itation (mm/ year^{-1})	Runoff (mm/ year^{-1})	Harvest Area		Maximum Potential Water Yield Response					
		(million gallon/ year)	(%)			(km^2)	(%)	(mm/year^{-1})		(billion gallons /year)		(%)	
								Clear-cutting	Thin-ning	Clear-cutting	Thin-ning	Clear-cutting	Thin-ning
Aroostook	Maine	5,643	0.2	1,044	592	229	1.4	87	73	403	339	15	12
Somerset	Maine	3,798	0.2	1,143	672	152	1.5	90	75	254	212	13	11
Piscataquis	Maine	3,786	0.2	1,130	657	142	1.4	93	78	277	231	14	12
Oxford	Maine	3,529	0.3	1,229	729	124	2.4	111	92	162	135	15	13
Penobscot	Maine	3,256	0.2	1,130	634	120	1.4	97	81	236	196	15	13
Washington	Maine	3,051	0.2	1,227	729	119	1.8	93	77	171	142	13	11
Franklin	Maine	2,891	0.3	1,229	763	108	2.5	104	88	125	105	14	11
St. Louis	Minnesota	2,890	0.2	705	266	252	1.7	39	34	178	155	15	13
Douglas	Oregon	2,376	0.1	1,361	700	116	1.0	72	60	250	209	10	9
McCurtain	Oklahoma	2,069	0.3	1,299	482	76	2.6	65	55	85	72	13	11

Table 7.3 | The 10 Counties That Have the Highest Relative Water Yield Response (%) to Forest Biomass Removals under the Baseline ML 2017 Scenario

County	State	Projected Water Yield Response		Precipitation (mm/year)	Runoff (mm/year)	Harvest area		Maximum Potential Water Yield Response					
		(million gallons/year)	(%)			(km^2)	(%)	(mm/year)		(billion gallons/year)		(%)	
								Clear-cutting	Thinning	Clear-cutting	Thinning	Clear-cutting	Thinning
Dunn	North Dakota	1,078	1.7	424	44	5	68.2	1	1	1	2	1	3
Middlesex	Virginia	379	1.3	1,170	339	20	8.7	52	43	4	4	15	13
Fairfield	South Carolina	1,379	1.2	1,084	245	61	3.5	93	72	45	35	38	29
Lancaster	South Carolina	864	1.0	1,082	246	43	3.2	85	71	30	25	35	29
Warren	North Carolina	964	1.0	1,125	320	44	4.3	78	62	24	19	24	19
Erie	Ohio	649	0.9	922	413	28	62.4	6	8	1	1	1	2
Brantley	Georgia	888	0.9	1,291	312	45	4.1	76	58	24	18	24	19
Lawrence	South Dakota	831	0.9	620	178	57	3.7	41	40	23	22	23	22
Echols	Georgia	687	0.8	1,288	280	39	3.7	72	54	21	16	26	19
Marshall	Kentucky	746	0.8	1,254	440	25	9.0	38	36	8	8	9	8

