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# Private Forests, Housing Growth, and America's Water Supply

## A Report From the *Forests on the Edge* and *Forests to Faucets* Projects

Miranda H. Mockrin, Rebecca L. Lilja,
Emily Weidner, Susan M. Stein, Mary A. Carr

A Forests on the Edge Report




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Private forests provide a vast array of public goods and services, including abundant, clean surface water. *Boys fishing, thinkstock.com.*

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## ABSTRACT

America's private forests provide a vast array of public goods and services, including abundant, clean surface water. Forest loss and development can affect water quality and quantity when forests are removed and impervious surfaces, such as paved roads, spread across the landscape. We rank watersheds across the conterminous United States according to the contributions of private forest land to surface drinking water and by threats to surface water from increased housing density. Private forest land contributions to drinking water are greatest in the East but are also important in Western watersheds. Development pressures on these contributions are concentrated in the Eastern United States but are also found in the North-Central region, parts of the West and Southwest, and the Pacific Northwest; nationwide, more than 55 million acres of rural private forest land are projected to experience a substantial increase in housing density from 2000 to 2030. Planners, communities, and private landowners can use a range of strategies to maintain freshwater ecosystems, including designing housing and roads to minimize impacts on water quality, managing home sites to protect water resources, and using payment schemes and management partnerships to invest in forest stewardship on public and private lands.

***Key words:*** forest, drinking water, development, stewardship, community

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# INTRODUCTION

Forested lands in the United States provide multiple goods and services to the American public, including: forest products, fish and wildlife habitats, and opportunities for outdoor recreation and education. One of the most vital benefits provided by forested ecosystems is clean and abundant supplies of water for drinking and agricultural and manufacturing uses, as well as for aquatic habitats and numerous other ecological, social, and economic purposes.

Both public and private forests contribute to maintaining the quality of the water supply, but private forests are uniquely vulnerable to being converted to or affected by housing development. This report focuses on the role of privately owned forests in providing clean drinking water, and how increasing housing density may alter these forests and water quality.

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Forested ecosystems provide high-quality water for drinking and other human uses.

Larry Jernigan, volunteer, US Fish and Wildlife Service Southeast Region

Clean water flowing from private forests supports a myriad of recreational opportunities.

This report is one of several produced by the U.S. Department of Agriculture (USDA), Forest Service as part of the ongoing Forests on the Edge project; it is also produced in conjunction with the Forests to Faucet project (see box). We display and describe information at a national level that can improve understanding of the connection between forest land development and water. The report draws on the scientific literature to describe how increased housing density in private forests affects water quality. We then combine national datasets on water quality and housing density to answer the questions:

- Where, nationwide, do private forests make substantial contributions to clean water?
- Where are projected increases in housing density expected to negatively affect private forests and water?

We present several examples of how land use planners, natural resource managers, and communities are responding to these threats and taking action to maintain water quality in the face of forest development.

Fed by forested streams, California's Lake Shasta is a critical source of water for irrigation, drinking water, and power supply.

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For these analyses, we focused on water quality and housing characteristics for which nationally consistent data were available. Similar to other Forest on the Edge reports, the data are analyzed by watershed—an area of land that drains into a river, stream, or other body of water. We chose watersheds as the unit of analysis to emphasize the vital connection between private forests and clean water. Analysis at the watershed scale also provides information useful for States, counties, and national forests. However, as with previous Forests on the Edge reports and other national assessments, the final results are not intended to assess individual watersheds of interest, but rather to give a wider understanding of the trends and patterns across the landscape.

## FORESTS, WATER, AND HOUSING—A COMPLEX RELATIONSHIP

Forests are critical to America's clean water supplies, but they are also very desirable places to live. As the U.S. population increases, in forests and elsewhere, so does our need for reliable sources of clean water. However, housing growth in forested areas is associated with negative impacts on water supply.

### About the Forests on the Edge and Forests to Faucets Projects

Sponsored by the State and Private Forestry, Cooperative Forestry staff of the U.S. Forest Service, in cooperation with Forest Service Research and Development and other partners, the Forests on the Edge project (http://www.fs.fed.us/openspace/fote/) uses data prepared and analyzed by scientists across the country to increase understanding of the many public benefits derived from private and public forests, and of the pressures that might affect these benefits. The Forests on the Edge project is one of several efforts to assess the status, condition, and trends of forests across the United States.

The Forests to Faucets project, sponsored by the Cooperative Forestry Ecosystem Services staff, uses geographic information systems (GIS) to model and map the continental United States land areas most important to surface drinking water; the role forests play in protecting these areas; and the extent to which these forests are threatened by development, insects and disease, and wildland fire. The spatial dataset can be used to identify areas of interest for protecting surface drinking water quality, can be incorporated into broad-scale planning, and can help identify areas for further local analysis. For more information visit http://www.fs.fed.us/ecosystemservices/FS_Efforts/forests2faucets.shtml.

NRCS / Jeff Vanuga

Handline sprinkler irrigation germinating crops in Yuma, AZ.

## Forested Ecosystems and Water

Water supply begins as precipitation. Water that seeps underground into pores between sand, clay, and rock formations is termed groundwater. In this report we focus on surface water—water derived from precipitation that enters streams and rivers, eventually flowing downstream to oceans. Approximately two-thirds of the U.S. population relies on surface water for drinking, with the rest using groundwater (EPA 2009).

The health of the lands through which freshwater passes play an important role in the supply and quality of surface water resources. Forests are known to play a particularly important role in water quality, reliably producing the highest quality stream water (Neary and others 2009). Forests are highly efficient at capturing precipitation (owing in part to organic matter, such as leaves, on the forest floor) and at maintaining water quality (owing to the filtration functions played by high quality soils) (Neary and others 2009). Forests also maintain effective nutrient cycles and prevent erosion and sediment runoff (Neary and others 2009, Vose and others 2011, Wickham and others 2011). These water resources in turn support vital riparian and wetland habitat for aquatic and terrestrial animals as well as high-quality water for drinking and other human uses.

In total, an estimated 53 percent of the water supply in the conterminous 48 States originates on forests (Brown and others 2008)[1]. Consequently, the U.S. population relies heavily on healthy forested watersheds to produce a stable and high quality supply of water. For example, urban areas throughout Arizona, California, and Nevada derive most of their water from the Colorado and Green Rivers, which originate in high-elevation forested headwaters in Colorado and Wyoming (Neary and others 2009). Not all water resources originate on public lands: most of New York City's water supply comes from New York's Catskills area, a region that is 75 percent privately owned (Postel and Thompson 2005).

Maintaining forest health can minimize the cost of additional treatment by local governments. In fact, some U.S. cities—such as Seattle (WA), Boston (MA), Portland (OR), and New York (NY)—have chosen to invest in land conservation and watershed protection rather than in additional water treatment facilities to maintain water quality (Carpe Diem West 2013, Postel and Thompson 2005). In other cities (such as Denver, CO, Santa Fe, NM, and Flagstaff, AZ), the drinking water supplier or city residents have invested money in forest restoration and wildfire risk reduction in watersheds that supply drinking water (see Innovative Payment Schemes, later in this document).

USFS / Susan Stein

More than half of the water supply in the conterminous United States originates on forests.

## Importance of Private Forests

More than half of America's forests (56 percent, or 423 million acres) are privately owned (Fig. 1)—that is, they are owned and managed by individuals, families, corporations, tribes, and the forest industry (Butler 2008).

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North-South Lake and the Hudson Valley in the Catskills Mountains, upstate New York.

[1] Brown and others (2008) derived vegetation cover from the 1992 National Land Cover Database, with forest cover composed of cover classes 41 (deciduous forest), 42 (evergreen forest), and 43 (mixed forest).