7.3.2.2 Baseline Case ML 2040

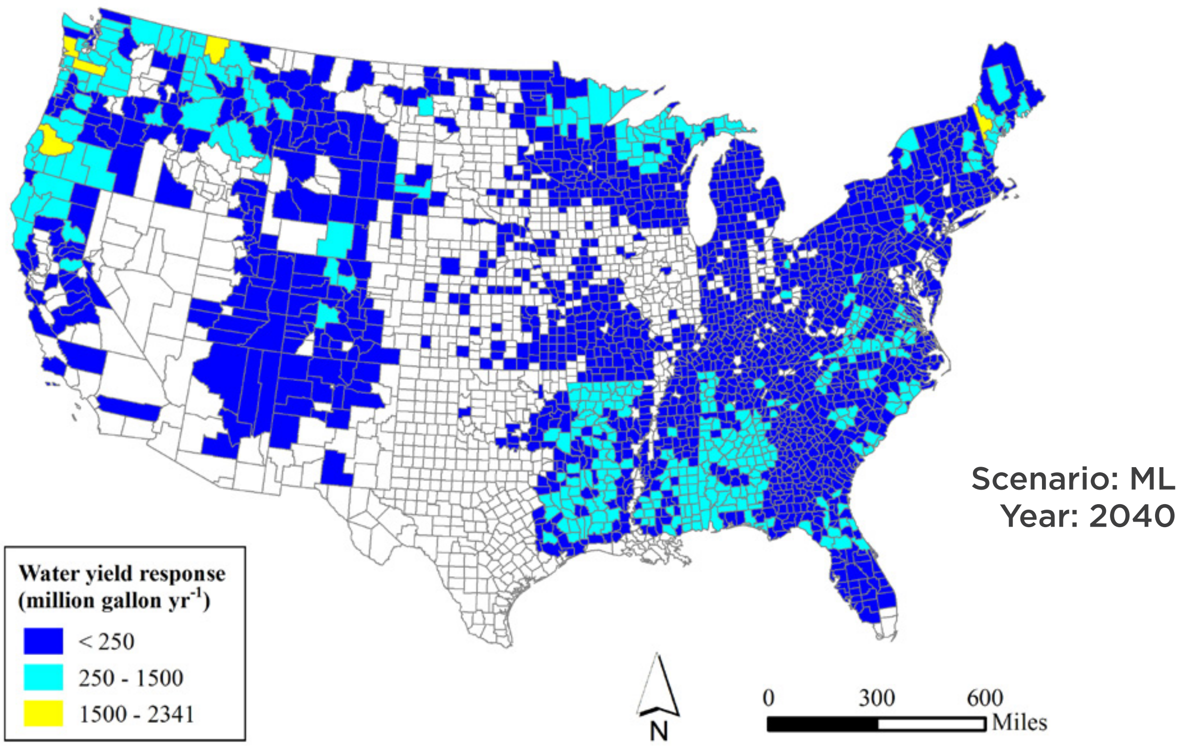
Compared to the water yield response under the baseline ML 2017 scenario, the water yield response under the ML 2040 scenario was found to be even smaller in both absolute and relative terms. A majority of the counties have annual water yield increases of less than 250 million gallons or 0.5% of background water yield (fig. 7.8). The decreased water yield response is due to the reduced forest harvesting area in 2040 as compared to 2017 (figures 7.2A and 7.2B).

7.3.2.3 High Yield Case HH 2040

Similar to the ML 2040 scenario, a majority of the county-level water yield responses under the HH 2040 scenario are less than 250 million gallons per year or 0.5% of background water yield (fig. 7.9). This scenario represents the lowest impacts on water yield among the three scenarios.

Figure 7.8 | WaSSI modeled projected response of county-level mean annual water yield to under the ML 2040 harvesting scenario across the United States, showing A, absolute response in million gallons per year and B, relative response in percentage change from reference conditions

A.



B.