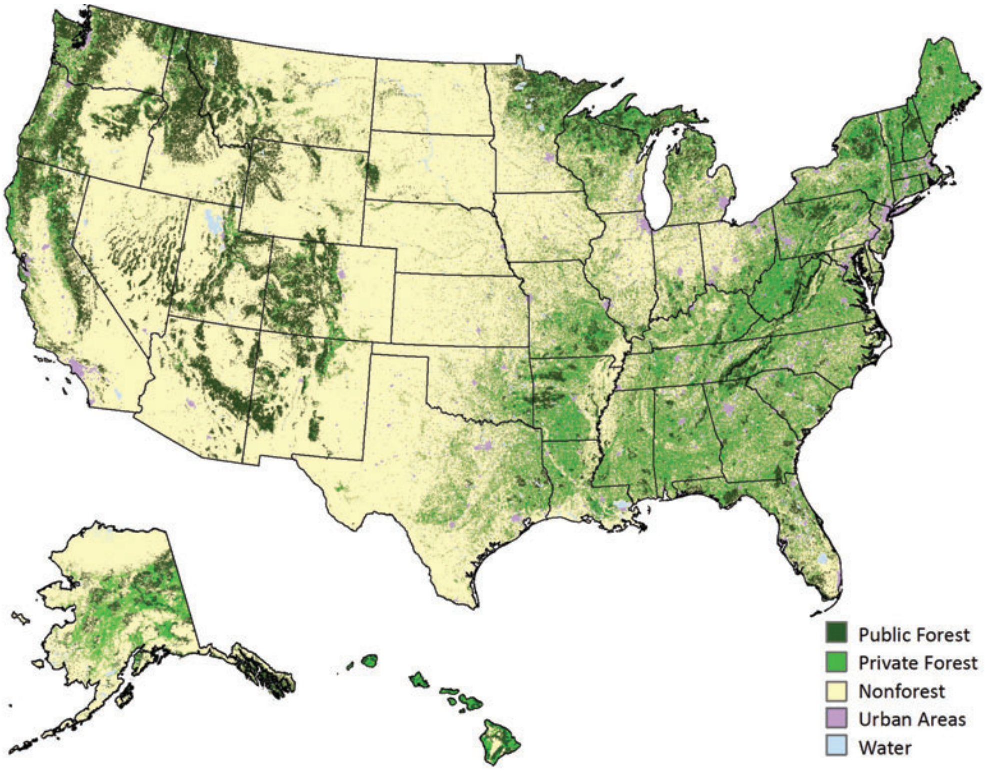


Figure 1. Location of private and public forest, nonforest, and urban areas. Private Forest includes private conservation land and easements. SOURCE: CBI (2012), Fry and others (2011).

Private forests are not distributed equally across the U.S.: three-quarters are in the Eastern United States, although private lands in the Western United States are also ecologically important.

Private forests make valuable contributions to our water supplies: more than a quarter of our fresh water flows from and is filtered by private forest lands (Brown and others 2008). Public lands—those areas owned by Federal, State, or local governments—were not included in the analysis presented here because these lands are typically not at risk of increased housing density.

Private forests come in all sizes, from smaller than 10 acres to larger than 10,000 acres. Most private forest acreage is owned by "family forest" owners—individuals and families—while others are owned by corporations; these owners have diverse management goals, styles, and resources (Butler 2008). However, this is a time of uncertainty and change, both for corporate and family forest owners. Among corporations, traditional forest industry owners have been increasingly replaced by institutional investors, leading to a higher frequency of land turnover and subdivision of large land holdings (Clutter and others 2005).

## Who Are U.S. Private Forest Owners?

Data from the Forest Service's *National Woodland Owner Survey* (Butler 2008) show that most of the 11 million diverse owners of private forests have relatively small properties—close to 8 million landowners have fairly small holdings of fewer than 50 acres each. Although there are fewer large properties, their bigger size means that those owners with more than 100 acres hold some two-thirds of the private forest acreage (Fig. 2).

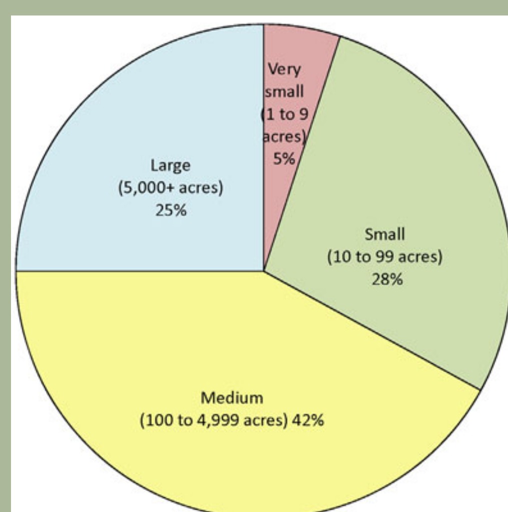


Figure 2. Percentage of private forest acres by parcel size. SOURCE: Butler (2008).

Many family forest owners are older than 55 years, and 22 percent of all family forest land may be available for sale or transfer to new owners in the near future (Butler 2008). In combination, the rising costs of owning family forests, demand for housing in many forested areas, and shifting economic realities for timber production will likely increase land subdivision and housing development on private forests. These trends are expected to continue into the future, despite the economic downturn and slowdown in the housing market that started in 2007.

## Housing Development Effects On Water

When forests are developed for housing, wide-ranging environmental impacts can ensue. During development, forest vegetation is cleared and slopes and soils are graded for construction, which can lead to erosion and sedimentation. After construction, impervious surfaces (those that do not allow water to seep through) such as roads, parking lots, and rooftops are introduced; and new infrastructure (such as gutters and storm drains) enables fast removal of surface water from the landscape (Hansen and others 2005, Liu and others 2003).

## The Economic Downturn and Housing Growth

The economic downturn that started in 2007 had wide-ranging effects on the American economy, lowering rates of home ownership and slowing the record housing development that had been seen in the previous 2 decades (Congressional Budget Office 2008, Jacobsen and Mather 2011, Yen 2011). The 30-year period used for our housing projections (from 2000 to 2030) does not factor in these economic changes and their impacts on the housing market (Theobald 2005). However, economists and housing experts expect that housing growth will recover with the economy (Williams 2012), so that the rate of land conversion for residential development is expected to rise again in the future.

The slowdown in housing expansion may offer a valuable opportunity to plan for the future of residential development and land conservation. For example, as land has become more affordable and development has slowed, land trusts have been able to expand conservation efforts, often through easements that allow continued forestry, timber, or agriculture (Christensen and others 2011). The housing downturn is also allowing time for communities to address planning concerns; for example, county governments and local groups are working to reshape unfinished housing and resort developments that are common across the West (Best 2012).


Private forest landowners have diverse objectives for their forests, ranging from sheer enjoyment to forest products to conservation and family legacy.

New housing development also leads to expanded infrastructure far beyond the site of the house, including roads and transportation networks. (See Building Roads and Infrastructure, later in this document.)

Thus, housing development not only removes existing forest vegetation that had been protecting the water supply, but also significantly alters freshwater systems by increasing the amount of impervious surface, mostly roads (Jacobson 2011, Schuler and Ince 2005). As impervious surface expands, less precipitation is able to recharge the groundwater supply, and more is lost to surface runoff, thus altering the timing of stream flows (Fig. 3). Additional impacts of housing and associated development include more pollutants in the water, more variable water flow due to increased impervious surface (which may cause in-stream sedimentation), and increased water temperature due to loss of vegetation and expansion of impervious surface (Allan 2004, Brabec and others 2002).

These alterations in water quality and quantity have far-reaching effects on people and wildlife. As surface water runoff is altered, riparian zones experience reduced abundance and diversity of many organisms, including algae, invertebrates, amphibians, and fishes (Paul and Meyer 2001, Price and others 2006, Riley and others 2005) (Fig. 3). A review of scientific studies (Brabec and others 2002) found a decline in the diversity and abundance of fish, invertebrates, and other aquatic organisms when impervious surface ranged from 3 to 15 percent of the area, as a result of habitat degradation (turbidity, altered flow regimes, increased temperatures).


USFS / Susan Stein

The addition of homes and other structures to the landscape can cause higher streamflow rates, and greater stream bank erosion during rains.


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More impervious surfaces means less water is absorbed into the ground to recharge groundwater supplies.

As water quality declines, challenges for human use increase, including rising costs for filtration and treatment (Davies and Mazumder 2003, Dearmont and others 1998, Grolleau and McCann 2012). And while such treatment might clean up certain aspects of water pollution for direct human consumption, water treatment facilities operate in only one location and do not address water quality issues across the entire landscape, as a healthy forest can do.

These impacts have become more prevalent across the United States as housing development has intensified, with a notable increase in housing in rural areas with high natural amenities, such as mountains, forest cover, or lakes (Hammer and others 2004, McGranahan 1999,

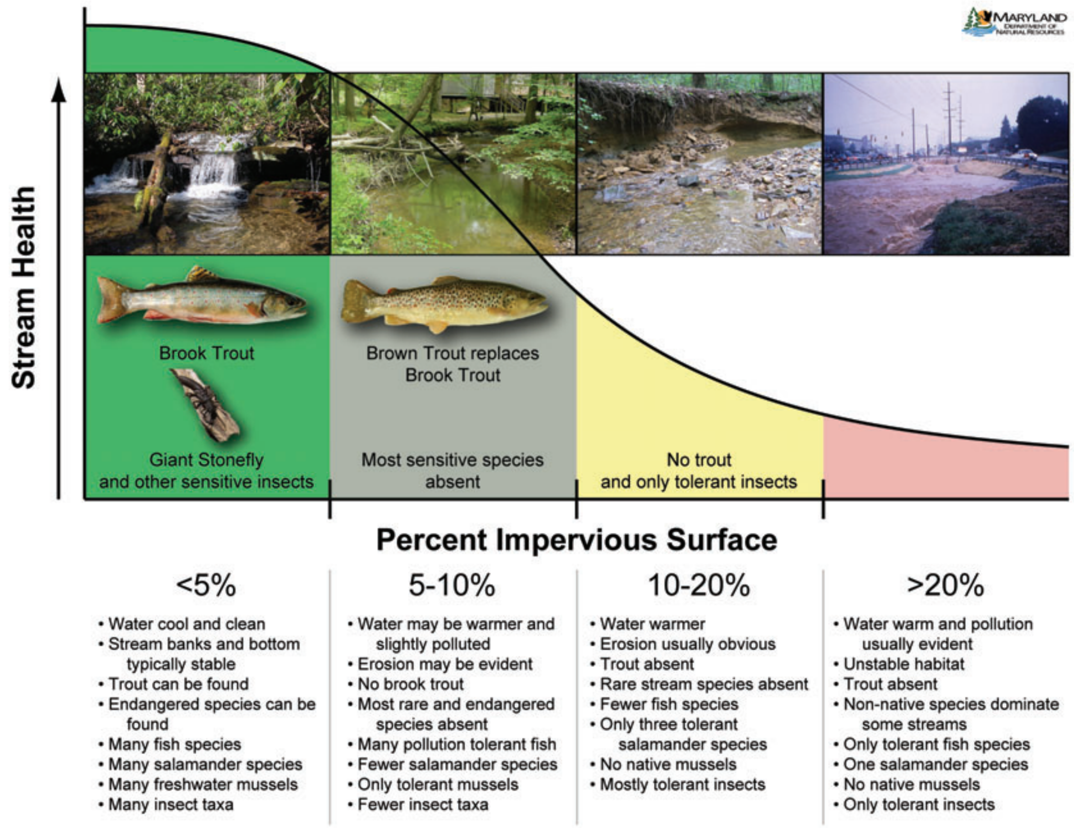


Figure 3. Impacts of impervious surface on water quality and biodiversity. Used with permission from the Maryland Department of Natural Resources.

Theobald 2005). Nationally, housing and infrastructure are expanding at higher rates than are human populations, as a result of decreasing household size, more widespread home ownership, and multiple home ownership (Hammer and others 2004). By 2000, urban and exurban settlement in the United States had expanded to cover four to five times the area they had covered in 1950 (Brown and others 2005).

Development in rural or exurban areas is of particular concern because the average housing unit in these areas causes more development impacts than the average urban housing unit, largely because of the additional roads and infrastructure needed for each household (Brabec and others 2002, Brown and others 2005).

## METHODS: ESTIMATING THE IMPORTANCE OF PRIVATE FORESTS TO DRINKING WATER

To determine the relationship between private forests, housing growth, and water quality and supply, we first determined where watersheds with private forests are located. We then created a measure of how important each watershed is for surface drinking water, and we estimated the relative contribution of private forests to the supply of surface drinking water. We combined this information about where private forests are important to surface drinking water with projections of where housing densities are expected to increase, to identify those areas where future housing development may threaten water supplies.

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New housing development leads to expanded infrastructure, such as roads, which can affect water quality.

The analyses summarized and presented here originated in the Forests to Faucets project (Weidner and Todd 2011) and the Forests on the Edge project conducted by the Forest Service (e.g., Stein and others 2009). The methods used here in combining layers and ranking watersheds, including the housing density categories used, were first developed by the Forests on the Edge project. Weidner and Todd (2011) developed the surface drinking water importance index and worked at the finer 12-digit watershed level (see box, What is a Watershed?). See the appendix for further methodology details.

## Estimating the Presence of Private Forests

Where do private forests make substantial contributions to clean water, and where might future increases in housing density affect private forests vital to our drinking water supplies?

To answer these questions, we made a map identifying the percentage of private forest by watershed, based on data from the National Land Cover Dataset (NLCD) (Fry and others 2011), data on National Forest System (NFS) land locations (USDA Forest Service 2009), and the Protected Areas Database (CBI 2012). The watersheds used are referred to as 6$^{th}$-level or 12-digit hydrologic units (HUCs). The definition we used for "forest land" is the same as that used by the U.S. Geological Survey (USGS) when creating the NLCD: land with at least 25 percent tree crown cover from trees that are greater than 20 feet tall (Fry and others 2011).

## Measuring a Watershed's Contribution to Drinking Water

To determine what areas are most important for surface drinking water, we used a data layer created by Weidner and Todd (2011), which is an index of the relative importance of surface drinking water in each watershed across the United States. Weidner and Todd created this index by combining information on the volume of water available (water supply), the landscape surface flow patterns and the natural processes that affect water quality, and the need for drinking water downstream (water demand). Extra importance was given to watersheds that generate more water supply.

### What is a Watershed?

A watershed is an area of land that catches rainfall and other precipitation and funnels it into a network of marshes, streams, rivers, lakes, soils, or groundwater. The U.S. Geological Survey (USGS) has classified all U.S. lands according to a series of nested watersheds, referred to hydrological units. For this analysis, the 6$^{th}$-level or 12-digit hydrologic unit (HUC) was used (USDA/NRCS). Within the hierarchy of hydrological units, these 12-digit units are termed subwatersheds, but we refer to them as watersheds throughout this report for simplicity. There are more than 90,000 of these watersheds in the United States, with a mean size of 35 square miles, and ranging in size from 0.62 to 986 square miles.

USFS / Susan Stein

Much of the Potomac River is fed by surrounding private and is affected by the use of these lands.

We focus on human drinking water needs, at the 12-digit HUC level, although we recognize that research studies at smaller scales have focused on additional aspects of water quality, such as water temperature or concentrations of chemical pollutants and their effects on larger ecological systems.

## Determining the Role of Private Forests in Supplying Drinking Water

To understand the relative contribution of private forests to surface drinking water, we multiplied the surface drinking water importance index by the percentage of each watershed identified as private forest. This new value represented the importance of private forest land to surface drinking water. Watersheds with small amounts of private forests or low importance to surface drinking water had a small value for private forest contribution to surface drinking water.

### Assessing the Impacts of Housing Development

To assess the relative impact of future housing increases on private forests we relied on a dataset showing the percentage of a watershed predicted to experience a substantial increase in housing density, based on a method used by Stein and others (2009). Projected increases in housing density were derived from a spatially explicit model of housing growth, which simulates future patterns of development based on historical growth and accessibility to urban areas and protected lands (Theobald 2005). Housing densities were divided into three categories: rural 1 (more than 40 acres per housing unit), rural 2 (10–40 acres per housing unit), or exurban/urban (fewer than 10 acres per housing unit). Any areas projected to change from a rural category to a higher category were considered areas of substantial increase in housing density. We then determined the percentage of each watershed expected to experience an increase in housing density in private forested areas between 2000 and 2030.

### The Bottom Line: Combining Data Layers

Finally, for each watershed, we multiplied the percentage of the watershed projected to experience increased housing density in forested areas by the index of contribution of private forest land to surface drinking water (the index, as described above, includes information on water supply, water demand, and percentage of private forests). In this way, we identified those privately owned forested areas that are important for surface drinking water and are likely to be affected by future increases in housing density.

We ranked the top 100 watersheds according to the importance of private forests to surface drinking water supplies, 50 each from both East and West of the Mississippi River. Examining critical watersheds by region allowed us to highlight areas and States of importance across the U.S.

## FINDINGS

### Private Forest Contributions to Drinking Water

Highest ranked watersheds, shown in dark green on the map (Fig. 4), are those where private forests are of greatest importance to surface drinking water.

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Lake Fanny Hooe, Upper Peninsula, MI, an area that is an important resource for drinking water, fishing, and recreation.

Watersheds where private forests make the greatest contributions to surface drinking water are found across much of the Eastern United States. This finding makes sense as, relative to other parts of the country, many Eastern States have high population densities, high percentages of private forest, and a greater reliance on surface water than on groundwater. Notable areas include southern New Hampshire and eastern Massachusetts; eastern New York, the New Jersey Highlands and eastern Pennsylvania; western Pennsylvania; and the southern Appalachian highlands. In the West, higher values occur along the northern coast and high-elevation areas, such as the Pacific Coast ranges, the Sierra Nevada, and Colorado's Front Range. Values are lower for much of the arid West, owing to both lower population density and a much greater reliance on deep groundwater systems than in other areas of the country.

This model does not explicitly consider water scarcity; as a result, much of the arid West, although facing challenges with water supply issues, does not get high values in the *surface* water drinking importance index. Many other States that also rely on groundwater sources for drinking water (such as Wisconsin, Florida, and other southeastern coastal States) also have lower values of surface drinking water importance in this analysis.

## Future Housing Increases on Private Forests

More than 150 million acres of the conterminous United States, including 55 million acres of private forest lands, are predicted to experience a substantial increase in housing density between 2000 and 2030 [(Stein and others 2009)]. Among private forests, the 55 million acres expected to experience a substantial increase in housing density represents about 17 percent of rural private forests (rural 1 and 2). By 2030 we predict that the percentage of the United States with housing densities in the urban/exurban category will have doubled (Table 1). Nearly half the new acreage in urban/exurban areas will have come from rural 2 areas, with a similar amount going from rural 1 to rural 2 (Fig. 5).