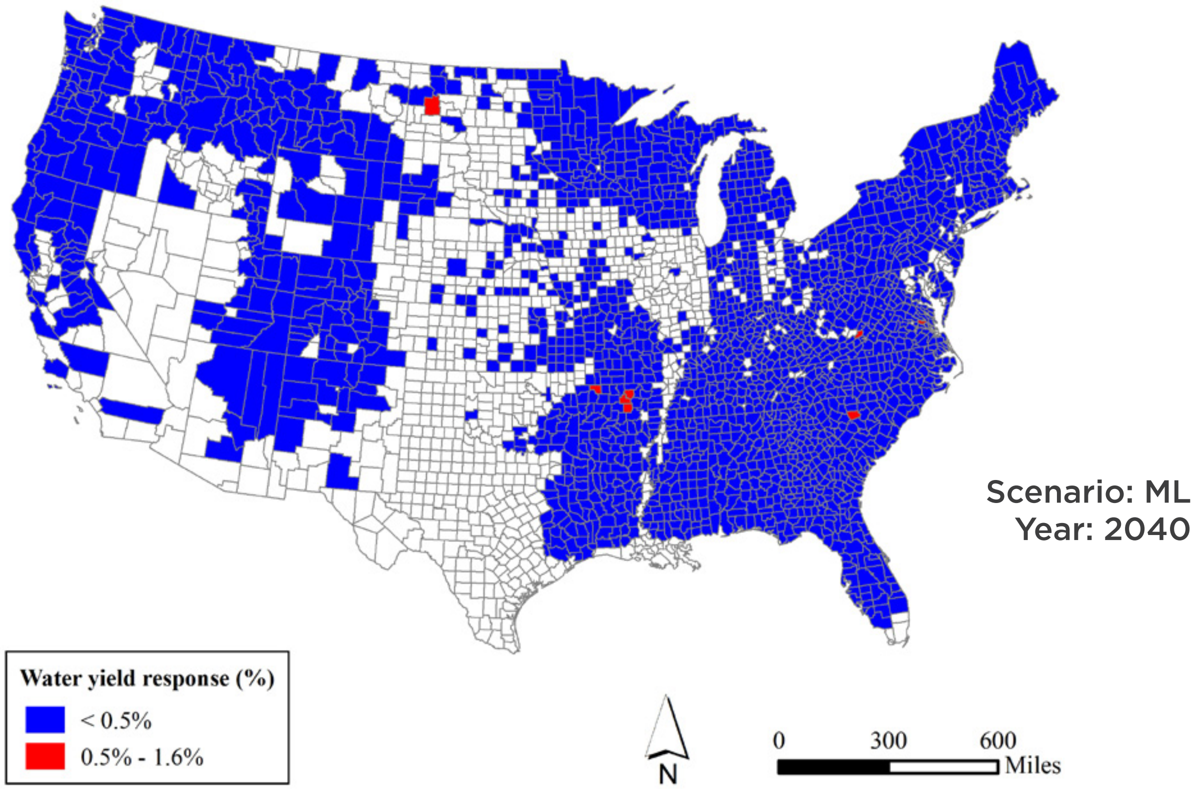
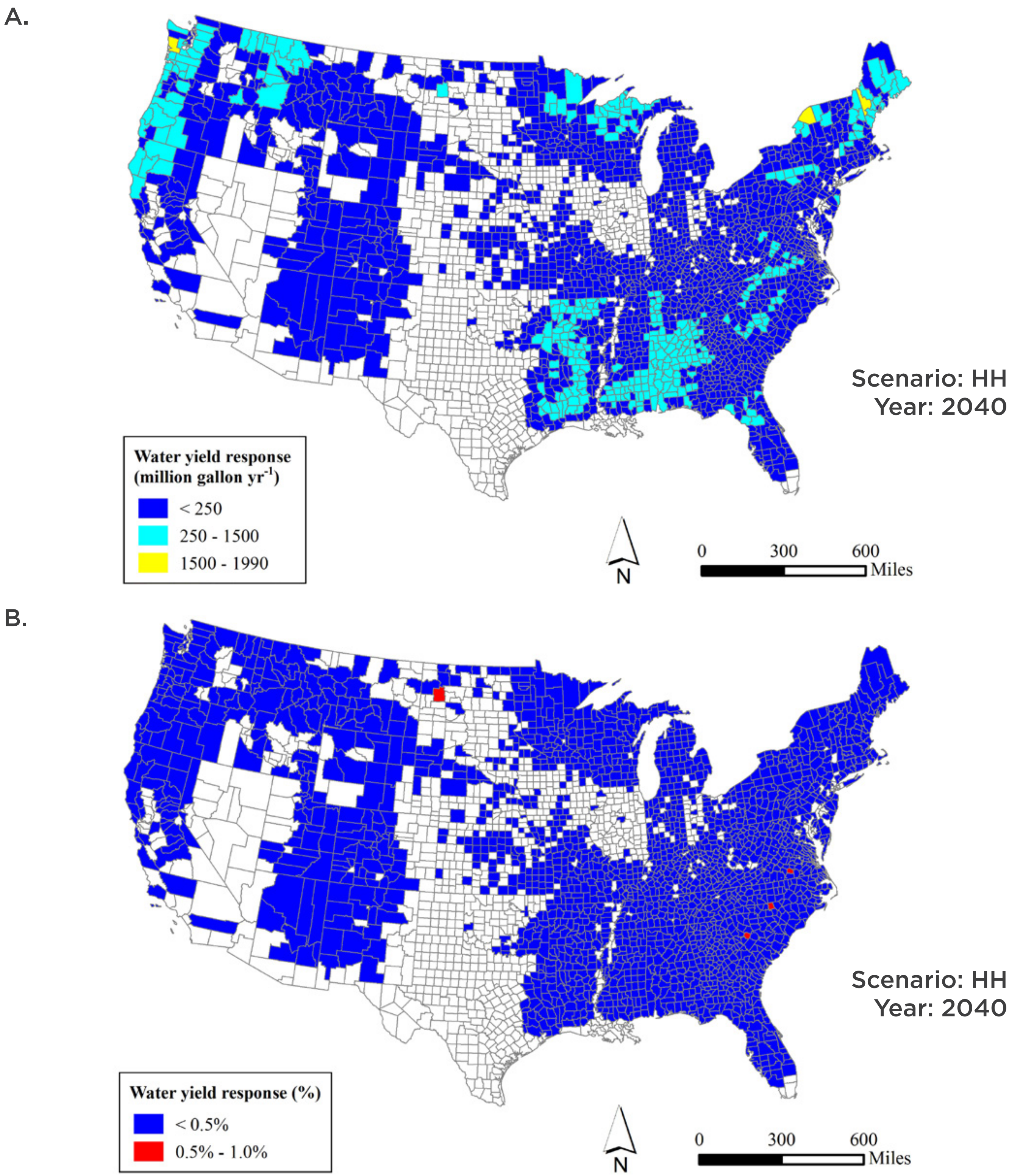


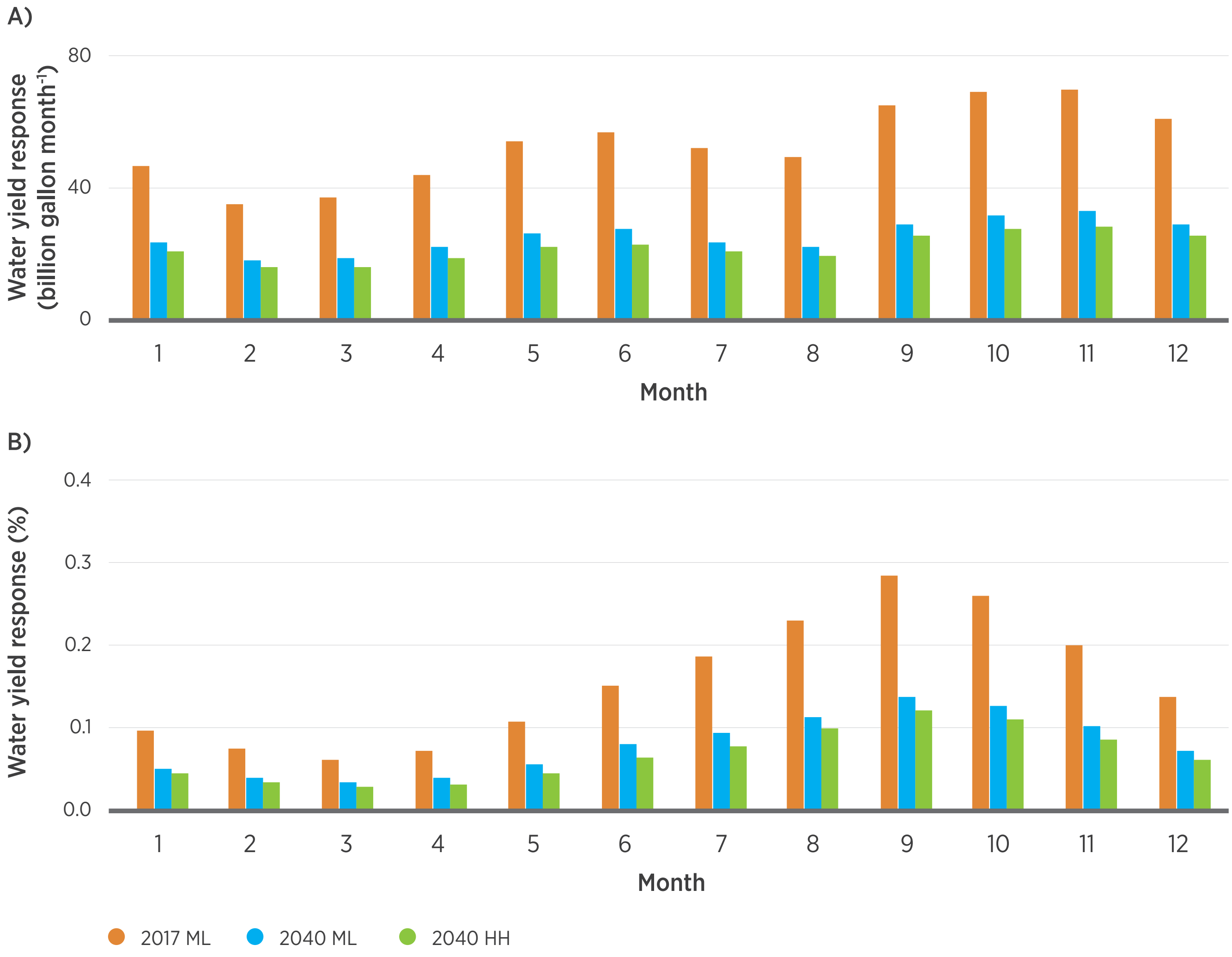
Figure 7.9 | WaSSI modeled projected response of county-level mean annual water yield under the HH 2040 harvesting scenario across the United States, showing A, absolute response in million gallons per year and B, relative response as a percentage change from reference conditions