Watersheds where private forest lands are predicted to experience a substantial increase in housing density

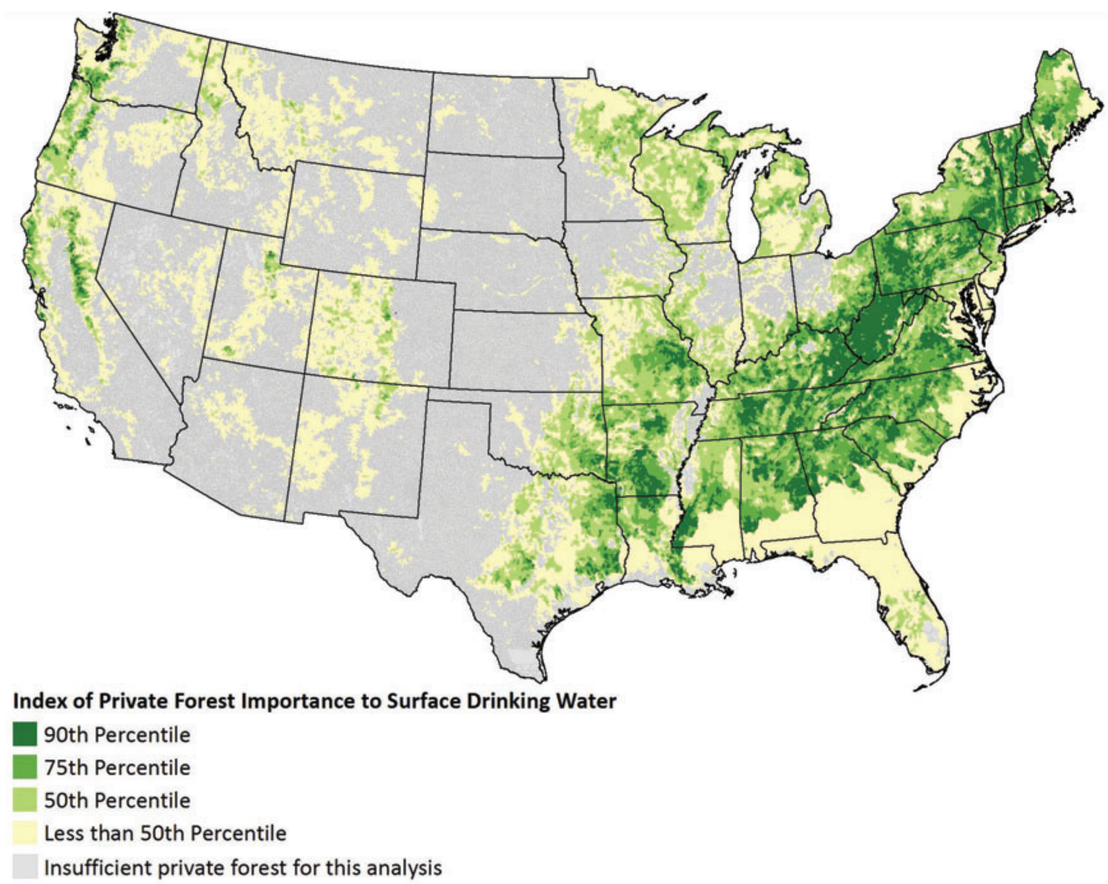


Figure 4. Private forest importance to surface drinking water (see Step 2 in the appendix) identifies those watersheds where private forest lands are most important in protecting surface drinking water. SOURCE: CBI 2012, Fry and others 2011, NRCS 2009b, Weidner and Todd 2011.

Table 1. Acreage and percentage of private forest in housing density classes from 2000 to 2030

| Housing density class | Acres (2000) | Percent of total land (2000) | Acres (2030) | Percent of total land (2030) |
|---|---|---|---|---|
| Rural 1 | 244,025,619 | 70 | 213,124,773 | 61 |
| Rural 2 | 76,820,759 | 22 | 78,728,937 | 23 |
| Exurban/urban | 26,960,774 | 8 | 55,953,441 | 16 |
| TOTAL | 347,807,151 | | 347,807,151 | |

are located throughout the East, concentrated along the Boston–New York–Washington DC corridor as well as in the Southeast, particularly in Florida (Fig. 6). Other areas where a substantial increase in housing density is expected in private forests include pockets in the upper Midwest and the Gulf Coast States, as well as watersheds along Colorado's Front Range, the northern California coast and the Sierra Nevada, and the Cascade Mountains in Washington State.

### Future of Private Forests and Water Quality

Watersheds where water quality is most likely to change due to increased housing density on private forests are most prevalent in the East. Eastern watersheds in the 90th percentile include many in New England and in the highland areas of the Southeast, well as the upper Midwest and southern Missouri (Fig. 7). In addition, the Colorado Front Range and high-elevation areas in Oregon, Washington, and California contain watersheds where private forest land development is likely to affect drinking water.

Looking at the top 50 watersheds where development is likely to affect surface drinking water in the East, we find high-ranking watersheds throughout the region: in the Mid-Atlantic and New England areas, but also in the Southeastern United States (Table 2, Fig. 8). At the state level, New Hampshire and Georgia combined have more than half of these high ranking watersheds. In the West, the top 50 watersheds are found in only 7 States, with more than half in California.

## STRATEGIES TO CONSERVE WATER QUALITY

Given the vital role that private forests play in preserving water quality and supply, and the forecasts for continued and widespread housing development, planners and communities across the country are using

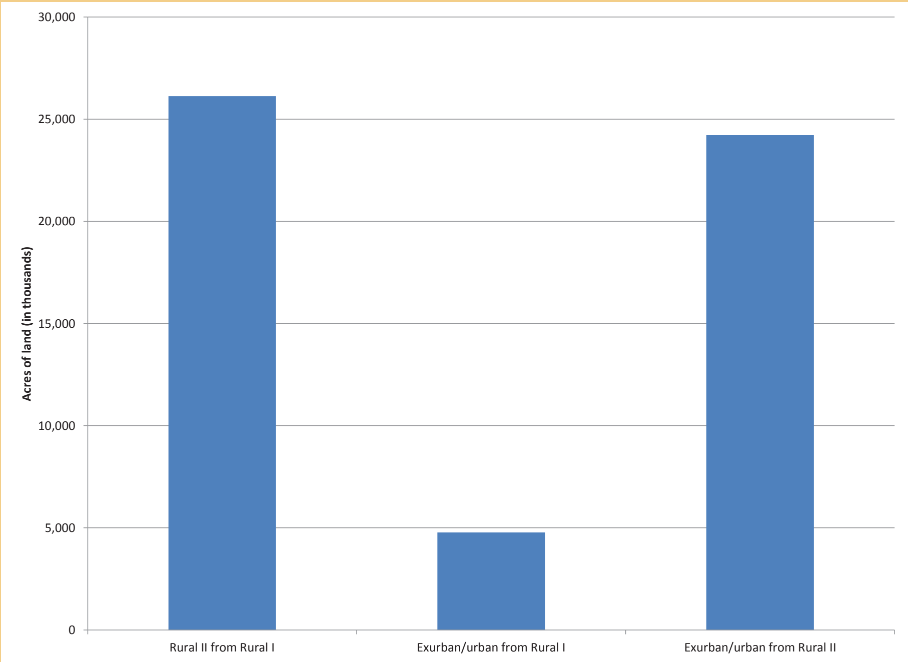


Figure 5. Acres of land predicted to transition between housing density classes, 2000–2030 (in thousands).

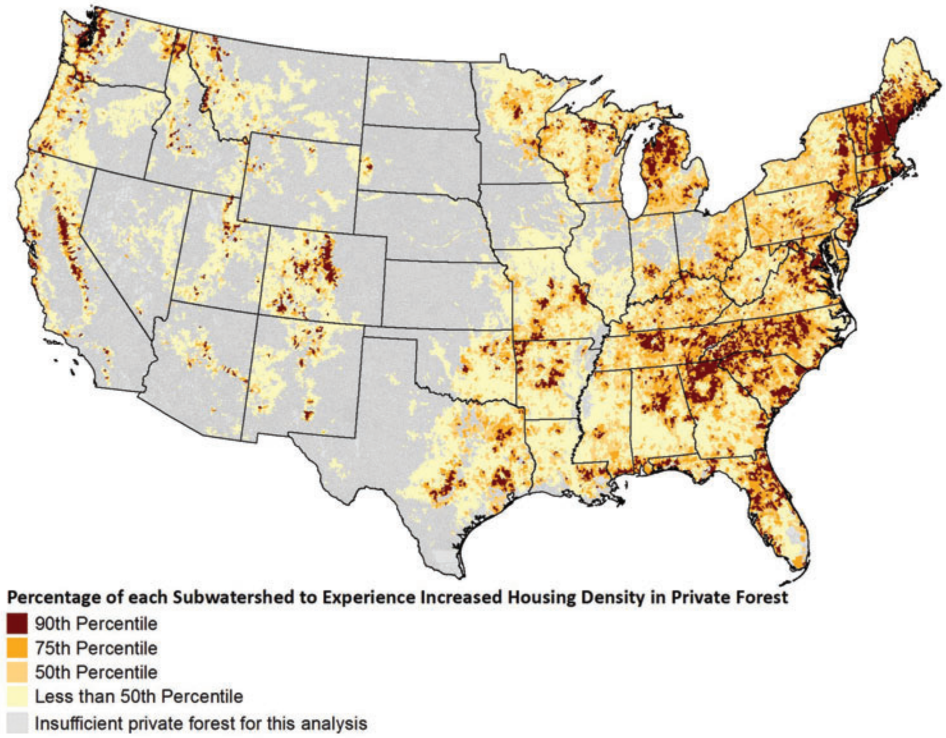


Figure 6. Percentage of each watershed expected to experience an increase in housing density in private forested areas between 2000 and 2030. SOURCE: CBI 2012, Fry and others 2011, NRCS 2009b, Stein and others 2009.

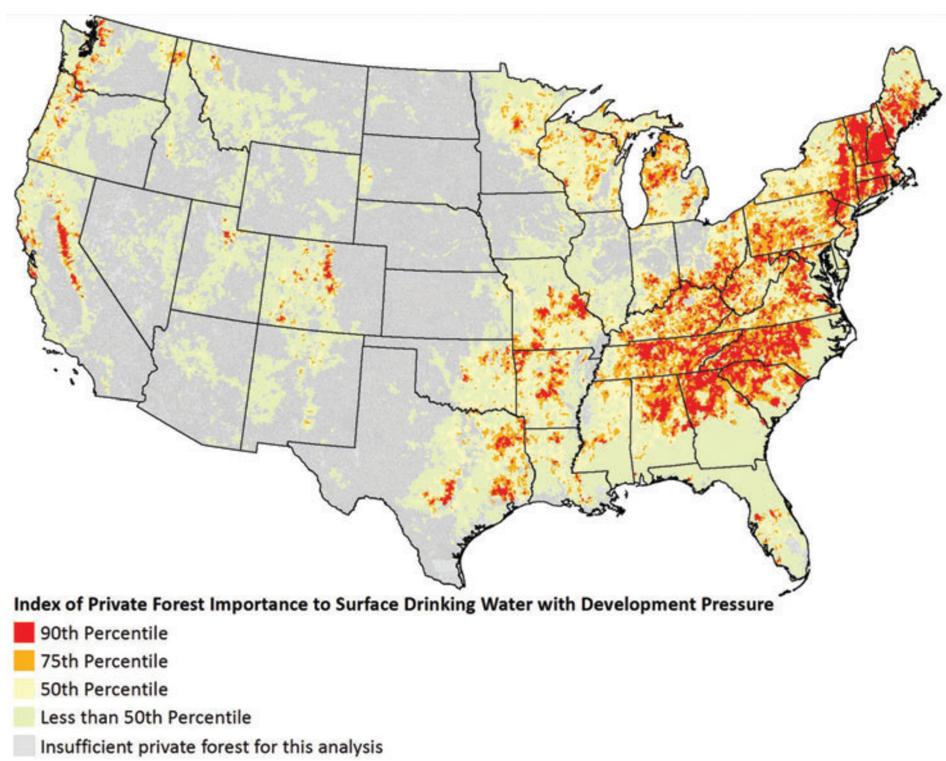


Figure 7. Watersheds ranked by importance of forests for both drinking water importance and future housing density increases combined (see Step 3 in the appendix. SOURCE: CBI 2012, Fry and others 2011, NRCS 2009b, Stein and others 2009, Weidner and Todd 2011.

Table 2. Number of top-ranked watersheds at risk, by State, west and east of the Mississippi River

| State | Number of top 50 Western watersheds |
|---|---|
| Arkansas | 3 |
| California | 27 |
| Colorado | 5 |
| Missouri | 7 |
| Texas | 5 |
| Utah | 2 |
| Washington | 1 |
| **State** | **Number of top 50 Eastern watersheds** |
| Alabama | 1 |
| Connecticut* | 1 |
| Georgia | 11 |
| Maine | 4 |
| New Hampshire | 16 |
| New York | 3 |
| North Carolina | 1 |
| Pennsylvania | 4 |
| Rhode Island* | 2 |
| South Carolina | 1 |
| Tennessee | 5 |
| Virginia | 1 |
| West Virginia | 1 |

*Watershed crosses State boundaries. See Fig. 8 for a visual distribution of high-ranking watersheds by State.

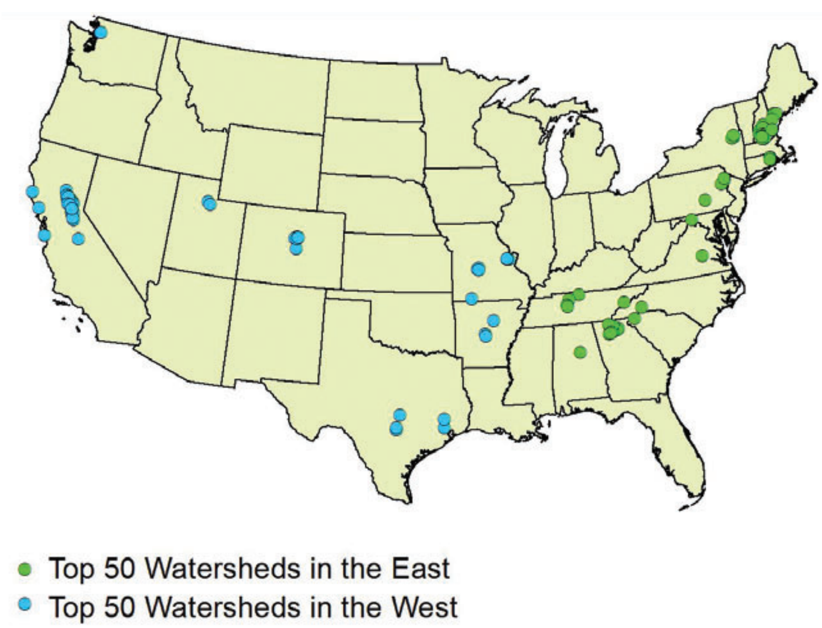


Figure 8. One hundred highest ranking watersheds where water quality on private forests is threatened by increased housing density. In some States the dots on the map overlap or are too close to distinguish individually because of multiple high-ranking watersheds; see Table 2 for the number of watersheds in each State.

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At-risk watersheds are found throughout the southeastern United States.

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McIntosh Lake, Rocky Mountains. Colorado contains five watersheds where private forest land development is likely to affect surface drinking water.

a number of strategies to maintain water quality before, during, and after residential development (Carpe Diem West 2013). Practices reviewed here include working with developers to design infrastructure, roads, and homes wisely before housing is built, as well as working with homeowners to ensure that their management practices around the home preserve water quality over the long term.

Although the focus of this section is on preserving the quality of water flowing from private forest lands, we also recognize that private individuals and municipalities have powerful incentives to protect both public and private watersheds, in order to preserve drinking water. This section also highlights several examples of how unique payments for ecosystem service arrangements can help protect water quality on both private and public land.

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Louis Cook / Philadelphia Water Department

Roof-top gardens, permeable pavements, and rain gardens can help reduce negative impacts of heavy rains in the built environment.

## Designing Development To Preserve Water Quality

### Low-Impact Development (LID)

As environmental impacts of residential development on water quality have become better understood, urban planners have responded by improving the design of residential neighborhoods to preserve water quality (Dietz 2007). The most commonly discussed strategy is low-impact development (LID), a set of techniques for land development (or re-development) that uses natural processes to manage stormwater (water originating during precipitation events), as close to its source as possible (Ahiablame and others 2012, Dietz 2007). LID is often implemented in concert with other planning strategies such as conservation developments (see next section) to reduce the environmental impact of housing development.

The main goals of LID are to reduce runoff, increase water infiltration back into the soil and eventually groundwater, maintain the natural flow of water after storm events in local streams and rivers, enhance water quality, and remove pollution (Ahiablame and others 2012, Dietz 2007). LID minimizes changes to water flow and quality by retaining and infiltrating runoff through plants and soils and minimizing impervious service, instead of conventional processing that gathers stormwater through pipes and deposits the water in large detention basins and outfalls.

Many practices to improve stormwater management can be considered LID, including rain gardens (specially selected plants in shallow depressions that capture runoff), vegetated rooftops, rain barrels, and permeable pavements (Ahiablame and others 2012, Dietz 2007).