7.3.3 Seasonal Response to Biomass Removal

Effects of different harvesting scenarios on water yield vary by scenario as well as by season (fig. 7.10). Figure 7.10A shows that biomass removal in 2017 has a much higher impact (>two times) on water yield than it does in 2040 at both harvesting levels. In general, the absolute water yield responses vary little seasonally, showing a uniform pattern (fig. 7.10A), while the relative changes peak during the fall season, when streamflow is the lowest in most of the U.S. watersheds (fig. 7.10B).

Figure 7.10 | WaSSI modeled response of seasonal water yield to three harvesting scenarios across the United States, showing A, total absolute response in billion gallons per year and B, relative response as a percentage

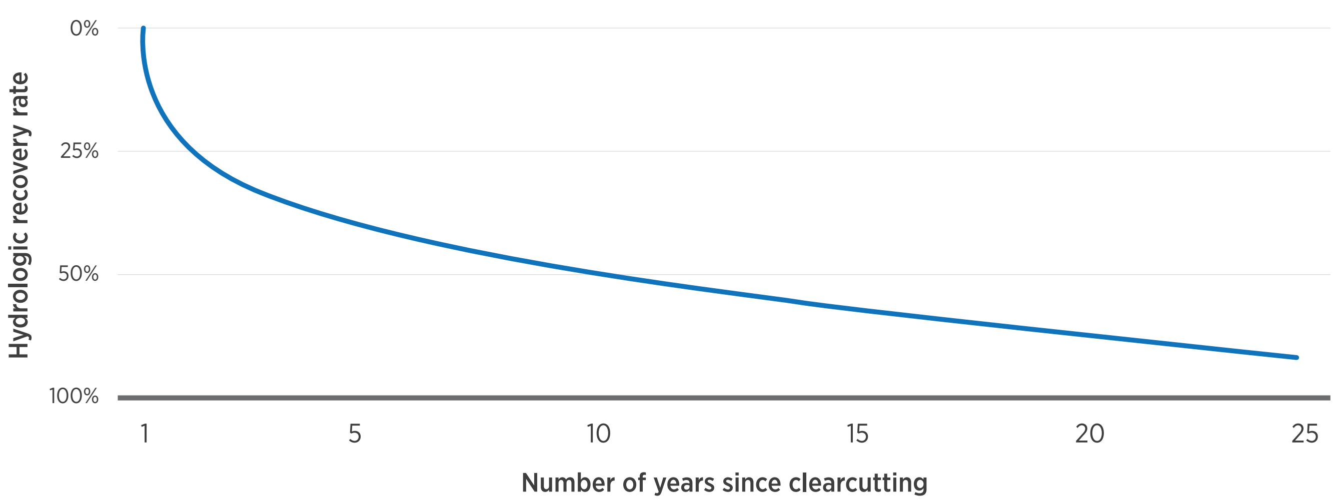


7.4 Discussion

This study applied a watershed water balance model, WaSSI, to estimate seasonal and mean annual hydrological responses to three scenarios of biomass removals. Water yield changes are expressed at the county level, since biomass harvesting data are reported at that spatial scale. Removal of forests by clearcutting or severe thinning (70% reduction in LAI) has the potential to increase water quantity up to 50% in some regions. However, because the cutting areas are relatively small (<5%) when compared to the total forestlands at the county scale, this study projects that the hydrologic responses would be rather minor in the three biomass removal scenarios. The simulation results are consistent with the empirical notion that removing less than 10% of forest cover in a watershed does not have measurable impacts on streamflow.

Harvesting impacts presented in this study represent the immediate annual responses of water yield to forest clearcutting or thinning, or the maximum water supply change at the county scale. Since trees are likely replanted or would regenerate naturally, water yield impacts in subsequent time periods would gradually decrease while total forest ET rates increase (Ford et al. 2011). Depending on local climatic and vegetation characteristics, the hydrology of disturbed watersheds may recover within a few years to decades in the United States. For example, a watershed dominated by deciduous hardwoods in the southern Appalachians can recover to pre-disturbance levels 5–10 years after clearcutting. Similarly, clearcutting loblolly pine plantations can increase drainage up to 50%, but the increase of water may diminish after 10 years of replanting {Sun, 2004 #1661}. However, it may take over 50 years for forests in areas with low growth rates, such as the Rocky Mountains, to recover their hydrology. Fig. 7.11 presents a hydrologic recovery curve developed from experimental data at the Coweeta Hydrologic Laboratory in North Carolina to illustrate that water yield response to forest harvesting decreases over time. In this case, more than 85% of the initial increase in water yield (about 350 mm per year) diminishes by year 25 after the watershed was clearcut and trees are regenerated (fig. 7.11).