By implementing LID principles and practices, water can be managed in ways that reduce the impact of built areas and promote the natural movement of water within an ecosystem or watershed. Applied on a broad scale, LID can maintain or restore a watershed's hydrologic and ecological functions. As climate change leads to more variable precipitation, including both more frequent intense storm events and droughts, LID can be a cost-effective method to retain stormwater locally and reduce flooding (Pyke and others 2011).

## Conservation Developments

Conservation developments, sometimes termed open-space or clustered developments, are residential developments that purposefully restrict the footprint of housing while providing functional protection for natural resources (Pejchar and others 2007). By clustering or concentrating homes and infrastructure into one portion of a residential area while leaving open space elsewhere, conservation developments provide an alternative to the dispersed homes and infrastructure seen in many rural or exurban settings.

Because conservation developments are designed and managed to protect natural resources, they may include environmentally beneficial design and management, such as LID practices for stormwater management. Modeling simulations show that development with this higher density but smaller footprint can lead to better water quality than traditional development (Jacob and Lopez 2009, Williams and Wise 2006). Strategically siting the open space portion of a conservation development to protect water resources, such as stream corridors, can preserve watersheds and help maintain water quality (Carter 2009).

## Building Roads and Infrastructure To Maintain Water Quality

Proper planning for and design of roads and infrastructure (such as bridges and culverts) not only can save money and construction time but also will protect and minimize the impact to streams, lakes, and wetlands (Daniels and others 2004). Such cost-effective and water-protective road planning considers not only construction site specifics (soil, vegetation, geology, and the like) but also how the road will be used in the future; coordination with neighboring landowners is also important. Temporary roads can be a good option if the situation is appropriate because temporary roads can lessen the impact on local water quality compared to a permanent road (Daniels and others 2004).

Metropolitan Design Center Image Bank © Regents of the University of Minnesota.

Conservation developments are designed to protect natural resources.

To help minimize the impact of road construction on water quality, the Wyoming Department of Environmental Quality (WDEQ 2012) offers some general guidelines when developing road construction plans; examples include:

- Construct roads a safe distance from a water body.
- Minimize the number of stream crossings.
- Carefully design stream crossings with bridges, culverts, rip-rap, and other measures.
- Construct stream crossings during periods of low streamflow.
- Fit upland roads to the topography using culverts, waterbars, stabilized slopes, and the like.
- Route road runoff to a filter strip and not directly into a water body.
- Provide energy dissipaters (such as bales, rocks, or logs) to reduce the erosive force of runoff.

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The provision of passageways for water flow reduces the amount of erosion associated with road construction.

- Carefully locate, and properly reclaim, borrow pits and gravel sources.
- Seed or otherwise stabilize disturbed areas as soon as possible.
- Complete road construction prior to the main runoff season to minimize exposure of unfinished roads to heavy runoff.

## Best Management Practices For Homeowners To Preserve Water Quality

Homeowners can make positive contributions to the protection of water quality by taking a number of steps to reduce negative impacts of stormwater runoff, such as the following (adapted from EPA 2003):

- Use porous pavement materials for driveways and sidewalks.
- Use native vegetation and mulch to replace high maintenance (and high water-use) grass lawns.
- Keep litter, pet wastes, leaves, and debris out of street gutters and storm drains, because these outlets typically drain directly to bays, lakes, streams, rivers, and wetlands. Instead of disposing of yard waste, use the materials to start a compost pile.
- Apply lawn and garden chemicals sparingly and according to directions. Consider using Integrated Pest Management, which promotes multiple pest control strategies (biological, cultural, and chemical).
- Clean up spilled brake fluid, oil, and grease, and dispose of used oil, antifreeze, paints, and other household chemicals properly; don’t dump or hose such products into storm sewers or drains. Many communities have programs for collecting household hazardous wastes.
- Use “green” car wash facilities that do not generate runoff, to avoid washing detergents and grease into local streams and lakes.
- Control soil erosion by planting ground cover and stabilizing erosion-prone areas.
- Have septic systems inspected and pumped at least every 3 to 5 years to ensure they operate properly.

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Instead of disposing yard waste, use the materials to start a compost pile.


Cindy Cornett Seigle

Signs like these help to make people more mindful of the connection between ground surfaces, water flow, and the quality of water in our waterways.

Practice water conservation measures to extend the life of septic systems.

- Purchase household detergents and cleaners that are low in phosphorous to reduce the amount of nutrients discharged into lakes, streams, and coastal waters.

## Innovative Payment Schemes and Forest Management Partnerships

Many of the management actions discussed here can be taken by private landowners and developers. However, private and public lands must often be considered together to deliver the biggest conservation benefit. A growing number of projects are accomplishing water quality goals through collaborative restoration and management on public (Federal, State, or local) and private lands, sometimes sharing payment for these ecosystem services with local consumers and municipalities. Working to identify the needs of local users and conduct forest management through partnerships can be a cost-effective way to deliver better water conservation outcomes over landscapes (Carpe Diem West 2013, Weidner and others 2013). Some examples of effective forest management partnerships are described in this section.

### Denver, CO: Conducting Forest Restoration with the Forest Service To Protect Water Quality

In 2010, the Denver Water Authority and the U.S. Forest Service conducted a partnership called From Forests to Faucets, to jointly fund forest restoration and watershed protection. Denver Water serves 1.3 million people in the metropolitan region—one-quarter of the State's population—with 2 percent of the State's water (Denver Water 2011a). The water comes from rivers and streams fed by mountain snowmelt that is stored in reservoirs. Severe forest fires in the late 1990s and early 2000s led to forest degradation and substantial sedimentation in some of these reservoirs. Denver Water spent more than $26 million on water quality treatment, sediment and debris removal, and reclamation after these fires.

In response to these costly expenditures, and with concern about the risk of additional forest fires and declines in forest health due to bark beetle outbreaks, Denver Water and the Forest Service each agreed to contribute $16.5 million toward fuel treatments designed to reduce the risk of future catastrophic wildfire (Denver Water 2011b). Denver Water's funds for the restoration partnership are included in customer water fees, with each household paying $27 on average over the course of the 5-year project. Denver Water has been working on its own lands to restore forest and reduce wildfire risks since the late 1990s and is beginning to collaborate with agencies to complete more work on private lands.

### Washington County, OR: Funding Restoration on Public and Private Land To Protect Endangered Species

Serving more than 500,000 residents west of Portland in Washington County, OR, the Tualatin River is intensively used for agriculture and urban development; it also must sustain high water quality to serve human needs and to protect federally endangered salmon species. New State regulations in 2001 meant the local water utility had

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Forests in South Platte, CO, are critical to protecting Denver's water supply.

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Downtown Denver.

to find a way to minimize the impacts of wastewater discharge on stream temperatures. Managers concluded that restoring riparian habitat and shade, along with building two new reservoirs to temporarily hold treated water, would be the most cost-effective way to restore water quality (Cochran and Logue 2011).

By 2007, the riparian restoration had cost $4.3 million, a 95 percent cost savings in comparison to more traditional options such as installing cooling/refrigeration equipment or building discharge pipelines to larger water bodies (Cochran and Logue 2011). From 2004 to 2008, more than 1.6 million native trees and shrubs were planted throughout the watershed on both public and private lands, an effort so large that the utility established its own nursery for plants. A variety of groups led replanting efforts: in urban areas volunteers with community organizations and professional restoration crews managed by the public water utility conducted restoration work, while in rural areas local committees including farmers and private forest owners managed the restoration (Cochran and Logue 2011). A diversity of funding sources and mechanisms also helped pay for restoration, including Federal grants, a modification of the USDA's Conservation Reserve Program, and resources from municipalities and the water utility.

### Bethlehem, PA: Managing a Watershed with The Nature Conservancy To Protect Water Quality And Generate Revenue

The city of Bethlehem, PA, recently agreed to manage their 22,000-acre watershed in the southern Pocono Mountains through a long-term conservation easement with The Nature Conservancy (TNC), a non-profit conservation organization. The Bethlehem Water Authority provides water for approximately 115,000 customers in 10 municipalities. The Bethlehem Authority's water comes entirely from surface sources in the Pocono Mountains.

Through TNC's Working Woodlands Program, Bethlehem's watershed will be protected as a working forest throughout the 60 years of the agreement, through a combination of easements, Forest Stewardship Council forest management certification, and forest carbon payments (Sadowski 2011, TNC 2011). There will be no commercial development on the land, but recreation will continue.

The Bethlehem water authority benefits from the sustainable management of timber and preservation of their watershed, as well as the additional revenue streams from certified timber sales and carbon credits. Water managers had incurred substantial debt through infrastructure upgrades and considered the outright sale of land (City of Bethlehem 2008), but the Working Woodland program will allow the water authority to retain and manage their watershed, while also providing additional revenue streams.

## SUMMARY AND CONCLUSIONS

Americans rely on forested ecosystems for clean and abundant supplies of water for drinking as well as for agricultural and manufacturing inputs and other values. Both public and private forests play an important role in preserving natural hydrological systems and water

USDA APHIS

Riparian restoration has helped to conserve habitat for federally endangered Chinook salmon (*Oncorhynchus tshawytscha*).

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Autumn in the Poconos, Pennsylvania.

quality, but private forests are uniquely vulnerable to environmental threats from residential development.

Over the next 30 years, we expect to see widespread increases of housing in private forests that currently have low housing density (rural 1 or rural 2); by 2030 we predict that the percentage of the conterminous United States in urban/exurban housing densities will have doubled. Using national data sets on land cover, housing development, and water quality and demand, we examined where housing density increases are expected to have the most substantial impact on water resources.

Those watersheds where private forests make the highest contributions to surface drinking water are found predominantly across the Eastern United States, reflecting both the high human population densities and water demand in that region relative to other parts of the country, and a greater reliance on surface water than on groundwater. Watersheds where water quality is likely to change owing to increased housing density on private lands are also concentrated in the East, but there are other regions where private forest land development is likely to affect drinking water, including the Colorado Front Range and mountain regions of Oregon, Washington, and California.

Of the States located East of the Mississippi River, Georgia and New Hampshire contain the greatest number of watersheds with private forests that are important to drinking water *and* are threatened by high levels of development. More than half of the West's top 50 threatened watersheds are located in California. Analysis at this scale provides information useful for States, counties, and national forests; however, similar to other Forests on the Edge reports and other national assessments, the final map results are not intended to assess individual watersheds of interest. Our work also does not explicitly consider water scarcity or groundwater; as a result, much of the arid West and other areas that rely on groundwater sources for drinking water, though they may face challenges with water supply issues, do not have high levels of *surface* drinking water importance reflected in this report.

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Private forests play a critical role in the health of the Mississippi River, flowing from Minnesota (top) to Louisana (bottom) and the Gulf of Mexcio.

In response to development threats to water quality, planners, communities, and private landowners are using a range of strategies to preserve water quality and healthy freshwater ecosystems. Developers can design housing and roads to minimize impacts on water quality, homeowners can manage their properties to protect water resources, and innovative payment schemes and management partnerships can allow municipalities and water users to invest in forest stewardship on public and private lands. Further investing and refining these strategies to protect water resources in the face of housing development will be essential to conserving private forest lands and the high-quality water resources they provide nationwide.

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# APPENDIX: Methodology

The analyses presented in this report are the same as those conducted by Weidner and Todd (2011) when they examined freshwater provided by the Nation's forests, both private and public, at the 12-digit hydrologic unit code (HUC) sub-watershed[2] scale. Several of the datasets have been updated since the original Forests to Faucets analysis (Weidner and Todd 2011). Newer data versions were used for this publication and therefore results vary slightly from the original analysis. Below we provide more information on their methods and updated data layers, and we refer readers interested in obtaining more information to the original report (Weidner and Todd 2011).

## Updated Data

We updated watershed boundaries from USDA NRCS (2009a) to USDA NRCS (2009b). We updated the results of the original step 1 analysis into the new watershed boundaries by first converting the new watershed boundaries (NRCS 2009b) to a point file. Next, we ran a spatial join between the new points and the original step 1 forests to faucets data. This gave the attributes of step 1 forests to faucets data to the new watersheds. Steps 2 and 3 were rerun according to the original methods below for this publication using updated data layers for forest ownership and housing density datasets (CBI 2010; Fry and others 2011; NRCS 2009b; Theobald 2008.)

To focus this updated analysis on watersheds with private forests, we analyzed only watersheds with at least 10 percent forested land and more than 50 acres of private forest. All other watersheds were labeled as "insufficient private forest for this analysis."

## Methods

Weidner and Todd used a three-step approach to produce three unique but interrelated sets of model outputs, as shown in Figure A-1. These data were combined to produce a measure of the importance of private forest to drinking water:

$$P_{ri}FIMP_n = (Q_n) * PR_n * (P_{ri}FOR_n) ,$$

Where $P_{ri}FIMP_n$ (the measure of private forest contribution to surface drinking water) is equal to the combination of Qn, a measure of water supply; PRn, a measure of drinking water demand over the landscape; and PriFORn, the proportion of a watershed that is privately owned forestland. Below, we explain each step in the model in succession.

## Step 1: Important Areas for Surface Drinking Water

To calculate an index of surface drinking water importance by sub-watershed, Weidner and Todd considered the land's contribution to water supply (volume), the landscape surface flow patterns and the natural processes that affect water quality, as well as downstream drinking water demand (consumption). In its most basic form, the index of importance to surface drinking water (IMP) model [was] broken down into two parts:

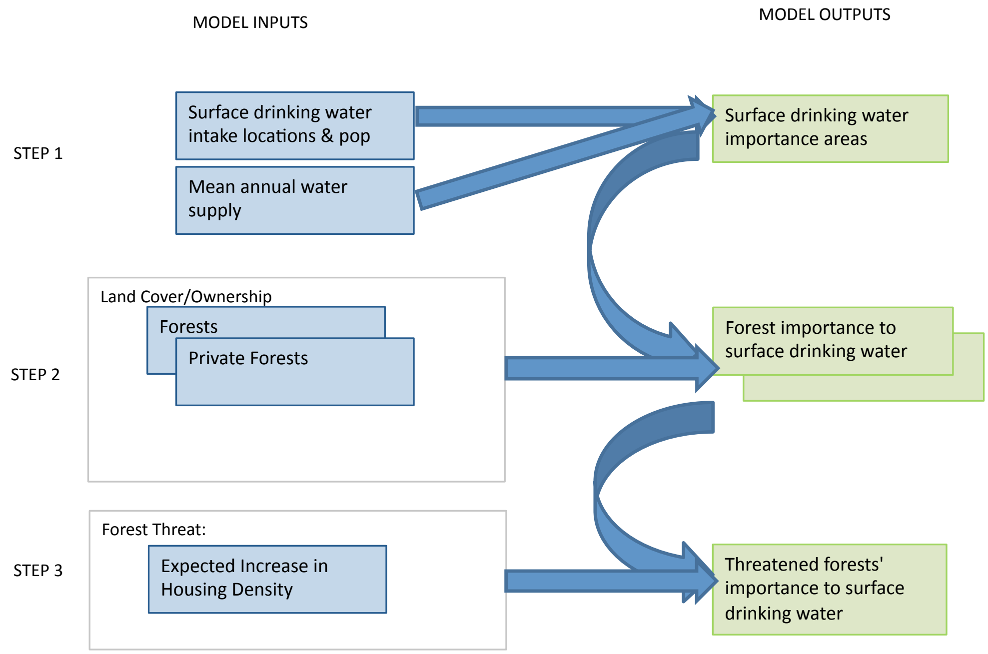
$$IMP_n = (PR_n) * (Q_n),$$

where IMPn is the index of importance to surface drinking water for watershed n; PRn is the risk-based drinking water protection model for each watershed n; and Qn is the mean annual water supply for each watershed n. For IMP, the final non-zero outputs were split into 100 quantiles, or 100 groups with approximately 1 percent of the data each. This ranks the relative importance from least, 0, to most, 100.

The risk-based drinking water protection model, $PR_n$, models the magnitude of demand and the flow patterns of water to sites of withdrawal for use, while the mean annual water supply, Qn, represents the supply of water and weights a sub-watershed based on how much water supply is generated on that land. The model therefore shows which areas have the highest potential to affect water quality through the input of sediments and contaminants from the land, because it includes areas important for providing water (water supply), areas where drinking water is removed for use (water demand), and lands that connect the water supply and demand.

Locations and number of people served by each intake were provided by the U.S. EPA Safe Drinking Water Information System (SDWIS) (EPA 2009). In these analyses only the surface water springs, surface water

Weidner and Todd generally used the term sub-watershed to describe the 12-digit HUC but they sometimes also used "watersheds." With the exception of this appendix, elsewhere in this report we have simplified the terminology to refer to these 12-digit HUCs as watersheds. In this appendix we retain Weidner and Todd's terminology.




intakes, surface water reservoirs, and surface water infiltration galleries were used. Wells were included only where the SDWIS database specified that groundwater was directly influenced by surface water. In general, groundwater wells were not included. Consecutive connections, treatment plants, sampling stations, and non-piped drinking water were not included in the analyses. All drinking water facilities are referred to as "surface drinking water intakes" or simply "intakes." The population served at each intake was derived by dividing the number of people served in a drinking water system by the number of intakes in the system. Intake locations are sited at the point of water extraction, not at point of use.