Figure 7.11 | A hydrological recovery curve for a watershed dominated by deciduous hardwood forests in the southern Appalachians, showing that the initial water yield increase due to forest clearcutting diminishes over time as a result of tree regrowth and associated increase in ET (Sun et al. 2004)



7.4.1 Implications of Modeling Results

The baseline 2017 biomass harvesting scenario (ML 2017) represents the largest hydrological disturbance related to forest biomass–based energy development. However, this study suggests that the projected biomass removal levels are rather low and may not cause concerns or large benefits to water quantity and water resources at the county scale. It is important to note that although the hydrological effects are negligible at the county level, the impacts can be significant if the biomass harvesting activities are concentrated within a watershed in a county. In such a case, forest removals may increase stormflow volume, potentially causing water quality concerns. Forest best management practices such as implementing forest riparian buffers may be effective to mitigate negative harvesting effects on stream hydrology and water quality (Cristan et al. 2016). Geographically, forest biomass removals may have fewer environmental issues in areas with a flat topography and vegetation that recovers quickly.

7.4.2 Uncertainties and Limitations

This study took a top-down approach in modeling the likely impacts of forest biomass removal on water quantity at the county level rather than a bottom-up approach that examines hydrological processes in forests in a spatially explicit manner. Although the WaSSI model considers the effects of climate, soil, and forest structure (LAI) on water balances at the watershed scale within a county, the simulated water yield responses by WaSSI represent a mean condition. Errors may occur as a result of not knowing the exact location that biomass removal activities would occur. Localized forest harvesting may have much higher impacts on the hydrology in certain watersheds than at the county level. In addition, the water balance component of the WaSSI model was developed using ecohydrological data for multiple ecosystems and has been used to understand impacts of forest thinning, but results have not been thoroughly verified, specifically under forest disturbance conditions, because of the lack of experimental data.

This analysis used long-term (1991-2001) mean climate to simulate the hydrological effects of forest cover change and assumed that the climate in 2040 would remain the same as in 2017 (e.g., the historic conditions). Recent studies suggest that by 2040 the climate may be much warmer, and water yield is expected to decrease because of the rise of ET (Sun et al. 2015a; Duan et al. 2016). Thus, forest biomass harvesting in 2040 is expected to have more pronounced effects in terms of relative change in water yield in most regions across the United States.

7.5 Summary and Future Research

The amount and distribution of forest live biomass is closely related to water yield and water supply, one of the important ecological functions and services of forest ecosystems. Biomass harvesting has the potential to alter water quantity by altering ecohydrological processes (ecosystem ET in particular).

This analysis applied a monthly watershed hydrological model, WaSSI, to the 88,000 HUC 12 watersheds and quantified how three select BT16 forest-harvesting scenarios affect mean seasonal and annual water yield at the county level. The research shows that all scenarios would have minor impacts on water quantity at the county level because of the small areas of harvesting (<5%) in most counties. The small magnitude of hydrological response (<2%) to biomass removal may not have much significance, positive or negative, in terms of water supply at the county level. However, it is important to note that concentrated biomass-removal activities may cause substantial local impacts on watershed hydrology. Unfortunately, current projections of biomass harvesting do not provide the spatial information sufficient for watershed-scale assessment, and therefore, the study presented here only shows county-level water yield responses. Research is needed to model biomass removal at finer spatial scales, such as a watershed rather than a county.

This analysis assessed water yield impacts on an annual basis; however, hydrological and environmental impacts are cumulative. Future studies should examine the cumulative effects of forest biomass removal in specific watersheds where harvesting activities are expected to occur. This study only examined total water yield, without looking at other hydrologic parameters, such as base flow and peak flow rates. Future watershed-scale studies should focus on ecologically relevant indicators of streamflow. In addition, future studies should link water quantity and quality to allow for a comprehensive assessment of water resources at the watershed to county levels.

7.6 References

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