The model component representing the critically important areas close to intakes and the upstream areas from where the water flows is represented by this drinking water protection model (PR),

$$PR_n = \Sigma (W_i * P_i),$$

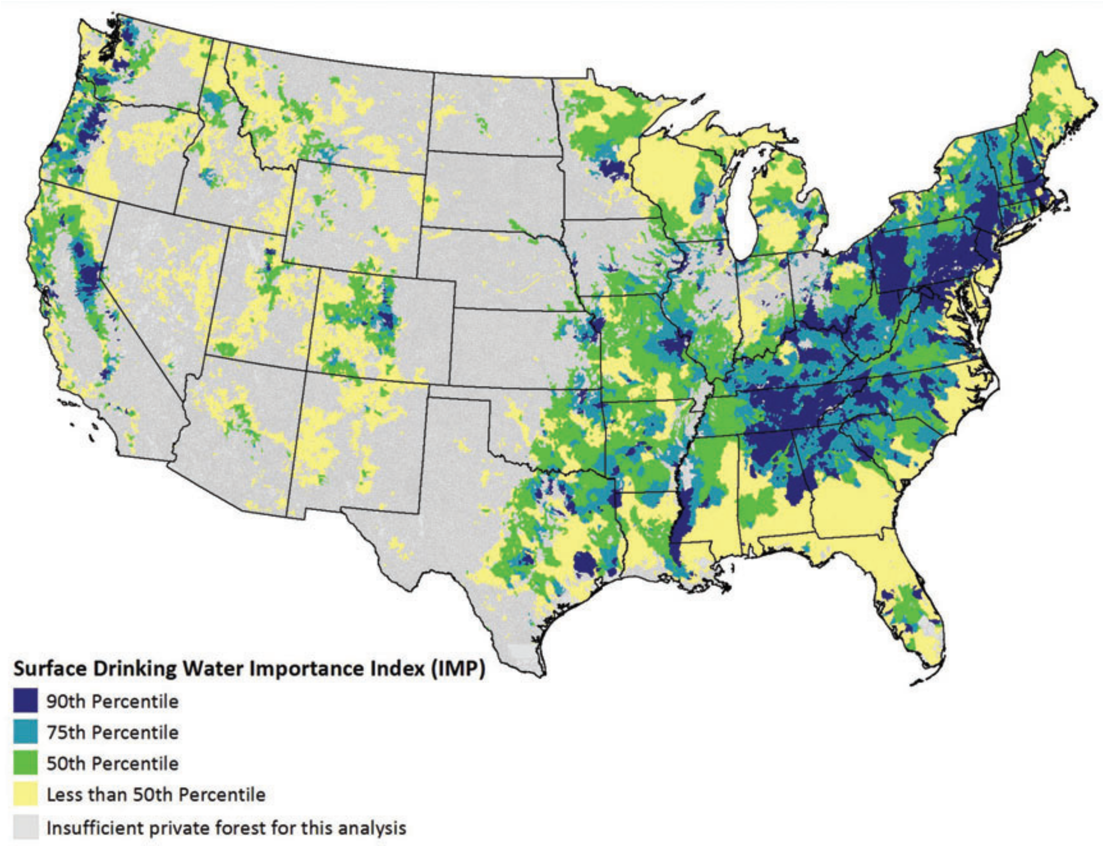
where $PR_n$ is the drinking water protection model for each sub-watershed n; $P_i$ is the population served by intakes in the ith downstream sub-watershed from sub-watershed n; and $W_i$ is the proportional weight for ith downstream sub-watershed from sub-watershed n.

As contaminants move through streams and rivers, they are affected by many processes including dilution, dispersion, decay, and deposition. Weidner and Todd represented these processes in a generalized way for multiple drinking water contaminants including sediment, using an exponential decay relationship to represent the relationship of distance from intake and relative importance to the surface drinking water. The proportional weights, $W_i$, for the ith sub-watershed away from an intake in watershed n are based on the equation,

$$W = (1 - 0.01) \wedge (d),$$

where W is the proportional weight and d is the distance from the intake, with each sub-watershed assumed to be 25 km (15 mi) in stream length distance to the next sub-watershed. Therefore, for every sub-watershed on the map, the surface drinking water protection model value equals the number of people served by intakes in that sub-watershed plus a fraction of the population served by downstream intakes. In this way it considers that risk to an intake declines with distance, and that peak concentrations decline moving downstream.

Because of the national focus of this assessment, and recognition of the heterogeneity of water yield across the [United States], we used Brown and others' (2008) water balance based modeling of mean annual water supply to create a weighting of geography for water supply. Brown and others estimated water supply across the United States as precipitation minus evapotranspiration across the period 1953 to 1994. The final model of surface drinking water importance (IMP, Fig. A-2) combines the surface drinking water protection model ($PR_n$),capturing the flow of water and water demand, with Brown and others' (2008) model of mean annual water supply ($Q_n$).




## Step 2: Forest Importance to Surface Drinking Water

The surface drinking water importance index (IMP) described in the previous section shows the relative importance of geographic areas across the country for surface drinking water, but it does not distinguish between land cover types. To determine the extent to which private forests in particular are currently protecting these areas, Weidner and Todd created an index of forest importance to surface drinking water by weighting the surface drinking water importance index, IMP, by the percentage of forest in each watershed. This is represented by:

$$FIMP_n = (IMP_n) * (FOR_n) / 100,$$

where FIMPn is the index of forest importance to surface drinking water, $IMP_n$ is the surface drinking water importance index, and $FOR_n$ is the percentage of forest land in each sub-watershed n. Both IMP and FOR range from 0 to 100, so the final FIMP values also fall between 0 and 100. In this way areas with small amounts of forests will have a small FIMP value no matter what IMP value the sub-watershed had. Similarly, areas with small IMP values will have small FIMP values no matter what FOR values they had. Only areas with both high IMP and high FOR values will also have high FIMP values.

The data used to distinguish between non-forest, protected forest, and private forest were derived from the National Land Cover Dataset (Fry and others 2011), data on National Forest System land locations (USDA Forest Service 2009), and the Protected Areas Database (PAD) (CBI 2012). Classes 41, 42, 43, and 95 from the National Land Cover Dataset were considered forest. All remaining areas were labeled as non-forest. We used NFS data for National Forest system holdings, and the land owner description in PAD to determine other protected lands (other Federal Land, Native American Land, State Land, Local Land, Private Conservation Land). The index of forest importance to surface drinking water was repeated for each forest type; thus, for private forest [the model is]:

$$P_{ri}FIMP_n = (IMP_n) * (P_{ri}FOR_n).$$

## Step 3: Threats to Private Forests Important for Surface Drinking Water

In this third and final step of the analysis, Weidner and Todd identify private forest areas important for surface drinking water that are likely to be affected by future increases in housing density, insects and diseases, and wildland fire. The procedures used for this step were tiered from similar analyses undertaken by the Forests on the Edge project (Stein et al. 2009).

To begin, we multiplied the index of forest importance to surface drinking water (the output from step 2) by a value 0–100 that represents the percentage of a watershed that is highly threatened by housing development. This is expressed as,

$$(P_{ri}FIMP_n) *(THR_n) / 100,$$

where $THR_n$ is the percentage of watershed n that is "highly threatened" by development. To measure the threat of development, Weidner and Todd focused on increases in housing density, which reflects a change in the landscape more accurately than does population density alone. Projections of future housing density increases on rural forest lands (as defined below) were used to quantify the threat of development across all U.S. forests.

The Forests to Faucets analysis used data layers produced by Stein and others (2009) and Theobald (2008), who condensed 12 categories of housing density produced by Dave Theobald's SERGoM v3 housing density model for 2000 and 2030 (Theobald 2005) into 3 categories. We subtracted the 2000 values from values expected for 2030 to highlight areas with expected increase in housing development over this 30-year period.

The three categories (Stein and others 2009) were based on a review of the literature on impacts of development on benefits provided by forests. The categories were: rural 1 (fewer than 40 acres per housing unit), rural 2 (10–40 acres per housing unit), or exurban/urban (fewer than 10 acres per housing unit). Any change from rural 1 to rural 2, rural 2 to exurban/urban, or rural 1 to exurban/urban between 2000 and 2030 were considered as areas "highly threatened" by development.

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## FORESTS ON THE EDGE

Forests on the Edge is a project of the U.S. Department of Agriculture, Forest Service, State and Private Forestry, Cooperative Forestry staff, in conjunction with Forest Service Research and Development, National Forest System staff, universities, and other partners. The project aims to increase public understanding of the contributions of and pressures on America's forests, and to create new tools for strategic planning. The first report (Stein and others 2005) identified private forested watersheds in the conterminous United States most likely to experience increased housing density. Subsequent reports have provided more in-depth discussion and data on related topics, including: development pressures on America's national forests and grasslands (Stein and others 2007), impacts of increased housing density and other pressures on private forest benefits (Stein and others 2009), threats to at-risk species (Stein and others 2010), sustaining America's urban trees and forests (Nowak and others 2010), understanding and preparing for wildfire in the wildland-urban interface (Stein and others 2013), and threats to forests on U.S. Pacific and Caribbean islands (Stein and others 2014). This report presents an overview of the role of forests in providing clean drinking water and the impacts of increasing housing density on private forests and water quality.

**For further information on Forests on the Edge, contact:**

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